The Benefits of Procurement Auctions: Competitive Pressure vs. Selection of Efficient Suppliers

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Abstract

We study how the quantity of regional train services and the procurement price in Germany change when an agency uses procurement auctions rather than negotiations. We exploit a 1996 reform that allowed regional rail agencies to use procurement auctions. Our empirical analysis shows that procurement auctions increase the frequency of service by 12%, and decrease the procurement price of a train kilometer by about 23%. Adopting a structural auction framework, we find that the price reduction has two sources. Competitive pressure reduces markups substantially, and more efficient suppliers participate in the auction, reducing costs. Procurement auctions increase surplus on regional railway lines by about 20%.

Keywords: Auctions, negotiations, liberalization, passenger railways, public procurement

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1 Introduction

The nature of public procurement has changed dramatically over the last decades. Until the nineteen eighties, state-owned companies provided a wide range of goods and services. Most importantly, network industries such as electricity, gas, water, railways and postal services were state monopolies in many countries. The wave of privatization and deregulation in the nineteen eighties led to institutional change all over the world. The retreat of the state and the introduction of competition were supposed to foster efficiency and help to reduce taxes. Yet, early enthusiasm for privatization and liberalization has given way to a more critical assessment of policies introducing competition in the public domain. Reasonable arguments can be made for privatization and competition, but the efficiency-enhancing effects of these measures cannot be taken for granted.

We focus on the effects of competition in public procurement. This is an important topic because procurement amounts to approximately 13% of GDP on average in OECD countries (OECD 2013, p.18). In addition, auctions and negotiations are the main forms of public procurement of goods and services. Yet it is not clear which of the two modes is superior. There are at least two theoretical reasons why procurement auctions might lead to lower procurement prices than direct negotiations with an incumbent supplier. First, competition puts pressure on firms to submit lower bids. Second, procurement auctions tend to pick more efficient suppliers.[1]

However, the literature has cast serious doubts on the functioning of competitive procurement. First, it is not obvious that the benefits of competitive procurement will indeed materialize. The desirable effects of competition on prices may be absent if firms collude or bid conservatively because they are afraid of the winner's curse in a common value framework. Second, competitive procurement may have substantial costs. Whenever quality is non-verifiable and price competition is unlimited, there is a strong reason that low prices come at the cost of low quality. This study will deal with the first rather than the second concern. We provide an example where competition has had strong beneficial effects on prices and on the supply of services (in quantitative terms). We also argue, much more tentatively, that there are no strong reasons to believe that these positive effects mirror quality reductions in the case at hand.

Specifically, this paper analyzes the effects of competition on the procurement of passenger railway services by public agencies in Germany. Many European countries gradually liberalized the sector since the nineteen nineties. As a result, negotiations and competitive procurement now coexist, sometimes even within countries. Germany is a case in point. In January 1996, the German *Regionalisierungsgesetz* ("Regionalization Law") came into effect. This law stipulates that state agencies are responsible for the assignment of public funds to individual lines; and that they can procure the services using direct negotiations with the dominant supplier, *DB Regio*, or via auctions. The law was part of a policy to expand public transportation and, in particular regional rail transportation. In the period under investigation (1994-2004), the funds for regional passenger transportation increased substantially, resulting in a drastic increase of the supply of railway services. There is widespread

[1] Also, it has sometimes been argued that an obligation to use competitive procurement can help to fight corruption (e.g., Chong et al. 2014) or "passive" waste (Bandiera et al. 2009).

agreement that regional passenger transportation has developed positively in the period under consideration, but it is less clear whether this was due to the introduction of competition or merely to the inflow of additional funds.

The German setting provides a unique opportunity to compare the performance of lines procured competitively with those procured via negotiations. The central empirical issue is whether these different types of lines are comparable. Agencies were free to select lines for procurement auctions. Thus, the choice of procurement mode is not random. We address this important issue by collecting rich information on the frequency of service on the lines before and after the introduction of the reform to characterize the choice of procurement mode. A key concern is that agencies might have selected lines that would have grown most with auctions, in ways unobserved to us. Selection based on expected growth has an important testable implication: auctioned lines would have lower service levels prior to the reform than negotiated lines, all else equal. Our data show that regional passenger service agencies used auctions predominantly on remote lines that were not very frequently served before the reform. This is consistent with selection of lines based on quantities before the reform or selection based on expected growth. However, once we condition on observed characteristics, we find no difference in the pre-reform frequency of service between lines to be auctioned and lines that were negotiated with the incumbent. This finding suggests selection was not based on the expected growth of service on a line.

We find that, compared to direct negotiations, procurement auctions increase the frequency of service by about 10-15%. Moreover, we show that winning bids in procurement auctions are about 20% lower than prices under negotiations. Procurement auctions in the German regional passenger rail sector thus produced substantial gains in service, at a substantially lower price. An open question is whether the advantages of competitive procurement indeed come at the cost of lower quality, as one might expect. While we do not have adequate data to answer this question definitely, the limited evidence we have provides no reason for the conjecture that competitively procured lines are plagued by systematically lower quality than negotiated lines.

Auctions can reduce prices by forcing bidders to ask for lower markups to deliver a service, or by selecting providers who have lower costs of providing a service. Understanding which of the two channels operates is important. If auctions lower markups without picking a more efficient firm than negotiations, this does not merely redistribute rents from suppliers to agencies: It also increases welfare because agencies will choose a quantity that is higher and thereby closer to the optimum.[2] If auctions select a more efficient supplier, welfare increases further, because any quantity can be produced at lower costs.

Recall that our reduced form analysis shows that procurement prices are much lower with competitive procurement than without. This suggests that collusion and/or common values are not very important in the industry under observation. We take this as a starting point for the remaining analysis where we recover the distribution of bidders' costs in an auction framework where bidders have independent private values and cannot collude. Specifically, we estimate a structural model of the distribution of the lowest bids in the procurement auctions. We use this to recover bidders' costs in a second step, using the first order-condition for optimal bidding behavior (see Guerre et al., 2000). Due to data limitations – we only observe winning bids and the number of bidders, not their identity – our structural models is rather simple. We assume an independent

[2]For details, see Section 5.1.

private value environment and cannot account for endogenous entry (Krasnokutskaya and Seim 2011, Athey et al. 2011) or unobserved heterogeneity (Krasnokutskaya 2011). Still, we believe that there is value to this model as it provides a quantitative assessment if interpreted cautiously.

We have no direct measures of bidders' costs in negotiations, but we estimate upper and lower bounds. Using these bounds, we can also obtain some idea about the relative contributions of markup reduction from competitive pressure and cost reduction from selection of efficient suppliers. Auctions reduce the price of rail service from 8.20 EUR to 6.93 EUR per kilometer, or by 1.27 EUR. Using the upper bound on cost under negotiation, we find that procurement auctions reduce the average cost of providing the service from 7.49 EUR to 6.62 EUR, or by 87 Cents. Costs thus respond substantially to auctions, explaining as much as 69 percent of the price response to auctions. The absolute markup decreases from 70 Cents to 31 Cents, or by 39 Cents. Even in this scenario, the markup response to auctions explains at least 31 percent of the price response. Using the lower bound on costs before negotiation instead, we find that the cost does not respond to the procurement mode, so that the price reduction is entirely explained by a reduction in markups from 19.1 to 4.4%. Finally, adopting a simple functional form for surplus, we also find that the agency surplus increases by just over 20% due to competitive procurement.

The remainder of the paper is organized as follows. Section 2 provides a review of related literature, and Section 3 discusses the institutional background. In Section 4, we describe the data and provide the first results of our regression analysis. Section 5 introduces a structural model, the results of which are discussed in Section 6. Section 7 concludes.

2 Related Literature

Our paper contributes to a rapidly growing literature on the determinants of the performance of public procurement. We focus here on the part of the literature that compares procurement auctions and negotiations.[3] In addition, our paper provides insights on the success of reforms in the railway sector, an important example of a network industry. We thus provide a short summary of the literature on both issues.

Auctions vs. Negotiations: The literature has focused on the advantages and disadvantages of auction mechanisms, and it has identified circumstances under which procurement auctions are preferable to negotiations. Bulow and Klemperer (1996) give general conditions under which adding a competitor to an optimal sales mechanism with n buyers improves the outcome for the seller, and, in particular, auctions ($n > 1$) are preferable to negotiations ($n = 1$). Applied to a procurement context, the result identifies circumstances under which, from the perspective of the agency, competitive procurement is favorable to negotiations with a single supplier, no matter how cleverly these negotiations are designed.

With common or affiliated values, it is well-known that, because of fear of the winner's curse, rational bidders will bid less aggressively when the number of bidders increases. As a result, bids are not necessarily decreasing in the number of firms, and not even necessarily lower with competitive bidding than with direct

[3] Another broadly related strand of literature deals with how the procurement prices paid by government agencies are affected by corruption (active waste) and inefficiency (passive waste); see, e.g., Bandiera et al. 2009.

negotiations.[4] Empirical evidence supports this idea.[5] Collusion is another reason why potential price advantages from competitive procurement might not materialize.[6] While collusion between bidders does not necessarily prevent the selection of the efficient supplier, it reduces competitive pressure.

Some papers have gone futher, identifying actual disadvantages of competitive procedures. For instance, Manelli and Vincent (1995) have highlighted the potential disadvantages of auctions when the buyer has preferences for unverifiable quality; such disadvantages are also a common concern of procurement agencies. To solve this problem, Calzolari and Spagnolo (2009) and Albano et al. (2017) have advocated competitive procedures that give discretion to the buyer to take past performance into account and thus exploit reputation effects. On a related note, Coviello et al. (forthcoming) have applied a regression discontinuity design to Italian procurement data, showing that discretion tends to lead to repeated interactions between the same buyers and suppliers. They also provide (mixed) evidence on the relation between discretion and quality.

Finally, extending the work of Goldberg (1977), Bajari and Tadelis (2001) have emphasized that the necessity of ex-post adaptations of a project may limit the usefulness of competitive procurement mechanisms for complex goods; see Bajari et al. (2009) for a related empirical analysis. Herweg and Schmidt (2014) argue that, in such settings, participants in auctions will withhold useful knowledge on necessary design adaptations and that they will invest less into identifying possible adaptations than with negotiations.

Some authors have taken a positive rather than a normative approach, trying to identify the circumstances under which auctions are more likely to be chosen. For instance, Bajari et al. (2009) show that buyers tend to use negotiations when the number of potential bidders is low, when projects are complex and when sellers are reputable and experienced. Chong et al. (2014) identify a similar role of complexity with French procurement data.

The observation that procurement decisions depend on project characteristics suggests that a comparison of auctions and negotiations needs to take the potential endogeneity of the decision into account. Such issues also come up in the related decision between cost-plus and fixed price contracts, as discussed by Gagnepain and Ivaldi (2010) using data from the French public transportation sector.[7]

Railway Reforms: The paper also contributes to a literature on the evaluation of the railway reforms introduced in Europe in the nineteen nineties. Several papers deal with the efficiency effects of various reforms in an international context on an aggregate level (Cantos et al. 1999, Friebel et al. 2010), emphasizing the role of cross-country institutional differences. Friebel et al. (2010) identify positive efficiency effects of deregulation. Other authors resort to before-and-after comparisons in individual countries. For instance, Cowie (2002) and Pollitt and Smith (2001) analyze the outcomes of the U.K. reform, coming to more positive conclusions than the political debate in Britain. would suggest. In any event, the institutional differences between Germany and Britain are massive, so that it would be inadequate to jump to quick conclusions from the experiences of one of

[4]See, for instance, the examples of Wilson (1992) for the first-price sealed-bid sales auctions, and the analysis of Bulow and Klemperer (2002) for ascending bid auctions.

[5]For instance, using data from highway procurement in New Jersey, Hong and Shum (2002) argue that procurement costs are lowest with three bidders, so that unlimited competition is not necessarily advantageous for the agency.

[6]See Mc Afee and Mac Millan (1992) for a theoretical analysis of bidding rings in auctions.

[7]In a related paper on this industry, Gagnepain et al. (2013) analyze a model where the type of the contract (cost-plus or fixed-price) can be renegotiated. They find substantial welfare costs of renegotiation.

these countries to the other one. For instance, in Germany, contrary to the U.K., competition for the market was introduced gradually and concerned only regional passenger transportation.[8]

Contrary to these contributions, our paper allows the comparison of different institutions within one country, without relying on a before-and-after comparison. Also, it focuses on a specific aspect of the reform (competitive procurement) which has been important in several other countries as well.[9] It shares this feature with Lalive and Schmutzler (2008) who use a difference-in-difference approach to establish a positive relation between competition and the frequency of service for a small subsample of the one we use in the current paper. Lalive and Schmutzler (2008) considered only Baden-Württemberg, one of the 16 German states. Moreover, the present paper differs substantially from its precursor in at least three important dimensions. First, based on reduced form models, we discuss the problem of endogeneity of procurement choice. Second, because we now have procurement price data, we can identify that the previously found positive relation between competition and frequency of service reflects a negative relation between competition and procurement prices. Third, with our structural model, we can now obtain estimates of the effects of competition on cost, mark-ups and net surplus.[10]

3 Regional Passenger Railways in Germany

In most European countries, integrated state monopolies controlled the railways until the early nineteen nineties.[11] In West Germany, *Deutsche Bundesbahn* owned most of the infrastructure and was the dominant operator for passenger and freight services. In addition, there were several minor railroad companies (*NE-operators*) that were typically also vertically integrated and carried out freight and/or passenger transportation on small networks. In East Germany, *Deutsche Reichsbahn* was the integrated operator of the railway system.

In response to the EU-directive 91/440, a major railway reform became effective in Germany on January 1, 1994. *Deutsche Bahn AG* became the successor of *Deutsche Bundesbahn* and *Deutsche Reichsbahn.* In addition, the reform had several elements that are important for our analysis.

3.1 Financing

Before the reform, the railway system created large deficits. Local passenger transportation was responsible for a large part of this deficit, but as the central government took over the total deficit ex post, it was impossible to attribute the costs to specific lines. The reform changed the approach to financing passenger services radically. Whereas long-distance transportation is expected to be profitable, it is still taken for granted that the revenues from passenger service do not suffice to cover costs on the local passenger lines. Our analysis will deal exclusively with these non-profitable local passenger railway services. Procurement of these services now relies on contracts

[8] Other important differences concern the role of the network owner and the pricing flexibility of operators.

[9] The most prominent examples are the United Kingdom and Sweden, but several other European countries have followed suit.

[10] Beyond the railway sector, there is a substantial amount of (descriptive) evidence on competitive tendering in the bus industry, as surveyed by Hensher and Wallis (2005). The results are mixed, with reports of substantial efficiency gains in the early phase of the deregulation in London (White 2000), but essentially no effects in Italy (Boitani and Cambini 2006).

[11] This purely descriptive section has considerable overlap with Lalive and Schmutzler (2008); see this reference for additional details.

specifying the expected service level and the payments from the state to the railway companies ex ante. Starting in 1996, the federal state distributed a total of about 5-7 billion Euros per year to the 16 states, mainly to finance the services. The responsibility for the use of these funds (the so-called *Regionalisierungsmittel*) lies with the states. The funds were so generous that they allowed the agencies to expand regional passenger railway services.

3.2 Vertical Industry Structure

As a prerequisite for the introduction of competition, *Deutsche Bahn AG* was divided into two upstream subsidiaries (*DB Netz* for the network and *DB Station & Service* for the stations) and three downstream subsidiaries (*DB Regio* for regional passenger transportation, *DB Reise und Touristik* for long-distance passenger services and *DB Cargo* for freight). Thus, a move into the direction of vertical separation took place. Railway companies (including *DB Regio*) that want to use the network of *DB Netz* pay access charges determined by *DB Netz*. These access charges, which vary across lines, are an important cost component for the railway operators, which also influence the prices that agencies pay. In our analysis, we will therefore use them to construct procurement prices on negotiated lines.

3.3 Auctions vs. Negotiations

The 16 states have created agencies organizing the procurement process. These agencies receive a fixed budget for the procurement of railway services, but they have considerable freedom in the way they procure services. The crucial distinction for our analysis is between auctions and negotiated lines.

Throughout the period under consideration, direct negotiation with the incumbent supplier remained the dominant mode of procurement. Long-term contracts between the agencies and *DB Regio* covered a large majority of the regional passenger services. These contracts specified the expected service level over a period of 10-15 years and the payments to *DB Regio*. Also, the contracts typically contained clauses regulating the speed with which competitive procurement was to be introduced.

Competitive procurement usually involved a bidding procedure in which firms asked for transfer payments to carry out railway services. The successful bidder received his required transfer and obtained the franchise for a period of about 10 years. In the simplest case, the agency specified the frequency of service and detailed requirements about the expected service quality. The specifications included the rolling stock, the prices charged to customers, etc.[12] The contracts were awarded in a first-price sealed-bid auction, where the bids corresponded to the procurement prices.[13] In other cases, the agencies used multi-dimensional auctions where the bidders obtained scores for high quality as well as for low prices.[14]

[12]Regional public transport organisations (Verkehrsverbünde) decide on timetables, prices etc. on a large part of the network. This limits the freedom of railway operators to set prices. Similar restrictions apply to rolling stock which is usually tightly specified (Brenck and Peter 2007).

[13]This differs from textbook models of competition for the market (Viscusi et al. 2000). In those models, instead of the subsidy, contractors bid the price they want to charge to consumers and the lowest bid wins (Demsetz 1968).

[14]See Che (1993) for a formal analysis of such auctions. However, the role of the quality dimension is often not made absolutely clear ex ante, so that the mechanism corresponds to a beauty contest.

The extent to which competitive procurement was used varied considerably across agencies. In the period under consideration, agencies were essentially free to determine the procurement mode for any of the lines they served.[15] However, it became a common practice that the agency and the incumbent negotiated on which lines should be opened to competition during the lifetime of the contract.[16]

3.4 Types of Contracts

Our empirical analysis will account for the fact that the contracts in our sample are heterogeneous in several dimensions. Most of this heterogeneity arises between agencies rather than within agencies, however.

First, contracts differ according to the treatment of fare revenues. In *net contracts*, the train operator receives the revenues (and thus has an incentive to increase it), and the agency only pays the difference between costs and revenues. In *gross contracts*, the agency receives the revenues, whereas the operator receives a cost compensation (but carries the cost risk). In our data set, 67 % of competitive lines were procured in net contracts. The grand contracts with *DB Regio* were usually net contracts.[17] We take this asymmetry between competition and direct negotiations into account in our estimation.

Second, there are fixed price contracts and cost plus contracts. According to Brenck and Peter (2007), in a sample of contracts analyzed by Borrmann (2003) which contains many of our contracts, 40% of the contracts were fixed-price, whereas the rest contained cost-pass-through clauses for costs on which the operator has little influence, such as energy costs and infrastructure charges. Moreover, the contracts typically contained dynamic adjustment formulas, at least for access charges. Such provisions reduce the need for renegotiation. Further, the contracts typically described detailed provisions for negotiations (Brenck and Peter 2007).

Finally, the contracts contained various incentive elements to deal with quality issues, including sanctions and bonus payments (Brenck and Peter 2007).

3.5 Evolution of the Market

As a result of the introduction of competitive procurement, the market share of *DB Regio*'s competitors has grown substantially. In 1994, the *NE-operators* had a market share of 3% (based on train-km); in 2004, the share was 12% (Brenck and Peter 2007). However, these figures understate the dynamics of the competition: On lines with competitive procurement, the *NE-operators* won more often than *DB Regio*. (See also Table 1.)

There are several distinct types of competitors. First, there are the above-mentioned pre-reform *NE-operators*. Starting from their old infrastructure, they often have expanded their operations onto the network of *Deutsche Bahn* where they only provide the downstream services. Second, some companies have expanded their activities from other modes of public transportation into the railroad sector. Third, some new companies emerged. Fourth,

[15] This right has been challenged both by national courts and the EU. This is leading to a clearer move into the direction of more competition (Brenck and Peter 2007).

[16] The most competition-friendly authority (LVS in Schleswig-Holstein) signed a long-term contract in 2003, according to which the last part of the network will be opened to competition in 2014, 20 years after the railway reform. (See *http://www.premiumpresse.de/bahn-und-land-schleswig-holstein-unterzeichnen-verkehrsvertrag-PR156817.html*, visited July 4, 2011.

[17] According to private communication with Felix Berschin (Nahverkehrsberatung Heidelberg), the state of Hessen is an exception.

some railway operators are joint ventures between several companies, in some cases including *DB Regio*. Finally, foreign firms such as *Connex*, *Arriva* and *Abellio* have entered the market.

4 Does Competitive Procurement Work?

In this section, we first describe our data (Section 4.1). Thereafter, we provide regression results to show that competition increases the frequency of service and lowers procurement prices. In Section 4.2, we deal with the selection problem that competitively procured lines may differ from negotiated lines. Section 4.3 identifies the effects of competition on quantities and prices. We find a positive effect of competition on quantity and a negative effect on procurement prices. Section 4.4 provides some descriptive evidence on quality, suggesting that quality on auctioned lines is not systematically lower than on negotiated lines.

4.1 Description of data

Our data contains information regarding service frequency on more than 500 railway lines in Germany. We now provide background information and descriptive statistics on this data.

The empirical analysis uses information on our main dependent variables, service quantity and procurement prices. Following Lalive and Schmutzler (2008), we use the *frequency of service,* the ratio between train kilometers per year (tkm) and the length of a line (lkm), as a quantity measure.[18] The division of the network into different lines follows the 2004 timetable.[19] We collected all information on frequency of service "by hand" from timetables. Frequency of service is available for 1994, before the reform, and 2004, several years after the reform.

We compiled detailed data on whether a segment of a train line was competitively procured or not. In the vast majority of cases, the competitive status refers to procurement auctions. However, the definition was slightly broader.[20] Most lines were procured using only one procurement mode. A few lines had a mixed service, with a small number of competitively procured trains from neighboring lines. We somewhat arbitrarily classify a line as competitive ("auctioned") if at least 20% of the services were procured competitively, and as non-competitive ("negotiated") if less than 20% of the services were procured competitively.[21]

The incumbent, *DB Regio*, also won a considerable number of competitive tenders. These lines are defined as competitive, even though the operator is the incumbent. A few small lines were procured in direct negotiations with other companies. We include information on who operates the line, the incumbent or entrants, as a control

[18]Thus, the frequency of service corresponds to the average number of trains per year on each kilometer of tracks.

[19]In some cases, we had to make small adjustments to avoid double-counting of trains.

[20]We define a competitive line as in Lalive and Schmutzler 2008, Definition 1. Thus, apart from lines that were auctioned in an open tender procedure, our treatment group contains the following types of lines: (i) Services were procured in invitation procedures on the basis of offers from at least two firms that were approached directly by the agency; (ii) Apart from the incumbent, at least one firm offered a contract to the agency without having been asked to do so. (iii) A competitor took over the infrastructure and the task of running services from *DB Regio* for a symbolic price (see Lalive and Schmutzler (2008) for examples).

[21]The vast majority of the lines either has no competitively procured services or only competitively procured services. Note that the fuzzy treatment status on a few lines introduces a small amount of measurement error, dampening our estimates of the effect of competitive procurement.

variable in our regression.[22]

Obtaining information on procurement prices is difficult. We were able to get information on the winning bid in auctions.[23] The data contains the prices for 64 of the 139 competitively procured lines in the sample.[24] We have studied whether these lines represent a selected sample but, conditional on the observed line characteristics, we did not find any differences between the lines with price data and lines without price data.[25]

The prices resulting from direct negotiations are publicly available, but only quoted at the state level. We construct individual line-specific estimates of the negotiation price as follows. We assume that the incumbent negotiates a price to cover costs and guarantee a positive markup. Rail service providers face two costs. First, operators pay access fees to the network owner, *DB Netz*, and these access fees vary considerably across lines, even within the regions served by one agency. *DB Netz* charges a standard price on some lines. The *Regionalfaktor* (regional factor) captures by how much the access price on a specific line is inflated above this standard price. Regional factors are high on remote lines with low density of service, which is supposed to help the network owner to recover fixed costs. Second, operators incur costs of providing the service, e.g. energy, trains, labor. Absent direct information on these costs, we assume that they vary across German states, but not within them. We observe the state-level average negotiation price, and the regional factor for almost all lines. Using these two pieces of information, we reconstruct negotiation prices to match state-level average prices, as we show in the Appendix A.[26]

Apart from these basic variables, we added further controls, corresponding to the geographical line characteristics and to properties of the contract . We use the distance to the nearest city with at least 100,000 inhabitants as a measure of remoteness.[27] We also include the number of inhabitants of both the largest and the second-biggest city served by the line in 1994, again as proxies for demand along the lines. We also used information on whether a gross contract or a net contract was used and whether the contract was of a fixed-price or cost-plus type.

We collected information on the quality of services from several large agencies. This data covers a more recent period than our analysis of train lines. We will look into punctuality and train cancellations; one agency also carries out a more general quality monitoring of the competitively procured railway lines. Unfortunately, however, these data are not only incomplete, they also are not available on the basis of individual lines.

[22] In analogy to our definition of competitive lines, we define a line as operated by *DB Regio* if at most 20% of the services were run by competitors.

[23] The data were supplied by Felix Berschin from Nahverkehrsberatung Südwest in Heidelberg, a consulting firm that is specialized in regional passenger train services.

[24] For 41 of these lines, we also have data on the number of bidders; we use these lines for the structural model.

[25] We have also explored another source of data on prices. The official source of the European Union, the databank *Tender Electronic Daily*, contains useful information on which lines were grouped together in a particular auction and what the overall volume of the contract is. However, this source only provides procurement price data in a small number of cases.

[26] We are grateful to *DB Netz* for providing us with information on the access charges.

[27] We measure the distance as the length of the shortest connecting passenger railway line.

4.2 Choice of Procurement Mode

Agencies could choose between auctions (competitive procurement) and negotiations to procure railway services. We have no inside information on the determinants of the procurement decision. But the two most important ones are likely to be attitudes towards risk, and expected service growth due to competitive procurement. Attitudes towards risk matter because auctions were never tested in Germany before its regional rail market opened up in 1996, so that agencies neither had prior experience nor information with procurement auctions. As a result of risk aversion, agencies are likely to have chosen lines for competitive procurement that were not too important, so as to limit any damage due to a failed auction.

Our reduced form analysis will contrast frequency of service and procurement price on two different groups of lines. The treated lines are those defined to be competitive in Section 3.3. As discussed there, most of these lines were selected by the agency to have its services procured via an auction between 1994 and 2004. Therefore, we also refer to these lines as "auctioned lines". By contrast, negotiated lines, or control lines, are those selected by the agency to always have its services negotiated with the incumbent DB Regio between 1994 and 2004. Table 1 displays procurement prices, frequency of service, and line characteristics of all railway lines in our sample. Panel A shows the price and frequency of service from 2004, after the 1996 reform that opened up the regional rail sector; in addition, it shows the number of bidders. Panel B shows frequency of service information in 1994, before the railway reform. To repeat, procurement prices did not exists at the time. Procurement prices are significantly lower on lines with procurement auctions, compared to negotiated lines. Interestingly, the frequency of service is lower on auctioned lines, compared to negotiated lines. However, this was already the case before the reform: As Panel C shows, auctioned lines are more remote and thus less important than negotiated lines. Auctioned lines are 27 percentage points less likely to have electric traction, 8.4 km further away from the next city, and the population of the biggest city along the line is smaller.

Our reduced form analysis measures effects of procurement mode on service frequency in a difference-in-differences design (DiD). A standard assessment of the validity of the DiD is to test for parallel trends in frequency of service. We cannot implement a test of parallel trends, as we do not have any data on frequency of service before 1994. We propose a different test for selection based on expected service growth, the key identification challenge. If agencies selected lines with higher unobserved growth, a part of the effect that we attribute to competitive procurement just reflects selection. Unfortunately, it is not possible to assess this concern directly, as we would need to have information on service growth along auctioned lines if they had been negotiated instead. Note, however, that lines with large growth will have a high service level after the reform, and a low service level before the reform. Therefore, if agencies really select lines based on large growth, then the service level prior to the reform, observable for all lines, is lower for auctioned lines than for negotiated lines. A test for selection based on growth compares pre-reform service levels, conditional on line characteristics (see Appendix B).

Table 2, column (1), explains log service frequency in 1994 with the subsequent procurement status. Lines that were subsequently procured competitively were served 19 percent (21 log points)[28] less frequently than

[28] Change in percent is $\exp(\beta) - 1$, where β is the estimated coefficient.

Table 1: Summary statistics

Variable	Negotiated lines		Auctioned lines		Difference	
A. Outcomes 2004						
Price[a]	8.6988	(0.0617)	6.7236	(0.1784)	1.9752***	(0.1888)
Frequency	19295.1	(696.2)	17358.49	(1001.8)	1936.65	(1220.0)
Number of bidders[b]			4.6098	(0.2633)		
B. Outcomes 1994						
Price	NA		NA		NA	
Frequency	15696.55	(626.1)	11533.34	(651.2)	4163.20***	(903.4)
C. Controls (not time varying)						
Electric traction	0.5238	(0.0244)	0.2518	(0.0369)	0.2720***	(0.0442)
Distance to city (km)	15.5286	(1.2875)	23.9640	(3.0165)	-8.4355**	(3.2798)
Track length	60.0190	(2.2771)	59.8058	(4.1089)	0.2132	(4.6977)
Population largest city	474,351	(36,016)	225,469	(29,539)	248,882***	(46,580)
Pop 2nd largest city	83,741	(7,748)	47,783	(6.539)	35,959***	(10,138)
Regional factor	1.1249	(0.0118)	1.1954	(0.0270)	-0.0705**	(0.0295)
Number of observations	420		139			

Notes: Summary statistics for negotiated and auctioned lines. Standard errors are shown in the columns beside the coefficients. Differences are tested against zero using a t-test. *** (**, *) stands for significance at the 1% (5%, 10%) level.

[a] Number of observations is 64; [b] number of observations is 41.

Source: Own calculations.

lines to be negotiated in the future. Column (3) adds exogenous characteristics of lines such as technical aspects (electrification, length), proxies for demand (distance to next city in km, population in the largest and second largest city along the line), and determinants of operating costs (regional factor, identity of operator) as control variables. Electrification, remoteness, and size of the second-largest city explain frequency of service in 1994. Our first estimation, without controlling for line characteristics, shows that auctioned lines were served about 19% less frequently in 1994. Lower frequency of service is consistent with both risk aversion and selection based on gains. Our second estimation, adding controls for remoteness and traction, show that auctioned lines were not less frequently served than negotiated lines. Agencies did not systematically select lines with high unobserved growth potential to be auctioned. Agencies selected relatively unimportant lines, and we will explore below whether auctions were more effective on such lines.

4.3 The Effects of Competition on Service Frequency and Procurement Price

The results of Section 4.2 suggest that the selection of the procurement mode is based on observables, so that we can think of the lines as being randomly assigned conditional on observables. We therefore now use regressions of quantities and prices on procurement status and observables to identify the effects of competition. Table 3 shows

Table 2: Determinants of quantities in 1994

	(1)	(2)	(3)	(4)
Constant	9.399***	(0.087)	9.351***	(0.154)
Auctioned	-0.214**	(0.097)	0.070	(0.097)
Electric traction			0.329***	(0.049)
Distance to city (km)			-0.004***	(0.001)
Log track length			-0.096	(0.060)
Log pop largest city			0.048	(0.038)
Log pop 2nd largest city			0.124***	(0.027)
Regional factor			-0.091	(0.085)
Incumbent			0.108	(0.099)
Adjusted R-squared	0.016		0.337	
Number of observations	559		559	

Notes: Results from OLS estimations. In columns (1) and (3), the dependent variable is the logarithm of the quantity in 1994. Standard errors are clustered (on agencies) and are shown in the columns beside the coefficients. *** (**, *) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

the results from our model on quantities. Column (1) presents the results of a difference-in-difference model that explains growth in service frequency with procurement status. On lines that were competitively procured in 2004 the frequency of service grew 16.0 percent more than if these lines had been procured through negotiations. Column (3) adds line characteristics since auctioned and negotiated lines differ with respect to characteristics (see Table 1). After conditioning on line characteristics, we find that auctions increase the frequency of service by 12.0 percent compared to negotiations. Column (5) provides estimates of the effects of competition, explaining the level of service in 2004 with line characteristics and the level of service in 1994. The results in levels indicate that auctions increase service by 13.8 percent, which is very much in line with our result in column (3). Column (7) presents estimates that allow the effect of competition to vary with observed characteristics.[29] Auctions increase service by 18.6 percent on the line with average characteristics, somewhat higher than in column (5) that does not contain interaction terms. Auctions expand quantity less on lines served frequently already in 1994, and more strongly on lines where the largest city had a large population in 1994.

Table 4 displays our reduced form analysis of the effects of competition on procurement prices in 2004.[30] Column (1) indicates that auctioning the service reduces the price by 24.3 percent. Column (3), adding service frequency in 1994 and line characteristics, indicates that auctions reduce the procurement price by 22.0 percent, very similar to the estimates in column (1). Column (5) presents estimates that allow price effects to vary with

[29] We mean deviate all line characteristics before forming interactions. The main effect of competition refers to the line with average characteristics, i.e. zeros for all interaction terms.

[30] We cannot use a difference-in-difference approach to estimate the effects on prices, because procurement prices did not exist in 1994 (see Section 3.1).

Table 3: Determinants of quantities in 2004

	Growth in quantity				Quantity in 2004			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	0.246***	(0.022)	0.565***	(0.097)	2.743***	(0.273)	2.427***	(0.329)
Auctioned	0.148***	(0.040)	0.113*	(0.062)	0.129**	(0.057)	0.171**	(0.075)
Electric traction			-0.081*	(0.040)	-0.004	(0.036)	0.008	(0.039)
Distance to city (km)			0.000	(0.001)	-0.001	(0.001)	-0.001	(0.001)
Log track length			-0.059**	(0.022)	-0.081***	(0.015)	-0.062***	(0.022)
Log pop largest city			0.012	(0.020)	0.023	(0.017)	0.005	(0.013)
Log pop 2nd largest city			-0.005	(0.013)	0.024*	(0.013)	0.018	(0.013)
Regional factor			-0.245***	(0.076)	-0.266***	(0.074)	-0.190**	(0.071)
Incumbent			-0.042	(0.055)	-0.017	(0.043)	0.007	(0.049)
Log frequency in 1994					0.767***	(0.026)	0.789***	(0.033)
Auction ×								
log frequency							-0.143**	(0.069)
el. tract.							-0.008	(0.082)
dist. to city							0.001	(0.002)
log length							-0.076	(0.061)
log pop larg. city							0.068*	(0.035)
log pop 2nd larg. city							0.038	(0.036)
incumbent							-0.060	(0.050)
regional factor							-0.185	(0.205)
Adjusted R-squared	0.029		0.064		0.761		0.763	
Number of observations	559		559		559		559	

Notes: Results from OLS estimations. In columns (1) and (3), the dependent variable is the growth of quantity between 1994 and 2004; in columns (5) and (7) the dependent variable is the logarithm of quantity in 2004. Observations are from the pooled sample of negotiations and auctions. Standard errors are clustered (on agencies) and are shown in the columns besides the coefficients. *** (**, *) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

line characteristics. Auctions lower price by 23.7 percent for the line with average characteristics. Price effects differ with respect to the regional factor. Procurement prices on lines with high regional factor are high with negotiations, but no different than on other lines with auctions.

4.4 Potential Pitfalls of Competition

As indicated in the introduction, one may be concerned that our analysis overstates the beneficial effects of competition. High ticket prices, low service quality, renegotiation and winner's curse are potential problems of

Table 4: Determinants of negotiated and auctioned prices

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	2.153***	(0.034)	2.160***	(0.170)	2.110***	(0.165)
Auctioned	-0.278***	(0.050)	-0.249***	(0.050)	-0.271***	(0.060)
Log frequency in 1994			-0.032**	(0.016)	-0.030*	(0.015)
Electric traction			0.057**	(0.024)	0.068**	(0.026)
Distance to city (km)			-0.001	(0.000)	-0.001**	(0.000)
Log track length			-0.012	(0.013)	-0.009	(0.011)
Log pop largest city			-0.005	(0.009)	-0.007	(0.008)
Log pop 2nd largest city			-0.011	(0.009)	-0.005	(0.010)
Regional factor			0.214***	(0.046)	0.248***	(0.038)
Incumbent			0.055	(0.053)	0.046	(0.047)
Auction * log frequency					-0.012	(0.070)
Auction * el. tract.					-0.139	(0.083)
Auction * dist. to city					0.000	(0.002)
Auction * log length					-0.013	(0.042)
Auction * log pop largest city					-0.017	(0.054)
Auction * log pop 2nd largest city					-0.063	(0.061)
Auction * incumbent					0.030	(0.064)
Auction * regional factor					-0.333***	(0.094)
Adjusted R-squared	0.254		0.349		0.399	
Number of observations	484		484		484	

Notes: Results from OLS estimations. Dependent variable is the logarithm of price. Observations are from the pooled sample of negotiations and auctions. Standard errors are clustered (on agencies) and are shown in the columns besides the coefficients. *** (**, *) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

bidding competition in the railway sector. However, we find very little evidence that these problems are severe in the case at hand.

Ticket prices: If operators could set ticket prices freely after having been awarded a competitive contract, they might bid low procurement prices, but then charge high ticket prices. However, competing through ticket price is not an allowable option for the operators as ticket prices are coordinated by agencies.[31]

Quality: A more relevant issue is that bidders in procurement auctions reduce quality to save on costs, so that they can submit more aggressive bids. Ideally one would address this concern with a difference-in-difference approach as in Section 4.3. Unfortunately, we do not have detailed line-level quality data. However, the limited information we have suggests that, while quality problems are an issue in the industry, they are not more frequent

[31] The German Monopoly Commission has discussed this fact critically at several occasions. e.g., Monopolkommission 2009.

on auctioned lines than on negotiated lines.

First, agencies are clearly aware of the potential quality problem. In auctions as well as in negotiations, contracts contain detailed quality provisions. These provisions are enforced with punishments.[32]

Second, a few agencies have begun to publish quality data. This admittedly imperfect, purely descriptive evidence does not support the view that competition reduces quality. For instance, several agencies have collected punctuality data on their entire network. They report punctuality at an intermediate level of aggregation, with a typical data point referring to a subnetwork of lines. The subnetworks differ with respect to operators. Table 5 provides unweighted averages of the punctuality measures for the subnetworks of *DB Regio* and all other operators, respectively.[33] For each agency, we reported this number for the year which was closest to the end of the time period we investigated (2004). As *DB Regio* is the operator on the vast majority of negotiated lines, whereas competitors have a high market share on the competitively procured lines, an adverse effect of competitive procurement should show up in a quality advantage of *DB Regio*. However, there is no systematic tendency for *DB Regio* trains to be more punctual than those of the competitors. Even in the two states where *DB Regio* has better punctuality values than the competitors, this is mainly due to the fact that we are showing unweighted averages: The values for the grand contracts under which most trains were procured with *DB Regio* were 95.37 for Baden-Württemberg and 93.52 for Thüringen, which are much lower than the average values of *DB Regio*.

Table 5: Punctuality of trains

State / Agency / Year — Operator	Baden-Württemberg NVBW 2008	Schleswig-Holstein LVS 2010	Thüringen NASA 2009	Hessen RMV 2004	Nordrhein-Westfalen NRW (NWL, VRR, NVR) 2009
DB Regio	96.79	84.96	95.60	92.10	88.00
Others	95.20	94.60	94.06	98.91	91.47
Difference (DB Regio - Others)	1.59	-9.64	1.54	-6.81	-3.47

Notes: Punctuality statistics for several states. The paper presents the unweighted average of punctuality measures for different subnetworks within the state. Here punctuality refers to the percentage of trains arriving in time at the final destination. For clarity, we chose the most recent available figures for each state.

Sources: Klingel, Bernd, "Aktuelle Entwicklungen Im SPNV - Bericht Der NVBW," 2013, p.8-10; RMV, 2010, "Qualitätsbericht 2009," June, p.7; Kompetenzcenter ITF NRW 2015, "Qualitätsbericht SPNV Nordrhein-Westfahlen 2014," p.54-55.

An even smaller group of agencies provides data on the percentage of train cancellation for the above-mentioned subnetworks. Table 6 presents unweighted averages of these subnetworks. In Hessen and Brandenburg, there are indeed more train cancellations for "other" operators than for DB Regio. However, in the largest German state (Nordrhein-Westfalen) *DB Regio* cancelled a higher fraction of their trains than the competitors. Thus again there is no systematic quality advantage of *DB Regio*.

[32] As a recent example, in 2010 the Bavarian agency BEG fined the operators for delays and other quality problems with a total of 24 Million Euros. *DB Regio* whose contracts were mostly awarded non-competitively had to pay 84% of these fines.

[33] The number refers to the percentage of trains that arrived on time. The precise definition of "arriving on time" varies across agencies. Usually, it applies to trains with less than six minutes delay.

Table 6: Train cancelations

State / Agency, Year / Operator	Hessen RMV 2009	Berlin-Brandenburg VBB 2012	Nordrhein-Westfalen NRW (NWL, VRR, NVR) 2007
DB Regio	0.52	0.88	1.65
Others	3.62	1.51	0.73
Difference (Others - DB Regio)	3.1	0.63	-0.92

Note: This table shows the percentage of cancelled trains in three states.
Sources: RMW, 2010, "Qualitätsbericht 2009," June, p.12; VBB 2013, "Verbundbericht 2013," June, p.30; Kompetenzcenter ITF NRW 2015, "Qualitätsbericht SPNV Nordrhein-Westfahlen 2014," p.54-55.

Taken together, the two tables do not provide support for the view that there is an adverse effect of auctions on reliability (punctuality and cancellations). Information on other quality criteria is rare. However, the Bavarian agency (BEG) carries out yearly quality rankings based on cleanliness, the quality of passenger information and complaint management, the functionality of the equipment, and the service orientation of staff.[34] The most complete ranking (from 2015) investigated 27 subnetworks. The top 5 networks were operated by competitors of *DB Regio*; whereas 8 of the 10 networks on rank 6-15 and 8 of the 12 networks on rank 16-27 were run by *DB Regio*. If anything, therefore, this ranking suggests a slight advantage of the competitors compared to *DB Regio*. These quality rankings are less useful for our purposes, as they only concern competitively procured sub-networks. Thus, the observation that competitors do not offer lower quality than *DB Regio* does not rule out that all companies supply lower quality than they would have absent competition. In any event, however, the regularity and publicity of this kind of quality monitoring makes it risky for companies to shirk on quality.

Renegotiation: An often raised concern with competitive procurement contracts is the possibility of renegotiation. Large-scale problems apparently have been quite rare in the industry. The only frequently cited example concerns the line Hamburg-Westerland, where the successful operator *Nord-Ostsee-Bahn* demanded additional payments after the contract was awarded. A possible reason why these events are quite rare is that the contractual rules often state precise conditions for renegotiations (see Section 3.4).

Winner's curse: While rational bidders adjust their bids to a common-value setting by bidding conservatively, naive bidders will bid low when receiving overly positive cost or demand signals. In an industry with a substantial amount of entry, naive bidding may indeed be a problem. Again, there was one highly publicized case where a new firm went bankrupt very soon, but this was largely due to very special circumstances.[35]

Patronage: If quality was a big problem on the competitive lines, one would expect to see less growth in patronage on these lines than on-the non-competitive lines. If anything, the opposite seems to be true. For instance, *Allianz Pro Schiene*, a lobbying organisation supporting "safe and environmentally friendly rail

[34] See http://beg.bahnland-bayern.de/qualitaetssicherung/qualitaetsranking, visited on February 9, 2016.

[35] After *DB Fernverkehr* decided with short notice to stop serving the line Hamburg-Flensburg, the state agency searched for alternative solutions in an informal ad-hoc procedure. A newly founded company, *Flex AG* made an unrealistic offer and went bankrupt a year later.

transportation" published a list of 15 railway lines that were particularly successful in attracting passengers in the first 10-15 years after the railway reform. The majority of these lines were classified as competitive in our sample; in several cases, patronage increased by a factor of two to three or even higher.[36]

All told, there does not seem to be any evidence, quantitative or anecdotal, to support the view that competition in the German regional railway sector was accompanied by serious downsides.

5 Decomposition of Auction Prices

The analysis of the previous section shows that competition increases quantities and reduces price. This suggests that collusion is not a central issue. Moreover, though we cannot strictly rule out that there is a common value element in the auction, this does not appear to keep bidders from submitting fairly low bids. For the purposes of refining our reduced-form results, we thus work with the simplification of an independent private value setting without collusion. In Section 5.1 we first formulate a theoretical model; in Section 5.2 we describe the empirical approach that is based on this model.

5.1 Theoretical Framework

This section discusses a simple theoretical framework explaining procurement choice and price and quantity decisions. This framework allows us to estimate various interesting parameters and to carry out counterfactual calculations. We sketch the main points here; for details we refer to the Appendix C.

For simplicity, we suppose that costs on any given railway line are independent of the quantity supplied on other (in particular, neighboring) lines. Moreover, we assume that costs are linear on any line; thereby ruling out a decisive rule of capacity constraints. We suppose there are K ex-ante homogeneous firms (incumbents and potential entrants): All costs are drawn independently from the same distribution on the positive real numbers. We write c for the mean of the cost distribution; in particular, it is the expected cost of the incumbent, c_I.[37] We suppose the agency has an objective function $\left(s\sqrt{q} - pq\right)$ for some $s > 0$, which we refer to as (agency) surplus. The term $s\sqrt{q}$ in this function (gross surplus) is supposed to capture two effects. First, improvements in public transportation will generate direct benefits for the users (consumer surplus): Consumers take the train more often, and they can choose more convenient trains. Second, substitution from road to rail goes along with reductions in pollution and accidents (Luechinger, Lalive, and Schmutzler 2016). The term pq captures total payments to the operator; p is the price paid by the agency. On lines supplied by the incumbent, he cares about profits, which are given as $(p - c_I)\, q$. Given the exogenous characteristics of a line, prices can be determined either in an auction or a negotiation mechanism.

First suppose the agency uses a first-prize procurement auction. The agency specifies a fixed quantity q. After having observed this quantity, the firms simultaneously cast bids that correspond to the price at which

[36] See https://www.allianz-pro-schiene.de/presse/pressemitteilungen/2009-2009-47/, visited February 18, 2017.

[37] While there are reasons why the incumbent may have lower costs (for instance, experience or scale advantages), there are also reasons why entrants might have lower costs (for instance, less rigid employment contracts). We thus opted for a symmetric treatment.

they are prepared to supply each unit of quantity. The successful firm has to supply a quantity q announced by the agency at the submitted price. Suppose $N \leq K$ firms participate in the auction, where N is common knowledge. Denote the expectation of the lowest cost as $c_{(1)}$ and the expectation of the second-lowest cost as $c_{(2)}$. In the Nash equilibrium of the auction, the expected absolute markup is $m = c_{(2)} - c_{(1)}$ and the expected costs are $c_{(1)}$. Therefore, the expected price paid by the agency is $p_A = c_{(2)}$.

Second, we consider negotiations. We do not model the negotiation mechanism explicitly. We merely assume that the incumbent and the agency both expect the resulting price to be $p_N = c + y$ for some $y > 0$, that is, higher than the expected average cost.

Anticipating these prices p_M for the given procurement mode M, a risk-neutral agency therefore chooses q so as to maximize the expectation of

$$W_M \equiv s\sqrt{q} - p_M q. \tag{1}$$

The first-order conditions of this problem determine quantities and thereby welfare; see Appendix C for details. Clearly, a reduction in the procurement price p_M and an increase in the surplus parameter s increase quantity. For the empirical analysis, we note that the values of s and the respective cost terms for auctions and negotiations, $c_{(2)}$ and $c + y$ are identified by the model from price and quantity observations.

If the agency was concerned about total welfare rather than consumer welfare net of transfer prices, the term p_M in the objective function would have to be replaced by marginal costs. In situations where the procurement price p_M lies above the marginal cost, the agency who chooses (according to) (1) will therefore choose a quantity that is lower than the one that maximizes total welfare for given costs. The competitive pressure resulting from auctions alleviates this problem.

5.2 Estimation

We now discuss how we recover the distribution of costs among firms who bid on auctioned lines. The approach has two steps. We first estimate the distribution of bids. We then recover the distribution of bidders' costs in a second step by using the first order-condition for optimal bidding behavior (see Guerre, Perrigne and Vuong, 2000). With then use these estimation results to predict negotiation prices on lines that were auctioned, and other counterfactual scenarios.

Estimation of winning bids For the bidding model, we assume that each contract is procured with a standard first-price sealed bid auction. We assume that each contract is independent of the other contracts and allow for no dynamic or simultaneous strategic considerations by bidders. Bidders are risk neutral and symmetric. They know the number of bidders[38] and their own costs c_i, which are independent and private. We denote the distribution of bidders' costs as $F(\cdot|X)$, and assume that bidders' costs are independent conditional

[38]We assume that entry into the auctions is fixed and the number of potential bidders is equal to the number of participating bidders. Thus, our model does not allow for endogenous entry as for example the analysis on highway procurement in Krasnokutskaya and Seim (2011). Our main reason for this assumption is the lack of appropriate data. We only observe winning bids and the number of bidders, but not their identity. That does not allow us to estimate an econometrically more challenging model to identify entry cost.

on observable auction characteristics X. Given these assumptions, one can write the distribution of bids as $G(\cdot|X)$. We assume that, conditional on the observable auction characteristics X, the (log) bids are drawn from a Weibull distribution, with c.d.f.

$$G(b_i|X) = 1 - \exp\left\{ - \left(\frac{b_i}{\lambda^{bids}(X)} \right)^{\rho^{bids}(X)} \right\}, \tag{2}$$

where b_i is the bid of bidder i, X is a set of line characteristics X known to the econometrician and the bidders, $\lambda^{bids}(X)$ is the scale and $\rho^{bids}(X)$ is the shape of the Weibull distribution. We parameterize the scale as $\lambda^{bids}(X) = \lambda_0^{bids} + \lambda_X^{bids} X$ and the shape $\rho^{bids}(X) = \rho_0^{bids}$ to be constant. As we observe (log) winning bids only, we use the density of the first-order statistic of a Weibull distribution, which is

$$h(b_{[1]}) = \frac{N!}{(N-1)!}(1 - G(b))^{(N-1)} g(b), \tag{3}$$

where $b_{[1]}$ is the winning bid, G is the distribution function of the bids and g its density function.[39,40,41]

Determinants of negotiated prices According to our negotiation model, the incumbent sets a price equal to $c+y$, for some $y > 0$. We assume that, conditional on the observable auction characteristics X, (log) negotiated prices also follow a Weibull distribution, with c.d.f.

$$G(p_{negs}|X) = 1 - \exp\left\{ - \left(\frac{p_{negs}}{\lambda^{negs}(X)} \right)^{\rho^{negs}(X)} \right\}, \tag{4}$$

where p_{negs} is the price achieved on negotiated lines. We again parameterize the scale as $\lambda^{negs}(X) = \lambda_0^{negs} + \lambda_X^{negs} X$ and the shape $\rho^{negs}(X) = \rho_0^{negs}$ to be constant. This enables us to predict negotiated prices. However, we cannot back out marginal cost for negotiated lines, as without information on y we are not able to identify and recover c.

Likelihood We estimate the parameters of the model, $(\lambda^{bids}, \rho^{bids}, \lambda^{negs}, \rho^{negs})$, by maximum likelihood. With our assumptions regarding the distribution of the bids, we can form the likelihood for observed auctioned as well as observed negotiated prices. As our sample of auctions is relatively small, we combine the two samples for estimation. This, additionally, reduces the variance of our estimates. The likelihood has then two components and can be written as

$$l = d \times h(b_{[1]}) + (1 - d) \times g(p_{negs}), \tag{5}$$

where d is equal to one for the sample with winning bids and zero otherwise. For the estimations, we implement the log likelihood for the log winning bid and the log negotiated prices and interact the variables X with a dummy variable for auctioned lines. This allows the influence of line characteristics to be different on auctioned and negotiated lines.

[39] See for example, David and Nagaraja (2004) for more information on order statistics.

[40] In contrast to the theoretical model, the Weibull distribution does not have a finite upper bound. We follow Athey, Levin and Seira (2011) and truncate the very upper tail of the estimated distribution.

[41] We do not model (to the econometrician) unobserved cost heterogeneity. As there is only one observation per auction, it is not possible to identify this heterogeneity non-parametrically (see Krasnokutskaya 2011).

Recovering marginal cost: We can recover the distribution of costs with information on the distribution of winning bids and the number of bidders. Following Guerre, Perrigne and Vuong (2000), the first order condition for i's bidding problem is

$$c_i \equiv b_i - \frac{1}{N-1}\frac{1-G(b_i;X)}{g(b_i;X)}, \tag{6}$$

where $G(b;X) = F(b_j^{-1}(b;X))$ is the probability that j will bid less than b and $b_j^{-1}(b;X) = c_j$; $g(b_i;X)$ is the density function. This formulation provides the basis for estimating bidders' cost distributions. It also reflects that, in equilibrium, bidders use a markup strategy and bid their values minus a shading factor that depends on the equilibrium behavior of opponents.

Assuming bidders behave as predicted by the theoretical auction model, the distribution $F(\cdot|X)$ is identified from the distribution of observed winning bids.[42] Bidders' costs are then directly derived from equation (6). As we do not observe all bids, we back out marginal cost and calculate markups for winning bids only.[43] To back out marginal cost, we apply (6) to the observations from the auctioned lines, only.

Predictions To predict winning bids in-sample and out-of-sample, we calculate the expectation of the first-order statistic of a Weibull distribution, i.e.,

$$\hat{b}_{[1]} \equiv \mathbb{E}[b_{[1]}] = N\hat{\lambda}(X)\left(\frac{1}{N}\right)^{\left(\frac{1}{\hat{\rho}(X)}+1\right)}\Gamma\left(\frac{1}{\hat{\rho}(X)}+1\right), \tag{7}$$

where $\mathbb{E}[b_{[1]}]$ is the expected winning bid, Γ the gamma function, and $\hat{\lambda}(X)$ and $\hat{\rho}(X)$ are the estimated scale and shape of the Weibull distribution.[44] We may also predict the mean negotiated prices by calculating the mean value of the Weibull distribution as

$$\hat{p}_{negs} \equiv \mathbb{E}[p_{negs}] = \hat{\lambda}(X)\Gamma\left(\frac{1}{\hat{\rho}(X)}+1\right), \tag{8}$$

where $\mathbb{E}[p_{negs}]$ is the expected negotiated (log) price.

Approximation of incumbent's cost To obtain an estimate for the incumbents' costs under negotiations, we use two approaches. The first approach gives us an upper bound for this cost and the second approach provides a lower bound. The first approach starts from the symmetry assumption that the expected cost of the incumbent is the same as the expected cost of any other bidder. We cannot directly estimate this expected cost, as we have no explicit model of the negotiation. Instead of this expected cost, we therefore choose the winning bid in a second-price auction with two bidders. In expectation this winning bid corresponds to the expected cost of the bidder with the second lowest bid. The cost of the second bidder is the highest cost in the two-bidder case and thus higher than the expected average cost of the two bidders.

For our second approach, we use equation (6) to recover the incumbent's cost in auctions where the incumbent participated and won. We then regress these cost draws on line characteristics using OLS (sample size is equal to

[42] For a discussion on identification in first-price auctions, see Athey and Haile (2006).

[43] Once we have estimated the distribution function G and the density function g of the Weibull distribution, we are able to predict winning bids, but in principle also mean bids or any other order statistics.

[44] For the calculation of the expectation, see Appendix E.

23 out of 139)[45] and make predictions for all auctioned lines. We assume that, controlling for line characteristics, the incumbent is as efficient on auctioned lines where this firm has won and on those where it has not. As the lines where the incumbent has won will be those where he has particularly low costs, this approach underestimates cost on negotiated lines and will therefore exaggerate markups.[46]

Agency surplus To calculate surplus with the parameters $\hat{s}_{negs}$ and $\hat{s}_{bids}$, we use equation (1) and insert the expected winning bids, estimated cost, expected negotiated prices as well as expected quantities from the previous OLS regressions, separately predicted for auctioned lines.

6 How Do Auctions Reduce Prices?

In the following, we present the empirical implications of our structural model. Section 6.1 explains how we deal with the number of bidders. In Section 6.2, we redo the counterfactual analysis of Section 4.3 and replace the reduced form price estimations for auctioned lines by estimations based on the structural model. In Section 6.3, we investigate the contributions of competitive pressure and selection to the overall price effect of competition. Section 6.4 analyzes the effects of competition on agency surplus.

6.1 Predicted Entry

Before we carry out the counterfactual analysis, we also require an estimate for the number of bidders that would have participated in the bidding process if a negotiated line had been procured competitively. We run a Poisson regression with the number of bidders as the dependent variable and line characteristics as well as fixed effects for states as explanatory variables. Table 7 shows how the number of bidders depends on the control variables. Significant controls are the electrification dummy, line length and the population variables. The estimations are based on the small sample of auctions for which the number of bidders is available; we use them to predict this number on the remaining sample as well as to predict the number of bidders that would compete on negotiated lines.

When we calculate the average number of participating firms predicted by the Poisson model for the auctioned lines, we obtain a value of 4.6341. This is slightly larger than the average number of participating firms based on the observations and that is equal to 4.6098 (see Table 1). We also use this model to predict the entry of firms if negotiated lines would have been auctioned. The Poisson model predicts that on average, 4.6048 bidders would compete in that case. This number is roughly the same as we obtained for auctioned lines.

6.2 The Effects of Competition on Prices

We now investigate how prices and quantities would have evolved under different regimes. First, we would like to know how winning bids and quantities would have looked like if auctions had taken place on negotiated lines.

[45] The estimation results are shown in Table D1 in Appendix D.

[46] In principle, we can extend both approaches also to negotiated lines. We however have to make further (out-of-sample) assumptions on the behavior of incumbents and other bidders.

Table 7: Determinants of the number of bidders

	(1)	(2)
Constant	0.177	(0.746)
Incumbent	0.035	(0.067)
Log frequency	0.104	(0.064)
Electric traction	0.099*	(0.057)
Distance to city (km)	0.000	(0.002)
Log track length	0.071**	(0.028)
Log pop largest city	0.055***	(0.017)
Log pop 2nd largest city	-0.162***	(0.047)
Regional factor	0.226	(0.183)
Dummy variables for federal states	yes	
Log likelihood	-69.180798	
Number of observations	41	

Notes: Results from MLE estimations. The dependent variables is the number of bidders and the estimated coefficients are from a Poisson model; Standard errors are clustered (on agency) are shown in parentheses besides the coefficients. $***$ ($**$, $*$) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

Second, we estimate negotiated prices for auctioned lines. For that purpose, we present estimated parameters of the likelihood (5).

Table 8 presents the results of the price models. It shows the estimates for the scale parameter λ and the estimate for the shape parameter ρ. Column (1) shows determinants of negotiated prices; column (3) the deviations for auctioned prices. The relation between the control variables and the shape parameter of the Weibull distribution is generally plausible. For instance, as one would expect, on negotiated lines the regional factor has a substantial positive effect on the price. This effect is essentially wiped out on auctioned lines. This is consistent with the notion that auctions have a particularly strong price-reducing effect on less attractive lines where the regional factor is high. It is also interesting to note that the prices under negotiations are particularly high for electrified lines. This is plausible in view of the opportunity costs for *Deutsche Bahn*: Lines that are electrified are often used for long-distance passenger and freight trains, so that *Deutsche Bahn* will be reluctant to accept a large number of regional passenger trains without substantial payments.

Using these new price estimates, we obtain that, on auctioned lines, prices were 15.5% lower than if negotiations had been used (see Table 9). Moreover, on negotiated lines, prices would have been 16.9% lower if competitive procurement had been used. These results are somewhat lower than those obtained in the reduced form analysis as we also control for participation and allow for non-linear effects.

Table 8: Determinants of auctioned and negotiated prices

	(1)	(2)	(3)	(4)
Constant (scale λ)	2.311***	(0.208)	-0.006	(0.044)
Incumbent	0.066	(0.059)	-0.066*	(0.038)
Log frequency	-0.042**	(0.019)	-0.024	(0.041)
Electric traction	0.081**	(0.036)	-0.152**	(0.068)
Distance to city (km)	-0.001**	(0.001)	0.001	(0.001)
Log track length	-0.014	(0.014)	0.032	(0.032)
Log pop largest city	-0.005	(0.012)	0.002	(0.032)
Log pop 2nd largest city	-0.012	(0.011)	-0.001	(0.028)
Regional factor	0.204***	(0.048)	-0.218***	(0.081)
Constant (shape ρ)	15.890***	(1.208)		
Log likelihood	238.43003			
Number of observations	484			

Notes: Results from MLE estimations. The dependent variable is the logarithm of price and the coefficients describe the scale parameter λ and shape parameter ρ of the Weibull model. Column (1) shows determinants of negotiated prices; column (3) the deviations for auctioned prices. Standard errors are clustered (on agency) are shown in parentheses besides the coefficients. $***$ ($**$, $*$) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

Table 9: Comparison of predicted quantities and prices

	Mean quantities			Mean prices		
	Negotiations	Auctions	Difference	Negotiations	Auctions	Difference
in levels	(1)	(2)	(3)	(4)	(5)	(6)
Negotiated lines	18648.3	20815.5	-2167.1***	8.5078	7.0715	1.4363***
	(610.6)	(667.1)	(128.2)	(0.0262)	(0.0256)	(0.0366)
Auctioned lines	14280.3	16407.9	-2127.6***	8.1942	6.9281	1.2661***
	(679.9)	(769.9)	(186.3)	(0.0433)	(0.0407)	(0.0594)

Notes: Results based on OLS and MLE estimations in Tables 3 and 8. Mean predicted values in levels are shown. Standard errors are shown below the mean values. *** (**, *) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

6.3 Competitive Pressure vs. More Efficient Suppliers

So far, the analysis has established that competition increases the frequency of service and reduces procurement prices, but it has not uncovered the sources of these effects. As we argued before, the price reductions could potentially reflect increasing competitive pressure as well as a tendency for more efficient suppliers to win the auction (which would correspond to lower costs). We now analyze to which extent these two channels are responsible for the reduction in procurement prices. Table 10 provides information on mean estimated cost and markups on auctioned lines. We distinguish between auctions and negotiations. To capture the former, we calculate cost and markups using the auction model. To obtain an estimate of incumbents' cost under negotiations and to calculate markups, we employ the two different approaches outlined in Section 5.2. The first one provides a lower bound of the markup; the second one provides an upper bound.

In the first approach, we assume two bidders in the structural model and use the resulting winning bid as an upper bound for the incumbent's cost under negotiations. In the IPV setting, this is equal to the marginal costs of the second lowest bidder. Based on marginal costs, we then calculate absolute and relative markups. Absolute markups are the difference between prices and costs, and relative markups are calculated using the standard Lerner index, i.e., (price - cost)/price. Our results are presented in Table 10. The upper bound for expected costs (the estimated cost of the second-lowest bidder in a two-bidder auction) is 7.49. The corresponding lower bound for the markup under negotiations is 8.58%. We now use this lower bound of the estimated markup under negotiations to capture the pure effect of competitive pressure on prices on auctioned lines. Auctions reduce prices on auctioned lines from 8.1942 to 6.9281, a difference of 1.2662. Now assume hypothetically that costs remain at the pre-competitive level of 7.4900, whereas absolute markups fall from 0.7042 to 0.3069 and relative markups fall from 8.5789% to 4.4054%, which is the predicted effect of competition on markup on auctioned lines. The resulting hypothetical price after the fall of markups is 7.7969 (using the mean absolute markup of 0.3069) or 7.8200 (using the mean relative markup). Thus, the minimal effect of competitive pressure on procurement prices is that they fall from 8.1942 to 7.7969 (7.8200). This would amount to 31% (28%) of the total effect of competition on prices (the drop from 8.1942 to 6.9281).

Thus, even if we take a conservative approach to estimating the markups under negotiations, the potential for competition to reduce them still appears to be quite substantial. In particular, competitive pressure (as opposed to cost reduction) is responsible for at least 30% of the price reduction that occurred on auctioned lines.

As an alternative, we also present an upper bound for the estimated markups in negotiations in the lower panel of Table 10. We back out costs using the first order condition of optimal bidding of the incumbents, and we predict them out of sample for negotiations. In the auction sample, estimated costs are 6.6212 Euro on the auctioned lines and 6.6215 Euro on the negotiated lines. With this approach, which underestimates costs under negotiations, the cost-reducing effect essentially disappears and the entire price effect is due to the markup reduction from 19.1% to 4.5%.

6.4 Agency Surplus

We now discuss how auctions affect agency surplus. Recall that agency surplus is $W_M = s_M\sqrt(q_M) - p_M q_M$, where M is the procurement mode, A for auction and N for negotiation. We observe q_A and p_A for auctioned lines, and q_N and p_N for negotiated lines. We use the predicted counterfactual quantities and prices we tabulated earlier (Table 9). Based on these predicted quantities and prices, we calculate the agency surplus parameters

Table 10: Comparison of estimated cost and markups on auctioned lines

	Upper/lower bound for costs/markups			Lower/upper bound for cost/markups		
	Negotiations	Auctions	Difference	Negotiations	Auctions	Difference
in levels	(1)	(2)	(3)	(4)	(5)	(6)
Price	8.1942	6.9281	1.2661***	8.1942	6.9281	1.2661***
	(0.0433)	(0.0407)	(0.0594)	(0.0433)	(0.0407)	(0.0594)
Costs	7.4900	6.6212	0.8688***	6.6215	6.6212	0.0003
	(0.0379)	(0.0370)	(0.0530)	(0.0319)	(0.0370)	(0.0644)
Absolute markups	0.7042	0.3069	0.3973***	1.5727	0.3069	1.2657***
	(0.0054)	(0.0065)	(0.0084)	(0.0313)	(.0065)	(0.0320)
Relative markups	8.5789	4.4054	4.1735***	19.0688	4.4054	14.6635***
	(0.0211)	(0.0795)	(0.0823)	(0.3261)	(0.0795)	(0.3357)

Notes: Results based on MLE estimations in Table 8. Mean predicted values in levels for auctioned lines are shown. Absolute markups are price - cost; relative markups are in % and the Lerner index, i.e., (price - cost)/price multiplied by 100. *** (**, *) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

$\hat{s}_{negs}$ and $\hat{s}_{bids}$ using the first-order conditions derived from equation (1) and obtain values for welfare.[47]

In Table 11, we compare the predicted ex-ante agency surplus under negotiations and auctions on auctioned lines. We show mean values for negotiations and auctions for auctioned lines. The loss from switching from auctions to negotiations on auctioned lines is 21%. The respective numbers in levels are about 19188 Euro per line kilometer and year.

Table 11: Comparison of mean predicted agency surplus on auctioned lines

	Negotiations	Auctions	Difference
in levels	(1)	(2)	(3)
Auctioned lines	92091.1	111278.7	-19187.6***
	(4274.693)	(4710.279)	(6360.796)

Notes: Results based on OLS and MLE estimations in Tables 3 and 8. Mean predicted values in levels for auctioned lines are shown.

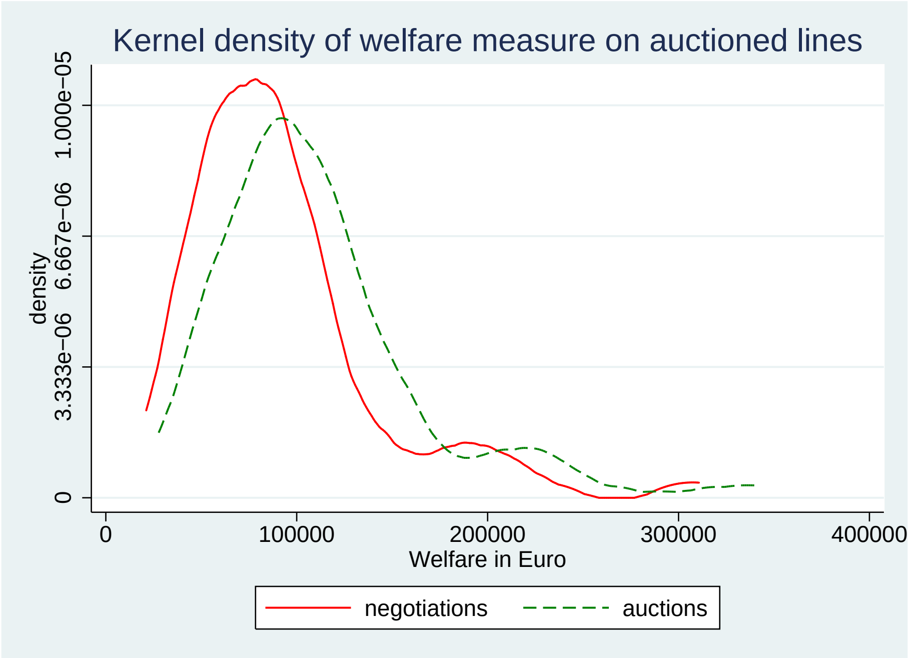
Source: Own calculations.

To show the effect of competition over the complete distribution, we also provide a kernel density estimate of the log surplus between procurement by auction and by negotiations on auctioned lines in Figure 1. Over nearly the whole distribution, we observe that the estimated surplus per line kilometer and year is higher with competitive procurement.

To interpret these numbers, recall that an increase of the frequency of service creates a higher gross surplus

[47]For details on the first-order conditions, see Appendix C.

Figure 1: Kernel density estimate of log difference in welfare on auctioned lines



Notes: Kernel density estimates of the log difference of welfare for auctioned and negotiated lines.

Source: Own calculations.

in two ways. First, there is a higher consumer surplus. Second, the demand shift involves a substitution from road to rail, which creates additional benefits from reductions in negative externalities. The functional form for the surplus, $S(q) = s\sqrt{q}$, imposes restrictions on the relation between quantity and surplus. Specifically, the elasticity of surplus with respect to q is 1/2 by assumption. Thus, we are not allowing any flexibility in this respect. Our estimation of s gives us the surplus from one unit of q, $S(1)$. However, at least the value of 1/2 for this elasticity appears to be reasonable. One way to rationalize it would be to say that (1) a 10% increase of q creates a 5% increase of demand and (2) that each unit of demand is equally valuable in terms of surplus generated. Part (1) is in line with what other papers have shown (Evans 2004). Part (2) is more debatable, as one might expect decreasing marginal benefits. It is not clear, however, how big this effect is for the relevant levels of the frequency of surplus.

7 Summary and Discussion

The reorganization of German railway passenger transportation after 1994 provides a unique setting for obtaining insights on the relative performance of the most important institutions for public procurement, auctions and negotiations. At the same time, the analysis allows us to contribute to the evaluation of reforms in network industries such as railways that took place in many European countries towards the end of the last century.

Our analysis indicates that auctions have been successful. According to our estimates, competitive procurement increases the frequency of service by 12-15%, and it reduces procurement prices by about 20%. Moreover, estimates from a structural auction model allow us to back out bidders' marginal costs and their markups. We find that markups decrease from between 8% and 19% to just above 4% when lines are auctioned instead of negotiated. The analysis also suggests cost reductions of up to 13% resulting from selection of more efficient bidders. These results translate into sizeable increases of agency surplus, which was about 20% higher under auctions compared to direct negotiations on lines that were auctioned.

Our data are not sufficiently detailed to rule out the possibility that competition reduced procurement prices and increased quantities at the cost of lower quality. However, anecdotal and descriptive evidence does not suggest that competitively procured lines are plagued by more serious quality problems than negotiated lines. Nevertheless, a systematic investigation of the quality effects would be an interesting and challenging subject for an entirely new paper.

These results contain several interesting implications. From the perspective of the agency, procurement auctions have substantial advantages over direct negotiations. Auctions should therefore be the preferred mode of procurement for regional rail service in a context like the one we study. The key impediment appears to be the willingness of the agency to set up the auction. Policies that support regional agencies in running the auctions (or make auctions compulsory) would therefore appear plausible.

There may be specific aspects of the market situation that fostered the positive effects of competition. Most importantly, the analysis concerned an early phase after the reform. At the time, there was substantial entry into the market, which limited the ability of suppliers to ask for high transfers in auctions. In later periods, market consolidation may reduce competition. Also, incumbency advantages may become persistent.[48]

[48] Iossa and Waterson (2016) observe a tendency for incumbents to be selected in the London bus market in later rounds of procurement.

A Appendix: Procurement prices under negotiations

We now show how we constructed line-specific prices with negotiations from the average price in the agency and from information on line-specific access charges. We make the following assumptions. For each individual line $i = 1, ..., I$, we assume that the negotiation price charged by DB Regio is calculated using the costs of delivering the service plus markup. The cost has two components: The costs of using infrastructure and the costs of running the service (a total number $k_i = q_i l_i$ of train kilometers, where q_i is the frequency of service, and l_i is the length of the line in kilometers).

First, note that the costs of using infrastructure are the access charges that have to be paid to DB Netz. These costs differ across lines. We have detailed information on these access costs for each line. Let a_i be the access charge for a line. We calculated the detailed access prices for 504 out of the 551 lines, or 91%, of the lines observed in our sample (the percentage with information on access price is 92% on lines that were negotiated with the incumbent). For the remaining 47 lines we could not match the start and end station with the data base providing information on access prices. We impute missing prices using linear regression.

Second, for simplicity, we suppose that the remaining costs of running the service, and the markup, are identical on the different lines but they differ across states (*Bundesländer*). Let x_j denote the sum of the remaining costs of running the service and an absolute markup charged by the incumbent, with $j = 1, ..., J$ indexing states. The resulting negotiation price is

$$p_{i,N} = a_i + x_j.$$

We recover the line specific negotiation price using information on the average negotiation price by state $p_{j,N}$. We estimate x_j assuming that the average (frequency of service weighted) negotiation price is identical to the state level negotiation price. Let $b_{ij} = 1$ if line i is situated in state j, and $b_{ij} = 0$ otherwise, and $D_i = 1$ if the line is auctioned, and $D_i = 0$ otherwise. It follows that

$$p_{j,N} = \frac{\sum_{i=1}^{I} b_{ij}(1 - D_i) k_{i,N} p_{i,N}}{\sum_{i=1}^{I} b_{ij}(1 - D_i) k_{i,N}}.$$

This means we can back out an estimate of the state specific price of running the service as

$$x_{j,N} = p_{j,N} - \frac{\sum_{i=1}^{I} b_{ij}(1 - D_i) k_{i,N} a_i}{\sum_{i=1}^{I} b_{ij}(1 - D_i) k_{i,N}}.$$

The resulting negotiation prices $p_{i,N}$ have a number of properties. First, the state average negotiation prices match the quoted prices exactly. Second, the resulting negotiation price components match published sources well. The average total negotiation price was 8.73 EUR per train kilometer, with the access charge amounting to 3.53 EUR on average. Thus, the access charge makes up 40% of the total price. This is consistent with LNVG (2010) who argue that infrastructure costs amount to about 40% of the costs of railway services.

B Selection on Unobserved Growth

This section discusses our test for selection based on unobserved growth. Let y_{it}^D denote the potential service frequency along line i. $t = 1$ after the reform, and $t = 0$ before the reform. $D = 1$ if services along a line have been auctioned, and $D = 0$ otherwise. In $t = 0$, $D = 0$ for all lines, and we omit the super-script. In $t = 1$, a line is either auctioned, or negotiated, so only one potential outcome exists. Also, let $y_{it} \equiv Dy_{it}^1 - (1 - D)y_{it}^0$ be the outcome we observe in our data.

For ease of exposition, we abstract from pure time effects, but include these in our empirical analysis. Service frequency prior to the reform is

$$y_{i0} = x_i'\alpha + \epsilon_{i0}$$

x_i has no time index, since line characteristics are time-invariant. ϵ_{i0} has mean zero.

Service frequency along auctioned lines after the reform is

$$y_{i1}^1 = x_i'\beta + \epsilon_{i1}^1$$

where ϵ_{i1}^1 has mean zero.

Thus, along auctioned lines, service growth is

$$\begin{aligned} y_{i1}^1 - y_{i0} &= x_i'(\beta - \alpha) + \epsilon_{i1}^1 - \epsilon_{i0} \\ &= x_i'\gamma + \epsilon_{i1}^1 - \epsilon_{i0} \end{aligned}$$

Supposes agencies select based on positive expected service growth, so $D = I[x_i'\gamma + \epsilon_{i1}^1 - \epsilon_{i0} > 0]$, where $I[A]$ is the indicator function that takes the value one if the condition A is true, and zero otherwise.[49] Auctioned lines are those with larger service growth if procured using auctions than negotiations.

Our test for selection based on service growth focuses on the average unobserved component of service, prior to the reform. Among auctioned lines, this is

$$\begin{aligned} E[\epsilon_{i0}|D = 1] &= E[\epsilon_{i0}|x_i'\gamma + \epsilon_{i1}^1 - \epsilon_{i0} > 0] \\ &= E[\epsilon_{i0}|x_i'\gamma + \epsilon_{i1}^1 > \epsilon_{i0}] \end{aligned}$$

Among auctioned lines, the distribution of the unobserved component of pre-reform service levels, ϵ_{i0}, is truncated from above. Truncation from above will dampen the mean unobserved service level among lines chosen to be no larger than the population mean of zero. Truncation is stronger the smaller the effect of auctions on service frequency, $x_i'\gamma$, relative to the support of the distribution of service frequency.

For negotiated lines, with $x_i'\gamma + \epsilon_{i1}^1 < \epsilon_{i0}$, ϵ_{i0} is truncated from below so the mean of ϵ_{i0} is positive. Truncation is weaker if $x_i'\gamma$ is smaller, contrary to auctions. Regardless of the size of $x_i'\gamma$, selection based on gains drives a wedge between the mean unobserved service component in the auctioned and negotiated group.

[49] Note that agencies may use any threshold, not just 0, and the test remains valid. If agencies select on the gains to growth from auctions compared to negotiations, i.e. $\epsilon_{i1}^1 - \epsilon_{i0} > \epsilon_{i1}^0 - \epsilon_{i0} = \epsilon_{i1}^1 > \epsilon_{i1}^0$, the test would not detect selection, as the selection condition does not involve service levels prior to the reform. But if there is persistence in unobserved service levels, as we find in our main estimates in section 4, selection based on service levels in period 1 would also show in period 0.

We test whether unobserved components of pre reform service differ using this regression

$$y_{i0} = x_i'\alpha + D_i\delta + \nu_{i0}$$

where $\nu_{i0} = \epsilon_{i0} - D_i\delta$. The parameter δ is a consistent estimator of $E[\epsilon_{i0}|x_i, D = 1] - E[\epsilon_{i0}|x_i, D = 0]$. A standard hypothesis test on δ informs on the presence of selection based on unobserved service growth.

C Appendix: Derivations of Quantities and Welfare

In the following, we derive the values of quantities and agency surplus for each procurement mode as a function of parameters.

Proposition 1 *(i) The quantity resulting in procurement mode is*

$$q = \frac{s^2}{4\left(p_M\right)^2}$$

(ii) The agency payoff is $W_M^* = \frac{s^2}{4p_M}$*, the incumbent payoffs are* $\Pi_A^* = \frac{s^2\left(c_{(2)} - c_{(1)}\right)}{4N\left(c_{(2)}\right)^2}$ *for auctions and* $\Pi_N^* = \frac{ys^2}{4(c+y)^2}$ *for negotiations.*

(i) $p = c + y$ follows from our assumptions. Inserting this into the agency payoff and taking the first-order condition with respect to q yields $2c\sqrt{q} - s + 2\sqrt{q}y = 0$. The unique solution is $q = \frac{1}{4}\frac{s^2}{(c+y)^2}$. The second-order condition holds globally.

The expected lowest bid in a procurement bid is $p^A = c_{(2)}$. Thus, the first-order condition for the agency is $\left(s - 2c^{(2)}\sqrt{q}\right)/2\sqrt{q} = 0$. Hence $q = s^2/4c_{(2)}^2$. The second-order condition holds globally.

(ii) Using (i), the payoff of the agency is $\left(s\sqrt{q} - pq\right) = \frac{1}{2}\frac{s^2}{(c+y)} - (c+y)\,\frac{1}{4}\frac{s^2}{(c+y)^2} = \frac{1}{4}\frac{s^2}{c+y}$. As the expected margin $p - c$ of the incumbent is y, his expected profit is $mq = \frac{ys^2}{4(c+y)^2}$.

The agency payoff is $\left(s\sqrt{q} - c_{(2)}q\right) = \left(\frac{s^2}{2c^{(2)}} - c_{(2)}\frac{s^2}{4\left(c_{(2)}\right)^2}\right) = s^2\left(\frac{1}{4\left(c_{(2)}\right)}\right)$. The expected incumbent payoff from an auction is $\frac{mq}{N} = \frac{s^2\left(c_{(2)} - c_{(1)}\right)}{N4\left(c_{(2)}\right)^2}$.

D Appendix: Results for auxiliary regression

Table D1 shows the estimation results, when we regress the incumbent's cost in auctions where the incumbent participated and won on line characteristics using OLS. From this regression, we make predictions for all auctioned lines.

Table D1: Determinants of the incumbent's cost

	(1)	(2)
Constant	2.250***	(0.276)
Log frequency	-0.024	(0.023)
Electric traction	-0.028	(0.021)
Distance to city (km)	0.001	(0.000)
Log track length	0.004	(0.015)
Log pop largest city	-0.001	(0.015)
Log pop 2nd largest city	-0.018	(0.018)
Regional factor	-0.089*	(0.044)
Adjusted R-squared	0.375	
Number of observations	23	

Notes: Results from OLS estimations. The dependent variables is incumbent's cost in auctions where the incumbent participated and won. Standard errors are clustered (on agency) are shown in parentheses besides the coefficients. $***$ ($**$, $*$) stands for significance at the 1% (5%, 10%) level.

Source: Own calculations.

E Appendix: Derivation of (7)

$$\begin{aligned}
\mathbb{E}[b_{[1]}] &= \int_{-\infty}^{\infty} x f(x_{[1:n]}) dx = \frac{n!}{(n-1)!} \int_{-\infty}^{\infty} x[1-F(x)]^{n-1} f(x) dx \\
&= n \int_{0}^{\infty} x\{\exp[-(x/\lambda)^{\rho}]\}^{n} (\frac{\rho}{\lambda})(\frac{x}{\lambda})^{\rho-1} dx \\
&= n\rho \int_{0}^{\infty} (\frac{x}{\lambda})^{\rho} \{\exp[-(x/\lambda)^{\rho}]\}^{n} dx = \text{ (integration by substitution)} \\
&= n\lambda \int_{0}^{\infty} (\frac{1}{n})^{(1/\rho+1)} y^{(1/\rho)} \exp(-y) dy \\
&= n\lambda (\frac{1}{n})^{\left(1/\rho+1\right)} \Gamma\left(1/\rho+1\right) \text{ with } \Gamma(t) = \int_{0}^{\infty} x^{t-1} \exp(-x) dx \qquad (9)
\end{aligned}$$

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