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Transit Subsidies and their Effect on Ridership and Optimal Transit Supply

Introduction

As populations grow and traffic congestion worsens in urban areas, there is arguably a need for more mass transit. Perhaps one of the biggest obstacles for increasing mass transit is the high fixed costs associated with the operation of the various modes of mass transit. Transportation subsidies for passengers account for much of the high public expenditures related to public transit. In most agencies, passenger fares for public transportation are heavily subsidized (Parry and Small 2009, 700). An analysis of the 20 largest transit systems in the United States reveals that bus subsidies (measured by the difference between operating costs and passenger fare revenues) range between 57 and 89 percent of operating costs (Parry and Small 2009, 700). One purpose for such high subsidies is lower transit fares discourage automobile use, which translates into reduced external costs from traffic congestion, air pollution, and accidents (Parry and Small 2009, 700).

This capstone will analyze welfare maximization from the transit planner's perspective using a theoretical model. The theoretical model aims to maximize social welfare with respect to the number of trips demanded as well as the number of buses in order to inform decisions surrounding optimal transit supply. The authors of one utility maximizing study discovered that high subsidies are justified and that increasing the subsidy is welfare improving even while current subsidy levels are often over fifty percent (Parry and Small 2009, 717). This capstone also intends to analyze how changes in fare subsidies affect ridership. To help answer this question, an empirical investigation across agencies will be performed. The analysis will focus on panel data from 1992 to 2014 for agencies that operate in large urbanized areas (population greater than one million) that utilize all modes of transportation.

Zhou, H.S. Kim, Schonfeld and E. Kim (2008) analyzed the subsidies associated with both flexible route bus systems and fixed route bus systems. A fixed route system involves predetermined stops on a fixed schedule while a flexible system is sometimes known as an on-demand system. They found that for a wide range of subsidy values for a fixed route bus system, the net effect of producer and consumer surplus produced a rather flat optimal welfare curve (Zhou et al. 2008, 659). This presents a different viewpoint than the paper by Parry and Small. In 2001, Schmidt specifically analyzed federal transit subsidies and concluded that even though an output subsidy increased the amount of buses a transit authority provides, the subsidy did not really incentivize riders to use the additional service (Schmidt 2001, 255). Subsidies play a significant role in how mass transit is funded but are those seemingly high subsidies worth it? The purpose of this paper is to analyze which variables impact welfare optimization as well as to analyze the effect of subsidies on ridership.

Literature Review

Extensive scholarly research has been completed that can inform transit subsidy analysis. This literature review centers on four major themes. One major reason for the promotion of public transit is based on an externality argument. For example, mass transit promotes private investment. Second, when consumers choose mass transit instead of private transit, there is a reduction in the negative externalities associated with automobiles. Past research on subsidies in general has revealed a few cases where a subsidy has caused both negative and unintended consequences. In a transit context, subsidies are revealed to be welfare improving. Also, transit subsidies play a role in user demand for transit by affecting prices. Additionally, planners must decide the subsidy level as well as the amount of transit to provide. On a broader scale, when consumers are uncertain of the quality of the good, they look at signals of quality to determine their willingness to pay. This is relevant for transit because there is an element of uncertainty surrounding reliability. Analyzing these themes will assist in an analysis of a subsidy's effect on ridership.

Positive and Negative Transit Externalities

The majority of funding for state highway projects comes from taxes, federal highway grants, and the general fund (Nesbit and Kreft 2009, 94). Not only does public investment in transportation infrastructure support the movement of goods and people, it also has the opportunity to affect private investment as well. The Northeast United States is home to a mature transportation system and is the subject of a study completed by Chen and Haynes in 2015. This study found highway infrastructure to have a positive effect on regional economic output (Chen and Haynes 2015, 10). Additionally, the authors found public rail to have a significant positive impact on regional output, but highways still have a larger positive impact overall. However, public transit has a relatively smaller effect on regional output as compared to highway and public rail (Chen and Haynes 2015, 11). Overall, highway infrastructure has the largest influence followed by public rail, public airport, and public transit. (Chen and Haynes 2015, 12). In terms of public transit, it has a rather small effect on output even though it receives a relatively high level of public investment. Passenger rail, for example, functions as a complement to other forms of transportation. Pereira and Andraz (2005) discovered similar conclusions in their study of Portugal's less mature infrastructure from 1976 to 1978. They concluded that public investment in infrastructure crowds in private investment and employment (Pereira and Andraz 2005, 194). Additionally, infrastructure investment has improved labor productivity and promoted long-term growth (Pereira and Andraz 2005, 194). The largest effect on output comes from investment in ports followed by roads, airports and railroads. (Pereira and Andraz 2005, 194).

Automobiles are known to cause negative externalities including air pollution, oil dependency, traffic congestion, traffic accidents, noise, and urban sprawl (Parry, Walls, and Harrington 2007). Automobiles emit carbon monoxide into the atmosphere, which can cause breathing difficulty and cardiovascular problems (Parry, Walls, and Harrington 2007, 374). In one study about Belgian transportation, the authors found that more than 90% of the external costs related to road accidents, air pollution, noise and land use come from private passenger transportation (Lesceu 1993, 474). More than half of the external costs from transportation arise from traffic accidents and are then followed by cost of land use and cost of air pollution (Lesceu 1993, 474). Negative externalities are an issue because others have to bear these costs. Lesceu writes, "Consequently, the negative side-effects of transportation are not charged to the users of transportation services. There is a discrepancy between the private expenses of the *user* and the external costs borne by *all* members of society" (Lesceu 1993, 463). She mentions that market theory suggests a more rational use of natural resources can be obtained by internalizing the external costs of transportation services (Lesceu 1993, 475). Additionally, reducing transportation pollution and the external costs associated with it can be achieved by reducing vehicle miles traveled (Parry, Walls, and Harrington 2007, 375).

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One purpose for public transportation investment is to reduce these negative automobile externalities. In a study focused on Aragon, Spain, the authors found that travelling by bus or train resulted in an individual cost savings of 75% and 88% respectively compared to using a private automobile (Duarte et al. 2014, 420). This study also found if households choose public transportation over private, there will be a significant reduction in harmful emissions as a result of lower fuel consumption (Duarte et al. 2014, 424). Lenzen and Dey (2002) reached similar conclusions. In Australia, road vehicles consume 75% of all transport energy and more than 80% of that is the result of private cars (Lenzen and Dey 2002, 389). Shifting away from private cars and choosing to travel on public transportation can potentially reduce greenhouse gas emissions. Additionally, this will increase employment and income (Lenzen and Dey 2002, 394). In the scenario where spending on public transportation is increased to discourage private car use, Duarte et al. (2014, 427) found a reduction in the consumption of refined petroleum products. Overall, the authors conclude policies to promote household changes in transportation consumption may have positive environmental impacts without affecting other economic variables (Duarte et al. 2014, 427).

Unintended Consequences of a Subsidy

Subsidies are usually put in place to encourage consumption of a good but sometimes there are unintended consequences. As Just and Hanks (2015, 1397) note, an emotional response to a policy may cause different results than a traditional analysis would predict. If there is an emotional attachment to a good, then consuming that good brings either enjoyment or dissatisfaction. If a policy reinforces this emotional attachment then the emotion will be felt to a greater extent. (Just and Hanks 2015, 1390). For example if a parent is provided with a subsidy for child healthcare, they might feel more enjoyment because the subsidy reinforced healthcare, which is seen as a positive good (Just and Hanks 2015, 1390). Similarly, Gneezy, Meier, and Rey-Biel (2011, 206) discuss the role of intrinsic motivations when analyzing the effectiveness of an incentive. The effect of a subsidy, a type of incentive, will depend on its relationship to intrinsic motivation. Just and Hanks (2015, 1386) suggest policies that are more empathetic to consumer emotions will improve market welfare more than combative or confrontational policies. An example of a combative policy would be one that threatens individual freedom, such as mandatory vaccinations. A subsidy that is more empathetic to consumers is likely to be a more effective policy (Just and Hanks 2015, 1398).

Unintended effects of a subsidy appear in both consumption and production subsidies. A study about the effect of food price subsidies on nutrition for poor households in China found no measurable effect on nutrition and may have actually reduced caloric intake in one province (Jensen and Miller 2011, 1221). In the Hunan province, the subsidies induced substitution away from the subsidized staple food toward other foods with non-nutritional attributes (Jensen and Miller 2011, 1221). The authors note this result is consistent with Giffen behavior (Jensen and Miller 2011, 1219). Even though the subsidies did not improve nutrition, they did improve welfare. The findings of this study are driven by the wealth effect of the price change (Jensen and Miller 2011, 1221). The subsidies freed up income that consumers chose to spend on other, perhaps tastier but less nutritious, foods (Jensen and Miller 2011, 1222). The consumption of less nutritious foods is seen as a negative outcome. This nutrition study shows a negative unintended effect of a consumer price subsidy, but unintended effects can also be observed for production subsidies such as clean energy subsidies. The authors discovered that a subsidy promoting the production of low carbon energy actually found the subsidy to have a perverse effect (Hutchinson, Kennedy, and Martine 2010, 6). The subsidy did cause a shift toward cleaner energy production, but at the same time caused an increase in energy consumption because the subsidy caused the equilibrium price of energy to fall (Hutchinson, Kennedy, and Martinez 2010, 6). Even though clean energy production increased, however, due to increased consumption of energy overall, the authors found the subsidy resulted in an increase in carbon emissions (Hutchinson, Kennedy, and Martinez 2010, 6). This increase in carbon emissions is an example of how a production subsidy can result in an unintended consequence with potentially negative implications.

Transit Subsidies--Welfare

Improvements in welfare are another commonly cited reason for transit subsidies. Numerous articles point to estimating welfare as a way to determine optimal subsidy levels. In a 2009 study specifically about transit systems in Washington, D.C., Los Angeles, and London, the authors found increasing the subsidy beyond fifty percent for all modes, periods, and cities to be welfare improving in all but one case (Parry and Small 2009, 717). They note the majority of welfare gains came from reducing road congestion (Parry and Small 2009, 717). In a 1997 study about transit in Chicago, the authors explain increasing fare subsidies has a greater overall benefit to society than increasing bus service levels (Savage and Schupp 1997, 111). The authors suggest cutting service levels in order to lower fares is welfare improving. They also note the transit authority has tried to maintain bus frequency even during falling demand, and this has caused the transit authority to raise fares. Instead of fare increases that hurt welfare, they suggest decreasing service levels (Savage and Schupp 1997, 111-113). This will also result in an increase in consumer surplus. Zhou et al. (2008) found that as the subsidy increases for fixed route bus systems, where routes and stops are fixed, welfare also increases. This is shown as an increase in consumer surplus, but it is coupled with a decrease in producer surplus. The net effect is a rather flat optimal welfare curve over a range of subsidies. These authors recommend that welfare optimization should not be pursued to its absolute maximum for that reason (Zhou et al. 2008, 651-652). This would result in a relatively small decrease in welfare, but the budget deficit would be zero.

Transit Subsidies—User Demand

More than one study has found passenger sensitivity to the level of service: the number of scheduled miles in the transit system. In a study about transit in El Paso, the authors note riders are more sensitive to changes in the level of service than to changes in fare in the short run. Their analysis found increasing vehicle revenue miles[1] per month results in increased ridership (Fullerton and Walke 2013, 3928). Transit demand in Chicago is also more sensitive to bus frequency than to fares (Savage and Schupp 1997, 112). In Chicago, demand is inelastic with respect to service frequency, but the author notes the cost of increasing buses on existing routes would be too high (Schupp 1997, 112).

Other factors also determine transit demand and ridership such as car ownership, gas prices, and economic conditions. In the same study about El Paso, the authors mention increases in car ownership tend to lower ridership. At the same time, increases in gasoline prices can encourage consumers to ride public transport instead of taking a private car (Fullerton and Walke 2013, 3930). Additionally, the study discovered an increase in positive economic conditions in Mexico is connected to an increase in transit ridership (Fullerton and Walke 2013, 3930). In the study by Parry and Small (2009, 717), they found fares to have an effect on ridership. They found when fares are adjusted to optimal levels (in terms of total welfare), ridership decreased in Los Angeles while it increased in London.

Transit Subsidies—Planner's Decisions

One decision transit planners face is the decision about the level of the subsidy. Depending on the focus of the study, different conclusions are drawn about optimal subsidy levels. Parry and Small (2009, 717) found the current large subsidies in Los Angeles, Washington, D.C., and London to be justified. They discovered the optimal fare subsidies to be

[1] The number of scheduled miles for vehicles in revenue service

more than two thirds of average operating costs in eleven out of twelve cases (Parry and Small 2009, 717). Tisato (1997, 342) focused on user economies of scale for buses in Adelaide and the authors found subsidy levels are higher than can be justified. The author does not, however, advocate for a zero subsidy. He acknowledges the optimal subsidy still exceeds $40 million in most cases. In a different study by Zhou et al. (2008, 659), the authors found the effect of a subsidy on welfare was different for fixed route and flexible route bus systems. A fixed route system is the most familiar type of bus service where buses follow fixed routes on a fixed schedule. On the other hand, a flexible system operates more like an on demand service where people request rides. For a fixed route bus system, they suggest a low transit subsidy policy; however, that policy is less preferable for a flexible route system.

Another decision transit planners face is the amount of transit routes and frequency to provide. One reason federal mass transit operating subsidies exist is to encourage transit agencies to increase their service. A 2001 study that analyzed data from the mid-1990s concluded these subsidies have increased bus output by six to eight percent per year as compared to output without the subsidy (Schmidt 2001, 255). Schmidt (2001, 256) claims these subsidies specifically incentivize increasing output regardless of demand and do not actually incentivize increasing ridership. Federal transit subsidies with the intent to increase transit supply only increase output to a certain extent. As transit output increases, marginal costs also increases, so there is a natural limit to how much output can be increased through subsidies that are limited (Schmidt 2001, 255). Sakano et al (1997,121) examined the impact of increasing output without regard for demand and found federal subsidies create allocative inefficiencies. Since operating subsidies are used to cover losses, transit agencies do not have an incentive to reduce labor and fuel costs (Sakano, Obeng, and Azam 1997, 121). The authors suggest using subsidies to incentivize firms to operate efficiently. They argue firms should only get subsidies if they are facing a loss after making every effort to operate efficiently by reducing costs (Sakano, Obeng, and Azam 1997, 121).

Demand with Uncertain Quality

Buyers use signals to help determine willingness to pay when the quality of a good is unknown. Oftentimes, consumers can observe price before purchasing a product and can only perfectly observe the quality of the product after the purchase. However, quality signals exist prior to the purchase of that product. In the case of high prices, consumers associate high quality with the product (Hey and McKenna 1981, 64). For example, in the cherry market, some sellers sort cherries based on their size while other sellers don't sort by size. It turns out buyers pay a higher price for cherries from non-sorting firms. Over time, buyers have discovered through experience, reputation, and other signals, that cherries from non-sorting firms are of higher quality (Rosenman and Wilson 1991, 656). This occurs even though buyers cannot observe differences in quality among cherry sellers of a certain standard (Rosenman and Wilson 1991, 658). The signal of quality in the cherry market is the firm's sorting behavior and buyers are willing to pay more for cherries they perceive to have a higher quality. In the cherry market, higher quality is associated with a higher price.

Coins sold in online auctions on e-bay rely on quality signals similar to transit agencies. Since a buyer is unable to directly observe the quality of the coin before purchasing, they need to rely on quality signals to inform their willingness to pay. Melnik and Alm (2005, 326-327) found a seller's reputation has a positive and statistically significant impact on the consumer's willingness to pay. A better reputation signals a higher quality of good. Additionally, complaints about the seller have a negative impact on willingness to pay (Melnik and Alm 2005, 327).

Essentially, buyers use the reputation of the seller as a signal of the good's quality. A perceived higher quality leads to a higher willingness to pay. Similarly, Ma, Ferreira, and Mesbah (2013, 13) recognize improving transit service reliability is the most cost-effective approach to encouraging increased transit use. Longer wait times and longer traveling time suggest unreliability. Here, transit reliability, a signal of quality, impacts the reputation of the transit agency. Additionally, Van Vugt, Van Lange, and Meertens (1996, 384), acknowledge public transportation can compete with private cars when public transportation provided shorter average travel time and equally reliable travel time. Again, reliability, one way to measure quality, impacts a rider's decision to use public transportation. Demand in online auctions and for public transit both rely on perceived quality.

Theoretical Model

To assist in the analysis of public transport subsidies, a theoretical model can be used to help identify the optimal supply of public transportation. A working paper written by Nilsson, Ahlberg and Pyddoke (2014) analyzes the relationship between subsidies and optimal transit supply. One element of the model presented in this paper is particularly relevant to this capstone. Specifically, the authors examine the use of vouchers in a public transportation monopoly. Essentially, under a voucher system, both the passengers and the supply of bus trips are subsidized. Each passenger is charged a fare while at the same time the public sector provides a voucher for each trip to cover the remaining cost. The authors are interested in maximizing welfare in the bus system by choosing the quality (number of buses to operate) and the fare to charge.

In this model, a couple assumptions are made. Perhaps the most basic assumption is that the regional public sector body has decided a bus service should be operated. It is assumed that all decisions about bus supply are made with full information. For example, information regarding demand, costs, production costs, as well as any other information about the conditions the buses will be operated under is known. The authors assume the inverted demand function is concave in the number of trips and the number of buses. This means demand is nonlinear and increasingly responsive to changes in price. In terms of the cost function, it is assumed to be convex for producing a number of trips given a certain quality. For this model, there is a monopoly where only one bus operator exists. The following table (Table 1) shows the definitions of variables included in the model.

Table 1: Variable Definitions

Variable	Definition
π	Profits
x	Demand for trips (quantity)
b	Service quality (number of buses)
p	Price (or fare)
c	Cost
s_m^x	Subsidy targeting number of trips. m is optimal subsidy under monopoly
s_m^b	Subsidy targeting number of buses. m is optimal subsidy under monopoly
w	welfare
ε	Price elasticity of demand for trips

The overall objective of the model is to maximize social welfare with respect to x (trips) and b (service quality). Equation 1 relates welfare to the price or fare that is charged to riders per trip. Essentially, equation 1 represents revenue minus cost where revenue is found by integrating over the range of all users, or v.

$$max\ W\ (x,b) = \int_0^x p(v,b)dv - c(x,b) \tag{1}$$

The first marginal condition (equation 2a) is found by taking the first partial derivative of equation 1 with respect to x, the number of trips. This equation serves the purpose of setting price equal to marginal cost given b (service quality). It also shows how price responds to the number of buses chosen (service quality).

$$\frac{\partial w}{\partial x} = p(x,b) - \frac{\partial c}{\partial x}(x,b) = 0 \qquad\qquad p = \frac{\partial c}{\partial b}(x,b) \tag{2a}$$

The other marginal condition (equation 2b) is found by taking the first partial derivative of equation 1 with respect to b, service quality. Here, as the number of buses change, consumers will respond with a change in demand.

$$\frac{\partial w}{\partial b} = \int_0^{x^w} \frac{\partial p}{\partial b}(v,b)dv - \frac{\partial c}{\partial b}(x,b) = 0 \tag{2b}$$

With the welfare maximization objective established such that essentially, price must equal marginal cost with respect to service quality (2a) and marginal cost with respect to changes in quality must equal the effect of price responsiveness of consumers with respect to quality, it is now applied to a bus system operator who is a monopolist and uses vouchers under complete information. Under a voucher system, for each passenger trip, the operator receives a fare from the passenger and some amount from the government to make up for the costs the fare does not cover. Additionally, in this model, the operator receives a voucher (also known as a subsidy) for each bus that is operated. Equation 3 is the bus operator's objective function. The operator wants to maximize profit with respect to x (number of trips) and maximize profit with respect to b (service quality).

$$\pi(x,b) = p(x,b)x + s_m^x x + s_m^b b - c(x,b) \tag{3}$$

The following equations, equations 4a and 4b, represent the marginal conditions. The left side of equation 4a represents how profits change as the number of trips changes. With each additional trip, the agency receives *p*, which is the fare. The next part of the equation, $\frac{\partial p}{\partial x}x$, represents how if the number of trips is changed, then the price will probably also have to change, which will impact revenue. For example, if the price is dropped, it is likely the number of trips taken will increase so the agency will receive revenue from a greater number of trips. Even though the price has dropped, the subsidy targeting the number of riders, s_m^x , will make up for some of that lost revenue due to the lower price. The first three terms in the equation rise as the number of trips increases because the marginal revenue changes as the number of trips changes. The last term, $-\frac{\partial c}{\partial x}$, represents marginal cost. Essentially, equation 4a says if the correct number of trips is chosen, then marginal revenue will equal marginal cost. Equation 4b is very similar but instead describes how profit changes as the quality changes. The purpose of this equation is to show that ridership might change if quality is improved.

$$\frac{\partial \pi}{\partial x} = p + \frac{\partial p}{\partial x}x + s_m^x - \frac{\partial c}{\partial x} = 0 \qquad (4a)$$

$$\frac{\partial \pi}{\partial b} = \frac{\partial p}{\partial b}x + s_m^b - \frac{\partial c}{\partial b} = 0 \qquad (4b)$$

These marginal conditions are then combined with the marginal conditions from the welfare maximization for the transit authority (equations 2a and 2b) in order to make the monopolist abide by the conditions of the transit authority's welfare maximization. Here, $\varepsilon_x \equiv \frac{\partial x}{\partial p}\frac{p}{x} < 0$ is the price elasticity of demand for trips. Solving the above equations for s_m^x and s_m^b results in the following equations (5a and 5b) for the specification of the optimal subsidies for the transit authority to choose. The first condition (5a) represents the necessary subsidy level to induce the operator to charge passengers a welfare maximizing price given a certain amount of buses.

$$s_m^x = -\frac{\partial p}{\partial x} x^w = \frac{p^w}{\varepsilon_x} \qquad (5a)$$

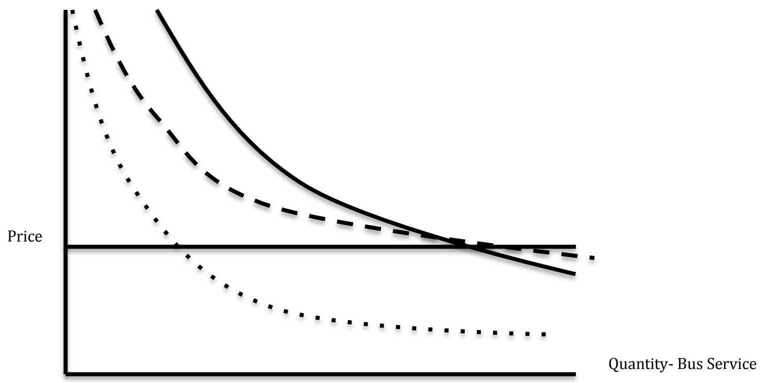
$$s_m^b = \int_0^{x^w} \frac{\partial p}{\partial b} dv - \frac{\partial p}{\partial b} x^w \qquad (5b)$$

The optimal passenger subsidy, s_m^x, that is chosen is related to the price elasticity of demand for trips. The following shows that price elasticity for trips helps determine whether the optimal passenger subsidy is lower, equal to, or higher than the welfare maximizing price. Basically, the subsidy will be higher with a higher price elasticity for trips.

$$s_m^x \begin{cases} > p^w \ if \ \varepsilon_x > -1 \\ = p^w \ if \ \varepsilon_x = -1 \\ < p^w \ if \ \varepsilon_x < -1 \end{cases} \qquad (6)$$

The solid curve in Figure 1 represents demand for bus service. The dashed line represents marginal revenue after the introduction of the subsidy. The dotted line represents marginal revenue for a monopolist before the introduction of subsidies. The horizontal line represents both price and the marginal cost of bus service. The figure shows that once the subsidy is added, the marginal revenue line shifts up.

Figure 1: Demand, Marginal Cost, and Revenue of Bus Service Under Monopoly



Overall, a voucher approach for subsidizing bus transit requires taxpayer funds but the benefit of a voucher system is the flexibility it provides. This type of system is able to adapt to changes in supply and demand. Under a voucher system, the transit authority receives some amount, or voucher, for every trip taken by a passenger in addition to the fare paid by the passenger, but the voucher does not cover the full cost of the ride. The transit authority still has discretion over what fare to charge (while keeping demand in mind), but the government determines the value of the voucher received for each ride. Here, the transit authority maintains flexibility over the fare to charge. Secondly, the transit authority also receives a voucher for each bus provided. They also maintain flexibility over the number of buses to run but the government determines the value of the subsidy for the quantity of buses.

The authors found in their analysis no evidence that vouchers would be hazardous to the market’s performance (Nilsson, Ahlberg and Pyddoke, 2014, 26). In contrast, in a completely unregulated public transportation market, issues with inefficiency, safety hazards, and conflict between operators and lack of price competition arise. These examples do not arise under a voucher system. In order for the voucher system to work, the vouchers would need to be linked to the number of passengers as well as to the number of vehicles the operator chooses to use. With social welfare maximization as the goal, it is important to subsidize both the supply and demand sides. On the demand side, the subsidy corrects the price to encourage ridership and welfare maximization. On the supply side, the subsidy encourages the optimal supply of buses and welfare maximization. Both of these elements work together to achieve total maximum welfare.

It is important for public transportation planners and operators to find the optimal subsidy in order to maximize welfare, maximize profit, and encourage ridership. In this model, the planners are able to choose the number of buses to run and have some flexibility in the level of fare to set, while keeping an eye on demand. When trying to find the optimal subsidy, many factors have to be taken into account. This model demonstrates the tradeoffs and incentives involved when determining a subsidy level when the number of buses and the number of trips are the parameters. A change in the subsidy level will result in a change in profit for the monopolist operator. It also recognizes that any change in the subsidy (which affects the fare) will result in changes in ridership. Using a model such as this one can help a transit planner predict how well their chosen subsidy level and bus supply level obtain the goal of welfare maximization and profit maximization.

The theoretical model shows the optimal supply of transit relies both on maximizing welfare and maximizing profit. The demand for trips as well as the quality of service play a role in this maximization. It is important to take the demand side into account in order to optimize supply and factors such as reliability (service quality) are essential to this model. For these reasons, variables impacting demand are included in the following empirical model. The empirical analysis also focuses on transit subsidies. Instead of a voucher system, the transit authority receives funding subsidies from the government whose value does not necessarily depend on the number of trips.

Empirical Analysis

The econometric portion of this paper analyzes how a change in the subsidy level affects ridership. Ridership, or the demand for bus service in the model above, plays a role in welfare maximization and profit maximization. Price elasticity with respect to trips, as also mentioned above, influences how the subsidy level is chosen. Since increasing ridership on public transportation is also one of the goals of the planner, it is necessary to analyze whether a change in the fare (via the subsidy) is a viable solution by empirically estimating the relationship between the subsidy levels chosen by planners and the corresponding ridership that results.

I. Data

The main data for this analysis comes from the U.S. Department of Transportation National Transit Database. The fifty largest metro areas in the United States are included in the analysis with the exception of a few. Puerto Rico was removed because it is not located in the United States even though it is included in the National Transit Database. Austin, Texas, New Orleans, Louisiana, and Las Vegas, Nevada were excluded due to insufficient data. Each metro area is identified by a UZA[2] number and each UZA contains multiple cities and transit agencies. For example, Everett Transit is included in UZA 14, which is considered the Seattle metro area. All modes of transportation from bus to various types of rail were included, due to the difficulty of extracting individual modes from the data. Even smaller forms of transportation like cable

[2] UZA stands for Urbanized Area

cars and ferries were included where applicable. The panel data used in this analysis is from 1992 until 2014.

The dependent variable is abbreviated UPT, which is defined as unlinked passenger trips. Every time a passenger boards a public transportation vehicle, it is counted as an unlinked passenger trip. In other words, a transfer from a train to a bus would count as two trips instead of one. This variable is used to measure ridership. In order to obtain one ridership data point per UZA, all of the unlinked passenger trips for each mode of transportation across all agencies in the UZA were summed.

The variable subsidy was calculated using fare revenue data and funding data from the National Transit Database because explicit subsidy numbers are not available. Essentially, fare revenue only covers a certain amount of the funding that is needed to run the agency, and it is assumed that a subsidy covers the rest. The subsidy variable represents the percent of funding that is not covered by fare revenue. The total funding figures across all modes of transportation across all agencies in the UZA were summed. Fare revenue figures across all modes of transportation across all agencies in the UZA were also summed. To calculate subsidy, the formula (1—(fare/funding)) was performed for each UZA. For example, if King County Metro fare revenue accounts for 30% of their total funding then it is assumed there is a 70% subsidy.

The variable fleet age was calculated using active fleet data and average age of fleet for each transit authority within a UZA. Only bus fleet data from active authorities was used in the calculation. A weighted average was used so that transit agencies with a larger fleet would proportionally influence the average age. This variable is used as an indicator of reliability and is based on the assumption that older fleets are more likely to break down. The variables included in the econometric model are found in Table 2.

Table 2: Variable Definitions and Sources

Variable	Variable Definition	Source
UPT	Unlinked passenger trips. Used to measure ridership	USDOT National Transit Database
UZA population	Population of each urbanized area (UZA)	Bureau of Economic Analysis
Fleet age	Weighted average bus age for the urbanized area using active fleet data and average age of fleet for each transit authority within the UZA	USDOT National Transit Database
Hours of delay	Annual hours of delay per auto commuter. Used as a measure of roadway congestion.	Texas A&M Transportation Institute
Subsidy	Calculated using the formula 1—(fare/ funding)	USDOT National Transit Database
Gasoline cost in 2014 dollars	Average state gasoline cost in dollars per gallon for the year. Adjusted for inflation	Texas A&M Transportation Database using CPI from The Federal Reserve Bank of St. Louis
Income in 2014 dollars	Annual per capita personal income for each urbanized area adjusted for inflation	Bureau of Economic Analysis using CPI from The Federal Reserve Bank of St. Louis

Table 3 includes descriptive statistics for the given variables. The minimum unlinked passenger trips is zero because Virginia Beach reported zero trips from 1992 to 1999. This is likely due to a merger between agencies. Virginia Beach was kept in the data set because the rest of their data was complete. Unlinked passenger trips has a very high standard deviation because trips range all the way from zero to over four billion trips in New York. In terms of income, the minimum is associated with Cleveland in 1993 and the largest is associated with Bridgeport-Stamford in 2007. UZA population has a rather high standard deviation at 3,224,752 people because the population data ranges from a minimum of 588,751 people to a maximum of just over 20 million people in New York. The nine largest UZAs in 2014 all contained over five million people. Additionally, many of the cities included in this analysis have seen their populations increase since 1992. The mean of the weighted average fleet age for the sample is

7.36 years and has a relatively small standard deviation of 1.8 years. The maximum weighted average fleet age is 15.3 years. This indicates the majority of the agencies in the sample are using relatively up to date fleets. This does not mean all transit vehicles are new, it just indicates most agencies are trying not to let their fleets age substantially. The mean subsidy in this sample is 75% and the minimum subsidy is 41%. This indicates all cities in the sample rely on a sizable subsidy. Interestingly, the maximum subsidy is 99% which occurred in Phoenix in 1993 (it has since fallen).

Table 3: Descriptive Statistics

Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
UPT	1.72e+08 trips	5.02e+08 trips	0 trips	4.35e+09 trips
UZA population	3,270,919 people	3,224,752 people	588,751	2.01e+07
Fleet age	7.36 years	1.8 years	2.4	15.3
Hours of delay	44.01 hours	12.49 hours	16	86
Subsidy	.753	.089	.414	.991
Gasoline cost in 2014 dollars	$2.52	$0.77	$1.45	4.22
Income in 2014 dollars	$45,524.69	$9,695.93	$29,401.14	$101,403.1

II. Econometric Model

A fixed effects model is suitable for this data because it allows the intercept for each UZA to vary. Every UZA in this sample, even though they are large UZAs, have considerably different ridership levels. It is possible the relationship between the subsidy and ridership is similar among the UZAs even though the ridership varies greatly among each UZA. By allowing each UZA to have its own intercept, the model can account for the fairly different ridership numbers that are only a result of the different UZAs. Additionally, this model was run using the cluster command to fix heteroskedasticity and autocorrelation in the standard errors. The general notation for this model is:

$$\tilde{y}_{it} = \beta_2 \tilde{x}_{2it} + \beta_3 \tilde{x}_{3it} + \tilde{e}_{it} \quad (7)$$

A 2013 paper written by Fullerton Jr. and Walke uses an econometric model to predict changes in ridership in a border economy, specifically the border between El Paso and Mexico. The dependent variable in their model was also ridership. Their findings serve as a means to form predictions for the model in this paper. Fullerton and Walke (2013) used fare as an independent variable while the model in this paper uses subsidy. Fare and subsidy are expected to have an inverse relationship because as the subsidy increases, the fare usually adjusts downward to encourage ridership. Their model found a negative coefficient on fare, so therefore subsidy is predicted to have a positive coefficient in this analysis. Fullerton and Walke (2013) also found real income to have a negative coefficient and gasoline to have a positive coefficient. The coefficients on fare, real income, and gasoline are significant at a 5% level. It is predicted the model in this paper will find the same signs for these coefficients.

Intuitively, it is assumed the congestion measure (hours of delay), will positively impact ridership. As the freeways and roadways become more congested, commuters might be more inclined to take public transportation. This is especially true for trains and light rail because the travel time is not affected by roadway congestion. This might also be true in areas where there is a dedicated bus lane or the buses are able to travel in the HOV lane. This follows the argument outlined in Van Vugt, Van Lange, and Meertens (1996) where they conclude public transportation can compete with private cars when public transportation provided shorter travel time. Similar reasoning exists for predicting the sign on the population coefficient. As population increases, congestion likely increases and so does the demand for public transit.

The fleet age variable in this model is used as a measure for reliability. It is assumed older transit vehicles are more likely to break down and face delays, which would impact the reliability of the system. For this reason, fleet age is expected to have a negative coefficient. As the average fleet age increases, the reliability of the system declines which would discourage people from using public transit. This reasoning stems from the results presented in Ma, Ferreira, and Mesbah (2013) where they found improving transit reliability to be the most cost effective approach for encouraging increased transit use.

III. Results

In order to confirm the use of a fixed effects model, a Hausman test was conducted. The results revealed a fixed effects model is preferred to a random effects model. Table 4 shows the fixed effects estimates for this ridership model. None of the independent variables in this model are significant at the 10% level. However, the model is overall significant at the 10% level (p-value = 0.0670). The variables population, hours of delay and subsidy all have positive coefficients, which matches the predictions. Income has a negative coefficient as predicted. The coefficient on fleet age in this model is positive but was predicted to be negative. Gasoline cost was found to be negative while it was predicted to be negative. The R^2 within is 0.1644, the R^2 between is 0.7340, and the R^2 overall is 0.7108.

Table 4: Fixed Effects Estimates

Variable	Coefficient	Robust Standard Error	t-Statistic	$P > \|t\|$
Population	122.333	88.067	1.39	0.172
Fleet age	971,222.2	1,657,929	0.59	0.561
Hours of delay	2,766,495	2,880,607	0.96	0.342
Subsidy	6.83e+07	1.37e+08	0.50	0.620
Gasoline cost in 2014 dollars	-1.65e+07	1.37e+07	-1.21	0.233

Income 2014 dollars	-519.9174	2,003.527	-0.26	0.796
Constant	-3.43e+08	3.88e+08	-0.89	0.381

Conclusion

Even though this econometric model is unable to detect significant coefficients, that does not mean a significant relationship does not exist. It is possible subsidy does have a significant impact on ridership but it is not showing up in this data. One possible explanation for this is the way the data for each UZA was aggregated. Numerous agencies, of varying sizes, are included in each UZA and it is certainly possible that hid the effect. For example, the subsidy value for each UZA is actually an average of the subsidies of each agency in the metro area. Within one metro area, it is likely each agency faces different circumstances, funding, and subsidies. Aggregating this information probably disguises important details. Along these same lines, certain modes of transportation or certain kind of routes might respond to changes in the subsidy more than others.

Second, it is highly probable this model has omitted variables. While a number of important and necessary control variables were included, there are plenty of others that could have been included. For example, a more specific reliability measure could have been used instead of the average fleet age. An on time measure or average wait time would be two examples. Another example of a possible omitted variable is something that reflects the size of the system like miles traveled or route density. Examples like these were not included in this analysis mainly because the data was unavailable or didn't fit this data set. Further research on this model would include adding other variables.

A third potential problem with this model is endogeneity. This goal of this analysis was to model the impact of the subsidy on ridership. With the endogeneity problem in mind, it is important to recognize ridership might actually drive the subsidy level. For example, agencies experiencing low ridership might implement a subsidy to encourage more ridership. This is in contrast to the model in this paper, which is looking at how the subsidy drives ridership. Of course, the relationship probably goes both ways. If this is the case, which there is high suspicion it is, then adding additional control variables would not fix this problem. This would also mean the coefficients are inaccurate. Further research on this model needs to explore the endogeneity problem and ways to fix it.

Overall, public transit will continue to be a point of interest in the coming years. It will be particularly interesting to see how each area deals with their own unique transportation challenges. Transportation subsidies will likely continue for the foreseeable future and it would be interesting to analyze the effect of subsidy levels on specific modes of transportation. Additionally, future analysis could focus on the trend of subsidy levels in the coming years. Even though this particular empirical study was unable to find a relationship between the subsidy and ridership, the theoretical model still suggests a link. The theoretical model revealed the importance of demand, quality, and the rate of the subsidy. The demand side will continue to play a vital role in future studies examining subsidies and ridership.

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