Case Studies on Transport Policy 16 (2024) 101193

Contents lists available at ScienceDirect

Case Studies on Transport Policy

journal homepage: www.elsevier.com/locate/cstp

Performance-Based contracting of urban transport operation Services: Evidence from Porto's Light-Rail

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ARTICLE INFO

JEL Codes:
H40
L24
L33

Keywords:
Urban railroad operation
Performance-based contracting
Bonus/malus
Operating performance

ABSTRACT

This paper develops a bonus/malus incentive model for contracting out the provision of urban railroad operation services, and testing parts of its performance using Monte Carlo methods. We also provide evidence on the performance measures of Metro do Porto's (MdP) light-rail network operation, during the 2010–2016 term of a bonus/malus-based contract, incorporating some features of our model. Results document that the implementation of a performance-based contract with an embedded incentive bonus/malus mechanism may contribute to promoting ridership patronage, increasing the average ride, and ultimately promoting the overall economic operating efficiency of the system. The comparative operating performance analysis of MdP *versus* Metropolitano de Lisboa, a vertically integrated, governmentally-owned metro network, shows that MdP exhibits higher revenue, cost, and operating efficiency in the 2010–2016 period, and that the bonus/malus mechanism induces the private sub-concessionaire to respond more efficiently to changes in demand.

1. Introduction

Until the early 1980 s, public transport infrastructure, namely urban railway networks, was built and operated, predominantly, under governmental ownership and funding (Iossa and Martimort, 2011). Since then, pioneered by the private finance initiative (PFI) of the UK government, significant institutional changes triggered the adoption of new procurement and contract awarding practices (e.g., Estache et al., 2011; Nash, 2005).

In Europe, the operation of railway networks has been contracted under different forms of public procurement, awarding procedures - either through direct contract awarding or competitive tendering - and contractual arrangements (e.g., Preston and Walters, 2020; Papaioannou et al., 2020; Mandri-Perrott and Menzies, 2010).[1] This different way of contracting out models suggests the presence of a link between those contract awarding procedures and railway systems ownership. On the one hand, there is the operation of long-established metro and light rail networks under vertical integration, being operated mostly under public ownership (Iossa and Martimort, 2011).[2] On the other hand, because of, namely, governmental fiscal constraints and efficiency concerns, the operation of a significant number of those systems has been procured and contracted under vertical separation (e.g., Mallett, 2021; Poliak, 2017; Amaral, 2008; Välilä, 2005). Under these dual contract awarding procedures, the provision of operation and maintenance services has been typically procured under two distinct approaches: (*i*) conducted and governed under the organizational boundaries of a public sector concessionaire; or (*ii*) conducted through the competitive contracting of a private sector's sub-concessionaire, under the governance of a publicly owned concessionaire.[3]

Furthermore, the proliferation of different contract designs to 'bundle' the construction and the operation of transit systems stimulated the involvement of the private sector in infrastructure development and

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[1] See van de Velde et al., 2008, for a review of the contractual practices adopted by 33 European public transport entities, including the design, build, finance and operate concession contract awarded by Metro do Porto (MdP). Thereafter, we use interchangeably "competitive contracting", "competitive tendering", "performance-based contracting", "competitive bidding", and "incentive contracting".

[2] For greenfield projects, concession contracts are often an effective type of contract to accommodate the provision of a variety of assets and services, including the operation of new and existing transit system assets (see, e.g., Mandri-Perrott and Menzies, 2010).

[3] Thereafter, we use interchangeably "concessionaire", "concession contractor" or "contractor".

https://doi.org/10.1016/j.cstp.2024.101193
Received 25 June 2022; Received in revised form 31 July 2023; Accepted 24 March 2024
Available online 25 March 2024

operation services (e.g., Engel et al., 2021; Dolla and Laishram, 2020; Buso et al., 2017; Dewatripont and Legros, 2005). In addition, a wave of innovative financial instruments and customized structuring designs have significantly enlarged the supply of transport infrastructure financing arrangements, mainly via limited recourse project financing and public–private partnerships (PPPs).[4] In the urban railway passenger transport subsector, the appropriate allocation of revenue risk between the host government and the private developer, and the private developer's discretion to set tariffs are key structuring considerations for PPPs. Furthermore, PPPs have the advantages of reducing the need for government borrowing and achieving more efficient and effective management of the project (Klompjan and Wouters, 2002; Pinto, 2017).

Although the competitive procurement of operation services for urban railway networks became increasingly frequent in Europe, there is relatively scant literature on the design and performance of contracting arrangements, which aim at promoting the alignment of the interests of the various parties involved in such contracts. In this work, we intend to fill this gap in the literature. Therefore, the paper's contribution to the literature is threefold. First, it develops a performance-based bonus/malus (B/M) contracting model.[5] Second, because proprietary information for both the concessionaire and the sub-concessionaire required for conducting clinical research was unavailable, we conduct Monte Carlo simulation on MdP's network operation under a performance-based contract with an embedded incentive B/M mechanism. Simulation results over the 2010–2016 period indicate that MdP's operation contractual performance appears sensitive to the variability of the B/M drivers, and responsive to changes in the contractual performance factors out of the sub-concessionaire's control. In addition, using primary data drawn from MdP's publicly available annual reports, we show that the performance-based B/M contracting model contributed to improving ridership patronage and farebox revenues, while the capacity utilization rate remained stable, as well as the overall economic operating efficiency of the system, gauged by the coverage ratio of the operating costs.

Third, we provide evidence on a quasi-natural experiment in the form of an operating performance comparative analysis, to study the operating performance differential associated with the operation services provision of MdP (vertically separated) and Metropolitano de Lisboa (MdL), a (vertically integrated) governmentally owned metro network in the Lisbon metropolitan area, during the 2010–2016 period. Results indicate that MdP shows higher revenue, cost, and activity level efficiency when compared with MdL, since (*i*) MdP shows a higher revenue per passenger km (pax-km); (*ii*) MdP's operating costs per pax-km reduced significantly and was lower than those of MdL in the 2013–2016 period; and (*iii*) the capacity utilization rate is higher in MdL *vis-à-vis* MdP. We also show that the B/M mechanism induces the sub-concessionaire to respond more efficiently to changes in demand, and the concessionaire to be less dependent on governmental subsidization than MdL.

The remainder of this study is organized as follows: Section 2 discusses the theoretical and empirical background. The next section describes our methodological approach and model specification. Section four presents the results of a Monte Carlo simulation analysis for our B/M model. It then documents some MdP operating performance metrics during the 2010–2016 contract term, and presents a comparative analysis with MdL. The final section provides a summary and offers concluding remarks.

[4] See Pinto and Santos (2020), Annez (2006), and Duffie and Rahi (1995) for further details.

[5] In the international tender carried out by MdP that led to the award of a contract in 2010, a reduced version (with a single explanatory variable) of our B/M model was used.

2. Theoretical and empirical background

Over the past 30 years, important institutional changes have taken place in the urban public transport sector (e.g., Canitez, 2019). Namely, the increased use of competitive contracting instead of the direct awarding of contractual rights, expanded risk sharing with private operators, and the privatization of the provision of operation services. The use of PPPs in the transportation sector is a good example of this trend (e.g., Kappeler and Nemoz, 2010).

In this section, we parsimoniously review the key conceptual frameworks of the theory of contracts, foundational pillars of performance-based contracting, which are helpful in rationalizing the more recent decades of contracting activity in urban railway networks. The economic foundations of ownership transfers through the provision of infrastructure, operation and maintenance services, are anchored in incomplete contracting, property rights, transaction costs, and asymmetric information theoretical arguments. Therefore, we specifically focus on incomplete contracting, ownership, incentives, and contracting technology (Xiang et al., 2017; Hoppe-Fischer, 2011; Bolton and Dewatripont, 2005; Hart, 2003; Laffont and Mortimort, 2002).

2.1. Incomplete contracting

Writing complete contracts is an inefficient governance mechanism, whenever the economic relationships between parties are contingent on future states of nature (e.g., Hart, 2003). Therefore, in an incomplete contract environment, the contracting technology builds on assumptions related to the imperfect observability and contractibility of actions, the ability to renegotiate, the nature of information, parties' risk preferences, and the costs of writing, executing, and enforcing contracts. In this framework, the optimal contractual designs are the mechanisms able to mitigate the different types of conflicts, either of interest and/or informational, arising within agency relationships (e.g., Aghion and Holden, 2011).

In this incomplete contracting framework, non-human asset ownership, because of the state-contingent residual control rights it grants, becomes a determinant for stipulating ex-ante contractual obligations (e.g., Hoppe-Fischer, 2011).[6] As shown by Holmström (1979), as the agent's effort level cannot be observed, the optimal incentive contract makes the agent's compensation dependent on the project's realized returns. Considering Townsend's (1979) costly state verification framework, a project's realized returns are privately observed by the agent – say, a sub-concessionaire – who reports it to an uninformed risk-neutral principal – say, a concessionaire – who, ex-post, can audit the report for a cost.

2.2. Ownership

Over the last decades, governments worldwide have engaged in voluntarily transferring public ownership, namely, infrastructure assets and, in certain cases, bundling them with operating rights, to private investors. This trend can be justified by a branch of the literature suggesting that the private sector's managerial performance may dominate the governmental counterpart (e.g., Okten and Arin, 2006; Dewenter and Malatesta, 2001; Megginson and Netter, 2001; Sappington and Stiglitz, 1987). However, whether or not public ownership over productive assets matters in terms of relative economic efficiency, still

[6] Non-human assets include business machines, inventories, buildings, land, patents, client lists, copyrights, etc. As Hart (1995) points out, "Why does ownership of physical or nonhuman assets matter? The answer is that ownership is a source of power when contracts are incomplete. To understand this, note that an incomplete contract will have gaps, missing provisions, or ambiguities, and so situations will occur in which some aspects of the uses of nonhuman assets are not specified". See also Kim (2004).

remains ambivalent (e.g., Iossa and Martimort, 2011; Amaral, 2008; Tatahi, 2006).

The economic gains potentially associated with the transfer of ownership may arguably have been a relevant reason for contracting out the operation of urban railway networks through competitive performance-based contracting arrangements (e.g., Merkert et al., 2018; Macário et al., 2015; Regan et al., 2011; Levin and Tadelis, 2010; Amaral, 2008; Rodrigues and Contreras-Montoya, 2005). In addition, it is well-known that governmental sponsorship of the provision of public goods may have been constrained by budgetary and financial restrictions at the government level, as well as by concerns over the allocative efficiency of public resources. To address these policymaking constraints, the contracting of PPPs started to be extensively used by public administration bodies to procure design-build-finance-operate (DBFO) services, aiming at mitigating and reaping the performance improvements associated with the private delivery of public goods (e.g., ITF, 2017; Kwak et al., 2009).

However, the efficiency gains of PPPs associated with bundling the construction and operation services in a single contract to a private partner, as argued by Maskin and Tirole (2008), may be elusive because «the best developer might not also be the best operator». Further, it may encourage choices that reduce future costs at the expense of service quality (e.g., Kwak et al., 2009; Hart, 2003).[7]

2.3. Incentives

It is widely acknowledged that public procurement contracting is prone to problems related to informational and contractual incompleteness, which may be mitigated under competitive and incentive contracting (e.g., Saussier and Tirole, 2015).

In this framework, contract theory is an instrumental framework used to explore the coordination, information transmission, and motivation behind economic activities and relationships, including, the design of procurement mechanisms (e.g., Hoppe-Fischer, 2011; Campbell, 2006; Weitzman, 1980).[8] However, delegating a task or service to a private agent may entail costly contract execution problems. Among these are that the agent's level of effort cannot be observed when it comes to performing well-specified delegated tasks, in addition to the opportunistic behavior related to hidden information and hidden action raised by execution of an incomplete contract (e.g., Gibbons and Roberts, 2013; Lafont and Martimort, 2002).

As suggested, e.g, in Hoppe-Fischer (2011), contracts may be designed to provide incentives for the agent to disclose private information about service delivery. Further, the author shows that private contractors «have incentives to spend resources during the construction phase in order to obtain private information, so that he will be able to extract an information rent in the management stage». Focusing on the transport sector, Iossa and Martimort (2011) develop a model of procurement in a multitask environment where the agent (e.g., a concessionaire), not only manages the existing assets necessary to provide the service but may also design, build, and finance these assets. Under this framework, authors show that bundling and risk transfer are key features of PPP arrangements. Moreover, they show that when concessionaires rely exclusively on private finance, distortions in the choice of the length of the contract arise, resulting in reduced incentives for the contractor to invest in the quality of the infrastructure.

Overall, extant literature can help to rationalize that the bundling that characterizes PPPs, or concessions more generally, provides incentives to the private partner through, namely, the risk allocation and the contract length mechanisms (e.g., Dolla and Laishram, 2019; Hoppe-Fischer, 2011).

2.4. Contracting technology

Among other factors, economic deficits and liquidity shortfalls experienced by public transit agencies across the world during the last decades triggered increased interest in more effective contractual designs to address those problems. Yet, despite the advances in contract theoretical work, there are relatively few applications with respect to awarding the provision of urban railroad operation services (e.g., Hooper, 2008).

García-Ferrer et al. (2006) suggest that performance-based contracting (PBC), may be an appropriate vehicle «to combine the efforts of public and private institutions related to public transport for the purpose of coordinating services, networks, and fares so as to offer consumers at higher-capacity, higher-quality service, with the aim of promoting public transport use».[9] PBC focuses on linking contractual monetary compensation to the specific metrics of the service provider's performance, which are mutually agreed upon by the parties involved. This ensures that at least part of this payment is tied to performance, under a strictly defined set of contractual deliverable requirements. According to Nicosia (2001), this incentivized performance aims at motivating enhanced service delivery and, ultimately, improving performance.

As posited by Sheshinski and López-Calva (2003), theoretically, «it is known that incentive and contracting problems create inefficiencies due to public ownership». One of these problems relate to the equitability of the reward systems stipulated in PBC arrangements. Such provisions should not be sensitive to factors exogenous to the operatoŕs contractual activity. For example, changes in the level of (regulated) fares, either inducing the increase or the decrease in ridership, should not be reflected in the contractual performance measures of the sub-concessionaire (e.g., Hensher and Stanley, 2003). Typically, public transit system fares are governmentally regulated, and sub-concessionaires are vested, under, e.g., gross cost contracts, with contractual property rights over the farebox collection. In these instances, sub-concessionaires' contracts may require them to fulfill some stewardship duties, such as fare collection monitoring and fare evasion control, although they do not have incentives to ensure farebox revenue collection.[10]

According to Weitzman (1980), an incentive contract is «a linear payment schedule where the buyer pays a fixed fee plus some proportion of project cost». This theoretical approach to efficient contracting, based on a tradeoff between risk-sharing and incentives, may be suitable for practical implementation. Transit service contracts may include monetary incentives based upon a specific performance metric to motivate contractors to outperform services beyond the goals contractually stipulated. Similarly, contracts may also involve monetary penalties to be enforced whenever non-compliance with contractual service goals occurs. PBCs typically include monetary penalties - a malus - to be enforced whenever contractual service goals, such as ridership, service

[7] As posited in Maskin and Tirole (2008), «the marked increase in PPP contracts worldwide is often attributed less to the intrinsic qualities of such contracts than to governments' attempts to evade budget constraints by taking liabilities off the balance sheet». See also Vaslavskiy and Vaslavskaya (2019).

[8] According to Nash (1963), incentive contracting, and more generally performance-based contracting, was firstly used in the U.S. Armed Services procurement (see also, Xiang et al., 2017; Gericke et al., 2014).

[9] Prior work suggests that PBC of transit service provision is consistent, under specific budgetary, regulatory, and geographical conditions, with the principle of social surplus maximization. However, competitive tendering may be less effective (Hensher and Stanley, 2008). See Sheng and Meng (2020) for a recent comprehensive review of the literature on contracting out in transit service markets.

[10] During the 1990s, institutional initiatives emerged to foster modal integration as a facilitator of sustainable mobility in larger cities and their metropolitan areas (e.g., EMTA, https://www.emta.com). See Mulley and Yen (2020) for further discussion on modal integration, and Preston and Walters (2020) concerning multimodal integration - light rail, bus, and rail.

standards in terms of, e.g., quality and frequency, and level of customer satisfaction, are not met (e.g., Hillman and Feigenbaum, 2020).[11]

Literature on incentives contracting at large, and competitive tendering in transit services in particular, report, among the more ubiquitous contractual arrangements: (a) the cost-plus contract; (b) the gross cost contract; and (c) the gross cost contract with incentives (see, e.g., Glachant et al., 2012; Laffont and Tirole, 1993). Further, in a recent review of contract design, Preston and Walters (2020) identify the gross cost approach for urban public transport provision with penalties for underperformance, and incentives for outperforming, as a way to specify efficiently contract outputs.

In cost-plus contracts, the sub-concessionaire receives compensation for all the contractually stipulated expenses, as well as additional payment as profit. The more conspicuous features in a cost-plus contracting model, include: (*i*) the assignment of farebox revenue property rights to the concessionaire; (*ii*) the sub-concessionaire being reimbursed for operating costs, which may include a management fee; (*iii*) no commercial or operational risk-sharing; and (*iv*) the only incentive for cost control is the risk of contract non-renewal.[12]

A gross cost type of contract is awarded to the lowest gross cost bidder. In this case, property rights of farebox revenue are assigned to the concessionaire. The sub-concessionaire is compensated with a specified monetary sum, submitted to competition, for providing the specified operation services stipulated in the contract, which typically also includes penalties for non-compliance. Finally, the sub-concessionaire is not exposed to commercial risk but is exposed to operational risk.

In a 'gross cost with incentives' contracting arrangement, the farebox revenue is the property of the concessionaire. The sub-concessionaire is remunerated based on a demand-based criterion, for example ridership measured in pax-km, which is submitted to tendering. It constitutes an incentive for a sub-concessionaire to increase their remuneration, promoting actions to foster demand. In this contracting model, the sub-concessionaire is exposed to operational and demand risk, through a Bonus / Malus (B/M) monetary incentive mechanism, which provides the incentive for the sub-concessionaire to engage in actions to increase ridership over time.[13]

This paper develops a version of a gross cost with incentives contracting model, which served as the basis for an international tender offer to operate and maintain MdP's light-rail system.

3. Methodological considerations and model specification

3.1. Background

The set of assumptions underlying the specification of our 'gross cost with incentives' contracting model includes a 7-year contract term, transit fares set at the regulatory level, farebox collection under the concessionaire's responsibility, and a transit demand function estimated under the concessionaire's jurisdiction.

Transit demand functions have been estimated under different econometric specifications. Our modeling setup is methodologically anchored in a log–log regression econometric approach to estimate a transit demand function, the 'reference demand'. Several methodological arguments endorse the use of isoelastic demand functions to estimate the ridership of public transit systems. One argument, favoring the use of this non-linear regression specification, is anchored in the particularly interesting feature of the explanatory variable's coefficient estimators measuring the constant partial elasticities for the dependent variable (e.g., García-Ferrer et al., 2006; Nijkamp and Pepping, 1998; Oum et al., 1992).[14]

The regressors most frequently used in econometric models for estimating transit demand include, among others, disposable income, fuel prices, prices of other transport modes, and variables associated with demography, such as the resident population and the rate of activity (e.g., Holmgren, 2007; Garcia-Ferrer et al., 2006). Next, we present the model set-up.

3.2. Model Set-Up

The specification of our Bonus/Malus (B/M) model assumes that: (*i*) the transit system is fully integrated in a multimodal fare structure common to all transit modes - bus, light rail and commuter rail - in the relevant transit network; (*ii*) the fare structure is served by a contactless ticketing technological platform, which enables single fare revenue sharing among participating operators; (*iii*) the public concessionaire, thereafter the concessionaire, outsources from professional consultancy experts; (*iv*) a standard costing estimation of both the fixed and variable costs of the transit system's operation, to ensure that the sub-concessionaire's compensation is based on efficient costing benchmarks[15]; (*v*) a long-range (20 to 30 years), including a demand forecast under previously validated methodology and assumptions; (*vi*) the concessionaire defines a mandatory minimum system operation schedule (MOS) for the transit network on its current configuration, based on the 'reference demand' stipulated in the tender requirements; (*vii*) stipulates the maximum profit margin, m, which the sub-concessionaire is allowed; and (*viii*) defines the upper (UL) and lower limits (LL) of a demand band.[16]

The 'reference demand' (*RD*), is specified as:

$$Y = aX^b Z^c \tag{1}$$

where Y denotes *RD*; X, the ratio of the individual average monthly out-of-pocket expenses with individual private transportation (*EIT*), including fuel, parking, and freeway tolls, to the average monthly out-of-pocket expenses with public transportation (*EPT*), the average cost of a non-subsidized monthly season ticket; Z, is the active population in the geographical area of influence of the transit system; a, is the independent term of regression equation; b, is the partial constant elasticity of Y on X; and c, is the partial constant elasticity of Y on Z.[17]

The sub-concessionaire's compensation scheme has three components. The first, R_F, covers the operator's fixed costs incurred in fulfilling their contractual obligations computed:

$$R_F = [(k_F)(1 + m)]V_{km} \tag{2}$$

where k_F denotes 'vehicle_Km fixed cost', m denotes a percentage profit margin allowance, and V_{km} denotes the annualized vehicle_Km

[11] The rationale for stipulating the sub-concessionaire's contractual incentives should reflect the concessionaire's expectations on cost efficiency gains, operating improvements, and patronage increases.

[12] Cost-reimbursement contracts contrast with fixed-price contract, in which contractors are paid a negotiated monetary amount regardless of the expenses incurred in the provision of the services outlined in the contract.

[13] It is only exposed to the quantity component of the commercial risk because, in addition to transit fares being governmentally regulated, farebox revenue is collected by the concessionaire.

[14] Under a bonus/malus incentive contract, the mechanisms a sub-concessionaire may adopt to increase patronage to maximize bonus requires a minimum period for producing output effects and for internalizing the associated costs.

[15] Cost benchmarks should allow the 'vehicle_Km' standard cost to be estimated and decomposed into 'vehicle_Km fixed standard cost' (k_F), and 'vehicle_Km variable standard cost' (k_V), which are the main elements of the sub-concessionaire's remuneration contractual arrangement.

[16] As the MOS is not subject to competition, the contract should include penalty provisions for non-compliance.

[17] The inclusion of the ITC/PTC ratio as an explanatory variable is made based on the assumption that both the numerator and denominator vary inelastically to transit demand.

production during the time horizon of the contract. The expression $[(k_F)(1+m)]$, which quantifies the 'profit adjusted vehicle_Km fixed cost', is submitted to competitive bidding. The second, R_V, covers the operator's variable costs:

$$R_V = [(k_V)(1+m)]V_{km} \quad (3)$$

where k_v denotes the 'vehicle_Km variable cost'. The expression $[(k_V)$ x $(1 + M)]$, profit adjusted vehicle_Km variable cost, is submitted to competitive bidding.[18]

The third component is the B/M annual reward, which embeds a performance-based incentive mechanism, to promote the alignment of concessionaire and sub-concessionaire's interests in a public transit operation services contract.

For fairness and equitability, the performance of the B/M model should be insensitive to the changes in any factor out of the sub-concessionaire's control, which may affect contractual performance. To that end, the annual realized demand during the contractual term is adjusted on a yearly basis, for the changes in the elasticities computed for each year of the contract term, and the partial constant elasticities implicit in the reference demand function and contractually stipulated.

The annual B/M is a function of the relative performance of the 'adjusted realized demand' in period t, in relation to the 'reference demand' in the same period, both measured in 'Passenger x Km' (Pax_{km}), whenever the first is outside the 'demand band' (DB), defined by its lower (LL) and upper (UL) percentual limits (Fig. 1).

Whenever the annual adjusted realized demand falls within the DB, no B/M is due. The annual B/M value is computed using the following formula:

$$B/M_n = \alpha\left[abs\left(\frac{Adjusted\ Realized\ Demand_n - Reference\ Demand_n}{Reference\ Demand_n}\right)^{\beta}\right](R_{F_n} + R_{V_n}) \quad (4)$$

where α and β are parameters contractually defined by the concessionaire assuming a law of diminishing marginal returns.[19]

The realized demand is adjusted yearly through the quotient of the independent variable annual elasticities of X and Z to the realized demand dependent variable [see equations (6) and (7)] and the contractually stipulated implicit partial constant elasticities, b and c:

$$Adjusted\ Realized\ Demand_n = Realized\ Demand_n \frac{E_{Y_n\ to\ X_n}}{b}\frac{E_{Y_n\ to\ Z_n}}{c} \quad (5)$$

where $E_{Y_n\ to\ X_n}$ denotes variable Y elasticity to X in year$_n$, $E_{Y_n\ to\ Z_n}$ variable Y elasticity to Z in year$_n$, and b and c are the implicit partial constant elasticities of Y to X and Z, respectively as:

$$E_{Y_n\ to\ X_n} = \frac{\log\left(\frac{Realized\ Demand_n}{10^6}\right) - \log a - c\log Z}{\log X} \quad (6)$$

and

$$E_{Y_n\ to\ Z_n} = \frac{\log\left(\frac{Realized\ Demand_n}{10^6}\right) - \log a - b\log X}{\log Z} \quad (7)$$

[18] Contractual provisions should enact the annual application of an escalation formula to both k_F and k_V, to adjust for price level changes, and warrant that competitive market conditions are adequately enforced.

[19] The upper limit of the bonus mechanism is asymptotically limited by the maximum load factor implied by a maximum 4 per m^2 passenger occupation, assumed as the lowest admissible passenger's comfort level (e.g., Lomas, 2009).

4. Empirical analysis

4.1. Bootstrapping Monte Carlo simulation analysis

As a closed-form solution for the B/M model is not analytically tractable, and proprietary information for a clinical study is unavailable, we use Monte Carlo (MC) computational numerical methods to approximate a solution for the model (e.g., Charnes, 2012; Vose, 2008).

In the simulation procedure, we conducted a statistical bootstrapping multiple-simulation to describe the behavior of the B/M model, incorporating stochastic variability into our deterministic base case (e.g., Alexander, 2008; Siegl and West, 2001). The MC simulation analysis, was performed assuming the demand band limits, and parameters a, b, and c of equation (1) as deterministic (see Table 1).[20]

To implement the bootstrap multiple-simulation, we randomized Equation (4)'s parameters α, β, and the input variables "expenses with individual private transportation" (*EIT*), "expenses with public transportation" (*EPT*), respectively, numerator and denominator of the X independent variable, and "realized demand", which were heuristically specified and calibrated (see Table 2.).

Under those assumptions, specifications, and parameterizations, and defined the simulation's output variable the B/M for each year of the contract term, we performed ten simulation experiments, each one with the number of trials necessary to generate a numerical approximation to the true distribution of the output variable distribution, at the standard 95 percent confidence level.[21] Results are summarized in Table 3..[22]

Simulation results suggest that, over the contract term, the yearly and the accumulated B/M estimated under the deterministic approach tend, as expected, to overestimate the stochastic procedure, 0.760 percent *versus* 0.266 percent of the sub-concessionaire's contractual monetary compensation, respectively. It is worth noting that both percentages are evidence that the model's performance appears sensitive to the variability of the B/M drivers, and responsive to changes in the contractual performance factors out of the sub-concessionaire's control. The grand mean of the ten simulation runs documents a decreasing trend in the annual B/M percentual score, from a 1.331 percent bonus in the first year of the contract term, to a −0.662 percent malus, in the last year. This may be explained by the sub-concessionaire's incentives to control costs when approaching contract maturity.

4.2. MdP's operating performance analysis

MdP is a governmentally owned concessionaire, operating under vertical separation, and is one of the largest light-rail networks in Europe, in operation since 2002. It is worth mentioning that it received the International Association of Public Transport's (UITP) Light Rail Award/2008. It is also fully integrated into a multimodal fare structure that has been in place since MdP's operation debut.

According to concession rules XXI and XXII, at the end of the initial period of operation, MdP ought to contract the operation and maintenance of its entire light-rail system to a sub-concessionaire following a competitive procurement procedure, promoting significant and effective

[20] The Monte Carlo simulation was carried out using the software "Oracle Crystal Ball", release 11.1.2.4.900 (64-bits).

[21] Under the linearity principle, the mean of the means of 10 independent and identically distributed simulations, is equivalent to drawing 10 samples from a single simulation. However, the higher the number of simulation trials we run, the closer the approximation to the true distribution. For further details on Monte Carlo simulation implementation with Oracle's Crystal Ball, see, e.g., Charnes (2012).

[22] Detailed results are available from the authors, upon request from registered Oracle Crystal Ball (64-bits) licensees.

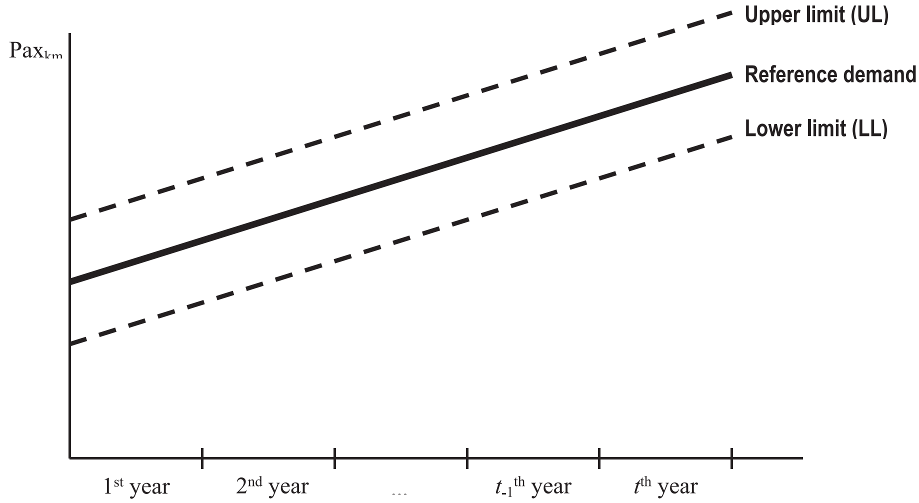

Fig. 1. Demand band.

Table 1
B/M simulation: base case assumptions. The demand band limits were set similarly to MdP's contract. Parameters a, b and c were assumed based on authors' own estimation of equation (1). The sub-concessionaire's compensation was estimated based on the value of MdP's 2010–14 contract, adjusted for a 7-year contract term.

Demand band limits	+3% / −3%
Equation A.2's parameter a	2.500
Equation A.2's parameter b	0.950
Equation A.2's parameter c	0.450
Sub-concessionaire's contractual compensation ($R_F + R_V$) (euros)	285,315,119

Table 2
B/M simulation: base case stochastic variables specification. Parameters, variable, and probability distributions were heuristically specified by the authors.

Variable / Parameter	Base Case	Probability Distribution	Parameter Estimates
Equation (4)'s parameter α	0.15	Uniform	minimum: 0.05; maximum: 0.20
Equation (4)'s parameter β	0.95	Uniform	minimum: 0.85; maximum: 1.00
EIT (euros)	825	Lognormal	mean 825; standard deviation 83
EPT (euros)	359	Lognormal	mean 359; standard deviation 36
Realized demand (Pax_{km})	270.10^6	Triangular	minimum: 250.10^6; most likely: 270.10^6; maximum: 300.10^6

risk transfer to the sub-concessionaire (article no. 413 of the Portuguese Public Procurement Code, Decree-Law no. 18/2008).[23] As of the 2008 year-end, MdP owned a railroad extension of 59.6 km in the Porto metropolitan area, of which 7.7 km was railway tunnel, with 70 stations.[24] In 2009, MdP conducted its first international tender to operate and maintain its light-rail system during the 2010–2014 contract period.[25] In 2014, this operation and management contract was extended to 2016.

To explore the differential operating performance of MdP and MdL over the 2010–2016 period, we conduct a quasi-natural experiment of those two urban railway systems, which operate, one under vertical separation (MdP), and the other under vertical integration (MdL).[26] In this analysis, we contrast the performance levels of ridership performance, operating, farebox revenue and cost efficiency, and coverage ratio.

Based exclusively on publicly available information from MdP's website, Table 4 presents some key performance indicators for the 2010–2014 contract term and its extension to 2016. During this period, the vertically separated operation of MdP experienced the following average performance improvements: (*i*) demand, measured in terms of pax-km, increased 10.9 percent, while supply, measured in seat-km, rose 8.9 percent, indicating that the private contractor was able to respond to the increase in ridership, at a slower pace in supply, therefore contributing to the cost efficiency effectiveness of the operation; (*ii*) the capacity utilization rate, measured by the pax-km to seat-km ratio, remained relatively stable around 18.1 percent (coefficient of variation: 3.0 percent); (*iii*) the operating revenue per pax-km (excluding operating subsidies) grew 23.7 percent, which dropped 10.5 percent when operating subsidies were included; (*iv*) a 19.5 percent decline in the operating cost per pax-km; (*v*) a 53.6 percent increase in the coverage ratio, measured by the quotient of operating revenue (excluding operating subsidies) to operating costs; and a 11.1 percent rise in the coverage ratio, where the numerator included operating subsidies.[27]

4.3. MdL's operating performance analysis

To conduct our natural-experiment analysis, we use MdL, a vertically integrated subway operation in the Lisbon metro area, as the control group. MdL is a more mature and relatively larger scale operation, both

[23] In 1998, MdP was awarded a concession to operate a light rail system in the Porto metropolitan area for a period of 50 years (Decree-Law no. 394-A/98, December 15, and Decree-Law no. 192/2008, October 1). For further details on the general description of MdP's concession (DBFO) contract, see van de Velde et al. (2008).See also, https://ec.europa.eu/growth/single-market/public-procurement/rules-implementation/concessions_en.

[24] 2008 was the first complete year of operation of MdP's full network.

[25] The contract term was extended to 2015 and 2016.

[26] See, e.g., Remler and Van Ryzin (2021) and Sun et al. (2020), respectively, for a methodological overview and application to a metro system of natural experiments.

[27] It is worth noting that MdP's and MdL's operation during the 2010–2016, was partially impacted by the application of a three-year (2011–2014) economic adjustment program, a financial assistance program signed between Portugal and the International Monetary Fund, the European Union and the European Central Bank.

Table 3
B/M simulation results. Parameters, variable, and probability distributions were heuristically specified by the authors. Base case refers to deterministic approach. A B/M is due only when the annual adjusted realized demand falls outside the demand band. The monetization of the B/M was estimated as the product of the B/M in percentage points by the sub-concessionaire's annual compensation (= € 285,315,119 / 5-year contract term, plus 2-year extension).

	Bonus/Malus								
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	
Simulation No.	Trials	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Total
1	10.150	1.316%	0.878%	0.539%	0.185%	-0.055%	-0.371%	-0.654%	1.839%
2	10.350	1.337%	0.893%	0.549%	0.187%	-0.054%	-0.377%	-0.665%	1.870%
3	10.050	1.330%	0.889%	0.546%	0.187%	-0.054%	-0.375%	-0.662%	1.861%
4	10.300	1.340%	0.894%	0.550%	0.189%	-0.054%	-0.374%	-0.663%	1.882%
5	10.550	1.329%	0.887%	0.544%	0.185%	-0.056%	-0.377%	-0.664%	1.848%
6	10.100	1.330%	0.887%	0.545%	0.184%	-0.056%	-0.378%	-0.663%	1.850%
7	10.450	1.334%	0.891%	0.547%	0.187%	-0.055%	-0.376%	-0.664%	1.863%
8	10.650	1.327%	0.886%	0.544%	0.186%	-0.057%	-0.377%	-0.663%	1.847%
9	10.000	1.327%	0.886%	0.545%	0.187%	-0.054%	-0.373%	-0.659%	1.860%
10	10.600	1.340%	0.895%	0.549%	0.189%	-0.057%	-0.378%	-0.667%	1.870%
Grand mean		1.331%	0.889%	0.546%	0.187%	-0.055%	-0.376%	-0.662%	1.859%
Base case		3.030%	2.052%	1.318%	0.726%	0.000%	-0.627%	-1.176%	5.323%
B/M simulation (euros)		542.496	362.217	222.505	76.040	-22.465	-153.093	-269.967	757.731
B/M base case (euros)		1,235,116	836.287	537.225	295.974	0.000	-255.376	-479.439	2,169,786

Table 4
MdP: Performance measures during the 2010–16 period. Operating revenue$_1$ refers to farebox revenue. Operating revenue$_2$ includes both farebox revenue and operating subsidies. Capacity utilization rate is computed as the ratio between Pax-Km and Seat-Km. Coverage ratio is computed as the ratio between Revenue/Pax-Km and Operating costs/Pax-Km.

MdP	2010	2011	2012	2013	2014	2015	2016
Pax-Km (10^6)	267.064	290.700	282.480	285.591	288.136	294.450	296.076
Seat-Km (10^6)	1,464.411	1,540.170	1,627.459	1,608.552	1,637.959	1,630.722	1,594.742
Operating revenue$_1$ (10^6 euros)	30.649	34.945	37.370	38.879	39.685	40.993	42.029
Operating revenue$_2$ (10^6 euros)	45.191	49.637	51.735	52.415	50.523	45.191	49.637
Operating costs (10^6 euros)	42.570	42.092	43.217	43.580	45.898	38.691	38.006
Capacity utilization rate (%)	18.2	18.9	17.4	17.8	17.6	18.1	18.6
Operating revenue$_1$/Pax-Km (euros)	11.48	12.02	13.23	13.61	13.77	13.92	14.20
Operating revenue$_2$/Pax-Km (euros)	16.92	17.08	18.31	18.35	17.53	14.94	15.14
Operating costs/Pax-Km (euros)	15.94	14.48	15.30	15.26	15.93	13.14	12.84
Coverage ratio$_1$ (%)	72.0	83.0	86.5	89.2	86.5	105.9	110.6
Coverage ratio$_2$ (%)	106.2	117.9	119.7	120.3	110.1	113.7	118.0

Source: Primary data drawn from Metro do Porto's 2010 to 2016 annual reports, publicly available at: https://www.metrodoporto.pt/pages/338.

Table 5
MdL: Performance measures during the 2010–16 period. Operating revenue$_1$ refers to farebox revenue. Operating revenue$_2$ includes both farebox revenue and operating subsidies. Capacity utilization rate is computed as the ratio between Pax-Km and Seat-Km. Coverage ratio is computed as the ratio between Revenue/Pax-Km and Operating costs/Pax-Km. To have comparable figures between MdP and MdL, for MdL: (*i*) overall operating revenues were divided between fare revenue and operating subsidies, based on the information contained in the Annual Report on the amount of subsidies received annually by MoL; and (*ii*) operating costs include, as for MoP, staff costs, cost of goods sold, and external supplies and services.

MdL	2010	2011	2012	2013	2014	2015	2016
Pax-Km (10^6)	865.521	857.101	745.589	639.750	650.710	685.640	735.160
Seat-Km (10^6)	3,511.000	3,361.000	2,730.000	2,752.000	2,802.000	2,865.000	3,039.000
Operating revenue$_1$ (10^6 euros)	62.530	63.752	78.381	77.488	86.022	88.644	95.876
Operating revenue$_2$ (10^6 euros)	89.033	108.931	124.483	122.852	115.985	90.492	97.823
Operating costs (10^6 euros)	128.938	119.160	112.849	120.428	101.716	103.900	97.040
Capacity utilization rate (%)	24.7	25.5	27.3	23.2	23.2	23.9	24.2
Operating revenue$_1$ /Pax-Km (€ cents)	7.22	7.44	10.51	12.11	13.22	12.93	13.04
Operating revenue$_2$ /Pax-Km (€ cents)	10.29	12.71	16.70	19.20	17.82	13.20	13.31
Operating costs/Pax-Km (€ cents)	14.90	13.90	15.14	18.82	15.63	15.15	13.20
Coverage ratio$_1$ (%)	48.5	53.5	69.5	64.3	84.6	85.3	98.8
Coverage ratio$_2$ (%)	69.1	91.4	110.3	102.0 %	114.0	87.1	100.8

Source: Primary data drawn from MdL's annual reports, publicly available at: https://www.metrolisboa.pt/institucional/informar/relatorios-e-documentos/.

in terms of demand and supply, than MdP (see Table 5).[28]

Over the 2010–2016 period, the vertically integrated operation of MdL exhibited the following average performance indicators: (*i*) demand side wise, a non-negligible −15.1 percent drop in ridership; (*ii*) supply side wise, a 13.4 percent reduction in seat-kms, suggesting a suboptimal response to the lower patronage level experienced; (*iii*) a relatively steady average capacity utilization rate around 24.6 percent (5.9 percent coefficient of variation) (*iv*) the operating revenue per pax-km (excluding operating subsidization) increased 80.5 percent, and the operating revenue per pax-km (inclusive of operating subsidies) grew 29.4 percent; (*v*) an 11.4 percent reduction in operating cost per pax-km; and (*vi*) a 103.7 percent increase in the coverage ratio (exclusive of operating subsidies), and 46.0 percent inclusive of operation subsidization.

4.4. MdP versus MdL operating performance analysis

MdP and MdL operate under the same macroeconomic environment and institutional framework, and are both submitted to common regulatory discipline. However, although they share ownership, the model of operation of their railroad networks is segregated. MdP is operated under vertical separation, and MdL under vertical integration.

Based on the evidence presented in Table 6., we conclude that during the 2010–2016 period, MdP experienced a 10.9 percent increase in demand (measured in pax-km), and an 8.9 percent expansion in supply (measured in seat-km); and MdL scored a −15.1 percent drop in demand, and a −13.4 percent decrease in supply. These findings document that MdP achieved a higher level of operating efficiency, measured by the pax-km to seat-km ratio. In terms of operating revenue efficiency (including governmental subsidization), MdP reflected a 23.7 percent improvement during the 2010–2016 period, and MdL 29.4 percent. However, over the period, the subsidization to farebox ratio was 27.9 percent for MdP and 35.6 percent for MdL. This result indicates that revenue efficiency for MdP was achieved with lower dependency on governmental subsidization. It should be noted that MdL's higher dependency on governmental subsidization might have been related, among other factors, to the 15.1 percent drop in demand during the period.

Regarding cost efficiency, measured by operating costs per pax-km, MdP achieved a 19.5 percent decrease, and MdL an 11.4 reduction. Finally, MdP exhibits, on average, an economic efficiency, measured by the operating revenue to operating cost ratio, of 90.5 percent, excluding operating subsidies, and 115.1 percent including operating subsidies, while MdL achieved 72.1 and 96.4 percent, respectively.

Overall, MdP, during the 2010–2016 contract term, exhibits higher operating, revenue, cost, and economic efficiency than MdL. Results document that a vertically separated operation of an urban railroad system under a performance-based contract, appears more responsive, in terms of performance efficiency, than a system operated under vertical integration. For example, concerning operating efficiency, MdP was more effective than MdL in adjusting supply to demand dynamics. In fact, whenever a sub-concessionaire is exposed to operating costs risk, they might need an incentive mechanism, like a B/M, to trade-off the potential cost gains associated with optimizing supply, eventual losses in quality service and ridership.

Finally, both MdP and MdL faced non-negligible economic unbalance, in 2010, measured by the coverage ratio (excluding governmental subsidization), in their operations: 72.0 and 48.5 percent, respectively. Therefore, it is fair to conclude that MdP, in terms of operation during the 2010–2016 period, was less dependent on public money when it came to balancing the economics of its operation.

Table 6

Performance measures during the 2010–16 period. This table presents the percentage variation during the 2010–2016 period, except for the coverage ratios for which we calculate the average for the same period. Operating revenue$_1$ refers to farebox revenue. Operating revenue$_2$ includes both farebox revenue and operating subsidies. Coverage ratio is computed as the ratio between Revenue/Pax-Km and Operating costs/Pax-Km.

	MdP %	MdL %
Operating efficiency		
Pax-Km	10.9	−15,1
Seat-Km	8.9	−13.4
Revenue efficiency		
Operating revenue1/Pax-Km	23.7	80.5
Operating revenue2/Pax-Km	−10.5	29.4
Cost efficiency		
Operating costs/Pax-Km (€ cents)	−19.5	−11.4
Economic efficiency		
Coverage ratio1 (%)	90.5	72.1
Coverage ratio2 (%)	115.1	96.4

Source: Tables 4 and 5.

5. Summary and concluding remarks

Despite the extensive literature on the benefits and pitfalls of contracting out the provision of public urban railroad operation services, few studies have addressed specific incentive mechanisms to promote the alignment of the interests of the parties involved in such contract arrangements. Extant literature highlights the promotion of ridership, and operating cost efficiency gains, as major determinants of competitive contracting out of public transit systems. This paper contributes to this field of literature by developing a bonus/malus (B/M) incentive model.

We use randomized computational methods to show that our B/M model is sensitive to the variability of the B/M drivers, and responsive to changes in the contractual performance factors out of the sub-concessionaire's control. In addition, the MdP light-rail data drawn from publicly available annual reports documents, in line with the predictions derived from our model design, that the implementation of a performance-based contract with an incentive B/M mechanism, may have contributed to improving ridership patronage, increasing the average ride, and ultimately significantly improving the overall economic operating efficiency of the system. In addition, when comparing MdP with MdL we show that the former, because the operation has been procured and contracted under vertical separation with a B/M mechanism, shows higher revenue, cost, and activity level efficiency. Additionally, results also suggest that the periodic competitive procurement of metro network operation services (as is the case of MdP) has the advantage of potentially capturing cost efficiencies. Furthermore, the fact that the incumbent sub-concessionaire has no contract renewal guarantee, creates incentives for reaping potential operating efficiency gains.

Overall, our results are important for policy makers concerned with the efficient allocation of public resources, as we show that MdP appears more responsive in terms of performance efficiency, and less dependent on governmental subsidization than the MdL.

The 2008 financial crisis, the European sovereign debt crisis, and the Covid-19 pandemic placed world economies under considerable strain, requiring innovative public policies to bring together the public and private sectors. The development of alternative contract awarding

[28] MdL received the concession for the installation and operation of the respective Public Service in 1949. Construction work began in 1955 and ended, on the current configuration of the network, in 2016. The operation of the first three lines of the system started in 1963. In 1978, after its nationalization in 1975, MdL became a publicly owned company (https://www.metrolisboa.pt/institucional/conhecer/historia-do-metro/, accessed on April 18, 2022). During the 2010–2016 period, MdL owned and operated a 44.5 km of subway system, with 4 lines and 56 stations.

mechanisms is thus of increasing importance, namely, those that allow the provision of public transit services that achieve the economic, social and welfare goals underlying governmental contracting out for infrastructure development and operation. We consider this to be an important avenue for future research. In addition, we think that further application of our incentive performance-based approach model to public services that are contracted out in general, using different case studies, would be very valuable in testing the robustness of our model.

Authors gratefully acknowledge the consent given on March 30th, 2011, by Ricardo Fonseca, former Chairman and CEO of Metro do Porto (MdP), to refer to MdP's 2009 international tendering in this paper. We are also very thankful for the insightful discussions, useful comments and suggestions of Álvaro Costa, Aníbal Santos, Carlos Cruz, José Magano, and the excellent research assistance provided by Ana Madeira. An early version of this paper circulated under the title "Contracting Out Public Transit Services: An Incentive Performance-Based Approach". Pedro Matos gratefully acknowledges financial support, via ADVANCE-CSG (ISEG), from the Fundação para a Ciência and Tecnologia (FCT Portugal) through the research grant UIDB/04521/2020. João Pinto also acknowledges financial support from FCT Portugal (through project UIDB/00731/2020). Mário Santos has not received any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. João Pinto is the corresponding author and can be reached at: jpinto@ucp.pt; Rua de Diogo Botelho 1327, 4169–005 Porto, Portugal. The authors confirm that there is no conflict of interest to declare.

CRediT authorship contribution statement

Mário Coutinho dos Santos: conceptualization, methodology, data curation, investigation, writing - original draft, writing – reviewing and editing, supervision. **João M. Pinto:** conceptualization, methodology, investigation, writing - original draft, writing – reviewing and editing, funding acquisition. **Pedro V Matos:** conceptualization, methodology, investigation, writing - original draft, writing – reviewing and editing, funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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