



Cost, production and efficiency in local bus industry: An empirical analysis for the bus system of Santiago

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ABSTRACT

The aggregate cost structure of the Santiago (Chile) urban bus transport industry is studied for the presence of economies of scale, return to scale and technical efficiency. Econometric models using both operator cost and revenue (fares plus subsidy) data show that larger operators under Transantiago had higher average operating costs than the smaller ones; we obtain a similar conclusion when analysing production and the efficiency of firms: we estimate decreasing returns to scale in production, and that larger operators would be more inefficient than smaller operators. The model results also indicate that cost per passenger carried for longer, articulated buses is greater than for shorter, conventional vehicles. These findings are important considerations for the design of the industry and its regulatory framework.

1. Introduction

In regulated markets such as public transport, the presence or absence of economies of scale (e.g. cost function), and return to scale (e.g. production function) is a fundamental consideration in achieving efficiency both in the transport system design and the regulatory framework. After reviewing the literature on returns to scale in public transport systems, the present study reports on an empirical study of the cost and production structure of the local bus service industry in Santiago, Chile for the period after its radical restructuring in early 2007.

Whereas the international evidence on bus industry economies of scale is mixed, our results for the Chilean capital's service suggest the presence of diseconomies of scale from a cost perspective, and decreasing returns to scale from a production perspective. In addition, using a stochastic frontier analysis (SFA) approach, we estimate that smaller firms are more efficient than larger firms.

The formalization of the industry with the advent of Transantiago, the new public transportation system introduced in 2007, has also made available much detailed official information on such phenomena as the supply and demand levels for each bus company. It is these data that have enabled us to contrast our hypothesis regarding the presence or absence of economies of scale, and they have also been used to design the contracts for the public tenders of the different bus lines, the next series of which will be held in February 2018.

A secondary but not unimportant result of this study, derived from an analysis of costs by type of bus after correcting for the number of passengers carried, is that articulated buses 18 m in length are significantly costlier to operate than conventional 12-m buses. This implies that future Transantiago contract designs should prioritize the latter type of vehicle.

The rest of this paper is organized into five sections. Section 2 surveys the literature on economies of scale in urban bus transport

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systems around the world; Section 3 discusses cost characteristics and company size for the Transantiago system and sets out some suggestive graphical evidence as the basis for the study's hypothesis on Transantiago's economies of scale; Section 4 specifies and estimates two alternative sets of econometric models based on annual operating costs and monthly payments to the companies to test the hypothesis; Section 5 estimates a production function for the industry, and develops a Stochastic Frontier Analysis to estimate relative technical efficiency among different firms. Finally, Section 6 presents our conclusions.

2. Literature survey

The issue of returns to scale in local public bus transport continues to be debated in the literature. From the standpoint of public policy, returns to scale play a role in determining fare regulation mechanisms, cost assignment, productivity and the structure of the industry. Views on the industry's returns to scale have also figured in arguments for subsidizing bus services.

As noted in the Introduction, empirical research on bus systems over the last few decades in various countries has produced mixed results in which all three possibilities (constant, decreasing and increasing returns) have been reported. Nevertheless, the studies do tend to suggest that in the majority of cases the conditions for economies of scale in urban bus service provision, where strict regulation is typical, do not exist.

That the evidence on scale returns is indeed mixed is evident from the review of previous studies in [Lai et al. \(2012\)](#), who also imply that the findings depend on the data available, the estimation methodology and the definition of the output metric variables. Earlier works by [Berechman and Giuliano \(1985\)](#) and [Hensher \(1987\)](#) had already cautioned that methodology and type of data would affect the outcome.

[Williams and Dalal \(1981\)](#) discovered decreasing returns for small firms and increasing returns for large ones, suggesting that the cost curve has an inverted "U" shape. By contrast, [Button and O'Donnell \(1985\)](#) reported increasing returns for small operators and decreasing returns for large ones. But [Caves and Christensen \(1988\)](#), using a multi-product function, found constant returns.

Studies by [De Rus and Nombela \(1997\)](#) for Spain, and [Lee and Steedman \(1970\)](#) for Britain, both concluded that returns to scale in the bus industry were constant while a second British study by [Wabe and Coles \(1975\)](#) as well as an investigation for the U.S. by [Koenker \(1977\)](#) pointed to diseconomies of scale. The latter conclusion was also arrived at for the U.S. by [Obeng \(1985\)](#) and for local services in Switzerland by [Filippini and Prioni \(2003\)](#).

Contrasting with the above are American studies by [Williams \(1979\)](#) and [Viton \(1981\)](#), an Israeli study by [Berechman \(1983\)](#) and a Swiss study by [Farsi et al. \(2007\)](#), all of which found that there were economies of scale both for buses and trams. The same result was reported for Taiwan by [Shaw-Er et al. \(2005\)](#), who concluded that returns to scale were increasing. [Williams and Hall \(1981\)](#), meanwhile, showed that there were potential economies of scale in U.S. intercity bus service.

For the UK bus industry, [Cowie and Asenova \(1999\)](#) estimated that small companies operating less than 200 vehicles experienced some economies of scale but also showed that the extent of these economies varied with the type of ownership (private limited company, public limited company, or municipal). [Sakano and Obeng \(1995\)](#) demonstrated that there were increasing returns to scale for the public urban bus industry in the U.S.

In general terms, there are a number of major empirical studies whose results are consistent with a U-shaped average cost function with increasing returns to scale for smaller operators that turn into constant and then increasing returns as the size of the operator grows. [Fernández et al. \(2005\)](#) consider congestion as a source of diseconomies to scale in large bus industries.

A study by [Iseki \(2008\)](#) concluded for the U.S. that there were diseconomies of scale for all bus agency sizes and levels of contracting. The author also noted that few studies report economies of scale whereas many have found that there are diseconomies. The rise in hourly unit operating cost as the size of a bus fleet increases is clearly observable in Iseki's data, graphed here in [Fig. 1](#).

A recent review of the literature by [Abrate et al. \(2016\)](#) concluded that economies of scale exist only for companies that provide multiple bus services (urban, intercity, charter/for hire). This implies that relatively small companies specializing in one or other of these services would experience a reduction in costs by evolving towards a multi-service (urban and interurban) operation. For interurban operators, the best solution appears to be integration with urban operators.

In another recent publication, [Ayadi and Hammami \(2015\)](#) evaluated the cost structure of public transport in Tunisia. They used a translog variable cost function to identify the providers' technological characteristics, with data from a sample of 12 regional operators collected over the years 2000–2010. The authors found diseconomies of scale in both the short and the long term.

[Avenali et al. \(2016\)](#) used a regression model for estimating unit costs and their variability for local public transport in Italy. They showed that economies of scale are limited and only present for small-scale services. Their results revealed a positive correlation between investment in bus fleets and cost of service provision.

Finally, an analysis published by [Fiorio et al. \(2013\)](#), though containing no analysis of cost structure variations by company size, nevertheless demonstrated by means of probit models applied to data from 33 European cities that the highest levels of satisfaction are correlated with the existence of a single local public transport provider, as opposed to an industry structure in which multiple providers operate in the same market area.

The principal findings of the 41 empirical studies from the specialized literature reported in the preceding paragraphs are summarized in [Table 1](#). They confirm that the evidence on economies of scale in bus service is mixed and varies with the specifics of the situation in question. Particularly influential are such phenomena as the size of the bus system, the specification of the variables in the model and the types of data analysed. The regulatory framework can also play a role in determining economies of scale. Regulation can affect the production function of bus operators by means of hampering flexibility and efficiency both regarding the input mix and the output. In the case of Transantiago, the main regulatory restrictions faced by bus companies are contained in the tender contracts. These include routes, frequencies, minimum fleet size and its technological equipment and parking areas. It is worth

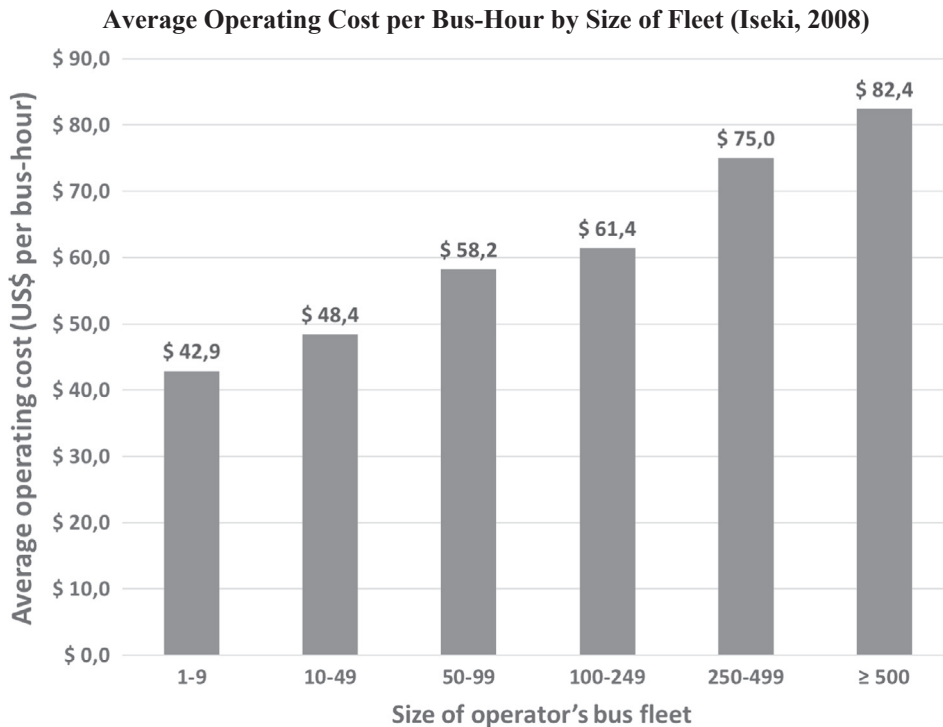


Fig. 1. Average operating cost per bus-hour by size of fleet (Iseki, 2008).

noting that these provisions, although contained in bilateral contracts, are common standard for all the existing companies. As a consequence, they could potentially hamper firm efficiency but do not affect comparisons of economies of scale across companies, such as the ones we explore in this paper. Moreover, frequencies are the same across companies while the minimum fleet fixed to each company does not appear to be a binding restriction: in practice all the companies operates with a larger fleet than the minimum.

3. Cost analysis of the santiago bus industry (Transantiago)

3.1. General

The old bus system that operated in Santiago was replaced in 2007. The pre-2007 system generated high levels of pollution and traffic accidents, and in its later years increasingly appeared headed for collapse. This latter perception was what finally convinced the authorities to intervene. An entirely new system called Transantiago, characterized by a larger, more formal enterprises incorporating many technological innovations and a renewed infrastructure, was inaugurated on February 10, 2007. A comprehensive review of Transantiago's initial design and implementation may be found in [Muñoz and De Grange \(2010\)](#) and [Briones \(2009\)](#).

The routes and service contracts under Transantiago were originally drawn up under a central planning approach that did not take sufficient account of the incentives facing either operators or users. The fundamental assumption was that the behaviour of the actors involved would simply adapt to the plan laid out by the "experts." Provision of the bus services under the new system was tendered out to 14 companies, 5 of which would serve major trunk routes while the other 9 would operate the local routes feeding the trunk lines as well as the stations in the Santiago Metro system. In addition to a completely redesigned route network, Transantiago began life with 2000 new vehicles and a new fare payment system based on pre-paid electronic cards that gave access to the Metro as well as the buses. Fare collection was, and continues to be, centrally managed, and the revenues collected, with the later addition of government subsidies, are used to pay the companies providing the services ([Tamblay et al., 2016](#)).

This radical redesign of the Santiago bus system, which had a highly traumatic debut, drastically changed the system's industry structure. The number of companies dropped from a total of 3868 in the older bus system to just 14 under Transantiago and the number of buses fell from 8000 to 4500 (6500 nowadays).

3.2. Company types and cost characteristics

In June 2012, a little more than five years after Transantiago was launched, the trunk-and-feeder design was abandoned. The number of companies in the system fell from 14 to 7 and each of the surviving operators was assigned a new concession that included some of what were formally classed as trunk and local feeder lines. The distribution of their respective fleets by type of bus as of the end of 2012 is given in [Table 2](#). These 7 operators continue operating Transantiago to this day. The next tender of bus lines and

Table 1
Summary of main findings in the literature on returns to scale in the bus industry.

Author(s)	Principal finding
Lee and Steedman (1970)	Constant
Koshal (1972)	Constant
Caves and Christensen (1988)	Constant
de Rus and Nombela (1997)	Constant
Dalen and Gomez-Lobo (2003)	Constant
Wabe and Coles (1975)	Diseconomies
Koenker (1977)	Diseconomies
McGillivray et al. (1980)	Diseconomies
Pucher et al. (1983)	Diseconomies
Morlok (1984)	Diseconomies
Obeng (1985)	Diseconomies
Perry and Babitsky (1986)	Diseconomies
Cervero (1988)	Diseconomies
Shughart and Kimenyi (1991)	Diseconomies
Savage (1993)	Diseconomies
Xu et al. (1994)	Diseconomies
Jørgensen et al. (1997)	Diseconomies
Matas and Raymond (1998)	Diseconomies
McCullough et al. (1998)	Diseconomies
Sclar (2000)	Diseconomies
Iseki (2008)	Diseconomies
Ayadi and Hammami (2015)	Diseconomies
Williams (1979)	Economies
Viton (1981)	Economies
Williams and Hall (1981)	Economies
Berechman (1983)	Economies
Hensher (1987)	Economies
Filippini and Prioni (1994)	Economies
Karlaftis and McCarthy (2002)	Economies
Farsi et al. (2007)	Economies
Walter (2011)	Economies
Williams and Dalal (1981)	Mixed
Tauchen et al. (1983)	Mixed
Berechman and Giuliano (1985)	Mixed
Button and O'Donnell (1985)	Mixed
Berechman (1993)	Mixed
Cowie and Asenova (1999)	Mixed
Singh (2002)	Mixed
Filippini and Prioni (2003)	Mixed
Lai et al. (2012)	Mixed
Abrate et al. (2016)	Mixed

Table 2
Bus companies operating transantiago (as of yearend 2012).

Company	Fleet of 9 m buses	Fleet of 12 m buses	Fleet of 18 m buses	Total fleet
Alsacia	29	492	238	759
SuBus	175	540	560	1275
Vule	159	1076	0	1235
Express	168	641	420	1229
Metbus	37	656	217	910
RedBus	311	335	0	646
STP	135	304	0	439
Total	1014	4044	1435	6493

services will be held in 2018 and may well witness changes to the current industry structure.

The creation of Transantiago brought about a greater formalization of the operators and of the drivers' working conditions, but also resulted in a significant increase in the costs of service provision. Indeed, the rise was such that the government found it necessary to implement a system of subsidies, something that had never existed during the older bus era. The system-wide annual costs of the older buses were approximately US\$400 million (SECTRA, 2003) while under Transantiago they climbed to about US\$1.1 billion, and in the last few years have continued to grow.

The implementation of the subsidy coupled with the installation of sophisticated fare payment technologies and the structure of the Transantiago contracts in effect since 2012 have had a positive external effect on research into the system in that a range of

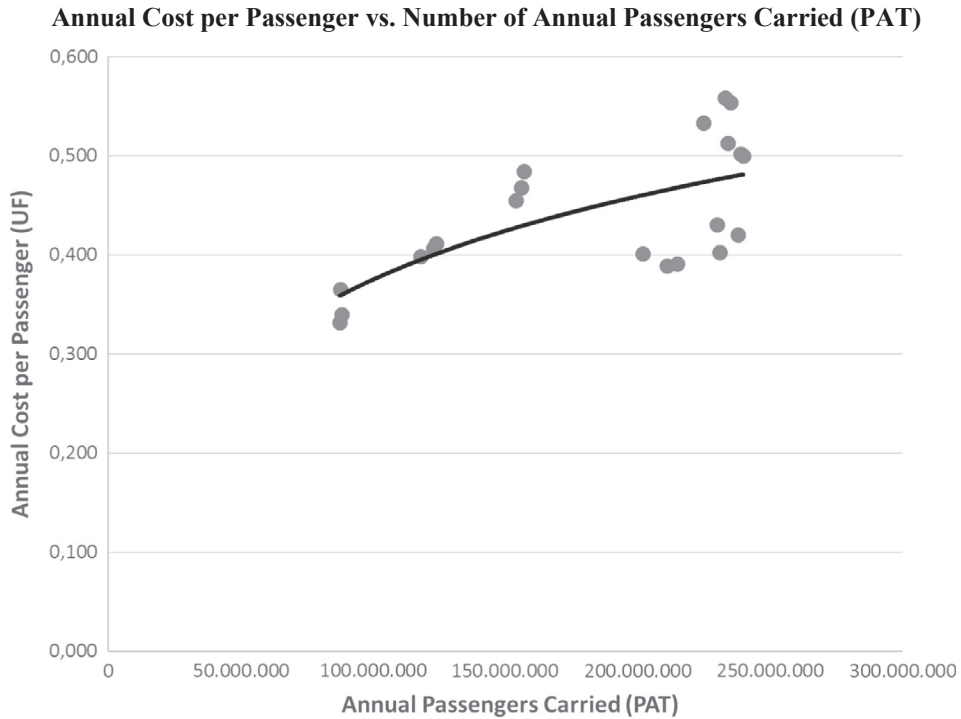


Fig. 2. Annual cost per passenger vs. number of annual passengers carried (PAT).

detailed data is now available on each provider company's supply of bus services (frequencies, kilometers traveled, regularity) as well as on user demand (number of passenger validations [i.e., fare-paying passengers] for each company). Every year the Ministry of Transport publishes a report on the operating results of the individual Transantiago companies containing such supply and demand indicators. Also reported are the payments made to each company under their individual contracts, which are financed by user fares (approximately 60%) and the government subsidy (approximately 40%) based on a formula negotiated by the government and each company that incorporates certain cost variables. In this sense, and assuming the contracts are reasonable and do not allow excessive profits, the amount paid to an operator per passenger carried may be seen as a proxy for the true cost and used to analyse a hypothesis regarding economies of scale.

Official monthly supply and demand data were available on each of the 7 Transantiago provider companies in the system since it was restructured in June 2012 for the period between January 2013 and December 2015, or 36 consecutive months. Given that payments to the companies are only a proxy for the real cost, we supplemented this information with official data on annual costs supplied by Chile's Internal Taxation Service.

The dispersion of the companies' average annual operating cost per passenger for each year as a function of the number of passengers carried in the corresponding years over the period 2013 through 2015 is shown in Fig. 2, while the dispersion of average monthly payments to the companies per passenger in each month as a function of the average number of passengers carried in the corresponding months over the same three-year period is depicted in Fig. 3. These two graphs suggest that the current Transantiago system is characterized by diseconomies of scale. This hypothesis will be tested in the next section.

4. Econometric analysis of diseconomies of scale hypothesis

To analyse our hypothesis suggested by Figs. 3 and 4 above of diseconomies of scale in the Transantiago bus system, we obtained annual operating cost data on the seven companies in the system from their financial statements on the website of the Chilean Internal Revenue Service (SII by its Spanish initials) plus information on the monthly payments to the companies from the Chilean Ministry of Transport (MT). Each set of data were used to represent cost in one of the two general econometric models we built to carry out the analysis. In both models, cost is the explained variable.

4.1. Annual data analysis (company operating costs)

The annual operating cost data covered the period 2013 through 2015. For each year and company, the cost (the explained variable) was contrasted with the following explanatory variables: the number of passengers carried, and the proportion of articulated vehicles in the fleet. More formally, the variables in the annual analysis were as follows:

Monthly Payments to Companies per Passenger vs. Number of Monthly Passengers Carried (PMT)

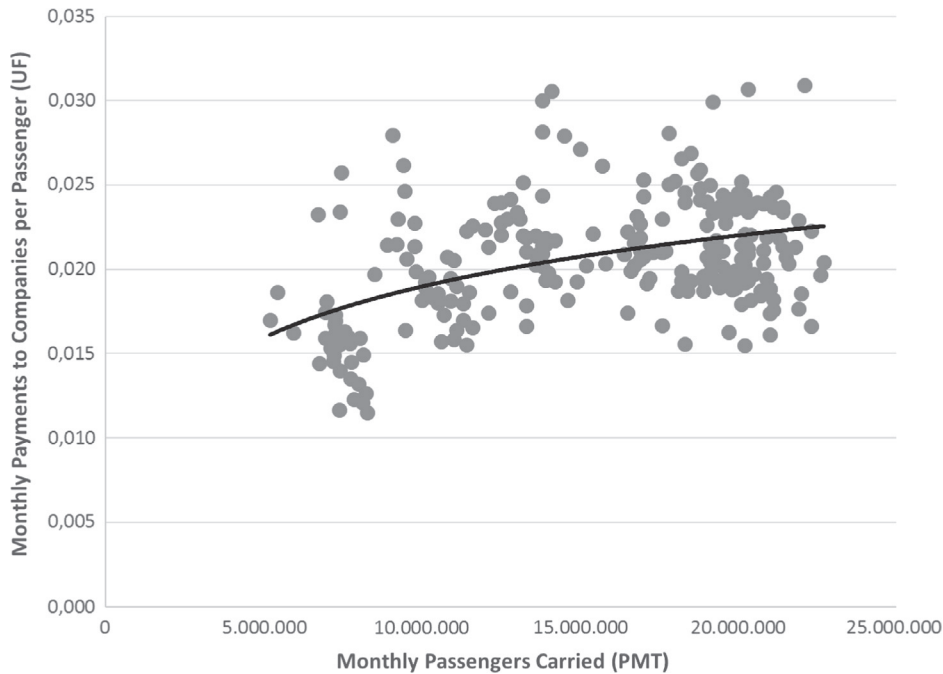


Fig. 3. Monthly payments to companies per passenger vs. number of monthly passengers carried (PMT).

- i. **Annual Company Cost (CAE):** The cost reported by each company in its official financial statements submitted to the SII (in thousands of Chilean pesos).
- ii. **Annual Passengers Carried (PAT):** The total number of passengers carried by each company’s services in each year. Includes validated passengers and company estimates of fare evaders.
- iii. **P18:** The proportion of each company’s fleet made up of articulated 18-m buses.

The proportion of 18-m articulated buses variable (P18) was included to act as a control given that this type of vehicle has a considerably higher operating cost than the shorter types. The use of buses with larger capacity has higher costs of operation per bus, but to the extent that they have a high occupancy, this would translate into a lower cost of operation per passenger. Nevertheless, for a given demand, unitary costs could be lower if such demand could be served with a smaller bus. Companies with higher operational costs have argued that among the main reasons for their higher costs per passenger is the contractual obligation to operate with large 18 m buses. We included the variable P18 to verify this hypothesis empirically.

The descriptive data gathered from the financial documentation for all five variables are summarized in Table 3.

The general version of the model to be estimated with these data is specified as follows:

$$\ln CAE_{it} = \beta_0 + \beta_{PAT} \ln PAT_{it} + \beta_{P18} P18_{it} + \varepsilon_{it} \tag{1}$$

where subindex *i* denotes the company and subindex *t* the year.

Two different variations on general model (1) were tested, each containing one or two of the explanatory variables (see Table 4). Models 1, 2 and 3 in particular check for robustness in the relationship between scale of operation and costs.

The estimates were computed by the method of ordinary least squares and the standard errors were estimated using the heteroscedasticity-robust variance-covariance matrix. The fixed effects model was not used as it eliminates the between variance reflecting the different company sizes, which is our main source of information.

Given the small size of our sample, we did not use the normal asymptotic distribution but rather the *t* distributions that the

Table 3
Summary of descriptive data for operating cost analysis variables (N = 21 observations).

Variable	Mean	Std Dev	Min	Max
CAE	8.29E+07	3.36E+07	2.95E+07	1.32E+08
PAT	1.82E+08	5.76E+07	8.75E+07	2.40E+08
P18	0.1901182	0.1727252	0	0.4392157

Table 4
Regression model parameter estimates (annual cost data).

Variable	Model 1	Model 2
$\ln(PMT)$	1.28*** (0.053)	1.14*** (0.042)
$P18$		0.527*** (0.084)
Const (β_0)	-6.139*** (0.988)	-3.583*** (0.783)
R^2	0.9494	0.9734
No. of obs.	21	21
Scale effect	1.28	1.14
p value of SW test	.235	.02587

Standard errors in parentheses.

*** Significance at the 1% level.

statistics would have if the errors followed a normal distribution. Normality was checked using the Shapiro-Wilk test on the residuals of each regression (Razali and Wah, 2011; Odeck and Johansen, 2016) given that it has greater statistical power with small samples than other, similar tests.

Since the model variables are specified in natural logs, the hypothesis test for the presence of diseconomies of scale is stated as follows:

$$\begin{aligned} H_0: \beta_{PAT} &\leq 1 \\ H_1: \beta_{PAT} &> 1 \end{aligned} \quad (2)$$

If H_0 is rejected, there is evidence of diseconomies of scale. The regression parameter estimates for the two versions of the general model (1) are displayed in Table 4. Also shown for each version are the respective p values of the one-tailed t test for (2) and the Shapiro-Wilk for the residuals, whose null hypothesis is that the distribution is normal. The values in the table for the “scale effect” are the parameters associated with the natural logs of the scale of variables.

Although a high R^2 does not necessarily validate a model, it is worth noting in Table 4 the good fit achieved by the models, despite using simple econometric models.

To contrast hypothesis (2) for both models of Table 4, we use the following expressions:

$$\text{Model 1: } \frac{\hat{\beta}_{PAT}-1}{se(\hat{\beta}_{PAT})} = \frac{1.28-1}{0.053} = 5.28 > t_{99\%;19} = 2.54 \quad (3)$$

$$\text{Model 2: } \frac{\hat{\beta}_{PAT}-1}{se(\hat{\beta}_{PAT})} = \frac{1.14-1}{0.042} = 3.33 > t_{99\%;18} = 2.55 \quad (4)$$

Based on these results, we may state the following:

- The hypothesis that there are diseconomies of scale in the Santiago bus industry is corroborated. This empirical outcome is consistent with the graph in Fig. 2.
- Correcting for each company's number of passengers carried and kilometers traveled, the cost for articulated (18 m) buses is about 50% higher than the cost for conventional (12 m) models. This suggests that substituting 18-m vehicles by 12-m ones could help in reducing costs. The intuition behind this result is that an 18-m vehicle is equivalent of being forced to cover a route with a 12-m vehicle and with a 6-m vehicle at the same time even if there is no enough demand. On the contrary, a 12-m vehicle provide more flexibility to adapt to this demand.

4.2. Monthly data analysis (payments to companies)

The monthly company payment data covered the period January 2013 through December 2015. For each month and company, the payment (the explained variable representing cost) was contrasted with the same explanatory variables: the proportion of articulated vehicles in the fleet and the passengers carried. More precisely, the variables in the monthly analysis are as follows:

- Monthly Company Payment (PME):** The amount of money paid to each company for the provision of bus services during each month. Although not exactly equal to the cost of providing the services, it is a reasonable proxy for it given that the tender contracts base the payments on cost factors. The payments are stipulated in *Unidades de Fomento*, a Chilean peso monetary unit determined by the Central Bank of Chile that is adjusted for inflation.
- Monthly Passengers Carried (PMT):** The total number of passengers carried by each company's services during each month. Includes validated passengers and company estimates of fare evaders.

Table 5
Summary of descriptive data for company payment analysis variables (N = 244 observations).

Variable	Mean	Std Dev	Min	Max
<i>PME</i>	323034.7	128636.8	86290.5	683.431
<i>PMT</i>	1.53E+07	4,981,210	5,199,705	2.27E+07
<i>P18</i>	0.1911353	0.1691104	0	0.4392157
<i>KMC</i>	5,529,418	1,877,082	1,920,306	8,267,814

iii. **P18**: The proportion of each company's fleet made up of articulated (18-m) buses.

Last row of **Table 5** corresponds to the monthly commercial kilometers (*KMC*) traveled by the buses of each firm. We use this variable in Section 5.

The general version of the model estimated with these monthly data is specified as follows:

$$\ln PME_{it} = \beta_0 + \beta_{PMT} \ln PMT_{it} + \beta_{P18} P18_{it} + \varepsilon_{it} \quad (5)$$

where subindex *i* denotes the company and subindex *t* the month.

Two different variations on general model (3) were tested. The economies of scale hypothesis is analogous to (2) in the annual operating cost analysis. The estimates of the different model versions are set forth in **Table 4** together with the values of the test statistics.

To contrast hypothesis (2) for the models of **Table 6**, we use the following expressions:

$$\text{Model 1: } \frac{\hat{\beta}_{PAT}-1}{se(\hat{\beta}_{PAT})} = \frac{1.236-1}{0.029} = 8.14 > t_{99\%;242} = 2.34 \quad (6)$$

$$\text{Model 2: } \frac{\hat{\beta}_{PAT}-1}{se(\hat{\beta}_{PAT})} = \frac{1.107-1}{0.029} = 3.69 > t_{99\%;18} = 2.34 \quad (7)$$

These estimates are consistent with **Fig. 3** and those of the cost analysis in **Table 4**. More specifically, the ranges of the diseconomies of scale are similar for both analyses with a scale factor of about 1.2. This implies that a 10% increase in the scale of operation variables translates into a 12% increase in costs.

5. Complementary analysis: Returns to scale in production and relative technical efficiency

The results presented in Section 4 can be complemented by an analysis of returns to scale and relative technical efficiency for the different firms that make up the bus industry in Santiago.

Returns to scale have to do with the relationship between output increases relative to increases in inputs. Returns to scale and economies of scale are related, but one condition does not necessarily imply the other. For this reason we perform this complementary empirical analysis.

Technical efficiency, on the other hand, estimates how close firms are to the production possibilities frontier. The firms closest to the frontier will be more efficient, while those farther away will be less efficient.

From the perspective of social evaluation, the social value added of the public transport system is related to the passengers it transports. In this sense, the displacement of buses is a means to achieve this purpose. This is why we consider the passengers transported as a measure of output, while the kilometers traveled represent a measure of input, to the extent that the inputs in the bus

Table 6
Regression model parameter estimates (monthly payment data).

Variable	Model 1	Model 2
ln(PMT)	1.236*** (0.029)	1.107*** (0.029)
P18		0.537*** (0.056)
Const (β_0)	-7.79*** (0.487)	-5.773*** (0.48)
R ²	0.8979	0.9221
No. of obs.	244	244
Scale effect	1.236	1.107
<i>p</i> value of <i>t</i> test	.000	.000

Standard errors in parentheses.

*** Significance at the 1% level.

Table 7
Regression model parameter estimates (production).

Variable	Model
ln(KMC)	0.928 ^{***} (0.014)
Const (θ_0)	2.141 ^{***} (0.213)
R^2	0.914
No. of obs.	252
Scale effect	1.236
p value of t test	.000

Standard errors in parentheses.

*** Significance at the 1% level.

industry are used in fixed proportions (Fernández et al., 2005). However, as discussed in Odeck and Alkadi (2001), both passengers and kilometers (seat-kilometers) can be considered valid measures of output from different perspectives, so the choice will depend on the objective of the study.

5.1. Analysis of returns to scale

For the production function we depart from the work of Fernández et al. (2005). They consider that three of the main production inputs for bus firms (i.e. fleet, drivers and terminals) are perfect complements. Thus, for the empirical work it is not necessary to have detailed information for all of them. Another relevant input is fuel (diesel in our case), for which consumption depends mainly on the kilometers traveled by the buses. Therefore, we use the monthly commercial kilometers traveled by the buses (see KMC in Table 5) as a proxy variable for inputs, and the monthly number of passengers carried (PMT) as the output variable. Then, for the firm i during month t , the econometric model is:

$$\ln PMT_{it} = \theta_0 + \theta_{KMC} \ln KMC_{it} + \varepsilon_{it} \quad (8)$$

The estimates of Eq. (8) are reported in Table 7:

To contrast the null hypothesis of increasing returns to scale ($H_0: \theta_{KMC} > 1$) we use the following expression:

$$\text{Model 1: } \left| \frac{\hat{\theta}_{KMC} - 1}{se(\hat{\theta}_{KMC})} \right| = \left| \frac{0.928 - 1}{0.014} \right| = 5.14 > t_{99\%;250} = 2.34 \quad (9)$$

Thus, the test rejects the hypothesis of increasing returns to scale. Our estimates suggests that an increase in commercial kilometers of 10% would increase by 9.28% the number of passengers carried.

5.2. Relative technical efficiency analysis

To estimate relative technical efficiency of Transantiago bus operators, we use the Stochastic Frontier Analysis (SFA) framework. This method considers that the relationship between inputs and outputs depends on a stochastic component and an efficiency component, idiosyncratic to each firm (Odeck and Bråthen, 2012; Suárez-Alemán et al., 2016; Pinjari et al., 2016).

In our case, the SFA model is:

$$\ln PMT_{it} = \alpha_0 + \alpha_{KMC} \ln KMC_{it} - \mu_i + u_{it} \quad (10)$$

where $-\mu_i$ represents the inefficiency of firm i , and u_{it} is the stochastic shock. The estimates of the set of parameters μ_i are a measure of technical efficiency for each firm according to the following expression:

$$\widehat{TE}_i = \exp(-\mu_i^{\max} - \hat{\mu}_i) \quad (11)$$

where $\mu_i^{\max} = \max[\hat{\mu}_i]$. Fig. 4 shows that as the average number of commercial kilometers increases for each firm, it tends to reduce their technical efficiency.

6. Conclusions and recommendations

The aggregate cost structure of the Santiago (Chile) urban bus transport industry was analysed to determine the nature of its economies of scale, returns to scale and technical efficiency, since 2007, when the industry was restructured and formalized by the creation of the Transantiago system, which consists of a relatively few large companies using formal management methods within a much stricter regulatory framework.

Econometric models were developed and used with data on both company costs and total company income payments (fares plus subsidies) as direct and indirect measures of the industry's cost structure. The models found that under Transantiago, there were

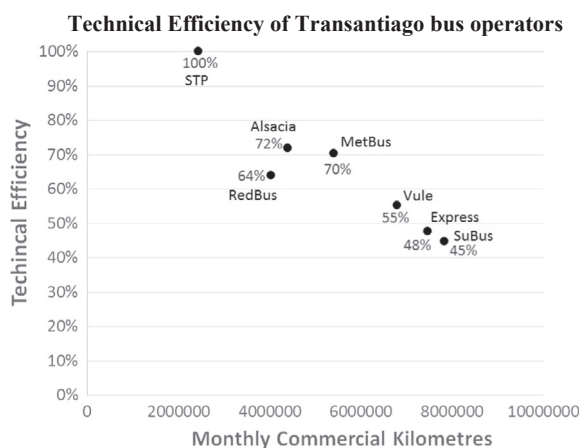


Fig. 4. Technical efficiency of transantiago bus operators.

diseconomies of scale, the companies' operating costs rising faster than the increase in their supply of bus services. In a complementary way, we find diminishing returns to scale in the production of trips, considering as a productive factor the commercial kilometers required to bus operators. Also, using the Stochastic Frontier Analysis framework, we found that smaller firms are more efficient than larger firms.

In light of these results, a number of recommendations are in order. First, in future tenders of Santiago bus route concessions, the regulatory framework should allow bids from smaller companies in order to reduce industry operating costs. Second, a larger number of smaller companies should be encouraged to participate as a way of promoting competition and facilitating the award of existing route concessions to new bidders where current service quality levels have fallen significantly below the established standards or industry averages. However, transport authorities may also be interested in operators maintaining certain quality standards related to service, safety, environmental care, and working conditions, which can mean higher costs and may require a minimum scale of operation.

The study also found that, after correcting for passengers carried and distance traveled, articulated (18 m) buses have significantly higher operating costs than conventional 12-m vehicles. This implies that future tenders should not stipulate the use of these longer models.

The heterogeneous results reported in the literature suggest that the presence of economies or diseconomies to scale in bus industries depends on different background conditions. Some characteristics of Santiago's bus system may help to interpret our results, based on other studies that also find diseconomies of scale or inefficiencies in the operation of buses. In the first place, other studies in developing countries also find the presence of diseconomies of scale. According to Ayadi and Hammami (2015) it can be explained by poor infrastructure, lack of a clear working strategy and the inability to meet the high demand of users during rush hours. Besides, only large companies operate in Transantiago (over 400 buses the smallest one) and in this range it is more likely to find diseconomies of scales as pointed out by Matas and Raymond (1998) and Obeng (1985) who find diseconomies of scale only among larger companies. Concerning the level of competition of the tenders, Jørgensen et al. (1997) conclude that tenders can bring efficiency gains, but it will depend on the design of the tender and the number of bidders. The contracts and conditions under which operate the companies in Transantiago were not the result of a competitive tender. Due to serious design errors of the contracts in Transantiago's original tender in 2007, the industry was restructured and the contracts renegotiated on several occasions under strong political pressure.

Finally, the continued publication by the Chilean authorities of the monthly and yearly data used in this study will allow the results presented here to be updated on a regular basis.

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