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An evaluation of optimal scale and jurisdiction size to improve efficiency in metropolitan bus systems

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ABSTRACT

Urban bus services operate under concession regime in many cities around the world. Their area boundaries are usually an institutional or administrative legacy, which do not necessarily meet the criteria of optimal jurisdictions. This means that some concessions suffer from a sub-optimal size, either because they are too small, and so fail to exploit economies of scale and/or density, or too big, and so operate in diseconomies of them. This study, by estimating the values of the economies of scale and density for the regulated concessions, identifies the dimensions for optimal exploitation in the Barcelona Metropolitan Area (AMB) for public and private bus providers. Our data cover the period 2012–2018 and we apply a stochastic frontier model for panel data to estimate both economies of scale and density. We found that the optimal size for a passenger bus service concession in terms of economies of scale in the AMB is between 0.5 and 1 million net km per annum. In the case of density economies, the size is considerably lower, at somewhere between 430,000 and 1,000,000 net km per year. We recommend ensuring that the size of the service provision area is optimal before the tendering process.

1. Introduction

The city of Barcelona and the *Àrea Metropolitana de Barcelona* (Metropolitan Area of Barcelona; henceforth, the AMB) employ a variety of modes of production for the delivery of all local public services. In both jurisdictions, we find both municipal and metropolitan service provisions, as well as private, public and mixed production modes. This diversity is also present in the delivery of those local services that have the greatest financial impact, in terms, that is, of either their budgetary implications or user payments. One such service is that of urban buses (both intra- and inter-municipal). This service is subject to metropolitan (collaborative) provision and mixed production, with services being delivered by a public company, *Transport Municipals de Barcelona* (TMB), and several private groups in different areas of the AMB.

This modal diversity in local service provision and production has facilitated innovation in the past, and several urban bus service reforms have been implemented. Indeed, several studies have evaluated the outcomes of these reforms (see, for example, Albalate, Bel, & Calzada, 2012; Bel & Rosell, 2016). City managers, policymakers and politicians try to improve the bus system, taking different actions: introducing competitive tendering, negotiating contract directly, bringing back in-house service delivery … As an example, in 2021 AMB has merged two concessions (one daily and one nightly) in Barcelonès Nord. This reform represents around one fifth of total supply in this area, and a one thousand million euros contract value for ten years. In fact, an aspect usually neglected is whether services are operating at the optimal scale. Perhaps because the importance of size is overlooked, or because there are administrative or institutional rigidities that make size reforms politically or administratively very difficult. It could be the case of using municipal boundaries to delimitate concession sizes that can imply that a bus service is operating at a suboptimal scale or other historical rigidities that may hamper reforms on bus network size. These actions are taken and should be aligned with demand requirements, social and environmental objectives linked to ensure a better public transport.

This present study examines the belief that a fresh impetus for innovation and reform could improve the conditions and outcomes of the production of bus services. This study analyses the design of earlier reforms implemented in the urban bus services in the AMB. We analyze the conditions that would enable new reform initiatives to be launched, based on the introduction or intensification of mixed management, which, in our context, does not mean production by a public-private joint venture, but rather the coexistence of public and private

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companies in the same service within the jurisdiction. These may be either municipal (city of Barcelona) or metropolitan (AMB), the latter coming under the heading of inter-municipal cooperation. In so doing, our study contributes to the literature by offering insights into the optimal design of concessional areas (jurisdictions) for promoting competition within a mixed delivery system and its subsequent policy application.

In short, this study evaluates the current framework regulating the delimitation of bus concessions in the AMB in order to recommend partial reforms that might boost operational efficiency and, as a result, optimize the resources devoted (subsidies) to public services. A very specific and relevant contribution of our study is to propose and to apply a method to analyze and design reform of public services in which economies of density and scale are important. Furthermore, because our analysis is conducted in a large metropolitan area with a complex management system of the bus service, our methodological proposal can be generalized to large urban areas even if they have much simpler delivery systems. It is worth noting that concerns other than efficiency can stimulate cooperation and reforms; for instance, stability, equity, and universality in service delivery (Warner, Aldag, & Kim, 2021; Zeemering, 2016). In this research, however, we emphasize the objective of improving efficiency as rationale for reform -thus focusing on 'collaborative efficiency' (Elston, MacCarthaigh, & Verhoest, 2018 and Zeemering, 2019), as our empirical analysis is associated with the relationship between provision, production, and efficiency.

The rest of the paper is organized as follows. First, we briefly review the existing literature on production forms in the bus services sector and their relationship with efficiency. Next, we describe the historical, geographical and institutional contexts of the bus services in Barcelona and its metropolitan area. After that, we discuss the conditions of optimal scale and the size of jurisdictions in the area in which the study is conducted. We then conduct an empirical exercise to establish the conditions of the scale and density economies under which public and private concessions currently operate in AMB. Based on the results from our empirical analysis, we suggest specific measures to reform concessional areas in Barcelona, to enhance productive efficiency in the provision of bus services. Finally, we report the main conclusions that can be drawn our analysis.

2. Bus service production and efficiency

Many cities and countries have experienced regulatory and privately-owned cycles in the delivery of their regular bus services. In general, private initiatives emerged in a market characterized by free entry, high fees, and quality asymmetries (Gwilliam, 2008). Rather than regulating these situations, many cities opted either to take into public ownership private companies or to create a local public bus company to deliver their transportation services. However, over time, inefficiencies emerged, due mainly to increasing staff expenditure. In response, several initiatives were taken to reduce these costs, including deregulation, private delivery, and subcontracting and/or competition, each of which serves the purpose, albeit that their consequences may differ.

One of the lessons learned is that deregulation is not socially optimal. Here, among the most frequently studied cases, is that of bus services in Great Britain. In 1985, the Transport Act deregulated the provision of local bus services outside of London; however, in the capital, they were not deregulated, and competitive bidding was gradually introduced (between 1985 and 2001) following the privatization of the public bus company. Deregulation and implementation of on-the-road bus competition can, it has been concluded, lead to "too much service at too high fares with too low quality of service" (Preston, 2005). In the late 1980s, several British cities suffered from excess bus services due to competition, generating obvious negative externalities in the form of congestion. Similar results from full deregulation have been reported for Santiago de Chile in terms of both congestion (Thomson, 1992) and bus fares (Darbéra, 1993). In London, the effects of privatization and regulation are not easily separated; yet, Mackie, Preston, and Nash (1995) argue that London's best performance can be attributed to the regulatory environment.

In the literature on bus service privatization, theoretical insights suggest that private parties are more exposed to the risks of poor economic performance, which makes them more determined and able to pursue economic efficiency. As such, they are better able to mobilize funds in private equity markets and often seek improvements in their position through innovation. Yet, at the same time, transaction costs appear, and public and private parties seek to fulfill different goals (Brown & Potoski, 2003a, 2003b). Government efforts to gather information can be both costly and time consuming, while regulatory capture can come to represent an especially challenging problem. As such, politicians and bureaucrats may use their power to satisfy their own interests in obtaining posts in the private sector, while the private sector may capture the regulator if competition is low, thereby increasing its profits. It was customary, though, among the earliest studies on privatization, to find cost savings and greater efficiency with private production (Filippini & Prioni, 2003; Lee Richard & Rivasplata, 2001; Savage, 1993; White, 1997).

Following the experience of deregulation in Great Britain, many countries introduced competitive bidding. This initially reduced service costs by between 10 and 50%, depending on the previous inefficiencies of existing monopoly operators. In subsequent bidding processes, however, the number of bidders fell and costs increased (Wallis & Hensher, 2007). Once labor costs have been reduced (which represent roughly half the total cost of regular buses), frequencies regulated, maintenance costs and average speeds cut, and fuel and network conditions exogenously reduced, it is relatively difficult to cut costs further.

However, most of the studies reported above did not assess whether the cost savings could be due to the competitive procedure for selecting a provider (Borger, Bruno, Kristiaan, & Alvaro., 2002); in fact, controlling for contract competition has been more frequently evaluated. For instance, when comparing the efficiency and effectiveness over time of US urban bus services, Leland and Smirnova (2009) found that privately owned/managed bus services ceased to save costs with respect to government-owned services. Scarce competition between private firms and high transaction costs were suggested as explanations for these findings. However, recent studies report opposite findings. For instance, Jerch, Kahn, and Shanjun (2017) find that full privatization of metropolitan bus services in the US have led to cost savings.

Yet, the market for bus services is imperfectly contestable (Mackie et al., 1995) and governments and regulators should be aware of restrictions on competition. Most bus markets, including those in Sweden (Alexandersson, Hultén, & Fölster, 1998), France (Yvrande-Billon, 2006) and Norway (Mathisen & Solvoll, 2008), among others, have suffered a fall in the number of bidders. In a trans-European study, Boitani, Nicolini, and Scarpa (2013) found that firms selected by means of competitive tendering were more productive. However, some years after the first tendering process, in the second round of tenders, most countries experienced an increase in costs. Besides this lack of sustainability of cost savings, service quality also suffered some deterioration (Mouwen & Rietveld, 2013).

For these reasons, Hensher and Wallis (2005) express a concern that regulatory capture by monopolist providers could negatively affect the results of tendering, and so call into question whether competitive tendering is, indeed, the best solution. Thus, if the benefits of tendering are transitory and have tended to be overstated (Hensher, 2015), negotiated performance-based contracts could be a better option (Hensher & Stanley, 2008).

A possible intermediate option to the total privatization of bus services and the organization of competitive bids is partial privatization by means of public-private joint ventures. The mixed firm can help reduce both the transaction and control costs for the service contractor (the public sector) and the service provider (usually a private partner) (Bel & Rosell, 2016). A further advantage enjoyed by the mixed firm is that the company can operate under private law and achieve greater labor flexibility. Swarts and Warner Mildred (2014) analyzed the partial privatization of public transport in Berlin and found a reduction in labor costs and an innovation in the transit system. However, mixed firms may also face significant governance issues, as suggested by Cruz, Nuno, and Marques (2012), which may impair efficiency.

An additional production choice that escapes the fully public vs. the fully private production of bus services is that of provision via a mixed model. In such a model, public and private companies coexist in the same jurisdiction, each within its own area of service (Miranda & Lerner, 1995). Various benefits of mixed management have been identified: First, it guarantees failure-free provision, as governments retain the material capabilities and knowledge that make it easier for them to enter into a contract owing to the poor production performance of the private contractor (Brown, Potoski, Slyke, & David, 2006); and second, it reduces asymmetric information between public and private companies by comparing the two types (Brown & Potoski, 2006), which reduces transaction costs (Brown et al., 2006).

In the case of bus services, the literature is extremely limited, with only the case of Barcelona having been studied in any detail. Albalate et al. (2012) analyze the regulation and production of the bus service in the AMB, while Bel and Rosell (2016) conduct an empirical evaluation of the efficiency of, and the costs incurred by, the government owned company and private firms offering regular urban bus services within the AMB. The latter conclude that the government owned and operated company, TMB, has better ratios of efficiency and relative costs than those presented by the private firms operating in the area, suggesting that they do not exploit the potential offered by the competition to manage some of the lines in the metropolitan area.

3. Context and regulation of bus services in the AMB

3.1. Geographical and historical context

The geographical context of this study is the *Àrea Metropolitana de Barcelona* (AMB), an institutional area made up of 36 municipalities, some of which, most notably Barcelona, L'Hospitalet de Llobregat, Badalona, Santa Coloma de Gramenet, Cornellà de Llobregat, and Cerdanyola del Vallès, have sizeable populations. The AMB covers an area of 636 km^2 and is home to more than 3.2 million inhabitants (42.8% of the total population of Catalonia), giving it a population density of more than 252 inhabitants per hectare. The metropolitan area is a territorial, social, demographic, economic and cultural construct that was shaped during the twentieth century, reflecting the growth and interconnection of the urban systems of the city of Barcelona and its satellites (Àrea Metropolitana de Barcelona, 2019).

At the end of the 1970s, the government owned company *Transports Municipals de Barcelona* was created by integrating *Transports de Barcelona (bus)* and *Ferrocarril Metropolità de Barcelona (metro)* under the same management system. In the early 1980s, priority was given to the need to modernize municipal transport and to stem increasing costs. As part of this plan, *Entitat Metropolitana del Transport* (EMT-Metropolitan Transport Organization) was created in 1987 to coordinate the operations of all the companies serving the municipalities surrounding Barcelona. The EMT was formed by bringing together 18 municipalities (compared to 36 today) and took responsibility for the joint provision of public transport services in this area, although municipal jurisdictions were maintained for intra-municipal bus lines. *Transports Municipals de Barcelona* was subsequently renamed *Transport Metropolità de Barcelona* (TMB-Barcelona Metropolitan Transport) and brought under the auspices of the EMT. Several private operators continued to operate their lines in the area, under a concession granted by the EMT.

While it maintained some suburban lines, TMB lost its monopoly on the bus services it operated in Barcelona. This was the case of the *Nitbus* (night bus) service, which was transferred to TUSGSAL and Mohn, following a call by the EMT for an open tender in 1990. The same occurred with the new *Aerobús* (airport service), operated under the management of *Transports Ciutat Comtal* (TCC). Other less significant examples included a number of smaller private operators, including *Autobusos Horta* SA (operating the Tajo-Av. Tibidabo line) and *Autotransportes Martí* (operating the Meridiana-Taulat line).

The result of the evolution outlined above has been the maintenance of administrative jurisdictions fixed at the municipal level for the intra-municipal lines, which do not necessarily meet economic or efficiency criteria. Hence, it is very likely that the size of the network under a single municipal concession is not optimal for exploiting economies of scale and density and, thus, minimizing the cost of the system. The size of the municipality and all its bus lines – a legacy of the past – have a notable impact on the systems efficiency, despite the management efforts of its public and private operators. In this study, we specifically seek to evaluate whether these jurisdictions correspond to the optimal size to maximize efficiency or whether the jurisdictional rigidity described has resulted in concessions that are sub-optimal, and so find themselves in a situation of diseconomies of scale and density.

3.2. Institutional context

Part of the role previously assigned to the EMT has today been transferred to the AMB. As regards mobility, the EMT remains in charge of regulating the different modes of transport that operate in the metropolitan area: that is, Bus, *Nitbus*, Metro, *Ferrocarrils de la Generalitat* (primarily urban light-rail), *Rodalies* (suburban rail services), TRAM, Taxi, Tourist Bus, and Cable car, among others. AMB's responsibilities in this area include the provision of underground as well as surface passenger public transport (except for the light-rail), the regulation of taxi services, and the promotion of sustainable transport, among others.

As a local entity of territorial character, AMB enjoys regulatory power, as well as the power to set fares and tariffs. As such, the AMB has the power to organize the transportation of passengers within its jurisdiction. AMB is responsible for regulating local bus traffic in the city of Barcelona and the municipalities in the metropolitan area. Likewise, AMB defines the characteristics of the service offered by private operators, establishes a network of routes, schedules, and quality levels, organises tenders, and covers the deficits incurred by private companies. The regulator has wide contract management experience, having organized tenders since the late 1980s and early 1990s. The system works under a net-cost contract scheme and, quality incentives represent around 5% of total costs. A land-value tax partially covers this deficit.

In addition, it should be noted that the regulator owns the bus fleet and part of the garages, which represent the largest investment in the bus industry. It should be further noted however, that in the case of private companies the fleet depreciation charge is transferred to, and borne by, the operator. This means reducing asset specification problems, increasing competition through short-term concessions, and removing barriers to entry. All in all, this should result in greater competition for the market and greater efficiency, which should translate into an improvement in social welfare.

Finally, it should be noted that AMB does not regulate all the bus passenger transport that operates in its territory, there being two types of service that fall outside its jurisdiction. The first consists of intercity lines that are under the jurisdiction of the regional government of Catalonia. In addition, the operator of bus services in some municipalities is the same as the intercity operator, a service provided via a contract negotiated with the regional government. The second service that is not subject to AMB regulation concerns bus services in certain municipalities that have opted not to relinquish their regulatory power over bus service management in their own municipalities, despite being part of the AMB.

3.3. Bus mobility and providers in the AMB

Table 1 reports data on collective bus transport in the AMB,

Table 1
Characteristics of the collective bus transport service in the AMB.

SUPPLY	2014	2015	2016	2017	2018
N° of bus lines AMB	203	203	203	200	212
1. Private management	103	103	104	102	111
2. Public management (TMB)	100	100	99	98	101
Length of bus network AMB (km)	2185	2200	2171	2147	2225
1. Private management	1314	1327	1314	1314	1395
2. Public management (TMB)	871	873	857	833	830
N° of stops in bus network	2544	4595	4565	4575	N.D.
1. Private management	N.D.	2047	2036	2034	N.D.
2. Public management (TMB)	2544	2548	2529	2541	N.D.
Distance traveled, vehicles-km (millions)	69.3	70.3	71.0	71.3	74.3
1. Private management	31.3	31.8	32.1	32.4	34.6
1.1. Day service	25.9	26.4	26.6	26.8	28.8
1.1. Night service	5.4	5.5	5.5	5.5	5.8
2. Public management (TMB)	38.0	38.5	38.9	39.0	39.6
Operational hours of bus service (10^6 h-km)	5.7	5.8	5.9	5.9	6.2
1. Private management	2.2	2.2	2.2	2.3	2.4
1.1. Day service	1.9	1.9	1.9	1.9	2.0
1.2. Night service	0.3	0.3	0.3	0.3	0.4
2. Public management (TMB)	3.5	3.6	3.7	3.7	3.8
Bus fleet	1588	1617	1618	1644	1707
1. Private management	589	630	634	636	644
1.1. Day service	470	511	510	512	519
1.2. Night service	119	119	124	124	125
2. Public management (TMB)	999	987	984	1008	1063

Source: Àrea Metropolitana de Barcelona (2019).

including information on supply and demand, revenues, and quality. Ridership has gradually increased in recent years, reaching a maximum of 303.3 million passengers in 2018. Note that as the urban bus service is under mixed delivery, public as well as private firms produce the service. Thus, the public company, TMB, carried 68% of passengers in 2018, which represents 207.5 million passengers, whereas the trips managed by private companies accounted for 95.8 million passengers, that is, 32% of the total. A new orthogonal network has been introduced every year since 2012 implying more frequency and users' satisfaction (Allen, Muñoz, & Rosell, 2019). This reform main objective is to increase frequency rather than covering all area, given that riders want to walk further for a more frequent service (Mulley, Ho, Ho, Hensher, & Rose, 2018). The latter companies were served by several private groups that run this service in different parts of the metropolitan area, operating, as mentioned above, under administrative concession. These eight private groups are Autobusos d'Horta, Baixbus, Nou Barris BCN, SGMT, Soler and Sauret, TCC, TUSGSAL and UTE Julià Travel-Marfina Bus.

Despite this diversity, the respective weights of those operators are quite dissimilar, with most trips being concentrated under the management of just a small number of operators. Fig. 1 shows the weight that each private operator has in the private market. In addition, it is worth noting that Mohn, Oliveras and Rosanbus belong to the same group, Baixbus. Thus, the level of concentration of passenger service production in the AMB is very high. The two largest groups, TUSGSAL and Baixbus, have an 86% market share and the Herfindahl-Hirschman Index is very high at 0.395.

Table 1 shows that the number of lines operated by the public and private firms is actually quite similar (around 100); but, note that while the total network length managed by private firms is much greater, the number of stops on privately managed lines is much smaller than on the lines run by TMB. This reflects the fact that private firms manage lines that connect the city of Barcelona with the surrounding metropolitan municipalities and those lying further away from the city on high occupancy through routes. The distance traveled is slightly higher in the case of TMB, and so is the number of operational hours, which means the frequency of service is higher in the case of the TMB. The TMB bus fleet is also larger and more environmentally friendly.

The system operated in the AMB has several potential advantages, including the possibility of dividing the jurisdiction into various areas and delivering the service publicly in at least one. This allows the regulator to compare production processes and the costs of the different private companies while maintaining direct involvement in service delivery. However, for a mixed production system to work properly and to effectively offer all these benefits, it is not enough simply for public and private companies to concur; there also needs to be a certain level of competition between them. Likewise, service areas need to be designed in such a way that basic economic conditions, such as economies of scale and density, are optimized. In the next section, we analyze specific aspects related to these conditions in the AMB.

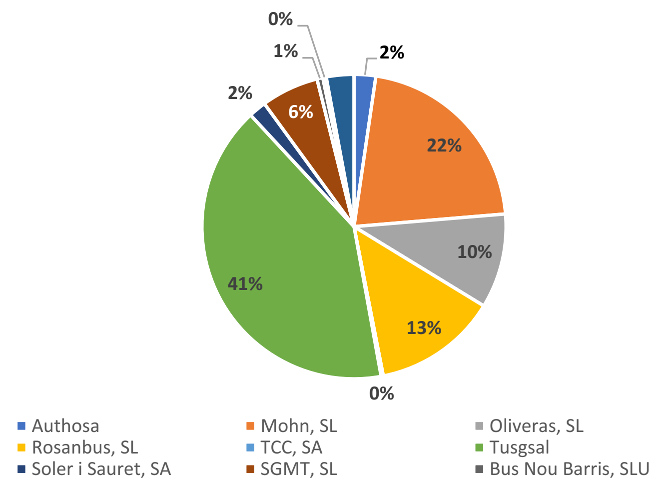

Fig. 1. Each operator's share (%) in the private market (2018).

3.4. Optimal scale and size of jurisdictions

The delimitation of concessional areas in the AMB adheres strictly to the fragmentation imposed by its municipal boundaries; for this reason, concessions are markedly heterogeneous in terms of size. This suggests that, in many of these concessions, the operation of the lines might not be efficient.[1] Here, we empirically evaluate whether the size of the different AMB jurisdictions in which its urban bus services are provided are of an appropriate size, in terms, that is, of their optimal scale, considering economic criteria that allow their economies of scale and density to be fully exploited. Specifically, we evaluate whether the current level of route allocation corresponds to productive efficiency criteria or, rather, solely or exclusively to an administrative criterion that hampers the system's efficiency.

In terms of public policy, the empirical evaluation presented below seeks to test whether large cities and concessions, such as those in Barcelona, L'Hospitalet de Llobregat, and Barcelonès Nord, could be managed optimally with more than one operator and to determine on what this would depend. It is worth noting that such a reform would increase the number of operators in a market characterized by very few operators and, above all, by the lack of replacement of established companies.

Indeed, this market is characterized by the high concentration of a very small number of companies, as well as by the fact that no company based outside the metropolitan area has ever been able to win a tender, even when making the best economic proposal – representing a lower

[1] In his study of bus services in small- and medium-sized cities in Catalonia, Rosell (2017) found that economies of density disappear at about 300,000 km a year, which corresponds to those municipalities with around 50,000 inhabitants. In a study of several large Spanish cities, Matas and Raymond (1998) typically found constant returns to scale, but diseconomies of scale in the larger firms.

subsidy from the regulator (Bel & Rosell, 2016). Moreover, the established metropolitan-based providers have never been replaced in a concession, having always had their contracts renewed following new tenders. Hence, such a reform could trigger more competition in the market, with new concession contracts available for award.

As well as evaluating a change in the number of concessional areas, our study also aims to determine whether the efficiency of the system could be improved by ignoring the limitations imposed by municipal boundaries, that is, either by merging concessions or by assigning routes to concessionaires operating in other contiguous municipalities, this depending on the optimum service size. This assessment is undertaken based on a measurement of economies of scale and, in particular, economies of density. Calculating economies of density allows us to establish the optimal size of the concessional area (in terms of annual km) and, thus, to make recommendations based on the size of each current concession.

4. Empirical approach

4.1. Data

Our database includes information on all bus concessions regulated by the *Àrea Metropolitana de Barcelona* authority under net contracts, with just two exceptions: (1) services for disabled passengers – characterized obviously by different service features, and (2) the bus service linking the city with the airport – due to data availability issues. In addition, we include two metropolitan municipalities that self-regulate their concessions (Sant Cugat del Vallès and Cerdanyola del Vallès) and other urban bus concessions not regulated by the AMB, because they fall outside the boundaries of the metropolitan area. The latter, all within the province of Barcelona, are concessions of similar size and are located, in the main, close to the AMB: Sabadell, Terrassa, Mataró, Granollers, Rubí, Vilanova I la Geltrú, Igualada, Manresa, Mollet del Vallès and Vic. Our data cover the period 2012–2018 for all concessions under AMB authority regulation. For the rest of the concessions, we only have data for the period 2012–2015, as reported by the Urban Transport Association of Municipalities (AMTU) (See Table A1 in the Appendix for information on the specific observations for each concession).

We have also been obliged to impute the costs for one of the concessions, which may have resulted in some ad hoc decisions being taken by evaluators. This was the specific case of the largest concessionaire, TMB, given that part of its costs are shared with the metro (subway), costs that we have estimated at around 30 million euros per annum, representing between 10 and 15% of total TMB costs. The imputation of costs was submitted to TMB for assessment and was confirmed to us as correct. As such, our results for TMB should be treated with caution in the light of this limitation. Table 2 show detailed information on service features, of all the concessions considered. Fig. 2 shows the percentage distribution of labor, materials, and capital costs in each of the concessions. In most concessions, labor costs represent the highest proportion, at around 50%, while material costs tend to account for around 40%. Finally, capital costs, that is the bus fleets amortization, are around 10%. Contracting out costs are classified according to the corresponding category.

4.2. Method

To examine the efficiency of concessions, we apply a stochastic frontier model for panel data to estimate both economies of scale and density, where the cost frontier is a function that links the minimum possible cost to produce an output given the input prices. In the case of a bus service, labor, capital (buses) and fuel and other materials are used to produce this output. Thus, the general cost function considered takes the following form:

$$\mathrm{TC}_{it} = f\left(Y_{it}, PL_{it}, PM_{it}, PC_{it}, N_{it}, SP_{it,}t\right) \tag{1}$$

where the total cost of the bus companies (TC) is a function of output (Y); factor prices (P) – including labor (L), material and energy (M) and capital (C); network length (N) and average speed (SP); and time (t). The chosen functional form is the translog cost function (Christensen and Greene, 1976), which is a common approach for interpreting parameters. The function was first introduced by Christensen, Jorgenson, and Lau (1973) and first applied to the bus sector in Viton (1981) and is often recommended for estimating economies of scale in bus services (e.g., (Ting Siew, Villano and Dollery, 2018). More specifically, and given the heterogeneity of output in our study, we choose a hedonic translog cost function, as a way to deal with the excessive aggregation bias.[2]

As an output measure, we use vehicle·kilometers, a supply-related measure. The literature is divided between demand or supply-related measures (De Borger et al., 2002). We decide to include the supply ones because concessions are under strong regulations: schedules, routes and number of buses, while demand ones (e.g., passengers) are not under regulator control. The output is expected to have a positive sign. Price of labor (PL) is salary costs divided by total number of workers, price of material, energy costs and maintenance (PM) are these costs divided by liters of equivalent diesel and, capital is bus amortization divided by fleet size. Related to network characteristic, two variables are included: network length (N) and average speed (SP). The network length line (N) serves as a proxy for exogenous characteristics such as public service obligations. Expectations regarding the effects of *line length* on costs are ambiguous. Average speed (SP) is the number of kilometers divided by service hours. We include this variable to control for congestion effects in a network. If a trip is covered in a shorter time, fewer vehicles and less labor force are required. Therefore, costs are expected to decrease with increasing network speed. Productivity in the bus sector is relatively low, so time (*t*) does not have an important role on total bus and its sign is unknown.

Thus, our equation for the stochastic frontier can be stated as:

$$\begin{aligned} ln\mathrm{TC}_{\mathrm{it}} = {} & \beta_0 + \beta_{\mathrm{PL}} ln\mathrm{PL}_{\mathrm{it}} + \beta_{\mathrm{PM}} ln\mathrm{PM}_{\mathrm{it}} + \beta_{\mathrm{Y}} ln\mathrm{Y}_{\mathrm{it}} + \beta_{\mathrm{L}} ln\mathrm{L}_{\mathrm{it}} + \beta_{\mathrm{SP}} ln\mathrm{SP}_{\mathrm{it}} \\ & + \frac{1}{2}\beta_{\mathrm{PL'}}(ln\mathrm{PL}_{\mathrm{it}})^2 + + \frac{1}{2}\beta_{\mathrm{PM'}}(ln\mathrm{PM}_{\mathrm{it}})^2 + \frac{1}{2}\beta_{\mathrm{Y'}}(ln\mathrm{Y}_{\mathrm{it}})^2 + \frac{1}{2}\beta_{\mathrm{L'}}(ln\mathrm{L}_{\mathrm{it}})^2 \\ & + \frac{1}{2}\beta_{\mathrm{SP'}}(ln\mathrm{SP}_{\mathrm{it}})^2 + \beta_{\mathrm{YSP}} ln\mathrm{Y}_{\mathrm{it}} ln\mathrm{SP}_{\mathrm{it}} + \beta_{\mathrm{YL}} ln\mathrm{Y}_{\mathrm{it}} ln\mathrm{L}_{\mathrm{it}} + \beta_{\mathrm{YPL}} ln\mathrm{Y}_{\mathrm{it}} ln\mathrm{PL}_{\mathrm{it}} \\ & + \beta_{\mathrm{YPM}} ln\mathrm{Y}_{\mathrm{it}} ln\mathrm{PM}_{\mathrm{it}} + \beta_{\mathrm{SPPL}} ln\mathrm{SP}_{\mathrm{it}} ln\mathrm{PL}_{\mathrm{it}} + \beta_{\mathrm{SPPM}} ln\mathrm{SP}_{\mathrm{it}} ln\mathrm{PM}_{\mathrm{it}} \\ & + \beta_{\mathrm{LPL}} ln\mathrm{L}_{\mathrm{it}} ln\mathrm{PL}_{\mathrm{it}} + \beta_{\mathrm{LPM}} ln\mathrm{L}_{\mathrm{it}} ln\mathrm{PM}_{\mathrm{it}} + \beta_{\mathrm{PLPM}} ln\mathrm{PL}_{\mathrm{it}} ln\mathrm{PM}_{\mathrm{it}} \\ & + \beta_{\mathrm{LSP}} ln\mathrm{L}_{\mathrm{it}} ln\mathrm{SP}_{\mathrm{it}} \beta_{\mathrm{T}} \mathrm{Time\_trend}_{\mathrm{t}} + \upsilon_{\mathrm{it}} + \mathrm{u}_{\mathrm{it}} \end{aligned} \tag{2}$$

(for) $i = 1, 2, \ldots, 23$ *and* $t = 2012, 2013, \ldots, 2018$where sub index i and t denote the unit (concession) and year, respectively. We imposed linear homogeneity in input prices dividing total costs and input prices by the price of capital. Costs are deflated using the Catalan inflation rate with 2012 as the base category. We apply True Fixed Effects (Greene, 2005) estimation method for panel data. The author assumes any individual-specific or unobserved heterogeneity is not captured by the inefficiency term $\mathrm{u_i}$. This methodology for a translog production function has been applied by Aloulou and Ghannouchi (2021), among others.

Specifically, we can estimate returns to density (RTD) on Eq. (3) and returns to scale (RTS) on Eq. (4) from Caves et al. (1984: 474):

$$\begin{aligned} RTD &= \frac{1}{\epsilon_y} = \left(\frac{\delta\, lnTC}{\delta lnY}\right)^{-1} \\ &= \left(\beta_Y + \beta_{Y'} lnY_{it} + \beta_{YL} lnL_{it} + \beta_{YSP} lnSP_{it} + \beta_{YPL} lnPL_{it} + \beta_{YPM} lnPM_{it}\right)^{-1} \end{aligned} \tag{3}$$

[2] We are aware that by choosing a hedonic translog cost function we introduce stronger restrictions in the functional form (Oum and Tretheway, 1989), which need to be kept in mind when interpreting our results.

Table 2
Detailed characteristics of bus services considered by concession: Supply.

	Thousand net vehicle km traveled	Thousand hours (net)	Average speed (km/h)	Number of workers	Number of vehicles	Network length (km)
Barcelonès Nord	9,357	803	11.65	579.7	198.9	271.53
Esplugues, Sant Just i Sant Feliu	747	62	11.91	61.0	19.7	52.49
L'Hospitalet	3,418	272	12.53	189.9	70.4	113.86
U1	3,433	201	17.04	180.4	50.4	153.01
U2	4,125	270	15.24	163.3	70.0	151.16
Castelldefels	4,238	204	20.69	183.9	55.0	136.24
Horta	355	40	8.79	28.6	11.6	7.34
Barcelonès Nord (Night)	3,451	212	16.23	198.2	73.3	227.98
Baix Llobregat (Night)	2,009	107	18.68	91.5	47.3	142.37
Port	231	113	20.31	13.7	–	13.65
TMB	38,800	3,201	12.12	3835.56	1004.29	861.86
Granollers	394	30	12.81	19.0	6.0	20.05
Mataró	1,132	94	12.03	75.3	27.0	80.25
Rubí	736	47	15.37	37.7	15.8	98.13
Sabadell	2,970	224	13.20	161.7	60.7	236.31
Terrassa	2,747	220	12.48	170.0	65.0	215.07
Vilanova i la Geltrú	466	37	12.54	24.0	11.0	44.61
Igualada	249	17	14.19	19.0	4.0	24.50
Manresa	709	57	12.36	43.7	16.0	57.15
Vic	282	16	17.00	10.0	4.0	43.00
Vilafranca del Penedès	89	9	9.76	7.3	3.0	19.50
Sant Cugat del Vallès	953	64	14.75	44.3	19.7	165.08
Mollet del Vallès	134	10	12.94	6.0	3.0	8.45
Cerdanyola del Vallès	226	16	13.37	12.0	5.0	56.30

Source: Àrea Metropolitana de Barcelona (2019).

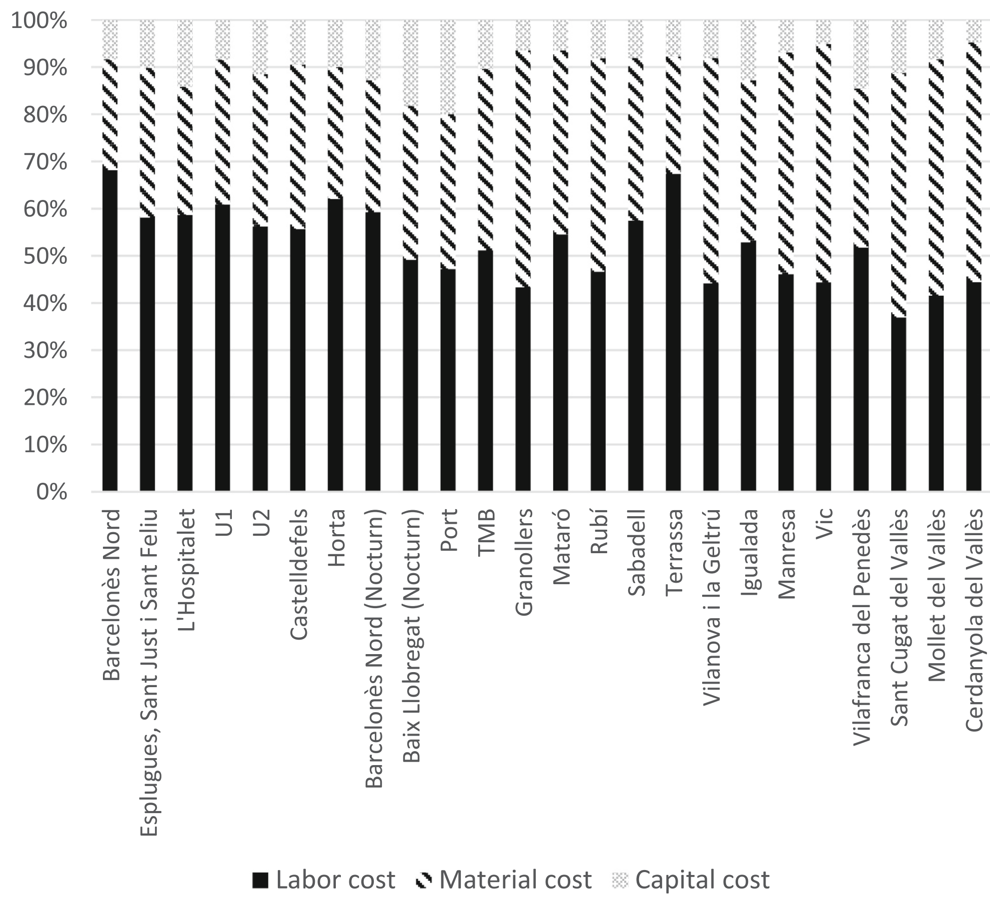

Fig. 2. Percentage distribution of costs for each concession.

$$RTS = \frac{1}{\epsilon_y + \epsilon_p} = \left(\frac{\delta\, lnTC}{\delta lnY} + \frac{\delta\, lnTC}{\delta lnL}\right)^{-1}$$
$$= \left(\beta_Y + \beta_{Y'}\, lnY_{it} + \beta_{YL} lnL_{it} + \beta_{YSP} lnSP_{it} + \beta_{YPL} lnPL_{it} + \beta_{YPM} lnPM_{it} + \beta_L + \beta_{L'} lnL_{it} + \beta_{LSP} lnSP_{it} + \beta_{LPL} lnPL_{it} + \beta_{LPM} lnPM_{it}\right)^{-1} \quad (4)$$

(where) $\epsilon_y$is the elasticity of total cost with respect to output and ϵ_p is the elasticity of total cost with respect to points served or network.

5. Results

We have tested our translog specification with a specification with only input prices, output and these factors squared. We reject the null hypothesis that both models are the same, so translog specification is preferred. From Eq. (2) above and using Greene (2005) true fixed model for coefficient estimation, in Table 3 we show the values of the different coefficients and their statistical significance. The labor price coefficient is positive, statistically significant and presents a magnitude close to 50%, indicating that about 51.6% of the total costs of the bus services are labor costs. This is consistent with our mean (Fig. 2). The price of materials has a magnitude of 23.4%, while the rest corresponds to capital. The output variable (number of net vehicle km traveled) is also positive and statistically significant. However, network length is not statistically significant; thus, a network extension does not seem to imply an increase in total costs. The average speed presents a negative and statistically significant coefficient, indicating that an increase in the commercial speed of buses would reduce concession costs. This reasoning is consistent with the fact that frequency can be maintained while having to use less staff and capital. Finally, we do not find any statistically significant common time trend in total costs.

Coefficients of economies of density and scale for each of the concessions can be estimated from Eqs. (3) and (4). Fig. 3 presents all our results for both types of economy for each year and concession. The first result to emerge is the fact that by increasing the size of a concession we shift from economies of scale and density to diseconomies of scale and density (consistent with the underlying assumption of the translog form). Although this is an overly general statement, it has the benefit of permitting a rapid summary of the results obtained. Economies of scale occur between 500,000 and 1,000,000 net vehicle km traveled per year (logarithms 13.1 and 13.8). Below this range, there are scale economies to be exploited, and above this range, concessions are in diseconomies of scale. As for density economies, the optimal number of km traveled is lower according to our results. Density diseconomies are already reached above 1 million km traveled (logarithm 13.8). The optimal range of unit values is around 430,000 and 1,000,000 km traveled. Note that one of the main differences between the scale and density economy estimates is that when estimating parameters for density economies, there is a higher variability in the values, which hinders accurate interpretations, at least in comparison with scale economies. Thus, intervals are wider for density economies, which is attributable to the small number of observations available. However, these figures are consistent with Rosell (2017), who finds unit values of density economies at around 300,000 net vehicle km per year for a larger sample of Catalan (i.e. the same region) municipalities (that is, slightly above logarithm 12).

Table 3
True Fixed Effects (Greene, 2005) coefficient estimates.

	Coefficients	Standard error
β_{PL} (labor price)	0.5160***	0.0610
β_{PM} (material price)	0.2336***	0.0517
β_{Y} (output)	1.2830***	0.0982
β_{L} (network length)	−0.2285	0.1415
β_{SP} (average speed)	−0.1467***	0.0415
$\beta_{PL'}$	0.2666***	0.0456
$\beta_{PM'}$	0.1271***	0.0105
$\beta_{Y'}$	−0.1223	0.0978
β_{L}'	0.0019	0.0577
$\beta_{SP'}$	−0.0660	0.0425
$\beta_{YPL'}$	0.3849***	0.0663
$\beta_{YPM'}$	−0.1867***	0.0331
β_{LPL}	−0.2349***	0.0547
β_{SPPL}	−0.1028**	0.0341
β_{SPPM}	0.0729***	0.028
β_{SPY}	0.1935***	0.0515
β_{LY}	0.1209	0.1532
β_{LSP}	−0.1415**	0.0683
β_{LPM}	0.1003***	0.0212
β_{PLPM}	−0.0770***	0.0102
β_{T} (time trend)	0.0001	0.0003
Constant	−0.5835	0.6186
Log likelihood	376.00	
N° Observations	94	

Note: Statistically significant at 1%(***), 5%(**) and 10% (*), respectively.

Fig. 4 displays our main results for each concession on economies of density. AMB concessions present evidence of density economies. This means that increasing the frequency leads to increases more than proportional in average costs; however, there are three concessions where this is not so clear. In Horta, there is a high degree of dispersion, which hinders its direct interpretation. Similarly, in L'Hospitalet, most values present density economies or close to unit values, which means that, as the frequency is increased, the cost may also increase proportionally or even at a lower rate (although there is a considerable dispersion and this result should be treated with caution). In the case of TMB, these parameters are estimated to be around the unit, or slightly lower than one, with no time trend detected between the different observations. In the rest of the concessions (the night services, Esplugues, U1, U2, Castelldefels and Barcelonès Nord), increasing the frequency implies average cost increases that are more than proportional.

Fig. 5 shows the economy of scale estimates for each concession related to network size (km). Among the concessions analyzed, we find that both Esplugues, Sant Just and Sant Feliu together with L'Hospitalet are optimally sized in terms of their economies of scale. In this case, economies of scale unitary values are reached around 50 and 110 km (between logarithm 4 and 4.7) Horta's concession, despite its abnormally low value, presents economies of scale. In the other concessions (the night services, U1, U2, Castelldefels, Barcelones Nord and TMB), increasing the km traveled means increasing the average costs more than proportionally.

In the light of the foregoing results related to economies of scale and density, policy recommendations can be made related to the optimum nature of the current size and delimitation of the concessions. From every concession and year, we obtain the value of economies of density and scale. We group them on concessions and we conduct a *t*-test whether these values are different than one in every concession (Table 4). Although previous values can be estimated directly from the underlying translog function, we prefer to summarize all the results next. Most concessions are larger than is desirable (optimal), given that an increase in both the number of km traveled and the network size entails more than proportional cost increases. The exceptions are L'Hospitalet (and Prat de Llobregat), operated by Rosanbus, where the economies of density and scale are the unity, operating at the optimal level. We cannot reject that Horta concession is operating on unitary

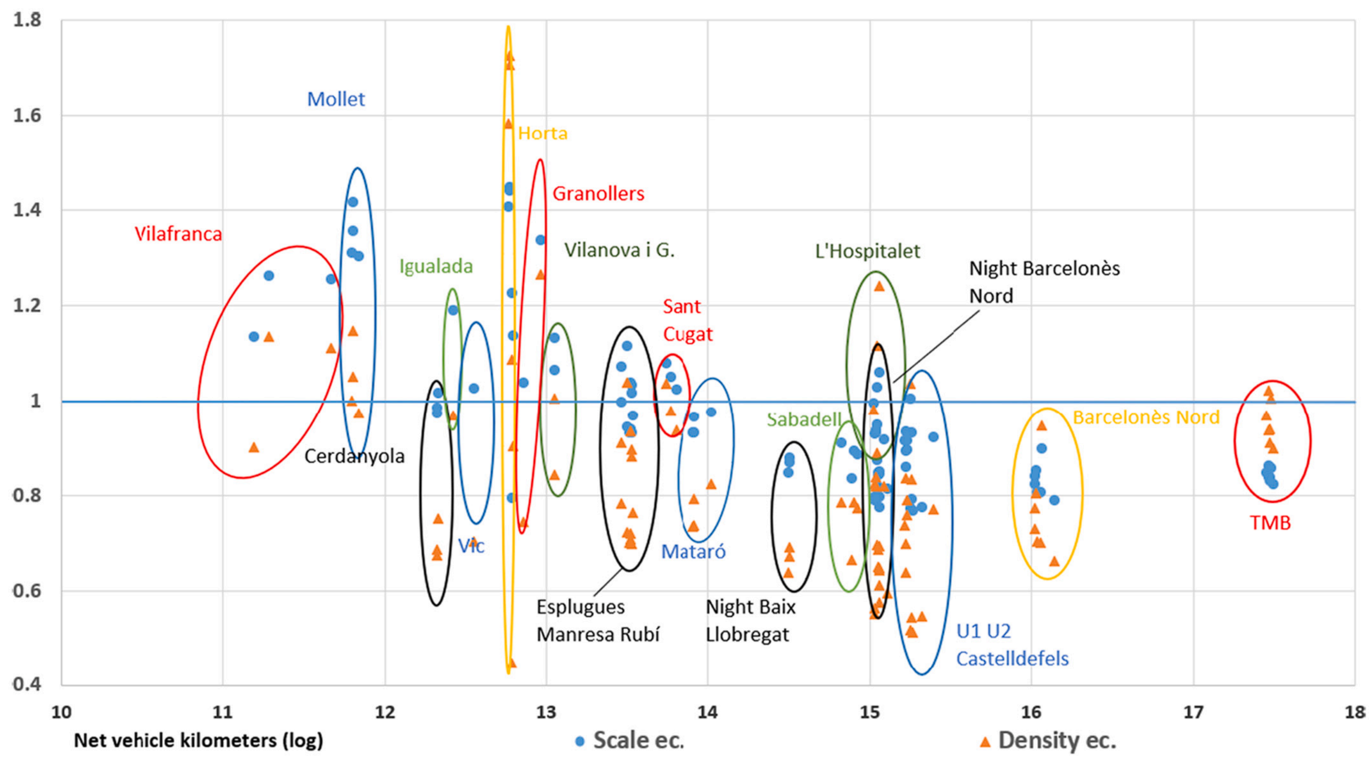

Fig. 3. Estimates of economies of density and scale by concession.

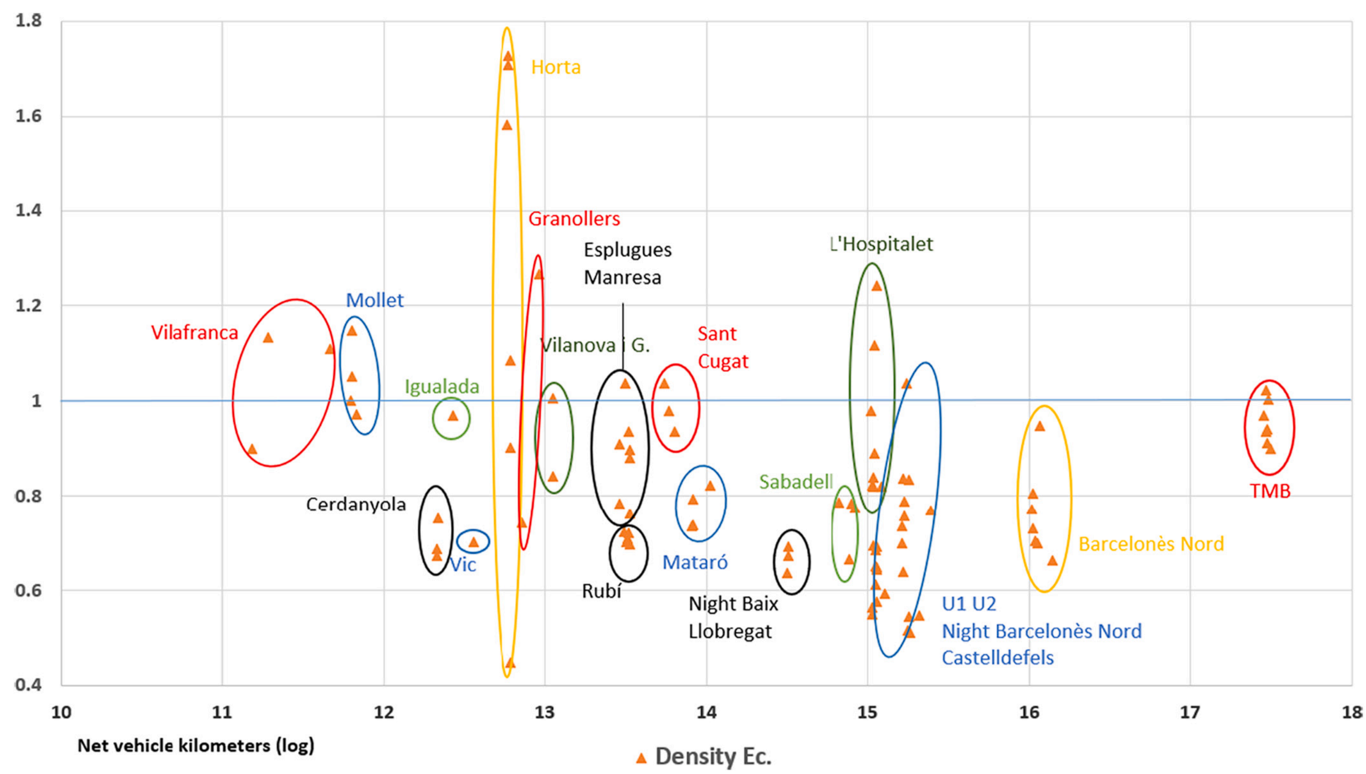

Fig. 4. Estimate of economies of density by concession.

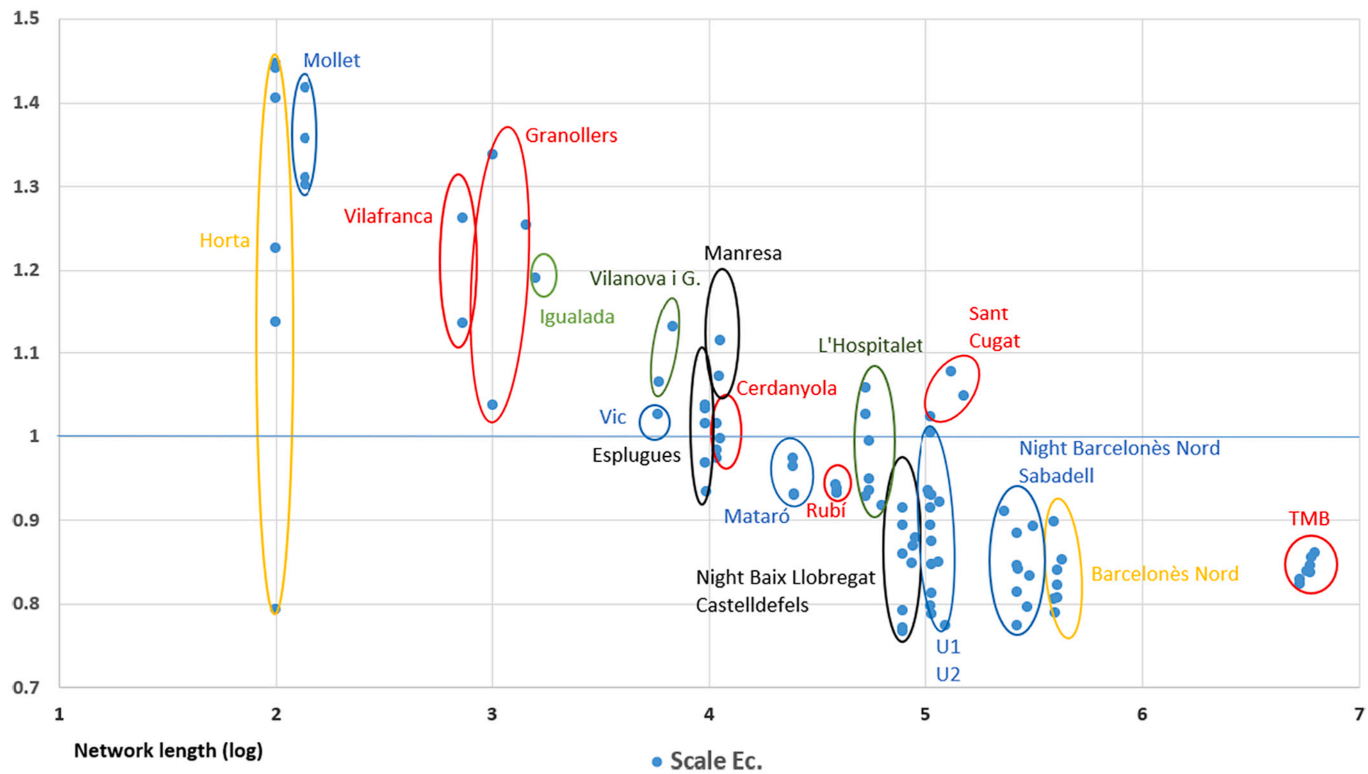

Fig. 5. Estimates of economies of scale by concession.

Table 4
Economies of density and scale per concession and recommended actions.

	ED	ES	Reduce size of concession	Reason
Barcelonès Nord	0.760***	0.832***	Yes	ED/ES
Esplugues, Sant Just i Sant Feliu	0.839***	0.998	Not clear	Only due to ED
L'Hospitalet	0.958	0.974	No	
U1	0.646***	0.844***	Yes	ES/ED
U2	0.800**	0.910**	Yes	ES/ED
Castelldefels	0.631***	0.845***	Yes	ES/ED
Horta	1.242	1.243*	No	
Barcelonès Nord (Night)	0.641***	0.815***	Yes	ES/ED
Baix Llobregat (Night)	0.666***	0.866***	Yes	ES/ED
TMB	0.955**	0.843***	Yes	ES/ED

Statistically different than one at 99%(***), 95%(**) and 90% (*) level, respectively.

values of economies of scale and density while Esplugues concession, is operating in diseconomies of density but at the optimal size on economies of scale. This means, on balance, that it would be better for Esplugues to reduce the frequency of the service, at least from the perspective of operating costs.

There are some areas where there seems to be no doubt that increasing both network frequency and size would lead to more than proportional cost increases. This is the case of both the day and night services in Barcelonès Nord, the Baix Llobregat night service, and the U1, U2 and Castelldefels concessions. It should be borne in mind that all these concessions are operated by just two operators and, in 2021, the regulator has decided to merge daily and nightly concession in Barcelonès Nord, contrary to what our results would suggest. Concessions in Barcelonès Nord overlay in the same area, but with different schedules. Also, a requirement for firms to be allowed to participate in this tender was that they had to be running more than seven million net vehicle kilometers every year All this taken into account, this recent merger goes in the opposite direction from what our analysis advice to do, as we recommend that these areas attempt to reduce their size by splitting up current concessions and by increasing their level of competition. This recommendation is discussed further in the following section. The case of TMB requires more specific consideration. Its parameters of density economies are estimated just close to the unit but with diseconomies of density, while those of scale economies are estimated to be below the unit; as such, these results point to the need for major reforms to the size of this large concession, reducing its size.

6. Discussion and implications for managerial practice

Barcelona's metropolitan bus passenger transport system is the legacy of a history of reforms – of changing institutional and regulatory frameworks – that have shaped the structure of the present-day market; above all, it has resulted in the establishment of jurisdictions which have the same size in the last decades. However, in these jurisdictions, there has been an increase of number of routes and frequency, due to public transportation expansion. Therefore, the concessions are awarded for markedly heterogeneous markets, especially as regards the size of these concessions (number of lines, network kilometers, km-routes, etc.). But this situation is not unique, many cities around the world as Barcelona or larger, are facing the same situation.

This variation in the size of the concessions makes it extremely hard to imagine that the system, and few of the individual concessions in particular, are operating at an optimal scale, with average costs being constant with the increase in the output delivered. Indeed, our results indicate that only a few companies are operating at a sub-optimal dimension and, thus, at higher unit costs than they would incur with an increase in network size. In fact, these concessions would reduce their unit costs at a rate more than proportional to an increase in the network and km traveled, which would allow them to better exploit economies of scale and density.

Similarly, our evidence identifies the existence of various concessions that operate at overly large scales, incurring as they do diseconomies of scale and, therefore, higher unit costs. While the solution for sub-optimal jurisdictions is to increase their size by adding lines, the reform for overly large concessions is to resize them by splitting up the concessions so that the resulting concessions fall within the estimated optimal range. As in the previous case, regulatory agencies could force segregation of concessional areas or transference of lines between concessions, because they have the power to do so.

The administrative barriers inherent to the current concessions –barriers that have confined the concessions to areas that have been maintained over time without any thought of review – seem to hinder the attainment of greater efficiency, something that ultimately could be transferred to the users of the service or to the taxpayers that fund them with subsidies, due to their deficit nature. That is why if a regulator wants to introduce a reform in their concessions (e.g., cost plus, gross contract, competitive tendering, negotiated contracts…), it should analyze previously if the size of these concessions is at the optimal level before taking these reforms.

In any case, it is important that these intervals be given some consideration in new calls and auctions when designing the boundaries of concessions subject to market competition. Indeed, in accordance with the results obtained here, the regulatory body ought to consider the need for viable reforms in its concession design and in the delimitation of the market to be awarded so as to improve the efficiency of the system. To achieve this, however, it is clearly necessary to overcome the administrative and regulatory obstacles that might prevent these modifications.

This experience from Barcelona metro area allows us to learn how neglecting to continuously assess the optimality of the concessions' scale of operations leads to suboptimal results. Regulatory agencies should monitor more carefully the conditions for efficient operation of concessions, thus considering those basic conditions on service area size when designing tendering processes and do not take them as unalterable. Indeed, our findings related to the AMB can be applied to many other metropolitan areas, implying a potential for improvement from the reorganization of the service.

7. Conclusions

The purpose of this study has been to propose potential reforms for the production of bus transit in the AMB. We have focused our attention primarily on evaluating the operational efficiency of the current regulatory framework of concessions and, specifically, on their delimitation in areas that generally coincide with municipal boundaries as regulated by the AMB. The present-day delimitations are essentially a legacy of the institutional evolution of the AMB and its earliest concessions for almost half a century. This has meant the presence of a variety of concessions of different sizes and features that do not necessarily meet the criteria of optimal, or even efficient, jurisdictions in terms of industrial organization. Indeed, they have often originated from the application of administrative as opposed to economic criteria. This means that some concessions suffer from a sub-optimal size, either because they are too small, and so fail to exploit economies of scale and/or density, or too big, and so operate in diseconomies of scale and/or density.

We found that the optimal size for a passenger bus service concession in terms of economies of scale in the AMB are between 0.5 and 1 million net vehicle km per annum or a network between 50 and 110 km. In the case of density economies, the size is very similar, at somewhere between 430,000 and 1,000,000 net vehicle km per year. Moreover, thanks to this exercise, we can make recommendations for regulatory reform in terms of the distribution and delimitation of concessions. First, and as might be expected, we find a size deviation in most of the regulated concessions with respect to the optimal size, either in their economies of scale and/or of density. And, second, the evidence reported in this study indicates that, in most cases, it would be advisable to reduce the size of the current concessions, creating new ones that can operate at lower unit costs; indeed, only in a very few specific cases, should the operational scale be expanded, either by adding lines or increasing frequencies.

The reforms proposed here can be expected to lead to a reduction in the costs of the system and, therefore, in the public resources (subsides) dedicated to these concessions. And although the impact would be lessened due to higher transaction costs, the creation of these new concessions would offer opportunities to increase competition in this market, characterized by its low competitive intensity, as shown by the lack of alternation of operating companies and by the small number of companies that actually bid for the concession. As stated above, when introducing our research, we are aware that efficiency is not the only rationale to take into consideration when evaluating the design of cooperative public service delivery and proposing reforms, which should be targeted to increase social welfare. In this regard, the reforms that we here propose can help to increase efficiency and save costs, while still maintaining the level of service; and even expanding it, if costs saved are used to improve the service. Therefore, they do not undermine equity or universality; on the contrary, our proposals have the potential to improve these.

Finally, we should highlight some of the limitations of the study reported here. First, we have been unable to include all the concessions due to problems of data availability. This explains, for example, why we were obliged to exclude from the analysis the Aerobús concession, the only profitable bus line in the AMB system, as well as a number of concessions operating in specific neighborhoods of Barcelona, including that of Nou Barris and the services serving the terminals of Barcelona's port. Second, we have imputed some indirect costs for TMB concession, so our results for TMB should be treated with caution in the light of this limitation. Third, financial costs in almost all concessions are borne by the metropolitan regulator, and therefore an individualization at the concession level is not feasible. As further research, having more experiences on how regulators adapt their concessions over time in other cities will allow to look for determinants of these jurisdictions size and their changes.

CRediT authorship contribution statement

Daniel Albalate: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Germà Bel:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Jordi Rosell:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization.

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Appendix A

Table A1
Number of observations and period by concession.

	Observations	Period
Barcelonès Nord	7	2012–2018
Esplugues, Sant Just i Sant Feliu	7	2012–2018
L'Hospitalet	7	2012–2018
U1 (Baix Llobregat)	7	2012–2018
U2 (Baix Llobregat)	7	2012–2018
Castelldefels	7	2012–2018
Horta	7	2012–2018
Barcelonès Nord (night service)	7	2012–2018
Baix Llobregat (night service)	7	2012–2018
Port	5	2014–2018
TMB	7	2012–2018
Granollers	3	2012–2014
Mataró	4	2012–2015
Rubí	4	2012–2015
Sabadell	3	2012–2015
Terrassa	3	2013–2015
Vilanova i la Geltrú	2	2012–2014
Igualada	1	2012
Manresa	3	2012–2014
Vic	1	2015
Vilafranca del Penedès	3	2012–2014
Sant Cugat del Vallès	3	2012–2014
Mollet del Vallès	4	2012–2015
Cerdanyola del Vallès	3	2012–2014
TOTAL	112	2012–2018

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