The demand for automated vehicles: A synthesis of willingness-to-pay surveys

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ABSTRACT

This paper synthesises the findings of surveys of consumer willingness-to-pay for vehicle automation. Some studies report only mean or median estimates of willingness-to-pay for vehicle automation. Other studies provide data enabling demand functions to be derived. Six demand functions have been estimated and are compared. Maximum willingness-to-pay (around 25,000 to 40,000 US dollars) exceeds low estimates of the added costs of automated vehicles (around 10,000 US dollars). On average, close to 30% of respondents state zero willingness to pay more for an automated car than for a conventional car. Based on current knowledge, it is likely that a majority of consumers will initially find automated vehicles too expensive. However, the price of automated vehicles can be expected to fall as technology matures and vehicles are manufactured in larger numbers.

1. Introduction

Extensive research and industrial engineering take place in order to develop cars that are partly or fully automated. Fully automated cars are expected to produce large societal benefits in terms of more efficient use of road capacity, fewer accidents and less energy use and emissions (see e.g. Fagnant and Kockelman, 2015). There are many studies of the potential impacts of automated cars on road capacity, accidents and emissions; for a recent review, see Elvik et al. (2020). An issue that has been less studied, is whether automated cars will be sufficiently demanded to replace manually operated cars. The aims of this paper are:

1. To synthesise the results of studies of the willingness-to-pay for automated cars,
2. To estimate demand functions for automated cars and compare these functions between studies,
3. To compare the estimates of willingness-to-pay to estimates of the costs of automated vehicles.

The paper is organised as follows. The next section (section 2) describes how studies of willingness-to-pay have been identified. Each study is then briefly presented (section 3). The results of the studies are summarised in terms of estimates of the mean willingness-to-pay for automated cars, median willingness-to-pay and the demand function, for studies providing enough data to permit the derivation of a demand function. Next, studies of the cost of automated vehicles are summarised

(section 4). Then, estimates of willingness-to-pay are compared to cost estimates (section 5) in order to assess the potential demand for automated cars. The paper is rounded off with a discussion of the results (section 6) and conclusions (section 7).

2. Literature survey

The ongoing Horizon 2020 project LEVITATE (Societal level impacts of connected and automated vehicles) has conducted a systematic survey to identify studies of the potential impacts of connected and automated vehicles. Part of this survey aimed to identify studies of willingness-to-pay for automated cars. The survey relied on a combination of sources: (1) A library of studies compiled in LEVITATE by one of the partners in the project; (2) Studies listed in the weekly newsletter "SafetyLit"; (3) A search of Science direct using "automated*" and "willingness-to-pay" as search terms occurring in the title, abstract or key words of papers; (4) The ancestry method, i.e. identifying studies in the reference lists of studies already obtained.

Studies were included if they referred to cars with an automation level of 3 or higher according to the SAE taxonomy of levels of automation, and included at least one of the following: (1) an estimate of the mean willingness-to-pay for automated vehicles; (2) an estimate of the median willingness-to-pay for automated vehicles (or information permitting median willingness-to-pay to be inferred); (3) data permitting the derivation of a demand function for automated vehicles. Studies that did not explicitly refer to the SAE automation levels were included if

they described cars as "automated" or "fully automated".

3. Willingness-to-pay surveys and demand functions

Studies of the willingness-to-pay for automated cars will be presented chronologically. For each study mean willingness to pay and, if possible, median willingness to pay is stated. For studies providing sufficient data, a demand function is derived. Six of the studies presented below allowed for a demand function to be derived.

To provide a benchmark for assessing study results, the mean price of a new car has been added to the figures showing demand functions. According to Statista (www.statista.com) the mean price of a new light vehicle sold in the United States in 2017, which is probably the most recent year data were collected in the studies presented below, was 34,340 US dollars. Five of the six studies providing data for demand functions state results in US dollars. Three of these studies were made in the United States, a fourth was based on data for 109 countries. Two studies were made in China. For these studies, the mean price of a new car in China was provided. An estimate of 130,000 Chinese yuan (corresponding to 18,800 US dollars) was used (www.numbeo.com).

The studies presented below were all reported between 2014 and 2019. Estimates of willingness to pay refer to different years but have not been adjusted to a common year. According to the United States Bureau of Labor Statistics, the consumer price index for new cars was stable between 2013 and 2017, i.e. the prices of new cars did not change during this period.

All studies of willingness-to-pay indicate how much more respondents are willing to pay for an automated vehicle on top of what they would pay for a conventional vehicle. The studies thus reflect the increase in the price of a car respondents are willing to accept.

3.1. Payre et al., 2014

The first study (Payre et al., 2014) was published in 2014. The sample surveyed consisted of 421 French drivers. They were asked, among other things, about their willingness-to-pay (WTP) for automated cars. Mean willingness to pay was 1624 Euros. This referred to those who envisaged that they would buy a fully automated vehicle. The paper reports that mean willingness-to-pay was 1468 Euros among women and 1877 Euros among men. It states that minimum willingness-to-pay was 0 and maximum was 10,000 Euros. Details of the WTP-studies that have been included are given in Table 1.

It is not possible to derive a demand function based on this information. While data are provided for several elements of a demand function (maximum WTP, overall mean WTP, mean WTP by gender) are provided, they are not sufficiently detailed to derive a demand function, nor to estimate median WTP.

3.2. Schoettle and Sivak (2014)

Schoettle and Sivak (2014) report the results of a study of public opinion about automated cars in six countries. One of the questions in the survey concerned willingness to pay for automated vehicles. Unfortunately, the report by Schoettle and Sivak (2014) presents few details about the results of the WTP-question. The only information that can be extracted is the percentage stating zero WTP and the median WTP for the full sample. This information is given in Table 1 for each country included in the survey.

It is interesting to note that median WTP was positive only in the two poorest countries included: China and India. In the other countries, more than half of respondents stated zero WTP, meaning that median WTP is also zero.

Table 1
Studies of willingness to pay for automated cars.

Study	Country (N)	Technology	Percentage with willingness-to-pay = 0	Subsample for willingness-to-pay	Mean willingness-to-pay	Median willingness-to-pay	Possible to derive demand function
Payre et al. (2014)	France (421)	Fully automated	22	WTP > 0	EURO 1624	No data	No
Schoettle and Sivak, 2014	Australia (505)	SAE level 4	55	Full sample	No data	USD 0	No
	China (610)	SAE level 4	22	Full sample	No data	USD 1600	No
	India (527)	SAE level 4	30	Full sample	No data	USD 160	No
	Japan (585)	SAE level 4	68	Full sample	No data	USD 0	No
	United Kingdom (501)	SAE level 4	60	Full sample	No data	USD 0	No
	United States (527)	SAE level 4	55	Full sample	No data	USD 0	No
Kyriakidis et al. (2015)	109 countries (4886)	Fully automated	22	Full sample	USD 6820	USD 519	Yes
Shin et al. (2015)	South Korea (675)	SAE level 3	No data	Full sample	USD 3727	No data	No
Bansal et al. (2016)	United States (347)	SAE level 4	19 (see text)	WTP > 0	USD 7253	USD 2570	Yes
Bansal and Kockelman, 2017	United States (2167)	SAE level 4	59	Full sample	USD 5857	USD 0	Yes
Daziano et al. (2017)	United States (1260)	Partial automation	No data	Full sample	USD 3538	No data	No
	United States (1260)	Full automation	No data	Full sample	USD 4917	No data	No
Bansal and Kockelman, 2018	United States (1088)	SAE level 4	31 (see text)	WTP > 0	USD 7589	USD 3470	Yes
Liu et al. (2019)	China (441)	Fully automated	31	Full sample	USD 3577	USD 763	Yes
Liu et al. (2019)	China (1135)	Fully automated	26	Full sample	USD 4454	USD 1114	Yes
Shin et al. (2019)	Japan (188089)	Fully automated	No data	Full sample	USD 1650	No data	No

3.3. *Kyriakidis et al. (2015)*

Kyriakidis et al. (2015) present the results of survey made in 109 countries. There were 4886 respondents in total. Among the questions asked, was how much respondents were willing to pay for a partially or fully automated car. The answers referring to a fully automated car have been studied further.

Kyriakidis et al. (2015) do not report mean or median WTP for fully automated cars. They state that 4.9% of respondents indicated that they were willing to pay 30,000 US dollars or more for an automated car. 22% answered that they were not willing to pay anything. More detailed information is given in Fig. 4 of their paper. In that figure the number of respondents is shown for the following categories of WTP: > 50,000; 30,001–50,000; 15,001–30,000; 10,001–15,000; 7,001–10,000; 5,001–7,000; 3,001–5,000; 1,001–3,000; 501-1,000; 1–500; and 0. The following mean values were assigned to these categories: 60,000; 40,000; 22,500; 12,500; 8,500; 6,000; 4,000; 2,000; 750, 250, 0. The percentage of respondents in each category was estimated, based on Fig. 4 in the paper by Kyriakidis et al.

Based on this information, mean WTP was estimated as 6,820 US dollars and median WTP as 519 US dollars (see Table 1). Note the large difference between the mean and median WTP. A demand function was developed by cumulating the number of respondents in the categories for WTP. Thus, 1.2% had a WTP of at least 50,000.1.2% + 3.7% had a WTP of at least 30,000.1.2% + 3.7% + 6.1% has a WTP of at least 15,000 – and so on. The resulting demand function is shown in Fig. 1.

It is seen that the demand function falls sharply and then becomes flatter when WTP is less than about 7,000 US dollars. From the 78th percentile, the function touches the abscissa, as 22% stated zero WTP. For a demand function with this shape, there will be a large difference between mean WTP and median WTP.

3.4. *Shin et al., (2015)*

Shin et al. (2015) conducted a stated preference study of consumer preferences and willingness to pay for advanced vehicle technology and fuel types. The study was made in South Korea and sample size was 675. The study did not refer to the SAE taxonomy of levels of automation. The characteristics of advanced vehicles were listed one-by-one. The vehicle type that most resembled an automated vehicle had the following characteristics: connectivity, voice command, autonomous speed control, and wireless internet. It did not have autonomous lane keeping. This suggests that the vehicle would mostly be able to drive autonomously, since connectivity would enable platooning, but that driver intervention would be needed in order to change lane. Based on this interpretation, the vehicle is classified as an SAE level 3 vehicle.

Willingness-to-pay, presumably mean WTP, is stated for connectivity, autonomous speed control and wireless internet. Total WTP for these systems was 3,727 US dollars (Table 1). The study does not provide information permitting a demand function to be derived.

3.5. *Bansal et al. (2016)*

Bansal et al. (2016) conducted an internet-based survey in Austin, Texas, about public interest in new vehicle technology. The survey included questions about the willingness to pay for SAE level 3 and 4 vehicle automation technology. Sample size was 347. In this paper, results for SAE level 4 vehicles will be discussed.

Mean WTP for an SAE level 4 car was 7,253 US dollars (Table 1). This included respondents with a positive WTP. The paper is not perfectly clear about whether everybody stated a positive WTP or if a share of the sample had zero WTP. It states, however, that (page 6): "19% of respondents were not at all interested in owning Level 4 AVs". In view of the fact that all other WTP-studies have found that many people are not
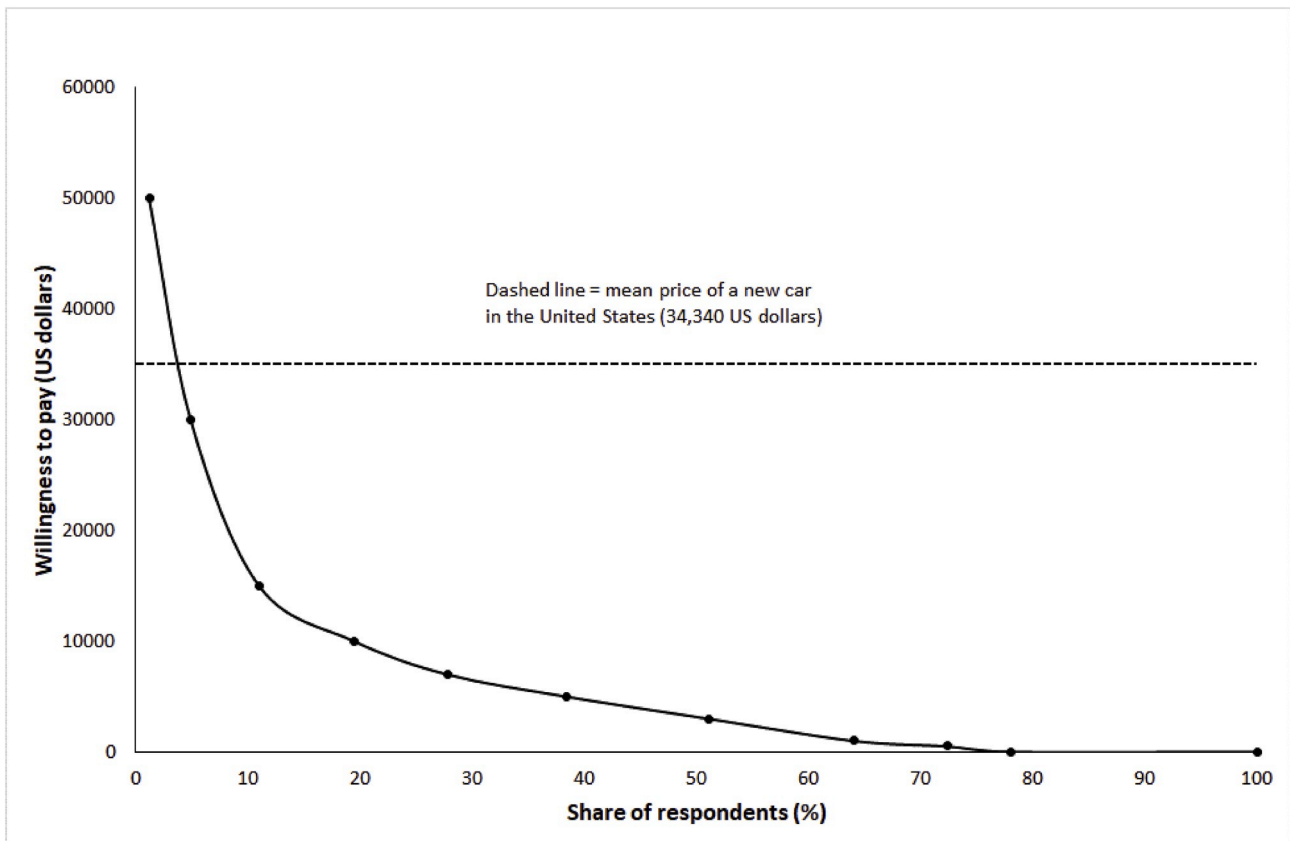

Fig. 1. Demand function based on Kyriakidis et al., (2015).

willing to pay anything at all for automated vehicles, this paper will, confer the quote above, assume that 19% of the sample had zero WTP.

WTP was given in the following categories: < 2,000; 2,000–5000; 5,000–10,000 and > 10,000. It will be assumed that mean WTP in the three first categories were, respectively: 1,000, 3,500 and 7,500. Mean WTP in the open-ended upper category (>10,000) was estimated so that overall mean WTP became 7,253. Mean WTP in the upper category based on this assumption was 17,350 US dollars. To be consistent with the midpoint of range adopted for the other categories, 17,350 US dollars was assumed to be the midpoint of the upper range. Thus, maximum WTP was estimated to be 24,700 US dollars. It was arbitrarily assumed that 1% of the sample had maximum WTP. Based on these assumptions, the demand function shown in Fig. 2 was derived.

Based on the demand function, median WTP can be estimated as 2,570 US dollars. Furthermore, if the assumption is made that 19% of the sample had zero WTP, the adjusted mean WTP becomes: (0.81 · 7253) = 5,875.

3.6. Bansal and Kockelman (2017)

Bansal and Kockelman (2017) presented a survey among 2167 Americans regarding, among other things, their willingness to pay for vehicle automation. The study investigated willingness to pay for several technologies, as well as SAE level 3 and 4 automated vehicles. Again, the focus in this paper is on SAE level 4 vehicles.

For the full sample, mean WTP for an SAE level 4 car was US dollars 5,857.59% of respondents answered that their WTP was zero. Median WTP was therefore zero. Mean WTP for those with a positive WTP was 14,196 US dollars. Willingness to pay was in the ranges: 0; less than 6,000; 6,000–13,999; 14,000–25,999; >26,000. It is assumed that mean WTP in these ranges, respectively, were: 0; 3000; 10,000; 20,000 and 34,726. Mean WTP in the uppermost open-ended interval was

determined so that mean WTP for all intervals equalled 5,857. It was assumed that mean WTP in the uppermost interval was located at midpoint of the interval. Maximum WTP was then estimated as US dollars 43,452. It was arbitrarily assumed that 1% of the sample had maximum WTP. Based on these assumptions, the demand function shown in Fig. 3 was derived.

The function resembles the demand functions presented in Figs. 1 and 2.

3.7. Daziano et al., (2017)

Daziano et al. (2017) conducted a stated preference survey in a sample of Americans designed to elicit willingness to pay for partly and fully automated cars. Sample size was 1260. No information was given about the share of the sample that had zero WTP. Mean WTP was US dollars 3,538 for partial automation and US dollars 4,917 for full automation (Table 1). Variation in WTP with respect to several variables was analysed in the paper, but it is not possible to derive a demand function based on the information given in the paper.

3.8. Bansal and Kockelman (2018)

Bansal and Kockelman (2018) report the results of a study of willingness to pay for automation technology in a sample of people living in the state of Texas, USA. Sample size was 1088. Mean WTP for SAE level 4 automation was estimates as US dollars 7,589. This was the mean WTP among those who had a positive WTP.

The study did not state the proportion with zero WTP for SAE level 4 automation. It does state, however, that 29% were not willing to pay anything for connectivity, a much cheaper technology than SAE level 4 automation. Furthermore, it states that the question about willingness to pay for automation technology was only presented to those who
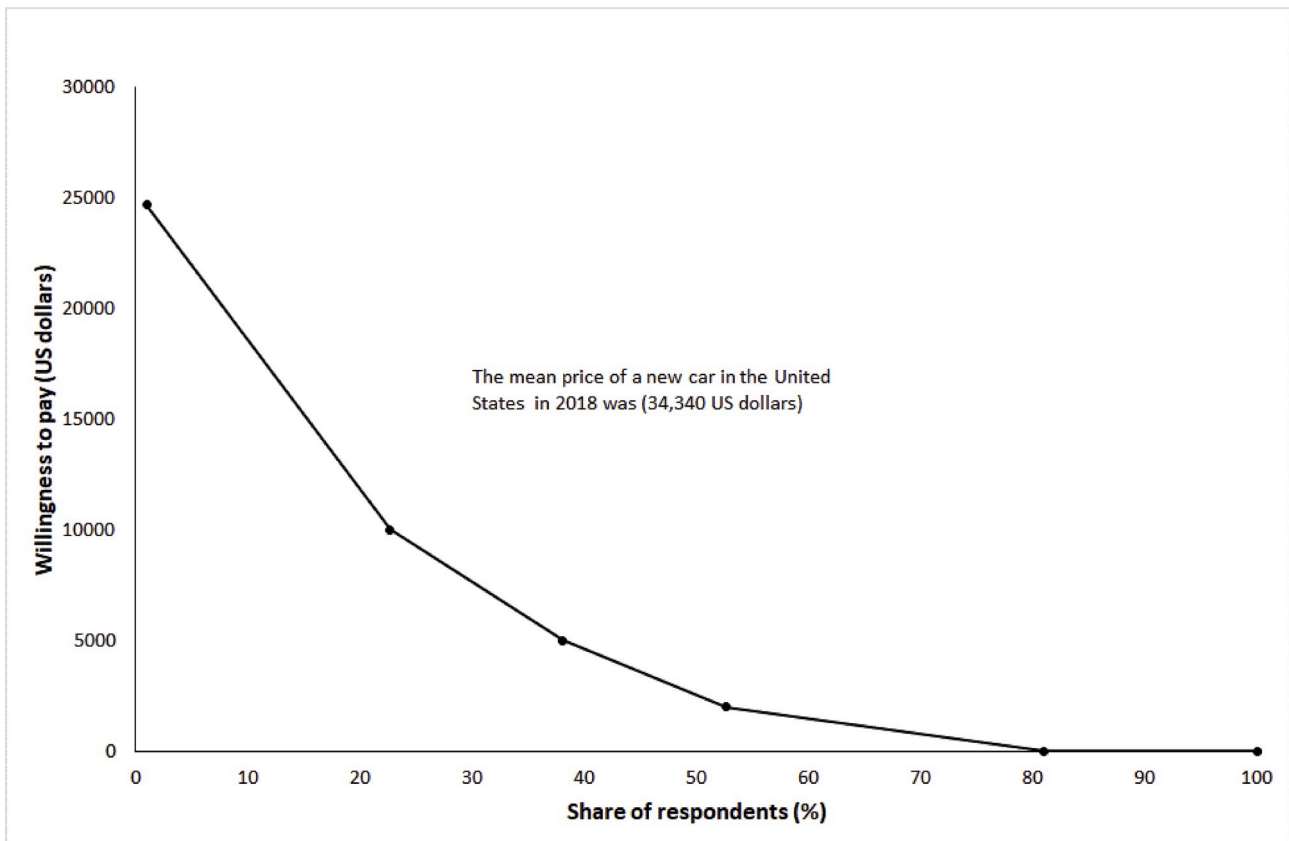

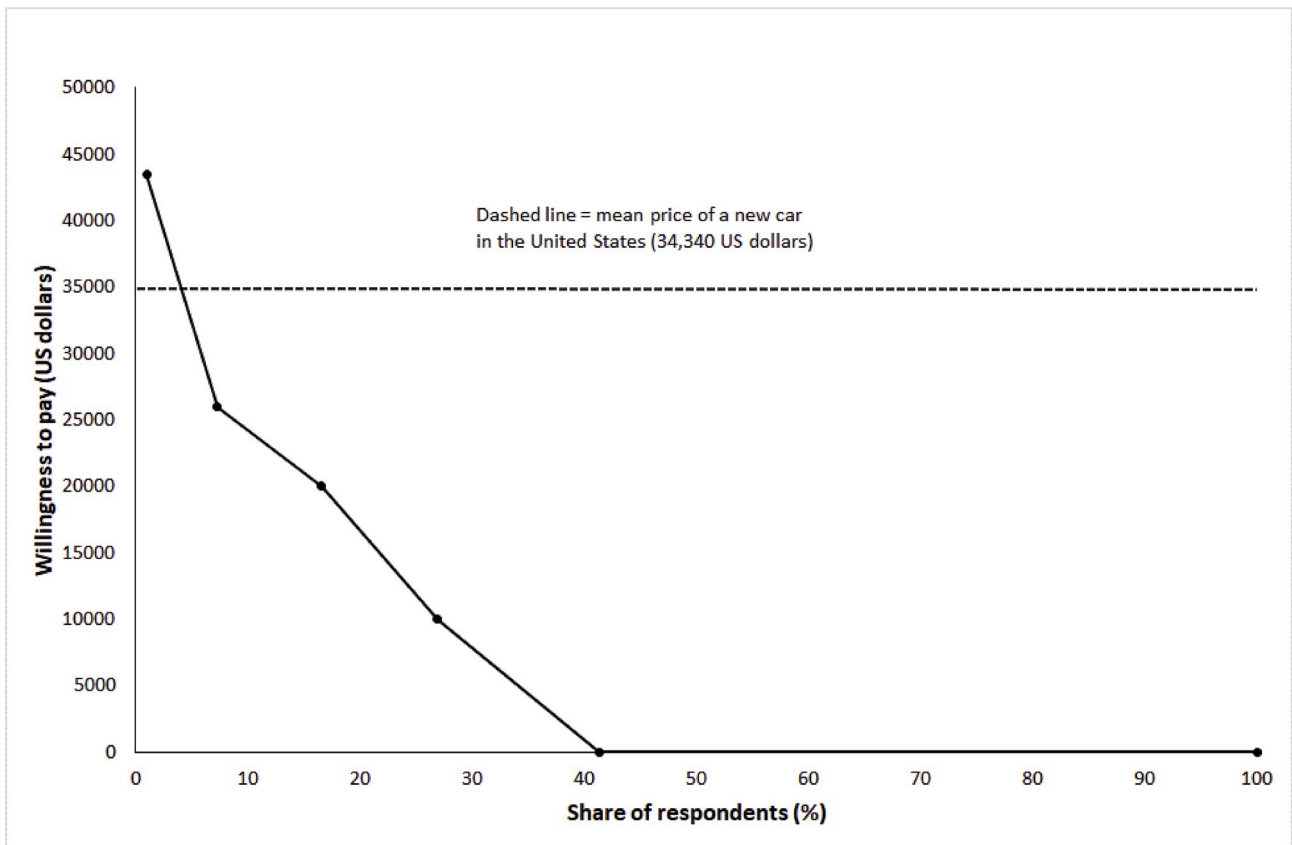**Fig. 2.** Demand function based on Bansal et al., (2016).

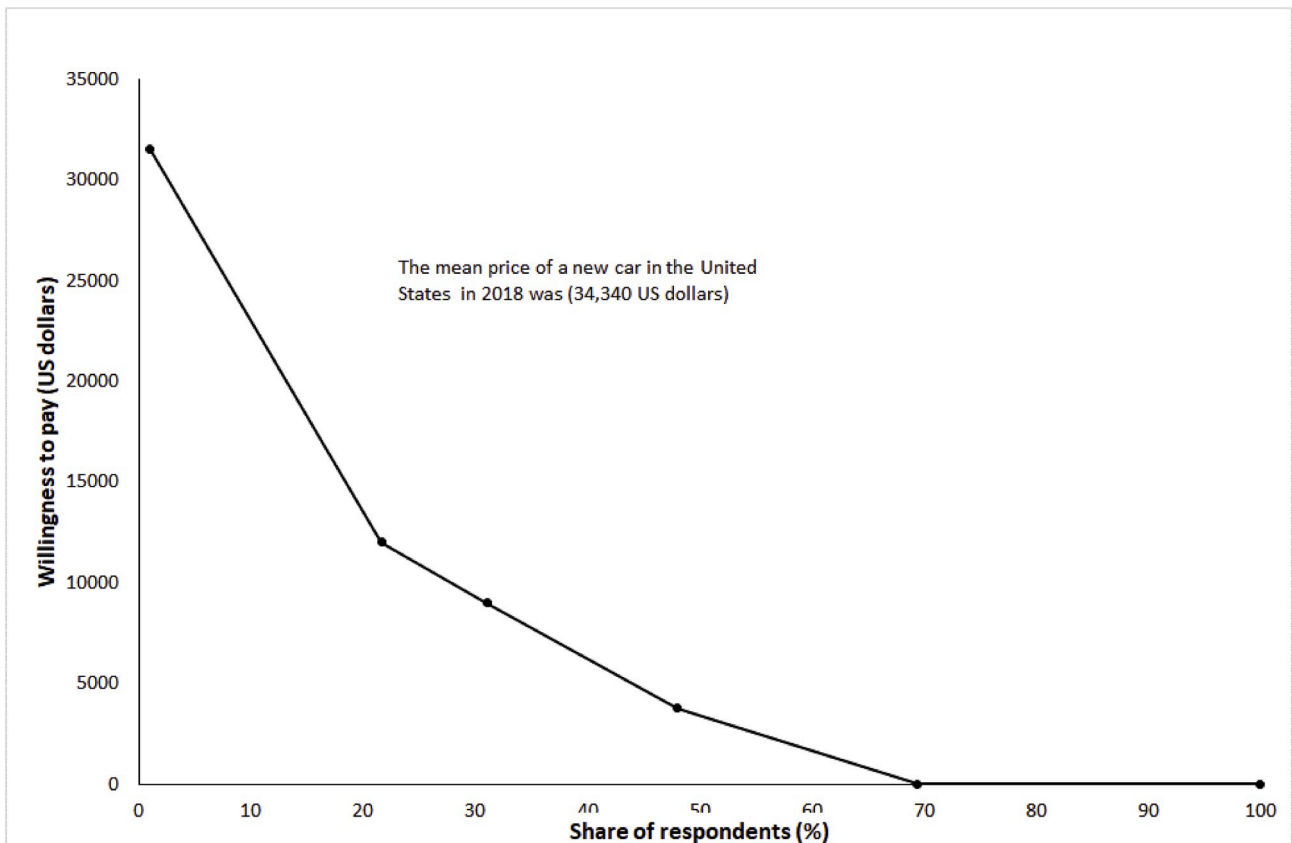**Fig. 3.** Demand function based on Bansal and Kockelman (2017).

Fig. 4. Demand function based on Bansal and Kockelman (2018).

indicated that they were planning to buy a new vehicle within the next five years. This group represented 69% of the sample. Considering the high proportion of zero WTP found, for example, by Bansal and Kockelman (2017), it is not altogether unreasonable to assume that those not planning to buy a new vehicle within the next five years (31% of the sample) had zero WTP for SAE level 4 automation technology. If this assumption is made, a demand function can be derived based on this study.

The following assumptions have been made regarding mean WTP in the intervals provided: Less than 1,500 = 750; 1,500–5,999 = 3,750; 6,000–11,999 = 9,000; 12,000 or more = 16,870. Maximum WTP = 31,500; assumed to apply to 1% of respondents. Fig. 4 shows a demand function derived by making these assumptions.

Based on the demand function, the adjusted estimate of mean WTP is: (0.69 · 7589) = 5,267. Median WTP can be estimated as US dollars 3,470. The difference between mean and median WTP is smaller than in the other studies discussed so far.

3.9. Liu et al. (2019b)

Liu et al. (2019b) conducted a survey in China about public acceptance of automated vehicles. Sample size was 441. One of the questions was about willingness to pay for automated cars. Answers were given in twelve categories, ranging from zero to more than 20,000 Chinese yuan. 31% of the sample stated zero WTP, the rest had a positive WTP for fully automated cars.

Applying the usual midpoint of interval assumption for mean WTP within each category, and assuming a mean WTP of 250,000 Yuan for the open-ended upper interval, mean WTP for the full sample can be estimated as 24668 CNY. Based on the conversion rate given in Liu et al. (2019a,b), this corresponds to US dollars 3,577. Median WTP was USD 763.

A demand function was derived based on data about the distribution of the sample between the twelve categories for willingness to pay. The function is shown, stating willingness to pay in Chinese yuan, in Fig. 5.

The figure shows a sharp decline in willingness to pay at the highest amounts, suggesting that mean WTP considerable exceeds median WTP, which was indeed found to be the case.

3.10. Liu et al. (2019a,b)

Liu et al. (2019a,b) repeated the study of Liu et al. (2019b), adding a sample from a second Chinese town, thus enlarging sample size from 441 to 1135. Willingness to pay for automated cars was elicited using the contingent valuation method, providing twelve categories (intervals) for WTP and asking respondents to choose one of these. The categories were the same as in Liu et al. (2019b).

Mean WTP was USD 4,454. Median WTP was USD 1,114. A demand function was derived, applying the same approach as for Liu et al. (2019b). The function is shown in Fig. 6.

Not surprisingly, the demand function is very similar to the one fitted to the study of Liu et al. (2019b).

3.11. Shin et al. (2019)

Shin et al. (2019) report a study made in Japan regarding advantages and disadvantages of automated cars and willingness to pay for automated cars. Mean WTP for the full sample was US dollars 1650. For those who indicated an intention to buy an automated car, mean WTP was US dollars 2520. Both these amounts are lower than what most other studies have found.

The study did not provide enough information to estimate median WTP nor to derive a demand function.
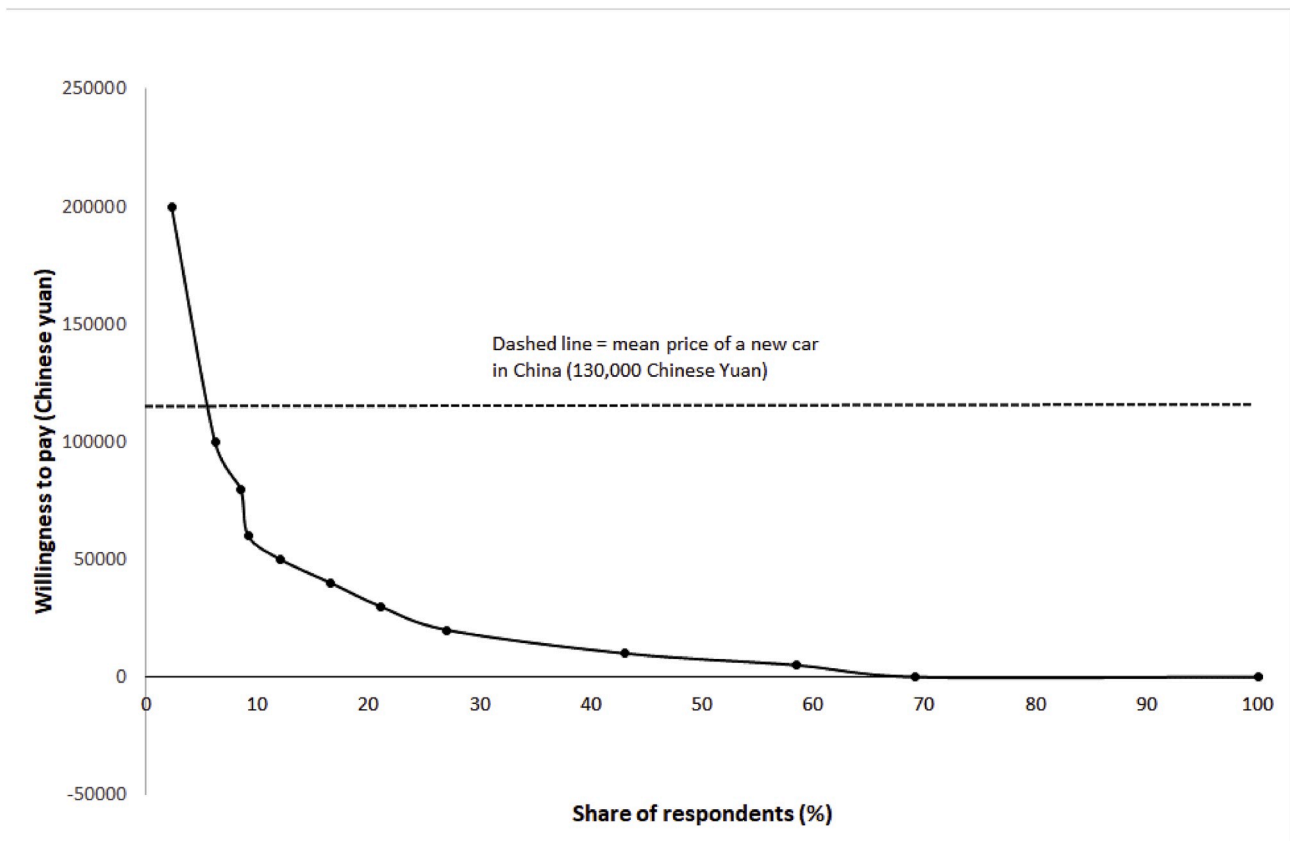

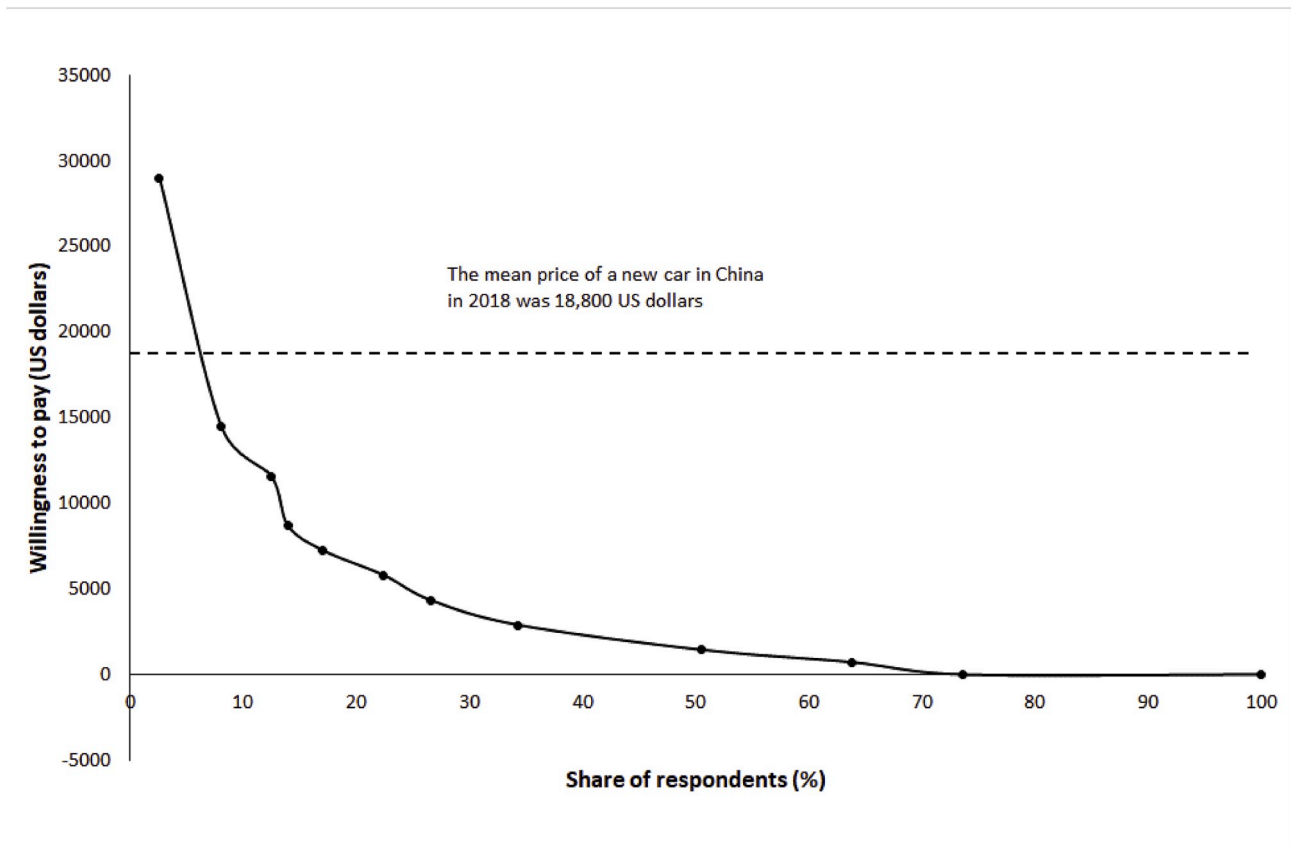**Fig. 5.** Demand function based on Liu et al., (2019a,b).

Fig. 6. Demand function based on Liu et al., (2019a,b).

3.12. Other studies

Two other studies that are related to willingness-to-pay studies, but do not estimate willingness-to-pay will briefly be mentioned. Shabanpour et al. (2018) identified factors that affected potential demand for automated cars positively or negatively. They referred to this as best case-worst case analysis. Respondents were given stated choice tasks, in which their task was to choose the most attractive and least attractive feature of an automated car. The values of the features were varied, as in any stated choice task. The price of the automated car, for example, was either 40,000, 50,000 or 60,000 US dollars. Utility weights were then estimated for the various features. Price was, unsurprisingly, found to have the largest negative utility slope, i.e. the higher the price, the less likely respondents were to buy the car. Improved safety, access to an exclusive lane and increased driving range (the maximum distance one could drive between refuelling/recharging) were found to increase the probability of buying an automated car.

Cunningham et al. (2019) report results of a survey of 6133 respondents in Australia and New Zealand. The study aimed to identify factors influencing willingness to pay for an automated car, not to estimate willingness to pay. The closest to an estimate of WTP found in the study was the answer to a question about whether respondents were willing to pay more, the same or less for a fully automated car than what they would pay for a manual car. 23% would pay less, 34% the same, 33% more and 10% a lot more than for a manual car.

3.13. Synthesising the studies

Is it possible to synthesise the findings of the studies presented above? There are two main questions a formal synthesis should answer:

1. What is the best estimate of mean and median willingness to pay for a fully automated car?
2. How does willingness to pay for an automated car vary in the population, i.e. how many are willing to pay more or less than the mean WTP and how much more or less?

To combine estimates of mean WTP, these must be made as comparable as possible. This means that they should be converted to a common currency, refer to the same level of automation and apply to the full sample, not just those with positive WTP. To accomplish this, the following changes were made in the estimates of mean WTP listed in Table 1:

1. The estimate of Payre et al. (2014) was converted to US dollars using 2013-exchange rate (EURO 1624 = USD 1222). Further it was adjusted to full sample (0.78 · 1222) = 953.
2. For Bansal et al. (2016) and Bansal and Kockelman (2018) full sample mean WTP as stated above (5,875 and 5,267) was used.
3. Only studies referring to fully automated cars or SAE level 4 or higher were included. The study by Shin et al. (2015) was omitted.

Following these adjustments, nine estimates of mean WTP were available. Fig. 7 shows a forest plot of these estimates. The simple mean WTP was US dollars 4,374. Median WTP was US dollars 4,917. The two low estimates of 953 and 1,650 US dollars pulled down the mean to a lower value than the median. Estimates were not weighted by sample size, as the study by Shin et al. (2019) would then dominate completely, due to its extremely large sample (188,089).

Except for the studies by Payre et al. (2014) and Shin et al. (2019), the estimates of mean WTP are between 3,500 and 7,000 US dollars. This range is quite small. The study by Schoettle and Sivak (2014) found that 68% of Japanese respondents stated zero WTP for SAE level 4

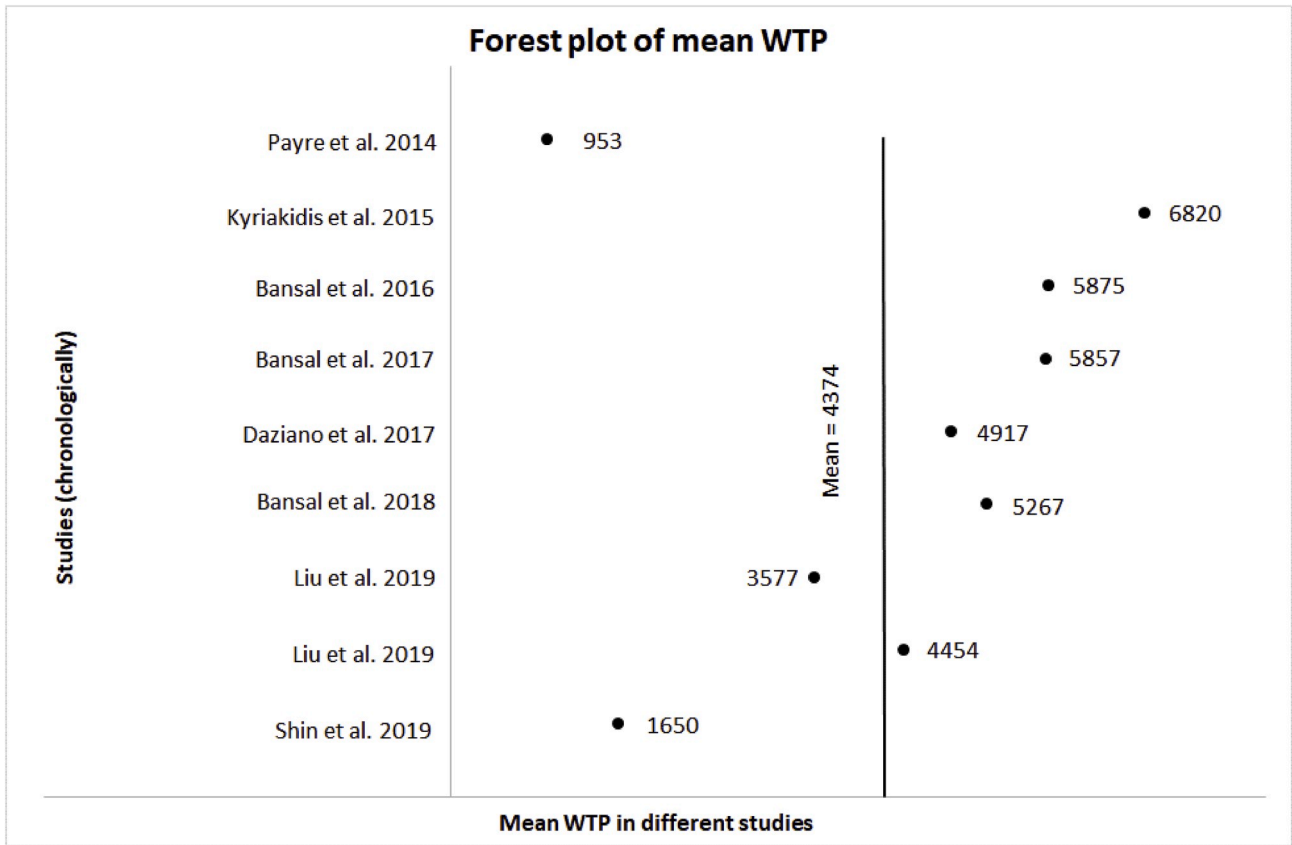**Fig. 7.** Forest plot of estimates of mean willingness to pay.
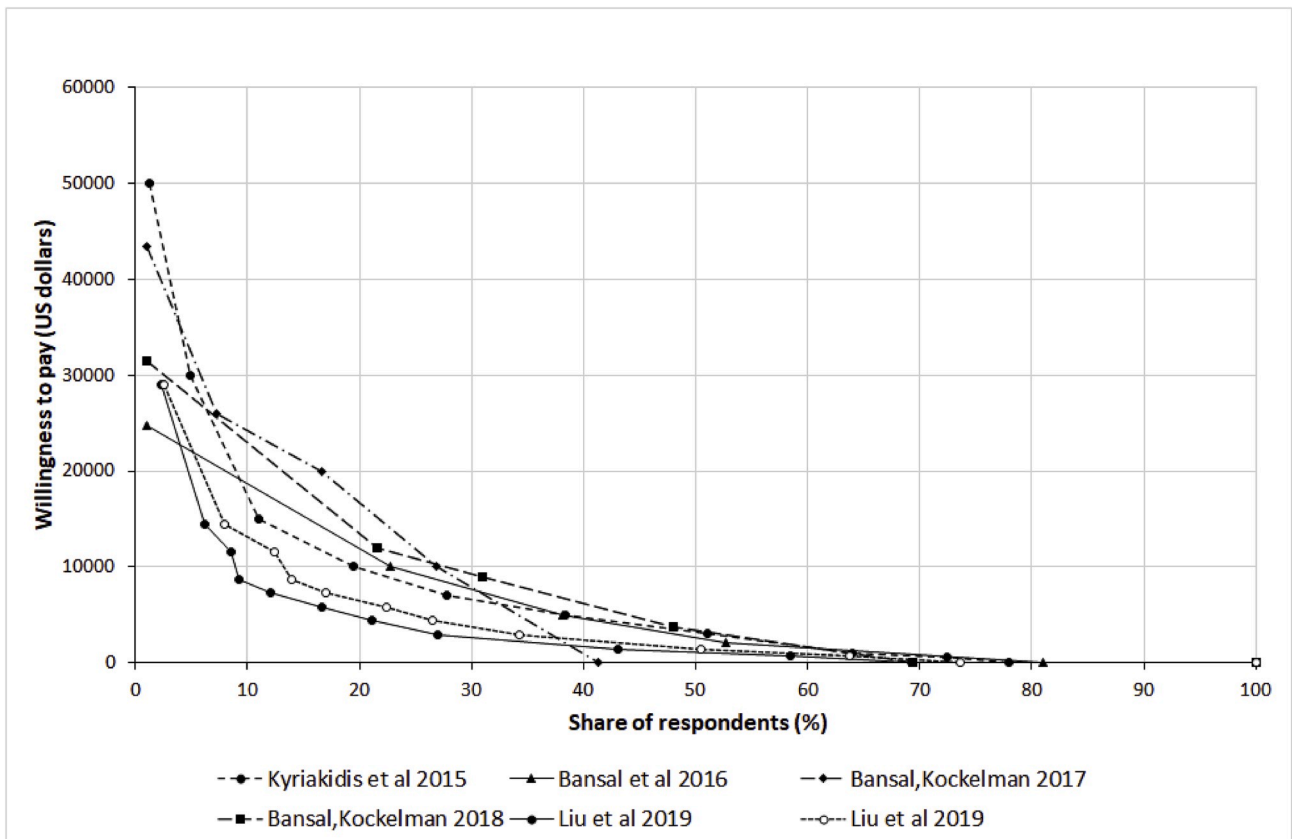

Fig. 8. Comparison of six demand functions for automated cars.

automation, the highest of the six countries included in their study. Apparently, willingness to pay for vehicle automation is lower in Japan than in the other countries where studies have been made. It is not clear why mean WTP in France was so much lower than in the other studies.

Demand functions could only be derived for some of the studies. Fig. 8 presents these demand functions. The demand function in Liu et al. (2019a,b) stated in Chinese yuan was converted to US dollars using an exchange rate of 1 yuan = 0.145 dollars. The functions have different ranges and are based on samples that differ with respect to income and other characteristics influencing willingness to pay. There were also differences in survey design that are likely to influence results. It is therefore not meaningful to try to develop a synthesised demand function. Based on Fig. 8, one may nevertheless identify some general tendencies of the distribution of willingness to pay:

1. Maximum willingness-to-pay ranges from about 25,000 US dollars to about 50,000 US dollars, with a median value of about 30,000 US dollars.
2. The share of respondents with a positive WTP of US dollars 10,000 or more varies between 9% and 27% with a median share of a little more than 20%.
3. Median willingness-to-pay (the amount where 50% are willing to pay more and 50% willing to pay less) ranges from zero to slightly less than 4,000 US dollars, with a median value of about 2,000 US dollars.
4. The share of respondents stating zero willingness to pay varies between 19% and 59% with a median value of about 30%.

As a rough approximation, it is suggested that 20% have a WTP of 10,000 US dollars or more. Median WTP is around 2,000 US dollars. About 30% have zero WTP for fully automated vehicles. This means that about 30% have a WTP between 10,000 and 2,000 US dollars and 20% have a WTP between 2,000 and 0 US dollars.

4. Costs of automated vehicles

The costs of an automated car include the costs of buying and keeping a car and the costs of operating it. Studies have been made to determine whether an automated car will cost more or less than a manual car. The studies do not easily lend themselves to a formal synthesis but will be referred to in chronological order.

Fagnant and Kockelman (2015) estimate that an automated vehicle initially will cost 10,000 US dollars more than a conventional vehicle, but that the additional cost will fall to 5,000 US dollars at 50% market penetration and to 3,000 US dollars when automated vehicles reach 90% market penetration.

Bansal and Kockelman (2017) estimate the cost of level 3 automation to 15,000 US dollars in 2015, dropping to 11,607 dollars in 2020 and 3, 220 dollars in 2045. The cost of level 4 automation was estimated as 40, 000 US dollars in 2015, reducing to 30,951 dollars in 2020 and 8,586 dollars in 2045.

Wadud (2017) reported a cost of ownership analysis for automated vehicles. He estimated current costs of owning and operating cars by income quintiles (shares of one fifth) in Great Britain. He estimated that buying an automated vehicle in 2020 would cost 16,600 US dollars more than a conventional vehicle, but that cost would fall by 5% per year. Total costs of ownership were estimated to increase by 29.6% in the lowest income quintile, falling to 16.3%, 7.9% and 2.9% in the next income quintiles. Only the upper fifth income quintile (the top 20% income earners) would save costs. For this group, a reduction of car ownership costs of 6.4% was estimated. For commercial vehicles, cost savings ranging from 15 to 30% were estimated. Thus, automated vehicles can save costs in commercial transport and for the richest private car owners. For 80% of the population, automated vehicles would be more expensive than current vehicles, even allowing for savings attributable to lower fuel consumption and more productive use of travel

time. It should be noted that no savings in insurance costs was assumed. Wadud argued that although automated vehicles will have a lower accident rate than conventional vehicles, they will be more expensive to repair or replace, resulting in an unchanged insurance premium.

Bösch et al. (2018) compared the costs of owning and operating conventional cars to automated cars. They assumed an increase in purchasing price of Swiss francs 15,000 for a small car, 35,000 for a midsize car and 66,000 for a van, all compared to a manually driven car. One Swiss franc corresponded to 0.98 US dollars in 2018. For private cars, the cost per kilometre of an automated car were found to be 4% higher than the cost of a conventional car. The main contributor to the increased cost was depreciation, which was higher because the automated car was assumed to be more expensive than the conventional car. Insurance costs were assumed to decline by 50%. The per kilometre cost of a taxi was estimated to be 85% lower for an automated taxi than for a taxi with a driver.

Shabanpour et al. (2018), in a stated preference study, assumed a purchasing price for an automated vehicle of either 40,000, 50,000 or 60,000 US dollars.

Slowik and Sharpe (2018) estimated the additional cost of level 5 automation technology for a truck to be 23,400 US dollars. The technology included sensors, communication systems and processing software.

Tirachini and Antoniou (2020) give cost estimates for fully automated vehicles of 29,490 Euro for a car, 43,433 Euro for a van, 281,234 Euro for a minibus, 419,429 Euro for a standard bus, and 627,696 Euro for an articulated bus. Presumably, all these estimates refer to the extra costs of an automated vehicle compared to an otherwise identical non-automated vehicle.

There is no consensus about what the additional cost of an automated vehicle will be, with estimates ranging from a low of 10,000 US dollars to a high of 40,000 US dollars. Some studies assume that costs will be reduced over time. This is probably reasonable, as technological innovation, learning-by-doing, and economies of scale in manufacturing will tend to reduce production costs as automation technology matures and automated cars are manufactured in large numbers. As an example, a colour TV had a price tag of about NOK 6,500 in Norway in 1975. Today, a flat screen TV can be bought from about NOK 10,000 (1 NOK = 0.09 US dollars in March 2020). During the same period consumer prices increased by a factor of almost 5.8. A colour TV (flat screen) is considerably cheaper today than it was in 1975 (the 1975-price multiplied by $5.8 \approx 37,500$).

5. Comparing costs and willingness-to-pay

It is likely that automated cars, like cars today, will be offered at different prices. If the cheapest model costs 10,000 US dollars more than a manually driven car, the synthesis of WTP-studies suggest that about 20% of consumers would be willing to pay at least that much extra for an automated car. An automated car priced at 10,000 US dollars above a manual car might therefore sell in sufficient numbers to be commercially sustainable.

An automated car priced at 40,000 US dollars above a conventional car would have a much smaller market. Yet, even at this price, the WTP-studies suggest that a few consumers, say 1–5%, might be willing to buy the car. There is a market for luxury cars today and it is likely that there would be a market for luxurious automated cars. Therefore, car manufacturers would probably offer an automated car priced at 40,000 US dollars above the price of a manual car to the market.

Based on current estimates of costs and willingness-to-pay, it is likely that the majority of consumers would initially regard an automated car as too expensive. This, obviously, would not necessarily prevent mass ownership from becoming a reality. In 1960, most Norwegian households could not afford a car. Today, nearly all households own a car, and many households own more than one car. A colour TV, as discussed above, was quite expensive in 1975. Today, most households have at

least one flat screen, available at a real price of only a little more than 25% of the 1975-price of a colour TV. It is likely that the market penetration of automated cars will follow the same pattern. Predicting how long it will take for automated cars to fully penetrate the market is outside the scope of this paper.

6. Discussion

The results of studies of willingness to pay for products that are not on the market are always hypothetical. It is only when automated cars reach the market that we can know how accurate the results of WTP-studies are. Moreover, comparing estimates of willingness to pay for automated cars to estimates of the additional costs of such cars, compared to manual cars, is also hypothetical, since the additional costs of automated cars are not known with greater certainty and precision than willingness to pay for them. It is known that hypothetical willingness to pay can differ substantially from actual willingness to pay, a difference often referred to as hypothetical bias (see the meta-analysis of Murphy et al., 2005). For the moment, however, testing for hypothetical bias in the willingness-to-pay surveys is not possible, as automated cars are not on the market.

The range of estimates both of costs and of willingness to pay is quite narrow. The range of estimates of costs is roughly from 10,000 to 40,000 US dollars. The range of estimates of mean WTP is roughly from 1,000 to 7,000 US dollars. These ranges (factors of 4 and 7) are quite narrow compared to the ranges of estimates found in most studies of willingness to pay in hypothetical markets. Thus, Wardman et al. (2016) report a much larger range in estimates of the value of travel time savings, although changes and variations in travel time is something most people are familiar with. The monetary valuation of travel time savings does therefore not involve an abstract and non-familiar good to any larger degree than the valuation of a car having automation technology.

The valuation of changes in the risk of injury, on the other hand, has produced an extremely large range of estimates. Lindhjem et al. (2012) collected 937 estimates of willingness to pay to reduce mortality risks from transport and environmental factors. The range of values of preventing a fatality was more than 44,000, i.e. the highest estimate was more than 44,000 times higher than the lowest. Compared to this enormous range, the quite small range found in WTP-studies of vehicle automation is reassuring.

On the other hand, three of the studies (Bansal et al., 2016, 2017, 2018) were made by the same team of researchers, using the same approach in all studies, although the samples were different. Still, one would expect the method in these studies to share important features, perhaps leading to what is known as common method variance, i.e. variance becomes artificially small because the studies employ the same method (Podsakoff et al., 2003). Against this, it can be argued that replications using the same method are valuable, because theory offers limited guidance about whether a positive WTP will exist at all, and, if so, how large it will be. In valuation studies in general, the use of different methods in different studies is a far larger problem than the consistent use of the same method to ensure comparable replications of studies.

Given the fact that mean WTP ranges roughly from 1,000 to 7,000 US dollars, and cost estimates range roughly from 10,000 to 40,000 US dollars, one might conclude that there will be no demand for automated cars. Mean WTP is, however, not very informative. There is always, in almost any market, large variation in WTP and the highest values for WTP are well within the range of the cost estimates. Perhaps around 20% of consumers will be able to afford an automated car priced at 10,000 US dollars above a current car, and a few would buy one even at an increased price of 40,000 US dollars. Thus, although initially a majority of consumers may find automated cars too expensive, this is unlikely to last very long. It is likely that prices, in real terms, will go down as technology matures and manufacturing becomes more efficient.

There is a possibility that vehicle automation can make shared

mobility more attractive, since it will become cheaper when the costs of a driver disappear. On the other hand, one could argue that vehicle automation "robs public transport of the advantage it has over driving your own car, by not having to make the cognitive effort a driver has to" (Fridstrøm, 2019). Surely, driving may become more attractive if you can leave it to a computer and relax or work during the trip.

7. Conclusions

The main conclusions of the study presented in this paper can be summarised as follows:

1. Studies of willingness to pay extra for automated cars show that mean willingness to pay is in the range of 1,000–7,000 US dollars.
2. About 20% of consumers indicate that they are willing to pay more than 10,000 US dollars more for an automated car than for a conventional car.
3. Estimates of the additional cost of an automated car, compared to a manual car, range between 10,000 and 40,000 US dollars.
4. It is likely that the first automated cars to be launched to the market will be too expensive for the majority of consumers. Over time, however, automated cars are likely to become cheaper and more affordable to most consumers.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecotra.2020.100179.

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