Modelling producer behaviour in fixed route private transport services

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Abstract

Objectives: While fixed route private transport services have grown in prominence in the recent times, there is a dearth of models that specifically tackle pricing in it. The current study aims to model producer behaviour in this model, keeping in mind its peculiar physical characteristics. Methods: This study develops a rational-actor model of the behaviour of producers operating in this market. There is however, an added assumption of the heuristic of least perceptible difference to add behavioural realism to the model. Results: The predictions derived from the model developed in this study include repeated usage of a single type of round-trip for a non-zero interval of time, the convexity of expected-waiting time with respect to changes in prices and a negative relation between external (exogenous) demand at one-point of a path and the price charged at the other. Conclusion: Pricing in this market, due to physical factors, can exhibit unique features as modelled.

Keywords: Private Transport; transport Pricing; producer behaviour in transport

1 Introduction

Transport economics has developed into a separate sub-field of economics largely due to the peculiar nature of operation in the sector, including unique problems such as congestion and timing issues. Several industries within transportation also warrant special models. In this study, by the 'Private Passenger Road Transport Industry', the author refers to a wide range of operators of private commercial vehicles, who provide road travel service directly to consumers rather than to firms for shipment. This may include e-rickshaws, cycle-rickshaws, auto-rickshaws etc. The model with little modification can also be used for ferries etc., however.

The empirical importance of the private passenger road transport industry is well documented in the literature. Estimates by Singh (1) claim, that the share of private and para-transport in mobility in India has risen from 16.2% in 1990-1991 to 21.2% in 2000-2001. Malik et al. (2) argue that in the next 3-4 years following 2018, e-rickshaws would generate "entrepreneurial opportunities" for nearly 5 lakh people in Delhi NCR alone. This growth, however, is largely informal. While attributing the rapid expansion of the industry to the fast pace of GDP growth in India and China, Pucher et al. (3) also highlight that the industry is under-regulated in India. In a more recent study by Majumdar and Jash in 2015 (4), it has been observed that while the...
number of e-rickshaws is rising, their operation is not properly regularised. From the empirical literature, it can be concluded that immediate policy attention to the industry is of crucial importance because of both its growing size and opportunities and its unmonitored and under-regulated nature and quality, possible lack of safety etc. Studies to gauge the effects of and response to various policies are, however, largely missing.

The drastic effect that such vehicles have had on commuting in central business cities, developed and developing cities was highlighted also in Bagul et. al. in 2018\(^5\). It was also suggested that these services should be integrated with public transport. An additional fact worth highlighting at this point is their finding that overall, 40% of the total commuting populations of daily users for fixed routes in their study used autorickshaws.

Other important developments include the increasing popularity of centralised transport-service platforms such as Ola and Uber, especially in large cities, as noted by Rupali and Chincholkar\(^6\). However, the nature of travel that these services provide, that is of choosing the pick-up and drop locations make them not “fixed-route” services. Furthermore, the pricing considerations are not of the driver, but of a centralised platform, making it deviate from the focus of this study. This is an important distinction to make, which without the mention of these services may have led to confusion. Similarly, other developments such as Intelligent Transportation Systems (ITS) are gaining popularity in the developed countries as noted by Singh and Gupta\(^7\). Such services however tend to be provided by centralised providers again, and need not necessarily operate in the fixed-route system, while possible. The focus of this study is instead on decentralised and largely independent providers of transport services such as e-rickshaws, auto-rickshaws etc. whose importance has already been outlined above.

Recent theoretical and model-based works in transport-modelling include Lin, Chen and Song\(^8\) and Grooves and Gini\(^9\) who studied pricing in the air-transport industry, following the classic work in railways by Meyer and Morton\(^10\). Effect of delays on fares and the use of data to optimise fares were topics discussed. Public transport, such as buses, railways and metros also find a place in the discussion, such as in Allport\(^11\) and Janson\(^12\). They discuss optimal timing and routes for the buses and rails and congestion respectively.

Certain models focussing on the interactions between producers and consumers have been made, but they include very long-distance travel. Ivaldi et. al.\(^13\) for instance, developed such a model to study inter-city travel. They also attempted to gauge the effect of infrastructural interventions on the market equilibrium, along with other policy measures. Many other theoretically innovative approaches have been adopted to study structural problems. Garcia and Marín\(^14\) studied the impact of parking space allocation and design on transport markets. Theoretically interesting explorations have had a further impact on research in this field. Banerjee\(^15\) found the remarkable fact, that despite no prior knowledge of Rabin's fairness axioms, New Delhi authorities have often proposed policies that satisfy them for instance.

A theoretical model studying how sellers behave in the private passenger road transport industry as defined in this paper is, however, difficult to find. The papers mentioned above diverge in their discussion from the behaviour of service providers in the said industry or are too generic to be directly applied to the industry. The decision-making by the sellers is also largely un-discussed.

### 2 Description of physical features of the problem

The private passenger road transport industry as defined in this paper faces a physical reality peculiar in certain respects. The operators usually operate on a fixed route, say from A to B and B to A. The demand is concentrated in the two end-points A and B. While this can be identified as a segmented market, it is important to note that the seller here cannot provide his or her services simultaneously in both the ‘segments’ unlike what is assumed in many segmented market models. This is plainly because of the physical condition that the seller can be travelling either A to B or B to A but not both at any particular point in time. This setting thus demands a separate model of its own to be analysed. The paper thus develops a model to analyse the behaviour of the sellers in this industry.

### 3 The model

The model to be developed assumes a fixed path of operation AB where the journey is made to and fro. While this path may be thought of, perhaps as the optimal path of operation, the model does not require it to be so and is not concerned with its determination, it assumes it to be given. The demand is concentrated at the two endpoints and is partly exogenously determined and partly affected endogenously. The following are the parameters and variables of the model:

- **t**: The time required to travel from A to B or B to A.
- **T**: The total time of operation where the exogenous demand is perceived by the seller to be fixed.
- **t_1(p_1,d_1)**: The time the seller must wait at A to have a passenger.
- **t_2(p_2,d_2)**: The time the seller must wait at B to have a passenger.
d₁: Exogenous demand at A.
d₂: Exogenous demand at B.
c: Non-time cost of travelling from A to B or B to A.
p₁: Price charged at A.
p₂: Price charged at B.

We also define the following variables:
τ₁ = t₁ + t₁: The time required to wait at A, then have a passenger and travel to B.
τ₂ = t₂ + t₂: The time required to wait at B, the have a passenger and travel to A.

We assume all the variables and parameters mentioned except p₁ and p₂, to be strictly positive. p₁ and p₂ are assumed to be non-negative.

We assume the following relations:
\[ \frac{\partial \tau_1}{\partial p_1} > 0 \quad \text{and} \quad \frac{\partial \tau_2}{\partial p_2} > 0 \]  \hspace{1cm} (1)
\[ \frac{\partial \tau_1}{\partial d_1} < 0 \quad \text{and} \quad \frac{\partial \tau_2}{\partial d_2} < 0 \]  \hspace{1cm} (2)

Note, that T is strictly positive, which implies that the seller perceives external demand to be stagnant for non-zero intervals of time. While in reality, exogenous demand may be continuously changing, we introduce this postulate to argue that the seller ‘aggregates’ demand behaviour across non-zero time intervals. Rather than reacting to changes in demand over every moment in time, he or she may divide a period, say the workday into finite sub-periods with fixed demands. For example, the seller may perceive the workday to consist of three sub-periods, the morning period with average demand x₁, the afternoon period with average demand x₂ and the evening period with demand x₃. Alternatively, the seller may divide the day into a ‘peak period’ (with a higher expected demand) and a ‘low demand period’ or view the entire day as a single period with fixed exogenous demand too. The model does not specify the exact length of a period and thus, does not impose any restrictions on the number and timings of the sub-periods. It does, however, assert that such a division happens. This may deviate from purely rational behaviour, and signify the use of a ‘heuristic’ to base seller behaviour, making assessments easier for the seller. Also, note that the last inequality relations assumed are regarding demand behaviour. We expect a rise in prices to reduce demand and thus increase the time the seller must wait to get a customer. The relation between exogenous demand and waiting time can be interpreted similarly, a rise in exogenous demand means the seller must wait for a lesser amount of time to get a customer. This can also be thought of as a consequence of the way the exogenous demand variables are defined- such that raising them reduces expected waiting times. Also note, that by ‘passenger’, we do not mean one single physical passenger— it means the number of passengers the seller is willing to or allowed to carry. For example, for an e-rickshaw, four physical passengers can count as one passenger in this paper’s sense, because the seller would wait until four passengers have come before leaving. In a pandemic, if the mandated number is reduced to, say 2, then a passenger in this paper’s sense would mean 2 physical passengers. The model in this sense requires no modification to account for such change in circumstances.

Having defined the key numerical variables, we define certain non-numerical variables:

pp: A round trip where the seller carries passengers from both A to B and B to A.
pe: A round trip where the seller carries passengers from A to B but not from B to A.
ep: A round trip where the seller does not carry passengers from A to B but does carry passengers from B to A.
ee: A round trip where the seller does not carry any passengers from both A to B and B to A.

We further define the following functions:

\[ n : \{pp, pe, ep, ee\} \rightarrow N \]

This function denotes the number of times a particular type of round trip is made in a period. For example, \( N(\text{pe}) \) is the number of times round trip type \( pe \) was made by the seller.

The times required to make each round trip type are respectively

\[ TT(pp) = \tau_1 + \tau_2 \]  \hspace{1cm} (3)
\[ TT(pe) = \tau_1 + t \]  \hspace{1cm} (4)
\[ TT(ep) = t_2 + t \] (5)

\[ TT(ee) = 2t \] (6)

The total time required to complete all round trips is, therefore,

\[ TT_{\text{Sum}} = \sum_{x \in \{pp, pe, ep, ee\}} n(x) TT(x) \] (7)

The seller earns the following profits for each type of round trip respectively:

\[ \pi(pp) = p_1 + p_2 - 2c \] (8)

\[ \pi(pe) = p_1 - 2c \] (9)

\[ \pi(ep) = p_2 - 2c \] (10)

\[ \pi(ee) = -2c \] (11)

The total profit in the period is

\[ \pi = \sum_{x \in \{pp, pe, ep, ee\}} n(x) \pi(x) \] (12)

Thus, the choice problem of the seller is

Choose \( p_1 \), \( p_2 \), \( N(pp) \), \( N(pe) \), \( N(ep) \) and \( N(ee) \) to maximise

\[ \pi = \sum_{x \in \{pp, pe, ep, ee\}} n(x) \pi(x) \]

Subject to the constraint

\[ TT_{\text{Sum}} \leq T \]

This completes the basic description of the model. We proceed to solve it now.

4 Equilibrium

We solve the seller's choice problem in a two-step process. First, we find the optimal values of \( n(pp) \), \( n(pe) \), \( n(ep) \) and \( n(ee) \) given the prices \( p_1 \) and \( p_2 \). This will enable us to evaluate the highest possible profit for each price pair. We then choose the prices \( p_1 \) and \( p_2 \) that yield the largest optimal profit.

Step 1: Note that, once we fix the values of \( p_1 \) and \( p_2 \), because the cost \( c \) is given, the values of \( \pi(pp) \), \( \pi(pe) \), \( \pi(ep) \) and \( \pi(ee) \) also get fixed.

Since these are the coefficients of the choice variables \( n(pp) \), \( n(pe) \), \( n(ep) \) and \( n(ee) \) in the objective function \( \pi \), the objective function essentially becomes linear.

Also note that the coefficients of the choice variables \( n(pp) \), \( n(pe) \), \( n(ep) \) and \( n(ee) \), that are \( TT(pp) \), \( TT(pe) \), \( TT(pe) \) and \( TT(ee) \) are also constants, because the times required are given. The constraint is also linear then.

The choice problem, when the prices are fixed thus becomes a linear programming problem with the given objective and constraint. The only possible solutions are the 5 corner solutions corresponding to the 4 choice variables and the origin. If \( (n(pp), n(pe), n(pe), n(ee)) \) are points in the choice space when prices are fixed, the following are the only possible solutions:

\[ (0, 0, 0, 0) \text{ where } \pi = 0 \] (15)
The results so far are intuitively plausible. Given the external demand and prices, it is optimal to repeat only one type of round trip throughout the period $T$ (note that in all the corner points except the origin, only one type of round trip has a positive number associated with it) or to not operate at all (the origin). Also, $ee$ is never gone for in equilibrium. This is because it yields a negative profit of $-2c \frac{T}{T^2}$, while it has a positive time cost. Once the type of round trip is determined, the total profit for the period $T$ is just the profit for one such round trip multiplied by the total possible number of round trips $\frac{T}{T^2} \pi(x)$. In step 2, we shall maximise the obtained objective function with the prices as the choice variables.

The seller's choice problem becomes

Maximise by choosing $p_1$ and $p_2$

$$Max \left( 0, \frac{p_1 + p_2 - 2c}{\tau_1 + \tau_2}, \frac{p_1 - 2c}{\tau_1 + t}, \frac{p_2 - 2c}{\tau_2 + t} \right)$$

First note that, because the number of each round trip has already been determined through linear-programming (that is, they are built into the current objective function), the only choice variables remaining are the prices. The only constraint on the prices is that they are non-negative.

**Step 2:** In this step, we seek to determine the first and second-order conditions for optima. Because, depending on the values of the prices and times, the optimal corner solution in the preceding linear programming problem may differ, with the four possibilities mentioned, we shall find the conditions for optima in all four cases.

Case 1 (The optimal point is $(0, 0, 0)$): In this case, the profit is identically equal to zero. Therefore, all values of $p_1$ and $p_2$ are compatible with the optimum. Empirically, the seller does not offer any services in this case, i.e. does not make any round trips at all.

Case 2 (The optimal point is $(\frac{T}{\tau_1 + \tau_2}, 0, 0)$): In this case, only type $pp$ round trips are made. The value of the objective function here is

$$\pi_n = \frac{p_1 + p_2 - 2c}{\tau_1 + \tau_2}$$
The following are the first and second partial derivatives:

\[
\frac{\partial \pi_s}{\partial p_1} = (\tau_1 + \tau_2)^{-1} + (\tau_1 + \tau_2)^{-2} (p_1 + p_2 - 2c) \frac{\partial \tau_1}{\partial p_1}
\]

\[
\frac{\partial \pi_s}{\partial p_2} = (\tau_1 + \tau_2)^{-1} + (\tau_1 + \tau_2)^{-2} (p_1 + p_2 - 2c) \frac{\partial \tau_2}{\partial p_2}
\]

\[
\frac{\partial^2 \pi_s}{\partial p_1^2} = -2(\tau_1 + \tau_2)^{-1} \frac{\partial \tau_1}{\partial p_1} \frac{\partial \pi_s}{\partial p_1} - (p_1 + p_2 - 2c)(\tau_1 + \tau_2)^{-2} \frac{\partial^2 \tau_1}{\partial p_1^2}
\]

\[
\frac{\partial^2 \pi_s}{\partial p_2^2} = -2(\tau_1 + \tau_2)^{-1} \frac{\partial \tau_2}{\partial p_2} \frac{\partial \pi_s}{\partial p_2} - (p_1 + p_2 - 2c)(\tau_1 + \tau_2)^{-2} \frac{\partial^2 \tau_2}{\partial p_2^2}
\]

Thus, the first-order conditions are

\[
\tau_1 + \tau_2 = (p_1 + p_2 - 2c) \frac{\partial \tau_1}{\partial p_1}
\]

\[
\tau_1 + \tau_2 = (p_1 + p_2 - 2c) \frac{\partial \tau_2}{\partial p_2}
\]

To attain simplified expressions for the second-order conditions, we note that the waiting times at A and B are independent of demand at the opposite ends B and A respectively. Also noting that the first partial derivatives at all critical points are zero, the second-order conditions simplify for the critical points to

\[
\frac{\partial^2 \tau_1}{\partial p_1^2} > 0 \quad \text{and} \quad \frac{\partial^2 \tau_2}{\partial p_2^2} > 0
\]

Note that the second-order conditions restrict demand behaviour rather than supply behaviour because the waiting-time changes due to change in price primarily because of favourable or unfavourable response from the demand side. The model, being developed to explain the behaviour of the sellers thus, interestingly has predictions regarding demand behaviour too.

Case 3 (The optimal point is \((0, \frac{T}{r \tau_1}, 0, 0)\)): In this case, only type pe round trips are made. The value of the objective function here is

\[
\pi_s = \frac{p_1 - 2c}{\tau_1 + t}
\]

This is a function only of \(p_1\) because the seller does not carry passengers from B to A, but only from A to B. The first and second-order derivatives are

\[
\frac{d \pi_s}{dp_1} = (\tau_1 + t)^{-1} + (\tau_1 + t)^{-2} (p_1 - 2c) \frac{\partial \tau_1}{\partial p_1}
\]

\[
\frac{d^2 \pi_s}{dp_1^2} = -2(\tau_1 + t)^{-1} \frac{\partial \tau_1}{\partial p_1} \frac{d \pi_s}{dp_1} - (p_1 - 2c)(\tau_1 + t)^{-2} \frac{\partial^2 \tau_1}{\partial p_1^2}
\]

The first and second-order conditions are respectively

\[
\tau_1 + t = (p_1 - 2c) \frac{\partial \tau_1}{\partial p_1}
\]
\[ \frac{\partial^2 \tau_1}{\partial p_1^2} > 0 \]  

(31)

Case 4 (The optimal point is \( (0, 0, \frac{T}{\tau_2+\tau_1}, 0) \)): In this case, the seller would only go for type \( e \) round trips. The value of the objective function here is

\[ \pi_s = \frac{p_2 - 2c}{\tau_2 + t} \]  

(32)

This is a function only of \( p_2 \) because the seller does not carry passengers from B to A, but only from A to B. The first and second-order derivatives are

\[ \frac{d\pi_s}{dp_2} = (\tau_2 + t)^{-1} + (\tau_2 + t)^{-2}(p_2 - 2c) \frac{\partial \tau_2}{\partial p_2} \]  

(33)

\[ \frac{d^2 \pi_s}{dp_2^2} = -2(\tau_2 + t)^{-1} \frac{\partial \tau_2}{\partial p_2} \frac{d\pi_s}{dp_2} - (p_2 - 2c)(\tau_2 + t)^{-2} \frac{\partial^2 \tau_2}{\partial p_2^2} \]  

(34)

The first and second-order conditions are respectively

\[ \tau_2 + t = (p_2 - 2c) \frac{\partial \tau_2}{\partial p_2} \]  

(35)

\[ \frac{\partial^2 \tau_2}{\partial p_2^2} > 0 \]  

(36)

In cases 3 and 4, only the equilibrium conditions for \( p_1 \) and \( p_2 \) are determined respectively. This is because the seller does not carry passengers from B to A and A to B respectively in the cases.

In all the four cases, the model demands or predicts that if the seller does carry passenger from a point to another, raising the price at the point of initiation must increase the waiting time of the seller at that point at an increasing rate, as otherwise, the seller fails to attain equilibrium. While this is a prediction about demand behaviour, this demand behaviour is seen at equilibrium not because of some demand-side phenomenon, but because the seller actively chooses prices such that this condition is met, as we have derived this by optimising the seller’s payoff and not the consumer’s payoff.

5 An application

We have already discussed a prediction of the model on demand behaviour at equilibrium. We here try to derive a prediction about producer behaviour explicitly. Specifically, we try to find out the effect of a marginal change in exogenous demand at point B on the price charged at point A. This exercise makes empirical sense only for cases 2 and 3, because in the other two cases, services are not being offered at point A at all. We examine case 2 here.

For case 2, the first-order conditions are

\[ \tau_1 + \tau_2 = (p_1 + p_2 - 2c) \frac{\partial \tau_1}{\partial p_1} \]  

From (24)

\[ \tau_1 + \tau_2 = (p_1 + p_2 - 2c) \frac{\partial \tau_2}{\partial p_2} \]  

From (25)

These conditions can be rearranged to yield

\[ \frac{\partial \tau_1}{\partial p_1} = \frac{\partial \tau_2}{\partial p_2} \]  

(37)
That is, at equilibrium, a marginal change in prices leads to an equal marginal change in the respective waiting times at equilibrium.

The first condition for optima can be differentiated with respect to $d_{1}$, keeping in mind that a change in $d_{1}$ does not affect $\tau_{1}$ (because the demands at both the points are independent) to get:

$$\frac{\partial \tau_{1}}{\partial p_{1}} \frac{\partial p_{1}}{\partial d_{2}} + \frac{\partial \tau_{2}}{\partial d_{2}} + \frac{\partial \tau_{2}}{\partial p_{2}} \frac{\partial p_{2}}{\partial d_{2}} = \left( \frac{\partial p_{1}}{\partial d_{2}} + \frac{\partial p_{2}}{\partial d_{2}} \right) \frac{\partial \tau_{1}}{\partial p_{1}} + (p_{1} + p_{2} - 2c) \frac{\partial^{2} \tau_{1}}{\partial p_{1} \partial d_{2}}$$

(38)

Using the fact that $\frac{\partial \tau_{1}}{\partial p_{1}} = \frac{\partial \tau_{2}}{\partial p_{2}}$, from equation (37), this result can be simplified to

$$\frac{\partial \tau_{2}}{\partial d_{2}} = (p_{1} + p_{2} - 2c) \frac{\partial^{2} \tau_{1}}{\partial p_{1} \partial d_{2}}$$

(39)

We know, $(p_{1} + p_{2} - 2c) \geq 0$ because otherwise, the case 1 corner point would yield a strictly higher profit, also $\frac{\partial^{2} \tau_{1}}{\partial p_{1} \partial d_{2}} > 0$ by the second-order condition. Finally, $\frac{\partial \tau_{1}}{\partial d_{1}} < 0$ (from inequality (2)).

By all of these, the sign of $\frac{\partial^{2} \tau_{1}}{\partial p_{1} \partial d_{2}}$ is unambiguously negative, and if $(p_{1} + p_{2} - 2c) > 0$. That is, a marginal increase in exogenous demand at point B leads to a decline in prices at point A. It can also be shown that a change in exogenous demand at point A has a similar effect on the price charged at point B. Combining these facts, it can be stated that a marginal increase in exogenous demand at a point results in a decline in the price charged at the opposite point.

This is a strong result. The price falls despite a rise in the total demand in the system.

It can also be shown that for case 3, there is no effect of change in exogenous demand at point B on the price charged at point A. This is understandable because in this case, the seller does not offer any service at point B and is therefore not affected by marginal changes in exogenous demand there. Similarly, for case 4, there is no effect of a marginal change in demand at A on the price charged at point B.

6 Conclusion

While the private passenger road transport industry is expanding, the industry is still under-regulated and under-monitored. Despite the abundance of empirical literature ascertaining this fact, there was a lack of theoretical models to understand decision making in this industry to guide policy. The model develop seeks to fill this gap.

The model, by and large, a rational-actor model also leveraged the behavioural reality of heuristics to suit reality better. It has led to interesting predictions. Firstly, despite being a model of producer behaviour, the model yields predictions regarding demand characteristics at equilibrium. Expected waiting times are a convex function of prices. Additionally, the change in waiting times due to a marginal change in price at the respective locations would be equal at both the endpoints of the path of operation.

Secondly, the model yields a very interesting and strong prediction regarding the pricing behaviour of a provider of transport services in this industry. A marginal rise in exogenous demand at a point would lead to a decline in price at the opposite end whenever service is provided at both the ends.

Thirdly, owing to the postulate that the seller behaves as if exogenous demand is constant for non-zero length intervals of time, we shall observe only one kind of round trip being repeated over an extended period.

The predictions derived in this study display the empirical meaningfulness of the model. The model restricts both demand and supply behaviour at equilibrium and can thus be tested empirically which can either support or oppose the validity of the model. This yields Popperian scientific content for the model. Empirical specification in future research may prove fruitful too. The model can then be used to anticipate and predict the response of the industry to change in policy.

The model must, however, still be used with caution and be properly tested. The heuristic postulated is untested in this industry. Also, the price making feature may not work due to nuances not included in the model. Future empirical research may augment the model to fill this gap.

The model, however, definitely serves as a strong tool to both guide policy and understand producer behaviour in this structurally and physically peculiar industry. This provides both empirical and theoretical relevance and importance to the model developed in this paper.
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