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ANALYZING THE EFFECTS OF TAXICAB DEREGULATION: A NEW EMPIRICAL APPROACH

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Analyzing the effects of taxicab deregulation: A new empirical approach

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Abstract

In many transport industries, such as trucking or air travel, that have been deregulated over the past years, prices have fallen rapidly with apparent gains to users. The taxicab industry has been a notable exception. Deregulation has often led to price hikes that seem to persist throughout the observed periods.

In the present study a recent taxi deregulation in Sweden is analyzed using a new empirical approach. A simulation model of the taxi market is applied that combines the traditional demand/supply framework with results from queuing theory. The theoretical properties of this model are analyzed in Burdett & Fölster (1993). Although not considered here, the methods utilized in the present study can be applied to study other markets for services.

Our simulation of the taxi market deregulation in one city, Stockholm, indicates that consumers probably gained in spite of large price increases. There is no indication that the price increases are due to price agreements among taxi companies. There does, however, seem to be a consumer search problem, particularly in the street pick-up market. As a result actual average prices are estimated to be about 30% higher than they would be in a perfectly competitive market.

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1. Introduction

In many transport industries, such as trucking or air travel, that have been deregulated over the past years prices have fallen rapidly with apparent gains to users. The taxicab industry has been a notable exception. Deregulation has often led to price hikes that seem to persist throughout the observed periods. Many have therefore drawn the same conclusion as Teal and Berglund (1987) that deregulation of taxicabs has "been a relatively disappointing policy" (p.37).

In the present study a recent taxi deregulation in Stockholm is analyzed using a new empirical approach. A simulation model of the taxi market is applied that combines the traditional demand/supply framework with results from queuing theory. The theoretical properties of this model are analyzed in Burdett & Fölster (1993). Although not considered here, the methods utilized in the present study can be applied to study other markets for services.

As the literature on the subject to date has indicated, markets for taxi services are complex and do not easily yield to economic analysis. Few general predictions follow from the standard economic analysis of taxi markets, and empirical investigations have led to somewhat surprising and unexpected results. The approach used by most when analyzing taxi markets is based on traditional supply and demand analysis with the added complexity that demand is assumed to be a function of waiting time as well as price (see, for example, Orr (1969), DeVany (1975), Beesley and Glaister (1983).

Manski and Wright (1977), first utilized results from queuing theory, showing how the time consumers spend waiting for a cab depends on market demand. In particular they showed that at least some taxi markets can be viewed as a queueing model yielding a precise relationship between the average time a consumer must wait for service and the market demand. Unfortunately, Manski and Wright, like many other contributions to this topic assume prices are fixed by a regulating agency and therefore have little to say about how an unregulated market would behave.

Empirical studies have also concentrated on regulated markets and generally ignore the queue-theoretical relationship between waiting time and demand. Schroeter (1983), for example, estimates a system of two simultaneous equations with waiting time and demand as the dependent variables.

Our simulation of the taxi market deregulation in Stockholm indicates that consumers probably gained in spite of large price increases. There is no indication that the price increases are due to price agreements among taxi companies. There does seem to be a consumer search problem in the street pick-up market which could imply that prices are higher than the social optimum.

Section 2 briefly describes the deregulation of taxi cabs in Stockholm. Section 3 explains the theoretical structure of the simulation model. Section 4 reports the empirical application and results.

2. Deregulation of taxi cabs in Stockholm

Before the 1 july 1990 both taxi prices and quantities of cabs were regulated in Stockholm. Price regulation was administered centrally for the whole of Sweden by a special transport agency. This agency negotiated price increases with the taxi owners' association. The stated aim was to permit price increases only to the extent warranted by cost increases. In practice price increases closely tracked the consumer price index.

The quantity of cabs was regulated locally. Local taxi owner associations generally had a dominating influence on local authorities' decision how many cabs to permit. In addition, local authorities required all cabs to join a single exchange which was run as a cab owners' cooperative. There were also requirements on the number of cabs in service during night hours and weekends.

All of these regulations were abolished in one sweep on the 1 july 1990. This immediately led to a drastic increase in the number of cabs. Until early 1992 the number of cabs had risen by 36%. At that point the number of cabs was still increasing albeit at a slower rate.

Initially there was one central cab company in Stockholm that operated 70% of the cabs in the greater Stockholm area. The remaining cabs were operated by small companies located in the larger suburbs. After deregulation two new central cab companies started. In addition a number of small, more specialized cab companies started operating.

Waiting time for telephone customers fell in Stockholm by an average of 4 minutes per trip only a few months after deregulation. At the same time capacity utilization (percent paid time per cab) fell from 0.62 to 0.35.

Prices rose rapidly. The picture is complicated by a VAT introduction and by the fact that many elderly and handicapped receive publicly paid taxivouchers.

For normal customers real price rose by 19% during the first 6 months after deregulation.[1] At that point a VAT of 25% was levied on taxi services. Apparently cab companies could initially pass most of the tax burden on to the consumer. In the first quarter of 1991 prices were thus 40% higher than before deregulation. After that prices began inching down. In Januari 1992 the VAT rate was lowered from 25% to 20%. Prices dropped some 5% reflecting the VAT change. All in all real prices were still about 33% higher in the

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[1] In the following analysis price refers only to the price that non-voucher customers pay. Half of the taxi customers in Stockholm are on a public voucher program. They pay a small nominal fee for each voucher which is good for any taxi trip within a certain radius. Taxidrivers are reimbursed for the vouchers by local authorities at a rate that is negotiated through a tendering process. In Stockholm all the major cab companies accepted the lowest bid and are allowed to carry voucher customers. Reimbursements for vouchers increased by about 15% during the first six months after deregulation. Since the tendering processd has not been repeated since then the rates (excluding VAT) have remained constant since then.

spring of 1992 than before deregulation.

In spite of the price increases revenue per cab decreased drastically as a consequence of the increase in the total number of cabs. Cab drivers' incomes plummetted by about 39% of initial real hourly wage. Many cab owners have declared bancruptcy. These bancruptcies rarely reduce the number of cabs however. They only imply a shift in ownership.[2]

3. The model

The overall structure of the model is briefly described here. This summarizes a full theoretical analysis in Burdett and Fölster (1993).

The approach used by most when analyzing taxi markets is based on traditional supply and demand analysis with the added complexity that demand is assumed to be function of waiting time as well as price. Hence, the market demand for taxi services (per hour), D, is assumed to be a function of price, p, and the expected time a consumer expects to wait for a cab, W^e ,i.e., $D(p,W_e)$, where $D_1 < 0$ and $D_2 < 0$.

However, if demand for taxi services is a function of the time customers have to wait for service, it appears reasonable to assume that the time a customer has to wait for service will in turn depend on the market demand. This implies the average time consumers will wait for a taxi, W^a , is an increasing function of the market demand for taxi services, D, as well as a decreasing function of the number of cabs in service, c, i.e. $W^a = v(c,D)$ with $v_1 < 0$ and $v_2 > 0$. In most studies, however, the focus has been on the demand function with scant attention paid to how the waiting time depends upon demand. In contrast with

[2] There have, however, been considerable problems maintaining law and order after deregulating. For example, up to half of all taxi income is now estimated not to be reported for taxation.

most contributions to this literature, Manski and Wright (1977), utilizing results from queuing theory, concentrated on how the time consumer wait depends on market demand. Unfortunately, Manski and Wright, like many other contributions to this topic assume prices are fixed by a regulating agency and therefore have little to say about how an unregulated market would behave.

Although not always explicitly recognized in previous studies, it is the interaction between the above intuitively reasonable functions that is the cause of many problems. To see this first note that the two functions specified imply that $W_a = v(c,D(p,W^e))$, and therefore the actual average waiting time is (a) a decreasing function of the consumers expected waiting time, (b) a decreasing function of the number of cabs, and (c) an increasing function of price. At any equilibrium it appears reasonable to assume that the expected waiting time equals the actual mean waiting time, i.e., $W^e = W^a$.[3] This implies the demand for taxis when the actual mean waiting time equals the expected waiting time can be written as $d(p,c) = D(p,W(p,c))$. For obvious reasons $d(.,c)$ will be termed the rational demand function for taxis services. Note that the properties of $d(.)$ depends upon the assumed properties of the demand function $D(.)$ and properties of the v function. For example, given the restrictions made above imply $d_1 < 0$ and $d_2 > 0$. This latter implication leads to the somewhat strange conclusion that an increase in supply, measured by the number of cabs in service, shifts the rational demand function upwards. This result almost alone leads to the problems encountered in the analysis of taxi market.

Before considering the supply side of the market it will be useful to briefly consider the institutional setting. There are basically three ways of obtaining taxi services:

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[3] Given mild restrictions, it can be shown for given p and c there exists a unique $W(p,c)$ where $W(p,c) = v(c,D(p,W(p,c))) = W^a = W^e$ (Burdett & Fölster, 1993).

(A) Telephone a taxi company and inform them where you want to be collected. The company radios a free cab (if one is available) and informs the driver where to make the pick up.

(B) Go to a recognized meeting area (termed a cab stand, or taxi rank). In this case free cabs wait at such areas for customers.

(C) Stand on the sidewalk and attempt to hail a free cab if one passes.

In the case of Stockholm all three modes are common. In what follows of the theory section we shall concentrate on telephone taxi markets. Nevertheless, much of what we have to say, is with suitable modifications, applied to the other two forms of taxi transactions in the empirical part.

Although there is a large variety of different taxi industry structures, the following stylized facts describe the telephone taxi market in Stockholm and many other cities.

(A) A small number of taxi companies usually serve a given market. Often one company supplies more than 50 per cent of the services.

(B) Taxi companies usually do not own the cabs. A taxi company's capital stock typically consists of a bank of telephones and a radio transmitter.

(C) Many cabs are owned by their drivers.[4]

(D) A cab owner pays a fixed amount a month to the taxi company. For this fee the cab radio is hooked into the radio transmitter. Further, the cab must charge the prices stipulated by the taxi company.

Looking at the taxi market as a queuing model each cab can be seen as a "server" and the time spent while a cab driver is working can be usefully partitioned into four time periods:

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[4] However, some drivers own more than one cab. Such owners employ a driver. These drivers who are not owners of cabs are paid by the owners of the cab in a deal that has nothing to do with the taxi company; usually they are paid a percentage of the revenue. Owners of a single cab often work out a similar deal with a driver who drives when they are not working.

idle time, response time, meter time, and dead-heading time.

A) Idle time is the time when the cab is free but waiting for business. During this time the driver may either drive around, or find a place to wait. On being informed that a customer requires services, the cab travels to the place where the customer wants to be collected.

B) The time it takes for the cab to collect the customer is termed response time.

C) Meter time is that time when the cab meter is running, i.e., the time between when the customer is picked up and when the customer leaves the cab.

D) After dropping off a customer, a cab may not be immediately free to pick up another one. For example, the previous customer may have been dropped off a long way out of the area served by the cab company. In such a case the cab will spend some time returning to the area. On return the driver informs the cab company by radio he or she is available for customers. Following the expression used in the United States, the time between dropping off a customer and being ready to receive new customers is termed dead-heading time.

Keeping things as simple as possible assume for the time being that both response time and dead-heading time are both equal zero at all times. Assume further that there is a single taxi company that serves a particular market.

The arrival rate of phone calls by customers faced by the taxi company can be described by a Poisson process with parameter a. Of course, the value of this parameter may well depend on many factors such as the price charged by the cab company as well as the quality of service. Such detail will be considered a little later. It is well known that if a Poisson process generates the arrival rate of phone calls, then the probability that any particular number of phone calls is received in particular small time interval Dt equals (approximately) aDt which is independent of both the starting date of the interval and the history of phone calls to date.

Some consumers will want a long taxi ride whereas others will want a short one - it cannot be predicted with certainty.

Focusing on essentials , assume the duration of a completed cab ride by customers can be described by an exponential random variable with parameter m. In this case the expected duration of a cab ride (before the driver knows where the customer wants to go) is 1/m. In what follows it is assumed that m does not change as the other parameters of the model change. For example, if there is a decrease in price it is assumed that consumers take more cab rides - not longer ones.

The assumptions made above imply the theory of queues can be used to analyze the cab services supplied by the cab company.[5] To completely characterize a queuing model of this type three elements need to be specified: (a) the distribution function describing the arrival rate of customers (here assumed to be Poisson), (b) the distribution of service times (here assumed to be exponential), and (c) the number of servers (assumed here to be c). These restrictions imply the taxi services supplied can be described by what is termed an M/M/C queuing model.

Given the M/M/C queuing model specified above, if a is the arrival rate of customer phone calls, it is possible to calculate the average time a customer will have to wait for a cab. Note as response time has been assumed to equal zero, the only reason a customer will wait is because all cabs are busy. The expected waiting time for a customer equals the probability all c cabs are busy multiplied by the expected time a customer must wait given all cabs are busy.

The actual mean waiting time, W_a , is a function of the arrival rate of phone calls and the number of cabs, i.e., $W^a = v(a,c)$, which is an increasing convex function of market demand as shown in Burdett & Fölster, 1993.

So far the determinants of market demand, a, have not been discussed. Assume now a is a decreasing function of price, p, where price is defined in units of time the meter is running,

[5] See, for example Heyman and Sobel (1988) for a detailed exposition of the basic results of the theory of queues.

and expected waiting time, W^e. Keeping things as simple as possible, assume a(.) is a linear function of both its arguments, i.e.,

(1) $a(p,W^e) = a_0 - a_1p - a_2W^e$

where a_0, a_1 and a_2 are positive parameters. The average waiting time can then be expressed as

(2) $W^a = v(a_0 - a_1p - a_2W^e, c)$

Hence, holding p and c fixed, the greater the expected mean waiting time, the smaller the actual mean waiting time. It follows therefore, for any fixed p and c such that $v(a_0-a_1p,c) > 0$, there exists a unique fixed point, W(p,c), such that

(3) $W(p,c) = v(a_0 - a_1p - a_2W(p,c), c)$

Figure 1 illustrates the simple proof of this claim. Further, as v(a,c) is a decreasing function of c, it follows that

(4) $W(p,c) > W(p,c+1)$

for any positive integer c. This is also illustrated in Figure 1.

However, (1) implies that for given p and c there exists a unique demand, d(p,c), where expectations are fulfilled, i.e., there exists a unique d(p,c) such that

(5) $d(p,c) = a_0 - a_1p - a_2W(p,c)$

It follows that d(p,c) represents the demand of consumers when p is the price and expected waiting time turns out to be the one generated for the given number of cabs. For this reason we term l(.,c) the rational demand function.

Both the waiting time function, W(.,.) and the rational demand function, l(.,.), are complicated functions as they have no closed form solutions for $c > 2$. Also, few general predictions can be made when the number of cabs serving the market is increased. In particular, an increase in the number of cabs can lead to an increase, or decrease, in both price and profit per cab. Placing restrictions on the functions so that they give clear results has obvious problems. A brief review of the empirical evidence indicates that an increase in the number of cabs in some circumstances increases the price charged and in other circumstances reduces it. This implies that any restrictions made that imply a definite sign to $dp(c)/dc$ would not fit the facts as they stand at present.[6]

An alternative to the theoretical derivation is to simulate the model outlined above for particular parameter values. This is the approach taken in Burdett and Fölster (1993).[7] In the remainder of this paper the parameter values are actually estimated from empirical data and used in simulation.

4. Empirical analysis

The empirical approach essentially follows the model described above. This means that a) the parameters of the random distributions of the M/M/c queueing model are estimated, b) the

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[6] In addition, it can be shown that the function v is such that a function $M(a,c,c+1) = v(a,c+1) - v(a,c)$ is positive for some values of a and negative for other values. Hence, a desirable property for a differentiable function that approximates v, is that v does not always have the same sign.

[7] Although such a method has the limitation that few general statements can be made, it has the advantage that given knowledge of the values of the parameters of market demand curve faced in a particular market, the equilibrium values of price, demand, profits, etc. can be approximated to a high degree of accuracy for any given number of cabs in the markets. Results for different numbers of cabs can then be compared.

linear demand equation is estimated and c) the M/M/c model and demand equation are combined to simulate how changes in the number of cabs affect prices, demand and cab owners' profits. In the empirical application a number of practical problems must be taken account of, such as that the market is split into a telephone- and street-pickup market, that demand varies over periods of the day, and that idle and deadheading times must be considered.

The data are described in more detail in the appendix. They consist of weekly logs from a sample of 19-35 cabs from each of the three cab companies that operate centrally. These were collected once before deregulation and then updated at three times after deregulation. In addition the companies provided information on the total number of cabs, telephone calls, and other aggregate variables.

Estimation of arrival distributions

Arrivals consist of telephone calls and street pick-ups. The distributions of these are analyzed separately.

The distribution of telephone arrivals is estimated from aggregate data for each of the cab companies on the number of arriving calls each minute. If each potential caller makes an independent decision to call so that there is a fixed probability of calling in any minute, the distribution of times between arriving calls should be exponentially distributed. This translates into a Poisson distribution of calls per minute.

Since the telephone arrival distribution changes over the course of the day one would like to identify periods during which demand remains constant. This was done by dividing the day into half-hour periods, calculating the mean and the variance of calls per minute in each half-hour period, and then performing a t-test indicating whether a period is significantly different from the preceding period. This was done for all seven days in each of the four observation periods.

The tests indicate that there are three periods during the course of a weekday during which demand generally remains stable: Morning (7 am - 10 am), day (10 am to 6 pm), and night (7 pm - 12 pm). During the remaining hours and over the weekends demand changes more continously and more erratically. Those periods are therefore not used in the estimations.

For each of the three weekday periods where demand remains stable (morning, day, night) it is then straightforward to derive the Poisson distribution of calls per minute.[8]

For the arrival of street pick-ups there is no aggregate data since the switchboard is not notified when a cab picks up a customer on the street. Instead the log data from the sampled cabs is used and extrapolated to all of the cab companies' cabs. First the number of free cabs is calculated from the sample for each half-hour periods and extrapolated to the total. Then the probability of getting a street pick-up given that a cab is free is calculated from the sample. Multiplying these two figures gives the estimated street arrival rate.

The probability of getting a street pick-up given that a cab is free is quite similar between cab companies.[9] Presumably this reflects the fact that street pick-ups most often choose the first cab they see rather than waiting for the cab of a particular

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[8] First, the hypothetical random distribution of calls per minute is calculated based on the average number of calls. The actual number of calls per minute were then divided into 20 categories (of number of calls per minute), thus generating a frequency distribution that was compared to the Poisson frequency distribution using a chi-square test. The calculated test-statistic was 12.6 which, with 20 degrees of freedom implies that there is no significant difference between the Poisson and the actual distribution.

[9] The chi-square statistics for pairwise comparisons of the three cab companies are 5.61, 4.20, and 8.19 using 12 observational periods. None of these statistics imply a significant difference.

company.

Arrivals of telephone calls and street pick-ups are closely correlated. Not surprisingly the street pick-ups display the same pattern of three weekday periods of stable demand. This was confirmed statistically by the same method as described above.

It could not be confirmed, however, that the street pick-up arrivals also follow a Poisson distribution of arrivals per minute. The reason this seems to happen is that some customers' arrivals are correlated, perhaps due to events that attract larger groups of customers such as bars closing or train arrivals. This should primarily affect customers that are picked up on the street, e.g. when a train arrives many customers want a cab at the train station. A significant fraction of street pick-ups occurs in places like train stations where cabs queue.

This reasoning suggests a "hazard" type arrival distribution. Given that an event occurs that causes one street arrival there is an increased chance that there will be an additional street arrival. This is similar to the argument for hazard functions in the estimation of unemployment duration. Given that a person has one unemployed day there is an increased chance that there are additional days of unemployment.

The simplest hazard function is an exponential distribution of arrivals per minute. Using chi-square to test the hypothesized distribution against the actual gives a fairly good fit.[10]

Service time distributions

The term service time is used here to describe the sum of cabs response time, meter time and dead-heading time, i.e. the time from when a cab is notified until deadheading has been completed and the

[10] First, the hypothetical random distribution of street arrivals is calculated based on the average rate. The actual number arrivals per minute is then divided into 20 categories (of arrivals per minute), thus generating a frequency distribution that was compared to the exponential frequency distribution using chi-square test. The calculated test-statistic was 8.2 which, with 20 degrees of freedom implies that there is no significant difference.

cab is waiting for a new customer.[11] For the service time the exponential distribution fits quite well. Average service time is 33 minutes for telephone arrivals and 25 minutes for street pick-ups. The difference is due to the fact that the response time for street pick-ups is virtually zero.

Service time distribution is remarkably constant over the course of the observation weeks. Also there appears to be no particular specialization of cabs to certain types of customers that have different service times than the average. Therefore service times can essentially be taken as constant.

Regression of arrival times

The empirical analysis essentially follows the model described above. The first step is to estimate equation (1), regressing arrival rates over prices and waiting times. However, empirical application requires some adjustments to equation (1).

The first adjustment is that telephone arrivals and street pick-ups have to be accounted for separately. Therefore two regressions are performed, one for telephone arrivals (TARR) and one for street arrivals (SARR). These two equations are interdependent in the sense that an increase in telephone arrivals reduces the number of free cabs available to serve street pick-ups. This relationship is taken account of by estimating the street arrival equation conditional on the number of free cabs.

A second adjustment is necessary because customers may face an information problem in comparing prices between companies, in particular since fare structures are quite complex. This would

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[11] Deadheading plays an important role. Since we want to think of taxi as a simple one queue system, rather than a geographical distribution of many local queues, one can argue that deadheading captures the time cabs spend spreading themselves evenly over the city. If by accident all customers want to go from A to B then queues could build up at A even though there are empty cabs at B. Adding deadheading into the serving time internalizes such problems in the service time distribution.

imply that customers may react more to the average price for a cab ride rather than to each company's relative price. Since our data covers both changes in average price over time and cross-sectional differences in companies' prices we can test for these effects by dividing the price variable into average price (AVPRICE) and relative price (RELPRICE).

A third adjustment is the inclusion of dummy variables for day or morning (DAY, MOR).

A fourth adjustment concerns the fact that the three cab companies have very different levels of arrivals even though they do not differ a whole lot in terms of waiting time and price. Presumably this is due to "telephone number" effects. One could correct for this with a dummy variable for each company. A more efficient solution, however, is to correct the arrival rate by the companies' share of the total number of cabs in the Stockholm area (SHARE).[12] The correction of the companies' share of cabs implies that changes in price and waiting time yield a greater absolute increase in arrivals for a company that has a greater share of the cabs.

The regression equation for telephone arrivals then is

$$(6) \quad TARR/SHARE = a_0 + a_1\ AVPRICE + a_2\ RELPRICE + a_3\ AW + a_4\ MOR + a_5\ DAY$$

For street pick-ups we have no explicit measure of waiting time. Instead, the total number of free cabs for all companies (TFCA) is used as a proxy of waiting time for street pick-ups. In addition the equation for street arrivals is estimated conditional on the number of each company's free cabs (FCA) by letting the dependent variable be SARR/FCA. This corrects for cab company effects, equivalent to the "telephone number" effect discussed

[12] One cannot correct for the size of companies using the absolute number of cabs, since the number of cabs increases during the sample period for reasons that are unrelated to demand.

above. Since, as shown above, street arrivals tend to choose the first cab they see, it is safe to conclude that a company with many free cabs will pick up a larger share of the street pick-ups. The estimated equation is then as follows.

$$(7) \quad SARR/FCA = b_0 + b_1\ AVPRICE + b_2\ RELPRICE + b_3\ TFCA + b_4\ MOR + b_5\ DAY$$

The regression estimates, shown in table 1, indicate the effects of a change in prices or waiting times assuming they are independent. The simultaneous nature of these relationships is analysed further below. Both equations are estimated in logarithmic form, so the coefficients can be interpreted as elasticities.

Table 1. Regression estimates for telephone and street arrivals.*

Variable	Telephone arrivals TARR/SHARE	Street arrivals SARR/FCA
Constant	5.00 (0.66)	3.02 (0.64)
AVPRICE	- 0.74 (0.26)	- 1.33 (0.27)
RELPRICE	- 0.18 (0.07)	- 0.10 (0.13)
AW	- 0.14 (0.05)	-
TFCA	-	0.04 (0.04)
MOR	0.21 (0.06)	- 0.19 (0.08)
DAY	0.57 (0.06)	- 0.24 (0.08)
$\bar{R}^2$	0.919	0.434

* Standard errors in parentheses. 30 Observations. All variables

except MOR and DAY are in logarithmic form.

The size of the coefficients for street arrivals and telephone arrivals cannot be compared directly, since street arrival coefficients are per free cab, while telephone arrival coefficients are calculated in terms of their effect on total demand. This also explains why R^2 is high for the telephone arrival equation. The morning and day dummies add much to the equation's explanatory power. In contrast these effects are much smaller for the street arrival equation since this is estimated per free cab and cabs go out of service as demand slows down in the off periods.

As one would expect, average price has a significant and large effect in both the telephone and street market. The relative price has a significant effect only in the telephone order market, but not in the street market. This presumably reflects the fact that customers tend to hail the first cab available on the street rather than compare prices. However, even in the telephone market, the size of the relative price effect is much smaller than that of the average price effect, indicating a consumer search problem.

Average waiting time has a significant effect in the telephone market. In the street market the total number of free cabs, that serves as a proxy for waiting time is of the right sign, but not significant. This could be because free cabs tend to queue at taxi terminals, so that waiting time for customers in other places than terminals does not change a lot when there are more free cabs.

From the coefficients one can calculate the ratio of the price and waiting time coefficients wich can be envisaged as the price of waiting per unit of travel time. For the telephone order coefficients this would imply 11.23 Swedish kronor per minute of waiting time.

At first sight this appears to be a very high estimate, implying a value of waiting time of about US $ 80 per hour. This can be explained, however, by the fact that even a small increase in waiting time implies a fairly large increase in the variance of waiting time. Since customers often take a cab to places where timing is important, such as airports or meetings, it seems reasonable that a reduction in waiting time variance is highly valued.

Even without engaging in a full scale cost benefit calculation it is clear such a high valuation of waiting time makes it more likely that customers gained when waiting times decreased after deregulation and even that customers' gain exceeded cab driver losses. For an average day time trip customers would value the reduction in waiting time of about four minutes that occurred in connection with deregulation at 45 Swedish kronor, while the price increase (excluding VAT changes) was only 28 Swedish kronor.[13] These values should be compared to the price of an average trip of 140 kronor.

Calculation of waiting time

The regression estimates reported above only show the partial effects that, for example, an increase in average waiting time has on demand, ignoring that an increase in demand in turn also increases waiting time. In some empirical applications the determinants of waiting time are estimated in a simultaneous equation system (e.g. Schroeter, 1983). There are however two problems with that approach. First, the theoretical functional form for the waiting time equation is complicated and cannot be approximated well by linear regressions. Second, when prices are not exogenous, as in a deregulated system, some difficult identification problems arise. Essentially there are three dependent variables (demand, price and waiting time) and it is

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[13] Cab driver losses are not as easily calculated. While we know how much income old cab drivers lost due to deregulation it is open to debate whether the income of newly entered cab drivers should be treated as a gain or a loss.

difficult to achieve separate identification.[14]

Since we have derived the waiting time equation (2) directly from queuing theory it need not be estimated as a regression. The exact functional form is complicated and can be found in textbooks that deal with M/M/C queuing systems (e.g. Heyman & Sobel, 1982). For larger numbers of servers it is common to use approximations to the exact formula in numerical calculations. The approximation used here follows the formula

$$W^a = (c/(\ln(c) - 3)) \;/\; (c - A)$$

where c is the total number of cabs, and A is the average number of occupied cabs which can be derived directly from the customer arrival rates (telephone and street pick-up) and the average service times.[15] The calculated average waiting time here refers to the telephone waiting time.

Treating demand as exogenous allows derivation of calculated average waiting times for the thirty observational periods. Comparing these to actual measured waiting times indicates that the null hypothesis that these are identical cannot be rejected.[16]

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[14] Schroeter (1983) examines regulated markets, so prices can be taken as exogenous. However his specification is problematic because it does not distinguish between customers' expected waiting time and the actual waiting time. Instead it assumes that customers demand in a given instance is a function of the actual waiting time at that point in time. This would imply that the demand equation picks up a spurious relationship between demand and waiting time. An additional problem is that waiting time as measured ignores telephone waiting time. Further the regressions force waiting time and travel time to have the same coefficient. This ignores that a rise in average waiting time implies a large rise in the variance of waiting time which may have a large effect on demand.

[15] The function is an extension of a standard approximation formula to the case where $c-A > 1$.

[16] Using a chi-square test with 30 degrees of freedom gives a statistic of 8.9 which is not significant.

Simulating the taxi market

Equations for demand and waiting time have been derived above. Recognizing the interdependency between the two gives rise to a simulation model of the taxi market. The simulations performed here are essentially a way of calculating the impact multipliers in the simultaneous system. Initially we treat two other dependent variables (prices and number of cabs) as exogenous. In subsequent steps these are then endogenized.

Table 2 shows the impact coefficients of prices and the number of cabs (CABS) on the customer arrival rates. These coefficients can be interpreted as elasticities and are comparable to those shown in table 1. Three important conclusions emerge from the impact coefficients. First, before deregulation a price increase would actually have increased demand. This confirms the argument above that consumers gained from deregulation. Second, the large differences in the impact coefficents before and after deregulation illustrate that waiting time is a highly non-linear function of price and the number of cabs. This supports the view that the waiting time function can not be approximated well by an estimated linear equation. Third, after deregulation the impact coefficients are quite small (in absolute terms). This can be explained by the fact that the number of cabs after deregulation is so large that additional cabs barely lower waiting times.

Table 2. Impact coefficients of prices and number of cabs on customer arrival rates*

Variable	Telephone arrivals TARR/SHARE	Street arrivals SARR/FCA	Average waiting time AW
Pre-deregulation (AVPRICE = 7 kronor/minute, CABS = 1350)			
AVPRICE	1.1	0.88	- 1.3
RELPRICE	- 0.05	0.01	- 0.4
CABS	1.4	0.81	- 1.2
Post-deregulation (AVPRICE = 10 kronor/minute, CABS = 2100)			
AVPRICE	- 0.70	- 1.29	0.16
RELPRICE	- 0.15	- 0.09	0.11
CABS	0.04	0.03	-0.19

* Based on 30 Observations. All variables are in logarithmic form.

Simulating prices

The next step is to endogenize prices. We assume that price setting is the outcome of an optimization. Therefore optimal prices can be calculated based on the number of cabs and the demand and waiting time equations described above. We analyse three different optimization possibilities:

A) A monopolist maximizes total profit in the cab market given equal price for all cabs.

B) Profits per cab are maximized, assuming that all cabs charge the same price. This can be envisioned as a cartel of cab driver/owners.

C) Each cab company maximizes its profit and can charge a price differently from what other company's charge.[17]

D) Perfect competition. Here it is assumed that cab companies compete as under C), but that the relative price elasticity in the demand equation is infinite. In the simulation this implies that if a cab company lowers its price demand is shifted toward that company up to the point where the shadow price of the additional waiting time as calculated above exceeds the consumer gain of lower relative prices.

Figure 2 shows the price per minute that would maximize profits according to these three proceduresn for a given number of cabs. In addition the actual price and number of cabs is shown.

The first observation is that the curve for the monopolist lies far from the actually observed curve. A monopolist would maximize profits at 900 cabs and a price of 18 kronor. However, it can be calculated that at the regulated price 7.4 the monopolist would prefer to allow 1300 cabs. In fact 1350 were allowed, indicating that taxi owners in fact controlled the quantity of cabs. This is a reasonable result given the institutional form of regulation. Price regulation was conducted at a national level, while quantity regulation was performed locally and often devolved to local taxicab branch organizations.

After deregulation the curves for the actual price, and price derived under maximization B and C coincide. The interesting point here is that curve C does not differ more from curve B. This is

[17] The numerical calculation here follows Nash competition. Each firm maximizes its profits based on the assumption of fixed competitors' prices. This procedure is repeated until equilibrium is reached.

clearly the result of the small effects of relative price on each cab company's demand.

As an experiment one can recalculate the simulation under the assumption (D) that consumer search works perfectly. This would lower prices by about 10% compared to actual levels after deregulation.

On a theoretical point figure 2 illustrates that an increasing number of cabs can increase the profit maximizing price. In the figure this occurs in the range of 40-120 cabs.

In sum the evidence indicates that the pre-regulation mechanism can best be described as a monopoly that accepted regulated prices but could choose the number of cabs it wanted. The post-regulation mechanism is clearly not monopolistic, but competition does not work perfectly either. Yet it is clear that even if competition worked perfectly prices would probably have risen as a result of deregulation.

Simulating the number of cabs

The next step is to determine what influences the number of cabs in the market. One important influence is that reservation wages may have changed since unemployment increased during the period. This effect is captured here by entering the change in unemployment (CHUNEMP) into the regression. Another factor is that the number of cabs only adjusted slowly to the new conditions after deregulation. For that reason the regression equation is specified in terms of the increase in the number of cabs (CHCABS) as a function of the differential between cab drivers incomes and the welfare payment level (INCDIFF). Details of how cab driver income is calculated are given in the appendix. In the regression all variables except the MOR and DAY dummies are in logarithmic form. Standard errors are shown in brackets.

$$\begin{aligned} CHCABS = \; & \underset{(0.03)}{-0.086} + \underset{(0.22)}{0.66}\, INCDIFF + \underset{(0.11)}{0.17}\, CHUNEMP + \\ & \underset{(0.06)}{0.11}\, MOR + \underset{(0.07)}{0.23}\, DAY \end{aligned}$$

$\bar{R}^2 = 0.317$

This equation implies that at a constant unemployment rate equal to the sample average the number of cabs would reach an equilibrium at a reservation wage 29% above welfare payment level. Assuming constant unemployment implies the following equilibria shown in figure 3 for the same alternative optimization mechanisms as shown in figure 2.

The interesting observation here is that the perfect competition equilibrium price would be about 30% lower than the actual price (compared to only 10% lower in figure 2). The reason for this is that in figure 2 prices were compared for a given number of cabs. Endogenizing the number of cabs means that price competition drives excess cabs out of the market, thereby increasing revenue for the remaining cabs. This, in turn, gives further possibilities of cutting prices.

5. Conclusion

In contrast to the conclusions of other authors we show that taking changes in user waiting time into account implies that rising prices after deregulation are natural and quite consistent with user gains. An empirical analysis of deregulation in Stockholm, where changes in user waiting time were measured, suggests that users probably benefitted in spite of substantial price increases.

It is not clear, however, that deregulation has achieved social optimum. For one, there seems to be little price competition in the street market. Price competition seems to be working better in the telephone order market. In addition all cab companies are in poor financial condition, so that moves toward a more concentrated market structure cannot be excluded. Price competition could then diminish even in the telephone order maket. A number of smaller Swedish cities that have only one cab company after deregulation have experienced larger and more persistent price increases.

Further, even if the taxi market eventually reaches a socially optimal equilibrium a question is whether the large price swings and upheaval in the taxi market could have been avoided.

A reasonable argument can be made that all of these problems are prevented by consumer law and competition law in other industries. For example, consumer law in most countries would not allow the complicated rate structure and ex-post price quotas that taxi cabs use in, say, a food store. In most countries the type of price collusion that cabs engage in via their cab company would be considered in conflict with competition law as applied to many other industries.

To enhance consumer search one could imagine regulations that require simple rate structures such as an index per trip minute. An alternative might be to give the consumer right to demand a binding pre-trip price quote.

A more drastic step would be to attack the cab company's price setting authority. Already a number of Swedish municipalities have reacted to the effects of deregulation by establishing municipal switchboards.

One could however achieve the same results - or a better one - without creating a public switchboard monopoly. This would require three regulations. First, a cab company's switchboard would have to serve all cabs that want to join. Further, given a price index, individual cabs could continually adjust their prices. The switchboard could then be required to route calls to the cheapest cab in the customer's vicinity.

Appendix

Data

During four observational periods a sample of cabs were tracked over the course of a week. The four periods are shown in table 1. During the first period only one cab company existed.

Table 2. Number of cabs sampled in each observational periods.

	Taxi Stockholm	Taxi Kurir	Taxi Ett
April 1990 (deregulation)	35	-	-
November 1990 (VAT introduction)	26	22	19
April 1991	23	20	19
Februari 1992	24	19	20

In addition to the logs from each cab data on the aggregate arrival of telephone calls and the telephone waiting time for customers were collected.

Income of drivers and cab owners

Using the estimated arrival frequencies and prices per minute the revenue per cab can be calculated. This calculation then has to be adjusted for the fact that only three periods are explicitly estimated. Using the average number of trips for the remaining times and weekends, and assuming that a cab is repaired 4% of the time, and that the cab is in service the average amount of time (15.3 hours a day) then the average monthly revenue for a cab is calculated.

Earnings for cab drivers are calculated using the average shift pattern and taking account of the change in the bonus system. Before deregulation cab drivers earned a fixed wage plus a 10% of the earnings plus tips. Now they receive a fixed 37.5% of earnings plus tips.

Table 3. Earnings of cab drivers and owners, in 1992 Swedish kronor.

	Before	After (Feb 1992)		
		T Stockholm	T Kurir	T Ett
Revenue per cab/hour	301	209	226	233

VAT	0	52	56	58
Driver income	98	59	63	65
Social security payments	35	21	23	24
costs per cab/hour[1]	67	65	65	65
Owner income	101	12	19	21

1 According to estimates by Transportrådet.

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Figure 1.

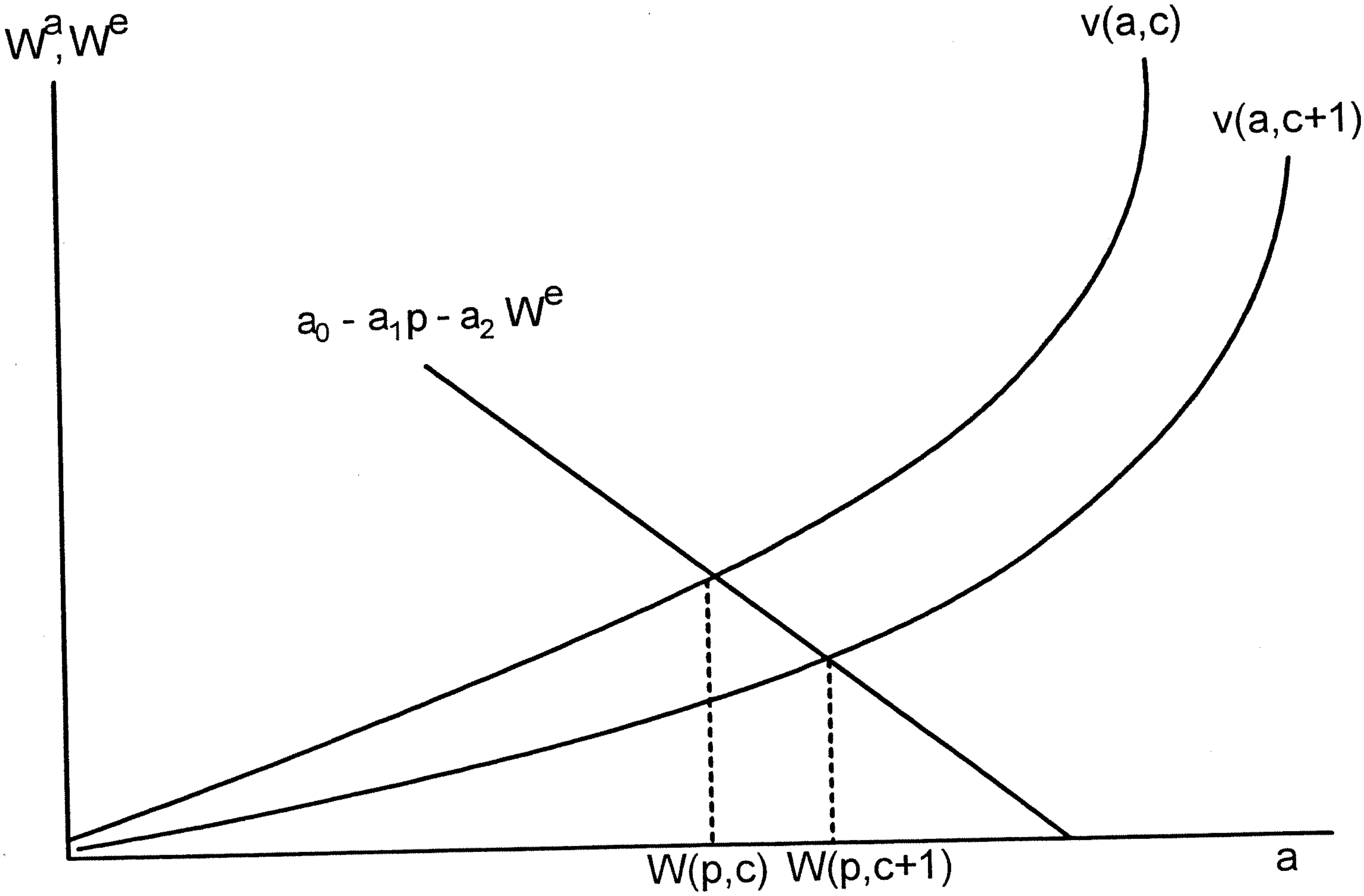

Figure 2. Profit-maximizing prices for a given number of cabs

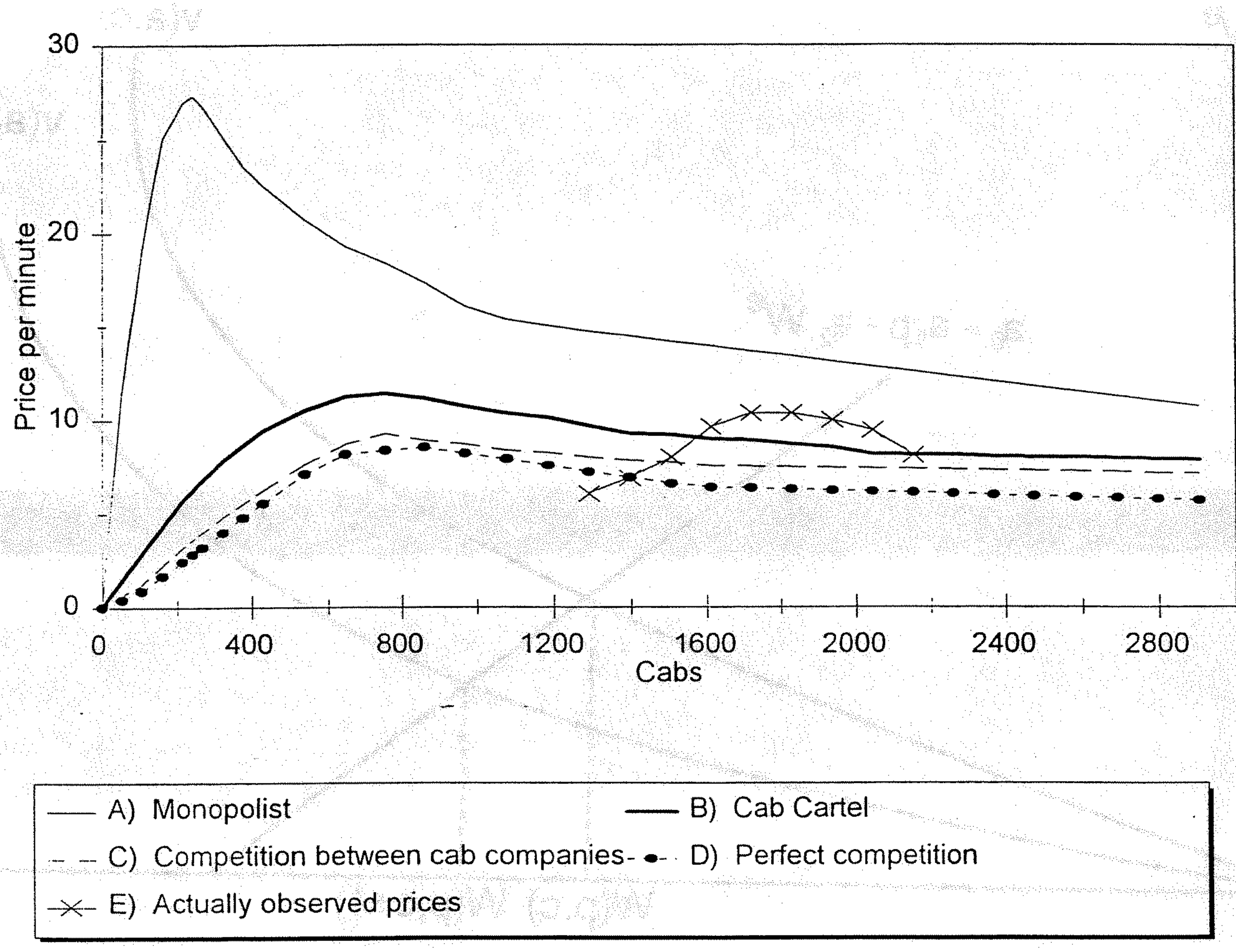

Figure 3. Equilibria after deregulation with endogenous prices and number of cabs.