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A review of the modeling of taxi services

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Abstract

This paper presents a review of the different models developed for the taxicab problem. The presented models are grouped in two categories, aggregated and equilibrium models. Each model is analyzed from different points of view, such as market organization, operational organization and regulation issues. Conclusions extracted by authors are presented, listed and compared, analyzing each affirmation in terms of market regulation and organization. Finally, a state of the practice is presented, analyzing the configuration of the taxi market regulations along the world, linking the conclusions obtained by the authors with the real market situations.

Selection and/or peer-review under responsibility of the Organizing Committee.
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1. Introduction

Actual cities are oversaturated, on one hand most of the population is concentrated in large cities (in 2030 more than 80% (UNFPA 2007) of the population will live in urban areas), on the other hand mobility needs of the modern population are growing continuously. While urban demand for trips is growing constantly, supply (capacity of city streets) is limited, and must be optimized, not increased (most of the times not possible inside the city). Well-planned, efficiently operated, and cost-effective transportation system management (TSM) strategies can improve mobility of existing systems for transportation users, especially in urban environments, where a good optimization of the infrastructure is needed (considering the high cost of building new facilities and the continuously increasing demand resulting from economical and population growth). Last years tendencies are shifting person trips from private vehicles to public vehicles, increasing the Public Transport share importantly. The most used Public Transports are the "Mass Transports" such as metro, tram or bus. This kind of transport usually has a centralized management which uses ITS technologies developed in the last decade for an optimal operation of the service. Unfortunately, inflexibility, long total travel time and insufficient service coverage of Mass Transport systems cause a lower usage of them in most metropolitan areas. Oppositely, the taxi-cab sector is a more convenient mode due to its speediness, door-to-door attribute, privacy, comfort, long-time operation and lack of parking fees. The great

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inconvenience is the lack of central management; each taxi is operated by an independent driver, taking his own decisions continuously, with a weak intent of control by the policy issues of each city such as license control or distributing the working days of the taxi vehicles (normally the control is imposed on vehicles, not on drivers, generating double shift and increasing the use of taxis). An important percentage of the cars (e. g. 60% in Hong Kong (Yang et al. 2000)) in the daily flow are taxis, most of them empty taxies. This situation is creating two problems, an internal problem to the taxi drivers (higher empty kilometers means lower benefits) and an external problem to the citizens (congestion and pollution). The first problem is being aggravated with the actual economic crisis, which is breaking the market equilibrium: demand is decreasing due to the lower incomes of the population and offer is increasing due to the increasing number of taxi drivers (not taxi licenses). Market equilibrium cannot be achieved in this concrete market because of the regulations (price is not established freely), and cannot go to the next equilibrium point due to the price policies imposed in each city. This is a vicious cycle, where empty hours are increasing, and taxi drivers need to work more time in order to have the same income, which means lower income per hour (Daniel (2006)). In this situation, taxi drivers prefer to stop at taxi stands and wait for a client, without expending fuel in empty trips and consequently saturating the taxi stands. If taxi stops network is not well designed, this situation will create a decrease in the Level of Service of the passengers, decreasing the demand and congesting the streets near the taxi stops.

The taxi sector has been traditionally a regulated market in terms of fares and entry control. The objective of this regulation is to correct the defects of the taxi sector, such as externalities (congestion and contamination), low level of service offered and anticompetitive behavior of the market. A fundamental distinction in types of taxi regulations is between quantity regulation, quality regulation and market conduct regulation. Quality regulation embraces the standard of vehicles, driver and operator; this type of regulation is more a safety regulation than a competitiveness one. Market conduct regulation includes rules regarding pick up of passengers, or affiliation to a radio network. Quantity regulations include price regulation and entry restriction. From now and on, the term regulation will refer to quantity regulation. Restrictions on entry to the taxi market have been applied by many cities around the world, but actually many cities are deregulating their markets. The most common justifications used for controlling the entrance to the taxi market are the protection of the taxi drivers incomes and the externalities (pollution and congestion) caused by the circulating taxis, but when decisions are taken without a good justification or implementation plan, entry restrictions and fare regulations are distorting economically the taxi sector, leading to important welfare losses. As a result of entry control, the price of the licenses in markets where taxi licenses are tradeable are higher (Paris 125.000 €, Sydney 300.000 $, Melbourne 500.000$, New York 600.000$ [OECD 2007]), and they are rising up constantly due to the exploitation of their owners. Reforms have often been opposed to reduce the incomes of drivers, which are normally low, and restrictive conditions have been applied in this direction, but there is no evidence that taxi incomes are higher in markets with regulated entry conditions. Oppositely, license owners is the group who is being beneficiated by these measures, and not the drivers (Melbourne, as commented above has taxi licenses valuated in 500.000$, but driver incomes are estimated at 8 – 14$ per hour [OECD 2007]). Deregulation has most of the times positive impacts, resulting in lower waiting times, increased consumer satisfaction and price falling (OECD 2007). Market liberalization is an interesting challenge for many cities, but in cities where strong supply restrictions have been applied, there will be a strong opposition to reform proposals from the license-owners. Arguments support that license-owners must be compensated in that case: one approach (first used in Ireland) is to give the additional licenses to each license-owner, ensuring that the new monopoly will remain in their hands; alternatively the new license can be given to taxi drivers without taxi license (OECD 2007). In Melbourne, a 12 year program is adding to the stock of licenses a number of licenses equal to the yearly demand growth. Other concepts are important in relation to deregulation, most of the times quantity deregulation means quality regulation, ensuring safety and minimum service standards.

The paper is structured as follows: the second chapter presents the taxi market, describing the operational modes. The third chapter resumes the different models presented in the literature, from the aggregated models until the equilibrium models. The next chapter highlights the most important ideas and results from the literature review, analyzing the operational modes, the market equilibrium and the regulation of the taxicab markets. The fifth chapter presents an overview of the taxi markets in different cities around the world, resuming the deregulation consequences observed in the deregulated markets. Finally, the last chapter contains the conclusions obtained from the literature and state of the practice review and proposes the development of a new model for the study of the taxicab market.

2. The taxi market

Taxis are private vehicles used for public transport services providing door to door personal transport. Taxi services can be divided into three broad categories: rank market, hail market and prebooked market.

- Rank places are designated places where taxi can wait for passengers and vice versa. Taxis and customers are forming queues regulated by a FIFO system. Disadvantages are that due to the FIFO policy established price has no effects on customer choice, and that customers must walk until the nearest taxi stop.
- In the hail market clients hail a cruising taxi on the street. There is uncertainty about the waiting time and the quality/fare of the service customers will find. Advantage here is that customer mustn't walk until the taxi stop. In this case a monopolistic market is possible.
- In the pre-booked market consumers telephone a dispatching center asking for an immediate taxi service or for a later taxi service. Only in this kind of market consumers can choose between different service providers or companies. At the same time, companies can fidelize clients with a good door to door service. The market here is a competitive market where larger companies can offer smaller waiting times.

3. Taxi models review

From the early 70's many studies have been published in relation to the taxi sector. While first studies (1970-1990) were related to the profitability of the sector and the necessity for regulation using aggregated models, later studies (1990-2010) implemented more realistic models in the taxi sector: from the most simple model of Wong developed in 1997 for a little taxi fleet until the most sophisticated model of Wong (2009) being able to simulate congestion, elasticity of demand, different user classes, external congestion and non linear costs, taking into account different market configurations. Douglas (1972) developed the first taxi model in an aggregated way, using economic relationships from other sectors (goods and services). Many authors (de Vany (1975), Beesley (1973), Beesley and Glaster (1983) and Schroeter (1983)) used the model proposed by Douglas for developing their models and tested them in the different market configurations. Manski and Wright (1976), Arnott (1996) and Cairns and Liston-Heyes (1996) developed structural models, obtaining more realistic results. Yang and Wong (1997-2010c) developed accurate models, taking into account the spatial distribution of demand and supply in the city using traffic assignment models. Last models proposed by Wong et al. (2005) and Yang et al. (2010b) assume a bidirectional function taking account the willingness to pay of customers, making it much more realistic. New technologies applied to the taxi market such as GPS, GIS and GPRS were also simulated in the different models, proving their benefits and justifying their use. Many of the models developed have been tested in different cities around the world using data from different sources. Beesley (1973) and Beesley and Gaister (1983) studied the data obtained from questionnaires in different cities in the UK, especially from London. Schroeter (1983) is the first to use data from taximeters in his model, using the data from a taxi company in Minneapolis (EEUU). Schaller (2007) uses interviews and questionnaires from taxi agents and customers in different cities of the EEUU.

3.1. Aggregated models

Douglas (1972) was the precursor of the first studies related to the taxi sector. He considered a taxicab market where taxicabs can be engaged anywhere along the city streets, with scheduled (by a regulatory authority) fares, and free entry. He concluded that the maximum revenue to the industry occurs at the point where demand is less than maximum, characterizing social welfare as an efficient but unfeasible (deficit) equilibrium. He also proved that taking into account the social welfare, the points where the number of taxi hours in service is maximized and where demand is max are the same. The formulation proposed by Douglas (1975) has been used as reference formulation by all the later authors. De Vany (1975) proposed solutions for different type of markets: the Monopoly market (with entry and fares regulated), the Competitive market (with free entry and regulated fares) and the Medallion market. In the monopoly solution, the firm's program proposed by De Vany (1975) is to maximize total benefits, while in the competitive solution the owners' objective is to maximize their own benefits. He proved that demand is maximized subject to a zero-profit constraint. He agrees with Douglas (1972) in that the efficient price minimizes output and observes that a comparable increase in the regulated price will be more likely to expand capacity under competition than under monopoly. Beesley (1973) and Beesley and Glaister (1983) also investigated the different markets and their characteristics, trying to establish guidelines for decision makers using a model for simulating relevant inferences in the taxicab market. He identifies and analyzes the important elements and the defects of regulation (monopoly rights, entry conditions and fare control), introducing the external cost (congestion produced by taxi cabs) and testing his ideas in the taxicab data obtained from London, Liverpool, Manchester and Birmingham. He concludes that bigger elasticity than 1 is only possible in a regulated market, and in consequence free markets have lower elasticity than 1 (as postuled by De Vany (1975)). Manski and Wright (1976) concluded that over a certain range, increasing the number of licenses will decrease expected waiting time and increase expected utilization rate. Schroeter (1983) developed a theoretical model in a regulated market where radio dispatch and airport cabstand are the primary modes of operation and applied his methodology to the Minneapolis taxi sector. Daganzo (1978) was the first that studied the travel and waiting time as physical variables. He studied the optimal size of the taxi fleet using the queue theory proposed by De Little. This minimum fleet ensures a minimum level of service at the end of the desired region (bigger waiting times are unacceptable). Foerster and Gilbert (1979) studied the effects of regulation within a framework of eight regulatory scenarios involving different prices, entry policies and type of industry concentration factors. They pointed out the following: in an unorganized industry, price will not be regulated by the market, it will tend to rise without any countervailing down pressure, decreasing the utilization rate; if prices are fixed, monopoly will produce a lower level of output in relation to the level produced by the competitive industry (as concluded by De Vany (1975)); entry control has the same effects, increasing price in both types of industry. They propose different guidelines for Public Policy in relation to their work and suggest that empirical data is necessary to document and prove regulatory impacts. Cairns and Liston-Heyes (1996) analyzed the monopoly market, the social optimum (maximizing the sum of the social and industrial benefits) and the second best (non-negative profits). They observed that profits are zero when taxis are used at their optimal intensity. They showed that price regulation is necessary for producing equilibrium in a simple model of taxi services, but second best can be only achieved if fares and intensity of use of taxi-cabs are controlled, concluding that regulation is needed for achieving second best. Arnott (1996) analyzed the shadow cost of taxis in the first best, proposing subsidization for covering these costs in the vacant trips. He developed a structural model considering a uniform customer demand distribution over a spatially homogenous two-dimensional city, and a dispatching center supply. He concluded that subsidization is necessary, justifying it with the decentralization of the social optimum, observing that the shadow cost is covered only when taxis are busy. Chang and Huang (2003) expanded the research of Douglas (1972) optimizing the vacancy rate and fares. Chang and Chu (2009) continued the work of Chang and Huang (2003) using a more generalized model with the welfare maximization objective for avoiding the elasticity constraint. Their model can analyze and optimize the vacancy rate and fares subsiding in a first-best environment. Daniel (2003) models a taxi-cab market in which fare and entry are regulated, testing it using the data obtained by Schaller (2007). He finds an inelastic relationship between vacant taxicabs and demand. He uses a demand function depending on the price of the service and the number of vacant taxi cabs. Fernandez et al. (2006) studied the characteristics of the cruising taxi market, proving that a unique equilibrium exists for a deregulated market and it corresponds to a monopolistic equilibrium. They conclude that entry regulations are redundant with fare regulations, producing worse industry conditions. They observed that, for an atomized supply of services where many small operators exist, the returns to scale make impossible to obtain the social optimum without subsidy, as postulated by Cairns and Liston-Heyes (1996) and Arnott (1996). They conclude that the need for regulation should be carefully considered case by case, due to the fact that the difference between second best and unregulated free market equilibrium depends on the specified case studied. Massow and Canbolat (2010) develop a model for simulating the taxicab behaviour in a dispatching market where taxis are assigned to virtual queues generated in each zone, and also in high demand points. They conclude that taxis will wait in the borders between zones and propose the creation of super zones for increasing the level of service to customers.

3.2. Equilibrium models

The above studies examined extensively both price and entry controls in the taxicab market, basing their models in aggregate demand and supply and testing them in different markets (monopolistic and competitive). The principal assumptions are the relation between the waiting time and the total number of vacant taxi hours, constant operating cost per hour and demand estimation based in fares and waiting time of passengers. Some of the authors presented above used structural models, going further in the taxi market simulation. These structural models include the work of Manski and Wright (1976), who provided a specified structural model of a single taxi stand, and Arnott (1996), who investigated the first best solution considering a spatial uniform customer demand distribution. Yang and Wong presented a series of models during the years 1997 – 2010 studying the taxicab market in the network of Hong Kong. Their spatial models are more realistic than the aggregated. Yang and Wong (1998) presented a network model describing how vacant and occupied taxis will cruise in an urban network searching customers and providing transportation services to them. They assume stationary taxi movements and customer demand, no demand elasticity, no congestion, "all-or-nothing" routing behaviour and that each taxi tries to minimize its travel time when searching for a new client. They supposed that the expected searching time in each zone is identically distributed following a Gumbel density function and that the probability of a vacant taxi in a zone to meet a customer in another zone follows a logit model, using a parameter of information for taking into account the taxi driver experience (older drivers will find a ride faster), proving that with better knowledge of the supply smaller fleets can have better results for both, taxi drivers and customers. They conclude that taxi fleet and information of taxicabs must be regulated in order to achieve better taxi utilization while maintaining a certain level of service. Wong and Yang (1998) improved the algorithm for guarantying convergence in large-scale applications. Yang et al. (2000) analyzed the demand (taxi availability)-supply (taxi utilization) relationship in the taxi market, developing a nonlinear simultaneous equations system of passenger demand, taxi utilization and level of service. The proposed model is based on the concept of queuing theory and demand-supply equilibrium, using the number of licenses, fare, income and occupied taxi time as exogenous variables, while demand, waiting time, taxi availability, utilization and waiting time of drivers are the endogenous variables. They estimated the parameters of their model using survey data, presenting the value of the endogenous variables listed above in relation to the number of taxis and the fares applied. Wong et al. (2001) added congestion to the network and elasticity to the demand. Evaluating their results they agree with Manski and Wright (1976), Schroeter (1983) and Arnott (1996) in the fact that an increase in the number of taxis will be beneficial for both, customer and drivers, but only in a small taxi fleet since this is an unstable situation, and seldom emerges in a realistic taxi market. Wong and Wong (2002) developed a more efficient solution algorithm and analyzed the social surplus of the taxi market. Wong et al. (2004) simulated the real mode choice with different types of users and mode classes. Yang et al. (2005) investigated the consequences of externalities in the different markets. They postulated that a profitable first-best social optimal emerges in a severely congested taxi market, where the entry of additional taxis into the market has a large marginal congestion effect (and thus the entry should be highly controlled at the social optimum). They conclude that in the competitive market the second-best solution leads to a more efficient use of taxis, with a higher demand served with a smaller fleet and higher fare. All the models commented above use a linear taxi fare structure, making long-distance (from/to the airport) trips more profitable and creating over-supply in airports, wasting many taxi service hours in the airport queue. Schaller (2007) proved that a free entrance to the market in the USA and Canada had as consequence the reduction of the level of service, because taxi drivers will only realize the most profitable trips. In order to diverge excess taxi supply from the airport to other areas, increasing the utilization of the taxi capacity and increasing the quality of the service, Yang et al. (2010a) included a nonlinear taxi pricing of taxi services in their model. They identified the win-win situation (surplus for both producer and consumer) created by a Pareto-improving situation, allocating more efficiently the taxi services in the whole territory. Hyunmyung et al. (2005) added the stochastic behaviour of the demand developing a stochastic modelling approach in a dynamic transportation network. They simulated taxi drivers' learning process implementing the day-to-day evolution approach introduced by Horowitz (1984), Vythoulaks (1990) and Cascetta and Cantarella (1991). They tested their model in a test network, generating demand at each node based on the demand rate at each peak period and the trip distribution pattern, proving drivers capacity in predicting passenger queues at nodes. They also investigate the effectiveness of taxi information systems in reducing unnecessary travels, proving that using information systems is equivalent to an increase in the number of taxis by 20% in regard to the quality of the service (as pointed out by Yang and Wong).

4. Critical review

The extended literature overview presented above is resumed below, highlighting the important factors presented and discussed in the above models, unifying conclusions and identifying debilities and gaps. All authors developed models for analyzing the effects of regulations in the taxi market. They proposed mathematical formulas for calculating demand and supply, simulating different types of markets and obtaining different results for each regulation scheme. Aggregated models calculated total demand and supply using different parameters: Douglas (1972) used the price of the trip and the expected waiting time for calculating the demand, and a flat cost rate for the supply, he stated that if different users have different willingness to pay, the regulator must find a price p for all, maximizing global benefits; De Vany (1975) added an index of the full prices to the calculation of the demand; Cairns and Liston-Heyes (1996) supposed uniform demand within the day decreasing with the increase of the waiting time; Chang and Huang (2003) and Chang and Chu (2009) used log-nonlinear and log-linear functions respectively for simulating demand; Daniel (1978) used a demand function depending on the number of vacant taxis and the price; Fernandez et al. (2006) used the generalized price for obtaining the demand; Manski and Wright (1976) assumed a Poisson process of customer arrivals in a FIFO queue discipline for the rank market. Massow and Canbolat (2010) develop a double queue model simulating a dispatching market, where drivers are assigned to queues in zones and high demand points. Equilibrium models calculated spatial demand and supply: Arnott (1996) considered a uniform demand distribution over a spatially homogenous two-dimensional city; Yang and Wong (1998) used the model of Douglas (1972) in an origin-destination matrix, where demand is fixed for each pair OD; Wong et al. (2001) considered separate demand exponential functions for each pair O-D, depending on waiting time, travel time and trip price, adding elasticity to the demand function; Wong et al. (2004) included multiple user classes and taxi models; Yang et al. (2010a) used a non-linear taxi pricing for treating long-distance trips; Hyunmyung et al. (2005) used a stochastic demand. Figure 1 below shows the evolution of the taxicab models in relation to the added value of each model.

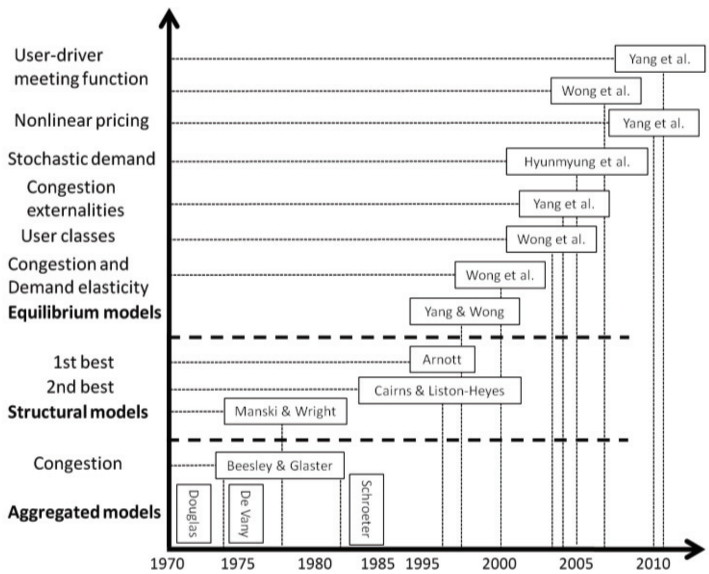

Figure 1 Evolution of the taxicab models

Different fundamental matters of the taxicab market have been investigated by the authors, such as elasticity of demand, external cost, returns to scale and the relation between supply and demand. Elasticity of demand has been an important issue: De Vany (1975) proved that unit elasticity represents zero profit, and higher elasticity than one a negative profit, concluding that elasticity must be less than one. Daniel (2003) obtained an inelastic relationship between vacant taxis and demand. Yang et al. (2005) concluded that the unitary elasticity achieves the maximum competitive taxi fleet size. Congestion was not present in the first models, but later models take it into account, becoming an important factor in the discussions about first best and second best solutions: Beesley (1973) introduced the external cost produced by the congestion generated by the taxis in the network; Fernandez et al. (2006) showed that externalities will reduce waiting time and operational cost. Wong et al. (2001) affirm that demand decreases with congestion, but at the same time trip income increases; Yang et al. (2005) prove that first best can be obtained with congestion. Returns to scale are a matter of discussion in many models: Manski and Wright (1976) assumed increasing returns to scale concluding that increasing the number of licenses, waiting time will decrease while utilization rate will increase; Schroeter (1983) was opposed to the scale economies announced by Manski and Wright (1976), affirming that an increase in the number of taxis will reduce waiting time, increasing demand, but reducing earning for each taxi, in opposition to Daganzo (1978), who stated that taxis do not have significant economies of scale; Fernandez et al. (2006) showed that economies of scale are produced by externalities, and affirms that these returns to scale make impossible the social optimum without subsidy (as observed by Cairns and Liston-Heyes (1996) and Arnott (1996)). All authors agree with the different market equilibriums commented above (first best/second best). Many models studied two equilibrium points for the competitive market, the first best and the second best. Cairns and Liston-Heyes (1996) identified the first best as the social optimum (maximizing the sum of the social and industrial benefits), finding its zero profit character (only covers busy trips) and concluding that regulation is needed for obtaining the second best (non-negative profits); Arnott (1996) proposed subsidization for achieving the first best (basically the subsidy will cover empty trips), oppositely, Yang et al. (2002) showed that in the point at which total surplus is maximized, industry profits are negative (first best). They propose the second best solution instead of subsidization; Chang and Chu (2009) optimized vacancy rate and fare subsidization for obtaining first best, obtaining analytical formulas for the vacant and occupied distance, vacancy rate and fare; Fernandez et al. (2006) agree with the idea that first best does not cover costs, while second best covers operation costs and maximizes social welfare; Yang et al. (2005) postulated that congestion can make profitable the first best, and that second best solution leads to a more efficient use of taxis (higher demand served with smaller fleet and fares). Many authors presented the equilibrium points (first and second best) graphically, representing demand and fare in the axes, and using different mathematical functions for obtaining optimum fleet and fares. Aggregated and equilibrium models have focused exclusively on the taxi availability for calculating the customer waiting time, and therefore the demand resulted. Schroeter (1983) presented a matching function between the taxi availability and the taxi demand; Cairns and Liston-Heyes (1996) used a model of search for drivers and customers; Wong et al. (2005) used stochastic searching behavior with a bilateral searching and meeting function between taxi drivers and customers; Matsushima and Kobayashi (2006) implemented a double-queue system simulating waiting and meeting between taxis and customers in a simple taxi stand; Yang et al. (2010b) modeled a network bilateral searching and meeting between taxis and customers. Yang et al. (2010c) investigated the properties of an aggregate taxi service model using bilateral searching and meeting functions (considering a specific form of the Cobb-Douglas type production function) for characterizing the meeting frictions between vacant taxis and customers. They examined the market profitability at social optimum, finding that taxi services should be subsidized only when there are returns to scale in the meeting function (same conclusion obtained by Fernandez et al. (2006)).

4.1. Market conditions

Most of the models were tested in different market conditions, such as competitive industry or monopoly. De Vany (1975) stated that in the monopoly market, industry tries to obtain the maximum benefit, while in the competitive industry each driver tries to maximize its benefits. General conclusions are that the monopoly industry will obtain the maximum total benefit with a small fleet and high prices, covering only the high-income demand sector, with a poor level of service. Douglas (1972) observed that in the point of maximum benefit for the industry, the total number of taxi hours is maximum, but the demand is not. Foerster and Gilbert (1979) affirmed that if price is fixed, the monopoly market will produce lower level of output. Fernandez et al. (2006) proved that the unique feasible equilibrium in a deregulated market is the monopoly solution. Yang et al. (2005) postulated that the monopolist would charge a price in excess of marginal cost per ride by an amount equal to the consumer´s marginal net willingness-to-pay for a ride. Different market configurations were proposed: De Vany (1975) studied a market with limited entry, but unrestrained price concluding that maximum demand is subjected to zero profit; Foerster and Gilbert (1979) proposed and studied eight different market configurations (monopoly-competitive/regulated-unregulated price/regulated-unregulated entry) concluding that price will rise without control in an unorganized industry while utilization rate decreases; entry control will have the same effects on both types of industry. Each market configuration has different optimal prices and capacities: De Vany (1975) affirms that price and capacity in the monopoly market are lower than price and capacity in the competitive market. From their findings:

- In the monopolistic market, without fare regulation higher fares will satisfy lower demand with a smaller fleet, maximizing the benefit of the operator (Douglas (1972)). With regulated fares, the same market will operate with the fleet in that the marginal benefit is equal to the marginal cost (De Vany (1975)).
- In the competitive market, the operator will try to achieve the first best (social optimum), maximizing the benefits of the society (taking into account externalities commented above). Douglas (1972) and Arnott (1996) proved that in the first best, the driver income will only cover the occupied time, creating the necessity of subsidizing the empty time and therefore achieving the second best.
- Fleet size is one of the most important factors for decision-makers. In a small market, fluctuations in fares will not affect demand because the waiting time has higher importance, but in a big market, fares are important for the demand generation as pointed out by Wong et al. (2001).

4.2. Operational modes

The three operational modes (rank, hail and dispatching center) have been modeled by many authors, some of them differencing the airport market from the rank market due to the special circumstances of the airport taxi stands. Arnott (1996) states that dispatching centers are used in small cities, while in big cities cruising markets are more frequent. The normal situation in many big cities is a mix of the three operation models, but no model has investigated them at the same time. Schaller (2007) proposes a very interesting representation of the situation of each city in relation to the operational modes, using a triangle with Dispacth, Hank and Rail operational mode in each vertex. He represents each city as a point inside the triangle in relation to the situation of the taxi market (only dispatching centers, only rank points, only hail or a mix of them). Farrell (2010) explored patterns of taxi engagement and relationships between generated trips and taxi rank locations for optimizing the taxi rank distribution in relation to the demand patterns in a 3 level (county, town, stand) model. She applies her findings to the Ireland taxicab market, and realized a comparative cost benefit analysis, identifying benefits and disbenefits resulting from developing new taxi stands. He obtained a cost-benefit ratio of 1-11 for the construction of a new rank, and 1-3 for the relocation of an existing rank. Massow and Canbolat (2010) propose the creation of super zones for reducing the waiting time of clients in a dispatching center environment.

4.3. Regulation

Historically most of the taxi markets were regulated (basically controlling entry and fares). Fares are easy to regulate, fixing a maximum price and regulating the way fares are applied to customers (per time, per distance, supplies, etc). Most of the entry regulations were done simply freezing the number of taxi licenses, without supporting in any way why the actual/current number of taxis was optimal, or simply good. Most of the cities maintained the number of taxis at 1980 levels, only some cities increased timidly their number of licenses following the GDP value or other economic indexes. Indeed, Daniel (2006) highlighted that in many regulated markets there is overcapacity. This mistake created in many cities a suboptimal taxi market, or an inefficient taxi market, with more taxicabs than needed or less vehicles than needed. Many authors support that the situation of the market has enormous influence in the results of the regulation, and this situation must be studied in the moment of the regulation for justifying each measure adopted, from the number of taxis until the value of fares, concluding that the starting point of the market is crucial in the success of the regulation policies. Loo et al. (2007) conclude that due to the economic nature of the market, the price of the taxi licenses depends more on economical factors than on the demand for taxi services. Fernandez et al. (2006) affirm that both regulations must not act simultaneously, entry regulations are redundant with fare regulation, and the effect of entry regulation is negative in a market where fares are regulated (and vice versa). A small number of authors tried to develop models for obtaining the optimum number of taxis, Schaller (2007) conducted a regression analysis on seven variables concluding that the taxi demand is generated by households without private cars or trips to the airport. There are two different arguments in favor of entry control in taxicab markets, economic and non-economic. The economic argument is the social welfare achievable with entry control, avoiding market failures. Non-economic arguments are potential cross-modal competition, congestion and pollution issues. Moore and Balaker (2006) stated recently that most of the economic opinions favor open entry to the taxi industry. OECD (2007) identifies arguments against free entry and arguments against controlled entry, (resumed in Table 1).

Table 1 Arguments against free entry and entry control. Source: Own elaboration from OECD (2007) and CENIT (2004).

Arguments	Against free entry	Against entry control
Productivity arguments	Excess of capacity	Augment of demand
	“Diversion” of demand from PT	Most efficient use of resources
Impact on congestion/pollution	More taxis than the optimum (more congestion)	Less Private Vehicles (less congestion)
Distributional arguments an competitiveness	Preserve the income position from incumbent laborers	Reduction of development of new products (rivalry)
Impacts on service quality and information	Reduced standards of taxi services	Absence of information, tools and rules for regulators

5. State of practice

Each country/city has its own regulation for the taxi market. Table 2 shows the regulation characteristics of some countries/cities along the world. As shown in Table 2, a few countries have deregulated the taxicab market; from their experience some deregulation effects can be exposed:

- Sweden (1990): greater taxi fleet, greater accessibility for customers, reduction of waiting time, different type of available vehicles.
- Ireland (2000): quadriplication of the number of license and fare and quality regulation needed for avoiding overcharging and uncompetitive operation of the market (uncertainity of waiting for another taxi and price competition unlikely to work at ranks).
- Japan (2002): 8.4% and 9.7% increase in the number of companies and taxis respectively. Introduction of a large variety of fares, discounts and flat rates.
- United States (Seattle 1979): 5% reduction in fares (taxi-stand rose while radio-dispatch fell); increase in service at the airport, generating queues, but without price reduction due to the FIFO queuing system applied.
- United States (Indianapolis 1994): Increase in the number of cabs and companies, fare reductions, service improvements and reduction in customer complaints.
- United States: fare control is needed for controlling the appropriate level of entry; use of contracts between firms and hotels/airport authorities for avoiding queues at those locations where waiting times are always low.
- Taiwan: over-supply and high vacancy rate, resulting in poor service, unhealthy competition and law-breaking behaviours.
- Number of taxis in Dublin increased by 216% in the two years after deregulation. In New Zealand, the number of taxies increased also by almost 200% following deregulation. In Sweden, the number of taxies was doubled in the first two years after deregulation, but simultaneously, significant innovations had occurred for encouraging taxi use in off-peak periods.

Most of the authors agree with the above, a liberalization of the market will increase the taxi fleet and level of service to the customers, but a fare regulation is needed. As exposed by Fernandez et al. (2010), a fare regulation is enough for controlling the taxi market as concluded in the USA example. The example of deregulation in the United States confirmed the exposed by Schaller (2007); taxi drivers will create over-supply in airports due to the lower waiting time and higher income if there are no regulations. It is important to highlight that the effects of deregulation will depend on the initial pre-deregulation situation. In markets where regulation kept supply close to free entry equilibrium levels and low license values there will be no changes, but in markets where the number of taxis is very low due to the strict applied regulation, supply will increase importantly after deregulation, as occurred in the examples listed above. This entry of new supply will lead to low incomes, high fares and business failure (short terms results), while the adaptation of consumers will be in a long term horizon.

For analyzing the relation between the number of taxis, the population and other economic values, analytical data from 19 European cities is presented below.

Table 2 Regulation issues in different cities around the world. Source: Own elaboration from OECD (2007).

Country - Zone/city	Fare regulation	Entry regulation	Period	Reestrictions / Characteristics
Belgium	yes	yes	5-10 years	1 vehicle per 1.000 hab / personal and intransferable
Czech Republic	yes	no		intransferable
Denmark	yes	yes	10 years	intransferable
France - Paris	yes	yes		100 new licenses per year
Germany	yes	no	5 years	license subjected to a quota
Hungary	yes			
Ireland	yes	no (2000)		license subjected to a fee and quota
Italy	yes	yes		4,5 per 10.000 hab / 1 lic per person
Japan	yes	no (2002)		
Korea	yes	yes		
Netherlands	yes (2004)	no (2002)		
Norway	depending on the city	yes		not tradable, not transferable
Sweden		no (1990)		
Switzerland	depending on the city	yes	3 years	not tradable, not transferable
United States - Seattle	no (1979)	no (1979)		
Romania	yes	yes		4 vehicles per 1.000 hab

Table 3 General data related to the taxi market of different European cities. Source: CENIT (2004)

City	Average trip fare*	Taxi vs Bus**	Taxi vs oil***	Monthly earnings ****	Monthly trips	Population	Urban population density	GDP per inhabitant	Number of taxis	Taxis per thousand inhabitants
Amsterdam	14.8	14.1	2.2	1404	95	850,000	57.3	34100	1504.5	1.77
Athens	7.4	23.1	1.6	256	35	3,900,000	65.7	11600	15249	3.91
Barcelona	8.5	17.7	1.8	594	70	4,390,000	74.7	17100	11765.2	2.68
Berlin	11.3	9.8	1.8	1199	106	3,390,000	54.7	20300	6949.5	2.05
Brussels	14.9	19	2.5	1495	100	964,000	73.6	23900	1243.56	1.29
Budapest	6.2	22.5	1.1	201	32	1,760,000	46.3	9840	5596.8	3.18
Copenhagen	14.9	13	2.3	2661	179	1,810,000	23.5	34100	2805.5	1.55
Dublin	6.2	8.5	1.2	919	148	1,120,000	25.9	35600	1993.6	1.78
Lisbon	5.3	5.6	0.8	441	83	2,680,000	27.9	17100	4529.2	1.69
London	12.5	11.4	1.8	1286	103	7,170,000	54.9	36400	55997.7	7.81
Madrid	9.8	15.8	2	594	61	5,420,000	55.7	20000	14471.4	2.67
Milan	9.9	17.6	1.6	997	101	2,420,000	71.7	30200	4573.8	1.89
Oslo	18.8	9.7	2.5	1570	84	981,000	26.1	42900	2148.39	2.19
Paris	8.7	12	1.3	1095	126	11,100,000	40.5	37200	17538	1.58
Prague	6.8	15.2	1.5	314	46	1,160,000	44	15100	3978.8	3.43
Rome	8.3	19	1.3	997	120	2,810,000	62.6	26600	5816.7	2.07
Stockholm	11.9	7.8	3.5	1879	158	1,840,000	18.1	32700	5207.2	2.83
Vienna	15.7	17.6	3	914	58	1,550,000	66.9	34300	4433	2.86
Warsaw	4.2	12.8	0.8	241	57	1,690,000	51.5	13200	5999.5	3.55

*2002 prices, 5 km trip, day fares, inside the city ** Taxi cost per km/bus cost per km *** Cost per km/cost of 1 liter of oil ****National average

Conclusions obtained from the table 3 are:

- A logic result is that average trip fare is higher in cities with higher GDP. A relation with monthly earnings and cost of taxi in relation to cost of oil exists also.
- The relation taxi cost versus bus cost grows with the density of the city, due to the economies of scale of the Mass Public Transport.
- The number of taxis has a very strong relation with the population of the city (excluding London and Paris). This relation is between 1.3 and 4 taxis per thousand inhabitants (in London this relation is 8 taxis per 1000 inhabitants).

6. Conclusions

As time goes by models are getting more and more realistic. First models used aggregated values, without taking into account that the taxicab market is working in an urban network, sharing the streets with daily traffic and other public transport modes. Later models introduced this spatial characteristic, and many other rules for simulating the real taxi market, as the network knowledge or the learning process of the taxi drivers, with a good effort in the calculation of the passenger trip generation-distribution and assignment. Lastest developed models concentrate their effort in the customer-driver search function, increasing the reality of the simulation of the finding process between a taxi and a customer. Many interesting ideas have been developed in parallel with the evolution of the models, such as the day to day learning process or the use of the logit model for the probability of finding a client in each zone. Main general conclusions obtained from the models presented are:

- Although many models tried to be a tool for decision makers, developed models cannot prove the performance level of the taxi markets. There are no optimum models of taxi supply to guide decision makers.
- Models proposed in the literature are characterized by significant data requirements due to the high number of determinants in the taxi demand and supply. Actually, with the use of GPS and GIS, data recollection is technically easy, but the reticence of the taxi sector to share this data is an important barrier.
- All the models have investigated the taxi market from the point of view of the taxi driver (income) and the customer (waiting time, level of service, total cost), but no model has studied the consequences of the market regulations on the city (contamination, congestion). It is important to add environmental considerations as a determinant factor in the future models since in most of the cities, taxi flows have not only negative consequences on the rest of the traffic, but also in the citizen's health.
- Regulation of entry and fares must not act together; deregulation of access to the taxi market must be achieved in most of the cities, increasing the supply and the level of service of customers. Entry deregulation must be accompanied with new regulations, such as fare regulation (almost with a maximum fare control) and special regulations on high-demand generation points, such as airports, train stations or hotels.

In the opinion of the authors, both approaches are useful, each one used in its respective scale. Aggregated models can explain major variations in the taxi market using fewer variables, simulating fare and entry regulations easily and obtaining clear results. More detailed models can better simulate the taxicab market, taking into account the spatial characteristics of demand and supply, the different types of operational modes working together in the same city, the external and internal factors that are generating the demand, and the congestion (because when the streets are congested is when the demand for trips is higher). They can also work with spatial variables that aggregated models cannot take into account, adapting each model to the reality of each city. Data availability is an important matter for modeling the taxi market, as the more detailed the model is the more accurate the results will be, but the data will be more difficult to recollect; on the contrary, aggregate models need less quantity and not such as high quality of data, but results are not as analytical as they can be in a more detailed model. With new developed ITS and other technologies, a lot of data can be recorded, and more detailed and complex models can be developed.

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