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Working paper

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1. Introduction

An important step in railway reforms in France was so-called regionalisation, whereby the State delegated the organisation and financing of regional rail services to the "Régions".[1] This measure has been trialled since January 1997 in seven volunteer regions, and was extended to all French regions on January 1st 2002. Unlike most other European countries, France has chosen to keep the incumbent operator in a monopoly position in each region. This situation ended on December 3, 2019, from when each region is free to choose another operator. As of December 25, 2023, competitive awarding will become the rule for rail services operated under public service contracts. Consequently, a period of intense negotiations between the historical operator (SNCF)[2] and each French region is about to begin. Indeed, a significant and continual rise in the production costs of regional rail and, consequently, the scale of public subsidies, raises serious questions about the financial sustainability of the current organisational model. While this issue is currently on the agenda of the regions, SNCF is also facing the challenge of remaining an attractive operator in this emerging competitive environment.

In this paper, we explore the productive efficiency of the regional passenger rail services (RPRS) in France, by econometrically studying the production frontier of regional rail operators. The use of the frontier method to measure productive efficiency in the rail industry has already given rise to several studies (Asmild, Holvad, Kronborg, 2009; Bouf and Peguy, 2001; Cantos and Maudos, 1999, 2001; Cantos and alii., 2012; Coelli and Perelman 1999; Cowie and Riddington 1996; Friebel, Ivaldi and Vibest, 2010; Gathon and Perelman 1992; Lerida-Navarro, 2019; Merkert, Smith and Nash, 2012; Oum and Yu 1994; Oum, Waters and Yu, 1999; Smith and Nash, 2014). These papers mainly focus on the benefits of competition

[1] Metropolitan France is currently divided into 13 administrative regions (as opposed to 22 before January 2016). These regions have extensive powers in the fields of transport, secondary and higher education and vocational training, economic development and innovation, spatial development and the environment.

[2] SNCF: Société Nationale des Chemins de fer Français.

and vertical or horizontal separation. Fewer studies specifically address regional rail passenger transport: Farsi, Filippini and Greene (2005) on regional railway companies in Switzerland, Mizutani, Kozumi and Matsushima (2009) on the situation in Japan, Link (2016) on rail franchises in Germany. Regional rail transport in France has almost never been investigated because of a lack of publicly available data.[3] However, this is an interesting topic because of the regional monopoly nature of the operators.

This paper focuses on the productive efficiency of French regional rail operators. In this framework, we shall address the following research questions: (i) what is the productive efficiency of each region and (ii) which factors are correlated with efficiency levels. In particular, we shall test whether factors related to the societal environment, the rail production system, the contractual arrangements and mode of governance, as well as to the quality of rail transport production are correlated with efficiency. Replying to the first research question also allows us to characterise and analyse the productive system of regional rail operators and the heterogeneity of French regions.

We shall answer these research questions by applying a stochastic frontier approach. The output of our model is the volume of production measured in train-kilometres and its inputs (or productive factors) are labour, energy and circulating capital (rolling stock). To determine the effect of the environment on productive inefficiency, we decided to test a set of four factors, some of which are not used in conventional studies: the socio-economic environment (population density and crime rate), the characteristics of the regional rail system (number of stations, length of network, age of rolling stock), the quality of the service (lateness and cancelation rates) and the ties between the operator and the transport authority in terms of contractual arrangements and mode of governance (contract accuracy and financial incentives).

[3] With the notable exception of two papers by Lévêque (2004, 2005).

This study takes advantage of two entirely unique databases, one on management data from the regional rail operators between 2012 and 2016, and the other on the characteristics of the contracts between the national railway operator, through its regional operational units, and each of the local authorities, the 20 regions, as institutional clients.

This paper contributes to the literature by explicitly addressing the regional monopoly nature of the operators in a productive efficiency framework. Moreover, following Link (2016, 2019), we introduce original variables related to the societal environment in the analysis and show how useful they are for understanding differences in efficiency between regions. Finally, our results feed into the scientific literature on productive efficiency in regional rail. In particular, we propose possible explanations for the differences in efficiency observed between regions in a monopoly context.

Our results are of interest for several reasons. As we describe the productive system of the regional rail industry in France, this analysis is important for each regional rail operator because it allows them to compare themselves with other regional operators. At the same time, it is also of interest to the transport authorities, namely the regions, as it provides them with the information they need to improve their calls for tender and contracts. There is a great need for knowledge of the productive system at this time when rail passenger transport is being opened up to competition.

The paper proceeds as follows: Section 2 outlines the institutional characteristics of the regulation of this sector in France. Section 3 presents successively our research hypotheses and the specifications of our model. Section 4 deals with our data. Section 5 estimates the production frontier and the determinants of inefficiency. Section 6 contains a discussion and recommendations for policy makers. Section 7 concludes.

2. The French regional railway: an untypical institutional framework

The institutional design of the regional rail passenger services in France is based on five nationally-specific characteristics.

2.1. A historical rail operator in a monopoly position on the regional market up until now

While the regional rail market in all major European countries is open to competition, this is not the case in France where the historic operator exploits a monopoly position: SNCF is the only firm that operates Regional Express Trains (also called *TER* for "Transport Express Regional").

Almost all European countries have abolished the monopoly of the incumbent operator for regional passenger rail services (RPRS), which allows regional services to be apportioned, either by direct award or by tender. Observations show that the vast majority of contracts for regional rail passenger services, operated as Public Service Obligations (PSOs) in European countries are awarded directly. Only four European countries allocate their regional rail passenger services by means of a bidding process: the United Kingdom, Sweden, Germany and Bulgaria. The few countries that, like France, have maintained the monopoly of the incumbent operator include Belgium, Luxembourg and Spain (IRG, 2019). In France, this liberalisation of the rail market only began in December 2019, the last date provided for by the European law EC 2007/1370, the so-called PSO Regulation. France finds itself in this very untypical position because of an unashamed and regularly reaffirmed political decision. Thus, while in the 1990s, the European Commission had set its sights on the revitalisation of rail transport through a reorganisation of the sector based on more competition (EC 1991, 1996; Di Pietrantonio, Pelkmans, 2004), France has been the spokesperson for a counter-project of "putting the incumbent operator under progressive pressure" by reforms instigated by rail regionalisation (Chauvineau, 2001). All in all, while most major European countries have decided to open regional rail passenger services to competition, the French legislator has deliberately opted for a different route (IRG-Rail, 2019).

2.2. A transfer of the organisation and financing of regional passenger rail services to regional authorities

In common with several other European countries (such as Germany, Italy, Poland, Spain, and Switzerland), France has decided to transfer the jurisdiction of the State's RPRS to local authorities, the so-called regions. The SRU Law of 13 December 2000 provides the legal framework for rail regionalisation in France. This law stipulates that in all parts of metropolitan France (except Ile-de-France and Corsica) the regions would, from 01/01/2002, become fully responsible for the organisation and financing of their public transport services. Thus, the regions determine the routes, pricing, quality of service targets and provide user information. In particular, they decide on the volume of supply (number of train kilometres) to be produced by the operator. To do this, the local authorities must enter into exclusive negotiations with the SNCF to obtain a contract for the production of this public transport service. In order to ensure the regions have the greatest possible financial neutrality, the State has undertaken to offset the cost of operating the transferred services on the basis of the services that ran in the year 2000. But in fact, since on average passengers pay only 25 per cent of the cost of the service, any increase in supply ordered by a local authority results in an increase in subsidies.

2.3. An economic model based on very low-incentive contracts

The model of contract required by the SRU law provides little incentive for the historical railway operator to increase its productive performance, as the Regions have to balance the SNCF operating account, *a posteriori*. The *ex post* operating deficit is made up in full by the Public Transport Authorities (PTAs). In more detail, the regional rail operating subsidy is calculated on the basis of the difference between the commercial target revenue and the operating costs. This regional public subsidy is, at the margin, modulated by the impact of a system of penalties and bonus penalties that target the quality of production. Expressed in terms of the economics of contracts, in France, the economic model of the RPRS is of the "Management contract" type, which is the inverse configuration of the "Net Cost contract" where both the industrial risk (costs) and the commercial risk (receipts) are borne by the operator. In contract theory the term for this is a Cost-Plus contract (Laffont and Tirole, 1993). This contractual design is doubly atypical. It is atypical in France for urban public transport where "net cost contracts" are now dominant (Roy, Yvrande-Billon, 2007), whereas, until 1990, cost-plus contracts prevailed (Gagnepain, Ivaldi, 2002). This configuration is also atypical in the RPRS market, since in Europe the rail operator generally bears both the industrial risk (costs) and the commercial risk (receipts) in return for a great deal of responsibility and real entrepreneurial freedom (ERRAC, 2006). Finally, compared to other European countries, the French regional rail framework testifies to a reluctance to introduce competition and a desire to protect the (precarious) financial equilibrium of the historic railway operator (Broussolle, 2002; Gauthier, 2003).

2.4. Risk sharing to the advantage of the rail operator

A detailed analysis of the sharing of risks between the rail operator and the regional public authority shows financing agreements that are broadly consistent with a risk-averse historical monopoly (Desmaris, 2010). The PTA and the railway operator share the commercial risk. In practice, this risk is generally limited for the SNCF, which is assigned an annual revenue target. Thus, the rail operator benefits from most of the revenue that exceeds the contractual objective, and conversely, the delegatee must bear the financial consequences of traffic below the objective.

Industrial risk, related to changes in production costs, is borne in full by the local authorities. The principle of flat-rate regional rail operating costs would normally mean the operator bears the industrial risk, but in reality, the situation is more complex, for three reasons. Firstly, only those charges that can be managed by SNCF are fixed, other operating expenses, such as tolls, are re-billed in full, as we have seen above, to the Regions. Secondly, the SNCF's operating costs are very carefully indexed in order to neutralise variations in exogenous factors that are not controlled by the operator (the cost of energy in particular). Thirdly, in half the regions, the operator benefits from a specific remuneration (which we shall refer to below as "Operator compensation") intended to cover this so-called "industrial risk". This additional remuneration, calculated as a percentage of the flat-rate operating costs, is sometimes very advantageous for SNCF (by example in the regions of Provence-Alpes-Côte-d'Azur and Alsace).

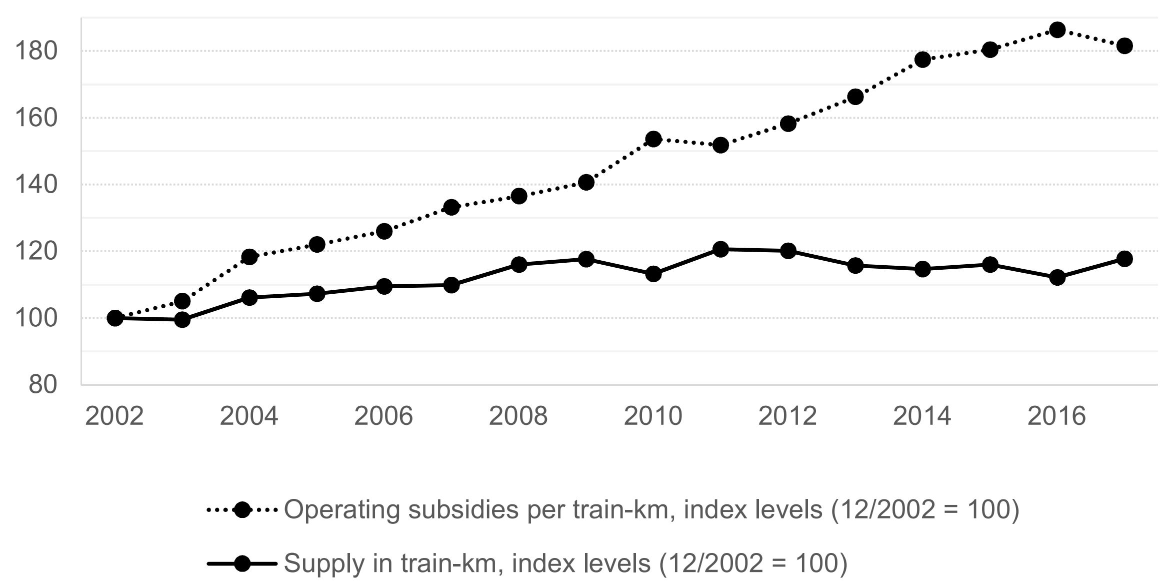
As regards the investment risk, the Regions are willing to bear most of the financial burden, more than 90 per cent on average (Desmaris, 2010). The French Regions, in a desire to make regional trains more attractive to passengers were keen to be highly proactive and therefore spend money on them. Part of this regional financial burden is nevertheless reimbursed by the State under the commitments made in the SRU law. In reality, this compensation has become marginal because of the considerable capital expenditure by the regions.

2.5. A continual rise of subsidies to public regional passenger rail services

The continual increase in subsidies makes the Regions doubt the financial sustainability and efficiency of this public policy. The public contributions allocated to the RPRS are rising in a sustained and almost constant manner. While in 2002, public subsidies were of the order of €1.986 billion, fifteen years later in 2017 they amounted to €3.379 billion, a 70 per cent increase or an average annual increase of 3.6 per cent in current values. And this growth does not correspond to an additional investment effort (in rolling stock, station modernisation or the rail network), the share of which in total public subsidies has been reduced from an average of 26.7 per cent in 2002-2009 period to an average of 14.8 per cent in 2010-2017.

This substantial increase in operating subsidies can hardly be explained by an increase in the volume of service provision. It is mainly due to a constant rise in the unit operating cost. In fact, the number of train-kilometres increased by only 18 per cent between the end of 2002 and the end of 2017, while the unit operating subsidy increased by approximately 82 per cent (€9.4 per train-kilometre in 2002 to €17.2 in 2017). Clearly, the price effect far outweighs the volume effect.

Figure 1. Operating subsidies and supply in French regional rail (2002-2018)



Source: our calculations from ARAFER, 2018; Region of France, TCR database; CGDD, 2018.

In theory, this "rail inflation" can be attributed to two main causes: the first is the PTA's transport policy, for example when new services are created at marginal costs that are higher than average costs or with socially advantageous pricing; the second is the inefficiency of the rail production system which is unable to achieve economies of scale and lower average operating costs.

This railway inflation in France is all the more of a problem since it is not an intrinsic feature of this industry which in other European countries has shown itself to able to achieve productivity gains and limit its need for public contributions.

In Switzerland, for example, we observe a sharp decline in the public contributions paid to the CFF, the incumbent operator, per unit produced for the RPRS. While there has been a significant increase in train-kilometres, public contributions have remained virtually stable; helping to reduce the contribution per train-km from 10.5 Swiss Francs in 2002 to 7.8 Swiss Francs in 2015 (Desmaris, 2014). According to some analysts, this performance can be attributed to the new contract design (Farsi and *alii*., 2005), or even more, to the public governance framework (Desmaris, 2014). Following the 1996 rail reform, the coverage of *ex post* deficits was replaced by coverage of *ex ante* deficits, which places much greater demands on rail operators.

A similar result was achieved in Germany by different means, an institutional reform using competitive mechanisms for the market. Since 1996, the Lander are able to award regional rail passenger services by tender (mandatory procedure in 2011). These reforms have several positive effects: a significant increases of the supply, an even greater increase in the volume of traffic and substantial savings in costs and public contributions (Link, 2019), while preserving the profitability of the incumbent operator in this segment of the market (Desmaris, 2010). On average, the competitive bidding procedures have lowered the level of public compensation by 20 to 30 per cent compared with DB's pre-regionalisation unit cost. Link and Merkert (2011) underline the point that the large number of PTAs allows competition of ideas and learning from best practices across the sector.

In Sweden, the institutional framework is different; regional and interregional transport market has been gradually opened up to competition since 1992. The reduction of the unit cost of rail transport, including services provided by the incumbent SJ, is of the order of 20 per cent for the public authorities (Alexandersson, Rigas, 2013).

In these three cases, the common factor is that the public service contracts are of the "Net cost" type, which means it is not possible for the operator to obtain *ex post* compensation for its unforeseen deficits. The anticipated deficit is the only deficit covered by the public authorities. With the changing legal framework of regional rail contracting in France, SNCF will no longer be the only available choice for the regional public authorities and the incumbent will also be seriously challenged in this traditional and significant market (50 per cent of all domestic SNCF circulations).

Our productive inefficiency estimation will make it possible to inform the incumbent about the efforts needed to remain competitive in each of the French regions. It will also inform the regional authorities, as an institutional client, about the business opportunities that may result from choosing to stay with the historical rail operator. Better identification of the explanatory variables that best explain productive inefficiency should also help the stakeholder community improve the efficiency of the regional railway system in France.

3. The Methodology

3.1. The hypotheses

In this paper we aim to model the productive efficiency of railway companies operating within a regional market. Some authors consider regulation and contractual variables (see a non-exhaustive review of related studies in Appendix 2), but only Link (2016) has introduced both environmental variables and policy variables into their rail productive efficiency function. We follow Link's methodology by introducing environmental and contractual variables that are appropriate to a monopoly context.

Let us detail and justify each of the hypotheses tested in the model.

Hypothesis 1. Each SNCF regional rail operator can be considered as an individual firm whose productive performance can be analysed.

Although many rules apply uniformly to railway production in all French regions, such as those relating to the status of employees (hiring, organisation of work and remuneration) or safety (commercial speed, on-train staff numbers, etc.), many other characteristics of railway production result from choices made regionally by the operator or the PTA or from local conditions (rail network or socio-economic characteristics).

In practice, each of the twenty French regional operators or DTERs ("Direction TER"), is an autonomous decision centre. It has its own budget and specialised management team. Analysis of the regional rail contracts reveals that specific types of relationship exist between the DTERs and their PTAs (Desmaris, 2004, 2010). The level of productive performance is therefore potentially different from one region to another.

Hypothesis 2. The rail operator's productive performance (minimisation of its inputs for an assigned output) depends on the entire system that surrounds it.

As observed in many studies in the field of urban public transport (Van de Velde, 1999; Roy, Yvrande-Billon, 2007; Hensher, Stanley, 2008; Sorensen, Gudmundsson, 2010; Faivre d'Arcier, 2014; Hirschlorn et al., 2019), but only a few in the case of rail (Leveque, 2004, 2005; Link, 2016), we have assumed that the productive efficiency of a public transport system results from a large set of factors. These include operational factors, which depend on decisions made by the operator or the PTA, as well as external factors, such as the demographic and socio-economic characteristics of the environment and aspects of governance (the influence of public policy objectives, contractual arrangements and procurement modes).

In this study, we introduce and test four correlations between efficiency and four groups of factors: the societal environment, the railway production system itself, the contract and governance by the PTAs and non-quality in rail production. The presumed role of each of these is described below.

Hypothesis 2.1. The societal environment affects the rail operator's efficiency.

Following Link (2016), we assume that the productive performance of the railway system is affected by a large set of environmental factors, which may constitute constraints or opportunities. These may be geographical (surface area, natural barriers, etc.), demographic (population density) or relate to the population's socio-economic status (car density; unemployment or delinquency rate). In this study, we consider two societal factors.

- Population density. As suggested by Link (2016), higher population density lowers production costs per unit. The consolidation of rail traffic and efficient interchanges with other modes permit higher train frequencies (or even interval-service timetables), making it possible to better optimise rosters. Rail remains a system that is suitable for mass transport. Peri-urban areas provide a very suitable environment for regional trains.
- Delinquency rate. To capture how sociocultural factors impinge on the rail system and the risks of additional costs associated with anti-social behaviour, we follow Lévêque (2004, 2005) and use the regional delinquency rate as an indicator. In fact, a high delinquency level obliges the railway operator to increase the number of staff working in the areas of rail safety and reception and screening of passengers on platforms. In addition, delinquent behaviours produce disruptions that affect the scheduling of traffic and increase costs as a result of additional regulatory demands and expenditure on staff and equipment. Indeed, the rail system is extremely vulnerable to anti-social behaviour.

Hypothesis 2.2. The rail production system affects the rail operator's efficiency.

Several parameters of the railway operation are not determined by railway operators, but by the network manager and the PTA. In this study, we will assess the impact of three main elements, the network, the stations and the rolling stock.

- The rail network, on which the regional services run, is obviously essential to the robustness of timetables and more generally to the quality of transport services. Its extent, technical quality (speed limits, single or double track, electrification, etc.) and even its morphology (whether or not it matches regional passenger flows) will affect an operator's ability to produce efficiently (Zembri, 1997). The older the network, the greater the risk of a slowdown in commercial speed, which leads to extra costs for rolling stock and on-train staff. Following established practice in rail studies (Smith and Nash, 2014), we describe the rail network on the basis of its length. This variable determines the returns to scale, that means how costs change when a firm grows geographically. In practice, the larger a network is, the greater the potential impact of the optimisation of rolling stock and staff rosters. Conversely, the longer the journeys, the higher the probability of delay or cancellation, with their consequent additional costs.
- The stations (in terms of their number and location) improve traffic flow. From a technical point of view, stations allow trains travelling in opposite directions to cross and rolling stock or staff to enter or leave the network. Conversely, in the case of large (national) stations or stations through which different types of traffic pass, the risk of congestion is high leading to additional costs. In this study, we have decided to consider the number of stations. This factor has not yet been used in regional rail efficiency studies, except for Great Britain (Wheat and Smith, 2014).
- The rolling stock plays an important role in the efficiency of a rail undertaking, especially tractive vehicles. Reliable, powerful, equipment helps to reduce delays or service cancellations due to reliability issues. The robustness of the rolling stock also tends to reduce maintenance costs. In line with Leveque (2004), we have retained the average age of the tractive vehicles. We would have liked to measure the variety of

rolling stock types, as was done by Wheat and Smith (2014), but our statistics were not sufficiently reliable.

Hypothesis 2.3. The type of public contract design and the governance mode affect the rail operator's efficiency.

While the literature recognises the importance of contracting for rail operator efficiency (Farsi, 2005; Link, 2016, 2019; Mizutani and *alii*., 2009; Nash and *alii*., 2019; Smith and Nash, 2014), the usual typology of contracts (cost-plus and fixed-price contracts) is inappropriate for France. This is because all contracts are "cost-plus" in a monopoly context. Consequently, we have used another methodology to analyse French regional rail contracts that is based on the new institutional economics (Williamson, 1985, 1996) and detailed by W. Powell (1990). This methodology had already been used fruitfully applied in transport research (Sørensen, Gudmundsson, 2010), but it seems to be completely new in the literature on rail productive efficiency.

To develop a practical approach to the analysis of regional rail transport governance, we have referred to three types of governance modes, namely 'market', 'hierarchy' and 'network' to characterise the relationship between the monopolistic rail incumbent and the regional PTA. 'Market', 'hierarchy' and 'network' are distinctive ideal types of governance modes, able to organise, coordinate and govern an activity or sector. Each of them has specific characteristics (Table 1).

Table 1. Characteristics of the governance modes

	Market	**Hierarchy**	**Network**
Key to coordinate	Mutual interest / "Invisible hand"	Constraints / Visible hand of management	Cooperation / Mutual trust
Means of communication	Prices and contracts	Procedures / Routines / Administrative fiat	Relational
Climate or tone	Accuracy / Complete contracts	Formal / Bureaucratic	Open-ended / Mutual benefits
Methods of conflict resolution	Resort to court for enforcement	Supervision / Constraints	Reputational concerns
Penalty type	Financial (bonus, malus, penalty)	Entry of competitors	Declining reputation
Operating conditions	Incentive contracts	Contestable Market	Common culture

Source: Adapted by the Authors from Powell (1990), Desmaris (2004) and Sørensen, Gudmundsson (2010).

- The market. Coordination is based on mutual interest through price mechanisms and complete and incentive contracts. If this coordination mode fails, the party responsible for the failure has to bear a financial burden.
- The hierarchy. Relationships are based on constraints and the authority of the supervisor through a set of procedures or routines in a formal and bureaucratic climate. If the contestability conditions of the market are met, the entry of new competitors will penalise transgressions.
- The network. Transactions are characterised by cooperation, mutual trust, open-ended relations and mutual benefits. In this context of a common culture, reciprocal and preferential actions, opportunist behaviours will tarnish and weaken the guilty party's reputation.

As ideal types, each governance mode does not include the others. Nevertheless, in practice, governance mechanisms are mixed: every governance arrangement combines a different mix of these three ideal types, depending on the context. (Sørensen, Gudmundsson, 2010).

We have constructed an index that characterises the degree to which the contract is market governance-based. For this, we follow the methodology used by Desmaris, 2004.[4] This index is between 0 and 1 and is called "incentive governance".

So far, we have introduced two variables in our model that are distinctive of the French regional rail governance context. One is the importance of the market governance mode in the contract (what we have termed 'Incentive governance'). We have added a second variable, which is easier to obtain and to explain, and quite well linked to economic contractual theory (Masten and Saussier, 2000; Ménard C. and Saussier S., 2000), the accuracy of the contract. This is basically expressed by its physical volume (number of pages in the contract and the technical specifications).

<u>Hypothesis 2.4. Non-quality in rail production affects the rail operator's efficiency.</u>

Non-quality (Link, 2019) in rail production is usually measured by two main indicators: the rate of delay and the rate of cancellation. There are many reasons for non-quality. In France, the official classification (AQST, 2018) distinguishes between internal causes due to operational problems (difficulties to do with managing rail traffic, the operation of stations, managing on-board personnel and rolling stock, managing passengers - influx, disabilities and connections) and external causes that are not associated with operation (railway infrastructure and causes that are external to transport such as the consequences of weather, strikes and delinquency). For French regional rail services, internal causes are generally more frequent than external causes, however this varies from one region to another and from one year to the next (AQST, 2018).

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[4] During 2012-2016, for each regional rail contract, we observed 17 significant items (detailed in Appendix 1), and detailed and quantified for each contract the number of features which are market-, hierarchy- and network-based. At the end of this process, we obtained for each of the 20 French regions the importance of the three governance modes. For example, for contracts in the PACA region in 2006-2016, the percentages were 19/19/62. This means that 'Market' and 'Hierarchy' governance modes are less prevalent (19 per cent each) than 'Network' governance (62 per cent in among the types of contract we observed.

Non-quality impairs the productive efficiency of the rail operator. Late trains disrupt the movement of other trains and impose additional operation costs, particularly during rush hours. In addition, non-quality increases organisational costs for the rail operator, which must be able to provide additional resources (equipment or personnel) to deal with the problem.

3.2. Measuring efficiency

The first objective of this paper is to measure the efficiency of regional rail operators. We have done this by means of stochastic frontier analysis. A few remarks are needed to justify this approach.

First, each regional rail operator can be considered as an individual firm whose productive performance can be analysed (Hypothesis 1). Although some uniform rules apply to railway production in all French regions, many characteristics of railway production result from choices which are made in a given region. Consequently, one can expect the productive performance to vary from one region to another.

Second, the regional rail operator does not choose the pricing scheme. The pricing strategy has an effect on demand. Therefore, it is not valid to examine the attractiveness of the service, also called 'marketing efficiency' (by comparing the commercial output, for example the passenger-km, with the supply, for example train-km) (Cantos and Crozet, 2014).

Third, the regional rail transport authorities and the regional rail operators are separate entities. The regional rail transport authorities decide on the output produced by the rail operator. For this reason, the inefficiency of the rail operator cannot be interpreted in terms of production shortfall in view of a certain level of inputs, but more in terms of an excess use of inputs to produce a given input.

For these reasons, what we want to measure is the degree to which inputs are minimised for a given output. This is what Smith and Nash (2014) have termed the technical efficiency. A range of econometric approaches can be used to estimate this. We have used stochastic frontier analysis applied to panel data. This frontier model is made up of a production function with an error term which includes an inefficiency part and a noise part, as described below.

The standard stochastic Cobb-Douglas production function for a rail operator i at time t implies that:

$$Y_{it} = \exp(\beta_0) \times \prod_{k=1}^{K} (X_{kit})^{\beta_k} \times e^{\varepsilon_{it}} \tag{1}$$

where Y_{it} is the output for firm i at time t, $\exp(\beta_0)$ is the total factor productivity, X_{kit} is the quantity of inputs (or production factor) k for firm i at time i, β_k is the output elasticity with respect to the input k, and $e^{\varepsilon_{it}}$ is an error term.

The log form of Equation (1), used for estimation, is

$$\ln(Y_{it}) = \beta_0 + \textstyle\sum_{k=1}^{K} \beta_k X_{kit} + \varepsilon_{it}. \tag{2}$$

The specificity of the frontier method is that the expectation of the error term is not null but negative. The error can therefore be split in two parts such that

$$\varepsilon_{it} = -u_{it} + v_{it} \tag{3}$$

where $u_{it} \geq 0$ accounts for technical inefficiency, and v_{it} for statistical noise. We have used Shepard's output-oriented technical efficiency, denoted by TE and defined as the ratio between the observed output and the frontier output, obtained when the inefficiency is null ($u_{it} = 0$):

$$TE = \frac{\exp(\beta_0) \times \prod_{k=1}^{K} (X_{kit})^{\beta_k} \times e^{-u_{it}+v_{it}}}{\exp(\beta_0) \times \prod_{k=1}^{K} (X_{kit})^{\beta_k} \times e^{v_{it}}} = e^{-u_{it}} \tag{4}$$

Several specifications of the inefficiency u_{it} and of the error v_{it} have been used in the literature. Following Henningsen (2019), we have assumed that the noise term v_{it} follows a normal distribution with zero mean and constant variance σ_v^2:

$$v_{it} \sim N\,(0, \sigma_v^2) \tag{5}$$

Since we have panel data, we tested the following specifications for the inefficiency term u_{it}:

$$u_{it} = u_i \quad u_i \sim N^+(\mu, \sigma_u^2) \tag{6}$$

$$u_{it} = u_i \times \exp\big(-\eta(t - T)\big) \quad u_i \sim N^+(\mu, \sigma_u^2) \tag{7}$$

The specification described in Equation (6) implies that each regional rail operator has a fixed individual efficiency that remains constant over time, whereas Equation (7) describes an individual efficiency for each operator that can change over time at a steady rate η and in the same direction. A positive (resp. negative) η indicates that efficiency rises (resp. decreases) over time. In both specifications the inefficiency term u_i follows a positive truncated normal distribution with mean μ and a constant scale parameter σ_u^2.

3.3. Identifying the causes of inefficiency

The second objective of this paper is to identify variables which are correlated with inefficiency. For this purpose we have applied the model proposed by Battese and Coelli (1995) in which the inefficiency term is affected by additional variables. In this specification the inefficiency term u_{it} is described as follows:

$$u_{it} \sim N^+(\mu, \sigma_u^2) \quad \mu = \delta_0 + \textstyle\sum_{j=1}^{J} \delta_j Z_{jit}. \tag{8}$$

Where Z_{jit} is the quantity of variable $j \in J$, and $\delta_0, \ldots, \delta_J$ are coefficients to estimate.

4. Data

We have used a unique panel dataset of 20 French regional rail operators between 2012 and 2016 (5 years). The regions of Île-de-France and Corsica are not included in the sample because of their specific organisational characteristics.[5] Table 2 gives a summary of the data and sources[6] for the 20 French regions and rail operators in our sample.

In the French regulatory context, the regional rail operator does not set prices, which have a direct effect on the number of passengers. Therefore the preferred operator output on which to base an efficiency analysis is the number of train-kilometres in one year, and not the number of passenger-km. This assumption is common in the literature (Roy and Yvrande-Billon, 2007; Asmild and *alii*., 2009, Mizutani and *alii*., 2009; Link, 2016). Couto and Graham (2009) tested both passenger-km and train-km as an output in their stochastic frontier cost model, and found that train-km gave the best goodness of fit.

The inputs in this study are the rolling stock, labour and energy. The rolling stock is measured by the number of tractive vehicles, precisely by the sum of the number of locomotives and self-propelled railcars. Labour is estimated on the basis of the train operation staff costs. We computed this variable as the sum of the costs for drivers, ticket inspectors, in-station staff and support staff. This is not problematic because all regional operators use the same salary grid. Similarly, energy is measured by energy costs in Euros.

The Z_{ijt} in Equation (8) represents variables for which we want to test the correlation with rail operator inefficiency (see Hypotheses 2.1 to 2.4 set out in Section 3. We introduced the following variables:

- Population density: the number of inhabitants per square kilometre

[5] The rail operator in Île-de-France does not operate conventional regional trains but suburban trains (namely the Transilien and RER services). There are two railway lines in Corsica, but they are not part of the national rail network. These two regions have therefore been excluded from the analysis.

[6] The management data on the TER have been provided by the Association of the Regions of France (ARF). The data are only available for 2012 to 2016 (five years). The data on the regional rail contracts signed between each French region and the rail operator were obtained after requests by the author to each region, under the right of access to administrative documents. Other data used in this study were obtained from public databases (INSEE, AQST) or from a specialized journal (Ville Rail et Transports).

- Delinquency rate: the number of crimes and offences per 100 inhabitants
- Network length: the length of the regional rail network
- Average age of rolling stock: the average age of the tractive vehicles (locomotives and self-propelled railcars)
- Number of rail stations: the number of railway stations in the region
- Contract accuracy: the number of pages of the contract and of the bill of specifications.
- Incentive governance: the regional rail contract can follow 3 contractual governance patterns. Incentive governance is a measure of the percentage of the observed contractual items in a regional rail contract that reflect the market governance mode.
- Lateness rate: the number of trains which are more than 5:59min late at the end of the line (terminus) per 100 trains
- Cancellation rate: the number of cancelled trains per 100 trains

Table 2: Descriptive statistics for the dataset.

Variable	Label	Mean	sd	Min	Max	No. of obs.
Output						
Train-km (Million km)[1]	$TrKm$	8.66	5.09	3.40	27.98	100
Inputs						
Rolling stock (Tractive Vehicle)[1]	RS	111.03	64.83	37.00	387.00	100
Labour (Million €)[1]	Lab	100.72	61.91	36.91	315.00	100
Energy (Million €)[1]	En	9.00	5.60	2.80	37.51	100
Efficiency determinants						
Population density (Inhab/km²)[2]	$Dens$	108.41	66.96	43.53	327.11	100
Delinquency rate (per 100 inhab.)[3]	$DelRa$	2.40	1.04	0.94	5.54	100
Network length (Thousand km)[4]	$Netlen$	1.09	0.35	0.57	2.00	100
Rolling stock average age (years)[4]	$RSAge$	14.15	3.77	6.70	22.51	100
Number of rail stations[4]	$NbSta$	130.93	54.41	49.00	344.00	100
Contract accuracy[5]	$ConAcc$	85.05	34.03	28.00	178.00	100
Incentive governance (per cent)[5]	$IncGov$	36.55	12.71	18.00	59.00	100
Lateness rate (per 100 trains)[6]	$LatRa$	8.31	3.05	3.42	17.29	73
Cancelation rate (per 100 trains)[6]	$CanRa$	1.95	1.18	0.80	7.33	73

(1) Source: Enquête annuelle sur les Transports collectifs régionaux - DGITM, CGDD, CEREMA – Régions de France - GART – UTP - FNTV, years 2012, 2013, 2014, 2015 and 2016.

(2) Source: INSEE. https://www.insee.fr

(3) Source: Interstats. https://www.interieur.gouv.fr/Interstats/

(4) Source: Ville, Rail & Transport N°564, 574, 587, 598 et 611.

(5) Source: C. Desmaris. Own database.

(6) Source: Autorité de la qualité de service dans les transports (AQST)

5. Estimation results

5.1. Measuring the technical efficiency of regional rail

Table 3 shows the results of estimation of the following log-transformed Cobb-Douglas production function:

$$\ln(TTrKm_{it}) = \beta_0 + \beta_1 \ln RS_{it} + \beta_2 \ln Lab_{it} + \beta_3 \ln En_{it} + \beta_4 TechChange + \varepsilon_{it} \quad (9)$$

We have used a panel Random Effects Model (REM) to estimate Equation (9) in column (1) in order to detect inefficiency.[7] We have used Stochastic Frontier Analysis (SFA) in columns (2), (3) and (4).[8] Column (2) contains the results of the estimation of the coefficients in Equation (9), with no technical change ($\beta_4 = 0$) and with individual fixed efficiency as described in Equations (5) and (6). In column (3) we have included the technical change variable. Column (4) contains the results of the estimation of Equation (9) with an efficiency that can change over time, as described in Equation (7).

[7] The random effects model assumes that the intercept in Equation (9) is regional operator-specific, such that $\beta_{0i} = \overline{\beta_0} + e_i$, where $\overline{\beta_0}$ is the population average. The error term of the random effects model is $e_i + \varepsilon_{it}$. It has zero mean, and a variance equal to $\sigma_e^2 + \sigma_\varepsilon^2$.

[8] The SFA estimations are performed by the "frontier" add-on package (Coelli and Henningsen, 2010) for the statistical environment R.

Table 3: Production frontier estimates.

Models	(1) OLS	(2) SFA Time-inv. eff.	(3) SFA Tech. change	(4) SFA Time-var. eff.
Frontier				
Intercept	-1.357***	-1.354***	-1.441***	-1.432***
	(0.246)	(0.156)	(0.166)	(0.156)
ln(Rolling stock)	0.026	0.038	0.049	0.042
	(0.037)	(0.038)	(0.038)	(0.037)
ln(Labour)	0.690***	0.722***	0.746***	0.749***
	(0.061)	(0.045)	(0.048)	(0.048)
ln(Energy)	0.090***	0.090***	0.058	0.061*
	(0.029)	(0.029)	(0.038)	(0.034)
Technical change			-0.005	
			(0.004)	
Efficiency				
η				-0.022
				(0.014)
Residuals				
$\sigma^2 = \sigma_u^2 + \sigma_v^2$		0.023*	0.024*	0.026*
		(0.012)	(0.013)	(0.014)
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$		0.937***	0.941***	0.945***
		(0.024)	(0.034)	(0.058)
R2	0.71			
Residuals skewness	-0.056			
Log likelihood		146.7	147.2	147.9
AIC		-279.34	-278.85	-279.78
BIC		-261.10	-258.01	-258.94
No. of observations	100	100	100	100
No. of individuals	20	20	20	20
No. of periods	5	5	5	5

Notes. This table reports estimations of Eq. (9) using the REM and assuming that $\beta_{0i} = \overline{\beta_0} + e_i$, $e_i \sim N\ (0, \sigma_e^2)$ and $\varepsilon_{it} \sim N\ (0, \sigma_\varepsilon^2)$ (column (1)), using SFA and assuming $\varepsilon_{it} = -u_{it} + v_{it}$ with $v_{it} \sim N\ (0, \sigma_v^2)$ in columns (2), (3) and (4). In columns (2) and (3), $u_{it} = u_i$ and $u_i \sim N^+(\mu, \sigma_u^2)$. In column (4), $u_{it} = u_i \times \exp(-\eta(t-T))$ and $u_i \sim N^+(\mu, \sigma_u^2)$. In columns (2) and (4), $\beta_4 = 0$. The dependent variable is ln(Train-km). The standard deviations are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

All the estimations were performed on the whole sample. The overall quality of our estimated models is acceptable: the R2 value is high for the REM (R2= 71 per cent), and the coefficients of the other models are of same order of magnitude as for the REM. The coefficient estimates seem to be acceptable as their signs are consistent with previous econometric work. As expected, the coefficients of the production factors are positive.

The REM regression in column (1) suggests that the three production factors used in the model are good predictors of the number of train-km (R2= 71 per cent). The skewness of the residuals is weakly negative (-0.06), meaning that the residuals are slightly left-skewed (the residual plot is available in Appendix 3). This suggests that not all regional rail operators are technically efficient and provides grounds for a more thorough efficiency analysis.

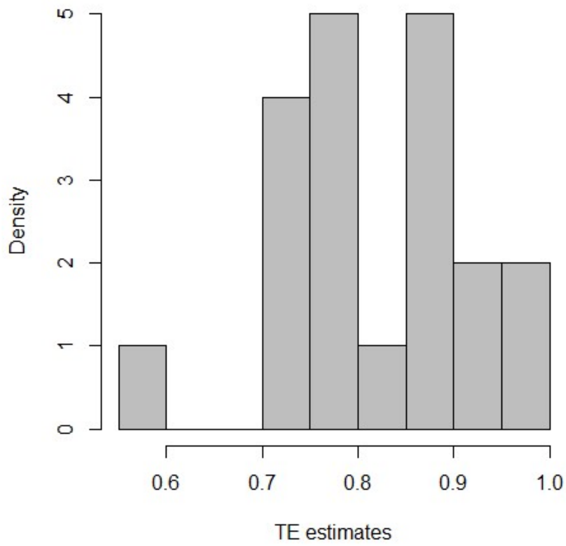
The additional coefficients estimated in columns (3) and (4), respectively relating to technical change and changes in efficiency over time, are not statistically significant. We have not observed any technical change or changes in efficiency in our sample. This is confirmed by comparisons between the AIC and BIC values. Our preferred model is therefore that in column (2).

We shall now consider the results for the production function. The correlation between the production frontier and two factors of production, labour and energy, is significant at the 0.01 level. The estimated coefficients show that the elasticity of the rail production frontier measured in train-km with respect to the labour costs stands at around 0.72 ($\hat{\beta}_2 = 0.722$), whereas the elasticity with respect to the energy costs is around 0.09 ($\hat{\beta}_3 = 0.09$). The measured total factor productivity in the industry is around 0.26 ($\exp(\hat{\beta}_0) = 0.258$).

The size of σ^2 and γ means that σ_u^2 and σ_v^2 are above zero. It indicates that both the inefficiency term u and the statistical residual v are needed to explain the deviations from the frontier, and that the inefficiency is greater than the noise.

We can estimate the time-invariant technical efficiencies of a regional rail operator by using the parameters estimated in column (2) of Table 3[9]. We give the distribution of these technical efficiencies in Figure 2. The estimated technical efficiencies range from 59 to 98 per cent and average 82 per cent with a standard deviation of 0.095. It should be borne in mind that these values are not absolute but relative to the best performers in the sample.

Figure 2. Distribution of estimated time-invariant technical efficiencies of regional operators



5.2. Identifying causes of regional rail production inefficiency

Table 4 shows results of estimation of the Cobb-Douglas specification described in Equation (2): (10)

$$\ln(TTrKm_{it}) = \beta_0 + \beta_1 \ln RS_{it} + \beta_2 \ln Lab_{it} + \beta_3 \ln En_{it} + \varepsilon_{it}$$

where $\varepsilon_{it} = -u_{it} + v_{it}$, $v_{it} \sim N\,(0, \sigma_v^2)$ and $u_{it} \sim N^{+}(\mu, \sigma_u^2)$, as described in Equations (6) and (7). We have assumed the following specification for the expectation of the truncated normal distribution of the inefficiency term u_{it}:

---

[9] We have calculated the values with the formula specified by Olsen & Henningsen (2011): $\widehat{TE} = E[e^{-u}] = \Phi\left(\frac{\mu_*}{\sigma_*} - \sigma_*\right) e^{-\mu_* + \frac{1}{2}\sigma_*^2} / \Phi\left(\frac{\mu_*}{\sigma_*}\right)$, where Φ is the cumulative distribution function of the standard normal distribution, $\mu_* = (1-\hat{\gamma})\hat{\mu} + \hat{\gamma}(-u+v)$, $\sigma_* = \sqrt{\hat{\gamma}(1-\hat{\gamma})\hat{\sigma}}$, $\hat{\sigma} = \hat{\sigma}_u + \hat{\sigma}_v$, and $\hat{\gamma} = \hat{\sigma}_u/(\hat{\sigma}_u + \hat{\sigma}_v)$.

$$\mu = \delta_0 + \delta_1 Dens_{it} + \delta_2 DelRa_{it} + \delta_3 NetLen_{it} + \delta_4 RSAge_{it} + \delta_5 NbSta_{it} + \delta_6 ConAcc_{it} + \delta_7 IncGov_{it} + \delta_8 LatRa_{it} + \delta_9 CanRa_{it}. \quad (11)$$

In column (1) the model estimates the effects of societal environment variables on efficiency. In column (2) we added the rail production system variables, and in column (3) the contractual governance variables. In the last column we tested the effects of the production quality variables. However, this last test suffers from a smaller sample size, as the production quality data were only available for 73 of the 100 observations.

The production frontier estimates in Table 4 are not directly comparable to those in Table 3 because the structure of inefficiency was specified differently. In particular, here inefficiency was assumed to vary across time and between different operators. We have therefore not commented on the coefficients of the production frontier function. The estimations are nevertheless interesting because they make it possible to identify the variables that are correlated with inefficiency.

Our interpretation of the coefficient of the efficiency effects is as follows: a negative coefficient means that μ in Equation (8) decreases with the related variable, which implies a smaller inefficiency term u_{it}, and, ultimately, greater efficiency.

The correlations between the societal environment variables and the rail operator efficiency are statistically significant. A higher population density (inhab/km²) increases production efficiency whereas a higher delinquency rate decreases it.

Some characteristics of the rail production system also affect efficiency. A larger number of stations is correlated with higher efficiency. The sign of the effect of network length is unclear, being non-significant in column (2), negative in column (3) and positive in column (4). We cannot reach a robust conclusion for this variable. In addition, the average age of the rolling stock does not appear to be significant, but we have some doubts about the quality of our data.

Contractual aspects are highly correlated with rail operator efficiency. Firstly, the coefficient that characterises the incentive nature of the contract is positively correlated with efficiency. The regions which include more financial incentives in their contract and develop market governance relations, in a spirit of mutual interest, obtain better efficiency levels than those whose approach is more focused on a "hierarchy" or "network" approach. Secondly, the coefficient associated with "Contract accuracy" is positive. This variable seems to have a negative effect on efficiency, in contrast with predictions based on contract theory. We have assumed that the less efficient the regional rail operator, the more the local authorities want to control its operational management point-by-point, and vice versa. By implementing an accurate and bulky contract, the public authority hopes to supervise every detail of the rail operator's production process.

Our results concerning the quality of rail service variables are difficult to interpret. The cancellation rate is not significant in terms of productive efficiency. The coefficient of the lateness rate is negative, which means that late trains are correlated with higher efficiency. We do not have plausible explanation for this relation.

Table 4: Frontier and efficiency estimates.

Model	(1)	(2)	(3)	(4)
Frontier				
Intercept	-1.927***	-1.605***	-1.655***	-1.869***
	(0.166)	(0.128)	(0.103)	(0.202)
ln(Rolling stock)	0.230***	0.177**	0.181***	0.206***
	(0.056)	(0.072)	(0.040)	(0.066)
ln(Labour)	0.658***	0.637***	0.655***	0.646***
	(0.068)	(0.076)	(0.044)	(0.097)
ln(Energy)	0.061	0.075**	0.047*	0.056
	(0.038)	(0.035)	(0.026)	(0.058)
Efficiency				
Intercept	-0.070	0.194*	0.085	-0.255
	(0.113)	(0.106)	(0.089)	(0.268)
Societal Environment				
Density	-0.002***	-0.001*	-0.001***	-0.003*
	(0.001)	(0.001)	(0.000)	(0.002)
Delinquency rate	0.135***	0.095***	0.095***	0.573***
	(0.038)	(0.030)	(0.018)	(0.218)
Rail production system				
Network Length		0.003	-0.128**	0.692**
		(0.092)	(0.057)	(0.291)
Average age of rolling stock		-0.000	-0.002	-0.005
		(0.004)	(0.003)	(0.009)
Number of stations		-0.002**	-0.002***	-0.007***
		(0.001)	(0.000)	(0.002)
Contractual Governance				
Incentive governance			-0.002***	
			(0.001)	
Contract accuracy			0.002***	
			(0.000)	
Rail production quality				
Lateness rate				-0.085**
				(0.034)
Cancelation rate				0.068
				(0.043)
Residuals				
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.022***	0.016***	0.005***	0.009***
	(0.009)	(0.006)	(0.001)	(0.003)
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	0.972***	0.973***	0.881***	0.291
	(0.027)	(0.023)	(0.093)	(0.285)
Log likelihood	90.3	95.7	139.0	76.03
LR Test Pr(>Chisq)	0.000***	0.000***	0.000	0.000***
No. of observations	100	100	100	73
No. of individuals	20	20	20	19
No. of periods	5	5	5	4

Notes. This table reports estimations of Eq. (10) and (11) with $\varepsilon_{it} = -u_{it} + v_{it}$, $v_{it} \backsim N\ (0, \sigma_v^2)$ and $u_{it} \backsim N^+(\mu, \sigma_u^2)$. The dependent variable is ln(Train-km). The standard deviations are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 4 does not allow us to analyse the magnitude of the effect of the variables on the technical efficiency. We have therefore estimated the marginal effect on the technical efficiency levels of the variables whose estimated coefficients are statistically significant.[10] These estimates are displayed in Table 5, and the complete distributions are available in Appendix 4. These marginal effects are of interest because they measure the possible gain in efficiency due to changes in the magnitude of the factors.

Table 5: Estimates of marginal effects on technical efficiency levels.

Factor	Mean	sd	Min	Max
Density	0,00005	0,000009	0,00001	0,00006
Delinquency rate	-0,00403	0,000768	-0,00478	-0,00085
Number of rail stations	0,00008	0,000016	0,00002	0,0001
Contract accuracy	-0,00013	0,000025	-0,00016	-0,00003
Level of incentives in the contract	0,00012	0,000023	0,00003	0,00014

6. Discussion

In this section, we shall discuss our results and set out their policy implications for each of our two research questions.

6.1. A better understanding of French regional rail's productive efficiency before the opening up to market competition

This study provides some original results about French regional rail's productive efficiency before the opening up to market competition. The regional technical efficiency levels were estimated by using parameters estimated by Model (3) of Table 4. This is our preferred model because it has the highest log likelihood. Due to data confidentiality, the regions have not been explicitly named in the following figures and commentaries.

The distribution of efficiency scores by region (Table 6) is of interest for two main reasons.

Firstly, the average efficiency is 82.2 per cent. This means that, on average and given their current provision of inputs, French regional rail operators could gain 18 percentage points in

[10] We computed the estimates of the marginal effects on the technical efficiencies according to the formula given in Olsen & Henningsen (2011).

efficiency if they all adopted the best practices of the incumbent operator (SNCF). This also means that huge efficiency improvements could be obtained in many regions without appointing a new operator, if technical efficiency success factors could be implemented throughout their network.

Table 6. Regional rail Technical efficiency in France. Average 2012-2016.

Region ranking	**Technical efficiency (in percentage)**	**Deviation from average (in percentage points)**	**Category**
1	97.8	15.6	Excellent
2	97.8	15.5	
3	93.3	11.0	Good
4	91.8	9.6	
5	89.9	7.7	
6	89.7	7.5	
7	88.6	6.3	Average
8	86.0	3.8	
9	85.1	2.8	
Mean	82.2	0.0	
10	81.3	-1.0	Average
11	79.4	-2.9	
12	78.5	-3.7	
13	78.0	-4.3	
14	77.7	-4.6	
15	76.5	-5.7	Poor
16	74.6	-7.6	
17	74.5	-7.7	
18	73.4	-8.8	
19	71.7	-10.6	
20	59.3	-22.9	Very poor

Source: own results.

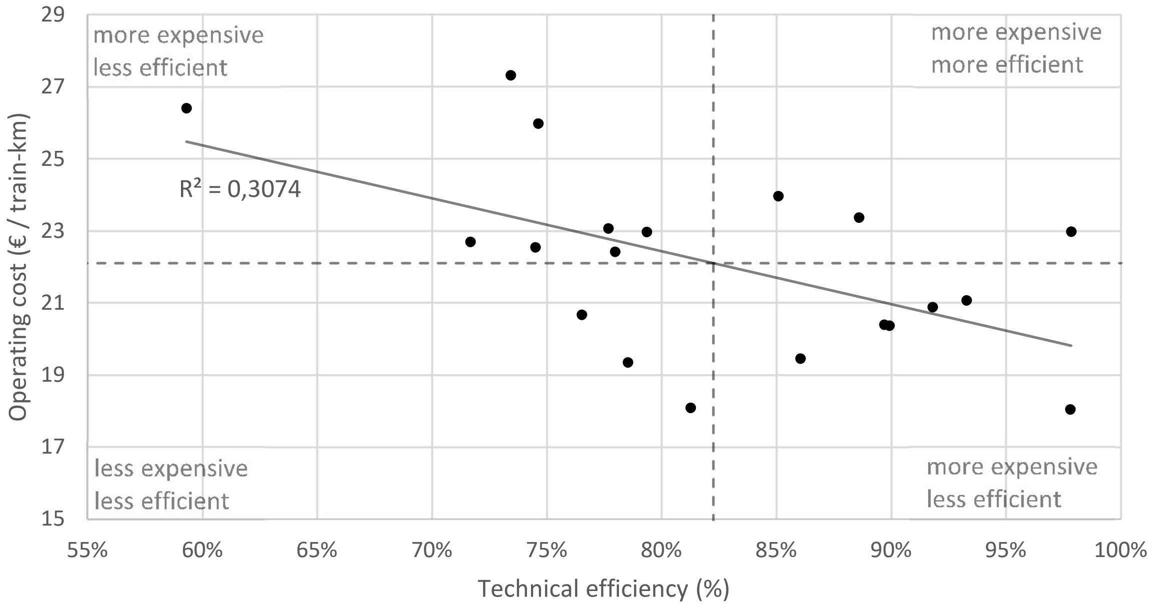
Secondly, the distribution of efficiency scores by region illustrates a broad range of situations with a wide distribution of scores, ranging from 59 per cent for the least efficient region (ranking 20th) to 98 per cent for the two most efficient regions (ranking 1st and 2nd).

Dividing the regions into 5 groups allows us to distinguish more clearly between the performance of the different regional rail operators. We have taken multiples of the standard deviation (value 10 per cent) as the threshold values. The categories are 57 per cent ≤ Very poor < 67 per cent ≤ Poor < 77 per cent ≤ Average < 87 per cent ≤ Good < 97 per cent ≤ Excellent. The results are quite clear. Eight regions (40 per cent) are close to the average, while six are above it and six below. Two regions are highly efficient, with around 98 per cent of the maximum efficiency. At the opposite end of the distribution, one region is marked out by an extremely low score (below 60 per cent). From the governance perspective, with a few exceptions, the contracts of the most efficient regions primarily adopt the "Market" governance approach, and conversely, the contracts of the least efficient regions primarily adopt the "Network" governance approach.

Technical efficiency levels are of interest because they consider the differences in the provision of inputs between regions. In Figure 3 we display the efficiency levels and the per km operating cost for each region. Interestingly, we do not observe a clear-cut correlation between operating cost and productive efficiency (R2=30.7 per cent).

Some regional operators have a high operating cost but are efficient, and others have a low operating cost but are not efficient.

Figure 3. Technical efficiency and operating cost per regional operator (2012-2016 average)



Source: own results.

Notes: Each dot represents a regional operator. The dashed lines show the sample averages. The full line is the first-order approximation of the relationship between technical efficiency and operating cost.

In 70 per cent of cases (14/20) a region obtains a similar positioning (with respect to the northwest to southeast diagonal) with the two methods. Thus, eight regions are both expensive and inefficient, and six regions are on the contrary well positioned in the two rankings, with inexpensive rail production and a high technical efficiency score.

This comparison is interesting in that it shows the importance of adopting various methods in order to obtain an accurate picture of railway performance, as suggested by Smith and Nash (2014).

6.2. A more comprehensive regional rail productive efficiency model

In this study, we have improved the methodology for measuring the productive efficiency of regional rail by applying a stochastic frontier model in two ways.

Firstly, to build our explanatory rail productive efficiency model, we decided to introduce a large set of efficiency factors. This "systemic perspective" is a new approach compared with conventional regional rail efficiency studies (see Appendix 2). We have introduced four kinds of variables, societal environment, rail production system, contractual and governance mode, and quality of the service.

Our results confirm the relevance of these variables, except for those related to service quality. The rail transport operator's productive performance appears to be correlated with many factors. These are not only internal to its own production 'box', but also involve the environment, in which we include societal (social, demographic or economic) factors as well as contractual and governance aspects.

The policy-making implication of this result is substantial: improving the regional rail operator's production efficiency is not easy. Improving the quality of management (achieving the best combination of the volume, quality and input prices) is obviously necessary, but not enough in itself. Factors for which the operator is not responsible also matter. It is necessary to improve the infrastructure (tracks, signalling equipment, the ability of trains to cross one another, the number of stations and platforms) as well as the rolling stock. All these aspects are the responsibility of the network manager, but also of its funders, the State and the regions. Decision-making is therefore long and complex. It is even more difficult to modify the societal environment. It is virtually impossible to act, at least in the short term, on macro-social variables such as population density or delinquency rate, for example.

The production efficiency of regional rail operators is also impacted by the contract specifications. It seems that the more accurate the contact, the more efficient the operator. This result is in line with the standard theory of the economics of contracts (Laffont and Tirole, 1993). We tested the effect of some other contractual clauses, such as the duration of the contract and additional remuneration of the operator for industrial risk, but our results were not sufficiently robust to be presented here. In this long term relationship, the policy-making implication is that public authorities should negotiate extremely comprehensive and accurate contracts. We have observed in the case of France that in all regions the size of the contracts grows each time they are renewed.

Secondly, we consider the specific contractual and governance features of each French region. To the best of our knowledge, our model is the first to propose a specific methodology for analysing regional rail contracts and their governance mode for monopoly operators. In this specific context, the usual contract categories (gross cost, net cost or management contracts) are not relevant. This is the first time our methodological approach based on institutional economics (Powell, 1990; Williamson, 1985, 1996) has been applied to regional rail studies.

We have observed that the public contracts and governance in the French regional rail sector are in fact a mixture between the "Market", "Authority" and "Network" patterns. This result is in line with the findings of other studies on public utilities (Ménard, Saussier, 2000) or other transport modes (Sørensen, Gudmundsson, 2010). Our model underlines the positive impact on rail productive efficiency of the level of "Market" governance in this contractual mix. It suggests that incentive contractual clauses and a business-oriented governance mode are beneficial.

The policy-making implication here is probably to recommend that public authorities should design their contractual relationship very carefully when dealing with a monopoly provider. The results set out in Table 5 show that this is the most promising (and least expensive) way to increase efficiency. We also suggest the national rail regulator should be more interested in contractual aspects and collect data about contractual specifications. This is not currently the case in France. The French transport regulator (ART, previously ARAFER) is tasked with collecting a large amount of technical and management data from rail operators[11]. It is, however, not allowed to collect contractual data. This is necessary in the perspective of sunlight

[11] Transport code, art. L. 2132-7 et L. 1264-2 and ARAFER Decision 2016-052 of 13 April 2016 and 2017-045 of 10 May 2017.

competition as is clear from the case of other countries with regional rail monopolies, such as Switzerland (Farsi and *alii*., 2005) and Japan (Mizutani and *alii*., 2009).

6.3. Limitations

It would be interesting to supplement our efficiency models by testing other variables. In the case of some variables this was impossible due to a lack of data, for example network morphology, age, intensity of use, or the load factor of trains. It is also regrettable that the lack of data prevents us from taking a longer view in order to grasp the dynamics of the contract and check the robustness of our results.

6.4. Further research

Further research could enhance our understanding of efficiency in several respects. Firstly, as the period covered by this study generally corresponds to the so-called "third generation" TER agreement, while a fourth generation agreement is in the process of being drafted we could extend the period under review. This would allow us to study the dynamics of contractualisation. Secondly, since 2015, the administrative division of France into regions has changed, with the number of regions falling from 22 to 13. It will be important to consider this and to address the question of optimal size from policy maker and operator perspective.

7. Conclusion

This paper has used a panel stochastic frontier model to measure and explain the productive efficiency of monopoly regional rail passenger operators in France. This study focuses in particular on the productive structure and the regional monopoly nature of rail operators, and also considers the effect on efficiency levels of societal factors. Our results are of two types. The first are empirical and specific to the French regional rail monopoly context. The second are methodological and therefore transferable to other regions and countries.

Supported by two unique databases, this study reveals that the levels of productive efficiency of the incumbent rail operator in France are highly contrasted from one region to another, with the technical efficiency score between 2012 and 2016 ranging from 59 to 98 per cent, with an average of level of 82 per cent. This means that many regions could improve their measured rail technical efficiency, without appointing a new operator, as soon as the SNCF is able to implement its best practices in all parts of the country.

We also show how the French rail operator's productive performance, in a monopoly situation, depends on a large set of factors. Some of them are exogenous to operators, making improvements long and complex to achieve. Regarding the contractual relation between the regional rail operator and the transport authority, the "Market" is beneficial for efficiency. This suggests that incentive contractual clauses and a market-oriented governance mode improve rail productive efficiency.

By using a stochastic frontier model, this study offers a complementary approach to simple productivity ratios (ARAFER, 2018; Court of Auditors, 2009; 2019). We have found that the levels of productive performance are not systematically the same in the two approaches.

These findings about the French regional rail market are useful for regional decision-makers, new comers and the incumbent operator in order to inform the ongoing and upcoming re-negotiations of their contracts. In the perspective of better regulation of the regional rail competition, our results suggest that the transport regulator should collect more detailed and comprehensive data, including on contractual aspects.

Regarding the methodology for measuring regional rail productive efficiency by using a stochastic frontier model, we can report three major findings.

First, labour and rolling stock are highly significant inputs for estimating the output, measured in terms of train-kilometres per year. This result is in line with the literature.

Second, the “systemic perspective”, based on a large set of explanatory factors, is well-suited to the French case. Variables from three of the four groups of factors considered in our model are correlated with regional rail’s technical efficiency: the societal environment criteria, in particular the population density and delinquency rate; the specifications of the railway production system, including the length of the network and the number of stations; contractualisation, the contractual completeness (accuracy) and the governance mode (‘market-oriented’). This result suggests that Link’s methodology (2016) is appropriate in order to explain regional rail efficiency (for cases other than Germany and France) and should be applied to other countries.

Third, this paper analyses regional monopoly railway contracts and governance patterns by using a specific methodology based on institutional economics. This approach highlights the importance of the contractual ties and governance patterns between public authorities and railway operators in order to analyze regional rail productive efficiency.

In the current context of widespread competition in regional passenger rail transport throughout Europe, these findings open up many possibilities for future research, both in France and in other European countries.

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