

1 **Evaluating the Impacts of Speed Limit Increases on Rural Two-Lane Highways using**
2 **Quantile Regression**

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1 ABSTRACT

2 Understanding speed selection behavior of drivers following speed limits increases is critically
3 important. To date, the literature has largely focused on freeways and the effects of speed limit
4 changes on two-lane highways remains under researched. Prior research has generally focused on
5 changes to mean speeds, though the speeds of both the highest and lowest drivers are also of great
6 interest. This study investigates trends in free-flow travel speeds following 2017 legislation that
7 increased the posted speed limit from 55 to 65 mph on 943 miles of rural highways in Michigan.
8 Speed data were collected for over 46,000 drivers at 67 increase segments where speed limit
9 increased and 28 control segments, where speed limits remained unchanged, before and during
10 each of the two successive years following the speed limit increases. Site-specific traffic,
11 geometric, and cross-sectional information was also collected. Impacts of the speed limit increases
12 on the 15th, 50th, and 85th percentile speeds were evaluated using quantile regression. Separate
13 analyses were conducted for passenger cars and heavy vehicles. Locations where the speed limits
14 were raised experienced increases in travel speeds ranging from 3.8 to 5.1 mph. The control sites
15 experienced marginal changes in speeds, which suggests any spillover effects of the higher speed
16 limits have been limited. Significant differences were observed across the quantiles with respect
17 to the effects of the speed limit increases, as well as numerous site-specific variables of interest.
18 The results provide important insights as to the nature of driver speed selection and the impacts of
19 speed limit increases.

20

21 **Keywords:** speed limit increase, non-freeways, rural highways, quantile regression

1 INTRODUCTION AND BACKGROUND

2 The impacts of speed limits on traffic operations and safety have been long-standing areas of
3 interest to transportation policy and research. Maximum statutory speed limits are posted to inform
4 drivers of the highest speed that is considered safe and reasonable under ideal traffic, road, and
5 weather conditions (1). Speed limits also provide a basis for the enforcement of unreasonably high
6 travel speeds.

7 Speed limits are generally applicable for a particular class of highways with specific
8 design, functional, jurisdictional, or location characteristics (2). These limits are typically
9 established in consideration of the design speed of the road, which influences various geometric
10 design features such as minimum stopping sight distance, minimum horizontal curve radius, and
11 maximum grade (3). The American Association of State Highway and Transportation Officials
12 (AASHTO) recommends using above-minimum criteria where practical (3) and, ideally, the
13 statutory speed limit should be set at or below the highway's prevailing design speed.

14 Speed limit policies in the United States have changed considerably over time, starting
15 with the implementation of the National Maximum Speed Law (NMSL) of 55 mph in 1974. In
16 1987, the Surface Transportation and Uniform Relocation Assistance Act allowed for increases
17 of up to 65 mph on rural interstates (4) and the NMSL was fully repealed in 1995, restoring the
18 autonomy of establishing speed limits to the individual states (5). Subsequent to the enactment of
19 these laws, speed limits were predominantly increased on limited-access rural freeways, which are
20 the types of roads with the highest speed limits and are also the safest when considering crash risks
21 per distance traveled (6) given their higher design standards. The research literature shows that
22 fatalities on rural interstates are consistently higher among those states with higher maximum
23 statutory speed limits (7). Despite this fact, at least 25 states have increased or proposed to increase
24 maximum speed limits since 2011 (5, 8–10).

25 In general, the research literature has focused predominantly on limited access freeways.
26 Some early studies following the 1987 NMSL relaxation found average speeds to increase by 2 to
27 7 mph following the speed limit increase to 65 mph (11–14). Subsequent studies have shown
28 increases on the order of 2 to 3 mph, in general, for 5-mph increases in the posted limit (15, 16).
29 Although speed limit increases generally increase operating speeds, the exact relationship is not
30 straight-forward and several studies demonstrate considerable variability in the magnitude of speed
31 increases after speed limits are changed (16, 17). Earlier research has shown drivers' speed
32 selection to be impacted by not only the posted speed limit, but also by roadway and roadside
33 characteristics, as well as traffic volumes (18–22). Design speed, pavement conditions, and
34 weather are some of the other factors that directly impact drivers' speed selection while differences
35 are also observed across vehicle types and among driver with different socio-economic
36 characteristics (22, 23).

37 In contrast, research on the effects of speed limit changes on two-lane highways has been
38 more limited. This is due, in part, to the significant variability in the design characteristics of such
39 highways, where speeds can range from 25 to 75 mph. This makes it difficult to assess the
40 magnitude of large-scale speed limit increases across states as has been done frequently in the case
41 of freeways (7). A National Cooperative Highway Research Program (NCHRP) project (15) found
42 that increasing speeds from 55 mph to 65 mph resulted in increases in average speed of 3.4 mph
43 from a before-after analysis. Additional studies have investigated the relationship between
44 roadway geometry and operating speeds, particularly on horizontal curves. The majority of these
45 studies have also focused on freeways (16–20), though a few recent studies have examined speeds
46 on rural two-lane highways (21, 22). The research literature shows that increases in speed limits

1 significantly affect speeds on two-lane roads, but the results are highly dependent on contextual
2 factors (24).

3 At least 27 US states have maximum speed limits that are lower on two-lane highways as
4 compared to freeways, while the remaining states provide the same maximum speed limit for both
5 roadway types (25). However, various states have also recently increased the speed limits on these
6 roadways, as well. The safety literature generally suggests that increasing speed limits on non-
7 freeways will result in an increase in the overall crash rate and will also result in a higher proportion
8 of more severe crashes due to the increase in the energy dissipated during crashes due to vehicles
9 traveling at higher speeds (15). However, further research in this area is warranted given
10 continuing consideration of speed limit increases in both the US and abroad.

11 Related to this issue, the State of Michigan passed Public Acts 445 and 447 in 2016, which
12 increased the state's maximum statutory speed limits from 55 to 65 mph on more than 900 miles
13 of state-maintained two-lane highways. Moreover, the speed limit for heavy vehicles, including
14 trucks and buses, also increased to 65 mph on these same highways (26, 27). Implementation of
15 the speed limit increases began in June of 2017 and concluded later that year. Consequently, this
16 provides an appropriate setting to obtain important insights as to the immediate and longer term
17 impacts on driver speed selection. To that end, this paper presents the results of a longitudinal
18 case-control evaluation that was performed to quantify changes in driver speed selection as a
19 function of speed limit, vehicle type, and various site characteristics.

20 In addition, this study addresses another gap in the research literature by examining the full
21 speed distribution of vehicles under free-flow conditions. Much of the prior research has
22 investigated impacts on mean speeds, often examining aggregate trends that include trailing
23 vehicles where the driver was not free to select their preferred speed (9, 12, 14, 15, 16). Such
24 methods are unable to fully exploit the rich information available in the speed data distributions.
25 For example, the aforementioned NCHRP project (15) utilized daily aggregated average speed
26 measures from permanent traffic recorders as a part of a before-after study, as well as cross-
27 sectional data that did not include any data from the period before the speed limit increases
28 occurred.

29 The speeds at either extreme of the speed distribution are of particular interest as crash
30 risks are significantly increased when there is substantive variability in speeds. To address these
31 concerns, this study involves the estimation of a series of quantile regression models to assess
32 changes in the 15th, 50th, and 85th percentile speeds following the speed limit increases. The results
33 help to advance our understanding of how speed limit increases affect the driving population and
34 how these underlying behavioral changes may help to explain related increases that are observed
35 with respect to crash risks.

36 **DATA COLLECTION AND SUMMARY**

37 This study evaluates changes in travel speeds along rural two-lane highways maintained by the
38 Michigan Department of Transportation (MDOT). The primary objective is to discern impacts
39 associated with the 2017 statewide speed limit increases. As a part of this effort, a case-control
40 analysis is conducted to compare speeds before and after this increase went into effect. The control
41 locations include highway segments where the 55-mph maximum limit was maintained and allow
42 for a determination of whether any spillover effects are observed where speeds increase at other
43 locations due, in part, to increases occurring elsewhere in the system. In addition, the speed data
44 from all locations are integrated with robust information detailing the roadway and roadside
45 environment, as well as prevailing traffic conditions. This is important as AASHTO notes that
46

1 driving speeds are affected by four general factors, including physical characteristics of the road
2 and roadside interference, weather, other vehicles, and the speed limit (3). This section provides
3 details of the site selection and data collection procedures employed as a part of this study.
4

5 **Site Selection**

6 Prior to the speed limit increases in mid-2017, the research team identified locations on the MDOT
7 rural two-lane highway network where periodic spot-speed data collection would be performed
8 before and after implementation of the increased speed limit. This included a sample of locations
9 where the speed limit was set to be increased to 65 mph, along with a comparison sample of similar
10 highways where the 55 mph limit would be retained. As the speed limit increases mostly occurred
11 in MDOT's most rural Superior and North regions, the majority of both the speed limit increase
12 and control sites were selected from those areas. Additional control sites were selected from central
13 and southern Michigan to provide representation among other regions where the 55 mph speed
14 limit was retained.

15 The data collection setup at most locations occurred along straight, flat (i.e., grades less
16 than 2 percent) sections of highway. However, a select group of horizontal curves with advisory
17 speeds below 55 mph were also included as such locations have been shown to exhibit
18 disproportionately high numbers of speed-related crashes. Generally speaking, no more than one
19 site was selected per county along a specific highway route. Figure 1 provides a map of the routes
20 where speed limits were increased to 65 mph, in addition to identifying locations where data were
21 collected for both the speed limit increase and control sites.

22 Data were collected from a total of 95 sites. At each location, spot speed data were obtained
23 from covert roadside locations using either elevated high-definition video cameras or handheld
24 Light Detection and Ranging (LiDAR) speed guns. The sites include 67 locations (30 camera sites
25 and 37 LIDAR sites) at which the speed limits were increased, as well as 28 control sites (18
26 camera sites and 10 LIDAR sites) where the 55-mph limit remained in place. Supplementary site-
27 specific information was also collected using aerial photography, including details such as lane
28 width, shoulder widths, horizontal curvature, and the presence of no-passing zones or passing relief
29 lanes.
30

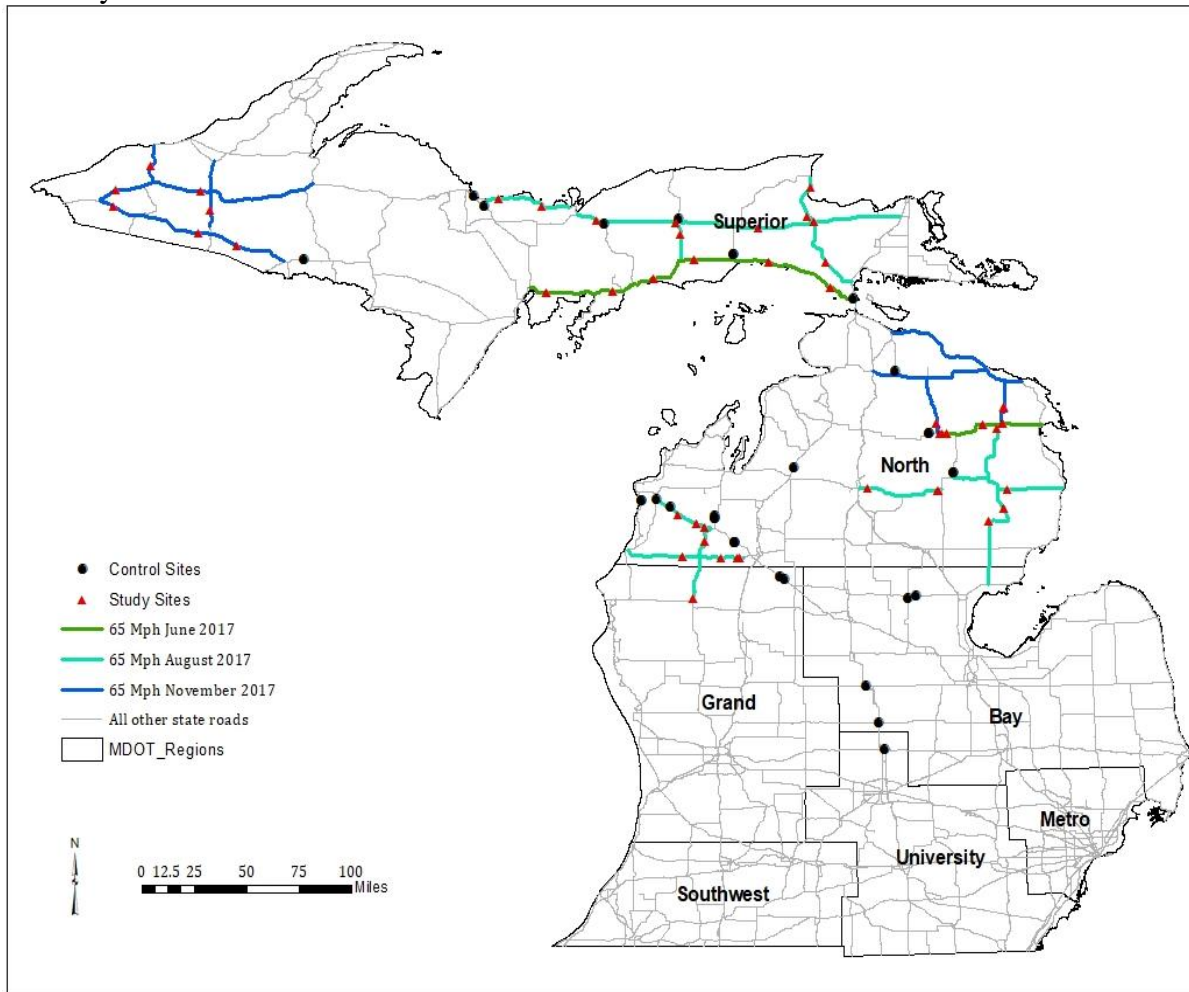
31 **Speed Data Collection**

32 Three waves of speed data collection were performed as a part of this study. The initial wave
33 occurred during the late spring and summer of 2017 prior to the speed limit increases. Data for the
34 periods after the speed limit increases were collected during late spring and summer of 2018 and
35 2019. Data were collected between the hours of 8:30 am and 6:30 pm on weekdays under clear
36 weather and dry pavement conditions.

37 For the LiDAR data collection, measurements were obtained from an unmarked vehicle
38 parked on a side street, driveway, or parking area that was not readily visible to motorists on the
39 subject highway segment. Specific attention was given to being covert so as not to impact the
40 speed of approaching drivers. At each site, the targets were to collect 100 speed measurements for
41 passenger vehicles and at least 10 for heavy vehicles in each direction of travel. During data
42 collection, only vehicles with a headway of at least 4.0 seconds were considered in order to reduce
43 potential impacts of platooning. Due to the rural nature of these highways, free flow conditions
44 were typically present during the data collection.

45 For the data collection with high definition video cameras, the cameras were temporarily
46 installed on a telescoping pole at covert roadside locations. After completion of the field video

1 recordings, a team of trained reviewers manually performed a frame-by-frame review of the videos
 2 to assess the time required for each vehicle to traverse a fixed distance between known reference
 3 markers. Vehicle classification, headway, and hourly volume in the direction of speed data
 4 collection during each study period were also recorded. Vehicles were classified as passenger
 5 vehicles, passenger vehicles with trailers, truck, single unit, tractor-trailer, motorcycle, farm
 6 equipment, or all-terrain vehicle. As the camera dataset included all the vehicles during the
 7 observation time, the dataset was filtered to include only vehicle observations with a minimum
 8 headway of 4.0 seconds.



9
 10 **FIGURE 1 Location of Speed Limit Increase and Control Sites for Speed Data Collection.**
 11

12 The collected and calculated data were tabulated and coded into a single data file for
 13 subsequent analyses. The initial data set included complete records for 62,939 vehicle observations
 14 collected across the three data collection periods from the 95 sites. Prior to the analyses, the dataset
 15 was filtered to exclude motorcycles, all-terrain vehicles, farm equipment, passenger vehicles with
 16 trailers, and any other observations where free-flow condition could have been compromised (e.g.,
 17 bicyclist or pedestrian on the shoulder, turning vehicles, passing vehicles, vehicles with brake
 18 lights on). Table 1 presents the descriptive statistics for each variable included in the final dataset,
 19 which included 46,162 free-flowing vehicles. Site types (increase or control) and data collection
 20 period (before or after the speed limit increase) were combined and categorized in four groups to

1 test the impact of speed limit change on increase and control segments. Observed vehicles were
 2 categorized into passenger cars and heavy vehicles allowing separate analysis for each vehicle
 3 types. Sites were also categorized based on the passing permission or presence of passing relief
 4 lane on both directions. Roadway geometric characteristics such as lane width and degree of
 5 curvature were also used to categorize the collected data. Furthermore, location of the data
 6 collection sites in different MDOT regions were also used to categorize collected data.

7 **TABLE 1 Descriptive statistics for study sites (n = 46,162)**

Parameters	Mean	Std. Dev.
Traffic volume (veh/hr)	280.00	247.84
Before-control sites (1 if yes; 0 if no)	0.13	0.33
Before-increase sites (1 if yes; 0 if no)	0.21	0.41
After-control sites (1 if yes; 0 if no)	0.24	0.43
After-increase sites (1 if yes; 0 if no)	0.42	0.49
Passenger vehicle (1 if yes; 0 if no)	0.89	0.31
Heavy vehicle (1 if yes; 0 if no)	0.11	0.31
Normal section or one-way passing lane (1 if yes; 0 if no)	0.90	0.31
Two-way passing lanes (1 if yes; 0 if no)	0.10	0.31
Passing permitted (1 if yes; 0 if no)	0.81	0.40
Passing restricted (1 if yes; 0 if no)	0.20	0.40
Lane width =12 feet (1 if yes; 0 if no)	0.74	0.44
Lane width =11 feet (1 if yes; 0 if no)	0.26	0.44
Degree of curvature =0 (1 if yes; 0 if no)	0.86	0.35
Degree of curvature <5 (1 if yes; 0 if no)	0.08	0.27
Degree of curvature =5-10 (1 if yes; 0 if no)	0.04	0.20
Degree of curvature >10 (1 if yes; 0 if no)	0.02	0.14
MDOT region =Superior (1 if yes; 0 if no)	0.43	0.50
MDOT region =Bay (1 if yes; 0 if no)	0.06	0.24
MDOT region =North (1 if yes; 0 if no)	0.46	0.50
MDOT region =Grand (1 if yes; 0 if no)	0.04	0.19
MDOT region =University (1 if yes; 0 if no)	0.01	0.11

8

9 **STATISTICAL METHODS**

10 Using the data described previously, a series of regression models were estimated in order to
 11 discern the impacts of the speed limit increases while controlling for the effects of other pertinent
 12 factors, including lane width, horizontal curvature, and the presence of passing restrictions and
 13 passing relief lanes. Most of the prior studies evaluating impact of speed limit increase utilized
 14 aggregated data and compared before-after speed metrics using ordinary least squares (OLS)
 15 regression techniques (16, 19, 28-30), ANOVA, and t-tests (31-33). These methods while were
 16 successful proving significant change in speed following the speed limit increases, lacked to
 17 provide further details on driver speed selection behavior. While ordinary least squares (OLS) has
 18 been the most widely applied method for the analysis of speed data in a regression setting, there
 19 are several important limitations to OLS considering the study context. First, speed data tend to be
 20 skewed and, as such, the estimates for the conditional mean are not necessarily reflective of the
 21 entire speed distribution. Secondly, there is particular interest in the higher and lower quartiles.
 22 For example, the 85th percentile is still widely used as a metric for establishing speed limits and,

1 as such, changes in this metric are of particular interest. There is also a potential concern as to
 2 drivers who are uncomfortable traveling at the highest speeds, which may result in platooning and
 3 high-risk passing by other motorists. Quantile regression is an appealing alternative to OLS as this
 4 allows for estimation of the entire conditional distribution rather than just the conditional mean. A
 5 few prior studies have successfully utilized quantile regression approach to analyze speed data (34,
 6 35). To the best of our knowledge, this is the first study using this technique to evaluate impact of
 7 speed limit policy change. For the purposes of this study, the analysis focuses on the 15th, 50th, and
 8 85th percentile speeds. In addition, separate models are estimated for passenger cars and heavy
 9 vehicles to determine how speed selection within both groups were impacted by the speed limit
 10 increase. Quantile models are similar to OLS linear regression models as they also assume an
 11 additive relationship between the dependent variable and the independent variables. However,
 12 unlike OLS, quantile regression does not make any assumptions about the distribution of the
 13 dependent variable and is more resilient to the influence of outliers (36).

14 The general form of the quantile regression model is similar to that of a linear regression
 15 model. Quantile levels are denoted by τ , which represents the value of the dependent variable
 16 below which the proportion of the conditional response population is τ . Within the context of this
 17 study, the quantile regression model takes the form shown in Equation 1:

$$18 \quad Q_{\tau}(y_i) = \beta_0(\tau) + \beta_1(\tau)x_{i1} + \beta_2(\tau)x_{i2} + \dots + \beta_p(\tau)x_{ip} + \varepsilon_i \quad (1)$$

19 where $Q_{\tau}(y_i)$ is the τ th quantile of the speed distribution, x_{ij} are observed independent variables
 20 associated with observation i , and ε_i is a random error term with mean equal to zero. The beta
 21 coefficients $\beta_j(\tau)$ are now the functions of quantile level τ . The $\beta_j(\tau)$ parameters are estimated by
 22 solving the minimization problem:

$$23 \quad \min_{\beta_0(\tau), \dots, \beta_k(\tau)} \sum_{i=1}^n \rho_{\tau}(y_i - \beta_0(\tau) - \sum_{j=1}^p x_{ij}\beta_j(\tau)) \quad (2)$$

24 where $\rho_{\tau}(r) = \tau \max(r, 0) + (1 - \tau) \max(-r, 0)$. The function $\rho_{\tau}(r)$ is referred to as the check
 25 loss which gives asymmetric weights to each of the individual error r for each data point,
 26 depending on the quantile and the sign of the error. The function $\max()$ returns the maximum
 27 value in the parenthesis. Thus, for positive errors, the check function multiplies the error by τ , and
 28 by $(1 - \tau)$ if the error is negative. Minimizing equation (2) results in minimum median absolute
 29 deviation for the quantile model. For each quantile level τ , the solution to this minimization
 30 problem yields a distinct set of regression coefficients (37). The quantile regression was conducted
 31 using R-Studio in order to estimate a model for the 15th, 50th, and 85th percentile speeds.

32 The same set of predictor variables were included in each model. This included binary
 33 indicator variables for the study period (before vs. after) and site type (increase vs. control), hourly
 34 volume during the observation period, lane width, degree of curve, MDOT region, and presence
 35 of passing lanes or passing restrictions. Although the dataset included several other variables,
 36 including shoulder width and type, terrain, pavement type, and time-of-day, these variables were
 37 not found to be statistically significant.

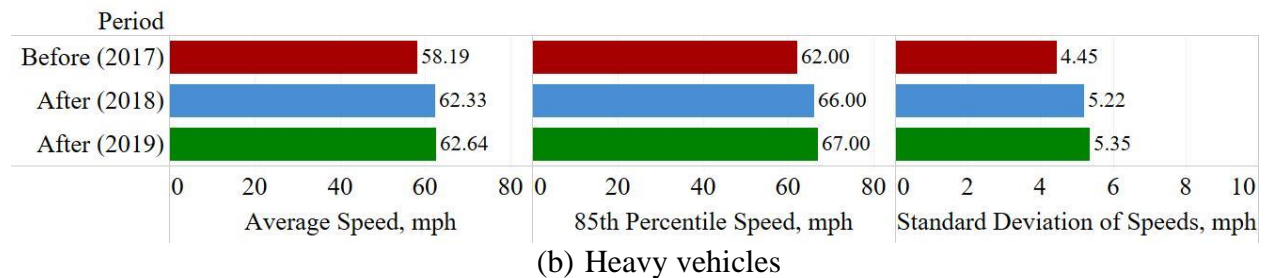
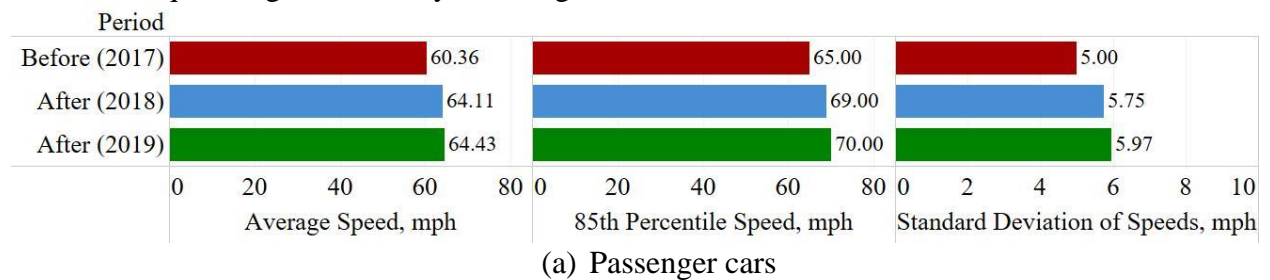
40 **RESULTS AND DISCUSSION**

41 Figure 2 provides an aggregate-level summary of changes in the average speed, 85th percentile
 42 speed, and speed standard deviation for both passenger cars and heavy vehicles at locations where
 43 the speed limit increases occurred. This figure provides details for the periods immediately before,
 44

1 one year after, and two years after the speed limit increases went into effect and only for the tangent
 2 segments (as speeds were significantly different during all periods at the horizontal curve
 3 locations).

4 These preliminary results show the average speeds of passenger cars were 3.8 mph higher
 5 after one year and 4.1 mph higher after two years compared to the pre-increase period. For heavy
 6 vehicles, these increases were 4.1 mph and 4.5 mph, respectively. The 85th percentile speeds
 7 increased by 4.0 mph after one year and 5.0 mph after two years for both vehicle types.
 8 Importantly, the speed standard deviation (averaged across all sites) also increased following the
 9 speed limit increase. This suggests there was significant variability in the magnitude of increases
 10 across the distribution of drivers.

11 It is important to note that these data provide results at an aggregate level and do not
 12 consider the effects of traffic volume and geometric characteristics. These factors were considered
 13 in the subsequent regression analysis, along with similar data for the control locations.



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18 **FIGURE 2 Trends in Mean, 85th Percentile, and Standard Deviation of Speeds on Tangent**
 19 **Segments where Speed Limit Increases Occurred**

20
21 As noted previously, separate quantile regression models were estimated for passenger cars
 22 and heavy vehicles at the 15th, 50th, and 85th percentiles (quantiles, $\tau = 0.15, 0.50, \text{ and } 0.85$). Results
 23 of these models are provided in Table 2 and Table 3 for passenger vehicles and heavy vehicles,
 24 respectively. For each quantile model, parameter estimates are provided, along with standard errors
 25 and the p-value that corresponds to the t-statistic used to evaluate whether each of these parameters
 26 was significantly different than zero. For each quantile, a separate model and the model equation
 27 can be written using the parameter estimates showed in Table 2. The parameters can be interpreted
 28 at different quantile levels separately. For example, at $\tau = 0.15$ (15th percentile) if Period and Site
 29 Type are set to “After-increase sites”, the speed will be 3.78 mph higher than the “Before-control sites”.
 30 The same will be higher by 5.01 and 4.91 mph at $\tau = 0.50$ and $\tau = 0.85$, respectively.

31 For comparison purposes, Figure 3 and Figure 4 provide graphical comparisons of the
 32 parameter estimates for each quantile, along with the same estimates for an OLS model of mean
 33 speeds for both vehicle types. When examining these plots, the OLS parameter estimates are
 34 reflected by a horizontal line, along with the associated 95 percent confidence intervals for each
 35 of the OLS parameters. If the quantile regression parameters fall outside of these bounds, it is

1 reflective of differences that are statistically significant at this same confidence level. It is clear
 2 from these respective tables and figures that quantile regression is able to identify relationships in
 3 the data that would not be possible under the more typical OLS framework. The remainder of this
 4 section details the results of these analyses and provides accompanying discussion of the practical
 5 implications of these results.

7 **TABLE 2 Linear Quantile Regression Model for Passenger Vehicle Speeds**

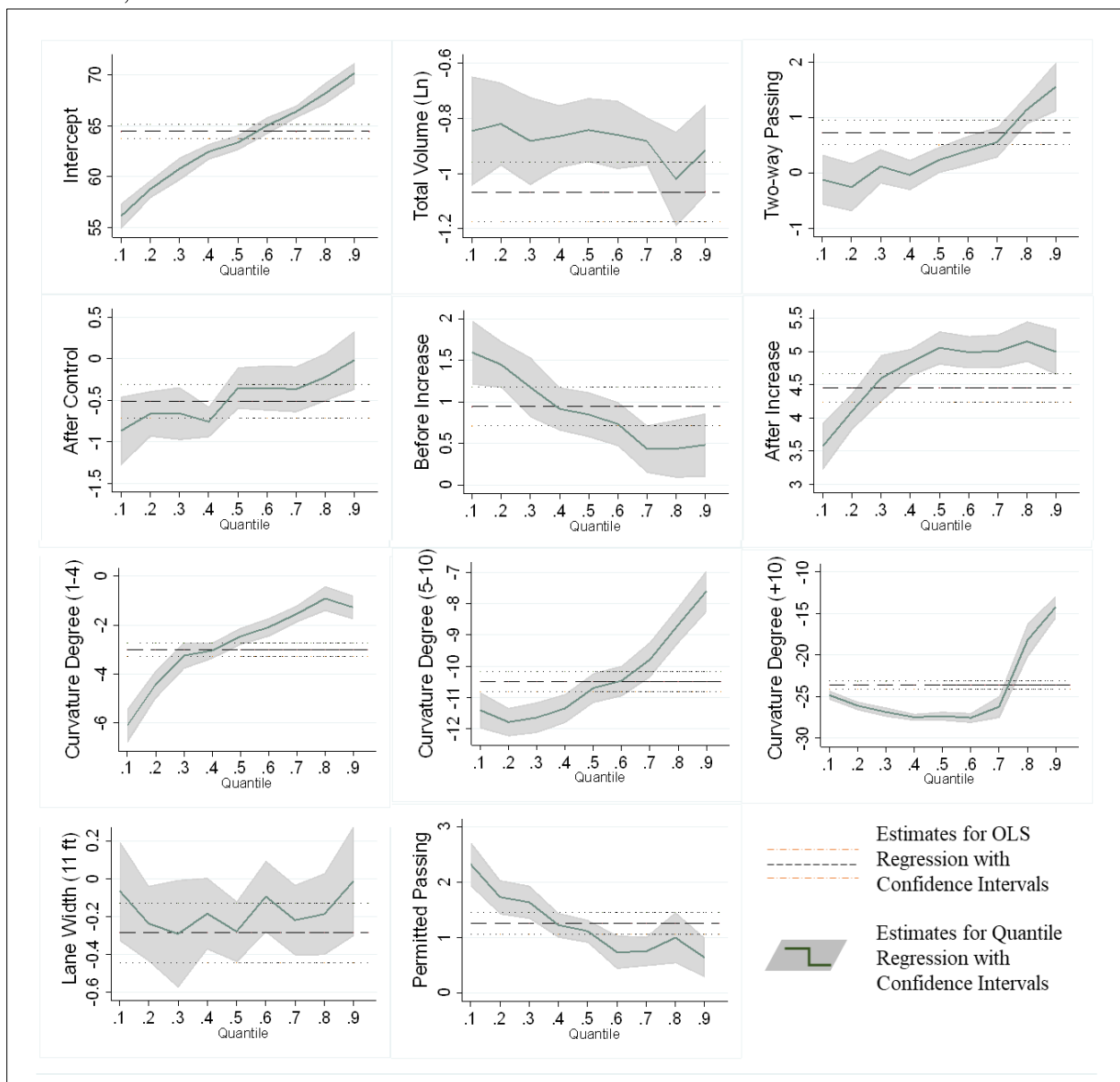
Dependent Variable= Speed of PC (n = 41,223)						
Parameters	$\tau = 0.15$		$\tau = 0.50$		$\tau = 0.85$	
	Estimate (Std. Error)	P- value	Estimate (Std. Error)	P- value	Estimate (Std. Error)	P- value
Intercept	57.72 (0.52)	<0.01	63.36 (0.35)	<0.01	69.57 (0.51)	<0.01
Ln(Hourly Total Volume)	-0.84 (0.08)	<0.01	-0.84 (0.05)	<0.01	-1.03 (0.08)	<0.01
Period and Site Type						
Before-control sites	<i>Base Condition</i>					
Before-increase sites	1.51 (0.17)	<0.01	0.85 (0.12)	<0.01	0.27 (0.17)	0.12
After-control sites	-0.78 (0.15)	<0.01	-0.35 (0.10)	<0.01	-0.25 (0.15)	0.09
After-increase sites	3.78 (0.16)	<0.01	5.05 (0.11)	<0.01	4.91 (0.16)	<0.01
Cross-section						
Normal/one-way passing	<i>Base Condition</i>					
Two-way passing	-0.06 (0.17)	0.72	0.23 (0.12)	0.04	1.34 (0.16)	<0.01
Lane Width						
12 feet	<i>Base Condition</i>					
11 feet	-0.07 (0.12)	0.55	-0.28 (0.08)	<0.01	-0.21 (0.12)	0.07
Passing						
Restricted	<i>Base Condition</i>					
Permitted	2.05 (0.15)	<0.01	1.12 (0.10)	<0.01	0.80 (0.15)	<0.01
Degree of Curvature						
0	<i>Base Condition</i>					
<5	-5.28 (0.20)	<0.01	-2.46 (0.14)	<0.01	-0.77 (0.20)	<0.01
5-10	-11.50 (0.24)	<0.01	-10.69 (0.16)	<0.01	-8.07 (0.23)	<0.01
>10	-25.64 (0.34)	<0.01	-27.34 (0.23)	<0.01	-15.60 (0.34)	<0.01
MDOT Region						
Superior	<i>Base Condition</i>					
Bay	-4.52 (0.21)	<0.01	-3.51 (0.14)	<0.01	-3.24 (0.20)	<0.01
North	-0.62 (0.11)	<0.01	-0.85 (0.07)	<0.01	-0.77 (0.10)	<0.01
Grand	0.61 (0.23)	<0.01	0.75 (0.16)	<0.01	1.32 (0.23)	<0.01
University	-3.24 (0.40)	<0.01	-2.12 (0.27)	<0.01	-1.80 (0.40)	<0.01

8
 9 **Effects of Speed Limit Increase**

10 First, it should be noted that the sites where the speed limits were increased tended to have higher
 11 speeds than the control sections. While the control sites were matched by traffic volume, geometric
 12 characteristics, and proximity to the sites where limits were increased, these results were expected,
 13 as the prior operating speeds were one of the factors considered in the selection of the segments
 14 where speed limits were changed (38). The 15th, 50th, and 85th percentile speeds were 57.7 mph,

1 63.4 mph, and 69.6 mph, respectively when the 55 mph limit was in place (with other parameters
 2 set to zero). Prior to the speed limit change, speeds ranged from 0.3 to 1.5 mph higher among
 3 passenger cars and 0.16 to 1.45 mph higher among heavy vehicles at the sites where the increases
 4 would subsequently occur.

5 It is interesting to note that these differences were largest for the lowest quartile and
 6 smallest for the highest quartile. This suggests that the drivers who tend to travel the fastest also
 7 tend to maintain these higher speeds irrespective of other roadway conditions when the speed limit
 8 is the same. In contrast, the drivers who travel at lower speeds tend to increase their speeds when
 9 conditions are more favorable, as they tended to be at the sites where speed limits were increased.
 10 While it is not possible to determine directly from the available data, this may help to explain why
 11 crash risks tend to be exacerbated at higher speeds as this subset of drivers seems less apt to reduce
 12 their speeds based on contextual factors. This point will arise during subsequent portions of the
 13 discussion, as well.



14

15 **FIGURE 3 Plot of Parameter Estimates for Speed Quantiles for Passenger Car**

1 Following the speed limit increases, significant increases were experienced across the
 2 entire speed distribution at sites where the limits were increased. Among passenger vehicles, these
 3 increases were 2.3 mph, 4.2 mph, and 4.6 mph for the 15th, 50th, and 85th percentiles, respectively.
 4 The corresponding speed increases for heavy vehicles were 2.5 mph, 4.3 mph, and 4.5 mph for
 5 these same percentiles. The increase in speeds was again higher in the upper portion of the
 6 distribution (i.e., the 50th and 85th percentile), suggesting that the most aggressive group of drivers
 7 tended to increase their speeds by a greater margin.

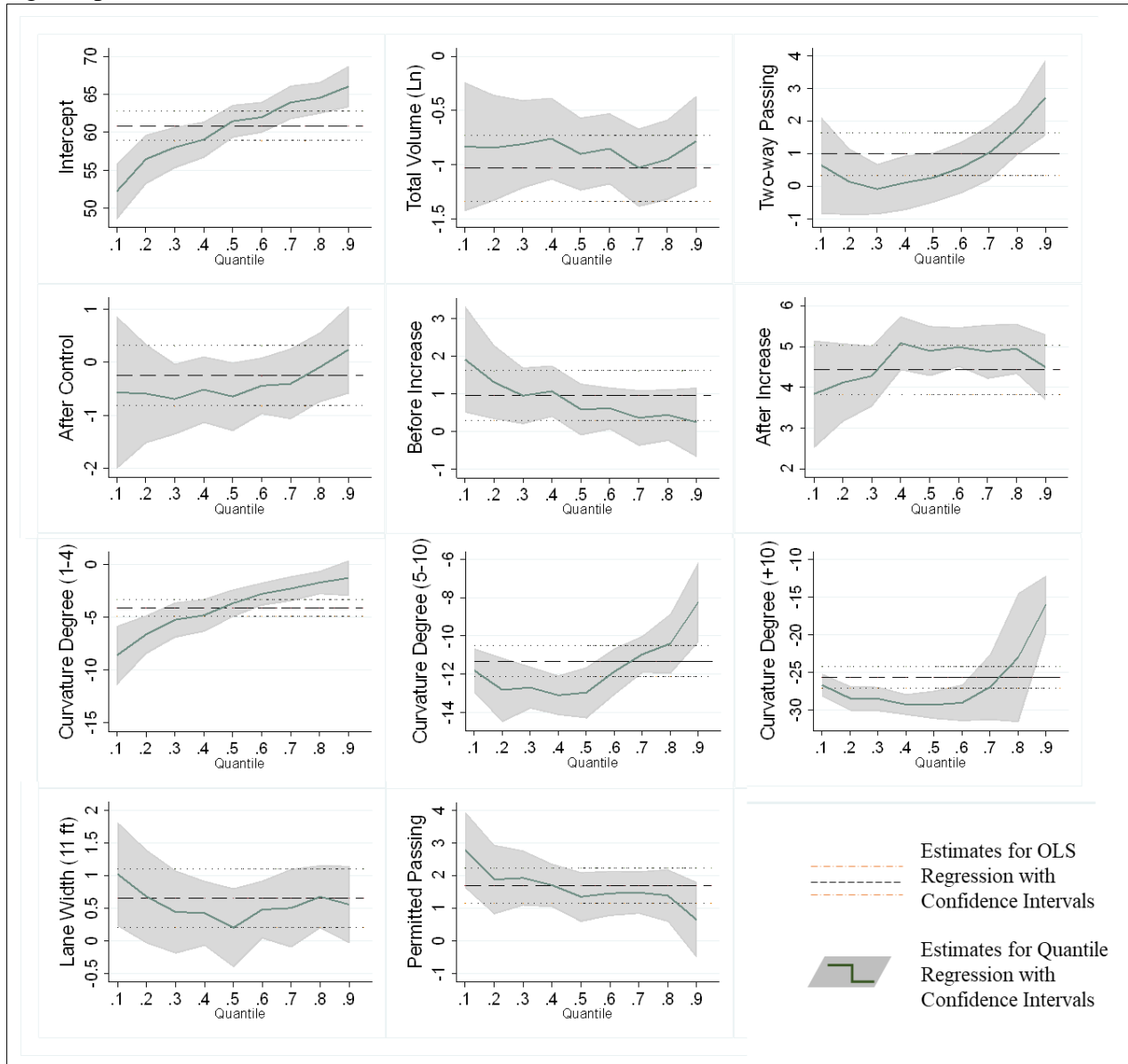
8 In general, these results are also similar to findings from prior studies, which have shown
 9 that operating speeds increase by roughly half the magnitude of the actual speed limit increase (11,
 10 13–15, 19). Interestingly, speeds either remained unchanged or decreased at the control sites across
 11 all quartiles and for both vehicle types. This is in contrast to prior research, which has suggested a
 12 potential spillover effect on adjacent roads (39).
 13
 14

TABLE 3 Linear Quantile Regression Model for Heavy Vehicle Speeds

Dependent Variable = Speed of HV (n = 4,939)						
Parameters	$\tau = 0.15$		$\tau = 0.50$		$\tau = 0.85$	
	Estimate (Std. Error)	P- value	Estimate (Std. Error)	P- value	Estimate (Std. Error)	P- value
Intercept	54.35 (1.72)	<0.01	61.48 (0.96)	<0.01	65.85 (1.11)	<0.01
Ln(Hourly Total Volume)	-0.73 (0.27)	<0.01	-0.90 (0.15)	<0.01	-1.03 (0.17)	<0.01
Period and Site Type						
Before-control sites			<i>Base Condition</i>			
Before-increase sites	1.45 (0.58)	0.01	0.59 (0.32)	0.07	0.16 (0.38)	0.66
After-control sites	-0.62 (0.50)	0.21	-0.65 (0.28)	0.02	0.17 (0.32)	0.60
After-increase sites	3.95 (0.53)	<0.01	4.90 (0.29)	<0.01	4.65 (0.34)	<0.01
Cross-section						
Normal/one-way passing			<i>Base Condition</i>			
Two-way passing	0.20 (0.58)	0.72	0.29 (0.32)	0.36	2.05 (0.37)	<0.01
Lane Width						
12 feet			<i>Base Condition</i>			
11 feet	0.95 (0.40)	0.02	0.20 (0.22)	0.36	0.69 (0.25)	<0.01
Passing						
Restricted			<i>Base Condition</i>			
Permitted	2.34 (0.47)	<0.01	1.35 (0.26)	<0.01	1.16 (0.30)	<0.01
Degree of Curvature						
0			<i>Base Condition</i>			
<5	-7.23 (0.71)	<0.01	-3.66 (0.40)	<0.01	-1.47 (0.46)	<0.01
5-10	-12.60 (0.72)	<0.01	-12.97 (0.40)	<0.01	-10.30 (0.47)	<0.01
>10	-27.71 (1.26)	<0.01	-29.34 (0.70)	<0.01	-18.04 (0.81)	<0.01
MDOT Region						
Superior			<i>Base Condition</i>			
Bay	-4.27 (0.70)	<0.01	-2.94 (0.39)	<0.01	-2.60 (0.45)	<0.01
North	0.09 (0.34)	0.79	0.01 (0.19)	0.99	0.71 (0.22)	<0.01
Grand	0.16 (0.73)	0.83	0.06 (0.41)	0.88	-0.60 (0.47)	0.21
University	-6.10 (1.50)	<0.01	-4.19 (0.84)	<0.01	-3.60 (0.97)	<0.01

1 **Effects of Site Characteristics**

2 Turning to the other site characteristics that were found to be related to speed selection, several of
 3 the roadway-related variables also showed interesting associations with specific quartiles of the
 4 speed distribution. First, speeds were consistently reduced during periods when traffic volumes
 5 were higher. Since all of the vehicles included as a part of this analysis included headways of at
 6 least 4.0 seconds, this is likely reflective of the relative density of traffic over the course of the
 7 segment, including upstream of the speed observation location. This is reinforced by the fact that
 8 the speed reductions were most pronounced among the highest quartiles. If these segments tended
 9 to experience higher volumes, there is less opportunity for the fastest vehicles to maintain these
 10 higher speeds.



11 **FIGURE 4 Plot of Parameter Estimates for Speed Quartiles for Heavy Vehicles**

12 Similar findings emerged when considering the effects of geometric and traffic
 13 characteristics that related to passing. Speeds tended to be marginally different among the 15th and
 14
 15

1 50th percentiles along four-lane cross-sections, which included passing relief lanes in both
2 directions. However, the 85th percentile speeds were 1.3 mph higher among passenger vehicles
3 and 2.0 mph higher among trucks. This shows that the most aggressive drivers tend to increase
4 their speeds significantly along these extended passing sections.

5 Related to this same result, two-lane segments where passing was allowed (without passing
6 relief lanes) showed higher speeds across the entire distribution, although the magnitude of this
7 difference was greatest at lower speeds. This reinforces some of the same patterns alluded to
8 previously. The lowest speed drivers appear to adapt their speeds more based upon changes in the
9 driving environment. It is difficult to determine what the causes are for this behavior, though
10 potential explanations may include greater risk aversion among this group or lower levels of
11 comfort under higher stress driving environments. This finding generally aligns with previous
12 results (18, 20, 22).

13 One of the most interesting results related to horizontal curvature. There was significant
14 variability in the sharpness of the curves included in the sample of study sites. Each site was
15 classified into one of four groups based upon its degree of curvature, which ranged from 0 (tangent
16 sections), to 5 degrees (radius = 1,146 ft), to 10 degrees (radius = 574 ft), or more. For both vehicle
17 types and all quartiles, speeds were consistently reduced as the horizontal curves became tighter.
18 These speed reductions were again consistently greater among the lowest speed quartiles and lower
19 among the highest speed quartiles. On the largest radius (i.e., broadest) curves, the 85th percentile
20 vehicles reduced their speeds by only 0.8 mph and 1.5 mph among passenger vehicles and trucks,
21 respectively. In contrast, speed reductions among the 15th percentile were 5.3 and 7.2 mph. These
22 same general trends held for the intermediate radius curves. For the sharpest curves in the sample,
23 reductions among the 85th percentile vehicles were 15.6 mph and 18.0 mph among passenger
24 vehicles and trucks, while these reductions were 25.6 mph and 27.7 mph within the 15th percentile
25 vehicles.

26 Lastly, lane width had marginal impacts on speed selection. Passenger vehicles reduced
27 their speeds very slightly on 11-ft lanes as compared to 12-ft lanes, with the greatest differences
28 being only 0.3 mph. Among heavy vehicles, speeds were actually marginally higher on the 11-ft
29 lanes. Collectively, these results suggest that lane widths do not have a substantive impact on
30 speeds at widths of 11 feet or above. Pronounced differences were also exhibited within several
31 MDOT regions, though these are largely an artifact of the dataset since these regions tended to
32 include a disproportionately large number of control sites and very small numbers of segments
33 where speed limit increases occurred.

34 35 **CONCLUSIONS**

36 This study provides important insights into the impacts of speed limit increases on the underlying
37 speed selection behavior of drivers. Spot speed data from 95 study locations provided very high-
38 fidelity data as to the speed selection of more than 46,000 drivers under free-flow conditions. This
39 included 67 road segments where speed limits were increased from 55 to 65 mph, as well as 28
40 control sites where the speed limit was a consistent 55 mph over the three-year study period. Three
41 waves of speed data were collected, including shortly before (2017), one year after (2018), and
42 two years after (2019) the increases occurred.

43 From a big-picture perspective, the results show that the 10-mph speed limit increases
44 resulted in travel speeds that were generally between 3 mph and 5 mph higher across the
45 distributions of both passenger vehicles and large trucks. These findings are largely consistent with
46 prior research and reinforce the fact that drivers adjust their speeds based upon the posted limit

1 and to their environments, particularly on two-lane highways. Notably, the travel speed increases
2 varied significantly among drivers: the magnitude of these increases tend to be highest among the
3 top end of the speed distribution. In contrast, the lowest speed drivers increased their speeds by
4 the least amount. This is important from a safety management perspective as these differences in
5 speed selection behavior also tend to increase the variability in travel speeds, helping to explain
6 the increases in the standard deviation in speeds among both passenger vehicles and heavy vehicles
7 following the speed limit increases. For both vehicle types, these increases were generally in the
8 range of 0.8 to 0.9 mph.

9 This increase in variability runs counter to the frequent argument that speed limit increases
10 tend to reduce the variability in speeds, as well as the resultant crash risk. For example most of the
11 previous speed limit increases have been justified with the argument that existing operating speeds
12 on high-speed roadways tend to exceed the posted speed limit anyways, often by significant
13 amounts (40). It would be very interesting to examine how these effects extrapolate to speeds
14 beyond 65 mph or to other facility types, such as limited access freeways.

15 The magnitude of the changes in speed limits also varied significantly based upon roadway
16 characteristics, including between passing and no-passing zones, along passing relief lanes, and,
17 particularly, on horizontal curves. In each of these instances, a few common trends emerged. When
18 opportunities to drive faster arose, the fastest drivers increased their speeds more so than middle
19 and lower speed drivers. Consequently, an important next step is to determine how these trends in
20 driver speed selection impact safety performance.

21 Such research would provide important support to inform future speed limit policy
22 decisions. While the 85th percentile speed has historically been viewed as a de facto performance
23 measure for determining appropriate speed limits, a 2018 survey conducted by the National
24 Committee on Uniform Traffic Control Devices (NCUTCD) Task Force shows that those
25 professionals who perform posted speed limit studies rarely use only the 85th percentile speed and,
26 instead, consider the context of the roadway where the speed limit change is being considered (41).
27 This includes factors explicitly noted in the Manual of Uniform Traffic Control Devices (2) that
28 may be considered when establishing or reevaluating speed limits, which include road
29 characteristics, roadside development, and reported crash experiences. Being able to relate
30 differences in speed distributions to these factors has the potential to provide a more robust,
31 quantitatively based analysis framework for selecting appropriate speed limits for specific site
32 conditions.

33 Lastly, this study appears to be among the first in the traffic safety research literature to
34 exploit the advantages of quantile regression. As clearly demonstrated herein, reliance on OLS
35 regression allows for important insights into impacts on the conditional mean speed of traffic based
36 upon speed limit increases and other site characteristics. However, significant information is lost
37 by considering only the average speed of traffic. Quantile regression is likely to provide valuable
38 insights across a range of other contexts in which there is particular interest amongst the highest
39 and lower quantiles of a distribution.

40 Lastly, there are several limitations that should be noted with respect to this study. First,
41 quantile regression as applied in this study allows for the investigation of differences in speed
42 selection behavior within the distribution of vehicles observed at specific roadway locations.
43 However, it is important to note that these quantiles do not necessarily represent the speeds of the
44 same drivers across locations. For example, a driver may be in significantly different quantiles
45 across study locations or at the same study location during a different time period. Nonetheless,
46 the consistency of these results across vehicle types and quantiles suggest that important

1 relationships do exist. This is an area where naturalistic driving study data, or other similar
2 methods, would be valuable as they would allow for inferences as to various quantiles of interest
3 while controlling for driver-specific effects.

4 Moving forward, the establishment of maximum speed limits on rural two-lane highways
5 will continue to be an area of substantive interest to researchers, legislatures, and the traveling
6 public. Ultimately, additional research is warranted to fully understand the nature of these
7 relationships. For example, the impacts of emerging concerns, such as distracted driving and the
8 integration of connective and autonomous vehicles, are among the issues that prompt the need for
9 such scrutiny.

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