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Final Thesis

Optimization of the Italian Taxi Sector
A General Equilibrium Model with Endogenous Congestion

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Introduction

The taxi sector has long been the subject of extensive analysis because its market characteristics make it inherently interesting to economists, social scientists, and local planners. Its traditional nature, somewhere between a public service and a private enterprise, has prompted numerous studies on the effectiveness of such a distinctive regulatory framework.
In particular, the many restrictions imposed by local authorities make the sector especially vulnerable to criticism, as they prevent it from benefiting from typical market mechanisms found in liberalized industries, such as the ability of supply and prices to adapt freely to demand. The motivations behind these regulatory choices are generally linked to the management of externalities such as pollution and congestion. However, the outcomes of this rigid framework have not always been ideal.
Since the 1970s, beginning with the early modeling work of Douglas [1], an intense debate has emerged regarding the desirability of market mechanisms shaped by such regulation. Building on Douglas's model, scholars such as de Vany [2], Beesley [3], and Beesley and Glaister [4] argue that there are no sufficiently strong reasons to regulate the market and that, where regulation exists, it is typically suboptimal. By contrast, Manski & Wright [5] and Schroeter [6] advocated for a controlled system, convinced that deregulation would not generate benefits large enough to offset the resulting increases in prices or the reduction in drivers' earnings.
Over time, increasingly sophisticated quantitative models have been developed. This has made it possible, on one hand, to design theoretical frameworks that reflect real-world conditions more accurately and, on the other, to take advantage of modern data collection technologies (such as GPS traces and app-based monitoring) to test these models more effectively.
Although even the more advanced contributions, such as the work of Yang and Wong [7],[8], tend to support some degree of market regulation, the broader literature appears to lean toward the idea that liberalizing the taxi sector can benefit both the industry and consumers. According to Moore & Balaker [9], among the 28 studies they reviewed, 19 concluded that deregulation is desirable, 7 found it harmful, and the remainder expressed mixed or inconclusive views.
Italy has also seen extensive examination of the sector and the emergence of several well-known critical issues. Since the work of Bentivogli [10], many of the same problems identified in other countries have been observed domestically. Over time, the AGCM [11] , the European Union [12], and the OECD [13] have each issued multiple assessments of the sector, and numerous attempts—both local and national—have been made to intervene. Regardless of whether these interventions are considered successful, two points clearly emerge: first, there is a persistent institutional desire to reform the sector, indicating the presence of structural problems that require attention; second, there is a consistent difficulty in implementing new reforms effectively. The key questions, therefore, are both why the sector demands reform and how such reforms can be designed and implemented in a feasible and effective manner.
This work aims to address both issues, namely:

Chapter I presents a review of Law 21 of 1992, the reference legislation for regulating the taxi

sector in Italy. We will examine the key articles, aiming to outline the main mechanisms and structure of the taxi market, the drivers' duties, and the requirements needed for operation. This analysis will provide the necessary information to properly assess the current state of the sector and develop an adequate model that captures the functioning of the industry.
Additionally, Chapter I includes an extensive analysis of the taxi sector in Italy. We will evaluate whether the current supply is sufficient to meet domestic demand, including fluctuations during tourist seasons in the major cities of the peninsula. We will also assess whether the NCC (Noleggio con Conducente) service has been used as an alternative to meet demand. Furthermore, we will review the structure of taxi fares in Italy and compare them with similar taxi services in other European countries.

In Chapter II, we will develop a model that represents the functioning of the taxi market using three agents: consumers, taxi drivers, and municipalities. The municipality has the authority to set prices and determine the number of licenses with the aim of maximizing consumer welfare while ensuring sufficient profits for taxi operators and balancing congestion. Using a general equilibrium approach, the municipality will be able to establish the optimal number of licenses and fare structures to make the taxi sector function optimally for both residents and taxi operators.

In Chapter III, using the data from Chapter I and taking the municipalities of Rome, Milan, and Naples as references for the estimation of the model parameters, we will test the model through various simulations, experimenting with adjustments to key parameters in order to formulate plausible policies that decision makers may adopt to improve the taxi service.

The need for this study is justified not only by the climate of discontent that has persisted among consumers, national antitrust bodies, and European institutions but also by the lack of adequate tools to properly organize the service at the municipal level. Current regulations offer only general, non-mandatory guidelines for assessing and setting up the service, and none of them can be considered adequate for organizing a complex and demanding service like taxi transportation. The only municipality (to my knowledge) that has provided a specific criterion for determining the number of licenses (N) available is Turin, which, in its report [14], provides the following formula:

$$N = \frac{Pop.}{5000} \times (F_a \times K_a) \times F_{a1} \times F_b \times (F_c \times K_c) \times (F_s \times K_s) + F_d$$

It is needless to say that basing the supply of a service without considering demand levels or clear rules for estimating all the relevant "correction parameters" $(F_a, F_b, \dots K_a, K_s, \dots)$ leaves significant room for improvement. It is in this context that this work takes place, aiming to clarify the issues in the sector and propose an adequate yet flexible model that could be readily adopted by municipalities to better organize the taxi sector. At the same time, it should also be suitable for national institutions, allowing for experimentation with transportation policies at a broader level.

Chapter 1

The Taxi Sector in Italy

The following paragraph presents a brief overview of the taxi sector in Italy. We begin by examining the regulatory framework, which provides an idea of how the sector operates, the actors involved and how they are supposed to behave. Next, we will collect key facts and findings regarding the state of the taxi sector in Italy, including the number of taxi and NCC licenses over time, tourist flows, and estimates of unmet demand. Additionally, we will analyze fares, their composition, and how they compare to other similar European markets. This initial research should provide us with a solid understanding of the taxi sector in Italy, offering some insights on what kind of policies could be useful to improve the service and enhance the well-being of the social groups involved.

1.1 The Regulatory Framework

The taxi sector is regulated by the Law 21 of 1992 [15]. Despite some minor updates during the years, this law remains the main legal reference for both categories of Taxis and NCCs[1] Taxis constitute a public non-scheduled transport service (Art. 1). This means that, unlike trains, trams, buses, etc. (scheduled services), the service is provided in a "non-continuous or non-periodic manner, on routes and according to timetables established from time to time."

The service is aimed at individuals or small groups of people. It must be provided in the areas designated for the service (taxi ranks) according to the procedures and tariffs set by the municipality where the service is provided. The taxi driver cannot refuse to provide the service within the designated areas, under penalty of corresponding sanctions (Art. 2 paragraphs 1, 2).

The municipality is responsible of the administrative organization of the service. The established regulation must comply with the criteria set by the respective regions on the matter (Art. 4 paragraphs 1, 2).

Therefore, the municipalities have the right and the obligation to establish (Art. 5):

[1] NCC stands for “Noleggio con conducente”. like taxis, NCC drivers must hold a municipal authorization (issued in limited numbers) be registered in the drivers’ register, and possess the required professional qualification certificate. Unlike taxi drivers, NCC vehicles must be linked to a garage located within the municipality that granted the authorization, and they may not wait for passengers in public areas. The service may also be carried out outside the municipal territory, provided that the passenger’s pick-up location is within the municipal territory that issued the authorization. Also, unlike taxis, an individual can hold multiple authorizations and fares are not fixed.

i) The number and type of vehicles to be used;

ii) The procedures for carrying out the service;

iii) The criteria for determining the tariffs for the taxi service;

iv) The requirements and conditions for the issuance of the license for operating the taxi service.

The provision of the taxi service can also take place outside the municipality that issued the license, provided that there is a prior agreement with the other municipalities (Art. 5-bis).

The taxi driver must have the necessary qualifications to drive the vehicle used for the service (hold a Category B driving licence and be at least 21 years of age), must have a Certificate of Professional Qualification, in addition to possessing the attached license (Art. 6 paragraphs 1-6).

The license for operating the taxi service is issued by the municipal administrations, through a public competition announcement. The accumulation of multiple licenses (taxi) by the same subject is not allowed (Art. 8 paragraphs 1, 2).

A licence holder may transfer it to third parties when certain requirements are met, namely after holding the licence for at least five years, reaching the age of 60, or in cases of permanent inability due to illness, injury, or death. (Art. 9 paragraphs 1-3). Taxi drivers can also be substituted by suitable drivers or may use second drivers in hourly shifts in addition to the ordinary ones (Art. 10 paragraphs 1, 2-bis, 5-bis).

Vehicles designated as taxis must begin the service at the appropriate areas in their municipality and can end the ride in another municipality, provided there is a prior agreement between the municipalities concerned (Art. 11 paragraph 2).

The taxi service is performed upon request of the passengers, with payment of a fee calculated using an approved taximeter, according to the tariffs established by the competent authorities. The tariff is based on a multiple system for urban rides and a kilometre-based system for extra-urban rides (Art. 13 paragraphs 1, 2).

The regulations make the taxi service a sector that is not subject to free-market competition. The supply of taxis is limited through the licensing system, with licenses issued directly by the municipality according to criteria established based on the needs of the local area. Likewise, fares and, to some extent, the level of service quality are determined by the municipality, which can choose or incentivize the type of vehicles that can be part of the taxi fleet.

Taxi drivers retain the freedom to provide the service, meaning they can choose where to wait for customers (e.g., at taxi stands or parking areas) and decide the route to deliver the passenger to their destination. However, they cannot choose their customers or refuse a ride. In addition, drivers are allowed to organize their work by employing substitutes or assigning different work shifts to them. This makes the license holder potentially an entrepreneur.

Entry into the market is limited by the availability of licenses. Their number is determined by the municipalities, as are the procedures for obtaining them. In general, licenses are awarded

through a public tender in which only drivers qualified for the service can participate. A ranking is established based on points, and the available licenses are allocated for a fee to the participants with the highest scores. A second method of entering the market is through the purchase of a license already assigned to its holder or its transfer by inheritance.
Still, both methods presuppose that the driver holds the Certificate of Professional Qualification and has a vehicle suitable for carrying out the service.

All these aspects, as already mentioned, are entirely under the control of the municipalities. In accordance with Law 26 and the relevant regional provisions, they are free to manage and supervise the service. Therefore, there are no further detailed regulations governing this matter, apart from a number of guidelines [2] issued by the Transport Regulation Authority (ART) to support municipalities in performing these functions.

According to the legislation, two distinct markets exist. The first is the street-hailing transport market, in which taxis hold a legal monopoly; the second is the pre-booked transport market, which relies on apps and phone calls, where taxis compete directly with NCCs. In both cases, the dynamics outlined above, make the taxi sector in Italy a peculiar market, characterized by barriers to entry, limited competition, a nearly homogeneous service and fixed prices.

1.2 Evidence on the Italian Taxi Sector

The market structure outlined by this legal framework has remained mostly unchanged. During the last 30 years some data have been collected regarding various aspects of the service. The goal is to give a clear, yet synthetic picture of how the sector is performing in Italy.

1.2.1 Supply and Demand Analysis

We begin the analysis by assessing whether the level of taxi service is adequate to meet demand. We therefore examine whether the number of taxi licenses is sufficient to satisfy residents' needs and to accommodate demand increases driven by tourism.

Table 1.1 shows the number of licenses per 10,000 inhabitants in the capital municipalities of Italian metropolitan cities from 2012 to 2023[3], while, Table 1.2 reports their relative growth rates (in %).
We can see that in the last decade, in some cities, there have been some positive increase in the number of licences compared to the population, like Firenze (+19.3%), Palermo (+11.6%) and Torino (+6.6%), with other minor increments in other cities, while at the same time, there have been substantial decreases like Cagliari (-19.7%), Catania (-22.7%) and Napoli (-10.1%), and some other minor decreases. Overall, on average, we observe a decrease in licences over the population of approximately 1.04%.
If we focus exclusively on the number of licences, we can note that over the same period

[2] These are included in Appendix A of *Delibera n. 146/2021 del 4 novembre 2021*[16], under the title "Linee guida in materia di adeguamento del servizio taxi per Regioni ed Enti Locali". The document provides guidelines and general rules for establishing the number of licenses, license assignment criteria, fares, mechanisms of surveillance and more.

[3] This is the longest time span available in the ART dataset, but it is sufficient to properly assess the evolution of the number of taxi licenses over time, since the latter remained essentially unchanged in the previous decade as well.

Comune	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Bari	6.241	6.199	6.154	6.109	6.079	6.024	6.037	6.061	6.066	6.228	6.192	6.202
Bologna	18.317	18.353	18.379	18.385	18.385	18.416	18.467	18.534	18.562	18.718	18.685	18.623
Cagliari	8.340	8.250	8.099	7.962	7.848	7.697	7.586	7.444	7.352	7.183	6.909	6.697
Catania	8.802	8.508	8.211	7.958	7.683	7.423	7.093	6.877	6.823	6.827	6.745	6.802
Firenze	18.192	18.504	18.799	19.158	19.515	19.906	20.340	20.843	21.110	21.789	21.744	21.709
Genova	14.700	14.722	14.715	14.718	14.664	14.634	14.554	14.526	14.487	14.617	14.579	14.631
Messina	6.775	6.764	6.724	6.702	6.706	6.657	6.646	6.645	6.625	6.905	6.886	6.851
Milano	36.323	36.318	36.242	36.098	35.995	35.651	35.316	34.892	34.685	35.545	36.002	35.560
Napoli	24.590	24.097	23.631	23.397	23.140	22.888	22.558	22.318	22.042	22.592	22.471	22.102
Palermo	3.677	3.688	3.695	3.710	3.740	3.785	3.826	3.873	3.927	4.070	4.099	4.103
Reggio C.	7.214	7.196	7.212	7.170	7.122	7.042	6.995	7.000	6.968	7.131	7.099	6.997
Roma	27.776	27.621	27.527	27.455	27.301	27.101	27.012	26.975	26.855	27.938	28.064	28.074
Torino	16.584	16.609	16.593	16.655	16.737	16.861	16.936	16.992	17.085	17.562	17.681	17.680
Venezia	8.812	8.843	8.862	8.860	8.891	8.872	8.872	8.847	8.882	9.080	9.067	9.059

Table 1.1: Taxi licences per 10,000 inhabitants in metropolitan city capitals (2012–2023). Source: ISTAT–ART[17].

Comune	Change 2012–2023 (%)
Bari	-0.623
Bologna	1.674
Cagliari	-19.701
Catania	-22.723
Firenze	19.329
Genova	-0.469
Messina	1.129
Milano	-2.103
Napoli	-10.118
Palermo	11.583
Reggio Calabria	-3.010
Roma	1.074
Torino	6.612
Venezia	2.802

Table 1.2: Growth rates of taxi licences per 10,000 inhabitants, same sample of Table 1.1

(2012-2023) licences increased significantly only in the municipality of Firenze (+17.30%), while Bologna and Palermo experienced a small but steady rise (+4.71% and +4.03%, respectively). In the other municipalities, the number of licences either remained unchanged or declined, sometimes drastically, as in the cases of Catania (-27.27%), Cagliari (-22.48%), Napoli (-15.26%), Reggio Calabria (-10.45%), Messina (-8.59%), and Genova (-8.15%).

The stagnation in the issuance of taxi licences becomes even more evident when considering the dates of the most recent licensing rounds in the municipalities of Rome, Milan, and Naples. In the case of Rome, the last licensing procedures date back to 2005, with two separate rounds that awarded 300 and 150 new licences. As for Milan, the last three licensing rounds were held in 1980, 1981, and 2003, the latter resulting in the allocation of 303 new licences. In Naples, the most recent rounds were conducted in 1994 and 1998, awarding 183 and 11 new licences respectively. During these years, several attempts were made to increase the number of licences in the main municipalities, but they were systematically met with strong resistance from taxi drivers' organisations. It is worth mentioning the large-scale protests organised in 2006 following the *Decreto Bersani*, in 2012 after the *Decreto Monti*, and again in 2022 in response to the *DDL Concorrenza* proposed by the Draghi government. In all three instances, taxi organisations successfully opposed and ultimately prevented the planned increase in the number of licences.

Moreover, the decline in service availability was not offset by a corresponding increase in NCC authorisations, a service which is a close substitute for taxi services.
As shown in the table Table 1.3, between 2018 and 2024 the number of NCC authorisations in the same cities remained unchanged or even decreased, in some case substantially, as in Reggio Calabria (-42%) and Palermo (-11.9%) with the sole exception of Milano, which saw an increase of 9 authorizations (+5.4%).

Comune	NCC 2018	NCC 2024	% Change
Roma	993	993	0.00%
Milano	203	214	5.42%
Napoli	154	154	0.00%
Torino	176	169	-3.98%
Genova	188	188	0.00%
Firenze	104	104	0.00%
Bologna	245	245	0.00%
Palermo	160	141	-11.88%
Catania	17	17	0.00%
Bari	14	14	0.00%
Venezia	116	116	0.00%
Cagliari	65	65	0.00%
Messina	18	18	0.00%
Reggio Calabria	50	29	-42.00%

Table 1.3: NCC licences in metropolitan city capitals (2018 vs. 2024). Source: ISTAT–ART[17].

Another interesting element to point out is the taxi share compared to NCC in various municipalities across Italy. Table 1.4 shows a strong positive correlation between population size and % of taxi share.

Population Ranges	Avg. Taxi Share (%)	Municipality Count
<20k	43.47%	31
20k - 50k	52.01%	50
50k - 100k	56.68%	50
100k - 250k	65.62%	33
250k - 500k	82.09%	5
>500k	86.61%	6

Table 1.4: Average taxi share percentage by population range. Source: ISTAT–ART[17]

The larger the municipality, the greater the taxi share. While the reasons for this trend may vary, the magnitude of the difference between smaller and larger municipalities is remarkable. Although we do not have specific data to prove it, it is reasonable to assume that in very small municipalities, NCCs are much more prevalent compared to taxis. One possible reason for this is the high expenses and administrative effort required to organize a taxi service in smaller towns. This process includes selecting and preparing suitable areas for taxi stands, setting prices, managing calls for taxi license assignments, and monitoring taxi drivers. Additionally, there may not be enough demand for drivers to actually purchase a taxi license in these smaller areas.
On the other hand, NCC services could be more profitable in these smaller municipalities. They require much less organizational effort from the municipality, and are more likely to operate across multiple nearby municipalities through a single company, since NCC licenses can be

cumulative for a single individual.
As the table shows, the availability of both services is almost equal on average in municipalities with up to 100,000 inhabitants. However, in larger municipalities, the share of NCC vehicles steadily decreases, with significant differences emerging in municipalities over 250,000 inhabitants. It is difficult to believe that demand for NCC services is insufficient to make them profitable, especially given that NCCs are allowed to set their own fares, which could potentially make them more convenient than taxis.
We can reasonably assume that taxi lobbies may be exerting influence on local authorities to limit the issuance of new NCC licenses, and this pressure is likely much stronger in cities with larger taxi fleets, as evidenced by the riots taxi drivers have staged in recent years to protest the increase in taxi licenses.

Another element to consider is tourism flows. Italy is among the most visited countries in the world[4], with Rome and Milan among the most attractive cities globally. It is evident that visitors impose additional pressure on the public transport system. Table 1.5 shows through annual precences, how tourism flows have increased substantially over the past decade in all the metropolitan city capitals.

Comune	**Presences 2012 (thousands)**	**Presences 2023 (thousands)**	**% Change**
Roma	24,180	27,810	+15.0%
Milano	9,070	14,500	+59.9%
Venezia	10,590	13,300	+25.6%
Firenze	8,860	9,800	+10.6%
Napoli	3,580	4,800	+34.1%
Torino	3,190	3,900	+22.3%
Bologna	2,190	2,900	+32.4%
Genova	1,890	2,400	+27.0%
Palermo	1,620	2,550	+57.4%
Catania	1,480	2,200	+48.6%
Bari	810	1,350	+66.7%
Cagliari	720	1,100	+52.8%
Messina	350	550	+57.1%
Reggio Calabria	290	400	+37.9%

Table 1.5: Tourist presences in metropolitan city capitals (2012 vs. 2023). Source: ISTAT [19]

Given these facts, it is reasonable to assume that the current taxi fleet may struggle to adequately meet users' needs. In this regard, convincing evidence is provided by the graphs below [11], showing the number of taxi requests compared with the number of unfulfilled requests[5] in the cities of Rome, Milan, and Naples in 2023 over a series of months[6].
The data (Figure 1.1, Figure 1.2, Figure 1.3) clearly show that the system is unable to satisfy demand even in months that are typically not affected by high tourist inflows, such as January and February: Rome records 15.8% of unmet requests, while Milan reaches 22%. These shortfalls become more pronounced as tourist volumes increase, reaching summer peaks of 46.4% in Rome, 42.3% in Milan (45.2% in September), and 48.7% in Naples.

[4] According to the UNWTO's World Tourism Barometer data[18], Italy ranked as the fourth most visited country in the world in 2023 in terms of international tourist arrivals.

[5] A request is considered unfulfilled when a client requests a taxi ride and the taxi dispatching service is unable to find a taxi to pick them up.

[6] These data were provided by the main local taxi-dispatching cooperatives at the request of the AGCM, which, with the exception of Milan, supplied observations only for selected months.

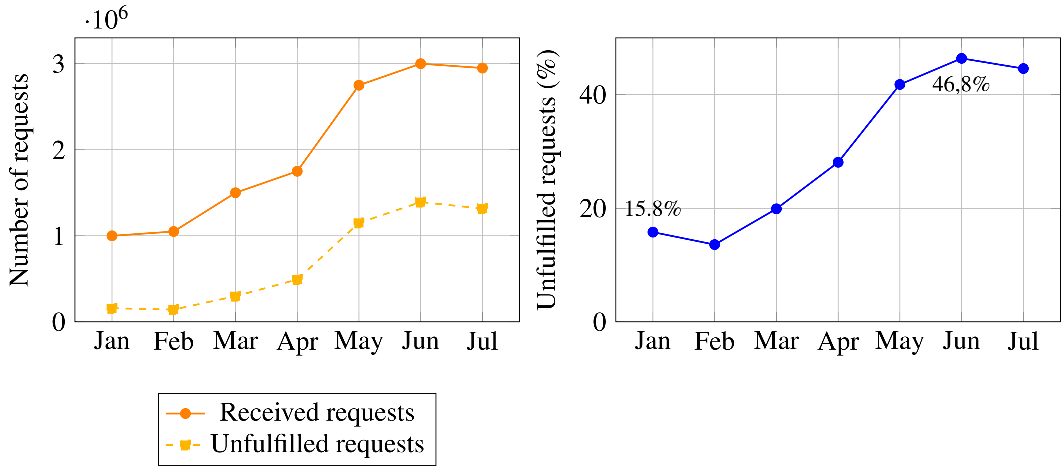

Figure 1.1: Received and unfulfilled taxi requests (left) and percentage of unfulfilled requests (right) in Rome, January–July 2023. Source: AGCM analysis based on RFI responses from *Radiotaxi 3570, Pronto Taxi 6645, Samarcanda, Mytaxi, and Uber*.

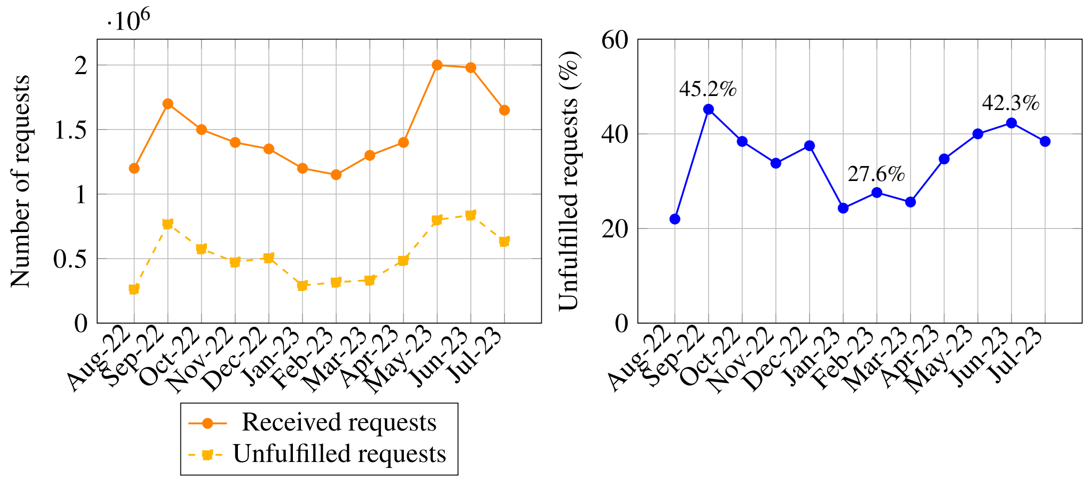

Figure 1.2: Received and unfulfilled taxi requests (left) and percentage of unfulfilled requests (right) in Milan, August 2022–July 2023. Source: AGCM analysis based on RFI responses from*Autoradiotassi, Cooperativa Taxiblu, Yellow Taxi, Mytaxi e Uber*

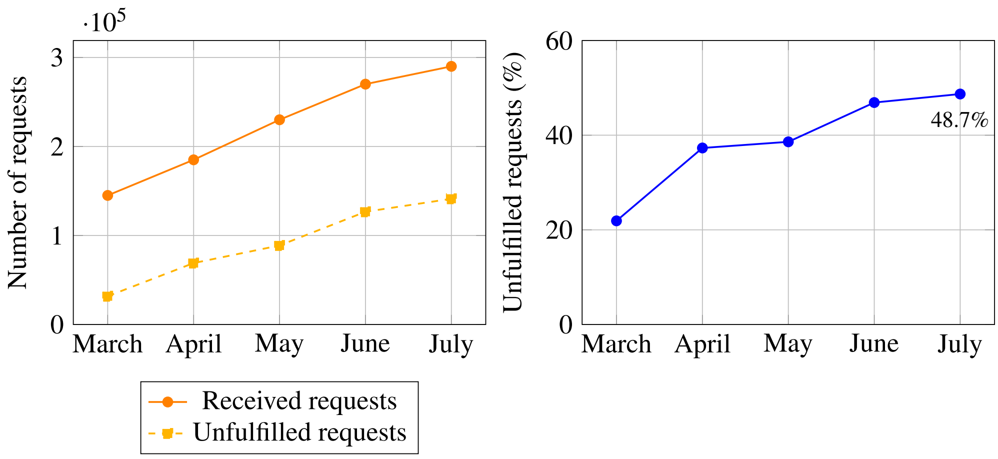

Figure 1.3: Received and unfulfilled taxi requests (left) and percentage of unfulfilled requests (right) in Naples, March–July 2023. Source: AGCM analysis based on RFI responses from *Consortaxi, Taxi Napoli, Radio Taxi Partenope, Mytaxi, and Uber*.

Using these samples, we can estimate the values for the missing months for Rome and Naples with a simple linear regression model, using tourist flows as predictors for the percentage of unfulfilled taxi requests. The identification strategy assumes that the resident population is largely time-invariant within cities, and thus weakly predictive of unmet demand, whereas variations in tourist flows are expected to be a key driver of unfulfilled taxi requests. The estimated values are reported in Table 1.6.

Tempo	**Roma (%UR)**	**Milano (%UR)**	**Napoli (%UR)**
2023-01	15.8	22.0	21.9
2023-02	13.6	45.2	37.3
2023-03	19.9	38.4	38.6
2023-04	28.1	33.8	46.9
2023-05	41.8	37.5	48.7
2023-06	46.4	24.3	53.5426*
2023-07	44.6	27.6	56.5253*
2023-08	34.1448*	25.6	57.8739*
2023-09	37.7942*	34.7	55.1809*
2023-10	38.9768*	40.0	47.8448*
2023-11	23.7350*	42.3	33.9105*
2023-12	20.2659*	38.4	32.4947*

Table 1.6: Monthly unmet request (UR%) for Roma, Milano e Napoli (2023). Values with "*" are estimated.

	Roma	**Milano**	**Napoli**
Coeff.	1.83×10^{-5}	5.8574×10^{-7}	1.65×10^{-5}
Const.	-32.16	$33,36$	25.08
R^2	0.88	1.82×10^{-4}	0.70

Table 1.7: Parameters of the model and R^2.

For Rome, the model achieves an $R^2 = 0.88$, while for Naples it reaches $R^2 = 0.7$, indicating that tourist presence is a reasonably strong predictor of unmet requests in both cities. In contrast, if we apply the model to Milan, we get an $R^2 = 0.000182$, meaning that tourist presence has virtually no explanatory power for Milan's unmet requests, suggesting that other factors drive the unmet demand in the city.

These results suggest that tourist flows may represent an important factor contributing to the lack of taxi supply in some cities. However, as the case of Milan shows, tourism is not the only determinant and may even be insignificant depending on the specific characteristics of each municipality. Nevertheless, the shortage of supply in the sector appears evident, even when its causes are not fully identifiable. For example, in Milan the percentage of unfulfilled requests averages 34.15%, despite the weak relationship with tourist presence. Although the available data do not allow us to draw a complete picture at the national level, it is reasonable to assume that taxi supply is insufficient across much of the territory, or at least, in the more crowded municipalities.

1.2.2 Fares: a Cross-country Analysis

Another factor that our analysis must take into account is represented by fares.
When considering fares, it is important to note that they are set at the municipal level and are typically composed of several distinct components.

i) Initial fare

ii) Dispatch fee

iii) Minimum fare

iv) Distance and time based fare

The initial fare is the amount charged at the start of the ride; the dispatch fee applies when a taxi is booked via phone or app; the minimum fare represents the amount paid when the total cost of the ride falls below a predefined threshold; finally, the distance and time based fare reflects the cost per kilometer traveled and, where applicable, the time spent in traffic. Additional surcharges, such as those for luggage, animals, or extra passengers, may also apply. To keep the analysis tractable, these supplements are excluded from consideration.
Given the high variability of taxi fares across cities, as well as their dependence on factors such as time of day and local regulations, we focus on the average fare for a standardized short and long trip, as reported in [7] in Table 1.8.

Comune	Long ride (€)	Short ride (€)	Year
Venezia	30.15	15.12	2014
Torino	25.07	15.09	2024
Firenze	27.18	14.79	2018
Cagliari	22.33	14.67	2017
Genova	22.64	13.99	2024
Napoli	21.94	13.90	2024
Milano	26.09	13.61	2024
Bologna	21.55	13.05	2018
Roma	22.82	13.01	2021
Messina	22.85	12.50	2014
Bari	18.37	11.09	2024
Catania	17	10.50	2008
Palermo	16.84	10.42	2020
Reggio Calabria	18.50	11.30	2015

Table 1.8: Standard fares in metropolitan city capitals in different reference years. Source: ISTAT–ART[17]

These values are calculated on the basis of the tariff schedules published by each municipality and refer to a standardized usage scenario. In particular, they exclude surcharges associated with special tariff zones and do not account for predefined or fixed-price routes, such as trips between airports or railway stations and city centers.
To assess whether the average taxi fare in Italy can be considered high or low, it is necessary to compare it with countries that exhibit similar regulatory and market structures in the taxi

[7] A standard ride is a booked daytime ride of 1 passenger with no luggage. The ride is short if it is 5 km long with 5 minutes of waiting time, while it is long if it is a 10 km long with 10 minutes of waiting time

sector. Germany, France, and Spain represent appropriate benchmarks, as their taxi markets are characterized by comparable institutional arrangements and fare structures, typically consisting of a base fare combined with distance and time based components.
The following tables (Tables 1.9 to 1.11) report the total estimated trip cost for major cities in each country (with more than 600,000 inhabitants). For comparability, we consider a standard daytime trip of 5 kilometers, including 5 minutes of waiting time, for a single passenger, and we exclude any additional charges related to luggage, booking methods, or other supplements.

City	Base Fare	Distance Cost (5 km)	Wait Cost (5 min)	Total Trip Price
Barcelona	€2.75	€6.60	€2.25	€11.60
Madrid	€2.55	€6.75	€2.21	€11.51
Valencia	€1.85	€6.20	€1.91	€9.96
Seville	€1.62	€5.50	€2.10	€9.22
Zaragoza	€2.08	€4.70	€2.19	€8.97

Table 1.9: Taxi fare estimates for a 5 km trip with 5 minutes of waiting time in major Spanish cities. Source: Official municipal taxi fare schedules

City	Base Fare	Distance Cost (5 km)	Wait Cost (5 min)	Total Trip Price
Nice	€4.00	€12.70	€2.88	€19.58
Bordeaux	€2.80	€10.60	€3.47	€16.87
Toulouse	€2.50	€11.30	€2.88	€16.68
Nantes	€2.60	€11.10	€2.69	€16.39
Marseille	€2.35	€11.10	€2.88	€16.33
Lyon	€3.00	€9.80	€3.29	€16.09
Lille	€2.00	€9.50	€2.69	€14.19
Paris	€3.00	€6.25	€3.24	€12.49

Table 1.10: Taxi fare estimates for a 5 km trip with 5 minutes of waiting time in major French cities. Source: Official municipal taxi fare schedules

City	Base Fare	Distance Cost (5 km)	Wait Cost (5 min)	Total Trip Price
Munich	€5.90	€13.50	€3.25	€22.65
Stuttgart	€4.50	€14.00	€3.17	€21.67
Cologne	€4.90	€13.00	€2.50	€20.40
Frankfurt	€4.00	€12.00	€3.17	€19.17
Düsseldorf	€4.50	€11.00	€2.90	€18.40
Leipzig	€4.00	€11.50	€2.92	€18.42

Table 1.11: Taxi fare estimates for a 5 km trip with 5 minutes of waiting time in major German cities. Source: Official municipal taxi fare schedules

Table 1.12 presents the average taxi fare for each country expressed in Purchasing Power Standards (PPS), allowing for a meaningful comparison that accounts for differences in overall price levels across countries.

[5] In the calculation are considered only the cities with more than 600.000 inhabitants (Roma, Milano, Napoli, Bologna, Firenze, Genova, Palermo, Torino).

[9] Berlin and Hamburg were excluded due to the lack of a licence cap.

Country	Average fare (€)	Average fare (PPS)
Italy[8]	11.76	12.00
Spain	10.65	11.71
France	16.03	14.84
Germany[9]	20.12	18.46

Table 1.12: Average taxi fare for a 5 km trip with 5 minutes of waiting time in selected European countries, expressed in euros and Purchasing Power Standards (PPS).

The results show that Spain and Italy exhibit very similar average taxi trip costs, while France and Germany are more expensive, with Germany being substantially more costly.
However, an important aspect not yet accounted for is the booking surcharge. This surcharge is systematically applied in Italy, whereas it is generally absent in the other countries considered. When incorporating the booking cost for the Italian cities included in the analysis, the average dispatch fee amounts to €3.11. Adding this component raises the Italian average fare to €14.87, corresponding to 15.17 PPS. Under this adjusted measure, taxi services in Italy become more expensive than those in both Spain and France. Although the analysis is necessarily limited,[10] there is sufficient evidence to suggest that taxi prices in Italy, relative to comparable European countries, are inflated by additional booking costs—a service that is typically free elsewhere.

In conclusion, despite the difficulties in comparing prices across countries, restricting the analysis to countries with comparable regulatory frameworks reveals that taxi services in Italy are relatively expensive, ranking second only to Germany. This outcome does not stem from higher operating costs, but rather from institutional pricing mechanisms, most notably the systematic application of booking fees, an element which is largely absent in the other countries considered.

[10] Given the similarity in the regulatory structure of the taxi sector, Portugal and Greece could also be considered. However, their smaller economic scale makes a meaningful comparison difficult. As expected, the average fares in these countries are substantially lower, amounting to €6.85 (7.87 PPS) in Portugal and €7.55 (8.78 PPS) in Greece.

Chapter 2

The Model

In this chapter, we develop a taxi market model that is consistent with the current Italian legislative framework governing the sector. The model is formulated within a general equilibrium framework. Although it relies on certain simplifying assumptions, these are introduced either to facilitate the analytical derivations or to highlight the underlying economic mechanisms more clearly, thereby assisting the regulator in designing policies based on transparent and well-defined criteria. Accordingly, the model is intended to serve as a practical tool that municipalities may use to improve the management of their taxi fleets.

2.1 Model Setup

2.1.1 Initial Assumptions

As discussed in Chapter 1, multiple actors operate within the taxi market in Italy, and numerous mechanisms govern their interactions. The model we propose, although expandable, is not intended to be sufficiently sophisticated to capture all these phenomena. Therefore, we focus exclusively on specific dynamics of the taxi market over which the municipality has full control. In particular, we refer to the number of licenses and the tariff structure.
In order to better isolate the mechanisms involving these variables, a set of preliminary assumptions is required:

1. The municipality has exclusive and full authority over the taxi service within its jurisdiction; therefore, any decision is taken autonomously, without influence from consumers, taxi drivers, or representatives of either group.

2. The taxi service is the only passenger public transport service permitted within the municipality.

3. All participants have perfect information, meaning they possess full knowledge of prices and market conditions.

2.1.2 Agents and Trips

We consider an economy populated by three types of agents: consumers, taxi drivers, and a single municipality. The city is inhabited by $N \in \mathbb{N}_+$ taxi consumers. Each consumer [1]

[1] From now on, we will refer to a taxi consumer simply as a "consumer".

is assumed to have only two modes of transportation: walking or taking a taxi. Walking is assumed to be the least preferred option [2].

Each taxi driver is also a license owner, and we assume there are no unused licenses, hence $J \in \mathbb{N}_+$ denotes the total number of taxi licenses, which also coincides with the number of taxi drivers operating in the city.

We assume there is a finite set of available taxi trips with different lengths. The vector collecting the lengths of all available taxi trips is given by:

$$\mathbf{d} \in \mathbb{R}^L_+ \qquad \mathbf{d} = (d_1, d_2, \ldots, d_L)$$

where d_1 and d_L represent, respectively, the shortest and the longest trips that can be provided by a taxi. Intermediate trip lengths are evenly spaced and given by:

$$d_l = d_1 + (l-1)\frac{d_L - d_1}{L-1}, \qquad l = 1, 2, \ldots, L.$$

Thus, each trip length d_l is obtained as the minimum distance d_1 plus $(l-1)$ increments of size $\frac{d_L - d_1}{L-1}$. By construction, trip lengths are strictly ordered, so that $d_j < d_k$ for all$j < k$ in $\{1, \ldots, L\}$.

2.1.3 Consumers

Consumers are indexed by $n \in \{1, 2, \ldots, N\}$. Consumer n chooses a bundle of taxi rides

$$\mathbf{x}_n \in \mathbb{R}^L_+, \qquad \mathbf{x}_n = (x_{n1}, x_{n2}, \ldots, x_{nL}),$$

where x_{nl} denotes the number of taxi rides of length d_l demanded by consumer n.
The total number of taxi rides demanded by consumer n is therefore:

$$t_n = \mathbf{x}_n^\top \mathbf{1}_L = \sum_{l=1}^{L} x_{nl}. \tag{2.1}$$

For instance, suppose that only three trip lengths are available, d_1, d_2, d_3, which we refer to as short, medium, and long trips. If consumer n chooses the bundle $\mathbf{x}_n = (2, 0, 1)$, then he is asking for $t_n = 3$ rides: two short trips and one long trip.

Given the bundle of taxi trips and their lenghts, we can calculate the total distance traveled by consumer n using taxis, which is given by:

$$y_n = \mathbf{x}_n^\top \mathbf{d} = \sum_{l=1}^{L} x_{nl} d_l. \tag{2.2}$$

We also assume that a taxi ride requires a certain amount of time to be completed. Let w_n denote the total waiting time needed to complete the trips of bundle $\mathbf{x}_n$. The latter consists of two components: the pick-up waiting time w_p and the trip completion time w_t. Thus, the total waiting time for consumer n to complete the demanded bundle of rides is given by:

$$w_n = w_p + w_t = t_n \frac{\theta}{\rho^{1/\lambda}} + y_n \tau \gamma^\rho$$

[2] It gives zero utility for all consumers

where

$$\rho = \frac{J}{N}, \qquad J \leq N,$$

represents the taxi density factor with respect to the population. We assume that the taxi fleet size can be as large as the city population, thus $\rho = [0,1]$.

The waiting time for pickup increases with the number of trips t_n and depends on the parameter θ, which represents the minimum waiting time for a taxi to arrive. This waiting time is divided by taxi density ρ, raised to the power of $\frac{1}{\lambda}$, where $\lambda > 1$, making the function concave with respect to ρ. Hence, as the number of taxis J increases, the taxi density ρ increases, which decreases the waiting time, but by a diminishing rate. The magnitude of the change is influenced by λ, a parameter that captures the efficiency of the taxi dispatching system. If drivers cannot easily find their next customer (i.e., if λ is large), the time benefit of increasing the taxi fleet may be substantially reduced. Therefore, we distinguish between two extreme cases:

- When $J \to N$ (i.e., $\rho \to 1$), the waiting time tends to the minimum value θ, meaning that the waiting time reaches its minimum when the number of taxis is equal to the population of the area served, and the system is fully saturated with taxis.
- When $J \to 0$ (i.e., $\rho \to 0$), the waiting time becomes (infinitely) high since no taxis are available, resulting in no service being provided, and the client cannot be served in any reasonable time frame.

Total trip time depends on a congestion factor γ^{ρ}. The latter amplifies τ, which represents the minimum time required to travel one unit of distance in the absence of taxis, while $\gamma > 1$ is a road infrastructure parameter.

Definition: Congestion
Congestion is defined as the endogenous increase in travel time generated by taxi fleet density. Formally, let the time required to travel one unit of distance be given by

$$T(\rho) = \tau\gamma^{\rho}$$

therefore, congestion is defined as

$$\frac{dT(\rho)}{d\rho} > 0,$$

that is, the raise in travel time due to an increase in taxi density.

The parameter γ represents the extent to which the municipality is able to absorb an expansion of the taxi fleet. In particular, γ captures structural conditions such as baseline traffic levels[3], limited road capacity, poor traffic light synchronization, and extensive low-speed sections. These factors may generate significant congestion even in response to a small increase in the taxi fleet. Conversely, in municipalities characterized by low baseline traffic, well-designed road networks, and high road capacity, congestion becomes negligible and $\gamma \to 1$.

[3]With baseline traffic we are referring to the amount of vehicles present on the streets before any taxi license is issued. We assume that baseline traffic is homogeneous across the road network and constant over time.

Since $\rho = \frac{J}{N}$, we can examine how congestion reacts to changes in fleet size. Taking the derivative with respect to J, we obtain:

$$\frac{\partial(\gamma^{J/N})}{\partial J} = \frac{1}{N}\gamma^{J/N}\ln(\gamma).$$

Therefore, if we use the number of consumers as a proxy for the population size, the impact of a marginal increase in fleet size on congestion is inversely proportional to the latter: the smaller the municipality, the larger the increase in congestion, whereas the same increment in a very large city has a negligible effect.
Again, we can distinguish between two extreme scenarios:

- When $J \to N$ (i.e., $\rho \to 1$), the trip time approaches its maximum value $w_{\max} = y_n\tau\gamma$, which is the time needed to cover the total trip under maximum congestion (when the density of taxis reaches its peak).
- When $J \to 0$ (i.e., $\rho \to 0$), the trip time decreases towards the minimum possible value $w_{\text{tmin}} = y_n\tau$, as congestion is minimal.

This means that we can define a function $\Delta(\rho)$ which expresses the extra time needed to do one unit distance when congestion is present ($\rho > 0$), compared to the no-congestion situation ($\rho = 0$), namely:

$$\Delta(\rho) = \tau\left(\gamma^{\rho} - 1\right) \tag{2.3}$$

This means that for each level of taxi density there is a level of inefficiency in the taxi system of transport, given by the extra time needed to bring customers to their destinations. The maximum level of inefficiency is when $\rho = 1$, therefore we have maximum ride time
$w_{\text{tmax}} = w_{\text{tmin}} + y_n\Delta(1) = y_n\tau\gamma$

We assume that consumers care only about taxi rides. We also assume that consumer n has well-behaved preferences [4] over $\mathbf{x}$ represented by a Cobb-Douglas utility function of the form:

$$u_n(\mathbf{x}_n) = \prod_{l=1}^{L} x_{nl}^{\alpha_{nl}}$$

where

$$\alpha_{nl} = \frac{\hat{\alpha}_{nl}}{\sum_{l=1}^{L}\hat{\alpha}_{nl}}$$

and where $\hat{\alpha}_{nl}$ is the actual weight of the preference of consumer n over trip l, while α_{nl} is the exponent after a normalization process, implying that all the exponents sum to one.

Each consumer is endowed with a taxi budget $\omega_n > 0$. We suppose that taxi drivers can charge two different tariffs: a price per unit distance $p_d > 0$ and a price per unit of time $p_t > 0$. The latter is involved only when the taxi stops. Also, there is an extra initial fare price $k > 0$. The consumer's budget constraint is therefore:

$$kt_n + (p_d + p_t\Delta(\rho))y_n \leq \omega_n \qquad \forall n$$

Thus, a bundle $\mathbf{x}$ is feasible for consumer n only if the total expenditure to afford it is lower or equal than his income. Notice that congestion may reduce the feasible set of trip bundles by augmenting the extra time $\Delta(\rho)$ needed to complete the requested rides.

[4] This implies that they satisfy completeness, transitivity, strict monotonicity and strict convexity.

2.1.4 Taxi Drivers

Taxi drivers serve the rides requested by the consumers. Therefore, driver j provides a vector of taxi rides:

$$\mathbf{X}_j \in \mathbb{R}^L_+ \qquad \mathbf{X}_j = (X_{j1}, X_{j2}, \dots, X_{jL}),$$

where X_{jl} denote the number of rides of length D_l supplied by driver j.
Let $\mathbf{D} = (D_1, D_2, \dots, D_L)$ denote the vector of effective distances traveled per ride. Each D_l includes both the trip distance d_l and the distance needed to reach the customer. Hence, the total distance for trip l is given by:

$$D_l = d_l + z = d_l + \frac{1}{2\sqrt{\frac{Z}{A}}} \tag{2.4}$$

where $A > 0$ is the area of the municipality in distance units squared and $Z > 0$ is the number of taxi stands. Hence, assuming that:

i) Taxi stands are uniformly distributed over the municipality area.

ii) Taxi drivers are always looking for the nearest taxi stand to pick up a client.

then, the effective distance traveled for each ride is given by the sum of the actual length of the trip d_l and the average distance z needed to reach the nearest taxi stand from any point in A, which is given by the Clark-Evans Index (see [20]). The latter implies that the denser the distribution of taxi stands, the shorter is the distance taxi drivers travel to find the next customer.

Also, taxi drivers incur operating costs: let's denote with $c_d > 0$ the cost per unit distance, while let's denote with $c_t > 0$ the cost per unit of time when the taxi is idle. Therefore, the profits of driver j are given by:

$$\pi_j = kT_j + p_d(Y_j - Z_j) + p_t(Y_j - Z_j)\Delta(\rho) - (c_d + c_t\Delta(\rho))Y_j$$

where

$$T_j = \mathbf{X}_j \mathbf{1}_L = \sum_{l=1}^{L} X_{jl} \tag{2.5}$$

$$Y_j = \mathbf{X}_j^\top \mathbf{D} = \sum_{l=1}^{L} X_{jl} D_l \tag{2.6}$$

$$Z_j = z\mathbf{X}_j = z\sum_{l=1}^{L} X_{jl} \tag{2.7}$$

Namely, (2.5) is the total number of rides supplied by driver j, (2.6) is the total distance traveled by driver j and (2.7) is the total distance traveled to pick up consumers. Therefore, π_j is given by the total number of fixed fees collected, the total revenues coming from distance traveled and time passed with customer on board, subtracting the total distance and time costs.

Taxi drivers offer trips as long as they don't exceed their available working hours Θ_j, namely:

$$W_j \leq \Theta_j \qquad \forall j$$

where

$$W_j = Y_j \tau \gamma^\rho \tag{2.8}$$

is the total time needed for driver j to complete all the rides supplied.

2.1.5 Municipality

A single municipality regulates the taxi market. It has the authority to choose the number of taxi licenses J, to set the prices p_d, p_t, and the fixed fee k.

The municipality chooses the policy quadruple (J, p_d, p_t, k) to maximize aggregate welfare:

$$U = \sum_{n=1}^{N} u_n(\mathbf{x}_n),$$

but at the same time wants to guarantee a minimum profit level $\bar{\pi}$ to each taxi driver, namely:

$$\bar{\pi} \leq \pi_j \qquad \forall j$$

This implies that taxi drivers face a participation constraint. Specifically, we assume that they are unwilling to supply their services unless a minimum level of profitability is guaranteed. This assumption is reasonable, as the financial commitment required to operate in the market is substantial for the average Italian citizen: both the taxi license and the vehicle represent substantial fixed entry costs, particularly in large municipalities.

In doing so, the municipality is also trying to match the demand and supply of consumers and taxi operators, without exceeding the working hours of the latter.

2.2 Solving the Model

2.2.1 The Planner's Problem

We know that the municipality must choose a set of prices and a number of licenses that maximize the aggregate utility of consumers while ensuring at least a minimum profit $\bar{\pi}$ for the drivers. In doing so, it must also guarantee market clearance, ensuring that the available working hours of taxi drivers are not exceeded. This means that the municipality wants to solve:

$$\max_{J,k,p_t,p_d \geq 0} \quad U = \sum_{n=1}^{N} u_n(\mathbf{x_n}) \tag{2.9}$$

$$\text{subject to} \quad kt_n + p_d y_n + p_t \Delta(\rho) \leq \omega_n \quad \forall n \tag{2.10}$$

$$\bar{\pi} \leq \pi_j \quad \forall j \tag{2.11}$$

$$\sum_{j=1}^{J} X_{jl} = \sum_{n=1}^{N} x_{nl} \quad \forall l \tag{2.12}$$

$$W_j \leq \Theta_j \quad \forall j \tag{2.13}$$

The way the problem is formulated falls within the framework of a Ramsey–Boiteux pricing problem [21],[22]. In particular, a planner seeks to maximize a welfare function by setting prices for the goods produced by a monopolistic public firm, subject to the requirement that a minimum level of profit must be guaranteed (participation constraint). Our model can be interpreted as a specific case of this problem, featuring additional constraints, namely market clearing and time budget constraint and using aggregate consumer utility as the welfare function.

First, observe that to approach the solution of the problem (2.9)-(2.13), a couple of assumptions are considered:

1. The Weierstrass theorem holds, so that (2.9)-(2.13) admits solution;
2. A constraint qualification condition is fulfilled for the feasible set of (2.9)-(2.13), so that KKT conditions can be written.

Although a simulation approach, namely, testing different combinations of prices and licenses until the objective function is maximized, could be an option for the policy maker, this method is not particularly useful for the latter, since it doesn't provide intuition on what action the social planner should take to improve the service.

It is simpler, yet more insightful, to approach a possibly suboptimal solution of the model using a general equilibrium approach. This involves splitting the problem into two separate optimization problems—one for the consumers and one for the taxi drivers—and then allowing the municipality to choose the set of prices and the number of licenses that solves (2.11)-(2.13)

2.2.2 Consumer Optimization

We begin by considering the consumer's optimization problem. Since prices are set exclusively by the municipality, consumers cannot influence them and therefore behave as price takers. Given the congestion value, represented by γ^{ρ}, they choose the feasible bundle of rides that maximizes their utility. Accordingly, the consumer's problem can be written as follows:

$$\max_{\mathbf{x}_n \geq 0} \quad u(\mathbf{x}_n) = \prod_{l=1}^{L} x_{nl}^{\alpha_{nl}} \tag{2.14}$$

$$\text{subject to} \quad kt_n + (p_d + p_t\Delta(\rho))y_n \leq \omega_n \tag{2.15}$$

Since the consumer derives utility exclusively from taxi rides, and preferences are locally non-satiated, it is optimal for them to spend the entire taxi budget on taxi rides. This implies that the budget constraint must be binding.
If we expand (2.15) using (2.1) and(2.2), we get:

$$k\left(\sum_{l=1}^{L} x_{nl}\right) + (p_d + p_t\Delta(\rho))\left(\sum_{l=1}^{L} d_l x_{nl}\right) = \omega_n$$

We group all coefficients associated with a single ride of type l, to get:

$$\sum_{l=1}^{L} [k + (p_d + p_t\Delta(\rho))d_l]\, x_{nl} = \omega_n$$

Hence, if we define $P_l = k + (p_d + p_t\Delta(\rho))d_l$ as the effective price per unit of ride l, we obtain the budget constraint in its traditional form:

$$\sum_{l=1}^{L} P_l x_{nl} = \omega_n$$

Therefore, given that the utility function is a Cobb-Douglas, we can use the well known formula (see [23]), to find the demand function of consumer n for ride l:

$$x_{nl} = \frac{\alpha_{nl}\omega_n}{P_l} \quad \forall n, l \tag{2.16}$$

Namely, each consumer demands a quantity of trip l equal to the ratio between their budget share $\alpha_{nl}\omega_n$ and its price P_l. Therefore, demand increases with wealth and decreases with rise in prices, and implicitly, through congestion, which slows down the ride, making it more costly. We can further simplify the ride price by splitting the tariff into its fixed and variable parts: if we define $m := p_d + p_t\Delta(\rho)$ as the marginal revenue per unit distance, we can rewrite P_l as:

$$P_l = k + md_l \tag{2.17}$$

Namely, since m is equal across all trips, the effective price differs across rides only through the distance traveled.
At this point, we know how the optimal demand of trip l for each consumer changes with respect to prices, budget and time, meaning that we have solved the consumer optimization problem.

2.2.3 Taxi Driver Optimization

Again, since only the municipality has the authority to set prices, also Taxi drivers are price-takers. Drivers seek to find the bundle of rides to offer that maximizes their profits without exceeding their working hours, given the value of congestion γ^ρ. Namely, they want to solve:

$$\max_{X_j \geq 0} \quad \pi_j(\mathbf{X}_j) = kT_j + p_d(Y_j - Z_j) + p_t(Y_j - Z_j)\Delta(\rho) - (c_d + c_t\Delta(\rho))Y_j \tag{2.18}$$

$$\text{subject to} \quad \bar{W}_j \leq \Theta_j \tag{2.19}$$

According to (2.4), (2.6) and (2.7) we notice that:

$$\begin{aligned}
(Y_j - Z_j) &= \sum_{l=1}^{L} (D_l X_{jl} - zX_{jl}) \\
&= \sum_{l=1}^{L} [(d_l + z)X_{jl} - zX_{jl}] \\
&= \sum_{l=1}^{L} d_l X_{jl}
\end{aligned}$$

Therefore, using (2.5) we can expand (2.18) to obtain:

$$\pi_j = k\left(\sum_{l=1}^{L} X_{jl}\right) + (p_d + p_t\Delta(\rho))\left(\sum_{l=1}^{L} d_l X_{jl}\right) - (c_d + c_t\Delta(\rho))\left(\sum_{l=1}^{L} D_l X_{jl}\right)$$

If we define $M := c_d + c_t\Delta(\rho)$ as the effective marginal cost of one unit distance, and we use the definition of m we get:

$$\pi_j = k\sum_{l=1}^{L} X_{jl} + m\sum_{l=1}^{L} d_l X_{jl} - M\sum_{l=1}^{L} D_l X_{jl}$$

By factoring out X_{jl}, the equation reduces to:

$$\pi_j = \sum_{l=1}^{L} (k + md_l - MD_l) X_{jl}$$

Using (2.17) we obtain:

$$\pi_j = \sum_{l=1}^{L} (P_l - MD_l) X_{jl} \tag{2.20}$$

We notice that the parentheses represent the marginal profit for ride l, so we can define it as $\mu_l := (P_l - MD_l)$ which gives us the simplified profit formula:

$$\pi_j = \sum_{l=1}^{L} \mu_l X_{jl}$$

Using (2.6) into (2.8), we can rewrite the time budget constraint as:

$$\sum_{l=1}^{L} \tau \gamma^{\rho} D_l X_{jl} \leq \Theta_j$$

If we define $W_l := \tau \gamma^{\rho} D_l$ as the effective time needed to supply one unit of ride l, the inequality reduces to:

$$\sum_{l=1}^{L} W_l X_{jl} \leq \Theta_j \tag{2.21}$$

We are now dealing with the much simpler optimization problem:

$$\max_{X_j \geq 0} \quad \pi_j(\mathbf{X}_j) = \sum_{l=1}^{L} \mu_l X_{jl} \tag{2.22}$$

$$\text{subject to} \quad \sum_{l=1}^{L} W_l X_{jl} \leq \Theta_j \tag{2.23}$$

Therefore, we build the Lagrangian:

$$\mathscr{L}(X_{jl}, \lambda_j) = \sum_{l=1}^{L} \mu_l X_{jl} + \lambda_j \left(\Theta_j - \sum_{l=1}^{L} W_l X_{jl} \right)$$

where λ_j denotes the shadow value of time for driver j, that is, the opportunity cost of time. For driver j to accept trip l, the marginal profit μ_l must at least compensate for the profit that could be earned by allocating the same amount of time, W_l, to an alternative trip in the market. If we compute the FOC we get:

$$\frac{\partial \mathscr{L}}{\partial X_{jl}} = \mu_l - \lambda_j W_l \leq 0 \tag{2.24}$$

Since it is reasonable to assume that the municipality aims to prevent:

- Cherry-picking behavior by taxi drivers, i.e., the selection of trips based solely on their profitability

- The absence of a universal service obligation, ensuring that any ride requested by a consumer is fulfilled

then prices will be set such that the marginal profit per unit of time for the taxi drivers is equal across all possible trips l. Hence, we make equation (2.24) binding, which implies that the following relation holds:

$$\frac{\mu_1}{W_1} = \frac{\mu_2}{W_2} = \cdots = \frac{\mu_L}{W_L} \quad \forall l$$

Therefore, given any two rides l, v where $l \neq v$, their marginal profit per unit of time must coincide, namely:

$$\frac{\mu_l}{W_l} = \frac{\mu_v}{W_v}$$

If we substitute the marginal profits and travel time of each ride with their definitions, we obtain:

$$\frac{P_l - MD_l}{D_l \tau \gamma^\rho} = \frac{P_l - MD_l}{D_l \tau \gamma^\rho}$$

Using (2.17) we can simplify the expression into:

$$\frac{k + md_l}{D_l} = \frac{k + md_v}{D_v}$$

By using (2.4) and by multiplying both sides by the denominators we have:

$$(k + md_l)(d_v + z) = (k + md_v)(d_l + z)$$

If we expand the relation and cancel the identical terms we have:

$$kd_v + md_l z = kd_l + md_v z$$

We can factor k and mz to obtain:

$$k(d_v - d_l) = mz(d_v - d_l)$$

Because $d_v \neq d_l$, we can simplify the expression to:

$$k = zm \tag{2.25}$$

So, if the marginal profits per unit of time is equal across all rides, it means that:

- The fixed fee must be set by the municipality such that it compensates the driver for the lost revenue from picking up the consumer. This value depends on z, which in turn depends on the density of taxi stands Z in the city. If the number of stands increases, the average pickup distance decreases, leading to a lower fixed fee. Conversely, if taxi stands are fewer, drivers must travel greater distances to find the next customer, which raises the fixed fee.

- Since taxi drivers consider all units of time equally profitable, they will spend their entire time budget, making equation (2.23) binding.

Also, we can combine (2.25) with (2.17) to express the effective price of ride l as:

$$P_l = m(z + d_l) = mD_l \tag{2.26}$$

2.2.4 Equilibrium Characterization

Now, the municipality wants to find the number of licenses J and the prices p_d, p_t such that:

i) The demand of consumers is always satisfied.

ii) Taxi drivers do not operate beyond their working hours.

iii) Taxi drivers earn at least a certain amount of profit $\bar{\pi}$.

Mathematically speaking, the municipality seeks to find the triplet (J, p_d, p_t) such that the following relations hold

$$\sum_{j=1}^{J} X_{jl} = \sum_{n=1}^{N} x_{nl} \qquad \forall l \tag{2.27}$$

$$\sum_{j=1}^{J} W_j \leq \sum_{j=1}^{J} \Theta_j \tag{2.28}$$

$$\bar{\pi} \leq \pi_j \quad \forall j \tag{2.29}$$

We start by determining the number of taxi licenses J. We assume, for simplicity, although reasonably, that the available working hours for each taxi driver is equal across all the category, namely $\Theta_j = \Theta$ for all j. We also recall that the optimal strategy for each driver is to exhaust the entire time budget, thus, (2.21) becomes binding. Therefore we can rewrite (2.28) as:

$$J\Theta = \sum_{l=1}^{L} W_l \sum_{j=1}^{J} X_{jl}$$

If (2.27) holds, we can plug the optimal consumer demand (2.16) to obtain:

$$J\Theta = \sum_{l=1}^{L} W_l \sum_{n=1}^{N} \frac{\alpha_{nl}\omega_n}{P_l}$$

If we define the aggregate wealth of the consumer as $\Omega := \sum_{n=1}^{N} \omega_n$ and we recall that utility exponents sum to one, the equation becomes:

$$J\Theta = \Omega \sum_{l=1}^{L} \frac{W_l}{P_l}$$

By substituting (2.8) and (2.26), we obtain J:

$$J = \frac{\Omega\tau\gamma^{\rho}}{\Theta m}$$

If we substitute m with its definition we obtain:

$$J = \frac{\Omega\tau\gamma^{\rho}}{\Theta(p_d + p_t\tau\gamma^{\rho})} \tag{2.30}$$

Notice that, since γ^{ρ} contains J, for the moment we must content ourselves with an implicit formula of the optimal taxi fleet size.

The municipality aims to guarantee a certain level of profit to taxi drivers. This means that it seeks to determine p_d and p_t such that (2.29) is satisfied.
By setting (2.20) equal to $\bar{\pi}$ and substituting (2.17) and (2.6) we get

$$\bar{\pi} \leq (m-M)Y_j$$

Which, in aggregate form becomes:

$$J\bar{\pi} \leq (m-M)\sum_{j=1}^{J} Y_j \tag{2.31}$$

Since the time budget constraint is binding for all drivers, (2.8) in aggregate form becomes:

$$J\Theta = \tau\gamma^{\rho}\sum_{j=1}^{J} Y_j$$

Combine the equation with (2.31) to obtain:

$$\frac{\bar{\pi}\tau\gamma^{\rho}}{\Theta} \leq m-M$$

This implies that the marginal profit per unit of distance must be greater than or equal to the left-hand side of the equation. It decreases when working hours are extended, while it must increase when congestion rises, since drivers need to be compensated for the lower number of rides provided.

Since the regulator aims to maximize consumer utility, the ideal "first-best" policy would be to set prices equal to the marginal cost of providing each ride. However, this scenario is not feasible under the requirement that taxi drivers maintain a minimum level of profitability to satisfy the participation constraint. If prices were set at marginal cost, the resulting loss would lead drivers to exit the market in favor of alternative employment. Conversely, setting prices that allow drivers to earn profits above their reservation threshold ($\bar{\pi}$) would imply that consumers are paying an unnecessary rent to the sector, or that the municipality is indirectly subsidizing the service. Therefore, the optimal regulatory strategy is to set prices such that taxi drivers earn exactly $\bar{\pi}$. This ensures that the participation constraint is met—keeping the supply side stable—while simultaneously maximizing consumer welfare by charging the minimum tariff necessary to sustain the service. Consequently, the constraint must be binding:

$$m-M = \frac{\bar{\pi}\tau\gamma^{\rho}}{\Theta} \tag{2.32}$$

Now, if we substitute m with its definition we obtain an equation in two unknowns, namely, p_d and p_t:

$$p_d + p_t\tau\gamma^{\rho} = M + \frac{\bar{\pi}\tau\gamma^{\rho}}{\Theta} \tag{2.33}$$

Therefore, the municipality could solve its maximization problem by using any arbitrary prices which satisfies (2.33). It is reasonable to assume that our municipality wants to find a relationship between price per unit distance and price per unit of time, which takes into account the free-flow of vehicles in the city, namely the aim is to determine a relationship between prices that guarantees drivers the same level of revenue regardless of the congestion faced.

Let R_t denote taxi drivers' revenue per unit of time, which is given by :

$$R_t(\rho) = \frac{p_d + p_t \tau(\gamma^\rho - 1)}{\tau\gamma^\rho}$$

With no congestion, $\gamma^\rho = 1$ and revenues are simply $R_t(0) = p_d/\tau$.
We require revenue per unit of time to be the same for any ρ hence,

$$\frac{p_d}{\tau} = \frac{p_d + p_t \tau(\gamma^\rho - 1)}{\tau\gamma^\rho}$$

By simplifying the denominator and multiplying by the congestion factor, we obtain:

$$p_d\gamma^\rho = p_d + p_t\tau(\gamma^\rho - 1)$$

We factor p_d to get:

$$p_d(\gamma^\rho - 1) = p_t\tau(\gamma^\rho - 1)$$

Since we assume that $\gamma > 1$ and $\rho \neq 0$, we can simplify the expression to:

$$p_t = \frac{p_d}{\tau} \tag{2.34}$$

This relation defines a traffic-neutrality condition. It requires that the price per unit of time be set equal to the product of the price per unit of distance and the average speed, $1/\tau$. Under this condition, the driver's revenue per trip is invariant to fluctuations in average speed induced by the congestion factor γ^ρ.

We can substitute (2.34) into the definition of m to find:

$$m = \tau p_t + p_t\tau\gamma^\rho - \tau p_t = p_t\tau\gamma^\rho$$

We can then substitute m into (2.32) to find the price per unit of time:

$$p_t = \frac{\bar{\pi}}{\Theta} + \frac{M}{\tau\gamma^\rho}$$

By using (2.34) we can easily find also the price per unit of distance:

$$p_d = \frac{\bar{\pi}\tau}{\Theta} + \frac{M}{\gamma^\rho}$$

Therefore, using (2.25) we can determine the fixed fee:

$$k = (p_t\tau\gamma^\rho)z \tag{2.35}$$

$$= \left(\frac{\bar{\pi}}{\Theta} + \frac{M}{\tau\gamma^\rho}\right)\tau\gamma^\rho z \tag{2.36}$$

$$= \left(\frac{\bar{\pi}\tau\gamma^\rho}{\Theta} + M\right) z \tag{2.37}$$

All prices depend on γ^ρ, which in turn depends on J. Thus, by substituting prices into (2.30), we obtain:

$$J = \frac{\Omega\tau\gamma^{\rho}}{\Theta\left[\left(\frac{\bar{\pi}\tau}{\Theta} + \frac{M}{\gamma^{\rho}}\right) + \left(\frac{\bar{\pi}}{\Theta} + \frac{M}{\tau\gamma^{\rho}}\right)\tau\gamma^{\rho}\right]}$$

which we can simplify to:

$$J = \frac{\Omega\tau\gamma^{\rho}}{\bar{\pi}\tau + \frac{\Theta M}{\gamma^{\rho}} + \bar{\pi}\tau\gamma^{\rho} + \Theta M}$$

We can group the terms by M and $\bar{\pi}\tau$:

$$J = \frac{\Omega\tau\gamma^{\rho}}{\bar{\pi}\tau(1+\gamma^{\rho}) + \Theta M(1+\frac{1}{\gamma^{\rho}})}$$

If we multiply by γ^{ρ} both the numerator and the denominator, and factorize $(\gamma^{\rho}+1)$ we obtain:

$$J = \frac{\Omega\tau\gamma^{2\rho}}{(\gamma^{\rho}+1)(\bar{\pi}\tau\gamma^{\rho} + \Theta M)}$$

By using the definition of M we obtain:

$$J = \frac{\Omega\tau\gamma^{2\rho}}{(\gamma^{\rho}+1)\left[(\bar{\pi}+\Theta c_t)\tau\gamma^{\rho} + \Theta(c_d - c_t\tau)\right]}$$

Notice that the above equation is still implicit, because congestion still appears on the left-hand-side of the equation, hence numerical methods are required to solve it.
Once the optimal number of licenses is found we can easily determine the equilibrium prices and the equilibrium bundles of rides. This solves the municipality's problem and completes the solution of the model.

2.2.5 Solving the Municipality Problem

Now, our aim is to prove that the solution found treating agents as independent decision makers, actually solves the initial welfare maximization problem of the municipality.

Consumers maximize utility subject to their endowment, prices, and the congestion value, representing a best response to the municipality's policy. Simultaneously, the municipality sets tariffs to equalize marginal profit per unit of time across all trip types, ensuring drivers are indifferent to supply any ride type and to exhaust their full labor endowment Θ. By calibrating the fleet size J and prices such that the drivers' participation constraint is satisfied with strict equality, the regulator eliminates producer surplus. This ensures that all requested rides are supplied while minimizing the transfer of utility from consumers to producers, reaching an equilibrium void of economic rent.

Despite the informality of the proof, these arguments are sufficient to asses that the two stage optimization problem maximizes the aggregate utility of consumers.

Chapter 3

Model Testing

In this chapter, we test the model presented in Chapter 2. We analyze how equilibrium quantities change in response to small variations in selected parameters. In particular, we focus on how the number of licenses and prices respond to changes in the following parameters:

- Number of consumers
- Taxi working shifts
- Urban traffic

We use data from the municipalities of Rome, Milan, and Naples as reference cases. Based on this analysis, we propose policy interventions that could improve the taxi service in each of the municipalities considered.

3.1 Testing Setup

As mentioned, we test the model using data from Rome, Milan, and Naples. We select these municipalities for two main reasons:

- The availability of data on taxi ride demand, presented in Chapter 1 (see figs. 1.1 to 1.3).
- Their different urban structures in terms of road network characteristics and traffic conditions.

The last point is particularly important in the context of the model. For instance, Rome is well known for being one of the most congested [1] cities in Europe. These characteristics are captured by the parameter γ, which, as previously discussed, reflects traffic intensity, road capacity, traffic light synchronization, and more generally all factors that determine the overall level of urban mobility and road efficiency in a city.
In particular, since γ represents the baseline component of the congestion factor γ^{ρ}, we expect it to take higher values in cities characterized by poor road conditions and high traffic flows. Conversely, we expect values closer to one (its minimum value) in municipalities that perform particularly well in this department.

[1] In this chapter, the term assumes the most colloquial sense of "level of traffic". Exceptions are explicitly indicated.

3.1.1 Reference Municipalities

Rome: Rome is considered one of the most congested cities in Europe. According to the INRIX Global Traffic Scorecard [24], it ranks fourth as the most congested European city in terms of annual hours lost in traffic per driver (76 hours). This suggests that the γ parameter is expected to take the highest value among the municipalities considered.
Moreover, Rome experiences high tourist flows throughout the year, which increases the internal demand for taxi services. In light of this, we assume that the average taxi budget is relatively high compared to other municipalities. It is also reasonable to assume that the standard of living in Rome is relatively high; therefore, an adequate profit margin for taxi drivers must be ensured.

Milan: Milan is also a highly congested city, ranking just two positions below Rome according to INRIX [24], with 67 hours lost in traffic annually. Therefore, we expect γ to take a value close to that of Rome. However, Milan's relatively high road capacity and the high availability of alternative routes may partially improve overall urban mobility.
Although tourist flows are less prominent than in Rome, demand for taxi services remains strong. We therefore expect a relatively high taxi budget and a substantial profit margin for drivers, especially considering that the cost of living in Milan is among the highest in Italy.

Naples: Although Naples is not as congested as Rome or Milan, its urban road layout must be taken into account. The city is characterized by numerous narrow streets and limited-capacity roads, as well as several dead-end streets. These structural features significantly slow vehicle flows and reduce the city's ability to absorb high traffic volumes. For this reason, we expect Naples to exhibit a relatively high value of γ.
Tourist flows are consistent, though the cost of living is significantly lower than in the other municipalities. Consequently, we expect both the average taxi budget and the guaranteed profit margin for drivers to be lower compared to Rome and Milan.

3.1.2 Parameter Estimates

Given that traffic is endogenous in our model and that the congestion factor γ^{ρ} affects all equilibrium quantities, the parameter γ plays a crucial role. Since it captures the overall viability of a municipality, it is difficult to precisely evaluate all the factors influencing this parameter. Therefore, we adopt a simpler—yet reasonably satisfactory—approach to approximate the various elements that determine urban mobility and traffic conditions.

We take Turin as our benchmark for urban viability. The municipality is comparable in size to the other cities considered and features an extensive grid-based road layout, which is widely regarded as efficient from a traffic-flow perspective. We therefore select a 5-kilometer route and compute the average time required to travel this distance at 10:00 a.m. on a weekday.
Specifically, we consider the route from the "Museo Nazionale dell'Automobile" to the "Museo Egizio". According to Google Maps, the average time required to cover this distance is 13 minutes. Using the same procedure, we identify routes of equal length (5 km) in Rome, Milan, and Naples at the same morning time and record the corresponding average travel times.
By normalizing $\gamma = 1$ for Turin, we then compute the parameter for the other municipalities according to the following formula:

$$\gamma_{\text{municipality}} = \frac{\text{Time required to travel 5 km in the municipality (minutes)}}{\text{Time required to travel 5 km in Turin (minutes)}}$$

Therefore, we have organized the results in the following table:

Municipality	**Route**	**Time (minutes)**	γ
Turin	Museo Nazionale dell'Automobile – Museo Egizio	13	1.00
Milan	Duomo – City Life (Piazza VI Febbraio)	19	1.46
Naples	Quartieri Spagnoli (Toledo) – Castel Sant'Elmo	21	1.62
Rome	Colosseo – Piazza San Pietro	24	1.85

Table 3.1: Travel time for 5 km and corresponding γ values by municipality

Another key parameter that we want to estimate is the consumer demand N in each city. Using the number of taxi requests from Figures 1.1 to 1.3 as a proxy of the actual number of consumers, we find the following daily average consumer demand for each municipality:
$N \approx 67.000$[2]for Rome, $N \approx 50.000$ and $N \approx 8667$ in Naples.

We also need reasonable estimates for fuel costs. We assume that, on average, a taxi driver consumes approximately 1 liter of fuel per hour while idling and 0.08 liters per kilometer when driving. Given a fuel price of 1.7€ per liter, the implied cost per unit of time is $c_t = 1.7$€ per hour, while the cost per unit of distance is $c_d = 0.136$€ per kilometer. We assume these cost parameters to be identical across all municipalities.

We further assume that taxi drivers work 8-hour shifts and operate 6 days per week. Under this conditions, if we assume that the municipality aims to guarantee a monthly income of 3000€ for drivers in Milan, 2500€ in Rome, and 2000€ in Naples, the corresponding daily profit margins per driver are $\bar{\pi} = 125$€ for Milan, $\bar{\pi} = 104$€ for Rome, and $\bar{\pi} = 83$€ for Naples.

Following the same cost-of-living considerations, we assume that the average taxi budget is equal across all consumers in a municipality and takes values: $\omega = 45$€ in Milan, $\omega = 40$€ in Rome, and $\omega = 30$€ in Naples.

To evaluate the time required to travel one unit of distance under free-flow conditions, we estimate the time needed to cover 1 km in each municipality when traffic is essentially absent, namely during nighttime hours. Using Google Maps, we compute the travel time along the same routes reported in Table 3.1 at 3:00 a.m. We then obtain the corresponding estimates for τ according to the following formula:

$$\tau_{\text{municipality}} = \frac{\text{Time required to travel 5 km in the municipality at free-flow (hours)}}{5}$$

Therefore, we report the results in the following table:

[2]We have evaluated these estimates by doing a simple average on the monthly taxi requests of Figures 1.1 to 1.3 filling the missing months in Figure 1.1 and Figure 1.3 by using a simple regression on monthly tourist arrivals and then dividing the results by 30.

Municipality	Time for 5 km (hours)	Time for 1 km (hours)
Rome	0.233 (14 min)	0.047
Milan	0.167 (10 min)	0.033
Naples	0.200 (12 min)	0.04

Table 3.2: Travel time in free-flow and corresponding τ values by municipality.

Consequently, we have all the parameters set to perform our simulations in each municipality. We group the results in the following table:

Municipality	γ	τ	N	ω	$\bar{\pi}$	Θ	c_d	c_t
Rome	1.85	0.047	67000	40	104	8	0.136	1.7
Milan	1.46	0.033	50000	45	125	8	0.136	1.7
Naples	1.62	0.04	8667	30	83	8	0.136	1.7

Table 3.3: Model parameters by municipality

3.1.3 Scripts

In order to perform our simulation, the following Python script is required. The necessity of this script arises from the fact that the optimal number of licenses is determined by the transcendental equation:

$$J = \frac{\Omega\tau\gamma^{2\rho}}{(\gamma^{\rho}+1)\left[(\bar{\pi}+\Theta c_t)\tau\gamma^{\rho}+\Theta(c_d-c_t\tau)\right]}$$

To solve such an equation, an iterative numerical method is employed. Starting from an initial guess for J, the program repeatedly updates the value until the difference between successive iterations is within a specified tolerance. In our case, the convergence threshold is set to five decimal places (10^{-5}).

The following script, therefore, uses the above equilibrium formula of licenses from chapter 2, to find the optimal J:

```
def optimal_licenses(gamma, c_d, c_t, Theta, tau, N, Omega, pi
    , max_iter=100, tol=1e-5):
    #Initial guess for J (start with a reasonable estimate,
       like N)
    J = N
    for _ in range(max_iter):
        #Rho (density)
        rho = J / N
        #Formula
        numerator = Omega * tau * gamma ** (rho*2)
        denominator = (gamma ** rho + 1) * ((pi + Theta * c_t)
            * tau * gamma ** rho + Theta * (c_d - c_t * tau)
        )
        #New value of J
        J_new = numerator / denominator
        #Check for convergence
```

```
        if abs(J_new - J) < tol:
            break
        #Update J
        J = J_new
    return J

while True:
    try:
        params = input("Enter parameter values in this order(
            comma separated): gamma, c_d, c_t, Theta, tau, N, 
            Omega, pi ")
        #Exit if 'exit' is detected
        if params.lower() == "exit":
            print("Exiting program")
            break
        #Split input string into a list and convert to
            appropriate types
        gamma, c_d, c_t, Theta, tau, N, Omega, pi = map(float,
            params.split(','))
        #Cast N to integer
        N = int(N)
        #Compute optimal number of licenses
        J_optimal = optimal_licenses(gamma, c_d, c_t, Theta,
            tau, N, Omega, pi)
        #Result
        print(f"Optimal number of licenses: {J_optimal:.2f}")
    except ValueError:
        print("ERROR: invalid input")
        print("Please enter valid numerical values, or type '
            exit' to quit")
```

3.2 Simulations

3.2.1 Consumer Increase

In Chapter 1 we showed how rigid taxi supply appears to be with respect to changes in the resident population. In Table 1.2 we highlighted that, over the last decades, only a few municipalities have actually increased the size of their taxi fleet, while others have even experienced reductions. At the same time, tourist flows have grown substantially, putting additional pressure on the service. Municipalities are therefore expected to address this imbalance by progressively adjusting the number of licenses as the number of consumers increases.

Suppose that the municipality has initially chosen prices and the number of licenses such that the taxi market is in equilibrium. We then analyze how this equilibrium changes when the number of consumers N increases.
Using the parameter values reported in Table 3.3, and assuming that total taxi demand increases by 2% (which we interpret as driven by higher tourist inflows while the resident population remains constant), we perform the simulations and report the results in the following table:

Municipality	Baseline licenses	Licenses after a 2% increase in N
Rome	11160	11383
Milan	7370	7517
Naples	1664	1697

Table 3.4: Change in licenses after a 2% consumer increase

We observe that, in response to a 2% increase in the number of taxi clients, the municipality should issue exactly 2% more licenses. In absolute terms, this corresponds to issuing 223 new licenses in Rome, 147 in Milan, and 33 in Naples. Hence, as the city expands, the optimal fleet size scales linearly, provided that wealth per capita (Ω/N) and congestion sensitivity (γ) remain constant.

Comparing these results with 2023 data, the actual number of licenses amounts to 7701 in Rome and 4855 in Milan. According to the model, the optimal number of licenses should be significantly higher: approximately 45% more in Rome and 51% more in Milan. Although these predicted increases may appear substantial (possibly reflecting an overestimation of the taxi budget parameter), they are not entirely inconsistent with the service shortages documented in Table 1.6.

By contrast, the prediction for Naples goes in the opposite direction. Compared to the current 2424 licenses, the model suggests an optimal taxi fleet size of only 1664 vehicles, implying that the existing fleet is about 42% larger than the equilibrium level. While some parameters could be re-calibrated, the magnitude of this discrepancy is noteworthy.
It is particularly interesting that, relative to the approximately 50000 taxi requests observed in Milan, Naples records fewer than 9000, yet its fleet size is roughly half that of Milan. This suggests that the fleet resizing implied by the model is not implausible and that additional institutional or regulatory mechanisms—beyond those captured by the model—likely play a significant role in determining the number of licenses.

To calculate the equilibrium prices, we use their respective formulas from Chapter 2. To evaluate them, the additional parameter z is needed, which represents the average distance a taxi driver must travel to find the next customer. We assume that the taxi stands are fairly dense in our municipality; therefore, we set $z = 0.5$ km. Equilibrium prices also display substantial differences compared to real data. However, since a marginal increase in the number of taxi users produces only negligible variations in prices, we report them using the baseline parameter values in Table 3.3, thus ignoring the effects of the simulated increase in demand.

Municipality	Price per hour (€)	Price per km (€)	Fixed fee (€)
Rome	15.77	0.74	0.41
Milan	19.60	0.65	0.34
Naples	13.62	0.55	0.30

Table 3.5: Taxi tariff by municipality

We use these prices to evaluate a short trip (5 km + 5 minutes of wait) and a long trip (10 km + 10 minutes of wait) in each municipality, in order to compare the results with the tariff reported in Chapter 1. Consistent with the data reports, we assume that the ride is taken by a single passenger during the daytime with no luggage. The results are reported in the table below:

Municipality	Short ride (€)	Long ride (€)
Rome	5.42	10.44
Milan	5.22	10.11
Naples	4.19	8.07

Table 3.6: Estimated taxi fares for selected trip lengths

We notice that the overall price for both the short and long rides are significantly different. On average, the model predicts prices that are between 50% and 70% cheaper than those shown in Table 1.8. This is likely due to the minimal fixed fee estimated by the model, which is determined by the equilibrium condition $k = mz$. This condition implies that the taxi driver must be compensated exactly for the profits lost in the trip to reach the taxi stand, which is typically very short (we set $z = 0.5\,\text{km}$ reasonably). Therefore, according to the model, the actual fixed fee is excessive, considering the negligible costs of reaching the next taxi stand, this means that this tariff is embedded with a transfer that the municipality guarantees to taxi operators. Additionally, the model does not take into account the increases in tariffs per kilometer and per time that the taximeter applies once a certain distance traveled in the taxi or a certain amount of time spent aboard has been exceeded. These are factors present in actual taxi tariff systems but are not captured by our model.

3.2.2 Extended Working Shifts

Another policy that the municipality could implement is the introduction of double working shifts for taxi drivers. The idea is to allow the sharing of a taxi license between two drivers, thus extending the available service hours Θ. Therefore, we aim to examine how the equilibrium number of licenses changes when the working hours are doubled (and consequently the profit margin $\bar{\pi}$ in each municipality. We present the results in the following tables:

Municipality	Licenses (8h Shift)	Licenses (16h Shift)	Variation (%)
Rome	11,160	5,420	−51.43
Milan	8,220	3,622	−55.94
Naples	1,664	809	−51.38

Table 3.7: Impact of doubling working shifts on optimal license quotas

We notice that doubling the working hours, accompanied by a corresponding doubling of profits, reduces the required number of licenses more than proportionally. This occurs because fewer vehicles on the street reduce the taxi density ρ, which in turn decreases the congestion factor γ^{ρ}. As a result, the system becomes more efficient, increasing the number of rides per license more than proportionally. This happens without significantly affecting the pricing system. Prices are only marginally impacted by the decrease of the congestion factor, thus remaining almost exactly as shown in Table 3.5.

Although disruptive from an equilibrium perspective, as it implies the withdrawal of a significant portion of licenses, this policy could be implemented in cities that are highly sensitive to congestion, proving that with a relatively low number of taxis, it is still possible to guarantee an extensive level of service.

3.2.3 Urban Mobility Improvements

Since our model captures the effect of congestion on the taxi system, we aim to test how improvements in city viability might impact the equilibrium. To do this, we will simulate a policy of optimal traffic flow management in the city. Specifically, the municipality implements interventions that increase road capacity, revisits traffic signs layout and traffic light synchronization. These interventions can be interpreted as a reduction in γ.
We assume that each municipality is able to improve viability by 35%, and we will examine how this policy affects licenses and prices. With the policy implemented, the updated values of γ becomes: $\gamma = 1.55$ for Rome, $\gamma = 1.29$ for Milan, and $\gamma = 1.4$ for Naples. These correspond to the updated license values reported in the table below:

Municipality	**Baseline licenses**	**Licenses after 35% decrease in γ**	**Variation (%)**
Rome	11,160	10,974	-1.67%
Milan	7,370	7,286	-1.14%
Naples	1,664	1,635	-1.74%

Table 3.8: Change in licenses after a 35% reduction in γ

Since the difference in the license count is not particularly substantial, the impact on price remains negligible. Although the improvement in viability brings marginal benefits to the taxi system, this is reasonable considering that the taxi quota is relatively small compared to the overall volume of vehicles in the city. Still, these results demonstrate a clear relationship between congestion and the efficiency of the taxi service. When the city is congested, trip times increase, taxi drivers reduce their supply of rides, and fares become more expensive.

We could expect a much larger impact of this policy in municipalities facing severe traffic flow issues, particularly those with higher values of γ and smaller populations. In such cases, the increase in taxi density exacerbates the problem. It is theoretically possible that a city with extremely poor viability could require such a large fleet of taxis that the service itself enters a cycle of inefficiency. Although fascinating, this scenario is certainly not the most plausible.

Conclusions

Despite relying on several simplifying assumptions, which we believe are reasonably justified, the model suggests that the taxi service in Italy has significant margins for improvement. This thesis does not advocate for a full liberalization of the sector, nor for a radical change in the way the market is organized. On the contrary, the model has been developed to remain as consistent as possible with the current regulatory framework governing the taxi industry.

We have shown that municipalities have a limited but meaningful set of variables they can act upon. Moreover, the data required to manage the service properly—at least those needed for the model—are not particularly difficult to obtain. Therefore, the service can remain under public regulation, provided that local authorities are able to make decisions with sufficient independence. In practice, taxi corporations often seem to exert considerable influence on institutions, which may slow or prevent necessary adjustments, weakening the decision process. This is to some extent reasonable, considering the distortions that the current taxi license assignment process creates, like the dependency of significant portion of driver's wealth and income to the policy decision taken by a relative small group of local policymakers. At the same time, this mechanism generates a strong leverage that the category could use to exert pressure on institutions and to limit market access.
Nevertheless, even considering the imperfections in the allocation mechanisms and their consequences, policymakers can still set a reasonable profit target $\bar{\pi}$—high enough to maintain incentives for drivers to invest in purchasing a license. The model, in fact, shows that profitability can be preserved through price adjustments, changes in working shifts, or improvements in efficiency, like for example through better traffic management.

In conclusion, municipalities appear to possess the essential tools to improve the functioning of the taxi sector within the current legislative framework. While the model abstracts from several important complexities—such as competition from NCC operators, demand seasonality, political frictions, and a richer time dimension—it nevertheless provides a coherent structure for thinking about the key variables that shape the market.

If regulatory decisions are guided by transparent criteria and supported by objective data, even gradual adjustments in licenses, prices, or efficiency conditions could substantially improve service quality. The analysis suggests that inefficiencies are not inevitable, nor are they purely structural. With informed and consistent policy choices, it is possible to reconcile fair driver profitability with better accessibility for consumers.
In this sense, the future of the taxi service does not necessarily depend on radical reforms, but on the willingness to use existing instruments more effectively. Even within current constraints, meaningful improvements remain within reach.

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