Efficiency and Productivity Analysis

Two Empirical Applications and a Methodological Contribution

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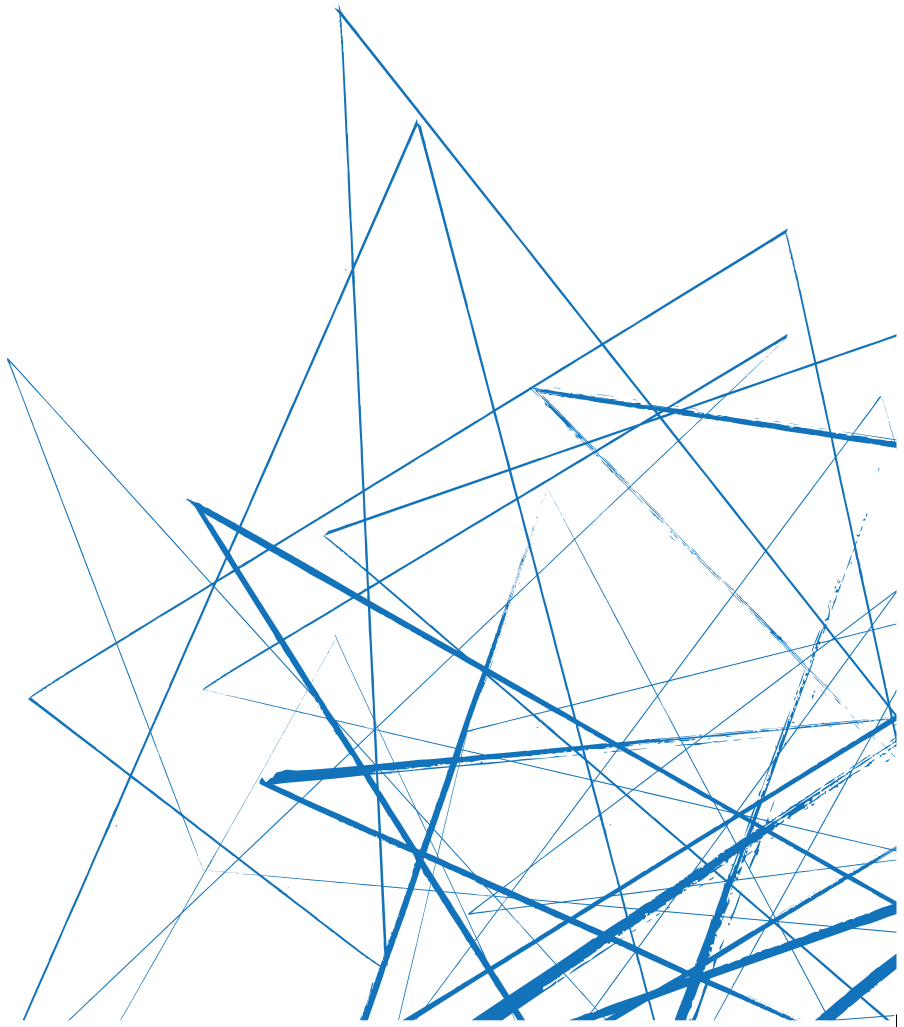

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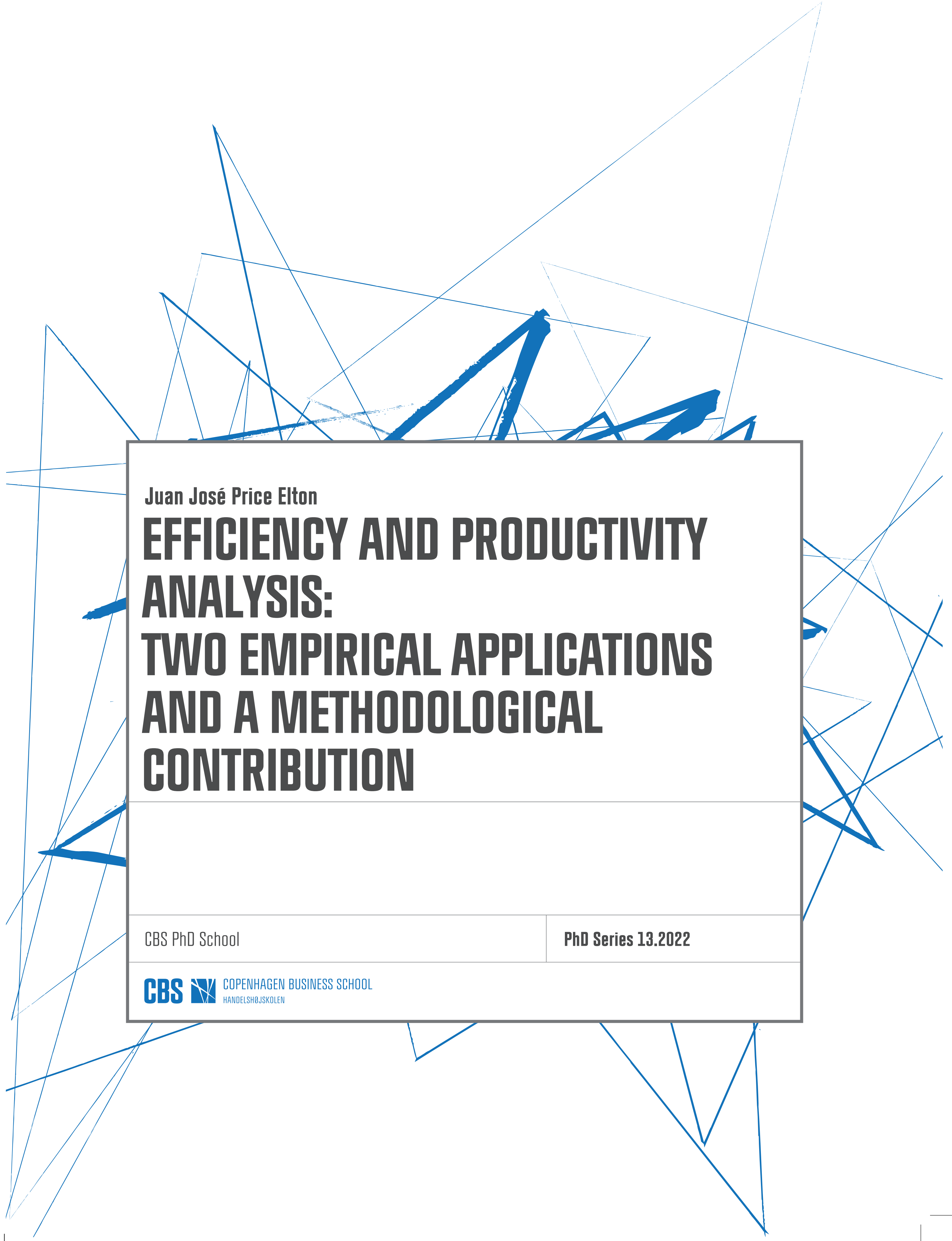

Juan José Price Elton

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EFFICIENCY AND PRODUCTIVITY ANALYSIS: TWO EMPIRICAL APPLICATIONS AND A METHODOLOGICAL CONTRIBUTION

JUAN JOSE PRICE ELTON

Submitted in partial fulfilment of the
requirements for the degree of
Doctor of Philosophy
in the Department of Management, Politics and Philosophy

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JUAN JOSE PRICE ELTON
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To my parents

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Frankly, I wonder how I reached this point, but here I am, and the people referred to above are partly to be blamed for that.

ABSTRACT

In this thesis some tools from the literature in efficiency and productivity analysis are relied upon to assess the economic performance of two sectors: the Danish state-recognised museums and the urban public transport systems of some Latin American cities. These sectors are regulated and partly funded by the state, hence these analyses are important not only from an academic perspective but also in terms of their policy implications. The thesis comprises an introductory chapter, three separate papers and a concluding chapter. The first paper analyses with stochastic frontier models the influence public funding may have on the technical efficiency of museums, considering the multiple cultural and educational services delivered by these organisations. Consistency with microeconomic theory is ensured by imposing monotonicity conditions, something that hasn't been done before in an input-oriented setting, which this model employs. The second paper (co-authored with Arne Henningsen) develops an input-oriented stochastic ray function, which is suitable for the analysis with logarithmic functions of sectors where control over inputs is greater than that over outputs and where some productive entities do not produce the entire set of outputs, a problem that is pervasive in various economic sectors. We also address a critique the ray function has been subject to, namely that it might be sensitive to the ordering of outputs, and demonstrate how to impose monotonicity conditions to its input-oriented version. We test the methodology with the same database as that of the first paper. The third paper (co-authored with Andrés Gómez-Lobo) examines the empirical validity of the Baumol Cost Disease theory in the transport sector. This theory, originally proposed in the field of cultural economics, states that whenever labour productivity is stagnant, labour-saving technical change is rather absent and labour markets are integrated, costs increase in relation to those of the general economy, which in the case of transit systems generates significant fiscal pressures. The paper tests this proposition, as well as possible (partial) solutions to the problem, using data for two less-developed countries, contributing to a body of literature that, besides being scarce, has focused only on developed countries.

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Summary

In this thesis some tools from the literature in efficiency and productivity analysis are relied upon to assess the economic performance of two sectors: the group of state-recognised museums in Denmark and the urban public transport systems in two Latin American countries. Given that both sectors are comprised of productive entities that are partly or totally funded by the state, these analyses are of particular importance not only from an academic perspective but also in terms of their policy implications. In addition, since the project makes in one of its chapters an original contribution in the field of productivity analysis, its findings are of interest when it comes to assessing the economic performance of other sectors as well.

The thesis comprises an introductory chapter, three separate but related papers, and a concluding section. The first paper analyses the group of museums referred to above in terms of the influence public funding may have on their technical efficiency. The paper estimates stochastic frontier models based on a Shephard's distance function considering the multiple outputs of these organisations. This is the first time parametric methods have been used to address these questions in a multi-output setting. Besides, a linear programming method is used to impose monotonicity conditions on the models estimated, thus making them consistent with economic theory. This is the first time this method is applied in an input-oriented setting, which this paper employs. We find that at least in the case of these museums, the effect of public funding on technical efficiency is positive and statistically significant, a conclusion that stands against that of the previous literature, which finds that effect to be negative, but considers a single-output setting, employs a different, less satisfactory indicator of public funding, doesn't control for (presumably important) environmental variables, and doesn't estimate the corresponding marginal effects.

The second paper (co-authored with Arne Henningsen) makes a methodological contribution in the field of productivity analysis. It develops and tests an input-oriented stochastic ray function, which is suitable for the analysis of sectors where control over inputs is greater than that over outputs. Moreover, the paper solves another problem, namely the impossibility to include in the analysis with stochastic frontier analysis based on logarithmic production functions (a common practice), those observations presenting one or more outputs that are not strictly positive. These aspects are of particular importance in the case of various economic sectors, including this group of museums. The paper also makes an empirical contribution in the field of cultural economics, as the model is tested with the same database as that of the first paper and allows to consider the entire universe of museums at the national level, regardless of whether they produce all or a subset of the outputs considered in the analysis. We estimate average technical efficiency, the elasticity of scale, and the influence of some environmental variables on the production frontier. We also demonstrate how to impose monotonicity on ray-based input distance functions and address a weakness of the stochastic ray function, namely its sensitivity to the outputs' ordering.

The third paper (co-authored with Andrés Gómez-Lobo) tests the empirical validity of the Baumol Cost Disease theory in the transport sector. This theory states that in some economic sectors labour productivity is stagnant, which may have undesirable consequences in terms of average costs of production, provided some assumptions are satisfied. It is theoretically plausible that the Baumol Disease may be present in urban public transport services. The paper tests this proposition using data from two less-developed countries (Argentina and Colombia), contributing to the analysis of this theory in a new setting, as it has only been applied so far to the analysis of transport services in two developed countries: Germany and the United States. The policy implications of this analysis are particularly important, as a stagnation of labour productivity coupled with the absence of labour-saving technical change may generate significant fiscal pressures. Possible aggravating factors are analysed, as well as a possible antidote, namely the gains in total factor productivity (TFP) and technical change. The evolution of labour productivity is analysed relying on panel-data regression models and the changes in TFP and technical change are analysed with non-parametric techniques. The findings suggest the Baumol disease does affect this sector. In terms of technical change there is mixed evidence.

The three papers are connected in a number of respects, the three most evident being the use of efficiency and productivity analysis to answer different questions that are relevant from an academic and policy perspective, the fact that the productive entities analysed, although not state-owned, are regulated and partly funded by the public sector, and the protagonism of the field of cultural economics, because one particular cultural sector is analysed (first and second papers) and a theory originally developed in this field has inspired an empirical analysis in another sector (third paper). In fact: (i) the first paper represents an empirical contribution in the economic analysis, with parametric methods, of museums as multi-output productive entities, thus making a contribution in the field of cultural economics; (ii) the second paper makes a contribution in the field of productivity analysis by developing a methodological approach that can be useful in the analysis of productivity and efficiency in many sectors where control over inputs is greater than that over outputs and where some productive organisations do not produce the entire range of outputs under analysis (this second paper uses museums' data to test this new methodology, although the methods developed are capable of much wider application, and the main contribution is in fact methodological); and (iii) the third paper makes an empirical contribution by testing the empirical validity of a theory originally proposed in cultural economics in public transport systems for the first time in less-developed countries.

Summary (Danish version)[1]

I denne afhandling anvendes værktøjer fra litteraturen i effektivitets- og produktivitetsanalyse til at vurdere den økonomiske ydeevne indenfor sektorer: gruppen af statsanerkendte museer i Danmark samt det urbane offentlige transportsystem i to sydamerikanske lande. Eftersom begge sektorer består af produktive enheder, som er helt eller delvist finansieret af staten, er analyserne af særlig vigtighed, ikke blot fra et akademisk perspektiv, men også i forhold til analysernes politiske implikationer. Da projektet tilmed kommer med et originalt bidrag indenfor produktivitetsanalyse i et af kapitlerne, er dets resultater af interesse, når det gælder bedømmelsen af andre sektorers økonomiske resultater.

Afhandlingen består af et indledende kapitel, tre separate, men relaterede artikler, samt et konkluderende afsnit. Den første artikel analyserer den ovenfor omtalte gruppe af museer med hensyn til den indflydelse, som offentlig finansiering kan have på deres tekniske effektivitet. Artiklen estimerer stokastiske grænsemodeller baseret på en Shephards afstandsfunktion under hensyn til organisationernes forskellige output. Desuden bruges en lineær programmeringsmetode til at pålægge monotonicitetsbetingelser på de estimerede modeller, hvilket gør dem i overensstemmelse med økonomisk teori. Det er første gang, at denne metode bliver brugt til at adressere disse spørgsmål i en output-orienteret setting som den, der er anvendt i artiklen. Vi finder, at i det mindste for disse museer er effekten af offentlig finansiering på teknisk effektivitet positiv og statistisk signifikant – en konklusion, der står i modsætning til den tidligere litteratur, som finder denne effekt negativ, betragter én enkelt outputindstilling, anvender en anden og mindre tilfredsstillende indikator for offentlig finansiering, mangler at kontrollere for (antageligt vigtige) miljøvariabler samt at estimere de tilsvarende effekter.

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[1] Translated by Kristina Kazuhara.

Den anden artikel (skrevet med Arne Henningsen) yder et metodisk bidrag inden for produktivitetsanalyse. Den udvikler og tester en inputorienteret stokastisk Ray funktion, som er velegnet til analyse af sektorer, hvor kontrol over input er større end over output. Desuden løser artiklen et andet problem, nemlig umuligheden af at medtage i analysen med stokastiske grænseanalyser baseret på logaritmiske produktionsfunktioner (en almindelig praksis) de observationer, der præsenterer et eller flere output, der ikke er strengt positive. Disse aspekter er af særlig betydning for forskellige økonomiske sektorer, herunder denne gruppe af museer. Modellen testes ved hjælp af den samme database som den første artikel, dog med et meget større antal observationer, inklusive dem med en værdi lig med nul for et eller flere output. Vi estimerer den gennemsnitlige tekniske effektivitet, skalaens elasticitet og indflydelsen af miljømæssige (kontrol) variabler på teknisk ineffektivitet. Nogle af resultaterne bekræfter resultaterne fra den første artikel, mens andre ikke gør det. Nogle mulige forklaringer på dette tilbydes. Vi adresserer også til en kritik, som den stokastiske Ray-funktion har været udsat for, nemlig at den er følsom over for rækkefølgen af output.

Den tredje artikel (skrevet med Andres Gomez-Lobo) tester den empiriske validitet af Baumol Cost Disease teorien i transportsektoren. Ifølge denne teori er arbejdsproduktiviteten i nogle økonomiske sektorer stagnerende og dette kan have uønskede konsekvenser i forhold til gennemsnitlige produktionsomkostninger, forudsat at nogle antagelser er opfyldt. Det er teoretisk sandsynligt, at Baumol-sygdommen kan forekomme i offentlige transporttjenester i byer. Artiklen tester denne proposition ved hjælp af data for to mindre udviklede lande (Argentina og Colombia), hvilket bidrager til analysen af denne teori i en ny kontekst, da den hidtil kun er blevet anvendt til analysen af transporttjenester i to udviklede lande: Tyskland og USA. De politiske konsekvenser af denne analyse er særligt vigtige, da en stagnation af arbejdskraftens produktivitet kombineret med fraværet af arbejdsbesparende teknisk forandring kan generere et betydeligt finanspolitisk pres. Mulige skærpende faktorer analyseres såvel som en mulig modgift, nemlig gevinsterne i total faktorproduktivitet (TFP). Udviklingen af arbejdskraftens produktivitet analyseres på baggrund af paneldata-regressionsmodeller, og ændringerne i total faktorproduktivitet (TFP) analyseres med ikke-parametriske tilgange. Resultaterne antyder, at Baumol-sygdommen påvirker denne sektor. I forhold til teknisk ændring er der blandet evidens.

Afhandlingens tre artikler hænger sammen i en række henseender, hvoraf de to mest tydelige er brugen af effektivitets- og produktivitetsanalyse til at besvare forskellige spørgsmål, der er relevante ud fra et akademisk og et politisk perspektiv; det faktum, at de analyserede produktive enheder, selv om de ikke er statsejede, er reguleret og delvist finansieret af den offentlige sektor; relevansen af det kulturøkonomiske forskningsfelt, hvor én bestemt kultursektor analyseres (første og anden artikel), og i og med at det var en teori, der oprindeligt var udviklet indenfor dette felt, der inspirerede den en empirisk analyse i en anden sektor (tredje papir). Faktisk: (i) repræsenterer den første artikel et empirisk bidrag til økonomisk analyse med parametriske metoder af museer som multi-output produktive enheder. Artiklen bidrager således til det kulturøkonomiske forskningsfelt; (ii) den anden artikel yder et bidrag inden for produktivitetsanalyse ved at udvikle en metodisk tilgang, der kan være nyttig i analysen af produktivitet og effektivitet i mange sektorer, hvor kontrollen over input er større end over output, og hvor nogle produktive organisationer gør ikke producere hele rækken af output under analyse. Denne anden artikel bruger museumsdata til at teste denne nye metode, selvom de udviklede metoder er i stand til at anvende meget bredere, og hovedbidraget faktisk er metodisk; og (iii) det tredje papir er et empirisk bidrag i forhold til at teste den empiriske gyldighed af en teori, der oprindeligt blev foreslået i kulturøkonomi indenfor offentlige transportsystemer for første gang i mindre udviklede lande.

Chapter 1

Introduction

1.1 Motivation for this project (or how I got here)

Some people have told me: "In my PhD project I started working on the topic A and have ended up working on the topic Z". In the case of this project the change between what I had in mind when I began working on it and what I present here was not so dramatic but it is true that what I have followed has been more a winding road with some diversions than a straight line.

I begin explaining what motivated me to get engage in this project in the first place. All started in July 2010 at Strand Bookstore, in New York. I was there taking a look at the titles in the Social Sciences section, and came across two titles: *The Economics of Art and Culture*, by James Heilbrun and Charles Gray (Heilbrun and Gray, 2001), and *The Economics of Cultural Policy*, by David Throsby, one of the main supervisors of this PhD project (Throsby, 2010). Cultural policy and economics? Arts and economics? What a surprise!, I thought. I wasn't aware of people taking a look at the realms of arts and culture with economic lenses. I bought those two books, became interested in the subject, went back to England to start the second year of my master's degree at The London School of Economics and ended up writing my dissertation comparing different public support schemes in the cultural sector.

I went back to my country, Chile, at the end of 2011, and started teaching an introductory course on this subject at two universities: Universidad de Chile and

Universidad Católica de Chile. I met at that time another prominent scholar in this field: Bruce Seaman. I sent him an email, without knowing him, asking whether he had an electronic version of a book chapter he had written back in 1987, a chapter that I wanted to give to my students. He sent me the document straight away and told me he was in Santiago (the capital of Chile) that day. This is too much of a coincidence, I thought. This man, who lives in the US, could be anywhere in the world and he happens to be here, in my country?! It seemed life wanted me to keep working in this research field. A few years later I met David Throsby in a conference in Santiago, where he had been invited as keynote speaker. I told him I was interested in doing a PhD under his supervision. We started exchanging emails and here I am, finishing my doctoral studies with him as one of the supervisors and supported by two universities: the Copenhagen Business School (CBS) an Macquarie University.

So then it was my turn to think about interesting research questions. And it is then when definitions became important. What is culture and how economics can shed light on some of its dimensions? As Throsby (2001) explains, agreeing on a definition of culture is not easy and, to illustrate this point, he quotes Borofsky (1998), who states that defining culture is *akin to trying to encage the wind*. Culture has, for instance, been defined by UNESCO as *the set of distinctive spiritual, material, intellectual and emotional features of society or a social group, and that it encompasses, in addition to art and literature, lifestyles, ways of living together, value systems, traditions and beliefs* (UNESCO, 2001). This definition doesn't however provide a terrain where meaningful economic questions can be addressed. We must instead adopt a more functional definition (Throsby, 2001). Culture defined this way is concerned with cultural goods, services and experiences, as well as with the institutions producing (or co-producing) them. I started focusing this project on one such institution, museums, by approaching a series of questions referring to their supply as productive organisations.

Why museums? My interest in museums is framed in the same terms as for cultural heritage organisations more generally. In fact, not only museums but also archives and public libraries are institutions related to this field of interest and I had done some work on libraries in my country before starting this project (Price et al., 2017). Moreover, in the economics literature dealing with the museum sector, there are important questions that haven't been approached satisfactorily, if they have been approached at all. Contributing to fill this knowledge gap would seem to be of interest not only from an academic point of view but also to inform the way these institutions are managed. In addition, this field involves a number of issues of relevance to the formation and implementation of public policy.

Thinking about all this, I came up with research questions that concern some related topics: (i) how does public funding affect museums' ability to reach their goals more efficiently?, and (ii) do museums present any particular characteristics related to their economic structure and/or the nature of their activities that prevent labour productivity from increasing over time?

Only the first of these questions had been addressed in the economics literature, but these studies were restricted to considering museums as single-output organisations or with methodologies that didn't consider the influence of statistical noise. In the case of the second question, only some theoretical speculations had been put forward in the literature, but there is not a single attempt to address the topic empirically. My motivation therefore was to fill a gap in the literature by approaching these questions in a way that treats museums as complex, multi-output organisations and that takes into account the statistical disturbances that may affect the results.

As part of my research effort in this area, I took a course on Efficiency and Productivity Analysis with Professor Peter Bogetoft at CBS, obtained good data from the Danish Ministry of Culture, and started writing my first paper, which addresses the first of the questions referred to above. My original plan was to use the same data to write the second paper, which aimed at extending the analysis of the first paper to examine that question in a panel data setting. As explained below, I tested two panel data models but the data proved not enough to make that analysis technically feasible: the degree of yearly variation appeared to be very low and the panel too short to allow for the individual effects at the museum level to be identified. Because of these problems, I started looking for other research questions that could be approached with that database. Happily, I found one such question, a more methodological one, which I worked on in the second paper (coauthor: Arne Henningsen).

With two papers now in hand, I began thinking about a third paper. It seemed that the second question presented above could be the subject of a third paper. I started working on it and made good progress, but I again found that the models were so data demanding that the information I had obtained was not enough.

However, the question of changes in labour productivity over time was still of interest, particularly because a significant theory in this field had arisen as one of the first major contributions in cultural economics, namely the Baumol Cost Disease (Baumol and Bowen 1966). I came up with an idea: let's look for an answer to this question in another field: transport economics. I had been working on that during my PhD and thought that it could be made part of this project – the production of public transport services presents many of the assumptions underlying this theory, and productivity analysis in transport is important from a policy perspective, given the amount of public funding involved in this sector.

Thus, the three papers that make up this thesis form an integrated whole, insofar as they present both empirical and methodological analyses in the field of productivity and efficiency analysis, they all address questions that are relevant from both a policy and a management perspective and the focus of analysis are productive organisations that are subject to public regulation.

1.2 Theories and methods

The theories and methods that this project relies on are presented in this section in general terms. The contributions made by each paper will be discussed in more detail in the next section.

The literature on efficiency and productivity analysis has developed tools that help to assess the economic performance of productive organisations as well as the effect of exogenous variables on that performance. This is of clear interest when it comes to state-owned, state-supported and state-regulated organisations, because there is public funding involved. In the case of arts production and the management of cultural institutions, support from the public sector, either direct (through subsidies) or indirect (through tax incentives), is pervasive in almost every country. In the case of public transportation, the public sector either owns and manages the whole urban transport system or delegates its operation to private companies that are strictly regulated.

In this research four concepts are examined: technical efficiency, labour productivity, total factor productivity and one of its components, namely technical change. Technical efficiency, a concept I examine in the case of the Danish museum sector, measures the degree to which inputs achieve the highest possible level of outputs (technical efficiency as an output-oriented indicator) or, conversely, the degree to which a certain level of outputs can be achieved with the lowest level of inputs (technical efficiency as an input-oriented indicator). The distinction between both *orientations* has mainly to do with the relative degree of control over inputs and outputs.

In the case of public transport systems, I analyse labour productivity, total factor productivity (TFP) and technical change in two Latin American countries, and complement this with a descriptive analysis for two other cities in the same region. The former concept measures the average contribution of each unit of labour to the level of output. TFP measures that part of the total output that is explained not by the levels of capital and labour employed in the production process but by the extent to which those factors are employed efficiently. Technical change explains the fraction of TFP change that is related with changes in the available technologies.

As Bogetoft (2012) explains, when it comes to measuring technical efficiency and changes in total factor productivity, the literature distinguishes between non-parametric and parametric methods. Non-parametric methods, of which the most popular in the literature is Data Envelopment Analysis (DEA), rely on mathematical programming methods to estimate the production frontier, i.e., the maximum level of output(s) achievable given a certain level of input(s). This maximum achievable production level corresponds to that of the most efficient productive entity among those under analysis. Parametric methods, on the other hand, include stochastic frontier analysis (SFA).

DEA outperforms stochastic frontier analysis in that it doesn’t require a specific functional form for the production technology (the way inputs are converted into outputs) to be defined ex ante. This is relevant because the production function is by nature unknown to the researcher. In fact, models based on DEA adjust the data to estimate the production technology in a way that satisfies a desirable property of production technologies in micro-economic theory, namely monotonicity conditions, which states that if any of the inputs is increased, holding the others constant, outputs cannot decrease.

SFA models, by contrast, approximate the unknown technology with different functional forms, so if that approximation is not particularly good, the results will be not be particularly good either. Besides, it is not guaranteed that these functions fulfil monotonicity conditions, something that can however be imposed in the estimation procedure. In the analysis of museums' technical efficiency, stochastic frontier models have a clear advantage over non-parametric approaches. In fact, non-parametric methods build the production frontier as was explained above, and the gap (distance) between a particular production level and what is attainable with that level of inputs is interpreted as technical inefficiency. In the case of stochastic frontier analysis, that gap is assumed to be partly explained by technical inefficiency and partly by statistical noise. In other words, the estimation of technical inefficiency is "cleaner" when stochastic frontier analysis is used (Kumbhakar and Lovell, 2000; Bogetoft, 2012). In what follows the way these methods are employed in the three papers of this thesis is explained in general terms (in the next section I provide a more detailed explanation).

The first paper relies on SFA models to estimate the influence public funding may have on museums' technical efficiency. One of the contributions of this paper to the literature in cultural economics is its consideration, using a parametric method, of multiple outputs in the same production function for a cultural institution. In order to do so, a Shephard's distance function is estimated (Kumbhakar and Lovell, 2000). To impose monotonicity conditions, I rely on a linear programming method proposed in the literature for output-oriented analyses (Henningsen and Henning, 2009) and adapt it here for the input-oriented framework in which Danish museums operate[1,2].

Also the second paper uses SFA models to estimate technical efficiency, but instead of estimating a Shephard's distance function, as in the first paper, we estimate a stochastic ray function, which we modify so it is suitable to an input-oriented setting and helps us to solve some limitations that are common in many analysis of this sort. This is the main contribution of this paper: presenting how the input-oriented stochastic ray function works theoretically and testing it empirically.

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[1] As it is explained in that paper, museums have less control over outputs because some of these are agreed upon with the Danish Agency of Museums and Palaces, which grants public support, and some others are *mostly* demand driven, such as events, visitors, and educational programs. In the case of inputs, state-recognised museums, insofar they are not owned by the state, have a significant degree of flexibility when it comes to make decisions regarding the composition and number of staff.

[2] I thank Arne Henningsen, because without his help, guidance and patience I couldn't have adapted this method to an input-oriented setting.

In the third paper, my co-author and I adopt a theory that was originally proposed in the cultural economics literature and is actually considered the first main contribution in the field, namely the Baumol Cost Disease (whether labour productivity is stagnant and what consequences that may have on average and total costs), and applied it in the field of transport economics, more specifically in urban public transport systems. The production of urban public transport services seems to satisfy the assumptions of this theory and the main contribution of this paper is testing it with data for less-developed countries. The evolution of labour productivity is estimated relying on panel data regression models. Once evidence for this phenomenon affecting this sector is found, technical change and changes of total factor productivity are estimated with non-parametric methods. Much more detail on the objectives of the three papers and the way these methodologies are used is provided in the following section.

1.3 The three papers: Findings and limitations

1.3.1 The economics of museums and the motivation for the first paper

Museums collect objects of scientific, historical, social and aesthetic interest, conduct relevant research so society can learn from those objects, give the wide population access to this heritage, and preserve it for the future generations. This heritage includes scientific knowledge, historical objects and testimonies of arts genius. The fact that museums store forms of material heritage make them not only organisations that produce services out of their collection, but also custodians of a stock of cultural capital. Often they are exclusively related to the nation in which they are located, thus echoing many aspects of national identity[3]. Sir David M. Wilson, former Director of British Museum, put this very clearly when he said: “Museums are about the material they contain. The first duty of the museum curator is to look after that material” (Feldstein, 1991, p. 13). In other words, collections are the *raison d’être* of museums and preserving them in optimal

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[3] A review of this topic can be found in McLean (1998), Klamer (1996, chapter 11) and Benhamou (2002).

conditions ranks at the top amongst the various priorities in museums' mission statements.

In the literature, there appears to be a general consensus about this way of conceptualising museums and stressing their social and cultural contribution (Hendon, 1979; O'Hagan, 1995; Ryan, 2017; Weil, 2002). Such an approach is also consistent with the definitions proposed by official organisations in the field, such as UNESCO's International Council of Museums, ICOM, which states that "a museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment" (ICOM, 2007).

From an economic perspective, it is interesting that this way of conceptualising museums, their mission and their functions, is consistent with these institutions being described as productive organisations, insofar they pursue a set of goals (objectives), produce a range of outputs (cultural and educational services), and for that they rely on a series of inputs (capital, specialised and non-specialised labour) and face multiple economic, legal and technological constraints. It is apparent that museums' economic performance should be assessed in a multi-output framework.

Many aspects of the museum sector have been analysed in the economic literature. Contributions include the pioneering articles by Peacock and Godfrey (1974) and Hendon (1979); the book sponsored by the United States' National Bureau of Economic Research (NBER) and edited by Martin Feldstein (Feldstein, 1991), which focused on art museums in the United States; and the special issue of the Journal of Cultural Economics more than twenty years ago (Johnson and Thomas, 1998). The latter publication stands out for its comprehensiveness, including articles by many scholars covering issues on the demand side such as habit formation as a dynamic determinant of attendance decisions, the way collections are managed and pricing policies, and, on the supply side, topics such as museums' governance and organisational structure, the changes in museums' technological structure, and the effects of regulations banning the practice of deaccessioning. The implications of museums' non-profit character have received some attention in the literature on non-profit organisations (DiMaggio, 1986). Others studies have dealt with tax breaks as a government means to stimulate private donations to museums, a form of indirect fiscal support (Schuster, 2006), and innovation in museums (Borowiecki and Navarrete, 2017; Castañer, 2014).

Despite this range of studies, there remain gaps in the literature. For instance, technical efficiency has been measured using mostly non-parametric methods, which do not allow to separate the inefficiency from statistical noise stemming either from measurement error or other random events. There is only one attempt to measure it, as well as the way it is affected by public funding, using parametric methods (stochastic frontier analysis, SFA), but in a way that is unsatisfactory from many perspectives. The first paper (***The effect of public funding on museums' efficiency: A distance function approach***) aims at shedding light on one of these issues: the effect of public funding on technical efficiency. The paper approaches this question using data of state-recognised Danish museums. This analysis is important because this group of museums, although not owned by the state, receive public funding. Only Bishop and Brand (2003) have estimated production functions and the effect of public funding on museums' technical efficiency relying on SFA models and focusing on a small sample of British museums[4], but they consider one, mostly demand-driven output (number of visitors). Besides, they use a very crude measure of public funding when trying to analyse its influence on technical efficiency. Finally, that article doesn't estimate the marginal effects, which represents another limitation, because the effect of public funding on technical efficiency is expected to be non-linear. These scholars acknowledge the first two limitations and suggest that future research will be needed to overcome them.

This first paper aims precisely at solving the limitations of that article. After defining indicators for the multiple outputs to be considered, which is always a challenge in the case of cultural institutions (Throsby, 1994), I estimate, with SFA models, the effect of public funding on technical efficiency. This paper makes several additional contributions: I use a continuous measure of public funding, which includes the subsidies from both the national and local governments, consider indicators of both scientific and non-scientific labour and estimate the marginal effects of this funding on efficiency. The analysis is based on a database for a six-

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[4] There are many very good articles analysing museums as multi-output organisations with non-parametric methods. See del Barrio et al. (2009), Taheri and Ansari (2013), del Barrio-Tellado and Herrero-Prieto (2019), Camarero et al. (2011), Mairesse and Eeckaut (2002) and Basso et al. (2018).

year period. I estimate stochastic frontier models based on a Shephard's distance function, which allows for simultaneous inclusion of several outputs. Finally, in what represents an additional contribution, this paper checks the results after imposing monotonicity conditions to the different models, something that is done for the first time in an input-oriented setting.

The main finding is that if we consider museums to be multi-output organisations, then public funding, at least in the case of this sample, does have a positive and statistically significant effect on technical efficiency, a result that stands against the existing literature, which, as mentioned, considers museums to produce one single-output and finds that effect to be negative and statistically significant. I also estimate a single-output model and the results indicate the effect of public funding on technical efficiency is null. So at least in the case of this data set the choice of a single versus a multi-output setting appears to matter.

Regarding the limitations of this first paper, it is worth pointing out that I have been able to estimate the models based only on pooled cross-section data, although I consider some environmental variables that according to the literature appear to be relevant. But I could not use panel-data models because, sadly, the degree of yearly variation is very low and the panel too short to allow for the individual effects at the museum level to be identified[5].

A second limitation of this paper relates to the impossibility of considering the whole sample of museums in the database, but only those of them producing all the outputs under analysis. This problem arises because in stochastic frontier analysis, the usual way to deal with multi-output production functions is the so-called distance function, which this first paper relies on. However, SFA models cannot handle missing values, so whenever the production function considers the logarithm of the outputs (a common practice in the literature and followed in this paper, which considers a trans-logarithmic production function), any observation containing at least one output equal to zero (which happens whenever a museum does not produce that specific output) is dropped from the analysis (the logarithm of zero is undefined). This is relevant in the case of museums because some of them do not produce all the outputs, e.g., some museums do not

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[5] I thank José Miguel Benavente and William Greene, whose comments were decisive in my decision of leaving panel-data models, which I spent part of this project's time working on, for future research ventures.

organise educational visits and/or they do not publish scientific articles every year. This implies the analysis cannot be considered to be representative of the whole universe of state-recognised museums in Denmark, but only of those museums producing all outputs[6].

1.3.2 A methodological contribution

As noted above, one of the limitations of the first paper is the impossibility of considering all the museums in the database, because some of them do not produce all the outputs under analysis. This limitation has motivated the second paper (***A ray-based input distance function to model zero-valued output quantities: derivation and an empirical application***, co-authored with Arne Henningsen).

Given that the practice of replacing zero output quantities by arbitrarily small numbers (a naive solution proposed by some scholars) has shown in the literature to be unsuitable besides being theoretically incorrect, a solution to this problem has been proposed, which is suitable to contexts where managers have more control over outputs than over inputs. This is the stochastic ray function (Löthgren, 1997; Henningsen et al., 2017). The way the stochastic ray function works is explained in detail in this second paper, but it suffices here to say that it allows consideration not only of those observations presenting a positive value for every output under analysis but also those observations presenting zero values in one or more of these outputs. This allows us to make the analysis more representative of the sector under analysis.

In a series of sectors, however, managers have more control over inputs than over outputs, hence an input-oriented version has to be developed. In this paper we develop such a function. Therefore, this second paper makes a contribution in the literature on productivity analysis, by deriving and testing an input-oriented version of the stochastic ray function, which adds to its output-oriented version already proposed in the literature. We demonstrate how to impose monotonicity on ray-based input distance functions and address a critique this function has been subject to, which is related to the ordering of the outputs.

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[6] Some other production functions -CES/CET and Generalized Quadratic- can handle zero-valued outputs but have their own shortcomings.

We test these specifications empirically by analysing input-oriented technical efficiency of state-recognised museums in Denmark, using the same database of the first paper. As it is explained in the first paper, these museums have more control over inputs than over outputs, so the database is suitable for our analysis. Given that this model can include also those observations presenting one or more outputs equal to zero, we rely on a sample that is much larger than that of the first paper.

This group of museums is only one example of those sectors where an input-oriented analysis is more appropriate, and the data about them is used only to illustrate how this new technique works. Even when we come up with measures of technical efficiency, scale elasticities, distance elasticities of the inputs and outputs and of how the production frontier is affected by some environmental variables that are of interest to the museum sector, this empirical analysis should be considered a by-product of the methodological analysis, which is definitely the main contribution.

1.3.3 Transport economics borrows from cultural economics

The Baumol Disease was originally proposed more than fifty years ago by William Baumol and William Bowen in their seminal book *Performing arts, the economic dilemma: A study of Problems common to Theater, Opera, Music and Dance* (Baumol and Bowen, 1966) and states that in some labour-intensive productive sectors, referred to as stagnant sectors, labour-saving technical change is virtually absent and labour productivity doesn't increase over time. However, given that labour productivity does increase in other sectors, the labour costs in stagnant sectors increase and hence the goods and services they produce become relatively more expensive (their costs increase at a higher rate than the general prices in the economy). This threatens the financial health and even the survival of these organisations.

One of the examples commonly offered of one such activities is the interpretation of a musical piece by a string quartet: four musicians are still required today, as they were a hundred years ago, to play the piece and playing it takes the same amount of time as a hundred years ago, but the salary of musicians is clearly not the same today than a hundred years ago. The same happens with plays and symphonic orchestras too, unless, of course, the musical piece and or the play is interpreted with half of the musicians/actors and/or in half of the time, but in that case they wouldn't be the same musical piece/play.

There are some criticisms to this theory, related to the way the output (and hence labour productivity) is measured (Cowen, 1996). In fact, if labour productivity is measured as production per number of staff per unit of time, the theory holds. However, if we define production in terms of the number of people (audience) that can be reached, labour-productivity has increased significantly since streaming services have come into scene (although it can be discussed whether online transmissions are a perfect substitute to live performances).

This theory was the first major contribution in the field of cultural economics (moreover, it is referred to as the contribution that founded this research field), and almost everywhere its predictions have been considered as a justification for public funding to the arts. However, that is not a valid justification. The presence of the Baumol Disease in a particular sector does not justify *per se* additional public funding being directed towards that sector. If that were a sufficient condition for funding to be justified then we would have to support with public money all those sectors producing goods and services that become *relatively* more expensive. We would agree to support those sectors that exhibit the symptoms of this illness and cannot rely on more funding coming from consumers themselves or other private sources (sponsors) if and only if they exhibit such a high social value that we are not willing, as a society, to risk their disappearance.

I was originally going to test this theory in the museum sector, a project that faced two challenges. Firstly, it would be necessary to build a labour productivity indicator that takes into account that museums are multi-output organisations. The first step to do that is aggregating the different outputs in a single unit of measurement, which could be then divided by the labour input indicator. The theory of index numbers could help us here, but traditional indexes require price information to aggregate different outputs. When it comes to museums' outputs such as their research functions, price information simply does not exist. Secondly, the Baumol Effect is a long-term phenomenon. In fact, the assumption that salaries in a stagnant sector should keep pace with those of other, dynamic sectors, is valid if and only if labour markets are integrated (sectors competing for labour), which seems to be a reasonable assumption in the long run only. That is why in order to test this theory a long data series is required. While working on this project I managed to find a solution to the first problem, by building a quantity index relying on a linear programming method that does not require price information (O'Donnell and Nguyen, 2013; O'Donnell, 2018). However, I couldn't manage to solve the second problem: getting a long panel database, including all the relevant outputs, the labour input and the main expenditure figures for a large enough sample of museums proved simply impossible.

Because of this, I decided to investigate the application of the Baumol disease in another sector. In fact, this theory has been tested empirically not only in the performing arts sector, but also in sectors as diverse as education and health (Baumol, 2012). Even when some technical change appears to be available in these two sectors (new surgery technologies and online courses that can reach a wider number of students), in the case of many educational programmes and health services the possibility of increasing labour productivity is rather limited. But salaries of doctors, nurses and teachers increase on time. The consequences in terms of total costs, and hence necessary resources to keep the quality and even the presence of these services, pose a dilemma from a policy perspective.

This theory could also be tested in the transport sector. This makes sense from a theoretical perspective, as the provision of transport services tend to be labour-intensive and labour-saving technical change tends to be absent, at least in surface services. Should this phenomenon really affect this sector, then the consequences in terms of costs would be a political concern: just letting the prices faced by passengers rise significantly has proven politically risky, and public funding might be warranted considering the positive externalities produced by this sector and the social cost associated with it shrinking.

Testing the theory in this sector is also particularly interesting because its consequences might be more serious than those in other sectors affected by this phenomenon. In fact, in the performing arts, health services and the education sector, there appears to be a natural antidote to the illness: a positive, and in some cases high income elasticity. In fact, when people and, in aggregate terms nations become richer, we observe that demand for higher-quality health, education and cultural goods increases, and at least in the case of the second and third of these sectors more than proportionally. In economic terms, we would say that the Baumol Disease gets reflected in a higher cost per unit produced (the supply curve contracts) but the higher income is reflected in an expansion of the demand curve (the people willingness to pay for these goods also increases). In other words, society is willing to pay more for those goods that become more expensive. This is especially true in the case of education, when either the public sector and/or the families are willing to pay more not only to maintain standards but to increase their quality (e.g., classes with a smaller number of students). On the contrary, the demand for public transport services tends to have a negative income elasticity: people tend to demand less of these services as they become richer (references to be provided in the third paper). An additional aggravating factor is vehicular congestion.

However, it is also true that, at least theoretically, positive technical change, and hence gains in total factor productivity, *may* help to compensate (at least partially) for the problems generated by the Baumol's disease in this sector. That is to say, technical progress *could* act as an *antidote* to the Baumol's disease.

This phenomenon has been tested empirically only in the transport sector of some German cities as well as in the United States (Morales Sarriera et al., 2018; Morales Sarriera and Salvucci, 2016; Evangelinos et al., 2012). In the third paper of this project (***Baumol's Cost Disease and Urban Transport Services in Latin America***, coauthored with Andrés Gómez-Lobo) we test this theory with data from two Argentina and Colombia. This analysis is carried out using panel data regression models. Also, a non-parametric technique (the Global Malmquist Index) is used to analyse both technical change and the evolution of total factor productivity.

We find some evidence suggesting the Baumol disease may affect this sector in the cities considered. In those cases the models suggest that the Baumol disease affects the urban transport services in terms of labour productivity. The contrast between surface and underground services is also emphasized. In the case of these two countries we also measure estimate technical change and changes in total factor productivity, and the evidence is mixed[7].

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[7] The chapter version was finalized after the corresponding paper was published in *Transportation Research: Part A*. Each version is based on a different indicator of productivity (and technical) change hence the results are not exactly the same. In this thesis both versions are presented in chapter 4

Summing up, we can see that the questions addressed by, and the methodologies employed in the different papers share many features and are in some cases clearly connected, as it is explained below:

- The first paper departs from the (not always considered) assumption that museums produce multiple outputs. In doing so, the paper adopts methodologies already developed in other areas of the economics literature and also contributes with a new methodological approach.
- The first and second paper are connected as the latter was inspired by one limitation of the former, and it ended up contributing with a methodological innovation in the field of productivity analysis. We can definitely say that the main contribution of the second paper is methodological.
- The three papers rely mostly on parametric approaches, although one linear programming method complements the analysis in the first and second papers in order to ensure the robustness of the results, and non-parametric techniques are used in the third paper to analyse changes in total factor productivity and technical change, after using econometric techniques to test the main hypothesis under analysis.
- The three papers address important concepts in efficiency and productivity analysis, and an important part of this project relates productivity measures with public support, in the first paper in a causal way (from public funding to technical efficiency) and in the third paper in terms of the likely need of increasing public funding in order to avoid a sector that presents many positive externalities and, to a great extent, public good characteristics, to become inefficiently expensive for users.
- Last but not least, the three papers show there are methodological tools that can be effective in analysing information of interest to inform policy and management decisions.

1.4 Invitation for further research

The first challenge for further research in the areas covered in this thesis is to find data covering a much larger number of periods. This would make possible to extend the analysis of the first and second papers to a panel data setting, hence controlling for unobserved, time-invariant factors.

In the case of the third paper, data for some variables is available for some countries and not for others, which makes the comparisons not entirely satisfactory. Finally, statistical tests of the estimates of TFP changes were not implemented, something that is left to a future research venture.

It is of course important to address the question of external validity, i.e., the extent to which the findings of this research hold in other countries. This is important in the case of all three papers. For instance, if labour markets were more rigid elsewhere than in Denmark (if it were easier to adjust the number of staff in the medium term) and/or the regulation in terms of outputs were more flexible than it is in that country, then it would be interesting to carry out the same analysis of the first paper in an output-oriented instead of an input-oriented setting. It would be also interesting to extend this analysis to countries where cultural policy traditions are different, as those traditions determine the way public support is granted and museums held accountable. Another research avenue would consider extending the analysis made in the first paper, relying on the same methodology, to examine the influence of other variables on the evolution of technical efficiency, such as the education level of both the managers and boards, as well as the governance structure. External validity is also an issue when it comes to analyse transit systems, given that both regulation and the ownership structure of operators vary across countries.

The possibility of tackling these limitations and addressing new questions depends mainly on data availability. This project has shown that the methodologies required for these tasks are available and work.

Bibliography

Basso, A., Casarin, F., and Funari, S. (2018). How well is the museum performing? a joint use of dea and bsc to measure the performance of museums. *Omega*, 81:67 – 84.

Baumol, W. J. (2012). *The cost disease: Why computers get cheaper and health care doesn't*. Yale University Press.

Baumol, W. J. and Bowen, W. (1966). *Performing Arts, the Economic Dilemma: a Study of Problems Common to Theatre, Opera, Music and Dance*. Twentieth Century Fund, New York.

Benhamou, F. (2002). *Économie du patrimonie culturel*. La Découverte.

Bishop, P. and Brand, S. (2003). The efficiency of museums: a stochastic frontier production function approach. *Applied Economics*, 35(17):1853–1858.

Bogetoft, P. (2012). *Performance Benchmarking: Measuring and Managing Performance*. Management for Professionals. Springer Science+Business Media, Germany.

Borofsky, R. (1998). Cultural possibilities. In *UNESCO World Cultural Report*, pages 64–75. UNESCO: Paris.

Borowiecki, K. J. and Navarrete, T. (2017). Digitization of heritage collections as indicator of innovation. *Economics of Innovation and New Technology*, 26(3):227–246.

Camarero, C., Garrido, M. J., and Vicente, E. (2011). How cultural organizations' size and funding influence innovation and performance: the case of museums. *Journal of Cultural Economics*, 35(4):247.

Castañer, X. (2014). Chapter 11 - cultural innovation by cultural organizations. In Ginsburgh, V. A. and Throsby, D., editors, *Handbook of the Economics of Art and Culture: Volume 1*, volume 2 of *Handbook of the Economics of Art and Culture*, pages 263 – 276. Elsevier.

Cowen, T. (1996). Why i do not believe in the cost-disease: Comment on baumol. *Journal of Cultural Economics*, 20(3):207–214.

del Barrio, M. J., Herrero, L. C., and Ángel Sanz, J. (2009). Measuring the efficiency of heritage institutions: A case study of a regional system of museums in spain. *Journal of Cultural Heritage*, 10(2):258 – 268.

del Barrio-Tellado, M. J. and Herrero-Prieto, L. C. (2019). Modelling museum efficiency in producing inter-reliant outputs. *Journal of Cultural Economics*, 43(3):485–512.

DiMaggio, P., editor (1986). *Nonprofit Enterprise in the Arts: Studies in Mission and Constraint*. Yale studies on nonprofit organizations. Oxford University Press, United Kingdom. Includes bibliographical references and index.

Evangelinos, C., Wieland, B., and Kühnhausen, T. (2012). Baumol's cost disease in the local transit sector: A comparative analysis for germany and the usa. *International Journal of Transport Economics / Rivista internazionale di economia dei trasporti*, 39(1):83–104.

Feldstein, M. (1991). *The Economics of Art Museums*. University of Chicago Press.

Heilbrun, J. and Gray, C. M. (2001). *The Economics of Art and Culture*. Cambridge University Press, 2 edition.

Hendon, W. S. (1979). *Analyzing an art museum / William S. Hendon*. Praeger New York.

Henningsen, A., Bělín, M., and Henningsen, G. (2017). New insights into the stochastic ray production frontier. *Economics Letters*, 156:18 – 21.

Henningsen, A. and Henning, C. H. C. A. (2009). Imposing regional monotonicity on translog stochastic production frontiers with a simple three-step procedure. *Journal of Productivity Analysis*, 32(3):217.

ICOM (2007). *ICOM Statutes, adopted by the 22nd General Assembly. Section 1. Article 3*. ICOM: Vienna.

Johnson, P. and Thomas, B. (1998). The economics of museums: A research perspective. *Journal of Cultural Economics*, 22(2/3):75–85.

Klamer, A. (1996). *The Value of Culture: On the Relationship Between Economics and Arts*. OAPEN (Open Access Publishing in European Networks). Amsterdam University Press.

Kumbhakar, S. C. and Lovell, C. A. K. (2000). *Stochastic Frontier Analysis*. Cambridge University Press.

Löthgren, M. (1997). Generalized stochastic frontier production models. *Economics Letters*, 57(3):255 – 259.

Mairesse, F. and Eeckaut, P. V. (2002). Museum assessment and fdh technology: Towards a global approach. *Journal of Cultural Economics*, 26(4):261–286.

McLean, F. (1998). Museums and the construction of national identity: A review. *International Journal of Heritage Studies*, 3(4):244–252.

Morales Sarriera, J. and Salvucci, F. P. (2016). Rising costs of transit and baumol's cost disease. *Transportation Research Record*, 2541(1):1–9.

Morales Sarriera, J., Salvucci, F. P., and Zhao, J. (2018). Worse than Baumol's disease: The implications of labor productivity, contracting out, and unionization on transit operation costs. *Transport Policy*, 61(C):10–16.

O'Donnell, C. (2018). *Productivity and Efficiency Analysis: An Economic Approach to Measuring and Explaining Managerial Performance*. Springer.

O'Hagan, J. W. (1995). National museums: To charge or not to charge? *Journal of Cultural Economics*, 19(1):33–47.

O'Donnell, C. and Nguyen, K. (2013). An econometric approach to estimating support prices and measures of productivity change in public hospitals. *Journal of Productivity Analysis*, 40(3):323–335.

Peacock, A. and Godfrey, C. (1974). The economics of museums and galleries. In Towse, R., editor, *Cultural Economics: The Arts, The Heritage and the Media Industries*. Edward Elgar.

Price, J. J., Seaman, B., Báez, A., and Rebolledo, A. (2017). Estudio de valoración contingente de la red de bibliotecas públicas de Chile. *Estudios Públicos*, 146:87–117.

Ryan, L. F. (2017). Australian museums in the 'age of risk': a case study. *Museum Management and Curatorship*, 32(4):372–394.

Schuster, J. M. (2006). Tax Incentives in Cultural Policy. In Ginsburgh, V. and Throsby, D., editors, *Handbook of the Economics of Art and Culture: Volume 1*, volume 1 of *Handbook of the Economics of Art and Culture*, chapter 36, pages 1253–1298. Elsevier.

Taheri, H. and Ansari, S. (2013). Measuring the relative efficiency of cultural-historical museums in tehran: Dea approach. *Journal of Cultural Heritage*, 14(5):431 – 438.

Throsby, D. (1994). The production and consumption of the arts: A view of cultural economics. *Journal of Economic Literature*, 32(1):1–29.

Throsby, D. (2001). *Economics and Culture*. Cambridge University Press.

Throsby, D. (2010). *The Economics of Cultural Policy*. Cambridge University Press.

UNESCO (2001). *Universal Declaration on Cultural Diversity*. UNESCO: Paris. Available at https://www.refworld.org/docid/435cbcd64.html [accessed 29 September 2020].

Weil, S. E. (2002). *Making Museums Matter*. Smithsonian Books.

Chapter 2

First paper: "The effect of public funding on museums’ efficiency: A multi-output distance function approach"

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Abstract

Using data of Danish museums and relying on a stochastic frontier approach, this paper analyses the effect of public funding on their technical efficiency. Only Bishop and Brand (2003) have explored this question with parametric methods, considering visitors as the single museums' output and finding some preliminary evidence that public funding reduces technical efficiency. These scholars invite for further research to analyse whether that result holds when all the museums' outputs, including education, exhibitions, conservation and research, are considered. Our database and our empirical strategy, based on a Shephard's distance function, allow to consider these multiple outputs in the same model, and the results suggest that public funding has a possitive effect on technical efficiency. In an analysis based on visitors as the only output this effect is null. As an additional contribution, consistency with economic theory is ensured by imposing monotonicity restrictions for the first time in an input-oriented setting.

2.1 Introduction

Museums can be described as multi-output organisations delivering educational and cultural services to society. In doing so they face economic, legal and technological constraints and rely on capital and labour inputs that have to be allocated efficiently subject to these constraints according to an appropriate objective function (Johnson and Thomas, 1998; Frey and Meier, 2006; Feldstein, 1991; O'Hagan, 1995, 1998). Moreover, a great majority of these organizations rely on public funding, hence the efficiency of their operations is a question of interest from a public policy perspective.

In this paper I analyse the effect of public funding on the technical efficiency of state-recognized Danish museums, that is museums that are not owned but partly funded by the state. Technical efficiency is only one of the economic concepts of efficiency. It refers to the extent to which an organisation produces the maximum level of output(s) given a certain level of input(s)[1].

This question has been analysed with parametric methods, specifically stochastic frontier analysis (SFA) in a single-output setting only by (Bishop and Brand, 2003). The literature based on non-parametric methods also considers a multi-output setting but has focused on measuring technical efficiency (and on some related questions) but not on analysing the effect of public funding on that measure of efficiency (del Barrio et al., 2009; Taheri and Ansari, 2013; del Barrio-Tellado and Herrero-Prieto, 2019; Camarero et al., 2011; Mairesse and Eeckaut, 2002; Basso et al., 2018). To the best of the author's knowledge this is the first time this question is analysed both in a multi-output setting and with parametric methods.

Bishop and Brand (2003) analyse this question relying on a sample of British museums. Their analysis considers attendance (number of physical visitors) as the sole museums' output. These scholars acknowledge that using only a single output may affect the validity of the conclusions; the estimated effect of public

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[1] Allocative efficiency (the degree to which the combination of input is optimal from a cost minimisation perspective) is not analysed here, as it requires information about prices.

funding on average technical efficiency could be biased if other (omitted) outputs are also affected by public funding (Bishop and Brand, 2003, p.1857-1858)[2].

SFA models assume that the level of production depends on the level of inputs as well as on a stochastic error. This last term has two components: an independent and identically distributed error term related to both measurement errors and factors that are beyond the control of the museums' manager, including unexpected events and omitted outputs and inputs, and a one-sided error term that reflects the degree of technical inefficiency. This way, this methodology may provide cleaner measure of efficiency compared to non-parametric approaches, as long as the researcher can successfully disentangle inefficiency and noise, and makes the right assumption on the inefficiency distribution[3]. In order to consider multiple outputs in the same production function, in this paper a Shephard's distance function is estimated. The Shephard's distance function is a stochastic parametric technique that has never been applied in the case of museums and accommodates well a multi-output setting[4].

Other contributions with respect to the previous literature include a continuous, more comprehensive measure of public funding, something that Bishop and Brand (2003) suggest as important for future research, and data that allows to separate labour into two categories: scientific and non-scientific labour. Last but not least, the database covers all the state-recognized museums at a national level, but, for the reasons explained in section 2.4, the analysis focuses on a subset of that database[5].

The paper is structured as follows. Section 2.2 briefly describes the museum sector in Denmark and the main objectives and regulation of state-recognized museums. Section 2.3 describes the empirical methodology. Section 2.4 presents the data and

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[2] I refer many times to the article by Bishop and Brand (2003) because, as mentioned, these scholars opened this line of research with parametric methods and invited for future research to solve some limitations of their analysis, something that, given the richness of the data set I rely on, I expect to do satisfactorily in this paper. Therefore, when I refer to the "previous literature" I refer to Bishop and Brand (2003).

[3] This advantage, however, comes at the price of less flexibility as SFA requires choosing a particular function to approximate the unknown production technology. See Bogetoft and Otto (2011).

[4] For examples in other cultural institutions see Fernandez-Blanco et al. (2017) and Last and Wetzel (2010).

[5] Counting with data for museums at the national level has been deemed as important, although difficult. See Bishop and Brand (2003, p.1858) and Ginsburgh and Mairesse (1997).

the variables included in the models, as well as some descriptive statistics. The estimation and main results are presented in section 2.5. Section 2.6 concludes.

2.2 State-recognized museums in Denmark

The museum sector in Denmark is comprised of different types of institutions. There are five state-owned museums and 97 state-recognized museums, which are not owned by the state but receive public funding. Both groups are subject to the Consolidated Act on Museums (hereafter Museums Act or simply the Act). That is why they are also referred to as "State subsidized museums according to Museum Act"[6]. Museums regulated by this Act are legally obliged to preserve and research the cultural and natural heritage they store and to give the broad population access to that heritage. Precisely because the Act establishes such various responsibilities, evaluating the efficiency of Danish museums in a multi-output setting is especially important.

This article focuses on the state-recognized museums, which are divided in different groups depending on the type (focus) of their permanent collection and their ownership and governance structure. In terms of the first dimension, these museums are grouped in four categories. The first three are cultural history, arts and natural history museums. Some museums manage a series of "units" or "visit sites", which are museums themselves. When some of these visit sites are in turn arts museums whereas others are cultural history museums then the institution grouping them is referred to as a mixed museum, which is considered to be the fourth category. But also some cultural history museums manage more than one (cultural history) unit. In terms of the second dimension (governance and ownership), state-recognized museums can be independent, owned by one or more local authorities or by an association specifically created to manage them.

Public funding for state-recognized museums includes mainly grants for operational expenses. This public support is regulated by an agreement that, complying with the Museums Act, establishes the objectives in terms of a series of activities

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[6] There are also the non-state museums, which include private entities, do not get public funding and are not covered by the Museum Act or any other Act.

related to the research, dissemination, collection, registration and conservation functions.

2.3 Methodology

2.3.1 Stochastic Frontier Analysis (SFA)

This paper relies on a stochastic frontier approach (SFA), a parametric method that specifies the following relationship between the maximum (frontier) and the actual level of production[7].

$$\ln y_i = f(x_i;\beta) + \epsilon_i \tag{2.1}$$

The term on the left indicates the observed output. The first term on the right represents the production frontier and therefore indicates the potential output, which depends on the inputs and their corresponding parameters, β. The difference between these two terms is explained by ϵ_i, a composite error term that corresponds to the sum of v_i, a classical (white noise) error term that captures measurement error and other statistical noise, and u_i, a measure of inefficiency. This last element is modelled as a one-sided, negative error[8]. Therefore, equation 2.1 can be expressed as:

$$\ln y_i = f(x_i;\beta) + v_i - u_i \tag{2.2}$$

The models can be estimated through maximum likelihood and allow not only to estimate the technical efficiency but also the determinants of it (Kumbhakar et al.,

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[7] The equations included in this section are taken from Kumbhakar et al. (2015, Chapters 2 and 3) and some of them have been modified to consider also environmental variables, z.

[8] It is negative because we are estimating a production function, but would be positive if we were estimating a cost function.

2015; Bogetoft and Otto, 2011). The focus of the present paper is on this last issue and particularly on the effect of public funding on average technical efficiency.

Modelling multiple-output technologies with standard non-parametric approaches (e.g. Data Envelopment Analysis and Free Disposal Hull) appears to be more common that doing it with stochastic frontier analysis, but distance functions makes SFA effective in this context too. Besides, SFA appears to be more effective in two key aspects. Firstly, stochastic frontier analysis allows counting with a cleaner measure of inefficiency, by separating it from the statistical noise, and non-parametric approaches. On the contrary, in the case of non-parametric approaches, given that there is not statistical noise, any gap between a particular observation's output and the frontier is assumed to be inefficiency. Secondly, even when in stochastic frontier analysis the researcher must choose an arbitrary function that she thinks might provide a good approximation to the unknown production function, non-parametric approaches arguably make a stronger assumption, as they assume that the production function is a locally linear function (i.e., a linear function with parameters that potentially vary from one data point to the next), ignoring the possibility that the unknown production function is, for example, locally log-linear, or the possibility that an environmental variable has been omitted. SFA also appears to be less sensitive (although not totally immune) than non-parametric techniques to the influence of outliers (Bogetoft and Otto, 2011).

In this paper I rely on a translog function to approximate the input distance function. This is a flexible functional form, compared to other popular production functions (e.g., Cobb-Douglas) insofar it doesn't require the elasticity of substitution to be constant[9].

Besides having to choose a functional form for the production function to approximate the unknown technology, also an assumption about the distribution of the inefficiency term has to be made. The model estimated in this paper assumes that the inefficiency term follows a half-normal distribution, whose variance can be specified as a function of a variable of interest. In this paper that variable is

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[9] I tested the translog against the Cobb-Douglas and the former was chosen based on a LR test. I am assuming thn that inputs and outputs are not strongly disposable, otherwise the production function couldn't be a translog (O'Donnell, 2018, p.282).

public funding[10]. I estimate both the production frontier and the influence public funding may have on average technical efficiency in the same model.

2.3.2 Shephard's Distance Function

In order to extend this analysis to a multi-output setting, I estimate a Shephard's Distance Function (hereafter SDF). The SDF builds on the concept of technical efficiency index. The most well-known index of technical efficiency is the Farrell Index (Bogetoft and Otto, 2011). In its input-oriented version, it corresponds to the maximum proportional reduction of inputs that is compatible with an unchanged level of output(s). Conversely, the output-oriented Farrell efficiency indicates by how much the output(s) can be proportionally increased without changing the level of inputs.

The so-called Shephard's efficiency index corresponds to the inverse of the Farrel's index. In its input (output) oriented version, the Shephard's efficiency index indicates the maximum (minimum) number by which inputs (outputs) can be divided keeping the outputs (inputs) constant. The SDF relies on the Shephard's efficiency index. In what follows I illustrate these ideas only for the input-oriented case, as state-recognized museums are expected to have less control over outputs and more flexibility in terms of input levels [11].

In equation 2.4, the term λ represents the maximum number by which x (the inputs) can be divided without reducing y (the output(s)). z is a vector of environmental variables, i.e. variables that affect the frontier that are not under the control of managers. In both equations, D represents the distance to the frontier. The function $V(y)$ is referred to as the input requirement set, which determines the minimum level of inputs that make the production plan feasible in environment z.

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[10] The variance of this distrinution is modelled as $\sigma_{ui}^2 = \delta_1 + \delta_2 z$, with z denoting our measure of public funding.

[11] Parmeter and Kumbhakar (2014) presents an interesting discussion about the issues at stake when choosing between the input and output-oriented version of the SDF.

$$f(x,z) = \max_{y}(y \mid \text{x can produce y in environment z}) \tag{2.3}$$

$$D_I(y,x,z) = \max_{\lambda}(\lambda \mid \frac{x}{\lambda}) \in V(y,z)) \tag{2.4}$$

The input-oriented distance function is non-increasing in each output and non-decreasing in each input. The intuition for this is straightforward: if outputs(inputs) increase and we keep inputs(outputs) unchanged, then technical inefficiency (the distance to the frontier) cannot increase(decrease). This function is also homogeneous of degree one in the vector of parameters. This last condition allows us to express equation (2.4) as follows:

$$\frac{D}{x_1} = f(\frac{x}{x_1}, y, z) \tag{2.5}$$

This transformation is key to estimate the distance function. In fact, by taking logs equation 2.5 turns into:

$$\ln D - \ln x_1 = \ln f(\frac{x}{x_1}, y, z) \tag{2.6}$$

In this paper function *f(.)* is assumed to be trans-logarithmic. In its log form, with K inputs, N outputs and J environmental variables (to be presented in section 2.4.3) and the error term v, this function can be expressed as in equation 2.7. The hat symbol over the inputs is used to indicate they have been divided by input 1. The term u is equal to the log of the input distance function, $\ln D$, and represents technical inefficiency, a random variable that by definition can take values greater or equal than zero.

$$
\begin{aligned}
-\ln x_1 = \alpha_0 + \sum_{k=2}^{K} \rho_k \ln \hat{x}_k + \frac{1}{2} \sum_{k=2}^{K} \sum_{l=2}^{K} \rho_{kl} \ln \hat{x}_k \ln \hat{x}_l + \sum_{n=1}^{N} \beta_n \ln y_n \qquad (2.7) \\
+ \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} \ln y_n \ln y_m + \sum_{k=2}^{K} \sum_{n=1}^{N} \epsilon_{kn} \ln \hat{x}_k \ln y_n + \sum_{j=1}^{J} \gamma_j z_j + \frac{1}{2} \sum_{j=1}^{J} \sum_{r=1}^{J} \theta_{jr} z_j z_r \\
+ \sum_{k=2}^{K} \sum_{j=1}^{J} \phi_{kj} \ln \hat{x}_k z_j + \sum_{n=1}^{N} \sum_{j=1}^{J} \omega_{nj} \ln y_n z_j - u + v
\end{aligned}
$$

2.4 Data

Counting with good measures for a comprehensive set of outputs so as to highlight the different functions of the museums is essential to conduct an efficiency analysis. However, in many countries this has proven difficult (Mairesse and Eeckaut, 2002, p.268). Denmark is an exception in this regard. The way the museum sector is organized in this country, and the information related to it is collected, makes it possible to count on good quality data. In fact, all the so-called state-recognized museums are requested to report information about a comprehensive set of financial, input and output indicators on a yearly basis.

We count on information for state-recognized museums over a six-year period: 2012 and 2014-2018[12]. However, the number of observations has to be adjusted because whenever at least one input or output variable is equal to zero the translog production function produces missing values (the logarithm of zero is undefined), which are dropped from the sample. That is why the following analysis is finally based on 366 out of the original 558 observations[13]. The model presented in this

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[12] Data for 2013 was collected relying on a different methodology so for comparability reasons is not included in this analysis.

[13] Other functional forms, even when do not present this problem, are not appropriate either. For instance, CES/CET functions assume constant elasticities of substitution in inputs/outputs, which might be construed as a non-sensible assumption in the case of museums, as depending on the mix of outputs produced some particular combinations of inputs are not feasible (for instance a museum focused more on producing more conservation or research rather than in opening the general collection to the public might have to rely more on scientific labour). This is true in other sector, like agriculture where a combination of land and labour might be optimal depending on whether more maze or livestock is produced. In the case of the quadratic function there are heteroscedasticity problems, especially in SFA, which might affect the precision of the technical inefficiency estimates.

paper is estimated with pooled cross-section data. Regrettably, panel data models cannot be estimated because the panel is too short and the degree of variation too low to identify the individual coefficients.

2.4.1 Outputs

An important question when analysing the performance of museums relates to the definition of the output[14]. In this paper, museums are analysed as multi-output organizations, and these outputs are related to the functions of museums. Our data allows to cover six outputs corresponding to four museums' functions: research, conservation, dissemination and education.

2.4.2 Inputs

Capital

The capital expenditure of a museum consists of the building, technical equipment and the collections. The first two items are never detailed enough neither in government reports (being the museums publicly funded) nor in the museums' official reports. As per the collection, the very *raison d'être* of museums, it is expected to be very large in economic terms, but it is rarely valued and there is not even a provision for its maintenance (O'Hagan, 1995; Feldstein, 1991; Frey and Meier, 2006; Grampp, 1989). This lack of data obliges us to rely on proxies. I follow Bishop and Brand (2003) and use the running and maintenance costs as a proxy for capital stock. The rationale for this proxy is the following: larger collections require more building space, for both storage and exhibition, and this additional space requires the museum to incur in additional operating (maintenance) expenses. These costs have been expressed in real terms (Danish Krones of 2014)[15].

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[14] This discussion is also present in the analysis of other cultural institutions. See Throsby (1994) and references therein.

[15] Expressing costs in real terms requires using an appropriate price index. This is not trivial, because even if the index is a good one, there is likely to be measurement errors (O'Donnell, 2018, p.134). But this is precisely another good reason for using a stochastic frontier model instead of non-parametric approaches.

Scientific and non-scientific labour

Our data allow us to consider the scientific and non-scientific staff separately. This appears to be interesting as some museums' activities are more related to different types of labour.

2.4.3 Environmental variables

I include the following two environmental variables, for they are expected to affect museums' ability to convert inputs into outputs (given the production technology) that are beyond the control of the museums' managers.

- Visit sites: Some museums manage more than one visit place. I include an environmental variable indicating the (log of the) number of visit sites. It is expected (hypothesis) that ceteris paribus museums managing less visit sites can take advantage of some scale economies in the use of certain inputs (e.g., security and reception staff).
- Special responsibilities: This is a dummy variable that takes the value 1 for museums having special responsibilities, and zero otherwise. Special responsibilities are those that go beyond those specified in the Museums Act. Examples of these special responsibilities include taking care of the archaeological sites located in the respective municipality and taking part in archaeological investigations. It is expected (hypothesis) that those museums having special responsibilities would require more inputs to produce the same amount of the outputs considered in this analysis.

Table 2.1 presents some descriptive statistics for the input, output and environmental variables.

2.4.4 Public funding and technical inefficiency

When estimating the influence of public funding on average technical efficiency, the existing literature (Bishop and Brand, 2003) measures that variable as the ratio of public funding over total sources of funding. However, in that analysis this

Table 2.1: Summary Statistics

Statistic	Mean	St. Dev.	Min	Median	Max
capital [thousands of real krones]	2,850.73	3,715.89	128.54	1,442.24	20,873.82
scientific labour [number of people]	9.03	8.43	1	6	59
non-scientific labour [number of people]	23.17	30.38	0.40	12.03	180.00
conservation [thousands of real krones]	232.29	287.03	0.19	116.13	2,340.55
exhibitions [number of exhibitions]	5.99	4.98	1	5	45
education [number of group visits]	195.04	288.71	3	127	4,461
events [number of events]	276.48	391.63	1	132	2,576
research [number of articles]	6.72	8.42	1	4	59
visitors [number of physical visitors]	108,666.30	144,306.90	4,762	52,490	835,606
visit sites [number of visit sites]	3.10	3.76	1	1	20
responsibilities [1 = special responsibilities]	0.38	0.49	0	0	1

ratio is treated as a categorical variable, taking the value 1 for those museums for which 90% or more of the income sources comes from the public sector and zero otherwise. Defining this variable in a dichotomous way "reflects a clear break point in the data" (Bishop and Brand, 2003, p.1856) but of course, defined this way, this is a rather raw measure of public funding, as these authors acknowledge (Bishop and Brand, 2003, p.1858). In our data there is not such break point. Hence it is here treated not as a dichotomous but as a continuous variable.

Public funding comes from both the municipalities and the national government and can be used to cover operational expenses. Other sources of funding, coming from the European Union and the Nordic Council of Ministers, cannot be used to cover operational expenses, are project-based and have favoured only a small percentage of the museums. Due to these reasons, they are excluded from the analysis. Therefore, in this paper public funding is defined as the percentage of the total sources of funding that is represented by the sum of municipal funding and the funding coming from the central government.

2.5 Analysis and main results

In this section equation 2.7 is estimated. All the variables are normalized by their geometric mean. As mentioned in section 2.3.1, the model assumes u follows a half-normal distribution whose variance is a function of public funding. The model has been estimated with the software R, using the package *sfaR*, developed by Dakpo et al. (2021).

In order to avoid perfect multicollinearity, we exclude the term $z_2 z_2 = z_2^2$, which corresponds to imposing the restriction $\delta_{22} = 0$. This is because z_2 is a dummy variable.

2.5.1 Monotonicity conditions

Unlike non-parametric methods, which impose monotonicity conditions by construction (Bogetoft and Otto, 2011), parametric methods do not do so, hence I must check whether they are fulfilled by our models and if they are not, they must be imposed. In stochastic frontier analysis this check procedure is rarely done, which is a bit of a surprise, for, as Henningsen and Henning (2009) point out, violations of these conditions can be a problem for both the reliability of technical efficiency estimates and the interpretation of the effect of exogenous factors on it (Henningsen and Henning, 2009)[16].

I proceed to impose these conditions, following Henningsen and Henning (2009) and Henningsen (2020)[17]. The method to do this consists on three steps: (i) estimating the model and extracting the vector of coefficients; (ii) finding a new vector of coefficients by means of a minimum distance estimator; and (iii) evaluating the model using the new coefficients. The intuition behind the second step is that we need to find a vector that satisfies two conditions: being the most similar (the closest) to the original one that guarantees that the model, when estimated with these new coefficients, satisfies the monotonicity conditions[18].

The following model explains in very simple terms how this constrained minimization problem works[19]. $\hat{\beta}$ and IM are the coefficients vector and the inverse of the variance covariance matrix of the original (non-restricted) model, respectively, and $\hat{\beta}'$ is the restricted vector of coefficients (which we want to find). $ln\hat{D}$ is the distance function evaluated in the restricted vector. In our exercise k takes the values 1 to 3 (our three inputs) and n takes the values 1 to 6 (our six outputs).

$$\begin{aligned} \hat{\beta}' \quad & = \text{argmin}(\hat{\beta}' - \hat{\beta}) * IM * (\hat{\beta}' - \hat{\beta}) \\ \text{s.t.} \quad & \frac{\partial ln\hat{D}}{\partial lny_n} <= 0 \quad \forall n = 1,2,3,4,5,6 \\ & \frac{\partial ln\hat{D}}{\partial lnx_k} >= 0 \quad \forall k = 1,2,3 \end{aligned} \tag{2.8}$$

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[16] Also, O'Donnell and Coelli (2005, p.282) draws our attention to the fact that "when the distance function is a translog function, then it is possible to find feasible input-output combinations where these monotonicity properties do not hold" and this is construed as a problem. See also O'Donnell and Coelli (2005). I am grateful to Arne Henningsen for telling me about this issue and for helping me to adapt the method he proposed in Henningsen and Henning (2009) to the input-oriented distance function.

[17] Another method to impose monotonicity, and curvature conditions more generally, was developed by O'Donnell and Coelli (2005).

[18] In this paper this procedure has been implemented using the R software (R Core Team, 2020) using the add-on packages Coelli and Henningsen (2020) and Turlach and Weingessel (2011). The corresponding R code is presented in Henningsen (2020, Section 8.5.6).

[19] For a complete derivation of the problem and the corresponding restriction matrix, see Henningsen (2020, section 8.5).

Once the restricted coefficients are obtained, they are used to estimate the adjusted frontier of each observation. This adjusted frontier is in turn used as the single independent variable in the new (correct) stochastic frontier model.

2.5.2 The production frontier

Table 2.2 presents the results of the unrestricted and restricted models[20]. It is worth pointing out that in the unrestricted model the monotonicity conditions are violated in between 1,4% and 9,7% of the observations. In the case of outputs, monotonicity violations account for between 7,9% and 54,4% of total observations[21].

In order to see what influence environmental variables may have on technical inefficiency I derive the distance function with respect to each of them[22]. These results are expected to be of interest to both museums managers and policy makers. The results show that those museums having special responsibilities require (on average) more inputs to produce the same amount of the outputs corresponding to the museums' traditional responsibilities (the outputs considered in this analysis), and that this additional amount of inputs can be substantial, as per indicated by a semi-elasticity of -0.21. This makes sense as fulfilling these additional responsibilities requires distracting resources from the main responsibilities. Museums managing more visit sites require, *caeteris paribus*, more inputs to produce a given set of outputs. The average distance elasticity of technical inefficiency with respect to the number of visit sites is -0.06. A plausible explanation for this relates to scale economies, as when managing more visit sites the fixed costs would probably be more relevant in the cost structure compared to what would happen if these sites were merged into one single visit site. It doesn't of course follow from this a policy recommendation in the line of subsuming museums' units into one single visit site, as because of their very

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[20] The reader is reminded that the dependent variable is the negative (log) of the capital input, and the other inputs have been divided by the capital input, as explained in section 2.3.2.

[21] Monotonicity is not violated in the case of those observations for which the derivatives of equation 2.7 with respect to each output are less or equal than zero and the derivatives of that equation with respect to each input are non-negative.

[22] Given that the number of visit sites is in log form the derivative measures a distance elasticity. In the case of the special responsibilities, given that it is measured as a dummy variable, the result indicate a distance semi-elasticity.

nature these units will probably have to continue operating as individual visit sites, for instance because they are very different in terms of the nature of their permanent collection or must be geographically scattered in order to reach a wider audience. An interesting comparison would be that between units functioning as autonomous entities with their own administration (i.e., before the merger takes place) and the same units being part of, and managed by, a central museum (i.e., after the merger takes place). That comparison cannot however be made in this paper, for these units have been part of a single museum during the whole period covered by our database.

I also estimated the model including environmental variables distinguishing between museums of different type (arts, cultural history and natural history) but this variable doesn't have a statistically significant effect on the frontier (the results are not reported because the table is already too large, but they are available upon request). This brings support to Ginsburgh and Mairesse (1997), who suggest that from a technical point of view, museums perform the same basic activities, so it makes sense to estimate the model considering all the museums, regardless of their type[23].

We cannot of course derive any conclusion about the effect of input and output variables on the dependent variable, because in this model the unknown technology is approximated with a functional form that is non-linear in the variables. We are not however interested in this aspect but on the sign and significance of the effect of public funding on technical inefficiency. Table 2.2 shows this effect is negative and statistically significant in both the unrestricted and the restricted model (see coefficients δ_0 and δ_1). It is worth pointing out however that in the restricted model the standard errors of this coefficient are likely to be downward biased (Henningsen and Henning, 2009), hence the real statiscal significance is expected to be lower. Therefore, this result must be considered cautiously. As an additional warning note, it is important to emphasize that given the stochastic nature of this model, we cannot be sure about the exogeneity of the regressors, hence these conclusions are only provisional.

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[23] The results with this additional environmental variable are not presented for the sake of visual presentation (the table is already too large) but are of course available upon request.

Table 2.2: Estimation results: unrestricted and restricted estimates

Coef.	Estimate	S.E.	Restricted	Coef.	Estimate	S.E.	Restricted
α_0	0.5828***	0.0741	0.4249	ϵ_{22}	0.0483	0.0271	0.0259
ρ_{21}	0.5433***	0.0557	0.5345	ϵ_{23}	-0.0676	0.0394	-0.0257
ρ_{31}	0.2089***	0.0561	0.2313	ϵ_{24}	-0.0290	0.0228	-0.0021
ρ_{22}	0.1092*	0.0530	0.1135	ϵ_{25}	-0.0362	0.0358	0.0024
ρ_{33}	0.2368***	0.0497	0.0881	ϵ_{26}	0.0633	0.0401	0.0176
ρ_{23}	-0.2123***	0.0393	-0.1231	ϵ_{31}	0.0435	0.0404	0.0042
β_1	-0.2972***	0.0506	-0.3283	ϵ_{32}	-0.0459	0.0282	-0.0175
β_2	-0.1789***	0.0371	-0.1615	ϵ_{33}	0.0290	0.0384	0.0256
β_3	-0.1164	0.0600	-0.0772	ϵ_{34}	-0.0457*	0.0207	-0.0126
β_4	0.0606	0.0317	-0.0242	ϵ_{35}	-0.0289	0.0273	-0.0153
β_5	-0.0933*	0.0436	-0.0518	ϵ_{36}	0.0071	0.0360	0.0151
β_6	-0.2763***	0.0468	-0.2298	γ_1	0.0561	0.1033	0.1509
β_{11}	-0.3407***	0.0663	-0.1197	γ_2	0.0931	0.1255	0.0676
β_{22}	-0.1066**	0.0335	-0.0433	θ_{11}	0.0836	0.0816	-0.0264
β_{33}	-0.0489	0.0517	-0.0148	θ_{12}	-0.4748***	0.0879	-0.3890
β_{44}	0.0165	0.0129	0.0032	ϕ_{21}	-0.0014	0.0413	0.0053
β_{55}	-0.0003	0.0254	0.0045	ϕ_{22}	-0.1905*	0.0873	-0.2495
β_{66}	-0.1064**	0.0344	-0.0433	ϕ_{31}	0.0964*	0.0435	0.0311
β_{12}	0.0596*	0.0288	0.0132	ϕ_{32}	0.1415	0.0842	0.1611
β_{13}	0.0616	0.0411	0.0122	ω_{11}	0.1536***	0.0466	0.0462
β_{14}	0.0507*	0.0252	0.0062	ω_{21}	0.0041	0.0300	-0.0036
β_{15}	0.0309	0.0321	0.0073	ω_{31}	-0.0350	0.0412	0.0232
β_{16}	0.0724*	0.0329	0.0022	ω_{41}	-0.0368	0.0205	-0.0201
β_{23}	-0.0089	0.0298	0.0037	ω_{51}	-0.0608	0.0320	-0.0111
β_{24}	-0.0082	0.0156	-0.0005	ω_{61}	-0.0530	0.0460	0.0120
β_{25}	0.0176	0.0207	0.0029	ω_{12}	-0.3878***	0.0881	-0.0601
β_{26}	-0.0800**	0.0255	-0.0321	ω_{22}	0.0878	0.0602	0.0319
β_{34}	0.0121	0.0223	-0.0015	ω_{32}	0.0251	0.0991	-0.1092
β_{35}	-0.0613	0.0340	-0.0002	ω_{42}	0.0074	0.0426	0.0142
β_{36}	-0.0105	0.0342	-0.0100	ω_{52}	0.2984***	0.0677	0.0499
β_{45}	-0.0354*	0.0175	-0.0006	ω_{62}	0.2428**	0.0887	0.0550
β_{46}	0.0136	0.0196	0.0038	δ_0	-1.4667**	0.4998	-0.8878*
β_{56}	-0.0066	0.0266	-0.0083	δ_1	-3.0332*	1.4329	-3.9868*
ϵ_{21}	-0.0053	0.0433	-0.0023	σ_v^2	-3.0695***	0.2097	-2.6905***

Notes: Asterisks indicate significance levels, where: *** ≤ 0.001, ** ≤ 0.01, * ≤ 0.05. Column 'Restricted' indicates the restricted estimates. The restricted estimates of the model coefficients, i.e., all coefficients except for the variance parameters σ^2 and γ, are obtained in the second-step minimum-distance estimation and, thus, do not have standard errors or significance levels. The restricted estimate of the intercept is adjusted by the intercept of the third-step stochastic-frontier estimation. The variance parameters σ^2 and γ are obtained in the third-step stochastic-frontier estimation.

2.5.3 Marginal effects

It suffices to take a look at the sign of the coefficients determining the influence of public funding on technical inefficiency (δ_0 and δ_1 in table 2.2) to get an idea about the direction of the effect of public funding on average technical efficiency but these coefficients tell us nothing about the magnitude of that effect (this model is non-linear in the variables), so the marginal effects would have to be computed. I therefore estimate the corresponding marginal effects. Equation 2.9 shows that the marginal effect of variable z (in our case public funding) on average technical inefficiency ($E(u)$) is given by (this is a slightly modified version of equation 3.38 in Kumbhakar et al. (2015)):

$$\frac{\partial E(u)}{\partial z} = w\frac{\sigma_{ui}}{2}[\frac{\psi(0)}{\Phi(0)}] \tag{2.9}$$

where w is the parameter of variable z in the variance of technical inefficiency and $\psi(0) \approx 0.399$

The results indicate that the mean (median) marginal effect is 0.49% (0.44%). That is for each percentage point increase in public funding average technical inefficiency decreases 0.49 percentage points. Average (median) technical efficiency is estimated to be 1.215 (1.164), which indicates that the museums use on average 21.5% more of each input than would be required to produce the given output quantities. Figure 2.1 shows the distribution of technical inefficiency scores and that of the marginal effects on average technical inefficiency.

This positive (negative) effect of public funding on average technical (in)efficiency stands against the negative effect that Bishop and Brand (2003) find, an effect they interpret to be consistent with what could be seen through the lens of public choice theory (i.e., subsidies seen as generating wrong incentives for museums to be more efficient). But, as mentioned, their analysis assumes a single-output setting, being the number of visitors that sole output, does not consider environmental variables and measures public funding with a dummy variable distinguishing museums with more than 90% of public funding and the rest).

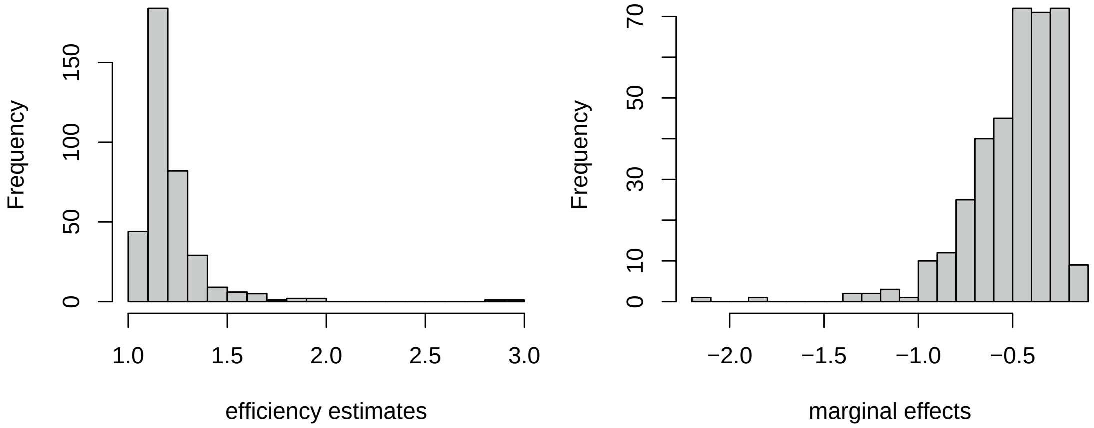

Figure 2.1: Technical Efficiency and Marginal Effects

To examine whether the difference in the results are due to these different assumptions, I estimate a single-output model, using the same sample that I have used for the multi-output model, with and without environmental variables, with both the continuous and the dichotomic measure of public funding, and assuming the two distributions of technical inefficiency referred to above. The results (not reported but available upon request) indicate the effect of public funding on technical inefficiency is not statistically significant in a single-output setting, no matter the other assumptions made.

Of course the question of external validity cannot be ignored; these results are to be considered valid only for this sample, as that considered by Bishop and Brand (2003) is different in many aspects (size and number of periods) and the way public funding is granted in England (the country that article focuses on) differs from that of the Danish system. However, if one question of interest is whether or not the effect of public funding on technical efficiency is different in a single versus a multiple output setting, then at least using our database and our model the answer seems to be positive.

We must acknowledge the limitations of this analysis, the main of them being the lack of enough data time periods, which precludes the estimation of panel data models, something that could allow to control for time-invariant museums' characteristics.

2.6 Conclusions and recommendations

In this paper the impact of public funding on average technical efficiency of museums has been analysed. So far, only Bishop and Brand (2003) had relied on parametric approaches to analyse this question although they specified a single output production function and do not estimate the marginal effects so we cannot be sure about the economic significance of their results. Still, an interesting point these authors made was that, when considering only that single output, the effect of public funding on average technical efficiency might be hiding the positive influence of funding on the production of other museum services, particularly those expected to have a high social value, such as conservation and research.

I have examined this question in a multi-output setting, also relying on stochastic frontier models, and I have shown that the effect of public funding on average technical inefficiency is negative. I have done this controlling for some environmental variables that are of interest to the museum sector. I have also examined some other hypotheses, including that of using the indicator of public funding as a dichotomic variable, in the line of Bishop and Brand (2003), so as to see whether the difference between my results and theirs may or not lie on that assumption vis a vis mine (public funding measured as a continuous variable). I have also estimated single output models with visitors as the sole output, in order to see whether or not considering multiple outputs makes any difference. It doesn't. I also estimated the model with the type of the collection as an additional environmental variable and no differences were found. These results hold when monotonicity conditions are imposed (this paper is the first to impose such conditions in an input-oriented setting).

Some results that might be of interest to both museums managers and regulators is the influence environmental variables may have on technical inefficiency. Museums managing more visit sites require, *caeteris paribus*, appear to require more inputs to produce a given set of outputs. A plausible explanation for this relates to scale economies, as when managing more visit sites the fixed costs would probably be more relevant in the cost structure compared to what would happen if these sites were merged into one single visit site. It doesn't of course follow from this a policy recommendation in the line of subsuming museums' units into one single visit site, as because of their very nature these units will probably have to continue operating as individual visit sites, for instance because they are very different in terms of the nature of their permanent collection or must be geographically scattered in order to reach a wider audience.In the case of the special responsibilities, the results suggest that those museums having special responsibilities require (on average) more inputs to produce the same amount of the outputs corresponding to the museums' traditional responsibilities (the outputs considered in this analysis). This makes sense as fulfilling these additional responsibilities requires distracting resources from the main responsibilities.

But going back to our main objective of this paper, if one question of interest is whether or not the effect of public funding on technical efficiency is different in a single versus a multiple output setting, then at least using our database and our model the answer seems to be positive.

Among the limitatios of our analysis, we must highlight the lack of enough data time periods. Having more periods would allow us to estimate panel data models, something that could allow to control for time-invariant museums' characteristics.

Bibliography

Basso, A., Casarin, F., and Funari, S. (2018). How well is the museum performing? a joint use of dea and bsc to measure the performance of museums. *Omega*, 81:67 – 84.

Bishop, P. and Brand, S. (2003). The efficiency of museums: a stochastic frontier production function approach. *Applied Economics*, 35(17):1853–1858.

Bogetoft, P. and Otto, L. (2011). *Benchmarking with DEA, SFA, and R*. Springer.

Camarero, C., Garrido, M. J., and Vicente, E. (2011). How cultural organizations' size and funding influence innovation and performance: the case of museums. *Journal of Cultural Economics*, 35(4):247.

Coelli, T. and Henningsen, A. (2020). *frontier: Stochastic Frontier Analysis*. R package version 1.1-8.

Dakpo, K. H., Desjeux, Y., and Latruffe, L. (2021). *sfaR: Stochastic Frontier Analysis using R*. R package version 0.1.0.

del Barrio, M. J., Herrero, L. C., and Ángel Sanz, J. (2009). Measuring the efficiency of heritage institutions: A case study of a regional system of museums in spain. *Journal of Cultural Heritage*, 10(2):258 – 268.

del Barrio-Tellado, M. J. and Herrero-Prieto, L. C. (2019). Modelling museum efficiency in producing inter-reliant outputs. *Journal of Cultural Economics*, 43(3):485–512.

Feldstein, M. (1991). *The Economics of Art Museums*. University of Chicago Press.

Fernandez-Blanco, V., Rodriguez-Alvarez, A., and Wisniewska, A. (2017). Measuring Technical Efficiency and Marginal Costs in the Performing Arts: The Case of the Municipal Theatres of Warsaw. ACEI Working Paper Series AWP-09-2017, Association for Cultural Economics International.

Frey, B. and Meier, S. (2006). The economics of museums. In Ginsburgh, V. and Throsby, D., editors, *Handbook of the Economics of Art and Culture: Volume 1*, volume 1, chapter 29, pages 1017–1047. Elsevier, 1 edition.

Ginsburgh, V. and Mairesse, F. (1997). Defining a museum: Suggestions for an alternative approach. *Museum Management and Curatorship*, 16(1):15–33.

Grampp, W. D. (1989). *Pricing the priceless : art, artists, and economics / William D. Grampp*. Basic Books New York.

Henningsen, A. (2020). Introduction to econometric production analysis with r. collection of lecture notes. 4th draft version. *Department of Food and Resource Economics, University of Copenhagen. Available at http://leanpub.com/ProdEconR/*.

Henningsen, A. and Henning, C. H. C. A. (2009). Imposing regional monotonicity on translog stochastic production frontiers with a simple three-step procedure. *Journal of Productivity Analysis*, 32(3):217.

Johnson, P. and Thomas, B. (1998). The economics of museums: A research perspective. *Journal of Cultural Economics*, 22(2/3):75–85.

Kumbhakar, S., Wang, H.-J., and Horncastle, A. P. (2015). *A Practitioner's Guide to Stochastic Frontier Analysis Using Stata*. Cambridge University Press.

Last, A.-K. and Wetzel, H. (2010). The efficiency of german public theaters: a stochastic frontier analysis approach. *Journal of Cultural Economics*, 34(2):89–110.

Mairesse, F. and Eeckaut, P. V. (2002). Museum assessment and fdh technology: Towards a global approach. *Journal of Cultural Economics*, 26(4):261–286.

O'Donnell, C. (2018). *Productivity and Efficiency Analysis: An Economic Approach to Measuring and Explaining Managerial Performance*. Springer.

O'Donnell, C. and Coelli, T. (2005). A bayesian approach to imposing curvature on distance functions. *Journal of Econometrics*, 126(2):493–523.

O'Hagan, J. W. (1995). National museums: To charge or not to charge? *Journal of Cultural Economics*, 19(1):33–47.

O'Hagan, J. W. (1998). Art museums: Collections, deaccessioning and donations. *Journal of Cultural Economics*, 22(2/3):197–207.

Parmeter, C. F. and Kumbhakar, S. C. (2014). Efficiency analysis: A primer on recent advances. *Foundations and Trends® in Econometrics*, 7(3–4):191–385.

R Core Team (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Taheri, H. and Ansari, S. (2013). Measuring the relative efficiency of cultural-historical museums in tehran: Dea approach. *Journal of Cultural Heritage*, 14(5):431 – 438.

Throsby, D. (1994). The production and consumption of the arts: A view of cultural economics. *Journal of Economic Literature*, 32(1):1–29.

Turlach, B. A. and Weingessel, A. (2011). *quadprog: Functions to solve Quadratic Programming Problems.* R package version 1.5-4.

Chapter 3

Second paper: "A ray-based input distance function to model zero-valued output quantities: derivation and an empirical application"

Arne Henningsen (Associate Professor at the University of Copenhagen's Institute of Food and Resource Economics) is co-author of this paper (see the corresponding "Co-author Statement" in the next page).

The same database of the first paper is used here. In the description of the museums under analysis and the outputs, inputs and environmental variables the reader will find information already presented in that paper. The number of observations is however larger than that of the first paper, given that also observations presenting one or more outputs equal to zero are considered, something that is explained in the text.

We are especially grateful to the comments made by Mette Asmild, Christopher O'Donnell and Peter Bogetoft to an earlier version. We also appreciate the comments made by participants in the North American Productivity Workshop, NAPW 2021, particularly those of Robin Sickles. We thank Lucas Alexander Kock and Berit Fruelund Kjarside, from the Danish Ministry of Culture, and Monika Bille Nielsen, from Statistics Denmark, who provided the data.

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CO-AUTHOR STATEMENT

Title of paper	A Ray-based input distance function to model zero-value output quantities: derivation and an empirical application
Journal and date (if published)	

1. Formulation/identification of the scientific problem to be investigated and its operationalization into an appropriate set of research questions to be answered through empirical research and/or conceptual development

Description of contribution:

This was done by Juan José Price.

2. Planning of the research, including selection of methods and method development

Description of contribution:

This was mostly done by Juan José Price. Arne Henningsen gave some advice related to the definition of the steps of the research, which helped Juan José Price to do the many required tasks in a framework that defined the milestones and deadlines clearly. Arne Henningsen gave some advice in the process of refining the model, particularly in what refers to the ordering of the outputs.

3. Involvement in data collection and data analysis

Description of contribution:

The data set was obtained (and put in a format that is compatible with the software R) by Juan José Price. The data analysis was mostly done by Juan José Price. Arne Henningsen gave some help with the coding in R.

4. Presentation, interpretation and discussion of the analysis in the form of an article or manuscript

Description of contribution:

Juan José Price drafted the manuscript, while Arne Henningsen read it, gave some comments, and made some minor revisions.

Publication

Please note that the article will be published electronically and in a limited edition in print as a part of the PhD thesis by the CBS library in connection with the PhD defence.

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08 March 2021

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Abstract

We derive and test an input-oriented distance function based on the stochastic ray production function suggested by Löthgren (1997, 2000). We show that the derived ray-based input distance function is suitable for modelling production technologies based on logarithmic functional forms (e.g., Cobb-Douglas and Translog) when control over inputs is greater than over outputs and when some productive entities do not produce the entire set of outputs, a problem that is common to various economic sectors. We also address a critique the stochastic ray function has been subject to, namely its sensitivity to the outputs' ordering. We estimate a ray-based Translog input distance function with a data set of Danish museums. These museums have more control over their inputs than over their outputs and many of them do not produce the entire set of outputs that are considered in our analysis. Given the importance of monotonicity conditions in efficiency analysis, we demonstrate how to impose monotonicity on ray-based input distance functions. As part of the empirical analysis, we estimate technical efficiencies, distance elasticities of the inputs and outputs, scale elasticities, and how the production frontier is affected by some environmental variables that are of interest to the museum sector.

3.1 Introduction

In econometric efficiency and productivity analysis, multi-output production technologies are usually modelled by so-called distance functions (Färe and Primont, 1990; Kumbhakar and Lovell, 2000), where the most commonly used functional forms are the Cobb-Douglas and Translog specifications. However, these functional forms are unsuitable whenever some producers in a given data set do not produce all outputs so that logarithms of the quantities of the non-produced outputs are undefined. It has been suggested to replace zero output quantities by arbitrarily small numbers but this approach has shown to be unsuitable (Henningsen et al., 2015; N'guessan et al., 2017).

The Cobb-Douglas and Translog stochastic ray production frontier functions (Löthgren, 1997, 2000), which are in fact output-oriented distance functions (Henningsen et al., 2015), can be applied to data with zero output quantities. However, in many production processes, managers have more control over inputs than over outputs and, hence, an input-oriented distance function would be more appropriate for an empirical analysis than an output-oriented distance function such as a stochastic ray production frontier function[1]. In this paper, we propose a solution to this problem by deriving input-oriented Cobb-Douglas and Translog distance functions based on the stochastic ray production frontier functions.

We test these specifications empirically by analysing input-oriented technical efficiency with data from state-recognised museums in Denmark. This data set appears to be especially suitable for testing the ray function, because many of these museums produce only some of the six outputs that we consider in our analysis. For instance, some museums produce exhibitions, educational programs and engage in conservation but do not do research. And these museums do in fact have less control over outputs and more over inputs. In fact, these entities are not owned by the state but get public funding. The goals in terms of some outputs, such as research and educational programs, are in part defined jointly with the granting and regulatory body, the Danish Agency for Culture and Palaces. The number of visitors is to a great extent a demand driven indicator, which in turn determines decisions in terms of number of exhibitions and other events.

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[1] See Kumbhakar et al. (2015) regarding the importance of choosing the right orientation for the distance function.

Hence, using an input-oriented distance function is more advisable than using an output-oriented distance function.

As part of this empirical analysis, we address a critique the ray function has been subject to, namely its sensitivity to the ordering of the outputs by using both a model selection approach and a model averaging approach. Given the importance of monotonicity conditions in efficiency analysis (Henningsen and Henning, 2009), we derive the monotonicity conditions for the inputs and outputs and demonstrate how to impose them on ray-based input distance functions. Furthermore, we derive and estimate the distance elasticities of the inputs and outputs, the elasticity of scale, and how the production technology is affected by environmental variables that are of interest in this sector, both from management and regulatory perspectives.

In the following section we derive and present the methodology and the specification of our model. Section 3.3 presents the data. Section 3.4 presents the results. The last section presents our conclusions and possible limitations.

3.2 Empirical model specification

3.2.1 Derivation of a ray-based input distance function

As mentioned in the introduction, traditional distance functions based on logarithmic functional forms cannot handle observations where one (or more) outputs have a quantity equal to zero. An alternative specification that solves this problem is the stochastic ray production function, originally proposed by Löthgren (1997). This functional form represents the vector of output quantities as polar coordinates rather than as Cartesian coordinates, i.e., vector of output quantities is represented by its (Euclidean) length and its direction as indicated by a vector of directional measures rather than by the individual output quantities.

A stochastic ray production frontier model is defined as:

$$\ln \left\| y \right\| = f^{*} \left(\ln x, \varphi \left(y \right), z \right) - u^{*} + v^{*}, \tag{3.1}$$

where $x = (x_1, x_2, \ldots, x_N)^\top \in \mathbb{R}^N_{>0}$ is a vector of N strictly positive input quantities, $y = (y_1, y_2, \ldots, y_M)^\top \in \mathbb{R}^M_{\geq 0}$ is a vector of M non-negative output quantities with at least one strictly positive output quantity $\exists i \in 1, \ldots, M : y_i > 0$, $\varphi(y) = \left(\varphi_1(y), \varphi_2(y), \ldots, \varphi_{M-1}(y)\right)^\top$ is a vector of the angles of the vector of output quantities y with $\varphi_i(y) = \arccos\left(y_i \middle/ \sqrt{\sum_{j=i}^M y_j^2}\right) \; \forall \; i = 1, \ldots, M-1$, $\left\|y\right\|$ is the length of the vector of output quantities, $z = (z_1, z_2, \ldots, z_K)^\top \in \mathbb{R}^K$ is a vector of K 'environmental' variables, $u^* \geq 0$ is the inefficiency term, v^* is the noise term, and $f^*(\cdot)$ is a function that can be of various functional forms, e.g., linear for a Cobb-Douglas stochastic ray production frontier or quadratic for a Translog stochastic ray production frontier. The stochastic ray production frontier (3.1) can be seen as a Shephard output distance function (Henningsen et al., 2015):

$$\ln D^o(x, y, z) = -u^* = f(\ln x, \varphi(y), z) + \ln \left\|y\right\| + v, \tag{3.2}$$

where $D^o(x, y, z) = e^{-u^*}$ with $0 \leq D^o(x, y, z) \leq 1$ is a Shephard output distance function, $f(\cdot) = -f^*(\cdot)$, and $v = -v^*$.

This specification of a stochastic-ray-based output distance function can be generalised to the following 'general' distance function:

$$\ln D(x, y, z) = f\left(\ln x, \varphi(y), \ln \left\|y\right\|, z\right) + v. \tag{3.3}$$

If function $\exp(f(\cdot))$ is linear homogeneous in output quantities y (e.g., $f(\ln x, \varphi(y), \ln \left\|y\right\|, z) = f(\ln x, \varphi(y), z) + \ln \left\|y\right\|$), function $D(x, y, z)$ can be seen as a Shephard output distance function. However, if function $\exp(f(\cdot))$ is linear homogeneous in input quantities x, function $D(x, y, z)$ can be seen as a Shephard input distance function. We can make this function linear homogeneous in input quantities x so that we get a Shephard input distance function, e.g., by:

$$\ln D^i(x, y, z) = f\left(\ln \tilde{x}, \varphi(y), \ln \left\|y\right\|, z\right) + \ln x_N + v, \tag{3.4}$$

where $\tilde{x} = (\tilde{x}_1, \tilde{x}_2, \ldots, \tilde{x}_{N-1})^\top = (x_1/x_N, x_2/x_N, \ldots, x_{N-1}/x_N)^\top$ is a vector of normalised input quantities.

By replacing the logarithm of the Shephard input distance measure $D^i(x,y) \geq 1$, i.e., $\ln D^i(x,y) \geq 0$, by the inefficiency term $u \geq 0$ and a little re-arranging, we get:

$$-\ln x_N = f\left(\ln \tilde{x}, \varphi(y), \ln\left\|y\right\|, z\right) - u + v \tag{3.5}$$

that we can estimate using stochastic frontier analysis.

Assuming a quadratic functional form for $f(\cdot)$, we get the following equation, which can be easily estimated as a stochastic frontier model:[2]

$$\begin{aligned}
-\ln x_N = {} & \alpha_0 + \sum_{i=1}^{N-1} \alpha_i \ln(\tilde{x}_i) + \frac{1}{2}\sum_{i=1}^{N-1}\sum_{j=1}^{N-1} \alpha_{ij} \ln(\tilde{x}_i) \ln\left(\tilde{x}_j\right) \\
& + \sum_{i=1}^{M-1} \beta_i \varphi_i(y) + \beta_M \ln\left\|y\right\| + \frac{1}{2}\sum_{i=1}^{M-1}\sum_{j=1}^{M-1} \beta_{ij}\varphi_i(y)\varphi_j(y) \\
& + \sum_{i=1}^{M-1} \beta_{iM}\varphi_i(y)\ln\left\|y\right\| + \frac{1}{2}\beta_{MM}\left(\ln\left\|y\right\|\right)^2 \\
& + \sum_{i=1}^{K} \delta_i z_i + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \delta_{ij} z_i z_j \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{M-1} \psi_{ij} \ln(\tilde{x}_i)\varphi_j(y) + \sum_{i=1}^{N-1} \psi_{iM} \ln(\tilde{x}_i)\ln\left\|y\right\| \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{K} \xi_{ij} \ln(\tilde{x}_i) z_j \\
& + \sum_{i=1}^{M-1}\sum_{j=1}^{K} \zeta_{ij}\varphi_i(y) z_j + \sum_{i=1}^{K} \zeta_{Mi} \ln\left\|y\right\| z_i - u + v
\end{aligned} \tag{3.6}$$

with $\alpha_{ij} = \alpha_{ji} \, \forall \, i,j = 1,\ldots,N-1$, $\beta_{ij} = \beta_{ji} \, \forall \, i,j = 1,\ldots,M-1$, and $\delta_{ij} = \delta_{ji} \, \forall \, i,j = 1,\ldots,K$[3].

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[2] The Cobb-Douglas functional form is a special case with $\alpha_{ij} = 0 \, \forall \, i,j = 1,\ldots,N$, $\beta_{ij} = 0 \, \forall \, i,j = 1,\ldots M$, $\delta_{ij} = 0 \, \forall \, i,j = 1,\ldots,K$, $\psi_{ij} = 0 \, \forall \, i = 1,\ldots,N; j = 1,\ldots,M$, $\xi_{ij} = 0 \, \forall \, i = 1,\ldots,N; j = 1,\ldots,K$, and $\zeta_{ij} = 0 \, \forall \, i = 1,\ldots,M; j = 1,\ldots,K$. As it is mentioned in Section 3.4, we test the Translog specification defined in equation (3.6) against the corresponding Cobb-Douglas specification. The test rejects the Cobb-Douglas specification in favour of the Translog specification. Therefore, the following derivations are based on the Translog specification.

[3] In the Appendix we present the derivation of equation (3.6).

3.2.2 Distance elasticities

Assuming that the inefficiency term u and the noise term v are both independent from the explanatory variables $(\tilde{x}, y, z)$, the distance elasticities of the N inputs and the M outputs are:

$$\begin{aligned}\frac{\partial \ln D^i(x,y,z)}{\partial \ln x_i} &= \alpha_i + \sum_{j=1}^{N} \alpha_{ij} \ln x_j + \sum_{j=1}^{M-1} \psi_{ij} \varphi_j(y) + \psi_{iM} \ln \left\| y \right\| \\ &\quad + \sum_{j=1}^{K} \xi_{ij} z_j \; \forall \, i = 1, \ldots, N\end{aligned} \tag{3.7}$$

$$\begin{aligned}\frac{\partial \ln D^i(x,y,z)}{\partial \ln y_i} &= \sum_{j=1}^{M-1} \beta_j y_i \Omega_{ji} + \beta_M \frac{y_i^2}{\left\| y \right\|^2} + \sum_{j=1}^{M-1} \sum_{k=1}^{M-1} \beta_{jk} \varphi_k(y) y_i \Omega_{ji} \\ &\quad + \sum_{j=1}^{M-1} \beta_{jM} \left(y_i \Omega_{ji} \ln \left\| y \right\| + \varphi_j(y) \frac{y_i^2}{\left\| y \right\|^2} \right) + \beta_{MM} \frac{\ln \left\| y \right\| y_i^2}{\left\| y \right\|^2} \\ &\quad + \sum_{j=1}^{N} \sum_{k=1}^{M-1} \psi_{jk} \ln x_j y_i \Omega_{ki} + \sum_{j=1}^{N} \psi_{jM} \ln x_j \frac{y_i^2}{\left\| y \right\|^2} \\ &\quad + \sum_{j=1}^{M-1} \sum_{k=1}^{K} \zeta_{jk} z_k y_i \Omega_{ji} + \sum_{j=1}^{K} \zeta_{Mj} z_j \frac{y_i^2}{\left\| y \right\|^2} \; \forall \, i = 1, \ldots, M,\end{aligned} \tag{3.8}$$

respectively, with:

$$\begin{aligned}\Omega_{ji} \equiv \frac{\partial \varphi_j(y)}{\partial y_i} &= \begin{cases} 0 & \text{if } i < j \vee \left(i = j \wedge y_j > 0 \wedge \sum_{k=j+1}^{M} y_k = 0 \right) \\ \text{undefined} & \text{if } i \geq j \wedge y_j = y_{j+1} = \ldots = y_M = 0 \\ \frac{y_j}{\left\| y \right\|_j^2} & \text{if } i > j \wedge \sum_{k \in [(j+1)..M] \setminus i} y_k = 0 \\ \frac{y_i y_j - I_{i=j} \left\| y \right\|_j^2}{\left\| y \right\|_j^2 \left\| y \right\|_{j+1}} & \text{otherwise} \end{cases} \\ &\forall \, i = 1, \ldots, M, j = 1, \ldots, M-1,\end{aligned} \tag{3.9}$$

$$\left\| y \right\|_i \equiv \sqrt{\sum_{j=i}^{M} y_j^2}, \tag{3.10}$$

$\alpha_N = 1 - \sum_{i=1}^{N-1} \alpha_i$, $\alpha_{Nj} = -\sum_{i=1}^{N-1} \alpha_{ij} \, \forall \, j = 1, \ldots, N$, $\alpha_{iN} = -\sum_{j=1}^{N-1} \alpha_{ij} \, \forall \, i = 1, \ldots, N$, $\psi_{Nj} = -\sum_{i=1}^{N-1} \psi_{ij} \, \forall \, j = 1, \ldots, M$, $\xi_{Nj} = -\sum_{i=1}^{N-1} \xi_{ij} \, \forall \, j = 1, \ldots, K$, and I_{cond} being an indicator function that takes the value one if the condition in the subscript *cond* is fulfilled and the value zero otherwise.

In order to quantity the effects of the environmental variables on the production technology, we derived the following semi-elasticities:

$$\frac{\partial \ln D^i(x,y,z)}{\partial z_i} = \delta_i + \sum_{j=1}^{K} \delta_{ij} z_j + \sum_{j=1}^{N} \xi_{ji} \ln x_i + \sum_{j=1}^{M-1} \zeta_{ji} \varphi_j(y) + \zeta_{Mi} \ln \left\|y\right\| \qquad (3.11)$$
$$\forall\, i = 1, \ldots, K.$$

3.2.3 Monotonicity conditions

Monotonicity conditions derived from microeconomic theory imply that the distance function (technical inefficiency) should be non-decreasing in input quantities and non-increasing in output quantities, i.e., $\partial D^i(x,y,z)/\partial x_i \geq 0\ \forall i = 1,\ldots,N$ and $\partial D^i(x,y,z)/\partial y_i \leq 0\ \forall i = 1,\ldots,M$, respectively. As $D^i(x,y,z) > 0$ and $x_i > 0\, \forall\, i = 1,\ldots,N$, the monotonicity condition $\partial D^i(x,y,z)/\partial x_i \geq 0$ is equivalent to the condition $(\partial D^i(x,y,z)/\partial x_i)\,(x_i/D^i(x,y,z)) = \partial \ln D^i(x,y,z)/\partial \ln x_i \geq 0$. Hence, we can use the right-hand side of equation (3.7) as the monotonicity condition regarding the input quantities. However, as we allow output quantities to be zero, we cannot use the right-hand side of equation (3.8) as the monotonicity condition regarding the output quantities because if an output quantity is zero (i.e., $y_i = 0$), the right-hand side of equation (3.8) is zero and, thus, non-positive even if the monotonicity condition regarding this output is violated, i.e., $\partial D^i(x,y,z)/\partial y_i > 0$. In order to have monotonicity conditions that can also be applied in case of zero output quantities, we use the semi-elasticity of the outputs (i.e., $\partial \ln D^i(x,y,z)/\partial y_i \leq 0\ \forall i = 1,\ldots,M$) as the monotonicity conditions regarding the output quantities. Using only the estimated coefficients and replacing the non-estimated coefficients by the respective homogeneity restrictions (e.g., $\alpha_N = 1 - \sum_{i=1}^{M-1} \alpha_i$) and the respective symmetry normalisations (e.g., $\alpha_{ij} = \alpha_{ji}\, \forall\, i > j$), we obtain the following monotonicity conditions for $x_i; i = 1,\ldots,N-1$, x_N, and $y_i; i = 1,\ldots,M$:

$$0 \leq \alpha_i + \sum_{j=1}^{i} \alpha_{ji} \ln \tilde{x}_j + \sum_{j=i+1}^{N-1} \alpha_{ij} \ln \tilde{x}_j \qquad (3.12)$$

$$+\sum_{j=1}^{M-1}\psi_{ij}\varphi_j(y)+\psi_{iM}\ln\|y\|+\sum_{j=1}^{K}\xi_{ij}z_j\;\forall\, i=1,\dots,N-1,$$

$$\begin{aligned}-1\le{}&-\sum_{k=1}^{N-1}\alpha_k-\sum_{j=1}^{N-1}\sum_{k=j}^{N-1}\alpha_{jk}\left(\ln\tilde{x}_j+I_{j\neq k}\ln\tilde{x}_k\right)\\&-\sum_{j=1}^{M-1}\sum_{k=1}^{N-1}\psi_{kj}\varphi_j(y)-\sum_{k=1}^{N-1}\psi_{kM}\ln\|y\|-\sum_{j=1}^{K}\sum_{k=1}^{N-1}\xi_{kj}z_j,\mathit{and}\end{aligned}\tag{3.13}$$

$$\begin{aligned}0\le{}&-\sum_{j=1}^{M-1}\beta_j\Omega_{ji}-\beta_M\frac{y_i}{\|y\|^2}-\sum_{j=1}^{M-1}\sum_{k=j}^{M-1}\beta_{jk}\left(\varphi_k(y)\Omega_{ji}+I_{j\neq k}\varphi_j(y)\Omega_{ki}\right)\\&-\sum_{j=1}^{M-1}\beta_{jM}\left(\Omega_{ji}\ln\|y\|+\varphi_j(y)\frac{y_i}{\|y\|^2}\right)-\beta_{MM}\frac{\ln\|y\|\,y_i}{\|y\|^2}\\&-\sum_{j=1}^{N-1}\sum_{k=1}^{M-1}\psi_{jk}\ln\tilde{x}_j\Omega_{ki}-\sum_{j=1}^{N-1}\psi_{jM}\ln\tilde{x}_j\frac{y_i}{\|y\|^2}\\&-\sum_{j=1}^{M-1}\sum_{k=1}^{K}\zeta_{jk}z_k\Omega_{ji}-\sum_{j=1}^{K}\zeta_{Mj}\frac{z_jy_i}{\|y\|^2}\;\forall\, i=1,\dots,M,\end{aligned}\tag{3.14}$$

respectively.

As all these monotonicity conditions are linear in the estimated coefficients, we can represent them in matrix form as $R\theta\ge r$, where $\theta=(\alpha_0,\alpha_1,\dots,\alpha_{N-1}$, $\alpha_{11},\dots,\alpha_{1,N-1}$, $\alpha_{22},\dots,\alpha_{2,N-1}$, $\dots,\alpha_{N-1,N-1}$, $\beta_1,\dots,\beta_M$, $\beta_{11},\dots,\beta_{1M}$, $\beta_{22},\dots,\beta_{2M}$, $\dots,\beta_{MM}$, $\delta_1,\dots,\delta_K$, $\delta_{11},\dots,\delta_{1K}$, $\delta_{22},\dots,\delta_{2K}$, $\dots,\delta_{KK}$, $\psi_{11},\dots,\psi_{1M}$, $\psi_{21},\dots,\psi_{2M}$, $\dots,\psi_{N-1,M}$, $\xi_{11},\dots,\xi_{1K}$, $\xi_{21},\dots,\xi_{2K}$, $\dots,\xi_{N-1,K}$, $\zeta_{11},\dots,\zeta_{1K}$, $\zeta_{21},\dots,\zeta_{2K}$, $\dots,\zeta_{MK})$ is a vector of all estimated coefficients, $R=[R_{i,\theta}]$ is a matrix with one row i for each of the $N+M$ monotonicity conditions and one column for each of the coefficients in θ, and r is a vector with one element for each of the $N+M$ monotonicity restrictions. Each element of the matrix R and of the vector r is defined in Appendix Section 3.B. Given that all these monotonicity conditions are linear in the estimated coefficients, we can use the method suggested by Henningsen and Henning (2009) to impose the monotonicity conditions.[4]

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[4] As the method proposed by Henningsen and Henning (2009) requires monotonicity conditions that are linear in the estimated coefficients, we cannot use the monotonicity conditions $\partial D^i(x,y,z)/\partial x_i=(D^i(x,y,z)/x_i)\,(\partial D^i(x,y,z)/\partial x_i)\ge 0\;\forall i=1,\dots,N$ and $\partial D^i(x,y,z)/\partial y_i$ $(D^i(x,y,z)/y_i)\,(\partial D^i(x,y,z)/\partial y_i)\le 0\;\forall i=1,\dots,M$, because they are non-linear in the estimated coefficients (given that $D^i(x,y,z)$ depends on the estimated coefficients).

3.3 Data

We estimate our model with data from state-recognized Danish museums[5]. The data set includes information from 93 museums over a six-year period: 2012 and 2014-2018[6]. This is an unbalanced panel database with 528 observations. The following inputs, outputs, and environmental variables are considered:

Inputs

- *Scientific labour*: Conservationists, researchers, and other scientific staff are considered here (full time equivalent).
- *Non-scientific labour*: This category considers the management, administrative and maintenance staff (full time equivalent).
- *Capital*: The capital stock is proxied with the running and maintenance costs. This appears to make economic sense, as larger collections require more space for both storage and exhibition, which in turns requires additional operating and maintenance expenses[7]. These costs have been expressed in real terms (Danish Kroner of 2014).

Outputs

- *Visitors*: Number of (physical) visitors.
- *Research*: Number of scientific articles published.
- *Exhibitions*: Number of temporary exhibitions (i.e., excluding the permanent exhibition).

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[5] State-recognized museums are not owned by the state but receive public funding, and are obliged to preserve, register, research and exhibit their collections. Complying with this wide set of responsibilities entail delivering multiple cultural and educational services so that evaluating their technical efficiency in a multi-output setting is warranted.

[6] Data for 2013 is not available.

[7] Information about museums' capital stock is generally not available. This has been pointed out in the existing literature for other countries (O'Hagan, 1998; Feldstein, 1991; Frey and Meier, 2006; Grampp, 1989; Peacock and Godfrey, 1974) and it is also the case in Denmark. To cope with this problem, (Bishop and Brand, 2003) use the same proxy as we use, whereas del Barrio et al. (2009) and del Barrio-Tellado and Herrero-Prieto (2019) use the museums' area in square metres. We choose here the first of these proxies because information about the museums' areas is not available in our data set.

- *Education*: Number of primary school classes in education visits to the museum. It seems better, from a supply perspective, to consider the number of school classes regardless of the number of students in each group, as there are fixed costs involved in each visit.
- *Events*: Number of events other than exhibitions (e.g., workshops, conferences, book presentations) that take place in the museums' premises.
- *Conservation*: This output corresponds to the expenditure in conservation activities (expressed in real terms, Danish Kroner of 2014).

Environmental variables

In order to control for factors that might affect the production frontier (i.e., the museums' minimum input quantities that are required to produce a certain level of output quantities), we include two environmental variables:

- *Number of visit sites*: Some museums manage two or more visit sites (up to twenty). It is expected that these museums would require more inputs for every given level of outputs than those managing one visit site. For example, museums that manage several (small) sites must likely have guards and receptionists at each visit site and, thus, are expected to need more inputs than museums that produce the same outputs but manage only one (large) visit site. We consider (the natural logarithm of) the number of visit sites as an environmental variable.
- *Special responsibilities*: Some museums have responsibilities that go beyond those specified by the legislation. Examples include taking care of the archaeological sites located in their municipality and collaborate in archaeological investigations. It is expected that these museums would require more inputs for every given level of the outputs under analysis than those managing with no special responsibilities. We consider a dummy variable taking the value one if museums have special responsibilities and zero otherwise.

Table 3.1 presents descriptive statistics of the input quantities, output quantities, and environmental variables[8]. As ray-based specifications are not invariant to

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[8] Table 3.1 presents the statistics for the number of visit sites, but as mentioned before, we use the natural logarithm of this variable as explanatory variable in order reduce the occurrence of extreme values and the skewness of the distribution of this variable.

units of measurement, we mean-scale all output quantities in order to make our results invariant to units of measurement.

3.4 Results

We estimate the ray-based Translog input distance function defined in equation (3.6) as stochastic frontier model[9] by using the R software (R Core Team, 2020) and its add-on packages "sfaR" (Dakpo et al., 2021) and "quadprog" (Turlach and Weingessel, 2011). Given that one of our 'environmental' variables (z_2: special responsibilities) is a dummy variable, we make one adjustment to equation (3.6). As the quadratic term z_2^2 of the dummy variable for special responsibilities equals its non-squared term z_2, i.e., $z_2^2 = z_2$, we exclude the term z_2^2 in order to avoid perfect multicollinearity. This corresponds to imposing the restriction $\delta_{22} = 0$.[10]

As the estimation results of ray-based production or distance functions depend on the ordering of the outputs, we estimate the model with all 720 possible orderings of the outputs[11] and select the ordering that gives the best fit in terms of the log-likelihood value as suggested by Henningsen et al. (2017). This is the model selection method. Additionally, we use the model averaging method and obtain weighted averages of estimation results (e.g., distance elasticities or efficiency estimates) over all possible orderings of outputs as suggested by Huang and pin Lai (2012) for stochastic frontier models in general and suggested by Tsionas et al. (2021) for the stochastic ray production frontier.

In order to include all observations in all orderings of outputs (so that the obtained log-likelihood values are comparable), we apply a small trick for orderings of

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[9] Regrettably, panel data models cannot be estimated, because the degree of yearly variation is very low and the panel too short to allow for the individual effects at the museum level to be identified. That is why we conduct a 'pooled' estimation. This of course might imply that the noise term is not i.i.d., and, hence, that the standard errors are not correctly estimated.

[10] We keep the quadratic term z_1^2, the interaction term $z_1 z_2$, and also the interaction terms between the environmental variables and the other explanatory variables in the model.

[11] As the ordering of the last two outputs should theoretically not affect the results (Henningsen et al., 2017), it should be sufficient to estimate the model with 360 different orderings of the outputs. As numerical inaccuracies could result in different estimates for the two models that only differ in the last two outputs, we estimate the model with all 720 different orderings of the outputs. However, our estimates for models that only differ in the last two outputs are always very close to each other or even virtually identical.

Table 3.1: Summary Statistics

Statistic	$n(=0)$	Mean	St. Dev.	Min	Median	Max
capital [thousands of real krones]	0	2,608.98	4,443.81	107.97	1,247.19	65,117.11
scientific labour [number of people]	0	7.76	7.76	1	4.8	59
non-scientific labour [number of people]	0	18.98	26.46	0.40	10.10	180.00
visitors [number of physical visitors]	0	88,677.27	125,810.90	2,473	39,884	835,606
conservation [thousands of real krones]	43	197.43	267.47	0.00	98.81	2,340.55
research [number of articles]	118	5.25	7.94	0	2	59
exhibitions [number of exhibitions]	15	5.52	4.57	0	4	45
education [number of group visits]	0	170.95	251.23	2	107	4,461
events [number of events]	0	246.82	361.67	1	118	2,576
visit sites [number of visit sites]	0	2.69	3.33	1	1	20
responsibilities [1 = special responsibilities]	367	0.30	0.46	0	0	1

outputs, where there are observations, in which the quantities of the last two (or more) outputs are zero, because whenever the quantities of outputs j to M are zero for $j \leq M-1$ (i.e., $y_i = 0 \ \forall \ i = j, \ldots, M$ with $j \leq M-1$), the angles $\theta_i; i = j, \ldots, M-1$ are undefined. In these (few) cases,[12] we calculate the undefined angles by assuming that $y_i = \kappa \ \forall \ i = j, \ldots, M$, where κ is an arbitrarily small strictly positive value. Under this assumption, we get $\theta_i = \arccos\left(1/\sqrt{2}\right) = \pi/4 \ \forall \ i = j, \ldots, M-1$, i.e., a 45-degree angle, independent of the value of κ.[13] This problem does not occur when using the ordering of outputs that gives the best fit to the model. Hence, we use this trick only when selecting the model that gives the best fit and when applying the model averaging method.

After estimating the models, we check to which extent they fulfil the monotonicity conditions by calculating the right-hand sides of equations (3.12), (3.13), and (3.14). These conditions are violated for at least some of the observations no matter which ordering of outputs is used. For instance, when using the ordering of outputs that gives the best fit, monotonicity conditions regarding the inputs are violated at 8%, 1%, and 10% of the observations, while monotonicity conditions regarding the outputs are violated at 4%, 52%, 9%, 16%, 38%, and 16% of the observations reported in the order of inputs and outputs used in Table 3.1. We proceed by imposing the monotonicity conditions using a procedure that is based on Henningsen and Henning (2009) and adapted to the ray-based Translog input distance function as described and explained in appendix 3.C.

We select the ordering of the outputs that results in the highest log-likelihood value of the restricted model.[14] This ordering is the one that is used in Table 3.1. The results of the unrestricted estimation and the coefficients of the restricted

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[12] In none of the 720 orderings of outputs, more than two of the last outputs are zero. When the last two outputs are ‘exhibitions’ and ‘research’, there are 7 observations with the last two outputs being zero. When the last two outputs are ‘conservation’ and ‘research’, there are 5 observations with the last two outputs being zero. When the last two outputs are ‘conservation’ and ‘exhibition’, there are 2 observations with the last two outputs being zero. In all other orderings, we do not need to apply the trick.

[13] It is worth pointing out that in our approach, the values of $\varphi_i(y)$ and, thus, the estimation results do not depend on how small or large the arbitrarily small value of κ is. Hence, this is not a naive solution as the one that replaces zero values by an arbitrary small number.

[14] As the number of estimated coefficients is the same for all orderings of the outputs, selecting the ordering of the outputs that gives the highest log-likelihood value is equivalent to using the Akaike information criterion (AIC) or the Bayesian information criterion (BIC) to select the ordering that gives the best fit to our data.

estimation (with monotonicity conditions imposed) for this ordering of outputs are presented in Table 3.2.

Given that we use a Translog functional form, most coefficients presented in Table 3.2 do not have a relevant interpretation. In order to obtain estimation results with relevant real-world meanings, we calculate distance elasticities of the inputs and outputs, the elasticity of scale, the effects of the 'environmental' variables on the production frontier, and the technical efficiency estimates (see Figures 3.5, 3.6, 3.7, and 3.8 in Appendix 3.D).

Figure 3.1 presents scatter plots between the log-likelihood value (indicating the fit of the model) and four important estimation results (i.e., mean and median technical efficiency estimates and mean and median elasticity of scale) for each of the 720 possible orderings of the outputs. The estimation results depend on the ordering of the outputs to a moderate extent. If one disregards those 50% of the orderings that give the worst fit, the estimation results depend even less on the ordering of the outputs. In our empirical application, the model-averaged estimates (indicated by the horizontal red lines in Figure 3.1) are rather close to the estimates based on the ordering of the outputs that gives the best fit (indicated by the dot furthest to the right in each panel of Figure 3.1). This result not only holds for mean or median values over all observations as presented in Figure 3.1 but also holds for results for individual observations (see Figures 3.9, 3.10, 3.11, and 3.12 in Appendix 3.E). However, this result should not be generalised as it could be different in other empirical applications.

Figure 3.2 presents the model-averaged efficiency estimates and elasticities of scale, while the corresponding distance elasticities of the inputs, outputs, and 'environmental' variables are presented in Figures 3.13, 3.14, and 3.15, respectively, in Appendix 3.F. Average technical efficiency is 1.33 (median: 1.27), which indicates that the museums use on average 36% more of each input than would be required to produce the given output quantities. The average elasticity of scale is 1.44 (median: 1.43) indicating considerable productivity gains from getting larger. While almost all museums with less than 70 employees (full-time equivalents, FTE, including both scientific and non-scientific staff) and with less than 300,000 visitors per year operate under substantial increasing returns to scale, most larger museums experience decreasing returns to scale (see Figure 3.3).

Table 3.2: Estimation results: unrestricted and restricted estimates

Coef.	Estimate	S.E.	Restricted	Coef.	Estimate	S.E.	Restricted
α_0	2.9338**	0.9056	3.1487	β_{66}	-0.0882	0.0552	-0.1408
α_1	0.3535	0.2206	0.3504	ψ_{11}	0.1437	0.1157	0.0144
α_2	0.6406**	0.2194	0.4768	ψ_{12}	-0.1017	0.0750	-0.0206
β_1	-0.4582	0.8768	-1.5045	ψ_{13}	0.0211	0.0653	-0.0407
β_2	-1.4983**	0.5441	-0.8931	ψ_{14}	-0.0607	0.0628	-0.0310
β_3	-1.1906*	0.4987	-0.8767	ψ_{15}	-0.2496***	0.0610	-0.0740
β_4	-0.6621	0.4886	-0.5019	ψ_{16}	0.0064	0.0391	-0.0023
β_5	0.4452	0.3807	-0.0374	ψ_{21}	-0.0418	0.1212	0.0156
β_6	-0.8971***	0.2515	-1.1393	ψ_{22}	-0.0426	0.0705	-0.0032
δ_1	0.7676**	0.2870	0.4296	ψ_{23}	-0.0885	0.0624	-0.0067
δ_2	-2.1321***	0.5419	-0.6700	ψ_{24}	0.1115	0.0633	0.0371
α_{11}	-0.0734	0.0381	-0.0508	ψ_{25}	0.0149	0.0649	0.0308
α_{12}	0.0611	0.0331	0.0278	ψ_{26}	0.0167	0.0396	-0.0066
α_{22}	0.1717***	0.0455	0.0890	δ_{11}	-0.1430*	0.0727	-0.1554
β_{11}	0.6188	0.5872	1.7856	δ_{12}	-0.2756***	0.0740	-0.2978
β_{12}	0.3395	0.2530	-0.0488	ξ_{11}	-0.1014*	0.0465	-0.0596
β_{13}	-0.1134	0.2287	-0.0611	ξ_{12}	0.1918*	0.0778	0.1732
β_{14}	0.3249	0.2534	0.0523	ξ_{21}	0.0571	0.0388	0.0158
β_{15}	-0.2831	0.2027	-0.0555	ξ_{22}	-0.3986***	0.0757	-0.3006
β_{16}	0.2269	0.1300	0.3080	ζ_{11}	-0.6834***	0.1508	-0.3542
β_{22}	0.5025*	0.2447	0.6827	ζ_{12}	1.4213***	0.2780	0.6247
β_{23}	0.2947*	0.1353	0.0590	ζ_{21}	0.1180	0.0647	0.0880
β_{24}	-0.0093	0.1171	-0.0068	ζ_{22}	0.2147	0.1367	-0.0404
β_{25}	-0.1398	0.1102	-0.0343	ζ_{31}	0.0637	0.0627	0.0280
β_{26}	-0.0661	0.0781	0.0113	ζ_{32}	-0.1254	0.1355	-0.1020
β_{33}	0.9841***	0.2269	0.9535	ζ_{41}	0.0711	0.0765	0.0037
β_{34}	-0.3160**	0.1113	-0.1310	ζ_{42}	0.2244	0.1454	0.1323
β_{35}	0.1964	0.1033	0.0192	ζ_{51}	-0.0296	0.0727	0.0166
β_{36}	0.1712*	0.0666	0.0975	ζ_{52}	-0.0832	0.1372	-0.0086
β_{44}	0.8215***	0.2204	0.5828	ζ_{61}	0.0454	0.0442	0.0983
β_{45}	-0.1825	0.1058	-0.0151	ζ_{62}	-0.0148	0.0875	-0.0855
β_{46}	-0.1135	0.0738	0.0073	$\log(\sigma_u^2)$	-2.6487***	0.3871	-2.0672***
β_{55}	-0.0242	0.2088	0.1562	$\log(\sigma_v^2)$	-2.8951***	0.1754	-3.0046***
β_{56}	0.0021	0.0630	-0.0224				

Notes: Asterisks indicate significance levels, where: *** ≤ 0.001, ** ≤ 0.01, * ≤ 0.05. Column 'Restricted' indicates the restricted estimates. The restricted estimates of the model coefficients, i.e., all coefficients except for the variance parameters σ^2 and γ, are obtained in the second-step minimum-distance estimation and, thus, do not have standard errors or significance levels. The restricted estimate of the intercept is adjusted by the intercept of the third-step stochastic-frontier estimation. The variance parameters σ^2 and γ are obtained in the third-step stochastic-frontier estimation.

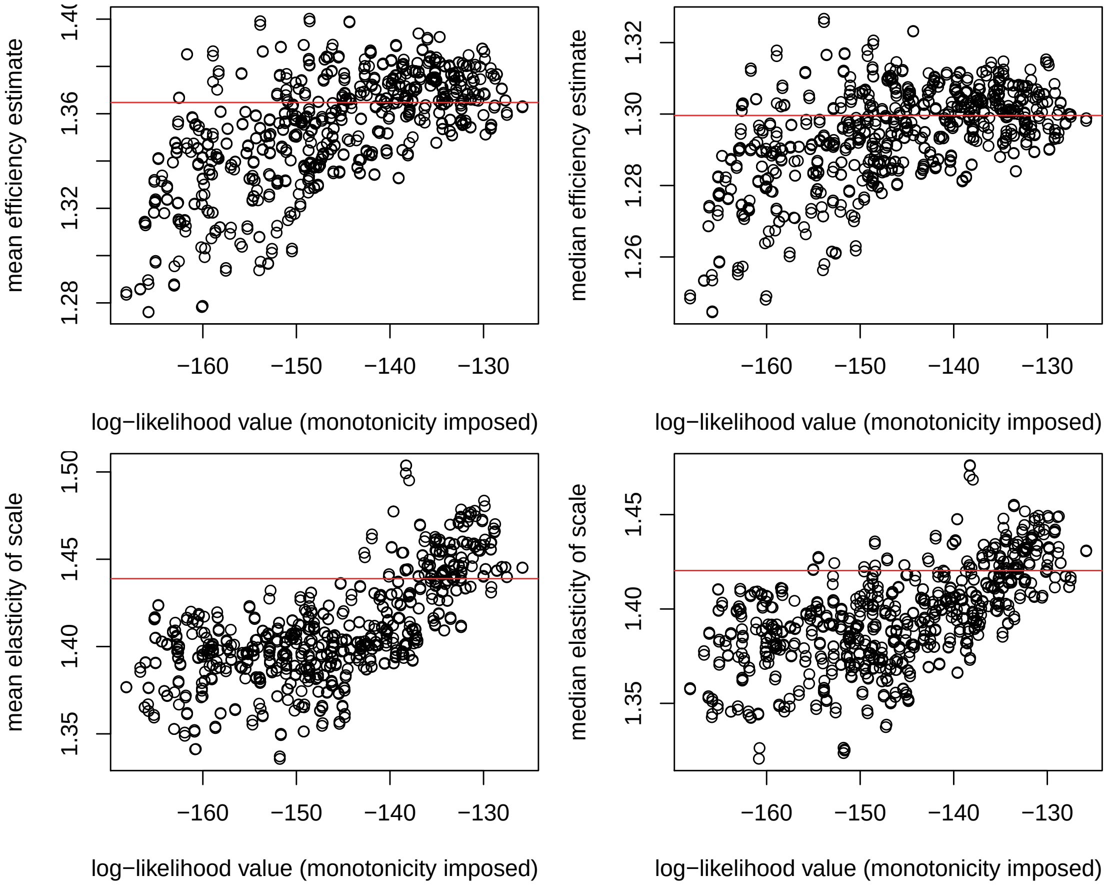

Figure 3.1: Relationships between the mean and median efficiency estimates and elasticities of scale and the fit of the model for all possible orderings of outputs (the horizontal red line indicates the model-averaged estimate)

Hence, the most productive scale size is roughly around 70 employees (FTE) and 300,000 visitors per year.

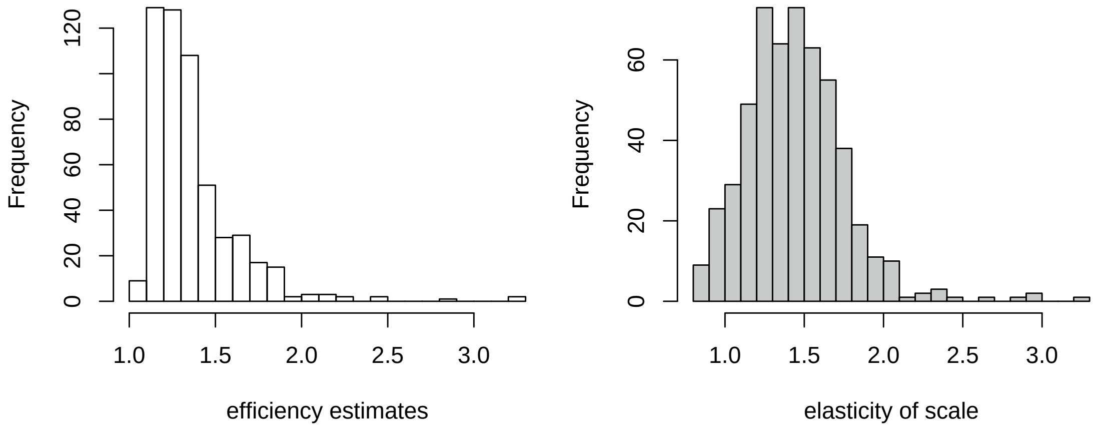

Figure 3.2: Model-averaged efficiency estimates and elasticities of scale

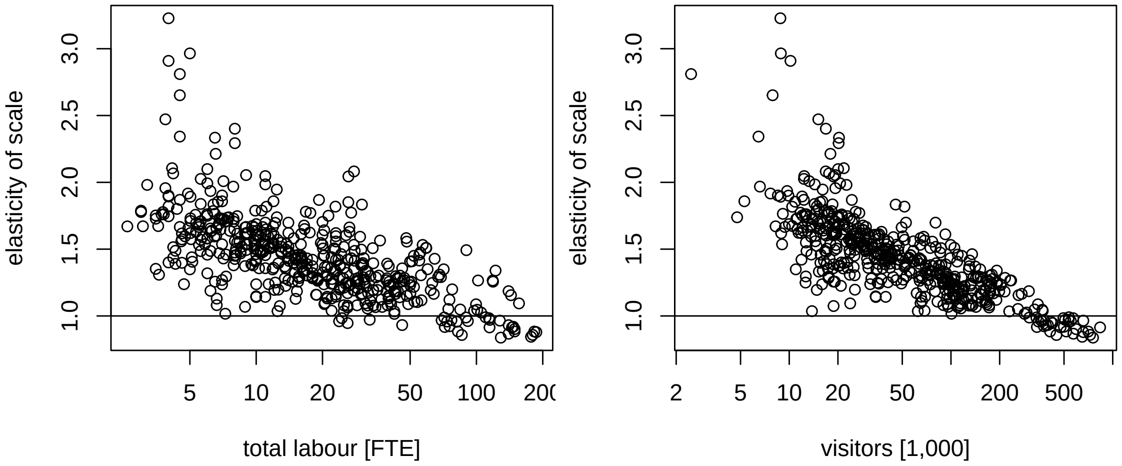

Figure 3.3: Relationship between the size of the museum and model-averaged elasticities of scale

Figure 3.4 presents the model-averaged distance elasticities and semi-elasticities of the 'environmental' variable for museums with different numbers of visit sites. For museums with one to three visit sites, changing the number of visit sites can be positively or negatively related to productivity. However, for almost all museums with more than three visit sites, increasing the number of visit sites is related to a decrease in productivity. Given that museums with more than three visit sites usually have distance elasticities of visit sites between −0.2 and −0.4, increasing the number of visit sites by 10%, e.g., from 10 to 11 visit sites, requires to increase all inputs by two to four percent for producing the same output quantities as with the current number of visit sites.[15] Hence, extending a museum to more than three visit sites seems to imply considerable additional costs.

The right panel of Figure 3.4 indicates that having additional responsibilities can be positively or negatively related to productivity for museums with just one visit site, while having special responsibilities requires substantially higher input use for virtually all museums with more than one visit site. As only around 9 percent of museums with only one visit site have special responsibilities, while around 71 percent of museums with more than one visit site have special responsibilities, we can conclude that the majority of museums that have special responsibilities need to substantially increase their input quantities (up to doubling the quantities as implied by a semi-elasticity of -1) to fulfil these additional tasks.

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[15] The interpretation of distance elasticities of 'environmental' variables requires some thoughts: a distance elasticity of $\partial \ln D^i(x,y,z)/\partial \ln z_i = \Gamma_i$ indicates that increasing the 'environmental' variable z_i by one percent changes the distance measure $D^i(x,y,z)$ by Γ_i percent. As we want to assess the effect of 'environmental' variables on the technology rather than on the (in)efficiency level, our interpretations have to assume a constant distance measure $D^i(x,y,z)$, e.g., $D^i(x,y,z) = 1$, which means that we are looking at the production frontier. As the input distance function is linearly homogeneous in input quantities, i.e., $D^i(k \cdot x,y,z) = k \cdot D^i(x,y,z) \, \forall \, k > 0$, an increase of the distance measure $D^i(x,y,z)$ by one percent corresponds to an increase of all input quantities x also by one percent. Similarly, in order to reverse a change of the distance measure $D^i(x,y,z)$ by Γ_i percent due to an increase of the 'environmental' variable z_i by one percent, all input quantities x need to change by $-\Gamma_i$ percent so that the distance measure $D^i(x,y,z)$ has again the same value as it had before the change of the 'environmental' variable z_i. Hence, an increase of the 'environmental' variable z_i by one percent is related to a change of all inputs by $-\Gamma_i$ percent when holding the (in)efficiency level constant. Thus, if a distance elasticity of an 'environmental' variable is positive, i.e., $\partial \ln D^i(x,y,z)/\partial \ln z_i = \Gamma_i > 0$, an increase of the 'environmental' variable z_i by one percent is related to a decrease of all inputs by Γ_i percent and, thus, to an increase of productivity when holding the (in)efficiency level constant. A more formal (although perhaps less intuitive) derivation of this result can be obtained with the implicit function theorem holding the distance measure $D^i(k \cdot x,y,z)$ constant, while allowing the input quantities to change proportionally by a factor $k > 0$. Hence the relative change of all input quantities due to a change in the 'environmental' variable z_i evaluated at the original input quantities, i.e., $k = 1$, can be obtained by:

$$\frac{\partial \ln k}{\partial \ln z_i} = -\frac{\frac{\partial \ln D^i(k \cdot x,y,z)}{\partial \ln z_i}}{\frac{\partial \ln D^i(k \cdot x,y,z)}{\partial \ln k}} = -\frac{\partial \ln D^i(x,y,z)}{\partial \ln z_i} = -\Gamma_i.$$

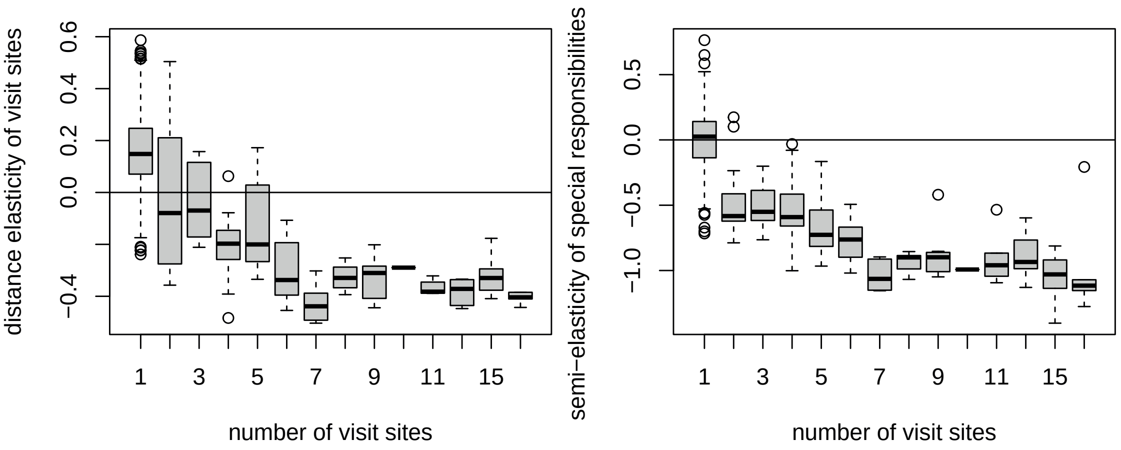

Figure 3.4: Relationship between the number of visit sites and model-averaged distance elasticities and semi-elasticities of the environmental variables

3.5 Conclusions

In this paper, we have derived an input-oriented distance function based on the stochastic ray production frontier, which is suitable for modelling production technologies based on logarithmic functional forms when control over inputs is greater than over outputs and when some productive entities do not produce the entire set of outputs under analysis.

We have applied this model empirically to a data set of state-recognised Danish museums. As part of this empirical analysis, we have estimated the technical efficiencies, distance elasticities, elasticity of scale, and how some 'environmental' variables that are of interest to the museum sector are related to the required level of inputs. One has to be cautious when interpreting our results as causal effects because there are certainly unobserved variables that affect the museums' 'production technology' and might be correlated to some of our explanatory variable.[16] However, the main contribution of this paper is the development of ray-based input distance functions and the illustration that this specifications is a useful tool for empirical analyses, particularly when the management has more control over inputs than over outputs and when some decision-making units do not produce all of the outputs that are considered in the analysis.

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[16] Time-invariant unobserved variables could be controlled for by estimating panel data models, something that as already mentioned, our data don't allow us to do.

As part of this analysis, we also demonstrate how to impose monotonicity on ray-based input distance functions. Finally, we address a critique the stochastic ray function has been subject to, namely its sensitivity to the ordering of the outputs. We follow two approaches. Firstly, we estimate the model with all possible ordering of outputs and select the ordering that outperforms the others based on the log-likelihood value. Secondly, we use model averaging over all possible orderings of the outputs. In our empirical application, the results based on the model with the highest log-likelihood value are very similar similar to our results based on model-averaging but whether this finding is generalisable or just a coincidence in our empirical application is a question for future research.

Bibliography

Bishop, P. and Brand, S. (2003). The efficiency of museums: a stochastic frontier production function approach. *Applied Economics*, 35(17):1853–1858.

Dakpo, K. H., Desjeux, Y., and Latruffe, L. (2021). *sfaR: Stochastic Frontier Analysis using R.* R package version 0.1.0.

del Barrio, M. J., Herrero, L. C., and Ángel Sanz, J. (2009). Measuring the efficiency of heritage institutions: A case study of a regional system of museums in spain. *Journal of Cultural Heritage*, 10(2):258 – 268.

del Barrio-Tellado, M. J. and Herrero-Prieto, L. C. (2019). Modelling museum efficiency in producing inter-reliant outputs. *Journal of Cultural Economics*, 43(3):485–512.

Feldstein, M. (1991). *The Economics of Art Museums*. University of Chicago Press.

Frey, B. and Meier, S. (2006). The economics of museums. In Ginsburgh, V. and Throsby, D., editors, *Handbook of the Economics of Art and Culture: Volume 1*, volume 1, chapter 29, pages 1017–1047. Elsevier, 1 edition.

Färe, R. and Primont, D. (1990). A distance function approach to multioutput technologies. *Southern Economic Journal*, 56(4):879–891.

Grampp, W. D. (1989). *Pricing the priceless: art, artists, and economics / William D. Grampp*. Basic Books New York.

Henningsen, A., Bělín, M., and Henningsen, G. (2017). New insights into the stochastic ray production frontier. *Economics Letters*, 156:18 – 21.

Henningsen, A. and Henning, C. H. C. A. (2009). Imposing regional monotonicity on translog stochastic production frontiers with a simple three-step procedure. *Journal of Productivity Analysis*, 32(3):217.

Henningsen, G., Henningsen, A., and Jensen, U. (2015). A monte carlo study on multiple output stochastic frontiers: a comparison of two approaches. *Journal of Productivity Analysis*, 44(3):309–320.

Huang, C. and pin Lai, H. (2012). Estimation of stochastic frontier models based on multimodel inference. *Journal of Productivity Analysis*, 38(3):273–284.

Kumbhakar, S., Wang, H.-J., and Horncastle, A. P. (2015). *A Practitioner's Guide to Stochastic Frontier Analysis Using Stata*. Cambridge University Press.

Kumbhakar, S. C. and Lovell, C. A. K. (2000). *Stochastic Frontier Analysis*. Cambridge University Press.

Löthgren, M. (1997). Generalized stochastic frontier production models. *Economics Letters*, 57(3):255 – 259.

Löthgren, M. (2000). Specification and estimation of stochastic multiple-output production and technical inefficiency. *Applied Economics*, 32(12):1533–1540.

N'guessan, Y. G., Featherstone, A., Odeh, O., and Upendram, S. (2017). Choice of the empirical definition of zero in the translog multiproduct cost functional form. *Applied Economics Letters*, 24(15):1112–1120.

O'Donnell, C. and Coelli, T. (2005). A bayesian approach to imposing curvature on distance functions. *Journal of Econometrics*, 126(2):493–523.

O'Hagan, J. W. (1998). Art museums: Collections, deaccessioning and donations. *Journal of Cultural Economics*, 22(2/3):197–207.

Peacock, A. and Godfrey, C. (1974). The economics of museums and galleries. In Towse, R., editor, *Cultural Economics: The Arts, The Heritage and the Media Industries*. Edward Elgar.

R Core Team (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Tsionas, M., Izzeldin, M., Henningsen, A., and Paravalos, E. (2021). Addressing endogeneity when estimating stochastic ray production frontiers: A Bayesian approach. *Empirical Economics*, forthcoming.

Turlach, B. A. and Weingessel, A. (2011). *quadprog: Functions to solve Quadratic Programming Problems*. R package version 1.5-4.

3.A Derivation of the ray-based Translog input distance function

Using the notation of Henningsen et al. (2017), a Translog stochastic ray production frontier is defined as:

$$\begin{aligned}\ln\left\|y\right\| = {} & \alpha_0^* + \sum_{i=1}^{N} \alpha_i^* \ln x_i + \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_{ij}^* \ln x_i \ln x_j \\ & + \sum_{i=1}^{M-1} \beta_i^* \varphi_i\left(y\right) + \frac{1}{2}\sum_{i=1}^{M-1}\sum_{j=1}^{M-1} \beta_{ij}^* \varphi_i\left(y\right)\varphi_j\left(y\right) \\ & + \sum_{i=1}^{K} \delta_i^* z_i + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \delta_{ij}^* z_i z_j \\ & + \sum_{i=1}^{N}\sum_{j=1}^{M-1} \psi_{ij}^* \ln x_j\, \varphi_i\left(y\right) + \sum_{i=1}^{N}\sum_{j=1}^{K} \xi_{ij}^* \ln x_i z_j \\ & + \sum_{i=1}^{M-1}\sum_{j=1}^{K} \zeta_{ij}^* \varphi_i\left(y\right) z_j - u^* + v^* \end{aligned} \tag{3.15}$$

with the normalisations $\alpha_{ij}^* = \alpha_{ji}^* \,\forall\, i,j = 1,\ldots,N$, $\beta_{ij}^* = \beta_{ji}^* \,\forall\, i,j = 1,\ldots,M-1$, and $\delta_{ij}^* = \delta_{ji}^* \,\forall\, i,j = 1,\ldots,K$. Function (3.15) can be seen as a Shephard output distance function (Henningsen et al., 2015):

$$\begin{aligned}\ln D^o\left(x,y,z\right) = -u^* = {} & \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln x_i + \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_{ij} \ln x_i \ln x_j \\ & + \sum_{i=1}^{M-1} \beta_i \varphi_i\left(y\right) + \ln\left\|y\right\| + \frac{1}{2}\sum_{i=1}^{M-1}\sum_{j=1}^{M-1} \beta_{ij} \varphi_i\left(y\right)\varphi_j\left(y\right) \\ & + \sum_{i=1}^{K} \delta_i z_i + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \delta_{ij} z_i z_j \\ & + \sum_{i=1}^{N}\sum_{j=1}^{M-1} \psi_{ij} \ln x_i\, \varphi_j\left(y\right) + \sum_{i=1}^{N}\sum_{j=1}^{K} \xi_{ij} \ln x_i z_j \\ & + \sum_{i=1}^{M-1}\sum_{j=1}^{K} \zeta_{ij} \varphi_i\left(y\right) z_j + v, \end{aligned} \tag{3.16}$$

where $D^o(x,y,z) = e^{-u^*}$ with $0 \le D^o(x,y,z) \le 1$ is a Shephard output distance function and $\alpha_0 = -\alpha_0^*$, $\alpha_i = -\alpha_i^* \, \forall \, i = 1,\ldots,N$, $\alpha_{ij} = -\alpha_{ij}^* \, \forall \, i,j = 1,\ldots,N$, $\beta_i = -\beta_i^* \, \forall \, i = 1,\ldots M$, $\beta_{ij} = -\beta_{ij}^* \, \forall \, i,j = 1,\ldots M$, $\delta_i = -\delta_i^* \, \forall \, i = 1,\ldots,K$, $\delta_{ij} = -\delta_{ij}^* \, \forall \, i,j = 1,\ldots,K$, $\psi_{ij} = -\psi_{ij}^* \, \forall \, i = 1,\ldots,N; j = 1,\ldots,M$, $\xi_{ij} = -\xi_{ij}^* \, \forall \, i = 1,\ldots,N; j = 1,\ldots,K$, $\zeta_{ij} = -\zeta_{ij}^* \, \forall \, i = 1,\ldots,M; j = 1,\ldots,K$, and $v = -v^*$.

This specification of a stochastic-ray-based output distance function can be generalised to the following 'full' Translog distance function:

$$\begin{aligned}
\ln D(x,y,z) = \alpha_0 &- \sum_{i=1}^{N} \alpha_i \ln x_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_{ij} \ln x_i \ln x_j \\
&+ \sum_{i=1}^{M-1} \beta_i \varphi_i(y) + \beta_M \ln \|y\| + \frac{1}{2} \sum_{i=1}^{M-1} \sum_{j=1}^{M-1} \beta_{ij} \varphi_i(y) \varphi_j(y) \\
&+ \sum_{i=1}^{M-1} \beta_{iM} \varphi_i(y) \ln \|y\| + \frac{1}{2} \beta_{MM} \left(\ln \|y\|\right)^2 \\
&+ \sum_{i=1}^{K} \delta_i z_i + \frac{1}{2} \sum_{i=1}^{K} \sum_{j=1}^{K} \delta_{ij} z_i z_j \\
&+ \sum_{i=1}^{N} \sum_{j=1}^{M-1} \psi_{ij} \ln x_i \, \varphi_j(y) + \sum_{i=1}^{N} \psi_{iM} \ln x_i \ln \|y\| \\
&+ \sum_{i=1}^{N} \sum_{j=1}^{K} \xi_{ij} \ln x_i z_j \\
&+ \sum_{i=1}^{M-1} \sum_{j=1}^{K} \zeta_{ij} \varphi_i(y) z_j + \sum_{i=1}^{K} \zeta_{Mi} \ln \|y\| z_i + v
\end{aligned} \tag{3.17}$$

where linear homogeneity in output quantities (as required by a Shephard output distance function) requires $\beta_M = 1$, $\beta_{iM} = 0 \, \forall \, i = 1,\ldots,M$, $\psi_{Mi} = 0 \, \forall \, i = 1,\ldots,N$, $\zeta_{Mi} = 0 \, \forall \, i = 1,\ldots,K$.

If restrictions $\sum_{i=1}^{N} \alpha_i = 1$, $\sum_{i=1}^{N} \alpha_{ij} = 0 \, \forall \, j = 1,\ldots,N \Leftrightarrow \sum_{j=1}^{N} \alpha_{ij} = 0 \, \forall \, i = 1,\ldots,N$, $\sum_{i=1}^{N} \psi_{ij} = 0 \, \forall \, j = 1,\ldots,M$, and $\sum_{i=1}^{N} \xi_{ij} = 0 \, \forall \, j = 1,\ldots,K$ are fulfilled, function (3.17) is linearly homogeneous in input quantities and, thus, can be used as a specification for a Shephard input distance function. We can impose these restrictions by replacing α_N by $1 - \sum_{i=1}^{N-1} \alpha_i$, replacing all $\alpha_{Nj}, j = 1,\ldots,N$ by $-\sum_{i=1}^{N-1} \alpha_{ij}$, replacing all $\alpha_{iN}, i = 1,\ldots,N$ by $-\sum_{j=1}^{N-1} \alpha_{ij}$, replacing all $\psi_{Nj}, j = 1,\ldots,M$ by $-\sum_{i=1}^{N-1} \psi_{ij}$, and replacing all $\xi_{Nj}, j = 1,\ldots,K$ by $-\sum_{i=1}^{N-1} \xi_{ij}$ so that we get a Shephard input distance function:

$$
\begin{aligned}
\ln D^i(x,y,z) = {} & \alpha_0 + \sum_{i=1}^{N-1} \alpha_i \ln(\tilde{x}_i) + \ln x_N + \frac{1}{2}\sum_{i=1}^{N-1}\sum_{j=1}^{N-1} \alpha_{ij} \ln(\tilde{x}_i)\ln\left(\tilde{x}_j\right) \qquad (3.18) \\
& + \sum_{i=1}^{M-1} \beta_i \varphi_i(y) + \beta_M \ln\left\|y\right\| + \frac{1}{2}\sum_{i=1}^{M-1}\sum_{j=1}^{M-1} \beta_{ij}\varphi_i(y)\varphi_j(y) \\
& + \sum_{m=1}^{M-1} \beta_{iM}\varphi_i(y)\ln\left\|y\right\| + \frac{1}{2}\beta_{MM}\left(\ln\left\|y\right\|\right)^2 \\
& + \sum_{i=1}^{K} \delta_i z_i + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \delta_{ij} z_i z_j \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{M-1} \psi_{ij} \ln(\tilde{x}_i)\varphi_j(y) + \sum_{i=1}^{N-1} \psi_{iM} \ln(\tilde{x}_i)\ln\left\|y\right\| \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{K} \xi_{ij} \ln(\tilde{x}_i) z_j \\
& + \sum_{i=1}^{M-1}\sum_{j=1}^{K} \zeta_{ij}\varphi_i(y) z_j + \sum_{i=1}^{K} \zeta_{Mi} \ln\left\|y\right\| z_i + v.
\end{aligned}
$$

By replacing the logarithm of the Shephard input distance measure $D^i(x,y,z) \geq 1$, i.e., $\ln D^i(x,y,z) \geq 0$, by $u \geq 0$ and a little re-arranging, we get:

$$
\begin{aligned}
-\ln x_N = {} & \alpha_0 + \sum_{i=1}^{N-1} \alpha_i \ln(\tilde{x}_i) + \frac{1}{2}\sum_{i=1}^{N-1}\sum_{j=1}^{N-1} \alpha_{ij} \ln(\tilde{x}_i)\ln\left(\tilde{x}_j\right) \qquad (3.19) \\
& + \sum_{i=1}^{M-1} \beta_i \varphi_i(y) + \beta_M \ln\left\|y\right\| + \frac{1}{2}\sum_{i=1}^{M-1}\sum_{j=1}^{M-1} \beta_{ij}\varphi_i(y)\varphi_j(y) \\
& + \sum_{i=1}^{M-1} \beta_{iM}\varphi_i(y)\ln\left\|y\right\| + \frac{1}{2}\beta_{MM}\left(\ln\left\|y\right\|\right)^2 \\
& + \sum_{i=1}^{K} \delta_i z_i + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \delta_{ij} z_i z_j \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{M-1} \psi_{ij} \ln(\tilde{x}_i)\varphi_j(y) + \sum_{i=1}^{N-1} \psi_{iM} \ln(\tilde{x}_i)\ln\left\|y\right\| \\
& + \sum_{i=1}^{N-1}\sum_{j=1}^{K} \xi_{ij} \ln(\tilde{x}_i) z_j
\end{aligned}
$$

$$+\sum_{i=1}^{M-1}\sum_{j=1}^{K}\zeta_{ij}\varphi_i(y)z_j+\sum_{i=1}^{K}\zeta_{Mi}\ln\left\|y\right\|z_i-u+v,$$

which can be easily estimated as a stochastic frontier model[17]. The Cobb-Douglas functional form is a special case with $\alpha_{ij}=0\,\forall\, i,j=1,\dots,N$, $\beta_{ij}=0\,\forall\, i,j=1,\dots M$, $\delta_{ij}=0\,\forall\, i,j=1,\dots,K$, $\psi_{ij}=0\,\forall\, i=1,\dots,N; j=1,\dots,M$, $\xi_{ij}=0\,\forall\, i=1,\dots,N; j=1,\dots,K$, and $\zeta_{ij}=0\,\forall\, i=1,\dots,M; j=1,\dots,K$.

3.B Monotonicity conditions in matrix form

We represent these monotonicity restrictions in matrix form as $R\theta\geq r$, where $\theta=(\alpha_0,\ \alpha_1,\dots,\alpha_{N-1},\ \alpha_{11},\dots,\alpha_{1,N-1},\alpha_{22},\dots,\alpha_{2,N-1},\dots,\alpha_{N-1,N-1},\ \beta_1,\dots,\beta_M,$ $\beta_{11},\dots,\beta_{1M},\beta_{22},\dots,\beta_{2M},\dots,\beta_{MM},\ \delta_1,\dots,\delta_K,\ \delta_{11},\dots,\delta_{1K},\delta_{22},\dots,\delta_{2K},\dots,\delta_{KK},$ $\psi_{11},\dots,\psi_{1M},\psi_{21},\dots,\psi_{2M},\dots,\psi_{N-1,M},\xi_{11},\dots,\xi_{1K},\xi_{21},\dots,\xi_{2K},\dots,\xi_{N-1,K},\zeta_{11},\dots,\zeta_{1K},\zeta_{21},\dots,\zeta_{2K},$ is a vector of all estimated coefficients, $R=[R_{i,\theta}]$ is a matrix with one row i for each of the $N+M$ monotonicity restrictions and one column for each of the coefficients in θ, and r is a vector with one element for each of the $N+M$ monotonicity restrictions. The elements of $R=[R_{i,\theta}]$ are:

$$R_{i,\alpha_o}=0\,\forall\, i=1,\dots,N+M \tag{3.20}$$

$$R_{i,\alpha_j}=\begin{cases}1 & \text{if } i=j\\ 0 & \text{if } i\neq j\end{cases}\quad\forall\, i=1,\dots,N-1; j=1,\dots,N-1 \tag{3.21}$$

$$R_{N,\alpha_j}=-1\,\forall\, j=1,\dots,N-1 \tag{3.22}$$

$$R_{N+i,\alpha_j}=0\,\forall\, i=1,\dots,M; j=1,\dots,N-1 \tag{3.23}$$

$$R_{i,\alpha_{jk}}=\begin{cases}0 & \text{if } i\neq j\wedge i\neq k\\ \ln(\tilde{x}_k) & \text{if } i=j\\ \ln\left(\tilde{x}_j\right) & \text{if } i=k\end{cases}\qquad\forall\, i=1,\dots,N-1; j=1,\dots,N-1; k=j,\dots,N-1 \tag{3.24}$$

$$R_{N,\alpha_{jk}}=-\left(\ln\left(\tilde{x}_j\right)+I_{j\neq k}\ln(\tilde{x}_k)\right)\forall\, j=1,\dots,N-1; k=j,\dots,N-1 \tag{3.25}$$

$$R_{N+i,\alpha_{jk}}=0\,\forall\, i=1,\dots,M; j=1,\dots,N-1; k=1,\dots,N-1 \tag{3.26}$$

---

[17] This equation is identical to equation (3.6).

$$R_{i,\beta_j} = 0 \, \forall \, i = 1,\ldots,N; j = 1,\ldots,M \tag{3.27}$$

$$R_{N+i,\beta_j} = \begin{cases} -\Omega_{ji} & \text{if } j < M \\ -y_i / \left\| y \right\|^2 & \text{if } j = M \end{cases} \forall \, i = 1,\ldots,M; j = 1,\ldots,M-1 \tag{3.28}$$

$$R_{i,\beta_{jk}} = 0 \, \forall \, i = 1,\ldots,N; j = 1,\ldots,M; k = 1,\ldots,M \tag{3.29}$$

$$R_{N+i,\beta_{jk}} = \begin{cases} -\left(\varphi_k(y)\,\Omega_{ji} + I_{j \neq k} \varphi_j(y)\,\Omega_{ki} \right) & \text{if } j < M \wedge k < M \\ -\Omega_{ji} \ln \left\| y \right\| - \varphi_j(y)\, y_i / \left\| y \right\|^2 & \text{if } j < M \wedge k = M \\ -\ln \left\| y \right\| y_i / \left\| y \right\|^2 & \text{if } j = M \wedge k = M \end{cases} \forall \, i = 1,\ldots,M; j = 1,\ldots,M; k = j,\ldots,M \tag{3.30}$$

$$R_{i,\delta_j} = 0 \, \forall \, i = 1,\ldots,N+M; j = 1,\ldots,K \tag{3.31}$$

$$R_{i,\delta_{jk}} = 0 \forall \, i = 1,\ldots,N+M; j = 1,\ldots,K; k = 1,\ldots,K \tag{3.32}$$

$$R_{i,\psi_{jk}} = \begin{cases} 0 & \text{if } i \neq j \\ \varphi_k(y) & \text{if } i = j \wedge k < M \\ \ln \left\| y \right\| & \text{if } i = j \wedge k = M \end{cases} \forall \, i = 1,\ldots,N-1; j = 1,\ldots,N-1; k = 1,\ldots,M \tag{3.33}$$

$$R_{N,\psi_{jk}} = \begin{cases} -\varphi_k(y) & \text{if } k < M \\ -\ln \left\| y \right\| & \text{if } k = M \end{cases} \forall \, j = 1,\ldots,N-1; k = 1,\ldots,M \tag{3.34}$$

$$R_{N+i,\psi_{jk}} = \begin{cases} -\ln\left(\tilde{x}_j\right)\Omega_{ki} & \text{if } k < M \\ -\ln\left(\tilde{x}_j\right) y_i / \left\| y \right\|^2 & \text{if } k = M \end{cases} \forall \, i = 1,\ldots,M; j = 1,\ldots,N-1; k = 1,\ldots,M \tag{3.35}$$

$$R_{i,\xi_{jk}} = \begin{cases} 0 & \text{if } i \neq j \\ z_k & \text{if } i = j \end{cases} \forall \, i = 1,\ldots,N-1; j = 1,\ldots,N-1; k = 1,\ldots,K \tag{3.36}$$

$$R_{N,\xi_{jk}} = -z_k \, \forall \, j = 1,\ldots,N-1; k = 1,\ldots,K \tag{3.37}$$

$$R_{N+i,\xi_{jk}} = 0 \, \forall \, i = 1,\ldots,M \wedge \forall \, j = 1,\ldots,M \wedge \forall \, k = 1,\ldots,K \tag{3.38}$$

$$R_{i,\zeta_{jk}} = 0 \, \forall \, i = 1,\ldots N; j = 1,\ldots,N; k = 1,\ldots,K \tag{3.39}$$

$$R_{N+i,\zeta_{jk}} = \begin{cases} -z_k * \Omega_{ji} & \text{if } j < M \\ -z_k y_i / \left\| y \right\|^2 & \text{if } j = M \end{cases} \forall \, i = 1,\ldots,M; j = 1,\ldots,M; k = 1,\ldots,K \tag{3.40}$$

and the elements of r are:

$$r_i = \begin{cases} -1 & \text{if } i = N \\ 0 & \text{if } i \in \{1, \ldots, N-1, N+1, \ldots, N+M\} \end{cases} \tag{3.41}$$

The monotonicity restrictions $R\theta \geq r$ defined above impose monotonicity at one data point $(x_1, \ldots, x_N, y_1, \ldots, y_M, z_1, \ldots, z_K)$. If one wants to impose monotonicity at more than one data point, e.g., at each observation in a data set, one needs to create one R matrix and one r vector for each data point, at which monotonicity should be imposed, and stack these matrices and vectors vertically:

$$\tilde{R} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_G \end{bmatrix} \tag{3.42}$$

$$\tilde{r} = \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_G \end{pmatrix}, \tag{3.43}$$

where G is the number of data points at which monotonicity should be imposed, $R_g; g = 1, \ldots, G$ is the matrix R at the gth data point at which monotonicity should be imposed, and $r_g; g = 1, \ldots, G$ is the vector r at the gth data point at which monotonicity should be imposed. In this case, $\tilde{R}\theta \geq \tilde{r}$ defines the $G \cdot (N+M)$ monotonicity restrictions.

3.C Procedure to impose monotonicity conditions

Following the three-step procedure proposed by Henningsen and Henning (2009)[18], we estimate in the first step the following (unrestricted) stochastic

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[18] Other methods to impose monotonicity conditions include O'Donnell and Coelli (2005).

frontier model:

$$-\ln x_N = \ln D\left(\frac{x}{x_N}, y, z, \theta_u\right) - u + v, \tag{3.44}$$

where θ_u is the vector of the estimated unrestricted coefficients.

In the second step, we use a constrained optimization procedure to find the vector of restricted coefficients. This is a minimum distance estimation, i.e., we search for the vector of coefficients that is closest to (has the minimum distance to) the unrestricted vector of coefficients, conditional on fulfilling the monotonicity conditions, and using the inverse of the variance-covariance matrix of the unrestricted coefficients as weighting matrix:

$$\begin{aligned} \hat{\theta}_r = \arg\min_{\hat{\theta}_r} & \left(\hat{\theta}_r - \hat{\theta}_u\right)^\top \hat{\Sigma}^{-1} \left(\hat{\theta}_r - \hat{\theta}_u\right), \\ \textbf{s.t. } & R\hat{\theta}_r \geq r, \end{aligned}$$

where $\hat{\theta}_r$ is the vector of the estimated monotonicity-restricted coefficients and $\hat{\Sigma}$ is the estimated variance-covariance matrix of the unrestricted coefficients $\hat{\theta}_u$.

In the third-step, we estimate the stochastic frontier model:

$$-\ln x_N - \ln D\left(\frac{x}{x_N}, y, z, \hat{\theta}_r\right) = a_0 - u + v \tag{3.45}$$

$$-\ln D\left(x, y, z, \hat{\theta}_r\right) = a_0 - u + v. \tag{3.46}$$

In contrast to equation (12) in Henningsen and Henning (2009), we only allow the intercept in $\hat{\theta}_r$, i.e., α_0, to adjust but we do not allow the other coefficients in $\hat{\theta}_r$ to adjust as done by Henningsen and Henning (2009). This is done because the input distance function must be linearly homogeneous in input quantities and an adjustment of the slope coefficient in $\hat{\theta}_r$ would either abandon the homogeneity restriction or—if one adjusts the non-estimated coefficients to maintain homogeneity—potentially abandon the monotonicity restrictions (that were just imposed). In order to avoid these problems, we do not adjust the slope coefficients in $\hat{\theta}_r$ by having the predicted distance values $D\left(x/x_N, y, z, \hat{\theta}_r\right)$ on the left-hand side of equation (3.45) rather than as explanatory variable on the right-hand side (as already suggested by Henningsen and Henning, 2009, in their footnote 7). However, we suggest to adjust the intercept in $\hat{\theta}_r$, i.e., α_0, by estimating coefficient a_0

(rather than restricting it to zero) because this allows the “height” of the restricted frontier and, thus, the general (in)efficiency level, to adjust after restricting the shape of the frontier (by imposing monotonicity conditions) given that restricting the shape of the frontier (by imposing monotonicity conditions) may change the general (in)efficiency level.

3.D Results based on the ordering of outputs that gives the best fit

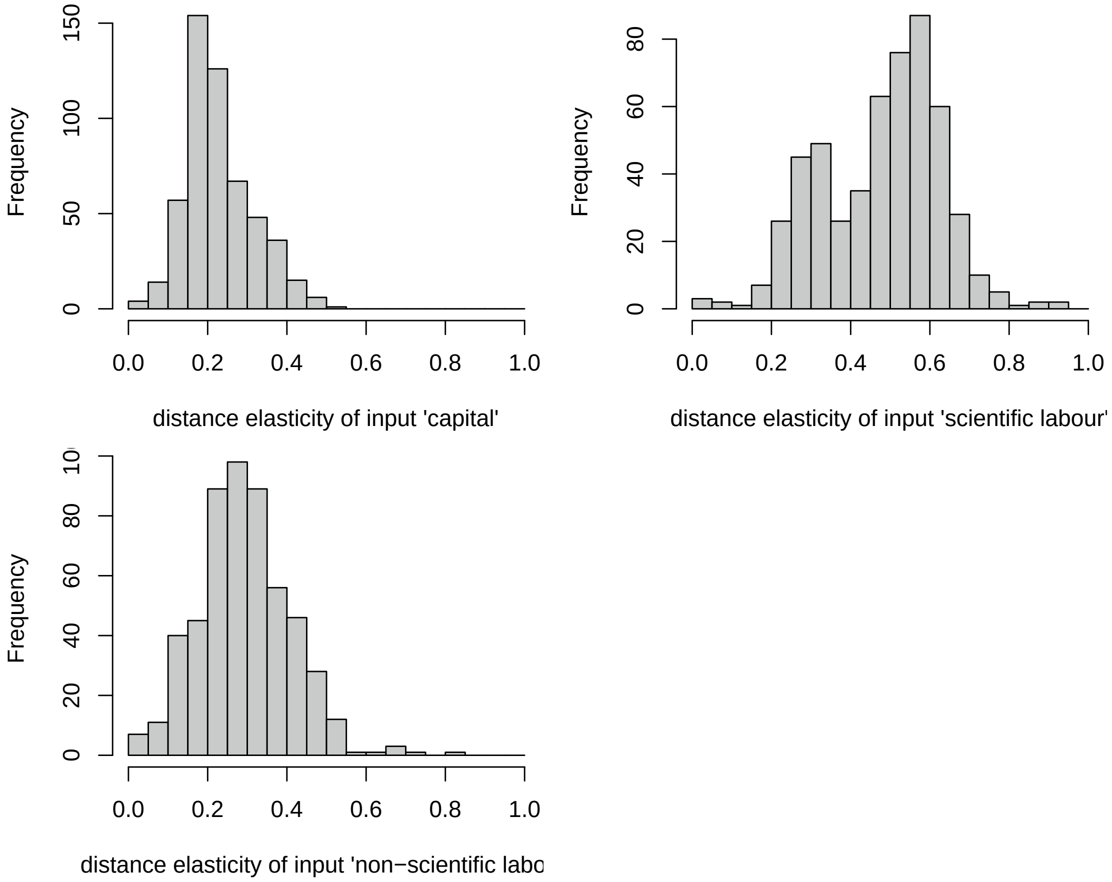


Figure 3.5: Distance elasticities of the inputs based on the ordering of outputs that gives the best fit

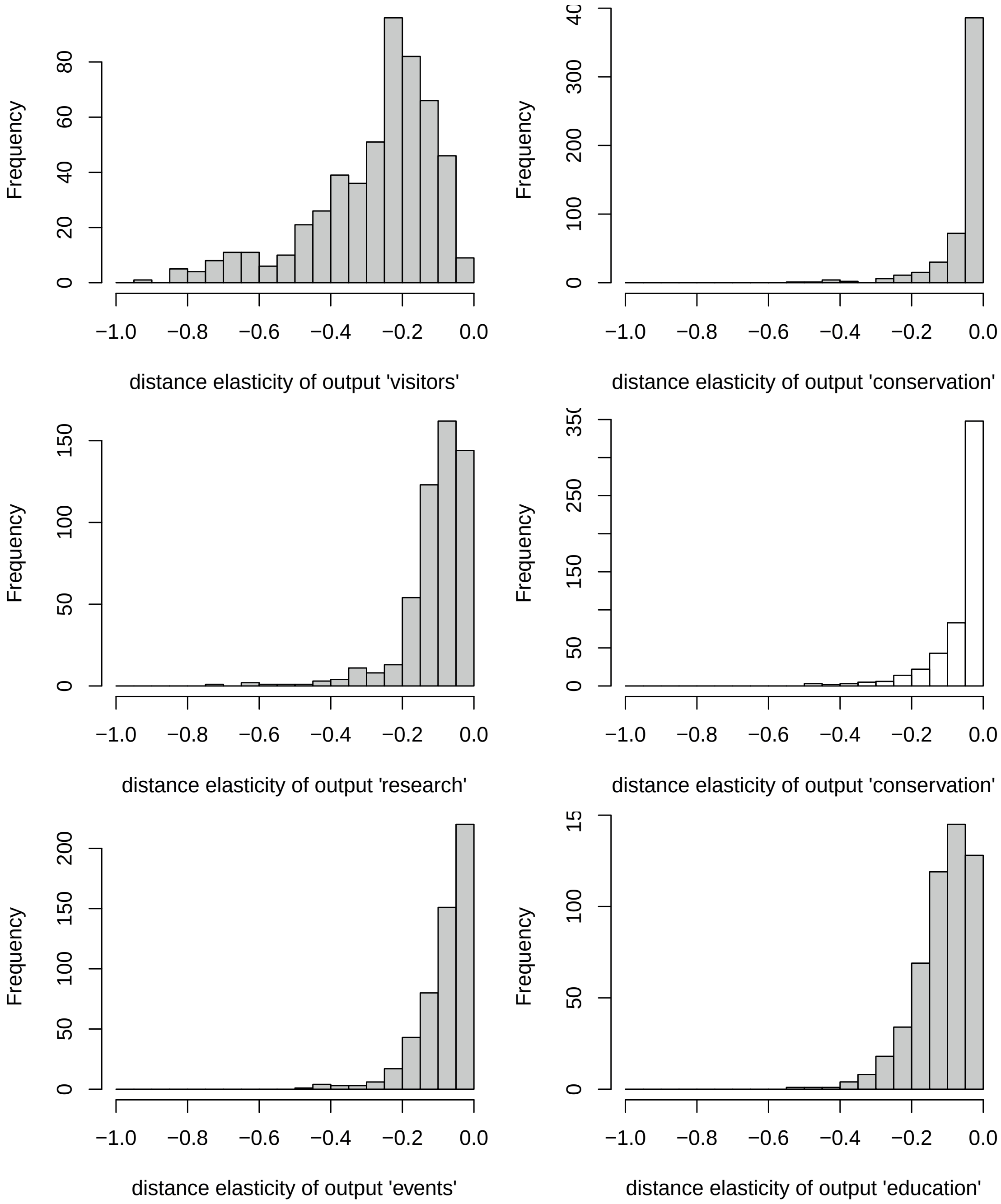


Figure 3.6: Distance elasticities of the outputs based on the ordering of outputs that gives the best fit

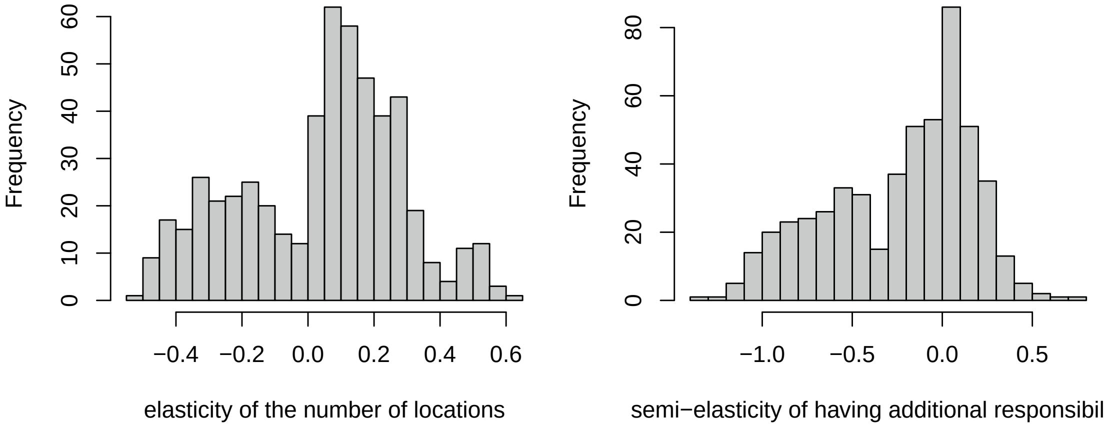


Figure 3.7: Elasticities and Semi-elasticities of the environmental variables based on the ordering of outputs that gives the best fit

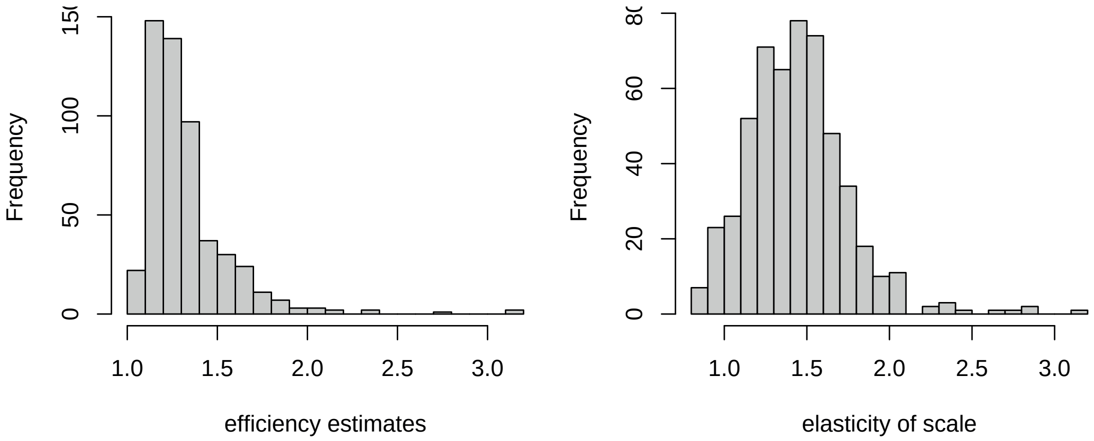
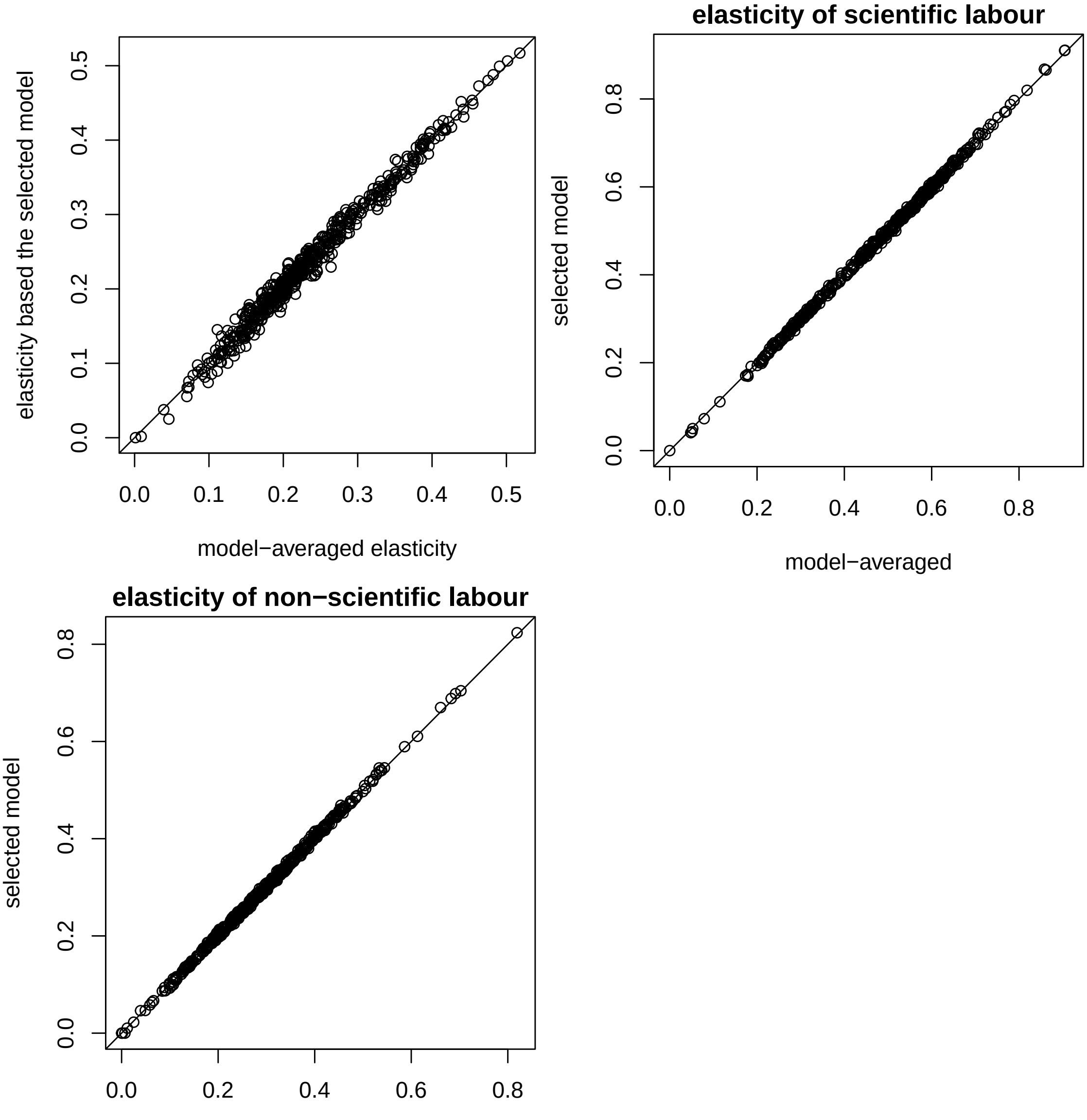


Figure 3.8: Efficiency estimates and elasticities of scale based on the ordering of outputs that gives the best fit

3.E Comparison of model-averaged estimates and estimates of the selected model


elasticity of scientific labour

elasticity of non−scientific labour

Figure 3.9: Comparison of the distance elasticities of the inputs based on model averaging and based on the ordering of outputs that gives the best fit

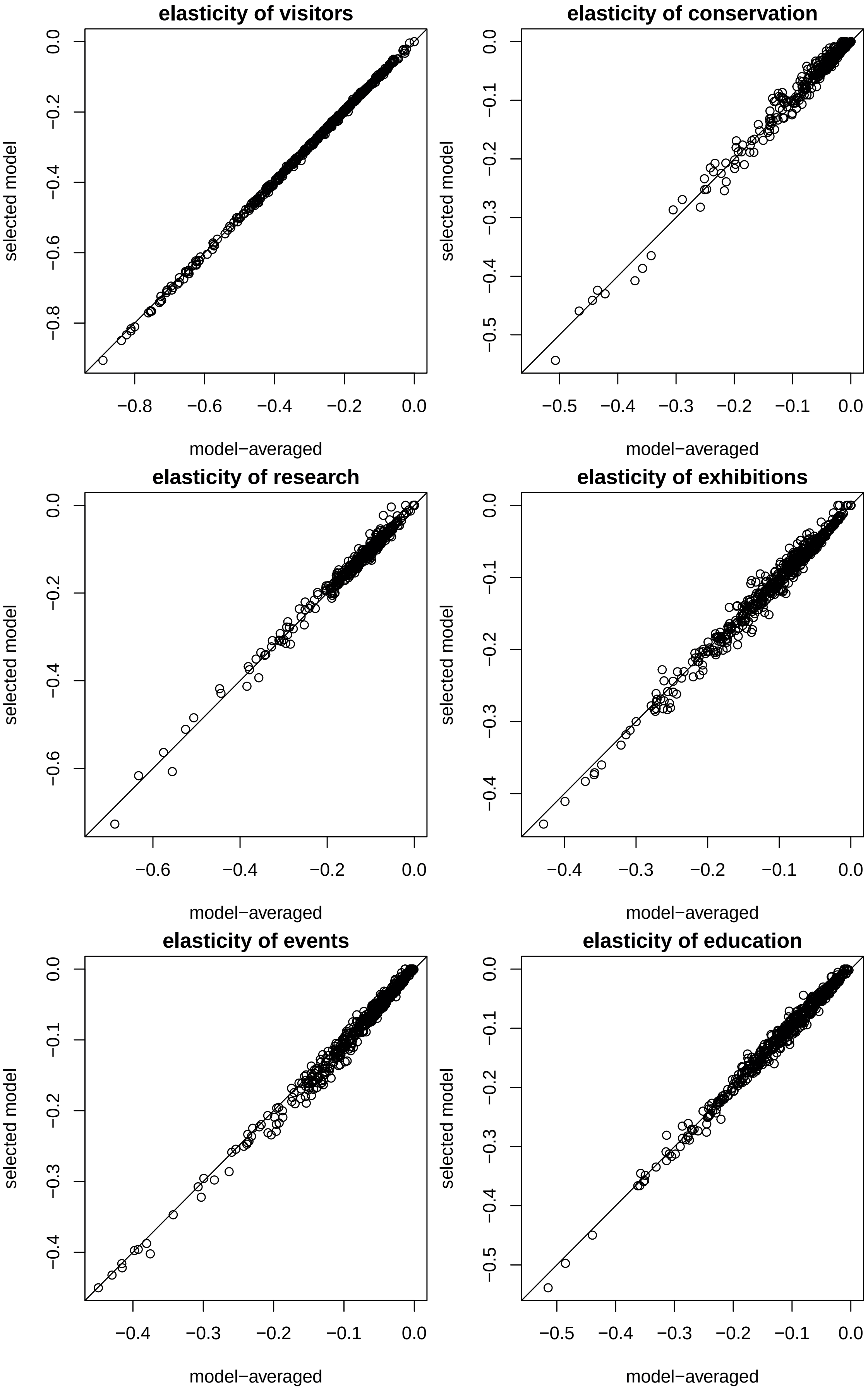


Figure 3.10: Comparison of the distance elasticities of the outputs based on model averaging and based on the ordering of outputs that gives the best fit

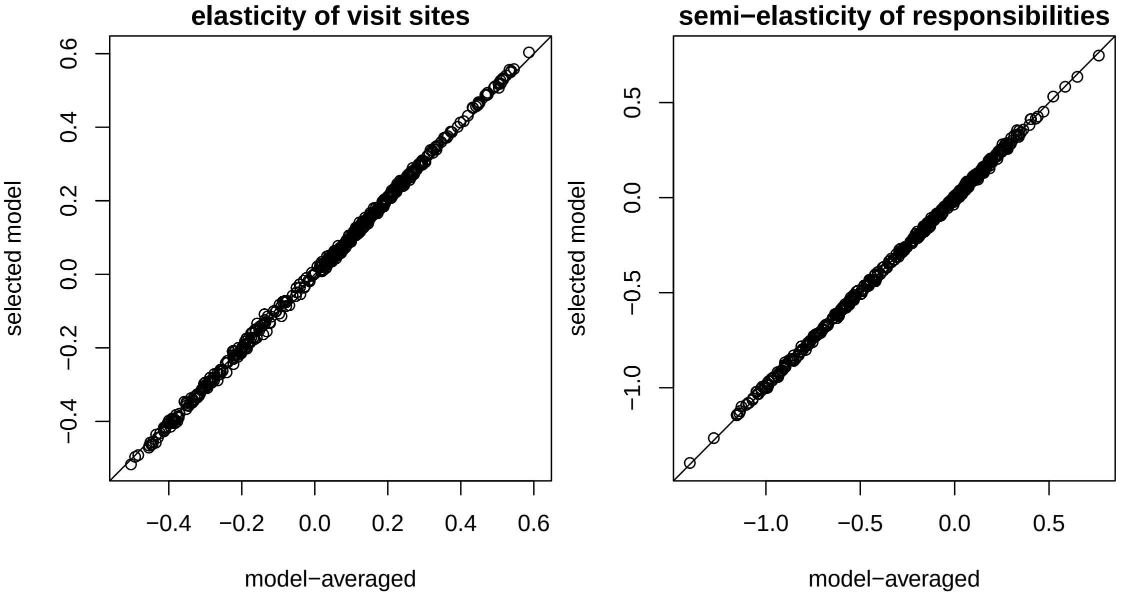


Figure 3.11: Comparison of the distance (semi-)elasticities of the ‘environmental’ variable based on model averaging and based on the ordering of outputs that gives the best fit

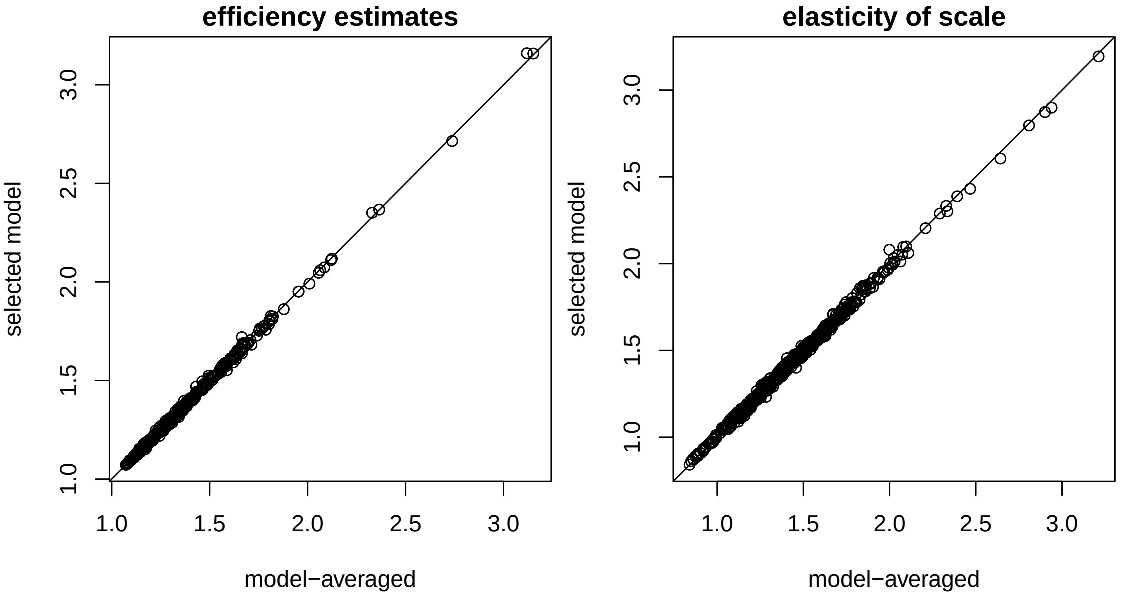


Figure 3.12: Comparison of the distance efficiency estimates and elasticities of scale based on model averaging and based on the ordering of outputs that gives the best fit

3.F Model-averaged distance elasticities

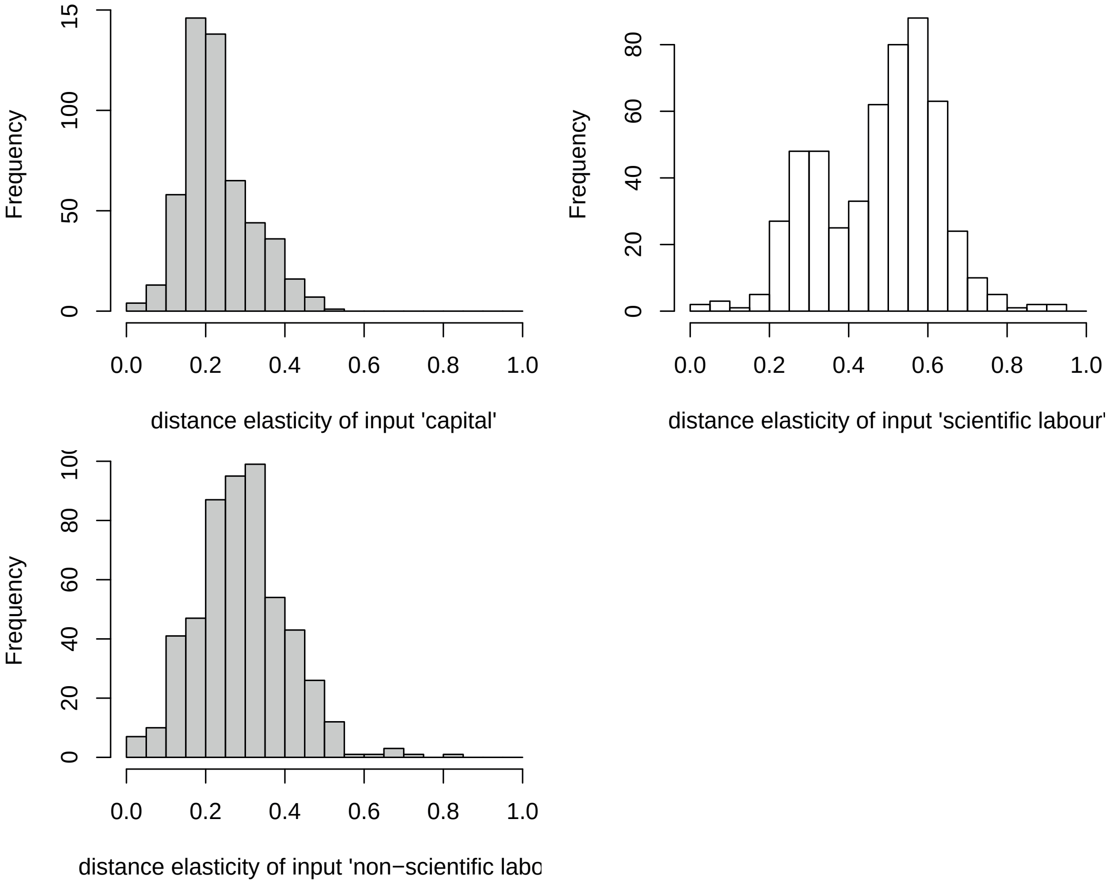


Figure 3.13: Model-averaged distance elasticities of the inputs

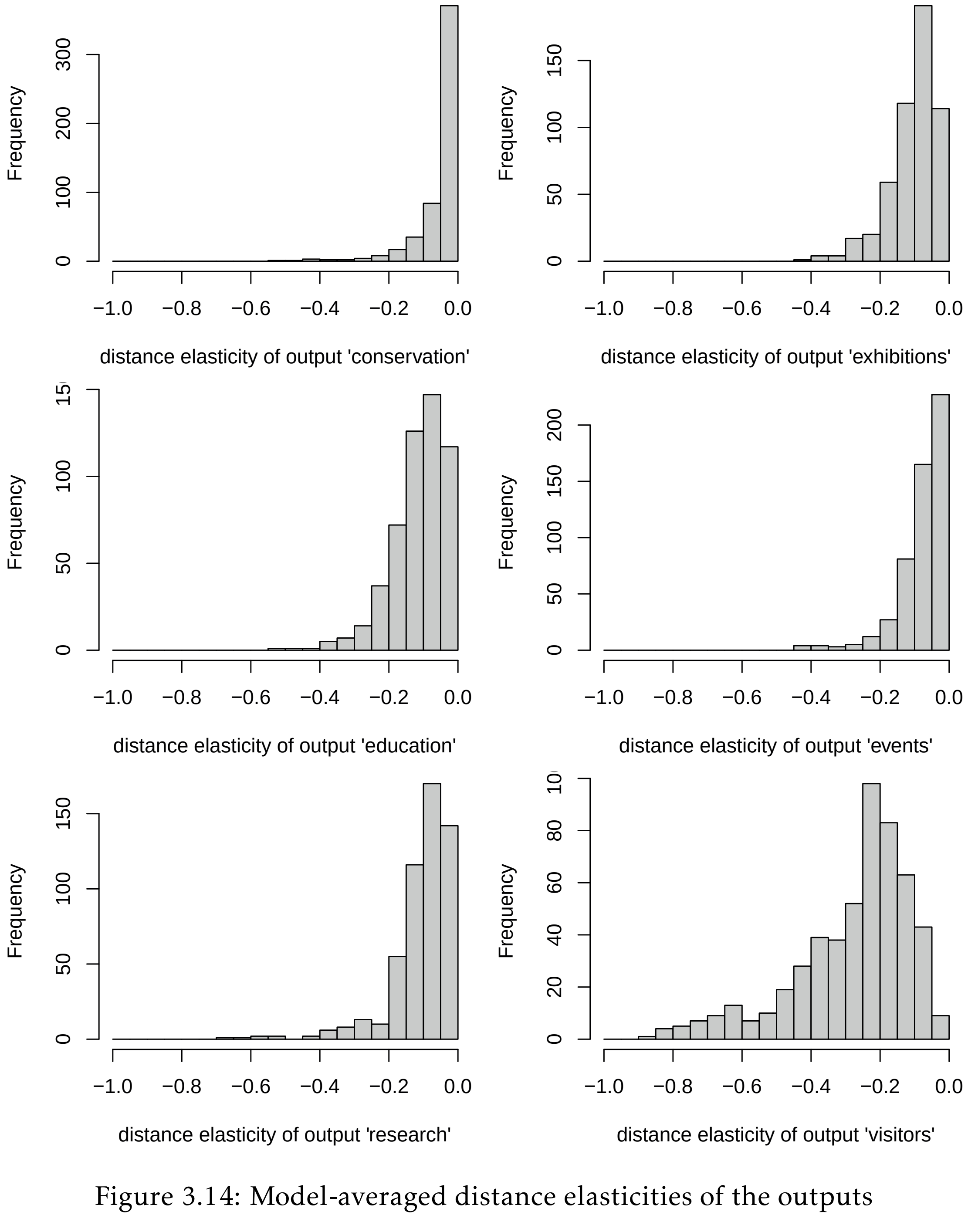


Figure 3.14: Model-averaged distance elasticities of the outputs

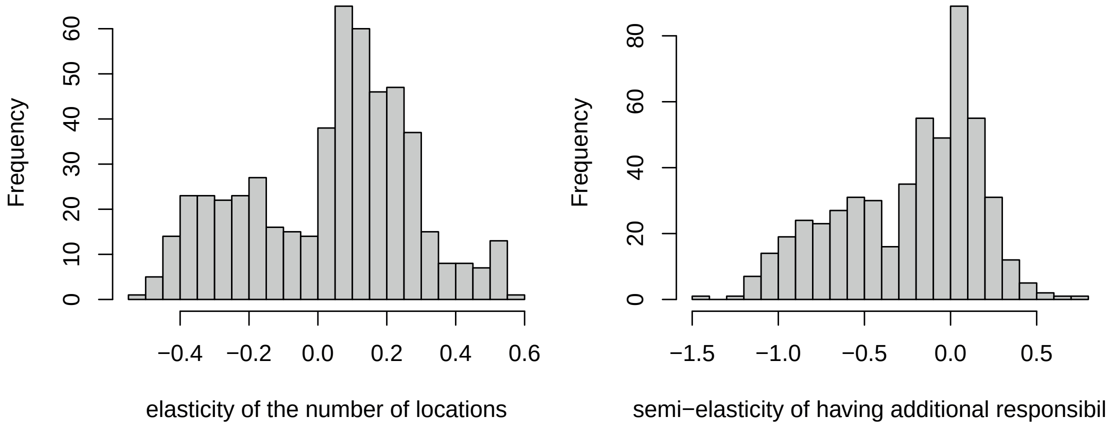


Figure 3.15: Model-averaged distance elasticities and semi-elasticities of the environmental variables

Chapter 4

Third paper: "Baumol's Cost Disease and Urban Transport Services in Latin America"

Andrés Gómez-Lobo (Associate Professor at the University of Chile's Department of Economics) is co-author of this paper (the corresponding "Co-author Statement" is presented before the Abstract)

Article published

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CO-AUTHOR STATEMENT

Title of paper	Baumol's Cost Disease and Urban Transport Services in Latin America
Journal and date (if published)	Revised and resubmitted to “Transportation Research: Part A”

1. Formulation/identification of the scientific problem to be investigated and its operationalization into an appropriate set of research questions to be answered through empirical research and/or conceptual development

Description of contribution:

None. This was done by the main contributor, Juan José Price

2. Planning of the research, including selection of methods and method development

Description of contribution:

I gave some advice related to the specification of the regression models but all the research planning and empirical analysis was carried by the main contributor, Juan José Price (please see the response to the following question for more details)

3. Involvement in data collection and data analysis

Description of contribution:

I got in contact with the people from buses operator companies in Santiago and with the Inter-American Development Bank's Transport Division, which helps with contacts in Buenos Aires and Panama. But it was the main contributor (Juan José Price) who got in contact with them and got the data. Also the official, public information, was collected by Juan José Price

4. Presentation, interpretation and discussion of the analysis in the form of an article or manuscript

Description of contribution:

The main contributor (Juan José Price) wrote most of the article. I contributed with the literature review about income elasticities and part of the discussion about the definition of outputs and with the discussion (in the section "Conclusions") of policy alternatives to overcome the problem under analysis. I also read the many drafts produced by Juan José Price along the process and made observations to them. Just to make things clear: Juan José Price was in charge of the framing of the problem, the definition and presentation of the research questions, most of the literature review, the coordination with people in Panama and Buenos Aires to get (non-public) data, looking for and getting official, public data in Colombia and Buenos Aires, getting in contact and working with the people in charge of the buses operator firms in Santiago (contacts in Santiago were made by me (Andrés Gómez-Lobo)), getting the data about the Metro system in Santiago, preparing the database for all four countries, doing the descriptive analysis, estimating the models (regression analysis and non-parametric analysis of productivity change), writing the addendum (technical note) to the thesis dealing with the analysis and estimation of indicators of productivity change, and writing of the paper.

Publication

Please note that the article will be published electronically and in a limited edition in print as a part of the PhD thesis by the CBS library in connection with the PhD defence.

1. Co-author (PhD student)	Juan José Price Name

I hereby declare that the above information is correct

08 March 2021 Date	Juan Price Digitally signed by Juan Price Date: 2021.03.13 16:43:39 -03'00' Signature

2. Co-author	Andrés Gómez-Lobo Name

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08 March 2021 Date	Andres Gómez-lobo Firmado digitalmente por Andres Gómez-lobo Fecha: 2021.03.13 17:37:03 -03'00' Signature

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I hereby declare that the above information is correct

Date	Signature

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Baumol's cost disease and urban transport services in Latin America

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ABSTRACT

According to Baumol's Cost Disease in some productive activities that are labor intensive and where labor saving technological change is low or absent, labor productivity tends to be stagnant. However, since these sectors compete for the same inputs, their wage bill increases according to the average productivity growth in the economy. As a consequence, production in stagnant sectors becomes more expensive relative to that of others. Examples of sectors affected by Baumol's disease include the performing arts, health, education and some public services. Some recent literature for developed countries suggests that public transport is also affected by the cost disease. In this article we present similar evidence suggesting that Baumol's cost disease might be present in transit services in several cities from four Latin American countries, with consequences in terms of costs and productivity that are probably made worse by rising urban congestion. We also analyze to what extent technical progress and gains in aggregate efficiency can offset the consequences of Baumol's cost disease. Finally, we discuss policy options to overcome these problems, refer to some possible limitations of our analysis and propose avenues for future research.

1. Introduction

The theory of Baumol's Cost Disease (hereafter simply Baumol's disease, Baumol effect or cost disease) states that in some economic sectors that are labor intensive and where technological change is (almost completely) absent, productivity gains are severely limited, but these sectors still face rising unit labor costs as they compete for labor inputs with other sectors of the economy where productivity is increasing. Therefore, production in stagnant sectors becomes more expensive relative to other goods and services in the economy (Baumol and Bowen, 1966; Baumol, 1967; Baumol, 2012).

In this article we provide evidence that suggests the Baumol's disease might be affecting the public transport systems in 25 cities from four Latin American countries: Argentina, Chile, Colombia and Panama. In the case of two of these countries (Argentina and Colombia) the data also allows us to analyze whether the consequences of Baumol's cost disease can be (at least partially) offset by technical progress and gains in aggregate productivity.

By covering a relatively large set of cities from diverse countries and using several empirical approaches we hope to provide cumulative evidence for the presence of Baumol's cost disease in the transit sector in the Latin American region. This adds to a small but growing literature on the presence of this cost disease in the transit sectors in developed countries (Evangelinos, et al., 2012; Morales

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Sarriera and Salvucci, 2016; Morales Sarriera et al., 2018). To the best of our knowledge, this is the first paper analyzing this issue for developing countries.

Understanding this phenomenon is essential to make correct policy decisions. If Baumol's disease is present, society will have to spend an increasing proportion of GDP in this sector if it wishes to keep output and quality levels unchanged. In addition, as transit is essential from a social welfare and environmental perspective, it may not always be feasible or desirable to pass on to users this gradual increase in provision costs. Therefore, the possible need for rising public funding may trigger political discussions that, due to the limited understanding of the underlying cause of cost increases, may lead to the under-funding of this service.

The cost disease in the case of public urban transport is accentuated by growing traffic congestion. This is particularly a problem in developing countries where private motorization rates are expected to increase substantially over the coming decades. Congestion, by reducing average bus speed, increases the fleet required to maintain a given frequency. There are policy options that might help to reduce or reverse the congestion problem.

This article is organized as follows. In Section 2 we explain Baumol's cost disease in more detail. Section 3 presents empirical evidence regarding the relevance of this phenomenon in the public transport systems of developed countries. Section 4 provides evidence from 22 cities of Colombia, Buenos Aires (Argentina), Panama City (Panama) and Santiago (Chile). Finally, in the conclusions we present lessons and policy alternatives to address the challenges raised by Baumol's cost disease in the transit sector in developing countries.

2. Baumol's cost disease

Baumol's cost disease was presented in its original version for the performing arts (Baumol and Bowen, 1966). However, its application is broader and includes other sectors, such as education and health (Baumol, 1967; Baumol, 2012). The argument is simple and is explained in what follows.[1]

Suppose we can divide the economy into two sectors, a dynamic one that groups those activities, such as manufacturing and agriculture, where labor productivity increases as a result of technological change, and another, called stagnant, where labor productivity does not grow. In this last sector, production is labor intensive and there are few possibilities of substituting capital for labor. Moreover, labor is part of the very essence of the service produced: a teacher in the teaching process, a doctor or nurse in health care, a bus driver in urban transport, the musicians who form an orchestra, among other examples.

It is difficult to imagine that the use of new technologies can significantly reduce the time that a teacher allocates to a class or significantly increase the number of students per class without sacrificing quality. Also, the duration and number of musicians required to play a musical piece written two hundred years ago is the same today. A nuance to this argument has to me made though, for its validity strongly depends on the way the productivity indicator is defined. In fact, if the audience were defined not as the maximum number of people a theatre can host but as the potential audience that can watch the interpretation of the musical piece (through streaming for example) then we could cast doubt on the unavoidability of the Baumol effect. This is a typical example of technological change helping to counteract the effects of Baumol's disease (see Cowen, 1996). The same could be applied to online teaching, although in this case the quality of the service could be negatively affected.

If labor markets are integrated, that is, if all sectors compete for labor, the payment to this factor should evolve at the same rate in both sectors, and this rate is determined by the growth of average productivity in the economy. Therefore, costs in the stagnant sectors will increase faster than in the dynamic sectors of the economy, where increasing productivity compensates for the higher labor costs. Without public support, the goods or services of the stagnant sectors will become relatively more expensive and *ceteris paribus* output will fall. In contrast, the goods and services produced in those sectors that exhibit higher-than-average productivity growth become relatively cheaper.

The effects of Baumol's disease could be especially dramatic in the case of surface transit (buses). One driver per bus is still an obvious requirement and there are limited possibilities of substitution between capital and labor.[2] For example, increasing vehicle size to increase labor productivity would compromise service quality (frequency). Furthermore, increasing levels of urban congestion, with a concomitant fall in average bus speeds, have a negative impact on productivity in this sector (akin to negative technical change). As we will see below, rail-based services –trains and metro– may be less prone to the Baumol effect since they are generally not affected by rising congestion and technological change in signaling and autonomous trains allow for continuous productivity increases.

Although only anecdotal, the workings of Baumol's cost disease in transit can be illustrated by one of the author's experience in Santiago, Chile. Every year one bus operator or another would have a wage bargaining process whose result would invariably be a rise in real wages. However, productivity was not increasing, nor could drivers or other workers be substituted with labor savings capital investments. Consequently, real operational costs rose each year. If wages did not keep up with the rest of the sectors, operators would have difficulty hiring or retaining drivers, mechanics or electricians, given their alternative options in the mining, logistics or other sectors that offered increasingly higher wages for these jobs. This is precisely the dynamics of Baumol's cost disease in action and was evident in a short period of time.

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[1] Annex 1 presents a simple model illustrating the basic structure of Baumol's cost disease. The simplicity of this basic model should not detract from recognizing the intellectual efforts to tackle one of the more pessimistic conclusions of Baumol's unbalanced growth model (Baumol, 1967); namely, that aggregate growth will slow down as resources are shifted to the production of the good from the stagnant sector. On this see Oulton (2001), Ngai and Pissarides (2007) and Dietrich and Krüger (2010).

[2] This problem could be reduced in the future with the advent of autonomous vehicles, a point we will come back to in the conclusions.

It could be argued that it is socially efficient for those services that lose competitiveness to wither away, but there are well known reasons why this may not be socially optimal in many cases. For example, most developed societies allocate an increasing amount of resources to ensure the provision of public education (at least at the primary and secondary levels) and in many countries the public health budget grows at a higher rate than that of other sectors.[3] Likewise, in the case of public transport, increasing returns (known as the Mohring effect) and the negative externalities associated with the use of private transport may well dictate that it is socially beneficial to invest increasing amount of resources (as a percentage of national income) in public transport systems.[4]

It is also important to mention that, unlike other sectors affected by Baumol's disease, public transport does not have a natural private "antidote". Education and the arts are usually superior goods, having an income elasticity greater than one. As individuals become richer, they allocate an increasing percentage of their income to these goods and services. In those cases, the contraction of supply driven by the Baumol effect is partially or totally compensated by an expansion of demand.[5] In other words, as an economy grows private demand can maintain or even increase the production level of these services, even as individuals must pay more for them.

This antidote does not work, however, in the case of urban public transport. The empirical evidence suggests that surface public transport is an inferior good –the income elasticity of demand is negative and high in absolute terms– so demand falls as incomes rise. Wardman and Shires (2003) perform a meta-analysis with data from 104 studies conducted in Great Britain between 1951 and 2002, finding that the income elasticity for urban transit services varies between −0.5 and −1.0 in the long-run, although it is somewhat smaller (in absolute value) in the short-run (see also Glaister and Graham, 2002; Goodwin et al., 2004; Oum et al., 1992; Pratt, 2004; Wardman and Shires, 2011). Trains, on the other hand, show a positive income elasticity, that is, they provide services that can be considered a normal good (Asquith, 2011). For Latin America and the Caribbean, Gandelman and Serebrisky (2018) estimate Engel curves and obtain income elasticities for public transport between −1.0 and 0.7, depending on the socioeconomic group. According to these results, public transport in Latin America would appear to be a necessary good for lower income households and an inferior good for richer households.

3. Literature review

Nordhaus (2008) tests the Baumol hypothesis econometrically relying on data from different sectors and confirms that the productivity of technologically stagnant industries (including transit) grows at a lower rate than that of sectors that exhibit technological progress. Consequently, as this author finds, costs grow faster in stagnant industries than in other sectors.

Evangelinos, et al. (2012) use data from US national accounts to calculate labor productivity for the local transit sector. They find that while at the aggregate level the average output per worker grew 1.4% per year during the period 1977–2007, sectors such as education, health, performing arts, state-owned companies and urban public transport exhibited a negative average growth, and in this last sector labor productivity grew the least, at an average of −1.6% per year.

These authors also undertake a disaggregated analysis with outputs, inputs and cost data for a sample of 250 bus transport companies in the United States and 75 in Germany. The sample includes 21 companies from the United States and 49 from Germany with mixed operations (buses, trains, monorails, trams or other modes). They first undertake a non–parametric production frontier analysis using Data Envelopment Analysis (DEA). As outputs they use commercial kilometers and as inputs the number of employees, number of vehicles and population density. They estimate total factor productivity (TFP) for each operator and, given that they have information for several periods, the Malmquist productivity index.[6] The results indicate that surface public transport (buses) has a very low productivity growth; in this case, an annual average TFP growth rate of only 0.5%.[7] This conclusion is confirmed by an analysis of the evolution of costs for buses and trains in New York and Chicago. These results are particularly important, for they suggest that, if Baumol's cost disease were present, as these authors' analysis suggests, the consequences couldn't be offset by gains in aggregate efficiency (total factor productivity, TFP). However, in both countries, productivity growth is higher for rail-based services (metro, light and heavy trains, trams and others). This points to the greater technological change available for rail-based modes. These scholars also suggest that congestion may contribute to explain the difference in performance between surface and rail-based services.

Morales Sarriera and Salvucci (2016) perform a similar analysis for the US and reach similar conclusions. They indicate that among 195 industries in the United States, the 'public transport and passenger surface transportation' sector presented the ninth smallest growth in average productivity per worker between 1990 and 2012. Furthermore, they estimate two measures of labor productivity, the number of commercial miles per worker and the number of passengers transported per worker using panel data for 49 companies

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[3] Early evidence for increasing government expenditure in public goods, the increasing share of public expenditure to GDP, and the possible link to Baumol's cost disease, are provided by Bradford et al. (1969), and Spann (1977).

[4] Parry and Small (2009) show that these two arguments justify an increase in the already high transit subsidies in cities such as Los Angeles, Washington D.C and London.

[5] As shown in Spann (1977), demand growth for goods and services subject to Baumol's cost disease will be equal to the sum of their price and income elasticity of demand multiplied by productivity growth in the dynamic sector. If the income elasticity is positive and higher than the (absolute value) of the own price elasticity, demand for the good or service of the stagnant sector will increase.

[6] In simple terms, the Malmquist index is the ratio of TFP of a given period to that of the previous period for each unit of analysis. For a more detailed explanation on Data Envelopment Analysis and the Malmquist Index see Coelli et al. (2005) and Annex 2 of this paper.

[7] This is consistent with older studies of TFP changes in local transit services where negative or very low productivity growth is found. See Pestana Barros and Peypoch (2010) for Portugal, Obeng and Sakano (2008) for the US, Odeck (2008) for Norway and Yu (2008) for Taiwan.

that operate buses, 16 that operate light railroads, 14 heavy railroads and 9 that operate commuter rail in the United States between 1997 and 2013. The results indicate that in almost all cases (the exception being heavy railroad when productivity is measured per passenger mile) average productivity growth is low and below the economy wide productivity growth. Again, the bus sector exhibits the lowest growth rate, even negative when productivity is measured using commercial miles as an indicator of supply.

Finally, these authors analyze the evolution of labor costs of the different transport agencies and confirm that they have grown more rapidly than the consumer price index and the average wage rate in the United States, which suggests that in addition to Baumol's disease there may be other factors operating in this case.[8] Morales Sarriera et al. (2018) suggest two hypotheses: the existence of strong labor unions in this sector (a result supported by Schwarz-Miller and Talley, 1995) and the monopolistic nature of urban transport services.[9] Due to lack of information, in the present paper we do not assess the possible impact of union power on productivity and cost inflation.

Another issue is whether subsidies may influence productive efficiency of transit firms and therefore confound our results. There is a long literature analyzing this issue. For example, De Borger et al. (2002) in their review of many efficiency studies using frontier techniques conclude that "Subsidies tend to worsen the performance of urban public transport in a variety of ways: higher costs, fewer revenue-passengers, excessive wage growth, and technical inefficiency."[10]

However, we believe that subsidies are not relevant in our analysis. First, in the case of Colombia and Santiago, there are no supply-side subsidies. In Santiago, for example, subsidies are used to avoid public fares from rising and do not affect how much is paid to transit firms. Some cities in Colombia with formal BRT systems also have subsidies, however we control for these cases in the empirical application. Subsidies may be an issue in Panama (public firm) and particularly in Buenos Aires were supply side subsidies cover a large fraction of operational costs. However, even in these cases there is no clear reason why efficiency should be deteriorating over time unless subsidy levels are also increasing over time. Although historical data are hard to come by, Basso and Silva (2014) report a subsidy level of 50% for buses in Buenos Aires, not too different from the 56% reported by the World Bank (World Bank, 2020) prior to the doubling of fares and reduction in bus subsidies in April 2016. Therefore, there is no evidence that subsidy levels have increased substantially in this city, at least in the second half of our 2007–2017 data period.

4. Analysis of selected Latin American cities

In this section, we analyze whether data supports the presence of Baumol's cost disease in urban passenger transport for a set of Latin American cities. Depending on the information available, we rely on three methodological approaches used by previous researchers in this area.

We first analyze the evolution of labor productivity, using commercial kilometers and passengers as measures of output and the ratio between each of those indicators and the number of buses as the measure of productivity.[11] The vehicle fleet has a direct relationship with the number of drivers and, therefore, the previous measures are a proxy for labor productivity.[12] For Argentina and Colombia, the data also allows us to use regression techniques to determine the dynamics of these partial labor productivity measures controlling for other factors including city level unemployment, calendar seasonal effects, motorization rates (Buenos Aires) and average vehicle size (Colombia). Given the panel structure we can also control for time-invariant non-observed effects at the level of each unit of analysis.

In the case of Chile and Panama we also have cost data. This allows us to use a second approach comparing the average growth of transit costs to the evolution of general inflation (consumer price index).

Finally, for Argentina and Colombia, the data allows us to estimate changes in total factor productivity (TFP) using the Malmquist Index. This analysis is used to gauge to what extent changes in TFP can help to offset the consequences of Baumol's disease.

In some cases, we compare surface transport (buses) with subway services (metro). This allows us to isolate the effect of some differential characteristics of both transport modes, particularly congestion (which affects the first mode) and technological progress (present in the second).

4.1. Partial labor productivity ratios

As a first approach we follow Evangelinos, et al. (2012) and Morales Sarriera and Salvucci (2016) and analyze labor productivity ratios.

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[8] During the 1997–2013 period, the average annual growth rate of labor costs was 3.5% for buses and between 2.9% and 3.6% for rail operations. This is higher than the average annual growth of salaries (2.8%) and average annual inflation (2.3%) during the same period.

[9] These researchers also distinguish between services provided by private and public (state-owned) transport operators. This analysis, although interesting, is not relevant in the present paper because, except for Panama, bus operators are all private in the cases analyzed.

[10] See also Savage (2004) and Winston and Shirley (1998) and references therein with respect to this topic.

[11] Small and Verhoef (2007) call the first output measure an *intermediate output* while the second would be a *final* or *demand-related output*. The intermediate output measure is more under the direct control of the firm and is recommended by these authors for efficiency analysis. In their words "No one would analyze a furniture manufacturer by counting as its output the number of its chairs that are occupied at any moment" (Small and Verhoef, 2007, page 57). However, by *intermediate output* we are referring to capacity output not as an intermediate input to another industry as in Oulton (2001). On the issue of output definition in frontier analysis see also the discussion in Obeng (2011) and De Borger, et al. (2002).

[12] The number of mechanics and other non-driver workers are also expected to be a positive function of fleet size.

4.1.1. Colombia surface transport

We rely on data from the Urban Passenger Transport Survey (ETUP, for its Spanish acronym) that reports monthly information on passengers, commercial kilometers and vehicles in operation for 57 municipalities for the period January 2005 to March 2018. We eliminate 26 smaller municipalities that have incomplete information, and the rest are grouped into cities or metropolitan areas. The final sample includes twenty-two cities.

The survey considers different transport modes including surface transport (buses, minibuses and other similar vehicles) and rail or cable car modes (metro, light-rail and cable-car in the case of Medellin). Our focus in what follows is mainly on the surface transport modes although we do analyze the Medellin metro data further below.

We present statistical results for city level panel data models. The analysis is performed for each of two partial labor productivity measures, the number of commercial kilometers per vehicle in operation and the number of passengers per vehicle in operation. Table 1 presents some descriptive statistics of the data.

All regressions include city fixed effects and calendar-month effects to control for possible seasonal variation. Some specifications also control for the average vehicle capacity of the bus fleet in each city-month. This last variable was constructed using the capacity (seated and standing passengers per vehicle) for each type of bus (bus, buseta, microbus, padron, etc.).[13]

In some models we also control for the entry into operation of the so-called Integrated Mass Transportation Systems (SITM, for its Spanish acronym). These were Bus Rapid Transit (BRT) type reforms introduced in six regional capitals with over 600.000 inhabitants.[14]

Finally, in some specifications we interact the time trend with the SITM variable to examine whether these reforms may have had a dynamic effect on productivity.

We then estimate the following general model:[15]

$$\ln(Prod_{it}) = \beta_0 + \beta_1 \cdot T_t + \beta_2 \cdot SITM_{it} + \beta_3 \cdot CAP_{it} + \beta_4 \cdot SITM_{it} \cdot T_t + \beta_5 \cdot UNEMP_{it} + d_i + z_m + v_{it} \tag{1}$$

where i denotes a city, t the month in the sample and m the calendar month. The dependent variable denotes the logarithm of the corresponding labor productivity indicator (kilometers per bus and passengers per bus), d_i is a city fixed effect, T_t is a time trend, $SITM_{it}$ is a dummy variable that takes the value 1 if an $SITM_{it}$ is in operation in city i in month t and zero otherwise, CAP_{it} measures the average capacity per vehicle in city i in month t, $UNEMP_{it}$ measures the unemployment rate in city i in month t, z_m is a monthly seasonal effect and v_{it} is the error term. The results are presented in Tables 2 and 3.[16]

Table 2 presents the results for the productivity measure based on kilometers per bus. The first column presents a model estimated with the city and time effects plus the time trend. The coefficient of the time trend is negative and statistically significant; productivity fell by an average monthly rate of 0.057% or close to 0.7% annually during this period. The entry into operation of a SITM (column 2) positively affects productivity, but the productivity trend remains negative and statistically significant (-0.069% per month). The third specification controls for the average capacity of buses.[17] The coefficient is positive and statistically significant, but the time trend in productivity remains negative (-0.072% per month).

The interactive term between the time trend and the SITM variable (fourth column) is not statistically significant.[18] Finally, if we also control for the unemployment rate (column 5), the coefficient of the time trend is still negative and larger in absolute terms compared to the other models (a fall of 0.117% monthly or 1.4% annually). The coefficient on unemployment has the expected negative sign.

The results using the ratio of passenger per bus as the productivity measure are presented in Table 3. In the first regression the coefficient of the temporal trend is negative, statistically significant and suggests an average productivity fall of 0.03% per month (or 0.36% annually). An SITM reform (column 2) would have counteracted the fall in productivity; this is reflected in the coefficient of the SITM variable, which is positive (0,108%) and statistically significant, and in the fact that the secular fall in productivity is even greater in this specification.

In the third specification we also control for possible differences between cities in terms of the average capacity of buses. The negative productivity trend remains practically unchanged but the coefficient of the variable SITM is reduced (although it is still statistically significant), which is consistent with the fact that SITM buses have a higher capacity. The interaction variable (column 4) suggests that the SITM reforms have had a positive and statistically significant effect on the temporal dynamics (rather than the level)

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[13] The exact parameters for each type of bus are available upon request from the authors.

[14] These reforms were part of the National Urban Transport Policy (PNTU) defined in 2002. The SITM began operating in Pereira (2006), Cali (2009), Bucaramanga (2010), Barranquilla (2011), Medellin (2012) and Cartagena (2016). In all these cities, BRT-type systems were created in addition to rationalizing the conventional transit fleet and the restructuring of routes. See Gómez-Lobo (2020) for more details on these reforms and their impact.

[15] This specification corresponds to the most general model since the other models are nested in this equation. An anonymous referee suggested that to the extent that wages are rewards for performance, they could be included as a regressor in this labor productivity equation. However, we do not have wage infromation to test this idea.

[16] The last column of each table is estimated with a smaller number of observations since the unemployment data for all cities is only available from January 2007.

[17] Average bus capacity increased by 0.0007% per month during this period.

[18] When the sample is restricted to the largest cities (those with more than 5 million passengers on average per month) the interaction variable is positive but fails to compensate for the secular fall in productivity.

Table 1
Summary statistics, Colombia, (January 2005 - March 2018).

	N	Mean	Median	Std. Dev.
Commercial kms	3,497	8,887,583	4,178,955	16,285,813
Passengers	3,497	14,017,988	5,254,345	30,154,320
Buses in operation	3,497	1,642	728	3,006
Average capacity	3,497	37.02	39.6	13.3
Unemployment	3,281	12.7%	12.2%	3.3%

Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia. DANE also produces the unemployment series.

Table 2
Productivity - Colombia (January 2005 - March 2018), Dependent variable: logarithm of kilometers per bus.

	(1)	(2)	(3)	(4)	(5)
T	−0.00057***	−0.00069***	−0.00072***	−0.00069***	−0.00117***
	(0.00006)	(0.00006)	(0.00006)	(0.00006)	(0.00009)
SITM		0.06022***	0.05419***	0.08015***	0.08665***
		(0.01031)	(0.01083)	(0.02326)	(0.02341)
CAP			0.07475**	0.07934**	0.10367***
			(0.03059)	(0.03142)	(0.03201)
T*SITM				−0.00025	−0.00020
				(0.00021)	(0.00021)
UNEMP					−0.01202***
					(0.00160)
N	3,497	3,497	3,497	3,497	3.281
R^2	0.767	0.769	0.770	0.770	0.772

Notes: Robust standard errors in parentheses. City level unemployment rate is only available from January 2007 to March 2018, so the number of observations is lower in the fifth column. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia. DANE also produces the unemployment series.

Table 3
Productivity - Colombia (January 2005 - March 2018), Dependent variable: logarithm of passengers per bus.

	(1)	(2)	(3)	(4)	(5)
T	−0.00030***	−0.00052***	−0.00066***	−0.00076***	−0.00078***
	(0.00006)	(0.00006)	(0.00006)	(0.00007)	(0.00007)
SITM		0.10840***	0.08150***	0.00177	0.01665
		(0.01071)	(0.00953)	(0.01598)	(0.01675)
CAP			0.33362***	0.31952***	0.32680***
			(0.02745)	(0.02701)	(0.02752)
T*SITM				0.00077***	0.00050***
				(0.00014)	(0.00014)
UNEMP					−0.00909***
					(0.00106)
N	3,497	3,497	3,497	3,497	3,281
R^2	0.815	0.820	0.835	0.836	0.847

Notes: Robust standard errors in parentheses. City level unemployment rate is only available from January 2007 to March 2018, so the number of observations is lower in the fifth column. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia. DANE also produces the unemployment series.

of productivity. If the coefficient of the temporal variable is added to that of interaction term, the result is close to zero (0.001% per month), which suggests that the introduction of these systems help to mitigate the secular fall in productivity. However, even with SITM in operation productivity in the sector is stagnant (close to zero growth).

Finally, if we control for the unemployment rate (column 5) the time trend is negative and the introduction of an SITM does have a positive dynamic effect but does not completely compensate for the secular fall in productivity. The coefficient on unemployment has the expected negative sign.

In summary, for Colombia, there is evidence of a negative productivity trend over time, regardless of how it is measured (kilometers per bus or passengers per bus). There is also evidence that the SITM, with its bus priority infrastructure, reduced but did not completely compensate for this fall in productivity in the cities that implemented such reforms. The implications of this last result will be discussed in the conclusions.

A hypothesis consistent with these results is that the service network might have increased during the period, extending the service to lower demand areas. However, this is unlikely, as in all 22 cities total kilometers of service decreased during the period studied.[19]

Therefore, we conclude that these results are consistent with a secular decrease in labor productivity, an important ingredient for Baumol's cost disease. However, the results obtained when using a productivity indicator based on the number of passengers must be interpreted with care, for they might be partially driven by demand factors. For instance, the drop of passengers per bus might be partly explained by a switch to private modes of transport, in response to higher disposable income. However, the question would then be why the demand for labor (and perhaps other inputs) has not adjusted to lower passenger demand.

4.1.2. The Medellin metro system

An exercise was also carried out with data from the Metro system that operates in the city of Medellin. For this mode we have 270 observations covering the period January 2007 to March 2018. We only compute the productivity measured as kilometers per fleet as we do not have information on passengers transported. During this period, the number of aggregate kilometers offered increased by 60% in absolute terms.

Fig. 1 shows kilometers per train in the metro system. There appears to be an anomaly in the data for the first eight months, so we present results using only the data from September 2007 to March 2018. These results are presented in Table 4 and indicate that there is a positive trend in productivity even when controlling for seasonality and city level unemployment (between 0.048% and 0.059% per month).

In other words, there seems to be productivity gains in the case of underground transport, a result that, as indicated above, is consistent with the received literature for developed countries.

4.1.3. Buenos Aires (Argentina)

Data is available for routes operating within two geographical areas in Buenos Aires: The Federal District (DF) and the Urban Subgroup I (SGI). The routes classified under the heading DF cover services exclusively within the Autonomous City of Buenos Aires (CABA), while those classified as SGI include routes having one of its terminal stations in the CABA, but that extend their operations up to 50 km outside the city, although always within the administrative region called Greater Buenos Aires. There is information on 30 routes within the DF area and 12 within the SGI area. These are not all the lines operating in these areas but a sample of operators for which it was possible to obtain information (in total there are approximately 200 routes in the city). The data covers the period from January 2007 to December 2017. We also obtained monthly data for the unemployment rate (also from January 2007 to December 2017) and for the motorization rate (vehicle stock divided by population) from January 2010 to December 2017, which we use as a proxy for congestion.

Table 5 presents descriptive statistics for the main variables and Fig. 2 shows the evolution of productivity aggregated across all routes, measured as kilometers per bus in service. We see a slight adjustment in this trend in 2015. This could be due (among other things) to changes in the measurement of this variable; GPS monitoring was introduced that year. However, despite this last effect, the trend is decreasing during the whole period.

Fig. 3 shows the evolution of the number of passengers transported per bus. Although this indicator exhibits year-to-year variations, it shows a stable behavior and a decreasing trend during the second half of the period.[20]

We undertake an econometric analysis of these partial labor productivity indices at the individual route level. We use route fixed effects to capture possible differences at the geographical level (DF versus SGI) as well as unobserved characteristics of each line that could affect their relative efficiency.

We also control for the possible impact that bus priority infrastructure may have had on productivity. During this period, several exclusive bus corridors came into operation (see Table 6 for the date that they became operational and the routes that potentially benefited from this infrastructure). In the regressions we include dummy variables that take the value one from the month after each corridor becomes operational and only for those routes that potentially benefit from this new infrastructure.

We also control in a separate regression for city level unemployment and the motorization rate. In all cases, calendar month time effects are also included.

The most general model estimated is:[21]

$$\ln(Prod_{it}) = \beta_0 + \beta_1 \cdot T_t + \beta_2 \cdot Corr\_Id_{it} + \beta_3 \cdot UNEMP_t + \beta_4 \cdot MOTOR_t + d_i + z_m + v_{it} \tag{2}$$

where *i* denotes the route, *t* the month in the sample and *m* the calendar month. T_t is the time trend, *Corr_Id* is the dummy variable for each corridor (the *Id* for each corridor are those presented in Table 6), $UNEMP_t$ is the city-wide unemployment rate in month *t*, $MOTOR_t$

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[19] Since we are using the number of buses in operation not the total fleet size, we can also discard that the results are driven by an increase in fleet size (due to fleet renovation for example).

[20] The evolution of productivity at the level of each route is consistent with the aggregate data presented here. Productivity remains relatively stable in the case of passengers and seems to decrease when output is represented by kilometers. These results are available upon request.

[21] The other models are nested in this general equation.

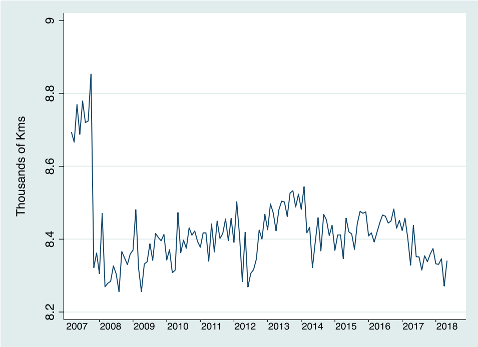

Fig. 1. Productivity: kilometers per train, Medellin, *Source:* National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia.

Table 4
Productivity of the Metro system in Medellin (September 2007 - March 2018), Dependent variable: logarithm of kilometers per train.

	(1)	(2)	(3)
T	0.00057***	0.00048***	0.00059***
	(0.0002)	(0.0001)	(0.0002)
UNEMP			0.00433
			(0.0031)
Constant	8.365***	8.344***	8.277***
	(0.0126)	(0.0204)	(0.0529)
N	127	127	127
R^2	0.070	0.287	0.294
Seasonality	No	Yes	Yes

Notes: Robust standard errors in parentheses. Seasonality variable are calendar month time effects. * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.
Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia. DANE also produces the unemployment series.

Table 5
Summary statistics, Buenos Aires, (January 2007 - December 2017).

	Obs	Mean	Median	Std. Dev.
Commercial kms	5,544	448,590	362,917	327,655
Passengers	5,544	1,229,532	1,116,061	594,330
Buses in operation	5,544	80.1	68	48.4
Total employees	5,544	232	192	141
Motorization rate	5,544	406.9	426.9	73,949
Unemployment	5,544	6.9%	6.4%	1.6%

Source: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area). The motorization rate was built using data from the Buenos Aires City Government and the National Bureau of Statistics and Censuses (INDEC).

is the motorization rate in month t, d_i is a route level fixed effects and z_m is a monthly seasonality effect.

Table 7 presents the results when the dependent variable is the number of kilometers traveled per bus. We see that the coefficient of the time trend is negative and statistically significant in the three specifications, which is consistent with Baumol's theory.[22]

Even more interesting is the fact that productivity falls more when we control for the different corridors. Seven of the nine relevant corridors have a positive and statistically significant impact on productivity for those lines benefiting from this infrastructure. In other words, as in the case of Colombia with BRT reforms, there is also evidence for the case of Buenos Aires that bus priority infrastructure helps to mitigate Baumol's disease.[23]

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[22] As in the case of Colombia, it is unlikely that this result is due to an increase in the network coverage over time. In 35 of the 42 routes, kilometers traveled decreased in the sample period. In the other 7, only 2 routes show a significant increase in kilometers traveled (between 10% and 20% in the ten years of data).

[23] In the case of the *May 25* corridor (Corr_Id_5), the coefficient is negative, which implies that productivity fell with the opening of that bus priority infrastructure. However, it is only significant at a 90% confidence level. Further research should analyze in more detail the impact of each corridor on productivity in the case of this city.

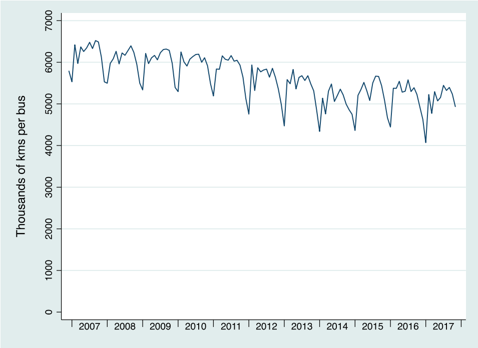

Fig. 2. Kilometers per bus, Buenos Aires, *Source*: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area), Ministry of Transport. This information was collected with the support of the Inter-American Development Bank's Transport Division.

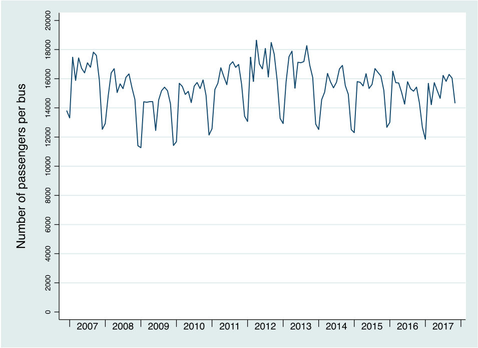

Fig. 3. Passengers per bus, Buenos Aires, *Source*: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area), Ministry of Transport. This information was collected with the support of the Inter-American Development Bank's Transport Division.

Table 6
Bus priority infrastructure for buses in Buenos Aires.

Name	Id	Beneficiary routes	In operation since
Juan B Justo	1	2003–1028	August 2011
9 de julio	2	1010–1013-1001–1003	July 2013
Sur	3	None (see note below)	August 2013
AU 25 de mayo	4	1009	October 2015
Norte etapa 1	5	1006–1010-1011–1014-1026	June 2015
San Martin	6	1015–1021-1024–1005-2008	April 2016
Norte etapa 2	7	1011–2006-1026–1010-1013–1012	November 2016
La Matanza	8	1029	May 2017
del Bajo	9	2011–1025-1007–1026-1018–2002	June 2017
Ruta 8	10	1015	October 2017

Notes: None of the routes in our sample used the *Corredor Sur*.
Source: Buenos Aires City Government (information obtained with the support of the Inter-American Development Bank's Transport Division).

The fall in productivity is lower (in absolute terms) when we control also for the unemployment and the motorization rate, with a fall of 0.06% per month or almost 0.75% annually. Especially interesting is the negative effect of the motorization rate over this measure of labor productivity.

In Table 8 we present the results using labor productivity as passengers per bus. We see that the coefficient of the time trend is negative in all three specifications and statistically significant in the last two. Regarding the corridors, three of them have a positive and statistically significant impact on the average number of passengers in the more general specification.

The fall in productivity is higher (in absolute terms) when we control also for the unemployment rate and the motorization rate, with a fall of nearly 0.2% per month or almost 2.5% annually.

Table 7
Productivity - Argentina (January 2007 - March 2017), Dependent variable: logarithm of kilometers per bus.

	(1)	(2)	(3)
T	−0.00152***	−0.00163***	−0.000613**
	(0.00004)	(0.00005)	(0.000307)
Corr_Id_1		0.05661***	0.0717***
		(0.01672)	(0.0134)
Corr_Id_2		0.05433***	0.0175
		(0.01066)	(0.0116)
Corr_Id_4		0.06803***	0.0510***
		(0.01092)	(0.0100)
Corr_Id_5		−0.00927	0.0122
		(0.01199)	(0.0155)
Corr_Id_6		0.03821***	0.0307***
		(0.01128)	(0.0111)
Corr_Id_7		−0.04018***	−0.0244
		(0.01557)	(0.0166)
Corr_Id_8		0.06999***	0.0715***
		(0.01313)	(0.0158)
Corr_Id_9		0.04309***	0.0241***
		(0.00730)	(0.00761)
Corr_Id_10		0.12665***	0.0933***
		(0.02399)	(0.0261)
UNEMP			−0.00822*
			(0.00426)
MOTOR			−0.401***
			(0.0815)
N	5,544	5,544	4,032
R^2	0.691	0.695	0.684

Notes: Robust standard errors in parentheses. The variables Corr_Id_1 to Corr_Id_10 indicate the corridors as per described in Table 6. The reader is reminded that corridor 3, as Table 6 shows, is omitted because none of the routes in our sample benefit from this infrastructure. The estimation that controls for the motorization rate considers data from January 2010 onwards, so the number of observations is lower in the third column. All regressions include route fixed effects and calendar month time effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: The data for kilometers, buses and corridors were obtained from the Buenos Aires City Government (information obtained with the support of the Inter-American Development Bank's Transport Division). The motorization rate is measured as the ratio of the vehicle stock to the population. The data for these last two variables were obtained from the Buenos Aires City Government and the National Bureau of Statistics and Censuses (INDEC), respectively.

As with the measure of productivity based on commercial kilometers, unemployment has a negative effect on productivity. The coefficient of the motorization rate is now positive and statistically significant. This result could be indicating that as congestion rates rise individuals may switch to public transport, particularly if infrastructure investments in corridors make this mode less prone to congestion. All effects considered, labor productivity still appears to decline, and this result is statistically significant.

In sum, there is suggestive evidence for the presence of Baumol's disease also in the case of Buenos Aires.

4.1.4. Panama City, Panama

In the case of Panama City, we rely on data from the company Transporte Masivo de Panamá S.A. (MiBus), a subsidiary of the state-owned Metro de Panamá. MiBus is in charge of the operation of the surface passenger transport services in the Metropolitan Area of Panama City. The information available covers the period January 2014 - December 2017. As in the previous cases, two partial labor productivity measures are used: kilometers per bus and passengers per bus.

Figs. 4 and 5 show the results for each indicator. When the number of passengers transported per bus is considered, there is an average monthly fall of 0.659% in productivity. When the number of kilometers per bus is used, we see an initial fall in productivity with a recovery after 2015.[24]

The results for the case of public surface transportation services in Panama City are qualitatively similar to those of Colombia and Buenos Aires, suggesting the presence of Baumol's disease. Unfortunately, there is no information for the Panama metro system to make a contrast analogous to the case of Medellin.

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[24] In this case, there is only one productive unit (MiBus), so an econometric analysis, as in the case of Colombia and Buenos Aires, is not feasible. Also, note that during this period the aggregate number of kilometers supplied increased by 5,7%.

Table 8
Productivity - Argentina (January 2007–March 2017). Dependent variable: logarithm of passengers per bus.

	(1)	(2)	(3)
T	−0.00003 (0.00005)	−0.00024*** (0.00006)	−0.00198*** (0.000373)
Corr_Id_1		0.26014*** (0.03355)	0.230*** (0.0121)
Corr_Id_2		0.11064*** (0.00960)	0.119*** (0.0110)
Corr_Id_4		−0.02357** (0.01195)	0.0180 (0.0145)
Corr_Id_5		−0.04921*** (0.01626)	−0.0205 (0.0203)
Corr_Id_6		−0.01206 (0.01041)	0.0105 (0.0101)
Corr_Id_7		0.02169 (0.01613)	0.0468*** (0.0150)
Corr_Id_8		−0.02012* (0.01102)	0.0151 (0.0141)
Corr_Id_9		−0.00620 (0.01918)	0.0299 (0.0200)
Corr_Id_10		0.13520*** (0.01936)	0.0951*** (0.0196)
Unemp.			−0.0228*** (0.00504)
Motorization			0.600*** (0.0890)
N	5,544	5,544	4,032
R^2	0.681	0.697	0.732

Notes: Robust standard errors in parentheses. The variables Corr_Id_1 to Corr_Id_10 indicate the corridors as per described in Table 6. The reader is reminded that corridor 3, as Table 6 shows, is omitted because none of the routes in our sample benefit from that infrastructure. The estimation that controls for the motorization rate considers data from January 2010 onwards, so the number of observations is lower in the third column. All regressions include route fixed effects and calendar month time effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: The data for passengers, buses and corridors were obtained from the Buenos Aires City Government (information obtained with the support of the Inter-American Development Bank's Transport Division). The motorization rate is measured as the ratio of vehicle stock to the population. The data for these last two variables were obtained from the Buenos Aires City Government and the National Bureau of Statistics and Censuses (INDEC), respectively.

In addition, it must be recognized that a four-year period may be too short to analyze a long-term phenomenon such as Baumol's cost disease. However, it is suggestive and consistent with the other case studies and evidence presented in this paper.

4.1.5. Santiago, Chile

The analysis for Santiago is based on information for seven surface bus operators and for the metro system. The information for buses is very limited (only three yearly observations per operator, for the period 2013–2015). In addition, there is aggregate information (for the complete bus system) for the period 2012–2017.

Fig. 6 shows the evolution of the average kilometers per bus.[25] We see a negative trend for all operators, and in the case of one of them the fall in labor productivity is particularly marked.

The partial labor productivity measured in terms of passengers transported also decreases more in the case of the bus system than the Metro system, as indicated in Table 9 where the annual information for both indicators is presented, both for the Metro and for the bus system as a whole.[26]

The fall in productivity could partly be explained by rising congestion in the city, an issue that will be highlighted in the discussion of policy options in the conclusions. Fig. 7 shows the quarterly evolution of average bus speeds between 2014 and 2016, considering off-peak and the morning and afternoon peak periods. These trends are all decreasing, which likely reflect increasing congestion levels

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[25] Aggregate kilometers supplied in Santiago remained constant during the sample period, so we can again discard that changes in network coverage may explain the evolution of kilometers per bus.

[26] In this table, the passengers per bus index may be influenced by changes in rate of non-payment (fare evasion), which fluctuated between 20% and 30% and has grown over time. This does not affect the number of Metro passengers, since non-payment in this mode is almost zero.

Fig. 4. Productivity: passengers per bus, Panama City, *Source*: Transporte Masivo de Panamá S.A. (MiBus).

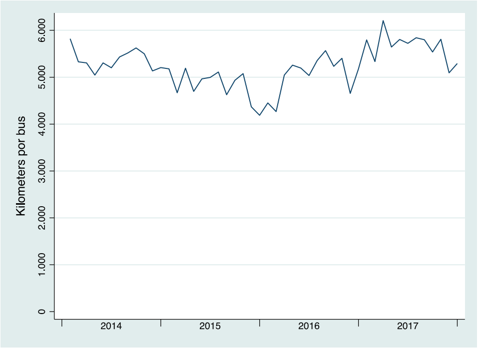

Fig. 5. Productivity: kilometers per bus, Panama City, *Source*: Transporte Masivo de Panamá S.A. (MiBus).

in the city.

In summary, as in the case of Colombia, Buenos Aires and Panama City, there is also some evidence that Baumol's disease might be affecting the public transport system of Santiago, particularly surface transport. In addition, in this case there is information, although limited, that suggests that congestion could be exacerbating the consequences of the Baumol effect for bus services.[27] As with the case of Panama City, however, it must be borne in mind that the data for Santiago covers a relatively short period and thus the results must be interpreted with care.

4.2. Labor costs and total costs

The previous results, based on labor productivity measures, suggest the Baumol effect might be present in the surface transport systems in our sample. In this section we present the evolution of operating costs where this information is available.

4.2.1. Panama City, Panama

For the case of Mibus in Panama City, we also have operational cost information. This information is presented in Table 10 separated into labor costs and other costs. Labor costs include drivers, as well as maintenance, administrative and operational personnel, while all other operational expenditures are grouped together as non-labor costs. Due to the need to preserve data confidentiality we present an index number for the evolution of the nominal costs in each category, with 2014 being the base year and equal to 100.

We can see that nominal labor costs increased by an average yearly rate of 10.6% while inflation (CPI) rose by an average annual rate of only 1.1%. Non-labor nominal costs grew by 1.4% on average during this period, more in line with the underlying inflation rate. Consequently, the share of labor costs in total operating expenditure rose from 43% to 50%. Overall operational expenditure rose by a

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[27] During this period, the bus fleet in Santiago remained practically constant so the results described here are not due to an increase in fleet size. Rather, the operational plans had to be adapted (offering fewer and less frequent services) to accommodate the lower average speed of the fleet.

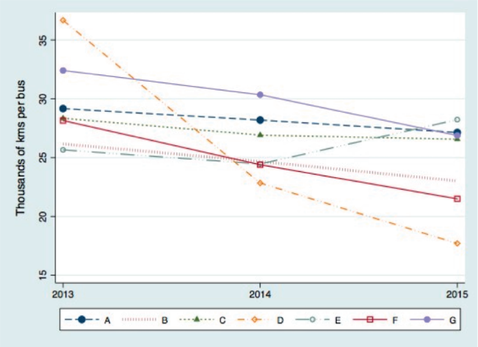

Fig. 6. Productivity: kilometers per bus, Santiago, *Source*: DTPM (Ministry of Transport, Chile). Letters A-G refer to the different operators (their identities are confidential).

Table 9
Buses versus Metro productivity, Santiago

	Kilometers/Fleet		Passengers/Fleet	
Period	Metro	Buses	Metro	Buses
2012	694,736	74,542	3,414,783	164,421
2013	768,064	71,422	3,589,625	155,597
2014	752,688	70,617	3,595,337	149,356
2015	740,698	70,229	3,558,120	140,690
2016	725,053	69,017	3,612,571	132,557
2017	672,945	67,770	3,396,687	129,932
2012–17	−3.14%	−9.08%	−0.53%	−20.98%
Yearly average	−0.63%	−1.82%	−0.11%	−4.20%

Source: Metro SA.

Fig. 7. Average bus speeds, Santiago, *Source*: DTPM (Ministry of Transport, Chile).

yearly average of 5.6% during this period.

Although using four years of data to infer long-term trends is questionable, it does suggest that the lower partial labor productivity trend shown above was not compensated by either wage reductions or input substitution. It also makes clear that rising real operational costs are driven by a rise in labor costs that have not been compensated by rising productivity. Furthermore, the rise in real costs cannot be explained by increased output as the number of kilometers operated grew by only 1.9% on average each year and passengers transported decreased over the period.

4.2.2. *Santiago, Chile*

Fig. 8 presents cost trends for six operators (one operator did not report cost data). Labor costs per kilometer in the metro system grew less than those of four of the six bus operators. Fig. 9 complements this evidence by comparing the labor cost per kilometer in the

Table 10
Evolution of operational costs, Panama City 2014–2017.

Period	Labor costs	Non-labor costs	Labor costs	Kms	Passengers (2014 = 100)	CPI
	(2014 = 100)	(2014 = 100)	(% total costs)	(2014 = 100)	(2014 = 100)	(% change)
2014	100.0	100.0	0.43	100.0	100.0	2.6%
2015	99.9	80.7	0.48	90.0	85.6	0.1%
2016	112.8	86.0	0.50	94.1	79.5	0.7%
2017	135.3	104.4	0.50	105.7	85.1	0.9%
Yearly average	10.6%	1.4%		1.9%	−5.2%	1.1%

Source: Mibus. Labor costs include drivers, as well as maintenance, administrative and operational personnel. The cost information is confidential so they are presented as index numbers.

case of buses as a group and the metro system with the evolution of the general consumer price index (CPI).[28] Once again, one can note that metro services are less prone to labor cost increases compared to bus services.

The cost data then shows that during this period, labor costs grew faster than overall inflation. The decrease in labor productivity noted above was not compensated by lower wages or capital-labor substitution.

4.3. *Total factor productivity and technical change*

As a final methodological approach, in this section we estimate changes in Total Factor Productivity (TFP) and its components: technical change and technical efficiency.[29] Available data allowed us to use this approach in the case of Colombia and Buenos Aires.

Estimating changes in TFP is important to determine to what extent the consequences of Baumol's disease (a phenomenon related to labor productivity) can be at least partially offset by changes in the overall productive efficiency of transport services considering all inputs. One of the components of TFP, namely technical change, is of particular interest to our analysis because it is normally assumed that sectors affected by Baumol's disease cannot take advantage of technological progress.

In what follows we estimate TFP change and technical change using the Malmquist Index, which is based on the (relative) efficiency measures produced by Data Envelopment Analysis (DEA). For more details regarding DEA and the Malmquist Index the reader is referred to Annex 2.[30]

Before presenting the results, a brief discussion on the degrees of freedom required for DEA to have discriminating power is warranted. A rule of thumb for the minimum number of units (DMU) for DEA analysis is the maximum K between $K > I \cdot O$ and $K > 3 \cdot (I + O)$, with I the number of inputs and O the number outputs (see Bogetoft, 2012; page 78). Bowlin (1998) coincides with the second criterion ($K > 3 \cdot (I + O)$). Other authors propose a less demanding rule. Golany and Roll (1989), for example, indicate the number of units should be at least twice the sum of the number of inputs and outputs; and the criterion suggested by Dyson et al. (2001) is that the number of DMUs should be at least two times the product of the number of input and output variables.

In our application we opt for the rule proposed by Bogetoft (2012) which is the more demanding of the four referred to in the previous paragraph. According to this rule, given that in both Colombia and Buenos Aires we use two outputs and two inputs in each case, at least 12 DMU are required. Therefore, 22 cities (Colombia) and 42 routes/services (Buenos Aires) are sufficient for the analysis to have discriminating power.

4.3.1. *Colombia*

We start by estimating the relative efficiency of each productive unit (hereafter decision making unit or simply DMU) using Data Envelopment Analysis (DEA). In the case of Colombia, each DMU is represented by a city, that is to say each city is conceptualized as a production unit that offers transportation services. In contrast, as explained below, in the case of Buenos Aires the DMUs are routes instead of cities.

We use an input-oriented relative efficiency measure; the ability to produce a given level of output with the minimum level of inputs.[31] We also assume a constant return to scale technology.[32] Because DEA is sensitive to outliers and measurement errors, we estimate the technical efficiency of each city using the yearly average of the variables.[33]

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[28] In Figs. 8 and 9 we use labor costs per kilometer traveled. To test the presence of Baumol's disease it is certainly better to have total cost data (not only labor cost) but this information was not available.

[29] When interpreting the results presented below (Tables 11 and 12) the reader must keep in mind that TFP change is defined as the product, not the sum of technical change and technical efficiency change (see Annex 2).

[30] We estimate the Malmquist Index in Stata 16 using the *malmq* command, developed by Lee (2011).

[31] Technical efficiency can also be formulated in an output-oriented version, indicating the maximum level of output that can be achieved with a given set of inputs. In this article we estimate an input-oriented version, as it is expected that transport operators have more control over inputs than over outputs (for more details, see Coelli et al., 2003, 2005).

[32] In the present context the constant returns to scale assumption is not crucial since we are calculating a Malmquist index which correctly measures changes in productivity even if the underlying technology exhibits variable returns to scale. This distinction would only matter if we were to decompose the TFP change among its different components. For more details see Coelli et al. (2005, pp. 72) and Odeck (2008).

[33] The results change only marginally if monthly data is used to estimate technical efficiency. However, results are harder to present due to space limitations and seasonal effects that generate volatility in the estimations.

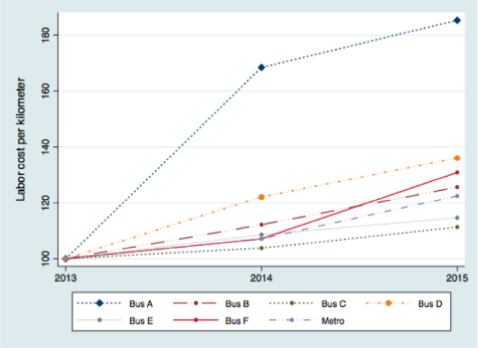

Fig. 8. Labor cost per kilometer, Santiago (Index, year 2013 = 100), *Source*: DTPM (Ministry of Transport, Chile). Letters A-F refer to the different operators (their identities cannot be revealed).

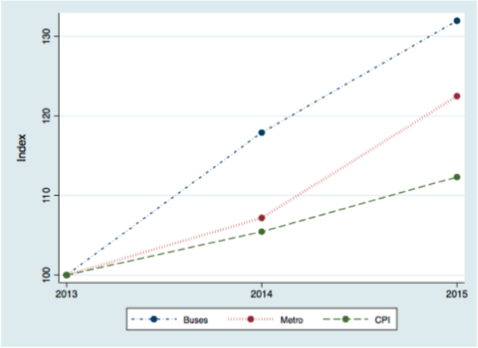

Fig. 9. Labor cost per kilometer (buses and metro) versus CPI Santiago (Index, year 2013 = 100), *Source*: DTPM (Ministry of Transport, Chile).

We then proceed to calculate the Malmquist index. This index measures the change in Total Factor Productivity between two (in our case yearly) periods for each city. In principle, the change in productivity could be measured with reference to the technology of the first period or that of the second. The Malmquist index avoids this problem by estimating the changes with reference to both technologies and calculating the geometric mean between these changes (see Annex 2).

Table 11 presents the results for Colombia. The analysis considers two inputs and two outputs. We proxy the labor input by the number of buses since a direct relation between the number of buses and the number of drivers is expected to exist.[34] As indicator of capital we use the total fleet capacity. That is, the product of the number of buses of each type and their corresponding capacity (seats plus standing room).[35] The outputs are the number of passengers and the total kilometers travelled.

The results indicate that TFP decreased 0.19% on average per year. It is also observed that instead of technical change there has been technical regress (-0.88% on average per year). Therefore, the fall in labor productivity has not been compensated by technical progress. There appear to be gains in technical efficiency, but insufficient to compensate for the technical regress, hence preveting TFP change to be positive.[36]

4.3.2. Buenos Aires

In the case of Buenos Aires, we estimate TFP change and technical change using as outputs kilometers and passengers. As to the inputs, we have information on the number of workers of each route, which allows to consider both the fleet size (number of buses in operation) and the number of workers. As mentioned above for the case of Colombia, a direct relation is expected to exist between the number of drivers and the number of buses in operation. However, turn-around times, driver scheduling, and other labor management

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[34] We recognize that this is an imperfect proxy for the labor input and future research should attempt to confirm the results presented below for Colombia if more data becomes available.

[35] Using total bus capacity is important for the case of Colombia as vehicle capacity varies widely from small 18 passenger microbuses to 160 passenger articulated buses. Qualitative results are unchanged if average capacity of the fleet is used instead of total capacity.

[36] The reader is reminded that change of TFP equals the product of technical change and technical efficiency change (see Annex 2).

Table 11
Malmquist Index for buses, Colombia 2005–2017.

Period	$TFP_t/TFP_{t\text{-}1}$	$TCH_t/TCH_{t\text{-}1}$	$ECH_t/ECH_{t\text{-}1}$
2005–06	0.9767	0.9587	1.0192
2006–07	1.0390	1.0424	0.9977
2007–08	0.9932	0.9934	0.9996
2008–09	0.9718	0.9530	1.0211
2009–10	1.0032	0.9918	1.0116
2010–11	1.0370	1.1135	0.9356
2011–12	0.9889	0.9816	1.0074
2012–13	1.0211	0.9292	1.1010
2013–14	0.9956	0.9775	1.0191
2014–15	0.9799	0.9750	1.0057
2015–16	0.9784	0.9916	0.9856
2016–17	0.9930	0.9868	1.0063
Average	0.9981	0.9912	1.0092

Notes: The inputs are the number of buses and the fleet's total capacity. The outputs are the number of kilometers and the number of passengers. $TFP_t/TFP_{t\text{-}1}$, $TCH_t/TCH_{t\text{-}1}$ and $ECH_t/ECH_{t\text{-}1}$ indicate change in total factor productivity, technical change and technical efficiency change in two consecutive years, respectively.

practices can influence the number of workers per bus. Therefore, having information on the number of workers and the fleet in operation is preferable to estimate efficiency levels and therefore total productivity changes in this sector. Unfortunately, due to data limitations this alternative was not available in the case of Colombia.

Table 12 presents the results for Argentina. We see that TFP each year is on average 98.98% of the TFP in the previous year (a yearly average decline of 1.02%). A negative technical change of 1.07% on average per year appears to have taken place. On the other hand, technical efficiency appears to have increased, but not enough to sustain gains in TFP. As in Colombia, the decline of labor productivity has not been offset by a rise in TFP, and technical regress has contributed to this result.

Summing up these last findings, TFP appears to have decreased between 0.29% and 1.02% on average per year, depending on the country considered, and technical change appears to have been negative. Comparable evidence for the transit sector in developed countries shows changes in TFP close to 0.5% in various sub-periods during the last two or three decades (see Evangelinos et al., 2012).

5. Conclusions and policy implications

In this paper, evidence has been presented for a group of Latin American cities that suggests that in urban surface public transport (buses) labor productivity is either stagnant or decreasing over time. This result is consistent with evidence found by other scholars for developed countries.

Although many factors can explain this result, our analysis, the previous academic literature, and a comparison with the underground (metro) transport services, suggest that one of the main causes could be Baumol's cost disease. In effect, in this sector the fundamental assumptions of the Baumol theory seem to hold: a labor-intensive production process, limited possibilities of factor substitution and lack of technological change. In addition, unlike other sectors prone to Baumol's disease, there are two aggravating factors in the case of transit: rising vehicle congestion (akin to negative technological change) and the absence of a demand antidote to this disease (the available evidence indicates a low and even negative income elasticity of transit demand). We have found that another potential antidote to this disease, namely gains in total factor productivity due, for example, to technical change, has been absent too.

As a result, we can expect public surface transport to become relatively more expensive for society; that is, the average cost of public transport will probably increase in real terms as an economy grows. The evidence for developed countries indicates that this increasing trend is significant and we find that this is probably also the case for the Latin American cities analyzed in the present research.

Societies will then have to resolve the following dilemma: how should a service that gets progressively more expensive in real terms be funded? One answer is that service provision will naturally decline through time as it becomes more expensive. As shown by Spann (1977), this will depend on the relative value of the price and income elasticity of demand for transit. The elasticities reviewed in this paper would imply that in many cases, absent public intervention, transit demand (and possibly expenditure) will decrease through time.[37]

However, given the many externalities in the transport sector, letting transit wither away through lower private demand may not be socially optimal. If there are welfare considerations for promoting and expanding transit services, then growing amounts of public funding will be required to keep fares sufficiently low to promote transit use. Care must be taken however that subsidies do not generate disincentives for productive efficiency and cost containment (X inefficiency). Effective regulatory mechanisms, or competitive bidding, must complement any subsidy policy to avoid excessive costs due to productive inefficiencies.

Interestingly, from an aggregate point of view the higher resources required to maintain the supply of a service that suffers from Baumol's cost disease can be funded from the surplus generated in the dynamic sectors. Economic growth in the dynamic industries

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[37] An interesting avenue for future research is to see whether Spann's (1977) approach for testing for Baumol's cost disease applies to transit expenditure.

Table 12
Malmquist Index for buses, Buenos Aires 2007–2017.

Period	TFP_t/TFP_{t-1}	TCH_t/TCH_{t-1}	ECH_t/ECH_{t-1}
2007–08	0.9558	0.9930	0.9626
2008–09	0.9597	0.9170	1.0465
2009–10	1.0263	1.0281	0.9984
2010–11	1.0406	1.0396	1.0018
2011–12	1.0099	0.9720	1.0393
2012–13	0.9838	0.9868	0.9974
2013–14	0.9284	0.9614	0.9658
2014–15	1.0424	1.1779	0.8887
2015–16	0.9657	0.8463	1.1464
2016–17	0.9855	0.9708	1.0154
Average	0.9898	0.9893	1.0062

Note: The inputs are the number of buses and the total number of workers. The outputs are the number of kilometers and the number of passengers. TFP_t/TFP_{t-1}, TCH_t/TCH_{t-1} and ECH_t/ECH_{t-1} indicate change in total factor productivity, technical change and technical efficiency change in two consecutive years, respectively.

more than compensate for the rising costs in the stagnant sectors. Society could allocate a rising share of GDP to stagnant sectors and still have more goods and services available from the other sectors. Dynamic industries are both the root cause of Baumol's cost disease as well as its solution (at least as far as funding is concerned).[38]

This is why if the share of public transport services to total production remains constant over time, public transport services could still be funded without any considerable problem even if subject to Baumol's cost disease.[39] In the end, it would be a political budgetary decision. Understanding the nature of the underlying cause of rising transit deficits, namely Baumol's cost disease, may be important in deliberations regarding this issue.

There are also other policy options to tackle the problem of stagnant (or falling) productivity in the transit sector. For example, measures to reduce traffic congestion. Evidence presented in this paper indicates that bus priority infrastructure, as in Buenos Aires, or BRT reforms as in Colombia, may help to increase productivity in this sector. Also, road pricing schemes could help boost the productivity of public transport, but to date they have not been introduced in the Latin American region.

Even if congestion is reduced, however, the productivity of public transport will most probably still grow at a lower rate than in other sectors of the economy. Therefore, transit costs are still expected to increase in real terms over time although perhaps at a lower rate if policies to tackle congestion are introduced.

We have seen that technological change does not seem to be present in the transit sector, at least as far as buses are concerned. The two metro cases (Panama City and Santiago) do seem to offer higher productivity growth, consistent with results from research in developed countries. In metro systems there are more technological possibilities to substitute labor for capital. In fact, new metro lines in the region (Sao Paulo line 4, Santiago lines 3 and 6 and others) are driverless systems. Switching and communications technology used in metro systems also provide opportunities for cost reducing technological change that counteract Baumol's disease.

Can something similar occur with bus technology? The development of autonomous vehicle technology may provide a solution to Baumol's cost disease for bus services in the future. This technology offers to transform this sector from a labor intensive into a capital intensive industry allowing for further technological improvements that would increase total factor productivity.[40] Unfortunately, this technological revolution seems to be far off into the future. Litman (2018) predicts that autonomous vehicles will become common and affordable probably not earlier than 2040 or 2050. This prediction is only for light vehicles with autonomous transit vehicles probably taking even longer to become a realistic technological option.

Although predicting the pace of technological diffusion is difficult and subject to uncertainty, with available information self-driving vehicles for public transport are still a distant development. Furthermore, it is still too early to assess the net effect that this technological innovation could have on the supply costs of transport systems and whether it could offer an effective antidote to Baumol's disease. For the foreseeable future then (i.e. next few decades) bus transit services will most probably remain a stagnant sector requiring increasing amounts of public funding to maintain supply and demand levels.

Regarding the possible limitations of this article, it is important to keep in mind that although the results seem to go in line with the presence of the Baumol's cost disease, the results must be interpreted with caution. This is especially important when considering the productivity indicator based on the number of passengers, for in this case demand factors might also be part of the explanation. It is also true that Baumol's cost disease is a long-term effect, and our data covers periods which, depending on the city analyzed, range from four to fourteen-years. Future research should attempt to confirm these results with data covering a longer time frame or more

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[38] Baumol (2012) attributes this intuition to the British economist Joan Robinson.

[39] Assuming an *iso*-elastic demand function, the evolution of the share of public transport services to total production will depend on the income and price elasticities of demand (Spann, 1977).

[40] For autonomous vehicles to counter Baumol's cost disease technological change using this technology must be continuous. For example, the communications, electronic and software components of these vehicles and the accompanying infrastructure must be subject to continuous improvements, something that seems to the case for rail services as noted above. A once and for all discrete jump in productivity does not solve Baumol's cost disease, it only postpones its effect until rising costs start kicking in again. We thank an anonymous referee for pointing this out to us.

data on labor inputs and other variables (e.g. motorization rates) for the case of Colombia. Other possible avenues for future research could be to widen the geographical coverage by including countries that differ in terms of the organization and regulation of urban transport.

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Appendix A. A basic model of Baumol's cost disease

The theory of Baumol's disease can be formally explained with a simple model.[41] Suppose there is only one input (labor) and that in sector 1 (stagnant) one unit of labor produces units of the good according to the following equation (Y_{1t} and L_{1t} represent the production level and the labor employed, respectively, and the subscript t refers to the time period):

$$Y_{1t} = a \cdot L_{1t}$$

In the dynamic sector one unit of labor produces $b \cdot e^{\tau t}$ units of good 2, where τ represents technical change:

$$Y_{2t} = b \cdot e^{\tau t} \cdot L_{2t}$$

An important assumption is that labor markets are integrated and thus wages in both sectors are the same and increase at the same rate τ:

$$w_t = w_0 \cdot e^{\tau \cdot t}$$

Production costs of good 1 (C_{1t}) and good 2 (C_{2t}) are given by:

$$C_{1t} = \frac{w_t \cdot Y_{1t}}{a} = \frac{w_0 \cdot e^{\tau \cdot t} \cdot Y_{1t}}{a}$$

$$C_{2t} = \frac{w_t \cdot Y_{2t}}{b \cdot e^{\tau \cdot t}} = \frac{w_0 \cdot Y_{2t}}{b}$$

The relative cost of good 1 (the ratio of average costs of goods 1 and 2) is given by:[42]

$$\frac{C_{1t}/Y_{1t}}{C_{2t}/Y_{2t}} = \frac{b \cdot e^{\tau t}}{a}$$

We then see that the relative cost of good 1 increases at a rate τ each period.

From this result we can make two related inferences. First, if productivity is stagnant in one sector of the economy relative to other sectors, then the relative costs of the products or services produced in the stagnant sector should increase through time. The flipside of this argument is that if relative costs of goods and services of a particular sector in the economy are observed to be growing relative to other goods and services in the economy, then this could be an indication of stagnant productivity growth in that sector.

Appendix B. Data Envelopment Analysis and the Malmquist Index

Data Envelopment Analysis (DEA) is as a mathematical, linear programming method that allows to estimate a production frontier and evaluate the efficiency of different entities in relation to that frontier (best practice). These entities are normally referred to as decision-making units (DMUs), and can be plants, firms, other (for-profit or non-for profit) organizations, or any identifiable productive unit. In this paper, the DMUs are defined as cities in the case of Colombia, and bus operators in the case of Buenos Aires, Argentina. Each DMU uses inputs that are transformed into outputs according to a given technology. The method assumes that all DMUs have the same production technology. This technology is of course unknown but, in what represents the main advantage of DEA, is built from the observed data, in a way that satisfies certain desirable economic properties.[43]

The Malmquist Index is used to measure the changes in productivity between two periods of time (Caves et al., 1982; Fare et al., 1994; Bogetoft, 2012). For any DMU we can define E_1^1 and E_2^1, as measures of efficiency in periods 1 and 2, considering the technology

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[41] This model is based on Baumol (1967), Evangelinos et al. (2012) and Peacock (1994).

[42] Given the assumed technology, average and marginal costs coincide.

[43] For more details see Bogetoft (2012) and Ray (2004).

of period 1; and E_1^2 and E_2^2, which measure efficiency in periods 1 and 2, considering the technology of period 2.

In order to estimate the productivity change from period 1 to period 2, considering that technology doesn't change, we can use as the reference technology that of period 1 or 2. If we assume the technology of period 1 is fixed, then the productivity change corresponds to $M_{1,2}^1 = E_2^1/E_1^1$ If the efficiency of the firm has improved (decreased) from period 1 to 2, then $E_2^1 > E_1^1$ ($E_2^1 < E_1^1$) and therefore $M_{1,2}^1$ is larger (lower) than 1. If the technology of period 2 is fixed, then the productivity change corresponds to $M_{1,2}^2 = E_2^2/E_1^2$. If the efficiency of the firm has improved (decreased) from period 1 to 2, then $E_2^2 > E_1^2$ ($E_2^2 < E_1^2$) and therefore $M_{1,2}^2$ is larger (lower) than 1. Given that there is no evident advantage of using the technology of either period, the Malmquist Index is defined as the geometric mean of both M_1 and M_2

$$M_{1,2} = \sqrt{M_{1,2}^1 M_{1,2}^2} = \sqrt{\frac{E_2^1}{E_1^1}\frac{E_2^2}{E_1^2}}$$

If $M_{1,2}$ is larger (lower) than 1, the DMU's productivity has improved (deteriorated). However, this change might be partly due to a change in the available technology (technical change), and partly to changes in the efficiency of the particular DMU (technological catch-up to the best practice frontier). The Malmquist index can be decomposed to separate both effects.

Technical change between periods 1 and 2 ($TC_{1,2}$) is defined as the geometric mean of two ratios. In the first ratio, we fix the production level of the second period and allow for the technology to change. If there is technological advance, then the efficiency in the second period is lower than that of the first period (producing the same level of output with a better technology means a lower efficiency). The second ratio has the same rationale but considers the production to be fixed at the level of the first period. If the geometric mean of these ratios is greater (lower) than 1 there is technological progress (regress).

$$TC_{1,2} = \sqrt{\frac{E_2^1}{E_2^2}\frac{E_1^1}{E_1^2}}$$

The efficiency changes between periods 1 and 2 is defined as $EC_{1,2} = E_2^2/E_1^1$. If $EC_{1,2}$ is larger (lower) than 1 the DMU gets closer to (farther from) the maximum output attainable given the available technology in each period.

The Malmquist Index, M, can be expressed as the product of the TC and EC

$$M_{1,2} = TC_{1,2}{*}EC_{1,2} = \sqrt{\frac{E_2^1}{E_2^2}\frac{E_1^1}{E_1^2}{*}\frac{E_2^2}{E_1^1}}$$

References

Asquith, B.J., 2011. Income Elasticity of Demand for Large, Modern Rapid Transit Rail Networks. Undergr. Econ. Rev. 7 (1), Article 20.

Basso, L.J., Silva, H.E., 2014. Efficiency and Substitutability of Transit Subsidies and Other Urban Transport Policies. Am. Econ. J. Econ. Policy 6 (4), 1–33.

Baumol, W.J., Bowen, W., 1966. Performing Arts, the Economic Dilemma: a Study of Problems Common to Theatre, Opera, Music and Dance. Twentieth Century Fund, New York.

Baumol, W.J., 1967. Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis. Am. Econ. Rev. 57 (3), 415–426.

Baumol, W.J., 2012. The cost disease: Why computers get cheaper and health care doesn't. Yale University Press.

Bogetoft, P., 2012. Performance Benchmarking: Measuring and managing performance. Springer, New York.

Bowlin, W.F., 1998. Measuring Performance: An Introduction to Data Envelopment Analysis (DEA). J. Cost Anal. 7, 3–27.

Bradford, D., Malt, R.A., Oates, W., 1969. The Rising Cost of Local Public Services: Some Evidence and Reflections. Natl. Tax J. 22 (June).

Caves, D., Christensen, L., Diewert, W., 1982. The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. Econometrica 50 (6), 1393–1414.

Coelli, T., Estache, A., Perelman, S., Trujillo, L., 2003. *A Primer on Efficiency Measurement for Utilities and Transport Regulators.* WBI Development Studies. World Bank, Washington, DC.

Coelli, T., Prasada Rao, D.S., O'Donnell, C.J., Battese, G.E., 2005. An Introduction to Efficiency and Productivity Analysis, second ed. Springer.

Cowen, T., 1996. Why I Do Not Believe in the Cost-Disease: Comment on Baumol. J. Cult. Econ. 20 (3), 207–214.

De Borger, B., Kerstens, K., Costa, A., 2002. Public transit performance: what does one learns from frontier studies? Transp. Rev. 22 (1), 1–38.

Dietrich, A., Krüger, J., 2010. Numerical Explorations of the Ngai-Pissarides Model of Growth and Structural Change. Darmstadt Discussion Papers in Economics, No. 199, Technische Universität Darmstadt.

Dyson, R.G., Allen, R., Camanho, A.S., Podinovski, V.V., Sarrico, C.S., Shale, E.A., 2001. Pitfalls and Protocols in DEA. Eur. J. Oper. Res. 132, 245–259.

Evangelinos, C., Wieland, B., Kuhnhausen, T., 2012. Baumol's Cost Disease in the Local Transit Sector: a Comparative Analysis of Germany and the USA. Int. J. Transp. Econ. 31 (1), 83–104.

Fare, R., Grosskopf, S., Lindgren, B., Ross, P., 1994. Productivity development in swedish hopsitals: a malmquist output index approach. In: Data Envelopment Analysis: Theory, Methodology, and Application, Chap 13. Kluwer, Boston, pp. 253–272.

Gandelman, N., Serebrisky, T., 2018. Household spending in transport in Latin America and the Caribbean: Understanding transport expenditure patterns. Inter-American Development Bank, Mimeo.

Glaister, S., Graham, D., 2002. The Demand for Automobile Fuel: A Survey of Elasticities. J. Transp. Econ. Policy 36 (1), 1–25.

Golany, B., Roll, Y., 1989. An Application Procedure for DEA. Omega 17, 237–250.

Gómez-Lobo, A., 2020. Transit reforms in intermediate cities of Colombia: an ex-post evaluation. Transp. Res. Part A 132, 349–364.

Goodwin, P., Dargay, J., Hanly, M., 2004. Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. Transp. Rev. 24 (3), 275–292.

Lee, C., 2011. Malmquist Productivity Analysis using DEA frontier in Stata. Stata Users Group.

Litman, T., 2018. Autonomous Vehicle Implementation Predictions Implications for Transport Planning. Victoria Transport Policy Institute, 24 July 2018.

Morales Sarriera, J., Salvucci, F.P., 2016. Rising costs of transit and Baumol's cost disease. Transportation Research Record: Journal of the Transportation Research Board, No. 2541. Transportation Research Board of the National Academies, Washington, D.C, pp. 1–9.

Morales Sarriera, J., Salvucci, F.P., Zhao, J., 2018. Worse than Baumol's disease: The implications of labor productivity, contracting out, and unionization on transit operation costs. Transp. Policy 61, 10–16.

Ngai, L.R., Pissarides, C., 2007. Structural Change in a Multi-Sector Model of Growth. Am. Econ. Rev. 97 (1), 429–443.

Nordhaus, W., 2008. Baumol's Disease: A Macroeconomic Perspective. B.E. J. Macroecon. – Contrib. 8 (1).

Obeng, K., Sakano, R., 2008. Public transit subsidies, output effect and total factor productivity. Res. Transp. Econ. 23, 85–98.

Obeng, K., 2011. Indirect production function and the output effect of public transit subsidies. Transportation 38 (2), 191–214.

Odeck, J., 2008. The effect of mergers on efficiency and productivity of public transport services. Transp. Res. Part A 42, 696–708.

Oulton, N., 2001. Must the Growth Rate Decline? Baumol's Unbalanced Growth Revisited. Oxford Econ. Papers 53, 605–627.

Oum, T., Waters, W.G., Yong, J., 1992. Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates. J. Transp. Econ. (May), 139–154.

Parry, I.W., Small, K.A., 2009. Should urban Transit Subsidies Be Reduced? Am. Econ. Rev. 99 (3), 700–724.

Peacock, A.T., 1994. Welfare Economics and Public Subsidies to the Arts. J. Cult. Econ. 18 (2), 151–161.

Pestana Barros, C., Peypoch, N., 2010. Productivity changes in Portuguese bus companies. Transp. Policy 17 (5), 295–302.

Pratt, R., 2004. Traveler Response to Transportation System Changes, TCRP Report B12-A, TRB. http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1034.

Ray, S., 2004. Data Envelopment Analysis: Theory and technics for economics and operations research. Cambridge University Press.

Savage, I., 2004. Management Objectives and the Causes of Mass Transit Deficits. Transp. Res. A 38, 181–199.

Schwarz-Miller, A., Talley, W.K., 1995. Public transit wage rates: pre-reagan and reagan-bush eras. J. Labor Res. 16 (2), 150–169.

Small, K.A., Verhoef, E.T., 2007. The Economics of Urban Transportation, second ed. Routledge.

Spann, R.M., 1977. The macroeconomics of unbalanced growth and the expanding public sector: Some simple tests of a model of government growth. J. Public Econ. 8 (3), 397–404.

Wardman, M., Shires, J.D., 2003. Review of fares elasticities in Great Britain, Working Paper. Institute of Transport Studies. University of Leeds, Leeds, UK.

Wardman, M., Shires, J., 2011. Price Elasticities of Travel Demand in Great Britain: A Meta-analysis, Paper 11-3544, TRB. http://trid.trb. org/view.aspx?id=1093095.

Winston, C., Shirley, C., 1998. Alternative Route: Toward Efficient Urban Transportation. Brookings Institution, Washington, DC.

World Bank, 2020. Argentina Smart Integrated Urban Mobility in AMBA Initiatives to improve metropolitan transport in the AMBA and strengthen resilience to COVID-19, Report No: AUS0001896. The World Bank, December 7, Washington DC.

Yu, M.M., 2008. Productivity Change and the Effects of the Enhancement of the Mass Transportation Programme on the Bus Transit System in Taiwan. Transp. Rev. 28 (5), 573–592.

Abstract

According to Baumol's Cost Disease, in productive activities that are labour intensive and where labour saving technological change is low or absent, labour productivity tends to be stagnant. However, since these sectors compete for the same inputs, their wage bill increases according to the average productivity growth in the economy. As a consequence, production in stagnant sectors becomes more expensive relative to that of others. Examples of sectors affected by Baumol's disease include the performing arts, health, education and some public services. Some recent literature for developed countries suggests that public transport is also affected by the cost disease. In this article we present similar evidence suggesting that Baumol's cost disease might be present in transit services in several cities from four Latin American countries, with consequences in terms of costs and productivity that are probably made worse by rising urban congestion. We also analyse to what extent gains in total factor productivity (TFP) can offset the consequences of Baumol's cost disease. Finally, we discuss policy options to overcome these problems, refer to some possible limitations of our analysis and propose avenues for future research.

4.1 Introduction

The theory of Baumol's Cost Disease (hereafter simply Baumol's disease, Baumol effect or cost disease) states that in some economic sectors that are labour intensive and where technological change is (almost completely) absent, productivity gains are severely limited, but these sectors still face rising unit labour costs as they compete for labour inputs with other sectors of the economy where productivity is increasing. Therefore, production in stagnant sectors becomes more expensive relative to other goods and services in the economy (Baumol and Bowen, 1966; Baumol, 1967, 2012).

In this article we provide evidence that suggests the Baumol's disease might be affecting the public transport systems in 25 cities from four Latin American countries, Argentina, Chile, Colombia, and Panama. In the case of two of these countries (Argentina and Colombia) the data also allows us to analyse whether the consequences of Baumol's cost disease can be (at least partially) offset by technical progress and gains in aggregate productivity.

By covering a relatively large set of cities from diverse countries and using several empirical approaches we hope to provide cumulative evidence for the presence of Baumol's cost disease in the transit sector in the Latin American region. This adds to a small but growing literature on the presence of Baumol's cost disease in the transit sectors in developed countries (Evangelinos et al., 2012; Morales Sarriera and Salvucci, 2016; Morales Sarriera et al., 2018). To the best of our knowledge, this is the first paper analysing this issue for developing countries. Understanding this phenomenon is essential to make correct policy decisions. If Baumol's disease is present, society will have to spend an increasing proportion of the gross domestic product (GDP) in this sector if it wishes to keep output and quality levels unchanged. In addition, as transit is essential from a social welfare and environmental perspective, it may not always be feasible or desirable to pass on to users this gradual increase in provision costs. Therefore, the possible need for rising public funding may trigger political discussions that, due to the limited understanding of the underlying cause of cost increases, may lead to the under-funding of this service.

The cost disease in the case of public urban transport is accentuated by growing traffic congestion. This is particularly a problem in developing countries where private motorization rates are expected to increase substantially over the coming decades. Congestion, by reducing the average speed of buses, increases the fleet required to maintain a given frequency. There are policy options that might help to reduce or reverse the congestion problem.

This article is organized as follows. In Section 4.2 we explain Baumol's cost disease in more detail. Section 4.3 presents empirical evidence regarding the relevance of this phenomenon in the public transport systems of developed countries. Section 4.4 provides evidence from 22 cities of Colombia, Buenos Aires (Argentina), Panama City (Panama) and Santiago (Chile). Finally, section 4.5 presents the conclusions as well as lessons and policy alternatives to address the challenges raised by Baumol's cost disease in the transit sector for developing countries.

4.2 Baumol's cost disease

Baumol's cost disease was presented in its original version for the performing arts (Baumol and Bowen, 1966). However, its application is broader and includes other sectors, such as education and health (Baumol and Bowen, 1966; Baumol, 2012). The argument is simple and is explained in what follows[1].

Suppose we can divide the economy into two sectors, a dynamic one that groups those activities, such as manufacturing and agriculture, where labour productivity increases as a result of technological change, and another, called stagnant, where labour productivity does not grow. In this last sector, production is labour intensive and there are few possibilities of substituting capital for labour. Moreover, labour is part of the very essence of the service produced: a teacher in the teaching process, a doctor or nurse in health care, a bus driver in urban transport, the musicians who form an orchestra, among other examples.

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[1] Appendix 4.A presents a simple model illustrating the basic structure of Baumol's cost disease. The simplicity of this basic model should not detract from recognizing the intellectual efforts to tackle one of the more pessimistic conclusions of Baumol's unbalanced growth model (Baumol, 1967); namely, that aggregate growth will slow down as resources are shifted to the production of the good from the stagnant sector. On this see Oulton (2001), Ngai and Pissarides (2007) and Dietrich and Krüger (2010).

It is difficult to imagine that the use of new technologies can significantly reduce the time that a teacher allocates to a class or significantly increase the number of students per course without sacrificing quality. Also, the duration and number of musicians required to play a musical piece written two hundred years ago is the same today. A nuance to this argument has to me made though, for its validity strongly depends on the way the productivity indicator is defined. In fact, if the audience were defined not as the maximum number of people a theatre can host but as the potential audience that can watch the interpretation of the musical piece (through streaming for example) then we could cast doubt on the unavoidability of the Baumol effect. This is a typical example of technological change helping to counteract the effects of Baumol's disease (Cowen, 1996). The same could be applied to online teaching, although in this case the quality of the service could be negatively affected.

If labour markets are integrated, that is, if all sectors compete for labour, the payment to this factor should evolve at the same rate in both sectors, and this rate is determined by the growth of average productivity in the economy. Therefore, costs in the stagnant sectors will increase faster than in the dynamic sectors of the economy, where increasing productivity compensates for the higher labour costs. Without public support, the goods or services of the stagnant sectors will become relatively more expensive and ceteris paribus output will fall. In contrast, the goods and services produced in those sectors that exhibit higher-than-average productivity growth become relatively cheaper.

The effects of Baumol's disease could be especially dramatic in the case of surface transit (buses). One driver per bus is still an obvious requirement and there are limited possibilities of substitution between capital and labour[2]. For example, increasing vehicle size to increase labour productivity would compromise service quality (frequency). Furthermore, increasing levels of urban congestion, with a concomitant fall in average bus speeds, have a negative impact on productivity in this sector (akin to negative technical change). As we will see below, rail-based services –trains and metro– may be less prone to the Baumol effect since they are generally not affected by rising congestion and technological change in signalling and autonomous trains allow for continuous productivity increases.

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[2] This problem could be reduced in the future with the advent of autonomous vehicles, a point we will come back to in the conclusions.

Although only anecdotal, the workings of Baumol's cost disease in transit can be illustrated by one of the author's experience in Santiago, Chile. Every year one bus operator or another would have a wage bargaining process whose result would invariably be a rise in real wages. However, productivity was not increasing, nor could drivers or other workers be substituted with labour savings capital investments. Consequently, real operational costs rose each year. If wages did not keep up with the rest of the sectors, operators would have difficulty hiring or retaining drivers, mechanics or electricians, given their alternative options in the mining, logistics or other sectors that offered increasingly higher wages for these jobs. This is precisely the dynamics of Baumol's cost disease in action and was evident in a short period of time.

It could be argued that it is socially efficient for those services that lose competitiveness to wither away, but there are well known reasons why this may not be socially optimal in many cases. For example, most developed societies allocate an increasing amount of resources to ensure the provision of public education (at least at the primary and secondary levels) and in many countries the public health budget grows at a higher rate than that of other sectors[3]. Likewise, in the case of public transport, increasing returns (known as the Mohring effect) and the negative externalities associated with the use of private transport may well dictate that it is socially beneficial to invest increasing amount of resources (as a percentage of national income) in public transport systems[4].

It is also important to mention that, unlike other sectors affected by Baumol's disease, public transport does not have a natural private "antidote". Education and the arts are usually superior goods, having an income elasticity greater than one. As individuals become richer, they allocate an increasing percentage of their income to these goods and services. In those cases, the contraction of supply driven by the Baumol effect is partially or totally compensated by an expansion of

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[3] Early evidence for increasing government expenditure in public goods, the increasing share of public expenditure to GDP, and the possible link to Baumol's cost disease, are provided by Bradford et al. (1969) and Spann (1977).

[4] Parry and Small (2009) show that these two arguments justify an increase in the already high transit subsidies in cities such as Los Angeles, Washington D.C and London.

demand[5]. In other words, as an economy grows private demand can maintain or even increase the production level of these services, even as individuals must pay more for them.

This antidote does not work, however, in the case of urban public transport. The empirical evidence suggests that surface public transport is an inferior good –the income elasticity of demand is negative and high in absolute terms– so demand falls as incomes rise. Wardman and Shires (2003) perform a meta-analysis with data from 104 studies conducted in Great Britain between 1951 and 2002, finding that the income elasticity for urban transit services varies between -0.5 and -1 in the long-run, although it is somewhat smaller (in absolute value) in the short-run[6]. Trains, on the other hand, show a positive income elasticity, that is, they provide services that can be considered a normal good (Asquith, 2011). For Latin America and the Caribbean, Gandelman et al. (2019) estimate Engel curves and obtain income elasticities for public transport between -1.0 and 0.7, depending on the socioeconomic group. According to these results, public transport in Latin America would appear to be a necessary good for lower income households and an inferior good for richer households.

4.3 Literature review

D (2008) tests the Baumol hypothesis econometrically relying on data from different sectors and confirms that the production of technologically stagnant industries (including transit) grows at a lower rate than that of sectors that exhibit technological progress. Consequently, as this author finds, costs grow faster in stagnant industries than in other sectors.

Evangelinos et al. (2012) use data from US national accounts to calculate labour productivity for the local transit sector. They find that while at the aggregate level

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[5] As shown in Spann (1977), demand growth for goods and services subject to Baumol's cost disease will be equal to the sum of their price and income elasticity of demand multiplied by productivity growth in the dynamic sector. If the income elasticity is positive and higher than the (absolute value) of the own price elasticity, demand for the good or service of the stagnant sector will increase.

[6] See also Graham and Glaister (2002); Goodwin et al. (2004); Oum et al. (1992); Pratt and Iv (2004); and Wardman and Shires (2011).

the average output per worker grew 1.4% per year during the period 1977-2007, sectors such as education, health, performing arts, state-owned companies and urban public transport had a negative average growth, and in this last sector labour productivity grew the least, at an average of -1.6% per year.

These authors also undertake a disaggregated analysis with outputs, inputs and cost data for a sample of 250 bus transport companies in the United States and 75 in Germany. The sample includes 21 companies from the United States and 49 from Germany with mixed operations (buses, trains, monorails, trams or other modes). They first undertake a non- parametric production frontier analysis using Data Envelopment Analysis (DEA). As outputs they use commercial kilometres and as inputs the number of employees, number of vehicles and population density. They estimate total factor productivity (TFP) for each operator and the TFP change using the Malmquist index[7]. The results indicate that surface public transport (buses) has a very low productivity growth; in this case, an annual average TFP growth rate of only 0.5%[8]. This conclusion is confirmed by an analysis of the evolution of costs for buses and trains in New York and Chicago. These results are particularly important, for they suggest that, if Baumol's cost disease were present, as these authors' analysis suggests, the consequences cannot be offset by gains in aggregate efficiency (total factor productivity, TFP). However, in both countries, productivity growth is higher for rail-based services (metro, light and heavy trains, trams and others). This points to the greater technological change available for rail-based modes. These scholars suggest that also congestion rates may contribute to explain the difference in performance between surface and rail-based services.

Morales Sarriera and Salvucci (2016) perform a similar analysis for the US and reach similar conclusions. They indicate that among the 195 industries in the United States, the 'public transport and passenger surface transportation' sector has had the ninth smallest growth in average productivity per worker between 1990 and 2012. Furthermore, they estimate two measures of labour productivity, the number of commercial miles per worker and the number of passengers trans-

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[7] In simple terms, the Malmquist index is the ratio of TFP of a given period to that of the previous period for each unit of analysis. A critique to the use of the index to average TFP changes across more than two periods, something Evangelinos et al. (2012) do, is presented in section 4.4.3.

[8] This is consistent with older studies of TFP changes in local transit services where negative or very low productivity growth is found. See Pestana Barros and Peypoch (2010) for Portugal, Obeng and Sakano (2008) for the US, Odeck (2008) for Norway and Yu (2008) for Taiwan.

ported per worker using panel data for 49 companies that operate buses, 16 that operate light railroads, 14 heavy railroads and 9 that operate commuter rail in the United States between 1997 and 2013. The results indicate that in almost all cases (the exception being heavy railroad when productivity is measured per passenger mile) average productivity growth is low and below the economy wide productivity growth. Again, the bus sector exhibits the lowest growth, even negative growth when productivity is measured using commercial miles as an indicator of supply.

Finally, these authors analyse the evolution of labour costs of the different transport agencies and confirm that they have grown more rapidly than the consumer price index and the average wage rate in the United States, which suggests that in addition to Baumol's disease there may be other factors operating in this case[9]. Morales Sarriera et al. (2018) suggest two hypotheses: the existence of strong labour unions in this sector, a result supported by Schwarz-Miller and K. Talley (1996), and the monopolistic nature of urban transport services[10]. Due to lack of information, in the present paper we do not assess the possible impact of union power on productivity and cost inflation.

Another issue is whether subsidies may influence productive efficiency of transit firms and therefore confound our results. There is a long literature analysing this issue in the transport economics literature. For example, Borger et al. (2002) in their review of many efficiency studies using frontier techniques conclude that "Subsidies tend to worsen the performance of urban public transport in a variety of ways: higher costs, fewer revenue-passengers, excessive wage growth, and technical inefficiency."[11].

However, we believe that subsidies are not relevant in our analysis. First, in the case of Colombia and Santiago, there are no supply-side subsidies. In Santiago, for example, subsidies are used to avoid public fares from rising and do not affect how much is paid to transit firms. Some cities in Colombia with formal BRT

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[9] During the 1997-2013 period, the average annual growth rate of labour costs was 3.5% for buses and between 2.9% and 3.6% for rail operations. This is higher than the average annual growth of salaries (2.8%) and average annual inflation (2.3%) during the same period.

[10] These researchers also distinguish between services provided by private and public (state-owned) transport operators. This analysis, although interesting, is not relevant in the present paper because, except for Panama, bus operators are all private in the cases analysed.

[11] See also Savage (2004) and Winston and Shirley (1998) and references therein with respect to this topic.

systems also have subsidies, however we control for these cases in the empirical application. Subsidies may be an issue in Panama (public firm) and particularly in Buenos Aires were supply side subsidies cover a large fraction of operational costs. However, even in these cases there is no clear reason why efficiency should be deteriorating over time unless subsidy levels are also increasing over time. Although historical data are hard to come by, Basso and Silva (2014) report a subsidy level of 50% for buses in Buenos Aires, not too different from the 56% reported by the World Bank prior to the doubling of fares and reduction in bus subsidies in April 2016. Therefore, there is no evidence that subsidy levels have increased substantially in this city, at least in the second half of our 2007-2017 data period.

4.4 Analysis of selected Latin America cities

In this section, we analyse whether data supports the presence of Baumol's cost disease in urban passenger transport for a set of Latin American cities. Depending on the information available, we rely on three methodological approaches used by previous researchers in this area.

We first analyse the evolution of labour productivity, using commercial kilometres and passengers as measures of output and the ratio between each of those indicators and the number of buses as the measure of productivity[12]

The vehicle fleet has a direct relationship with the number of drivers and, therefore, the previous measures are a proxy for labour productivity[13]. For Argentina and Colombia, the data also allows us to use regression techniques to determine the dynamics of these partial labour productivity measures controlling for other

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[12] Small and Verhoef (2007) call the first output measure an intermediate output while the second would be a final or demand-related output. The intermediate output measure is more under the direct control of the firm and is recommended by these authors for efficiency analysis. In their words "No one would analyse a furniture manufacturer by counting as its output the number of its chairs that are occupied at any moment" (Small and Verhoef, 2007, p.57). The same is emphasized by Hensher (1992), who referred to kilometres as a supply-side measure of output and to passengers as a demand-side measure of output. On the issue of output definition in frontier analysis see also the discussion in Obeng (2011), Oulton (2001) and Borger et al. (2002).

[13] The number of mechanics and other non-driver workers are also expected to be a positive function of fleet size.

factors including city level unemployment, calendar seasonal effects, motorization rates (Buenos Aires) and average vehicle size (Colombia). Given the panel structure we can also control for time-invariant non-observed effects at the level of each unit of analysis.

In the case of Chile and Panama we also have cost data. This allows us to use a second approach comparing the average growth of transit costs to the evolution of general inflation (consumer price index).

Finally, for Argentina and Colombia, the data allows us to estimate changes in total factor productivity and also technical change, which, if positive, could help to offset the consequences of Baumol's disease.

In some cases, we compare surface transport (buses) with subway services (metro). This allows us to isolate the effect of some differential characteristics of both transport modes, particularly congestion (which affects the first mode) and technological progress (present in the second).

4.4.1 Labour productivity ratios

As a first approach we follow Evangelinos et al. (2012) and Morales Sarriera and Salvucci (2016) and analyse labour productivity ratios.

Colombia surface transport

We rely on data from the Urban Passenger Transport Survey (ETUP, for its Spanish acronym) that reports monthly information on passengers, commercial kilometres and vehicles in operation for 57 municipalities for the period January 2005 to March 2018. We eliminate 26 smaller municipalities that have incomplete information, and the rest are grouped into cities or metropolitan areas. The final sample includes twenty-two cities. The survey considers different transport modes including surface transport (buses, minibuses and other similar vehicles) and rail or cable car modes (metro, light-rail and cable-car in the case of Medellin). Our focus in what follows is mainly on the surface transport modes although we do analyse the Medellin metro data further below.

We present statistical results for city level panel data models. The analysis is performed for each of two partial labour productivity measures, the number of commercial kilometres per vehicle in operation and the number of passengers per vehicle in operation. Table 4.1 presents some descriptive statistics of the data.

Table 4.1: Colombia - Summary Statistics

	Obs	Mean	Median	Std. Dev.
kilometers	3,497	8,887,583	4,178,955	16,285,813
passengers	3,497	14,017,988	5,254,345	30,154,319
fleet	3,497	1,642	728	3,007
capacity	3,497	37	39.6	13.3
unemployment	3,281	12.7	12.2	3.28

Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia. DANE also produces the unemployment series.

All regressions include city fixed effects and calendar-month effects to control for possible seasonal variation. Some specifications also control for the average vehicle capacity of the bus fleet in each city-month. This last variable was constructed using the capacity (passenger per vehicle) for each type of bus (bus, buseta, microbus, padron, etc.)[14].

In some models we also control for the entry into operation of the so-called Integrated Mass Transportation Systems (SITM, for its Spanish acronym). These were Bus Rapid Transit (BRT) type reforms introduced in six regional capitals with over 600.000 inhabitants[15].

Finally, in some specifications we interact the time trend with the SITM variable to examine whether these reforms may have had a dynamic effect on productivity.

We estimate then the following general model[16]:

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[14] The exact parameters for each type of bus are available upon request from the authors.

[15] These reforms were part of the National Urban Transport Policy (PNTU) defined in 2002. The SITM began operating in Pereira (2006), Cali (2009), Bucaramanga (2010), Barranquilla (2011), Medellin (2012) and Cartagena (2016). In all these cities, BRT-type systems were created in addition to rationalizing the conventional transit fleet and the restructuring of routes. See Gómez-Lobo (2020) for more details on these reforms and their impact.

[16] This specification corresponds to the most general model since the other models are nested in this equation.

$$\ln prod_{it} = \beta_0 + \beta_1 T_t + \beta_2 SITM_{it} + \beta_3 C_{it} + \beta_4 SITM_{it} T_t \\ + \beta_5 UNEMP_{it} + d_i + z_t + u_{it} \quad (4.1)$$

where i denotes a city and t a month. The dependent variable denotes the logarithm of the corresponding labour productivity indicator (kilometres per bus and passengers per bus); d_i is a city fixed effect, T_t is a time trend, $SITM_{it}$ is a dummy variable that takes the value 1 if an SITM is in operation in city i in month t and zero otherwise, C_{it} measures the average capacity per vehicle, $UNEMP_{it}$ measures the unemployment rate in city i in month t, z_t is a monthly seasonal effect and v_{it} is the error term. The results are presented in tables 4.2 and 4.3[17].

Table 4.2 presents the results for the productivity measure based on kilometres per bus. The first column presents a model estimated with the city and time effects plus the time trend. The coefficient of the time trend is negative and statistically significant; productivity fell by an average monthly rate of 0.057% or close to 0.7% annually during this period. The entry into operation of a SITM (column 2) positively affects productivity, but the productivity trend remains negative and statistically significant (-0.069% per month). The third specification controls for the average capacity of buses[18]. The coefficient is positive and statistically significant, but the time trend in productivity remains negative (-0.072% per month).

The interactive term between the time trend and the SITM variable (fourth column) is not statistically significant[19]. Finally, if we also control for the unemployment rate (column 5), the coefficient of the time trend is still negative and larger in absolute terms compared to the other models (a fall of 0.117% monthly or 1.4% annually). The coefficient on unemployment has the expected negative sign.

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[17] The last column of each table is estimated with a smaller number of observations since the unemployment data for all cities is only available from January 2007.

[18] Average bus capacity increased by 0.0007% per month during this period.

[19] When the sample is restricted to the largest cities (those with more than 5 million passengers on average per month) the interaction variable is positive but fails to compensate for the secular fall in productivity.

Table 4.2: Labor productivity - Colombia (January 2005 - March 2018)(*) Dependent variable: logarithm of kilometers per bus

	(1)	(2)	(3)	(4)	(5)
t	-0.00057***	-0.00069***	-0.00072***	-0.00069***	-0.00117***
	(0.00006)	(0.00006)	(0.00006)	(0.00006)	(0.00009)
sitm		0.06022***	0.05419***	0.08015***	0.08665***
		(0.01031)	(0.01083)	(0.02326)	(0.02341)
capac			0.07475*	0.07934*	0.10367**
			(0.03059)	(0.03142)	(0.03201)
tsitm				-0.00025	-0.00020
				(0.00021)	(0.00021)
unemp					-0.01202***
					(0.00160)
N	3497	3497	3497	3497	3281
R^2	0.767	0.769	0.770	0.770	0.772

Standard errors in parentheses
Robust standard errors
The estimation that controls for unemployment considers data from January 2007
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results using the ratio of passenger per bus as the productivity measure are presented in Table 4.3. In the first regression the coefficient of the temporal trend is negative, statistically significant and suggests an average productivity fall of 0.03% per month (or 0.36% annually). An SITM reform (column 2) would have counteracted the fall in productivity; this is reflected in the coefficient of the SITM variable, which is positive (0,108%) and statistically significant, and in the fact that the secular fall in productivity is even greater in this specification.

In the third specification we also control for possible differences between cities in terms of the average capacity of buses. The negative productivity trend remains practically unchanged but the coefficient of the variable SITM is reduced (although it is still statistically significant), which is consistent with the fact that SITM buses have a higher capacity. The interaction variable (column 4) suggests that the SITM reforms have had a positive and statistically significant effect on the temporal dynamics (rather than the level) of productivity. If the coefficient of the temporal variable is added to that of interaction term, the result is close to zero (0.001% per month), which suggests that the introduction of these systems help to mitigate the

Table 4.3: Labor productivity - Colombia (January 2005 - March 2018)(*) Dependent variable: logarithm of passengers per bus

	(1)	(2)	(3)	(4)	(5)
t	-0.00030***	-0.00052***	-0.00066***	-0.00076***	-0.00078***
	(0.00006)	(0.00006)	(0.00006)	(0.00007)	(0.00007)
sitm		0.10840***	0.08150***	0.00177	0.01665
		(0.01071)	(0.00953)	(0.01598)	(0.01675)
capac			0.33362***	0.31952***	0.32680***
			(0.02745)	(0.02701)	(0.02752)
tsitm				0.00077***	0.00050***
				(0.00014)	(0.00014)
unemp					-0.00909***
					(0.00106)
N	3497	3497	3497	3497	3281
R^2	0.815	0.820	0.835	0.836	0.847

Standard errors in parentheses
Robust standard errors
The estimation that controls for unemployment considers data from January 2007
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

secular fall of productivity. However, even with an SITM in operation productivity in the sector is stagnant (close to zero growth).

Finally, if we control for the unemployment rate (column 5) the time trend is negative and the introduction of an SITM does have a positive dynamic effect but does not completely compensate for the secular fall in productivity. The coefficient on unemployment has the expected negative sign.

In summary, for Colombia, there is evidence of a negative productivity trend over time, regardless of how it is measured (kilometres per bus or passengers per bus). There is also evidence that the SITM, with its bus priority infrastructure, reduced but did not completely compensate for this fall in productivity in the cities that implemented such reforms. The implications of this last result will be discussed in the conclusions.

A hypothesis consistent with these results is that the service network might have increased during the period, extending the serviced to lower demand areas.

However, this is unlikely, as in all 22 cities total kilometres of service decreased during the period studied[20].

Therefore, we conclude that these results are consistent with a secular decrease in labour productivity, an important ingredient for Baumol's cost disease. However, the results obtained when using a productivity indicator based on the number of passengers must be interpreted with care, for they might be partially driven by demand factors. For instance, the drop of passengers per bus might be partly explained by a switch to private modes of transport, in response to higher disposable income. However, the question would then be why the demand for labour (and perhaps other inputs) has not adjusted to lower passenger demand.

The Medellin Metro system

An exercise was also carried out with data from the Metro system that operates in the city of Medellin. For this mode we have 270 observations covering the period January 2007 to March 2018. We only compute the productivity measured as kilometres per fleet as we do not have information on passengers transported. During this period, the number of aggregate kilometres offered increased by 60% in absolute terms.

Figure 4.1 shows kilometres per train in the metro system. There appears to be an anomaly in the data for the first eight months, so we present results using only the data from September 2007 to March 2018. These results are presented in Table 4.4 and indicate that there is a positive trend in productivity even when controlling for seasonality and city level unemployment (between 0,048% to 0.059% per month).

In other words, there seem to be productivity gains in the case of underground transport, a result that, as indicated above, is consistent with the received literature for developed countries.

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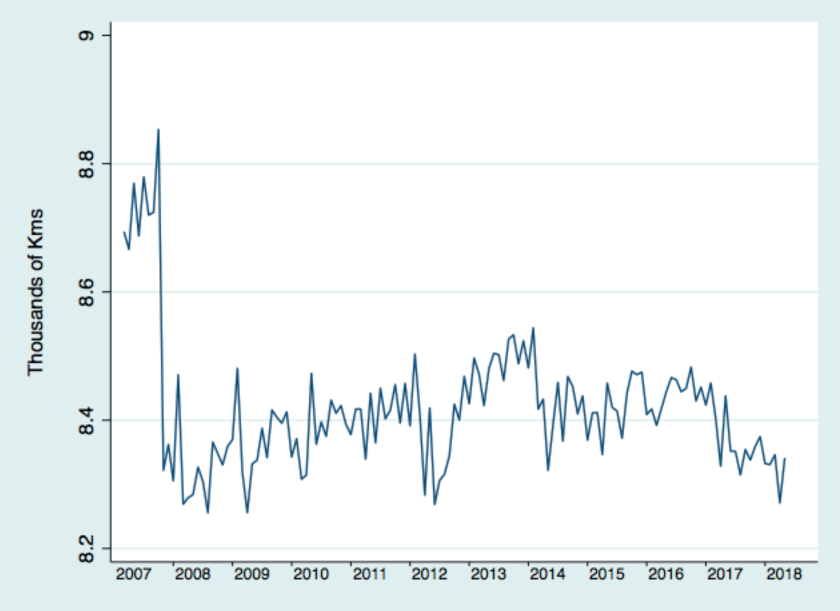
[20] Since we are using the number of buses in operation not the total fleet size, we can also discard that the results are driven by an increase in fleet size (due to fleet renovation for example).

Figure 4.1: Productivity: kilometres per train, Medellin



Source: National Survey of Urban Transport of Passengers (EUTP), National Bureau of Statistics (DANE), Colombia.

Table 4.4: Labor productivity - Metro Medellin (January 2005 - March 2018) Dependent variable: logarithm of kilometers per train

	(1)	(2)	(3)
t	0.00047^{**}	0.00047^{**}	0.00059^{***}
	(0.00016)	(0.00015)	(0.00017)
unemp			0.00433
			(0.00315)
N	127	127	127
R^2	0.070	0.287	0.294

Standard errors in parentheses

Robust standard errors

The estimation that controls for unemployment

considers data from January 2007 onwards

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Buenos Aires (Argentina)

Data is available for routes operating within two geographical areas in Buenos Aires: The Federal District (DF) and the Urban Subgroup I (SGI). The routes classified under the heading DF cover services exclusively within the Autonomous City of Buenos Aires (CABA), while those classified as SGI include routes having one of its terminal stations in the CABA, but that extend their operations up to 50 km outside the city, although always within the administrative region called Greater Buenos Aires. There is information on 30 routes within the DF area and 12 within the SGI area. These are not all the lines operating in these areas but a sample of operators for which it was possible to obtain information (in total there are approximately 200 routes in the city). The data covers the period from January 2007 to December 2017. We also count with monthly data for the unemployment rate (also from January 2007 to December 2017) and for the motorization rate (vehicle stock divided by population) from January 2010 to December 2017, which we use as a proxy for congestion.

Table 4.5 presents descriptive statistics for the main variables and Figure 4.2 shows the evolution of productivity aggregated across all routes, measured as kilometres per bus in service. We see a slight adjustment in this trend in 2015. This could be due (among other things) to changes in the measurement of this variable; GPS monitoring was introduced that year. However, despite this last effect, the trend is decreasing during the whole period.

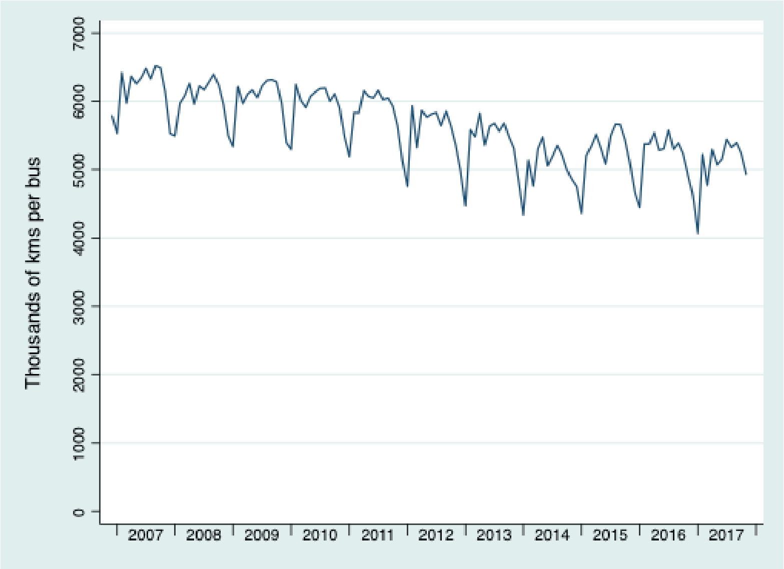
Table 4.5: Buenos Aires - Summary Statistics

	Obs	Mean	Median	Std. Dev.
kilometers	5,544	448,590	362,917	327,655
passengers	5,544	1,229,532	1,116,061	594,330
fleet	5,544	80.1	68	48.4
labor	5,544	232	192	141
motorization_rate	5,544	406	427	73.9
unemployment	5,544	6.91	6.43	1.61

Source: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area). The motorization rate was built using data from the Buenos Aires City Government and the National Bureau of Statistics and Censuses (INDEC)

Figure 4.3 shows the evolution of the number of passengers transported per bus. Although this indicator exhibits year-to-year variations, it shows a stable behaviour and a decreasing trend during the second half of the period[21].

Figure 4.2: Productivity: kilometres per bus, Buenos Aires



Source: Source: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area), Ministry of Transport. This information was collected with the support of the Inter-American Development Bank's Transport Division

We undertake an econometric analysis of these partial labour productivity indices at the individual route level. We use route fixed effects to capture possible differences at the geographical level (DF versus SGI) as well as non-observed characteristics of each line that could affect their relative efficiency.

We also control for the possible impact that bus priority infrastructure may have had on productivity. During this period, several exclusive bus corridors came into operation (see Table 4.6 for the date that they became operational and the routes that potentially benefited from this infrastructure). In the regressions we include dummy variables that take the value one from the month after each corridor becomes operational and only for those routes that potentially benefit from this new infrastructure.

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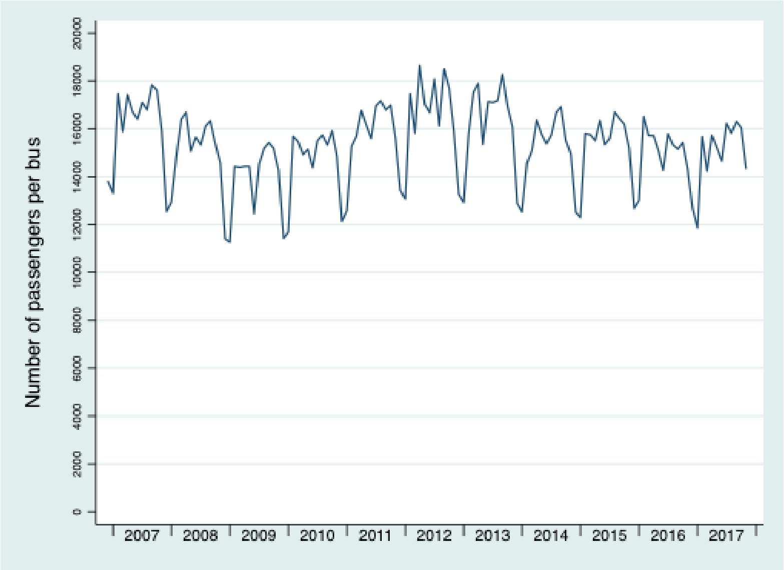
[21] The evolution of productivity at the level of each route is consistent with the aggregate data presented here. Productivity remains relatively stable in the case of passengers and seems to decrease when output is represented by kilometres. These results are available upon request.

Figure 4.3: Productivity: Passengers per bus, Buenos Aires



Source: Source: Buenos Aires City Government, Metrobus AMBA (Buenos Aires Metropolitan Area), Ministry of Transport. This information was collected with the support of the Inter-American Development Bank's Transport Division

Table 4.6: Bus priority infrastructure for buses in Buenos Aires

Name	Id	Beneficiary routes	In operation since
Juan B Justo	1	2003-1028	August 2011
9 de julio	2	1010-1013-1001-1003	July 2013
Sur	3	None (see note below)	August 2013
AU 25 de mayo	4	1009	October 2015
Norte etapa 1	5	1006-1010-1011-1014-1026	June 2015
San Martin	6	1015-1021-1024-1005-2008	April 2016
Norte etapa 2	7	1011-2006-1026-1010-1013-1012	November 2016
La Matanza	8	1029	May 2017
del Bajo	9	2011-1025-1007-1026-1018-2002	June 2017
Ruta 8	10	1015	October 2017

Note: None of the routes in our sample used the Corredor Sur. *Source:* Buenos Aires City Government (information obtained with the support of the Inter-American Development Bank's Transport Division).

We also control in a separate regression for city level unemployment and the motorization rate. The last column shows the results controlling for all the variables. All three regressions control for seasonality (calendar month time effects).

The most general model estimated is[22]:

$$\ln prod_{it} = \beta_0 + \beta_1 T_t + \beta_2 CORR_{it} + \beta_3 UNEMP_t + \beta_4 MOTOR_t \\ + d_i + z_t + u_{it} \tag{4.2}$$

where d_i is a route level fixed effects, T_t is the time trend, $CORR_{it}$ is the dummy variable for each corridor ($Corr_i d$ from Table 4.6), $UNEMP_t$ is the city-wide unemployment rate in month t, $Motor_t$ is the motorization rate in month t and z_t is monthly seasonality effect.

Table 4.7 presents the results when the dependent variable is the number of kilometres travelled per bus. We see that the coefficient of the time trend is negative and statistically significant in the three specifications, which is consistent with Baumol's theory[23].

Even more interesting is the fact that productivity falls more when we control for the different corridors. Seven of the nine relevant corridors have a positive and statistically significant impact on productivity for those lines benefiting from this infrastructure. In other words, as in the case of Colombia with BRT reforms, there is also evidence for the case of Buenos Aires that bus priority infrastructure helps to mitigate Baumol's disease[24] . The fall in productivity is lower (in absolute terms) when we control also for the unemployment rate and the motorization rate, with a

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[22] The other models are nested in this general equation

[23] As in the case of Colombia, it is unlikely that this result is due to an increase in the network coverage over time. In 35 of the 42 routes, kilometres travelled decreased in the sample period. In the other 7, only 2 routes show a significant increase in kilometres travelled (between 10% and 20% in the ten years of data).

[24] In the case of the May 25 corridor, the coefficient is negative, which implies that productivity fell with the opening of that bus priority infrastructure. However, it is only significant at the 10% confidence level. Further research should analyse in more detail the impact of each corridor on productivity in the case of this city.

Table 4.7: Productivity - Buenos Aires (January 2007 - December 2017). Dependent variable: Logarithm of kilometers per bus

	(1)	(2)	(3)
t	-0.00152***	-0.00163***	-0.00061*
	(0.00004)	(0.00005)	(0.00031)
corr_1		0.05661***	0.07174***
		(0.01672)	(0.01342)
corr_2		0.05433***	0.01754
		(0.01066)	(0.01163)
corr_4		0.06803***	0.05096***
		(0.01092)	(0.01004)
corr_5		-0.00927	0.01224
		(0.01199)	(0.01548)
corr_6		0.03821***	0.03070**
		(0.01128)	(0.01108)
corr_7		-0.04018**	-0.02436
		(0.01557)	(0.01657)
corr_8		0.06999***	0.07149***
		(0.01313)	(0.01575)
corr_9		0.04309***	0.02405**
		(0.00730)	(0.00761)
corr_10		0.12665***	0.09328***
		(0.02399)	(0.02615)
unemp			-0.00822
			(0.00426)
motor			-0.40059***
			(0.08147)
N	5544	5544	4032
R^2	0.691	0.695	0.684

Standard errors in parentheses

Robust standard errors.

All regressions include route fixed effects and calendar month time effects

Variables corr_1 to corr_10 indicate the corridors as per defined in Table 6

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

fall of 0.061% per month or almost 0.75% annually. Especially interesting is the negative effect of the motorization rate over this measure of labour productivity.

In Table 4.8 we present the results using labour productivity as passengers per bus. We see that the coefficient of the time trend is negative in all three specifications and statistically significant in the last two. Regarding the corridors, three of them have a positive and statistically significant impact on the average number of passengers in the more general specification.

The fall in productivity is higher (in absolute terms) when we control also for the unemployment rate and the motorization rate, with a fall of nearly 0.2% per month or almost 2.5% annually.

As with the measure of productivity based on commercial kilometres, and as expected, unemployment has a negative effect on productivity. The coefficient of the motorization rate is now positive and statistically significant. This result could be indicating that as congestion rates rise individuals may switch to public transport, particularly if infrastructure investments in corridors make this mode less prone to congestion. All effects considered, labour productivity still appears to decline, and this result is statistically significant.

In sum, in the case of Buenos Aires there is also evidence for Baumol's disease when analysing partial labour productivity measures.

Panama City, Panama

In the case of Panama City, we rely on data from the company Transporte Masivo de Panama S.A. (MiBus), a subsidiary of the state-owned Metro de Panama. MiBus is in charge of the operation of the surface passenger transport services in the Metropolitan Area of Panama City. The information available covers the period January 2014 - December 2017. As in the previous two cases, two partial labour productivity measures are used: kilometres per bus and passengers per bus.

Figures 4.4 and 4.5 show the results for each indicator. When the number of passengers transported per bus is considered, there is an average monthly fall of

Table 4.8: Productivity - Buenos Aires (January 2007 - December 2017). Dependent variable: Logarithm of passengers per bus

	(1)	(2)	(3)
t	-0.00003	-0.00024***	-0.00198***
	(0.00005)	(0.00006)	(0.00037)
corr_1		0.26014***	0.22970***
		(0.03355)	(0.01207)
corr_2		0.11064***	0.11938***
		(0.00960)	(0.01096)
corr_4		-0.02357*	0.01802
		(0.01195)	(0.01445)
corr_5		-0.04921**	-0.02046
		(0.01626)	(0.02029)
corr_6		-0.01206	0.01051
		(0.01041)	(0.01008)
corr_7		0.02169	0.04684**
		(0.01613)	(0.01498)
corr_8		-0.02012	0.01511
		(0.01102)	(0.01407)
corr_9		-0.00620	0.02995
		(0.01918)	(0.01999)
corr_10		0.13520***	0.09507***
		(0.01936)	(0.01964)
unemp			-0.02278***
			(0.00504)
motor			0.60048***
			(0.08898)
N	5544	5544	4032
R^2	0.681	0.697	0.732

Standard errors in parentheses

Robust standard errors.

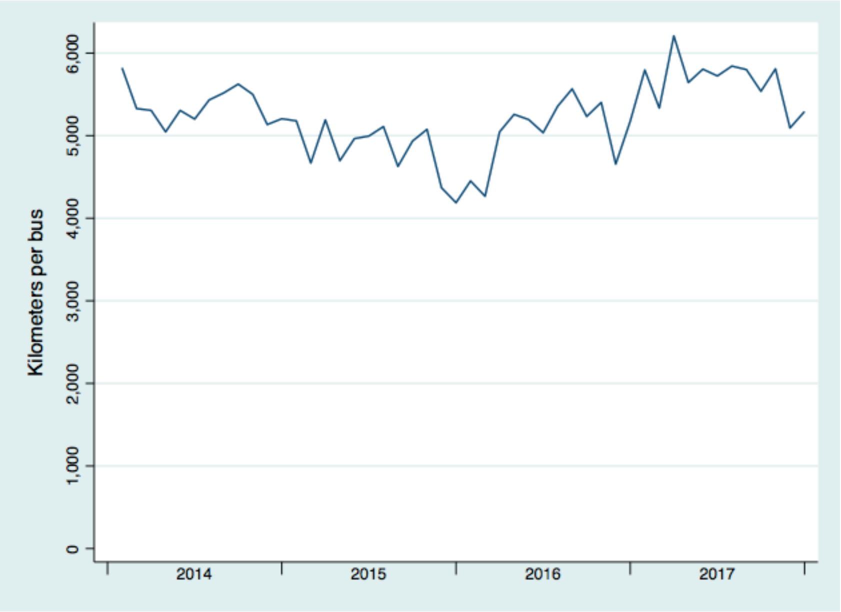
All regressions include route fixed effects and calendar month time effects

Variables corr_1 to corr_10 indicate the corridors as per defined in Table 6

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

0.659% in productivity. When the number of kilometres per bus is used, we see an initial fall in productivity with a recovery after 2015[25].

Figure 4.4: Productivity: kilometres per bus, Panama City



Source: Transporte Masivo de Panama S.A. (MiBus)

The results for the case of public surface transportation services in Panama City are qualitatively similar to those of Colombia and Buenos Aires, suggesting the presence of Baumol's disease. Unfortunately, there is no information for the Panama metro system to make a contrast like that made for Medellin.

In addition, it must be recognized that a four-year period may be too short to analyse a long-term phenomenon such as Baumol's cost disease. However, it is suggestive and consistent with the other case studies and evidence presented in this paper.

Santiago, Chile

The analysis for Santiago is based on information for seven surface bus operators and for the metro (underground train). The information for buses is very limited

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[25] In this case, there is only one productive unit (MiBus), so an econometric analysis, as in the case of Colombia and Buenos Aires, is not feasible. Also note that during the period the total number of kilometres supplied increased by 5,7% in the aggregate.

Figure 4.5: Productivity: passengers per bus, Panama City

Source: Transporte Masivo de Panama S.A. (MiBus)

(only three yearly observations per operator, for the period 2013-2015). In addition, there is aggregate information (for the complete bus system) for the period 2012-2017.

Figure 4.6 shows the evolution of the average kilometres per bus[26]. We see a negative trend for all operators, and in the case of one of them the fall in labour productivity is particularly marked.

The partial labour productivity measured in terms of passengers transported also decreases more in the case of the bus system than the Metro system, as indicated in Table 4.9 where the annual information for both indicators is presented, both for the Metro and for the bus system as a whole[27].

The fall in productivity could partly be explained by the declining aver- age speed of buses due to the congestion in the city, an issue that will be highlighted in the discussion of policy options in the conclusions. Figure 4.7 shows the quarterly

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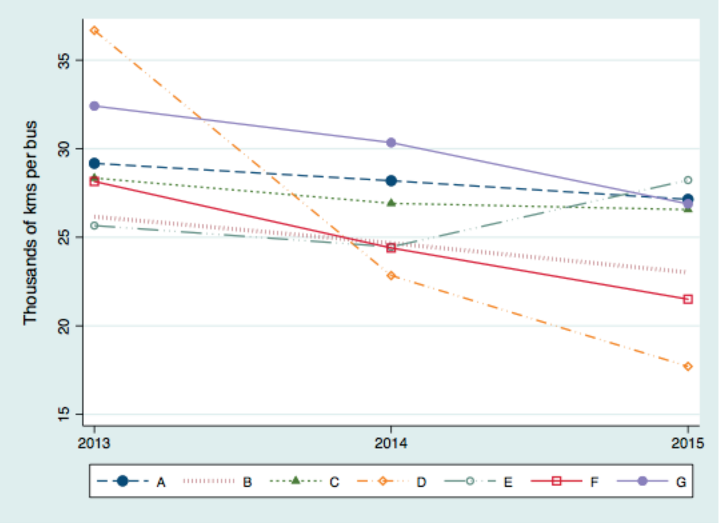
[26] Aggregate kilometres supplied in Santiago remained constant during the sample period, so we can again discard that changes in network coverage may explain the evolution of kilometres per bus.

[27] In this table, the passengers per bus index may be influenced by changes in rate of non-payment (fare evasion), which fluctuated between 20% and 30% and has grown over time. This does not affect the number of Metro passengers, since non-payment in this mode is almost zero.

Figure 4.6: Productivity: kilometres per bus, Santiago



Source: DTPM (Ministry of Transport, Chile).

Table 4.9: Buses versus Metro productivity, Santiago

	Kilometres/Fleet		Passengers/Fleet	
Period	Metro	Buses	Metro	Buses
2012	694,736	74,542	3,414,783	164,421
2013	768,064	71,422	3,589,625	155,597
2014	752,688	70,617	3,595,337	149,356
2015	740,698	70,229	3,558,120	140,690
2016	725,053	69,017	3,612,571	132,557
2017	672,945	67,770	3,396,687	129,932
2012-17	-3.14%	-9.08%	-0.53%	-20.98%
2012-17 (average)	-0.63%	-1.82%	-0.11%	-4.20%

. *Source:* Metro de Santiago S.A. and DTPM (Ministry of Transport, Chile).

evolution of the average bus speeds between 2014 and 2016, considering off-peak and the morning and afternoon peak periods. These trends are all decreasing, which likely reflect increasing congestion levels in the city.

Figure 4.7: Average bus speeds, Santiago

Source: DTPM (Ministry of Transport, Chile).

In summary, as in the case of Colombia, Buenos Aires and Panama City, there is also some evidence that Baumol's disease might be affecting the public transport system of Santiago, particularly in surface transport. In addition, in this case there is information, although limited, that suggests that congestion could be exacerbating the consequences of the Baumol effect for bus services[28]. As with the case of Panama City, however, it must be borne in mind that the data for Santiago covers a relatively short period and thus the results must be interpreted with care.

4.4.2 Labour costs and total costs

The previous results, based on labour productivity measures, suggest the Baumol effect might be present in the surface transport systems in the analysed cities. In this section we present the evolution of costs and labour costs where this information is available.

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[28] During this period, the bus fleet in Santiago remained practically constant so the results described here is not due to an increase in fleet size. Rather, the operational plans had to be adapted (offering fewer and less frequent services) to accommodate the lower average speed of the fleet.

Panama City, Panama

For the case of Mibus in Panama City, we also have operational cost information. This information is presented in Table 4.10 separated into labour costs and other costs. labour costs include drivers, as well as maintenance, administrative and operational personnel, while all other operational expenditures are grouped together as non-labour costs. Due to the need to preserve data confidentiality we present an index number for the evolution of the nominal costs in each category, with 2014 being the base year and equal to 100.

Table 4.10: Evolution of operational costs, Panama City 2014-2017

Period	labour costs (2014=100)	Non-labour costs (2014=100)	labour costs (% total costs)	Kms (2014=100)	Passengers (2014=100) (2014=100)	CPI (% change)
2014	100.0	100	0.43	100	100	2.6%
2015	99.9	80.7	0.48	90.0	85.6	0.1%
2016	112.8	86.0	0.50	94.1	79.5	0.7%
2017	135.3	104.4	0.50	105.7	85.1	0.9%
Yearly average	10.6%	1.4%	1.9%	-5.2%	1.1%	

Note: labour costs include drivers, as well as maintenance, administrative and operational personnel. Information is presented as an index number to protect confidentiality of information. *Source:* Transporte Masivo de Panamá S.A. (MiBus).

We can see that nominal labour costs increased by an average yearly rate of 10.6% while inflation (CPI) rose by an average annual rate of only 1.1%. Non-labour nominal costs grew by 1,4% on average during this period, more in line with the underlying inflation rate. Consequently, the share of labour costs in total operating expenditure rose from 43% to 50%. Overall operational expenditure rose by a yearly average of 5,6% during this period.

Although using four years of data to infer long-term trends is questionable, it does suggest that the lower partial labour productivity trend shown above was not compensated by either wage reductions or input substitution. It also makes clear that rising real operation costs are driven by a rise in labour costs that have not been compensated by rising productivity. Furthermore, the increase in real costs cannot be explained by increased output as the number of kilometres operated only increased by 1,9% on average each year and passengers transported decreased over the period.

Santiago, Chile

Figure 4.8 presents cost trends for six operators (one operator did not report cost data). labour costs per kilometre travelled by the Metro system grew less than those of four of the six bus operators. Figure 4.9 complements this evidence by comparing the labour cost per kilometre in the case of buses as a group and the Metro system with the evolution of the general consumer price index (CPI)[29]. Once again, one can note that Metro services are less prone to labour cost increases compared to bus services.

The cost data then shows that during this period, labour costs grew faster than overall inflation. The decrease in labour productivity noted above was not compensated by lower wages or capital-labour substitution.

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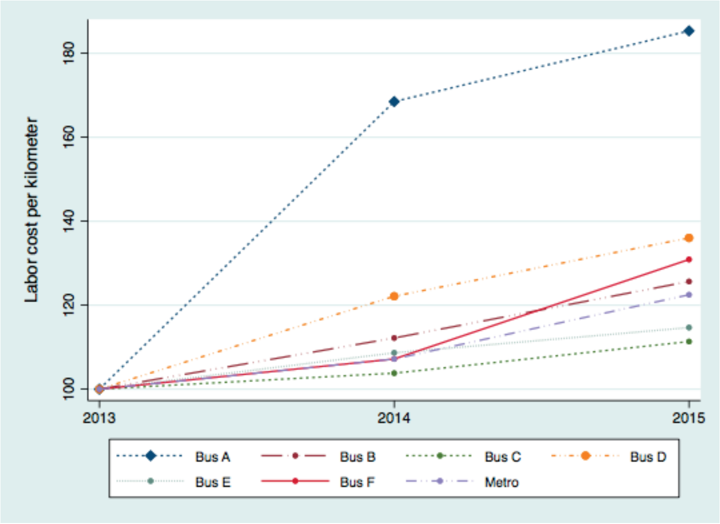
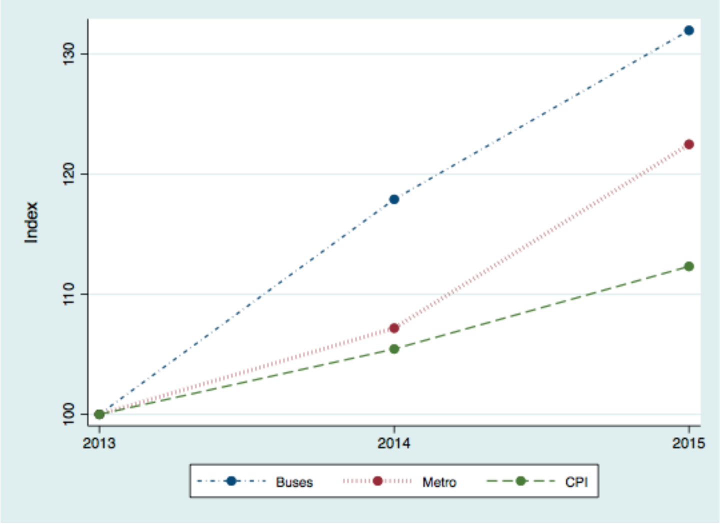
[29] In Figures 4.8 and 4.9 we use labour costs per kilometre travelled. To test the presence of Baumol's disease it is certainly better to have total cost data (not only labour cost) but this information was not available.

Figure 4.8: Labour cost per kilometre, Santiago (Index, 2013=100)



Source: Source: DTPM (Ministry of Transport, Chile). Letters A-F refer to the different operators (their identities cannot be revealed).

Figure 4.9: Labour cost per kilometre (buses and metro) versus CPI Santiago (Index, 2013=100)



Source: DTPM (Ministry of Transport, Chile).

4.4.3 Total factor productivity and technical change

In this section we estimate changes in total factor productivity (TFP) and technical change. Available data allows us to use this approach in the case of Colombia and Buenos Aires.

Estimating technical change is important because one the assumptions of the Baumol's disease is that those sectors affected by it cannot take advantage of technological progress. If that assumption doesn't hold then the consequences of the decline of labour productivity that we have found would be either partially offset (if there is technical progress) or worsened (if there is technical regress).

Technical change is one of the components of TFP change. The others are efficiency change and scale efficiency. We present the TFP change and the technical change. If providers of transportation services were technically efficient and its scale of operations were optimal (two underlying assumptions of the Baumol's disease theory) then TFP change would be equal to the technical change. We'll see if this is the case.

We proceed by estimating firstly a Global Malmquist Index of TFP change, hereafter GMI (Pastor and Lovell, 2005). We choose this index over the Adjacent Malmquist Index (Caves et al., 1982; Färe et al., 1994), which is the most commonly used in the literature, because the latter indicator is not transitive, which means that if $M(1,2)$ measures TFP change between periods 1 and 2 and $M(2,3)$ measures TFP change between periods 2 and 3, then we cannot say that $M(1,2)$ times $M(2,3)$ equals $M(1,3)$. This shortcoming is also referred to as the circularity problem. An indicator that measures productivity changes with respect to a unique (arbitrary) base period, as the one proposed by (Berg et al., 1992), is transitive but presents other shortcomings (for more details see Pastor and Lovell (2005)). The GMI measures the productivity indicators of all periods with reference to a unique benchmark technology that is defined as the convex hull of all period's technologies and is transitive. We use this index to measure technical change and changes of TFP between two periods for each productive unit (hereafter decision making unit or simply DMU: cities in the case of Colombia and routes in the case of Buenos Aires) and then estimate the geometric mean of those changes to get the yearly averages.

The index, as the Adjacent Malmquist Index, is estimated with base on the relative technical efficiency scores of the different DMUs, that are estimated through a Data Envelopment Analysis (DEA)[30]. We estimate these scores using an input-oriented relative efficiency measure: the ability to produce a given level of output with the minimum level of inputs[31]. We also assume a constant return to scale technology[32].

It is worth pointing out that in this paper, as in the previous literature, no statistical tests of these measures of productivity change and technical change have been carried out, hence the results must be taken as definitive[33].

Colombia

In the case of Colombia, each productive unit (DMU) is represented by a city, that is to say each city is conceptualized as a producer of transportation services. The analysis considers one output and two inputs. The output is defined as passengers per kilometre. The inputs are the number of buses and the average capacity of the fleet. The choice of inputs is motivated by data availability and the direct relation between the number of buses and both the number of drivers (labour input) and

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[30] Data Envelopment Analysis (DEA) is as a mathematical, linear programming method that allows to estimate a production frontier and evaluate the efficiency of different entities in relation to that frontier (best practice). These entities are normally referred to as decision-making units (DMUs), and can be plants, firms, other (for-profit or non-for profit) organizations, or any identifiable productive unit. In this paper, the DMUs are defined as cities in the case of Colombia, and bus operators in the case of Buenos Aires, Argentina. Each DMU uses inputs that are transformed into outputs according to a given technology. The method assumes that all DMUs have the same production technology. This technology is of course unknown but, in what represents the main advantage of DEA, is built from the observed data, in a way that satisfies certain desirable economic properties.

[31] Technical efficiency can also be formulated in an output-oriented version, indicating the maximum level of output that can be achieved with a given set of inputs. In this article we estimate an input-oriented version, as it is expected that transport operators have more control over inputs than over outputs. In fact, in all these countries buses operators are private firms regulated by the state, and the regulation is related in part to the level of some output indicators, particularly commercial kilometres. In the case of Chile, which the authors know well, the regulation considers an operational plan that establishes objectives in terms of frequency and kilometres travelled, among other indicators, and the authority assesses every six months the degree to which those goals have been reached.

[32] We estimate productivity changes in Stata 16 with the *malmq2* command, developed by Du (2019).

[33] Some methods for doing this have been proposed in the literature, including a novel method proposed by Asmild et al. (2018) (other methods are referenced in that paper). This task is left for a future research venture.

kilometres covered. The fleet capacity is a way of correcting for the raw measure represented by the number of buses.

Table 4.11: TFP and technical change for buses, Colombia (2005-2017)

Period	TFP change	Technical change
2005 2006	0,9834	0,9968
2006 2007	1,0136	0,9532
2007 2008	0,9718	0,9629
2008 2009	0,9852	0,9803
2009 2010	1,0094	1,0286
2010 2011	1,0154	0,9998
2011 2012	1,0248	1,0025
2012 2013	1,0610	1,0017
2013 2014	0,9560	1,0009
2014 2015	1,1482	0,9137
2015 2016	0,9913	1,0030
2016 2017	0,9632	1,0287
Average	*1,0091*	*0,9888*

Note: The inputs are the number of buses and the fleet's average capacity. The output is the number of passengers per kilometre travelled. Each figure indicates the change of the corresponding indicator between the corresponding consecutive years.

The results, presented in Table 4.11 indicate that the there has been technical regress rather than technical change. The assumption of the Baumol's disease theory is that technical change is absent. In this case it is actually negative, which might be reflecting other problems already identified in a previous section, such as congestion. We also see that the assumption of the Baumol's disease that DMUs are both technical efficient and operate at the optimal scale doesn't hold; in fact, it must be the case that the difference between technical change and TFP change is explained by gains in either technical efficiency, scale efficiency or both. It is also the case that TFP has increased over this period, so the negative technical change must has been more than offset by either efficiency change, scale efficiency or both.

Buenos Aires

In the case of Buenos Aires, we estimate TFP changes considering the routes as DMUs, and using as output the number of passengers per kilometre travelled. As to the inputs, we have information on the number of workers of each route, which allows to consider both the fleet size (number of buses in operation) and the number of workers. As mentioned above for the case of Colombia, a direct relation is expected to exist between the number of drivers and the number of buses in operation. However, turn-around times, driver scheduling, and other labour management practices can influence the number of workers per bus. Therefore, having information on total workers and fleet in operation is much better to estimate efficiency levels and therefore total productivity changes in this sector. Unfortunately, due to data limitations this alternative was not available in the case of Colombia.

Table 4.12 presents the results for Argentina. We see that, on average, TFP change has been positive and close to 1%, but technical change, although positive too, has been less significant from an economic perspective (0,4%). This might be due to changes in exclusive lanes for buses or other Bus Rapid Transit (BRT) reforms. This is the important result: in Argentina it seems that bus routes are able to harness some positive technical change. We also see, as in the case of Colombia, that the assumption of the Baumol's disease that DMUs are both technical efficient and operate at the optimal scale doesn't hold.

Table 4.12: TFP and technical change for buses, Buenos Aires (2007-2017)

Period	TFP change	Technical change
2007 2008	0,9271	0,9456
2008 2009	0,9202	1,0147
2009 2010	1,0688	0,9682
2010 2011	1,0757	1,0492
2011 2012	1,0652	1,0103
2012 2013	1,0175	1,0115
2013 2014	1,0105	1,0059
2014 2015	0,9770	1,0148
2015 2016	1,0182	1,0316
2016 2017	1,0293	0,9947
Average	*1,0096*	*1,0043*

Note: The inputs are the number of buses and the number of drivers. The output is the number of passengers per kilometre travelled. Each figure indicates the change of the corresponding indicator between the corresponding consecutive years.

Summing up the results indicate that in Colombia technical change, instead of being an antidote to the Baumol disease has made it more serious' its decline reinforces the negative time trend of labour productivity. The results for Buenos Aires are to be looked carefully as the data seems to be highly volatile and there are some (evident) extreme values. This contrasts with the previous literature for developed countries, which shows positive changes in TFP close to 0.5% (yearly average) in developed countries in various sub-periods during the last two or three decades (Evangelinos et al., 2012).

As mentioned before, no statistical tests of these measures of productivity change and technical change have been carried out hence these results must be interpreted carefully.

4.5 Conclusions and policy implications

In this paper, evidence has been presented for a group of Latin American cities that suggests that in urban surface public transport (buses) labour productivity is either stagnant or decreasing over time. This result is consistent with evidence found by other scholars for developed countries.

Although many factors can explain this result, our analysis, the previous academic literature, and a comparison with the underground (metro) transport services, suggest that one of the main causes could be Baumol's cost disease. In effect, in this sector the fundamental assumptions of the Baumol theory seem to hold: a labour-intensive production process, limited possibilities of factor substitution and lack of technological change. In addition, unlike other sectors prone to Baumol's disease, there are two aggravating factors in the case of transit: rising vehicle congestion (that acts as negative technological change at least when commercial kilometres are used as the output measure) and the absence of a demand antidote to this disease (the available evidence indicates the income elasticity of transit demand is low or even negative). We have found that another potential antidote to this disease, namely technical progress, seems to have been present (but modestly) in Buenos Aires, but not in Colombia.

Based only on the analysis of labour productivity (given that the analysis of technical change hasn't been validated with statistical tests) we could therefore expect public surface transport to become relatively more expensive for society; that is, the average cost of public transport will probably increase in real terms as the economy grows. The evidence for developed countries, reviewed earlier, indicates that this increasing trend is significant, and we found that this is probably also the case for the Latin American cities analysed in the present research.

Societies will then have to resolve the following dilemma: how should a service that gets progressively more expensive in real terms be funded? One answer is that service provision will naturally decline through time as it becomes more expensive. As shown by Spann (1977), this will depend on the relative value of the price and income elasticity of demand for transit. The elasticities reviewed in this paper would imply that in many cases, absent public intervention, transit demand (and possibly expenditure) will decrease through time and thus the pressure for additional funding would be reduced[34].

However, given the many externalities in the transport sector, letting transit wither away through lower private demand may not be socially optimal. If there is a welfare improving case for promoting and expanding transit services, then growing amounts of public funding will be required to keep fares sufficiently low to promote transit use. Care must be taken however that subsidies do not generate disincentives for productive efficiency and cost containment (X inefficiency and subsidies). Effective regulatory mechanisms, or competitive bidding, must complement any subsidy policy to avoid excessive costs due to productive inefficiencies.

Interestingly, from an aggregate point of view the higher resources required to maintain the supply of a service that suffers from Baumol's cost disease can be funded from the surplus generated in the dynamic sectors. Economic growth in the dynamic sectors more than compensate for the rising costs in the stagnant sectors. A society can allocate a rising share of GDP to a stagnant sector and still have more goods and services available from the other sectors. Dynamic sectors are both the root cause of Baumol's cost disease as well as its solution (at least as far as funding is concerned)[35].

For example, if the share of public transport services to total production decreases or remains constant over time, and according to Spann (1977) (assuming an iso-elastic demand function) will depend on income and demand elasticities, then public transport services could still be financed without any considerable problem even if subject to Baumol's cost disease. In the end, it will be a political budgetary decision. Understanding the nature of the underlying cause of rising

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[34] An interesting avenue for future research is to see whether Spann (1977) approach for testing for Baumol's cost disease applies to transit expenditure.

[35] Baumol (2012) attributes this intuition to the British economist Joan Robinson.

transit deficits, namely Baumol's cost disease, may be important in deliberations regarding this issue.

There are also other policy options to tackle the problem of stagnant (or falling) productivity in the transit sector. For example, measures to reduce traffic congestion. Evidence presented in this paper indicates that bus priority infrastructure, as in Buenos Aires, or BRT reforms in Colombia, may help to increase productivity in this sector. Also, road pricing schemes could help boost the productivity of public transport, but to date they have not been tested in the Latin American region.

Even if congestion is reduced, however, the productivity of public transport will most probably still grow at a lower rate than in other sectors of the economy. Therefore, transit costs are still expected to increase in real terms over time but perhaps at a lower rate if policies are introduced to tackle congestion.

The two metro cases (Panama City and Santiago) do seem to offer higher productivity growth, consistent with results from research in developed countries. In metro systems there are more technological possibilities to substitute labour for capital. In fact, new metro lines in the region (Sao Paulo line 4, Santiago lines 3 and 6 and others) are driver-less systems. Switching and communications technology used in metro systems also provide opportunities for cost reducing technological change that counteract Baumol's disease.

Can something similar occur with bus technology? The development of autonomous vehicle technology may provide a solution to Baumol's cost disease for bus services in the future. This technology offers to transform this sector from a labour intensive into a capital-intensive industry with ample possibilities for further technological improvements that increase total factor productivity growth[36]. Unfortunately, this technological revolution seems to be far off into the future. Litman (2018) predicts that autonomous vehicles will become common and affordable probably not earlier than 2040 or 2050. This prediction is only for

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[36] For autonomous vehicles to counter Baumol's cost disease technological change using this technology must be continuous. For example, the communications, electronic and software components of these vehicles and the accompanying infrastructure must be subject to continuous improvements, something that seems to the case for rail services as noted above. A once and for all discrete jump in productivity does not solve Baumol's cost disease, it only postpones its effect until rising costs start kicking in again. We thank an anonymous referee for pointing this out to us.

light vehicles with autonomous transit vehicles probably taking even longer to become a realistic technological option.

Although predicting the pace of technological diffusion is difficult and subject to uncertainty, with available information self-driving vehicles for public transport are still a distant development. Furthermore, it is still too early to assess the net effect that this technological innovation could have on the supply costs of transport systems and whether it could offer an effective antidote to Baumol's disease. For the foreseeable future then (i.e., next few decades) bus transit services will most probably remain a stagnant sector requiring increasing amounts of public funding to maintain supply and demand levels.

Regarding the possible limitations of this article, it is important to keep in mind that although the results seem to go in line with the presence of the Baumol's cost disease, they must be interpreted with caution. This is especially important when considering the labour productivity indicator based on the number of passengers, for in this case demand factors might also be part of the explanation. It is also true that Baumol's cost disease is a long-term effect, and our data covers periods which, depending on the city analysed, range from four to fourteen-years. Future research should attempt to confirm these results with data covering a longer time frame. It would also be interesting to test statistically the results found for the evolution of TFP and technical change, and to analyse that evolution relying also on parametric methods, which are less sensitive to extreme values and take into account statistical noise. Other possible avenues for future research could be to widen the geographical coverage by including countries that differ in terms of the organization and regulation of urban transport.

Bibliography

Asmild, M., Kronborg, D., and Rønn-Nielsen, A. (2018). Testing productivity change, frontier shift, and efficiency change. IFRO Working Paper 2018/07, University of Copenhagen, Department of Food and Resource Economics.

Asquith, B. (2011). Income elasticity of demand for large, modern rapid transit rail networks. *Undergraduate Economic Review*, 7:20.

Basso, L. J. and Silva, H. E. (2014). Efficiency and Substitutability of Transit Subsidies and Other Urban Transport Policies. *American Economic Journal: Economic Policy*, 6(4):1–33.

Baumol, W. J. (1967). Macroeconomics of unbalanced growth: The anatomy of urban crisis. *The American Economic Review*, 57(3):415–426.

Baumol, W. J. (2012). *The cost disease: Why computers get cheaper and health care doesn't*. Yale University Press.

Baumol, W. J. and Bowen, W. (1966). *Performing Arts, the Economic Dilemma: a Study of Problems Common to Theatre, Opera, Music and Dance*. Twentieth Century Fund, New York.

Berg, S. A., Førsund, F. R., and Jansen, E. S. (1992). Malmquist indices of productivity growth during the deregulation of norwegian banking, 1980-89. *The Scandinavian Journal of Economics*, 94:S211–S228.

Borger, B. D., Kerstens, K., and Álvaro Costa (2002). Public transit performance: What does one learn from frontier studies? *Transport Reviews*, 22(1):1–38.

Bradford, D. F., MALT, R. A., and OATES, W. E. (1969). The rising cost of local public services: Some evidence and reflections. *National Tax Journal*, 22(2):185–202.

Caves, D. W., Christensen, L. R., and Diewert, W. E. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometrica*, 50(6):1393–1414.

Cowen, T. (1996). Why i do not believe in the cost-disease: Comment on baumol. *Journal of Cultural Economics*, 20(3):207–214.

D, N. W. (2008). Baumol's Diseases: A Macroeconomic Perspective. *The B.E. Journal of Macroeconomics*, 8(1):1–39.

Dietrich, A. and Krüger, J. (2010). Numerical explorations of the ngai-pissarides model of growth and structural change. Darmstadt Discussion Papers in Economics 199, Darmstadt University of Technology, Department of Law and Economics.

Du, K. (2019). MALMQ2: Stata module to compute Malmquist Productivity Index. Statistical Software Components, Boston College Department of Economics.

Evangelinos, C., Wieland, B., and Kühnhausen, T. (2012). Baumol's cost disease in the local transit sector: A comparative analysis for germany and the usa. *International Journal of Transport Economics / Rivista internazionale di economia dei trasporti*, 39(1):83–104.

Färe, R., Grosskopf, S., Lindgren, B., and Roos, P. (1994). Productivity developments in swedish hospitals: A malmquist output index approach.

Gandelman, N., Serebrisky, T., and Suárez-Alemán, A. (2019). Household spending on transport in Latin America and the Caribbean: A dimension of transport affordability in the region. *Journal of Transport Geography*, 79(C):1–1.

Goodwin, P., Dargay, J., and Hanly, M. (2004). Elasticities of road traffic and fuel consumption with respect to price and income: A review. *Transport Reviews*, 24(3):275–292.

Graham, D. J. and Glaister, S. (2002). The demand for automobile fuel: A survey of elasticities. *Journal of Transport Economics and Policy*, 36(1):1–25.

Gómez-Lobo, A. (2020). Transit reforms in intermediate cities of colombia: An ex-post evaluation. *Transportation Research Part A: Policy and Practice*, 132:349–364.

Hensher, D. A. (1992). Total factor productivity growth and endogenous demand: Establishing a benchmark index for the selection of operational performance measures in public bus firms. *Transportation Research Part B: Methodological*, 26(6):435–448.

Litman, T. (2018). Autonomous vehicle implementation predictions: Implications for transport planning. Technical report, Victoria Transport Policy Institute.

Morales Sarriera, J. and Salvucci, F. P. (2016). Rising costs of transit and baumol's cost disease. *Transportation Research Record*, 2541(1):1–9.

Morales Sarriera, J., Salvucci, F. P., and Zhao, J. (2018). Worse than Baumol's disease: The implications of labor productivity, contracting out, and unionization on transit operation costs. *Transport Policy*, 61(C):10–16.

Ngai, L. R. and Pissarides, C. A. (2007). Structural change in a multisector model of growth. *The American Economic Review*, 97(1):429–443.

Obeng, K. (2011). Indirect production function and the output effect of public transit subsidies. *Transportation*, 38(2):191–214.

Obeng, K. and Sakano, R. (2008). Public transit subsidies, output effect and total factor productivity. *Research in Transportation Economics*, 23(1):85–98. Transit Economics.

Odeck, J. (2008). The effect of mergers on efficiency and productivity of public transport services. *Transportation Research Part A: Policy and Practice*, 42(4):696–708.

Oulton, N. (2001). Must the growth rate decline? baumol's unbalanced growth revisited. *Oxford Economic Papers*, 53(4):605–627.

Oum, T. H., Waters, W. G., and Yong, J.-S. (1992). Concepts of price elasticities of transport demand and recent empirical estimates: An interpretative survey. *Journal of Transport Economics and Policy*, 26(2):139–154.

Parry, I. W. H. and Small, K. A. (2009). Should urban transit subsidies be reduced? *The American Economic Review*, 99(3):700–724.

Pastor, J. T. and Lovell, C. K. (2005). A global Malmquist productivity index. *Economics Letters*, 88(2):266–271.

Pestana Barros, C. and Peypoch, N. (2010). Productivity changes in portuguese bus companies. *Transport Policy*, 17(5):295–302.

Pratt, R. and Iv, J. E. E. (2004). Traveler response to transportation system changes. TCRP Report B12-A, TRB.

Savage, I. (2004). Management objectives and the causes of mass transit deficits. *Transportation Research Part A: Policy and Practice*, 38(3):181–199.

Schwarz-Miller, A. and K. Talley, W. (1996). The relative bargaining power of public transit labor. *Research in Transportation Economics*, 4:69–85.

Small, K. A. and Verhoef, E. (2007). *The Economics of Urban Transportation*. Routledge.

Spann, R. M. (1977). The macroeconomics of unbalanced growth and the expanding public sector: Some simple tests of a model of government growth. *Journal of Public Economics*, 8(3):397–404.

Wardman, M. and Shires, J. (2003). Review of fares elasticities in great britain. Working Paper 573, Institute of Transport Studies, University of Leeds.

Wardman, M. and Shires, J. (2011). Price elasticities of travel demand in great britain: A meta-analysis. Working Paper 11-3544, TRB.

Winston, C. and Shirley, C. (1998). *Alternative Route: Toward Efficient Urban Transportation*. Brookings Institution.

Yu, M. (2008). Productivity change and the effects of the enhancement of the mass transportation programme on the bus transit system in taiwan. *Transport Reviews*, 28(5):573–592.

4.A Appendix 1: A simple model of the Baumol's Cost Disease

The theory of Baumol's disease can be formally explained with a simple model. Suppose there is only one input (labour) and that in sector 1 (stagnant) one unit of labour produces units of the good according to the following equation (Y_{1t} and L_{1t} represent the production level and the labour employed, respectively, and the subscript t refers to the time period):

$$Y_{1t} = aL_{1t} \tag{4.3}$$

In the dynamic sector, as shown in the following equation, one unit of labour produces $be^{\tau t}$ units of good 2, and τ represents the technical change that triggers productivity gains over time.

$$Y_{2t} = be^{\tau t}L_{2t} \tag{4.4}$$

An important assumption is that labour markets are integrated and thus wages in both sectors are the same and increase at the same rate τ:

$$w_t = w_0 e^{\tau t} \tag{4.5}$$

Production costs of good 1 C_{1t} and good 2 C_{2t} are given by:

$$C_{1t} = \frac{w_t Y_{1t}}{a} = \frac{w_0 e^{\tau t} Y_{1t}}{a} \tag{4.6}$$

and

$$C_{2t} = \frac{w_t Y_{2t}}{be^{\tau t}} = \frac{w_0 Y_{2t}}{b} \tag{4.7}$$

The relative cost of good 1 (the ratio of average costs of goods 1 and 2), is given by :

$$\frac{\frac{C_{1t}}{Y_{1t}}}{\frac{C_{2t}}{Y_{2t}}} = \frac{be^{\tau t}}{a} \tag{4.8}$$

We see that the relative cost of good 1 increases at a rate τ each period.

Another way of showing this is by taking logs of equation 4.6 and rearranging it to get:

$$\ln a = \ln w_0 + \tau t + \ln \frac{Y_{1t}}{C_{1t}} \tag{4.9}$$

Given that $\ln w_0$ and $\ln a$ are constant terms, we get that the log of average costs equals a constant c plus τt, which means that the average cost in the stagnant sector (sector 1) increases at the rate τ, which is the rate at which the productivity in the dynamic sector (sector 2) increases:

$$\ln \frac{C_{1t}}{Y_{1t}} = \alpha + \tau t \tag{4.10}$$

From this result we can make two related inferences. First, if productivity is stagnant in one sector of the economy relative to other sectors, then the relative costs of the products or services produced in the stagnant sector should increase through time. The flip side of this argument is that if relative costs of goods and services of a particular sector in the economy are observed to be growing relative to other goods and services in the economy, then this is an indication of stagnant productivity growth in that sector.

Conclusions: contribution, findings and limitations of this project

In this thesis I have examined questions related to the efficiency and productivity of institutions that are not owned but are regulated and partly funded by the state. In doing so, I have relied on both parametric and non-parametric methods and have tackled some methodological issues.

In what follows, a summary of the contribution, findings and limitations of this project is presented.

First paper

Contribution

This chapter analyses, in a multi-output framework and with parametric methods, the influence public funding may have on museums' technical efficiency. Other questions related to museums' technical efficiency have been considered previously in a multi-output setting but with non-parametric methods. The effect of public funding on that measure of efficiency has been studied in a single output setting with parametric methods. But this chapter (which I hope will turn into a journal article soon) is the first piece of work in which both multi-output and parametric aspects have been dealt with together. In addition, I consider the issue of monotonicity conditions by adapting and testing for the first time an input-oriented version of an existing linear-programming method to impose such conditions.

Findings

The conclusion I arrive at is that public funding has a positive and statistically significant influence on technical efficiency, with a marginal effect of 0.49%. This result holds when several environmental variables are included and also when different measures of public funding are considered. In a single-output setting the influence of public funding on technical efficiency appears to be null. Oher findings include museums requiring more inputs if they either have special responsibilities (which makes sense as producing more outputs requires employing more inputs) or manage more visit sites (which might reflect scale economies).

Limitations

It is unfortunate that panel data models cannot be estimated because the degree of variation is too low and the panel too short to allow the individual effects to be identified. It is likely that many unobserved characteristics at the museum level (which panel data models could control for) may alter the results. Secondly, many museums do not produce one or more of the six outputs included in our analysis. In such a case those observations are translated into missing values (the logarithm of zero is undefined), which stochastic frontier models cannot handle, so they are dropped from the sample. So this first paper can be considered to be representative of those museums that produce the entire set of outputs under analysis. Finally, given the stochastic nature of this model, we cannot be sure about the exogeneity of the regressors, hence these conclusions are only provisional.

Second paper

Contribution

This chapter is the first time a ray-based input distance function is derived and estimated (in the previous literature only an output-oriented version of this function had been derived and tested). This allows us to include all observations in a stochastic frontier model when logarithmic functions are used to approximate the unknown production technology, regardless of whether all the outputs under analysis or only some of them are produced by the corresponding productive entity. This methodological contribution is interesting because having productive units producing a subset of the outputs considered is a common problem in many sectors, and the fact that it is an input-oriented function means that it is suitable to model production processes in which managers have more control over inputs than over outputs. We expect this methodology to be an alternative to methods based on production functions that, although can accommodate zero-valued outputs and inputs, have their own shortcomings.

Finally, the chapter addresses a weakness of the ray stochastic function, namely that it may be sensitive to the ordering of outputs. We have implemented two approaches that the have been suggested in the literature to deal with this problem (Huang and pin Lai, 2012): the model selection method, according to which the ordering of model exhibiting the highest likelihood ratio is the one to be chosen, and the averaging selection method, which assigns weights to all possible orderings and based on them it estimates the final model.

Findings

We test the model with the same database used in the first chapter. The results indicate that state-recognised museums in Denmark appear to have an average technical efficiency of 1.33, which indicates that the museums use on average 33% more of each input than would be required to produce the given output quantities. The average elasticity of scale indicates considerable productivity gains from getting larger, although this appears to be the case of small to medium sized museums, whereas larger museums experience decreasing returns to scale. It is interesting that the results in terms of these two indicators proved very similar with both the model selection method and the model averaging method.

Museums having special responsibilities beyond those that the majority of museums are obliged to comply with, appear to need more inputs to produce a given level of the outputs under analysis. A result that appears to be counter-intuitive is that the greater the number of visit sites, the lower the level of inputs museums require to produce a given level of outputs, i.e., museums would not be taking advantage of scale economies related to operating in a single location. More in-depth research is required to clarify this, although, as we have indicated in the conclusions to both this and the previous chapter, with panel data models we could arrive at different conclusions (see paragraph below).

Limitations

As in the case of the first paper, panel data models proved infeasible to estimate because the degree of variation is too low and the panel too short to allow the individual effects to be identified.

Third paper

Contribution

This is the first time the Baumol Cost Disease is being tested in urban passenger transport systems of less-developed countries. This is important from a policy perspective, as the Baumol Disease, if present, may generate fiscal pressures requiring increasing subsidies as a source of funding of this sector. This is also the first time a transitive productivity index (the Global Malmquist Index, proposed by Pastor and Lovell (2005)) has been used in transport economics.

Findings

There appears to be some evidence of lagged labour productivity, a key component of the Baumol Disease theory. The results suggest that this problem affects surface transport but not underground systems, a finding that makes sense from a theoretical perspective and has been confirmed for developed countries by the previous literature. The majority of the results in the present paper have been obtained using regression models for apparently long-enough panel data in many Colombian cities as well as in Buenos Aires (Argentina), and complemented by some descriptive evidence based on short data series in Santiago (Chile) and the capital city of Panama. The results also indicate, in the cases of for which enough data is available, that there is technical regress in the case of Colombia, which reinforces the problem driven by the decline in labour productivity, hence aggravating the consequences of the Baumol effect. In Buenos Aires there appears to be some technical progress (although economically modest).

Limitations

It would be interesting to see whether the results for Colombia hold if the motorization rate at the city level were obtained and controlled for; this variable was obtained in the case of Buenos Aires. The variables chosen to estimate the technical change and the changes in total factor productivity in the case of Argentina are, according to the previous literature, appropriate, but in the case of Colombia one of these variables (number of workers) couldn't be obtained, and the analysis relied on a measure of capital that might not be ideal. In addition it would be useful to see whether the results obtained for Colombia hold if the number of buses operators' workers at the city level is included in the analysis. Finally, statistical tests of the estimates of technical and TFP changes were not implemented, something that is left for a future research venture and could be done relying on the method proposed by Asmild et al. (2018).

As noted above, the three papers that comprise this thesis make a number of contributions in different fields. They also suggest some questions yet to be addressed, hence contributing to defining an interesting research agenda for the future. This prospect is attractive for me, because I am keen to learn more about efficiency and productivity analysis with both parametric and non-parametric methods, and to continue making contributions in transport and cultural economics, as well as in other fields where these methods could be applied.

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