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Subject: Future privately-owned automated vehicle (PAV) scenarios in the Greater Toronto and Hamilton Area

This memorandum explores the predictors of future adoption of privately-owned automated vehicles (PAVs) and the outlook for PAVs to become a significant share of vehicle holdings in the future. 2018 consumer survey data is used to explore several future potential scenarios through which future PAV market shares among Greater Toronto and Hamilton Area residents are estimated.

Memorandum Purpose and Approach

This memorandum explores future PAV adoption scenarios in the Greater Toronto and Hamilton Area using data from a 2018 consumer survey (N=3,200). Logistic regression models are estimated to explore the predictors of prospective PAV adoption using stated preference data and these models form the basis for future-oriented forecasts. The binary decision (yes or no) is modeled regarding an individual's stated intent to pay at least a given price relative to conventional vehicles. Logistic regression model results (see Tables 2-5) indicate that predictors of willingness to purchase a PAV are strongest for the lower price thresholds (e.g. only a $1,000 premium).

Scenarios are estimated based on ten-, twenty, and thirty-year future timeframes but estimates should be interpreted along a continuum of possibilities. Five key factors are used to guide scenarios. First, adoption of PAVs is estimated based on different prices (premiums) of $1,000, $5,000, $10,000, and $15,000 more relative to conventional vehicles. Second, the underlying attitudes of GTHA residents are expected to change over time. Given that younger age cohorts are currently most interested in AVs, future scenarios explore changes such that current younger cohorts retain more of their current attitudes as they age (relative to current older generations). Third, land use factors (population density) are linked with greater interest in AVs – leading estimated changes in the intensity and geography of land uses to affect uptake. Fourth, information availability (consumer knowledge of Waymo) is expected to affect consumer interest in AVs. Finally, it is expected that future AV adoption is linked with household purchasing power. As such, recent recessionary conditions may be expected to affect long-term household income – thereby affecting AV adoption likelihoods. Table 1 further introduces scenarios explored through this initiative.

Some variables which drive scenarios are statistically insignificant (though coefficients retain the same direction) in models at higher price points (see Tables 2 through 5). Nevertheless, these are retained to both illustrate the relative magnitudes of their expected impacts and to enable comparisons with Laidlaw, Sweet, and Olsen (2018)[1]. As such, the predictors of early adopters are less certain (those at $15,000 price premium) than of later adopters (those at a $1,000) price premium. On this basis alone, scenario-based results would be expected to indicate weak roles for land use changes (in all models except the $1,000 premium) and knowledge of Waymo (in the $15,000 premium scenario only). Most fundamentally, before the market shares are estimated using model scenarios, the inferential models already indicate that PAV prices are the most significant factor in willingness to adopt a PAV among GTHA consumers.

[1] *Laidlaw, Kailey, Matthias Sweet, and Tyler Olsen. "Forecasting the Outlook for Automated Vehicles in the Greater Toronto and Hamilton Area using a 2016 Consumer Survey." Prepared for Metrolinx and the City of Toronto, March 9, 2018. http://transformlab.ryerson.ca/wp-content/uploads/2018/03/Laidlaw_Sweet_Olsen_Report3_scenarios_20180309.pdf*

Scenarios include:

1. Base Case - This acts as the effective base case in which PAVs are available for private purchase but there are no changes to public preferences or policy actions.
    a. Land uses - population density does not change
    b. Consumer information - consumer knowledge on Waymo remains the same (16.9% are aware of Waymo)[2]
    c. Demographic change - no demographic change (age-specific preferences are expected to remain the same as currently estimated in inferential models) and
    d. Household income - no household income effects.
2. Ten-Year Future – a medium term future in which most consumers replace their vehicle once
    a. Land uses - Population density grows (by 17%),
    b. Consumer information - consumer knowledge increases (65% are aware of Waymo), and
    c. Demographic change - no demographic change (age-specific preferences are expected to remain the same as in the base case) and
    d. Household income – no changes in household income.
3. Twenty-Year Future – a longer-term future in which significant social change is possible
    a. Land uses - population density grows (by 39%),
    b. Consumer information - consumer knowledge increases (70% are aware of Waymo),
    c. Demographic change - older demographic cohorts have more similar preferences to today's younger cohorts (cohort-specific effects are 10%) and
    d. Household income - 10% of households are shifted to the next lower household income bracket.
4. Thirty-Year Future – a longer-term future in which significant social change is possible
    a. Land uses - population density grows (by 61%),
    b. Consumer information - consumer knowledge increases (75% are aware of Waymo),
    c. Demographic change - older demographic cohorts have even more similar preferences to today's younger cohorts (cohort-specific effects are 20%) and
    d. Household income - 20% of households are shifted to the next lower income bracket.

Results

Within the range of tested changes (e.g. changes in cohort effects, land use patterns, information, and income) and price thresholds (ranging from a $1,000 to more than a $15,000 premium for an AV relative to conventional vehicles), the price at which AVs are sold is the single biggest expected determinant of PAV uptake. For example, for the thirty-year future scenario, the PAV market share decreases by 46.7% from 53.9% (for a $1,000 premium) to 7.2% (for a $15,000 premium) based on price differences alone. In comparison, even assumed changes in all other covariates (cohort effects, land use patterns, information and income) only affect a maximum of a 5.1% change in market share for the $1,000 premium (from 48.8% in the effective base to 53.9% for the 30-year future scenario).

[2] *While awareness of Waymo is not the same as knowledge of automated vehicles, this covariate is used as a heuristic for the information dissemination process.*

Factors other than price appear to impact PAV adoption, but within the range of scenario assumptions, no single factor is expected to affect PAV uptake by more than 3.6% in the 30-year scenario. This finding is not surprising given that the estimated effect of land use patterns is significant only in the $1,000 price premium model, while the estimated effect of Waymo knowledge is only insignificant in the $15,000 price premium model. Among non-price related effects, cohort effects had the strongest impact on market shares (a 3.6% difference in a thirty-year future for a $1,000 price premium), whereas income effects are relatively weaker in dampening market shares (i.e. 0.4% difference in a thirty-year future for a $1,000 price premium). Increasing consumer information (modeled as familiarity with Waymo from 17% to 65%) increases market shares by 2.6% from the base case to the ten-year future scenario. While land use changes have impacts on expected PAV adoption, the geography of land use changes is expected to affect the magnitude of impacts[3] and these scenarios assume equal percent increases in growth across all levels of geography – which is indicative of strong concentration.

Table 1. Scenarios Estimating Private Automated Vehicle Market Shares

Future Scenarios		Market Share of AVs			
Effective Base Case	No Change where 17% of Consumers know about Waymo	*$1,000* **48.8%**	*$5,000* **25.4.%**	*$10,000* **12.6%**	*$15,000* **6.5%**
Ten-Year Future	Population Density (1.17x) 65% of Consumers know about Waymo No Demographic Change No Income Effects	**51.8% (+3%)***	**27.6.% (+2.2.%)***	**13.3% (0.7.%)***	**6.8% (+0.3%)***
Twenty-Year Future	Population Density (1.39x) 70% of Consumers know about Waymo Decrease age effect by 10% 10% HH Income Effects	**52.7% (+3.9%)***	**28.0% (+2.6%)**	**13.6.% (+1%)***	**7.0% (+0.5%)***
Thirty-Year Future	Population Density (1.61x) 75% of Consumers know about Waymo Decrease age affect by 20% 20% HH Income Effects	**53.9% (+5.2%)*** **	**28.2% (+2.8%)***	**14.0% (+1.4%)***	**7.2% (+0.7%)*** ***

**Market Share % Increase (Difference from Base)*

***Assumed income effects decrease PAV shares by 0.4%, age effects increase PAV shares by 3.6%.*

**** Assumed income effects decrease PAV shares by 0.2%, age effects decrease PAV shares by 0.6%.*

All scenarios assume that PAVs would be available across all vehicle body types and styles and, as such, these forecasts are higher than one might expect if that is not the case. Nevertheless, without significant long-term

[3] *These scenarios assume constant percentage changes in land use intensity across the study area – making the absolute concentration of intensification most acute in already dense areas. Tests were performed based on different allocations – for example that land uses would intensify in equal absolute intervals across space. The more concentrated assumption in this exercise represents the strongest expected impact of land use changes on PAV uptake. More precise estimates of land use change were requested of the City of Toronto but were unavailable for these modeling exercises due to sensitivity concerns.*

changes in consumer preferences outside of the range of observed preferences, PAV market shares are unlikely to exceed 8% if a price premium of $15,000 is expected.

Conclusions

The results of these scenarios indicate that future PAV uptake hinges most fundamentally on the price premiums of automated vehicles. If prices are approximately $1,000 more than conventional vehicles, up to half of the vehicle fleet may become fully automated, if all vehicle types and styles are available using both conventional and fully-automated technologies. However, if a price premium of $15,000 relative to conventional vehicles is expected, it is unlikely for the PAV market share to exceed eight percent without significant changes in consumer preferences outside of the range of those currently-observed. While information provision (modeled in these scenarios very simplistically as awareness of Waymo) appears to play a meaningful role, the strongest non-price effect in these scenarios relates to cohort effects and whether the attitudes of younger generations (e.g. the Millennials) change significantly as they age.

Table 2: Logit Model – Additional Willingness to Pay for a Fully Automated Vehicle - $1000 premium
Reference group: 18-year old female who is unaware of Waymo with a household income of $60 to $99,999

Explanatory Variables	Value	Std. Error	T-Value	
Age	-0.031	0.003	-10.698	***
HH Income ($100,000 to $124,999) & HH Income ($125,000 to $175,000)	0.260	0.095	2.741	**
HH Income ($175,000 and above)	0.660	0.151	4.362	***
Prefer not to answer & I don't know	-0.646	0.133	-4.864	***
Gender (Male)	0.433	0.082	5.310	***
Aware of Waymo (formerly Google Car)	0.753	0.114	6.603	***
Population Density	0.068	0.032	2.109	*
Travelled yesterday by car	0.543	0.120	4.510	***
Residual Deviance: 3518.7				

Note: Significance indicated at 0 (***), 0.001 (**), 0.01 (*), 0.05(.), and 0.1( )-levels

Table 3: Logit Model – Additional Willingness to Pay for a Fully Automated Vehicle - $5000 premium
Reference group: 18-year old female who is unaware of Waymo with a household income of $60 to $99,999

Explanatory Variables	Value	Std. Error	T-Value	
Age	-0.029	0.003	-8.747	***
HH Income ($100,000 to $124,999) & HH Income ($125,000 to $175,000)	0.497	0.103	4.839	***
HH Income ($175,000 and above)	1.079	0.149	7.264	***
Prefer not to answer & I don't know	-0.545	0.178	-3.064	**
Gender (Male)	0.070	0.091	0.764	
Aware of Waymo (formerly Google Car)	0.740	0.110	6.748	***
Population Density	0.046	0.037	1.257	
Travelled yesterday by car	0.436	0.149	2.935	**
Residual Deviance: 3011.9				

Note: Significance indicated at 0 (***), 0.001 (**), 0.01 (*), 0.05(.), and 0.1( )-levels

Table 4: Logit Model – Additional Willingness to Pay for a Fully Automated Vehicle - $10,000 premium
Reference group: 18-year old female who is unaware of Waymo with a household income of $60 to $99,999

Explanatory Variables	Value	Std. Error	T-Value	
Age	-0.030	0.004	-6.766	***
HH Income ($100,000 to $124,999) & HH Income ($125,000 to $175,000)	0.274	0.135	2.028	*
HH Income ($175,000 and above)	1.021	0.175	5.841	***
Prefer not to answer & I don't know	-0.435	0.240	-1.811	.
Gender (Male)	-0.037	0.118	-0.311	
Aware of Waymo (formerly Google Car)	0.382	0.048	2.759	**
Population Density	0.037	0.048	0.771	
Travelled yesterday by car	0.951	0.242	3.929	***
Residual Deviance: 2055.4				

Note: Significance indicated at 0 (***), 0.001 (**), 0.01 (*), 0.05(.), and 0.1( )-levels

Table 5: Logit Model – Additional Willingness to Pay for a Fully Automated Vehicle - $15,000 premium
Reference group: 18-year old female who is unaware of Waymo with a household income of $60 to $99,999

Explanatory Variables	Value	Std. Error	T-Value	
Age	-0.023	0.006	-3.942	***
HH Income ($100,000 to $124,999) & HH Income ($125,000 to $175,000)	0.127	0.184	0.692	
HH Income ($175,000 and above)	0.941	0.219	4.292	***
Prefer not to answer & I don't know	-0.430	0.320	-1.344	
Gender (Male)	0.058	0.156	0.374	
Aware of Waymo (formerly Google Car)	0.244	0.184	1.322	
Population Density	0.070	0.066	1.070	
Travelled yesterday by car	0.794	0.314	2.531	*
Residual Deviance: 1336.2				

Note: Significance indicated at 0 (***), 0.001 (**), 0.01 (*), 0.05(.), and 0.1( )-levels