Does Supporting Passenger Railways Reduce Road Traffic Externalities?

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Abstract: Many governments subsidize regional rail service as an alternative to road traffic. This paper assesses whether increases in service frequency reduce road traffic externalities. We exploit differences in service frequency growth by procurement mode following a railway reform in Germany to address endogeneity of service growth. Increases in service frequency reduce the number of severe road traffic accidents, nitrogen monoxide and nitrogen dioxide pollution and infant mortality. Results for carbon monoxide and particulate pollution are negative but insignificant. Placebo regressions with sulfur dioxide and ozone yield no effect. Service frequency growth between 1994 and 2004 improves environmental quality by an amount that is worth approximately 28-40 % of total subsidies.

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1 Introduction

Road transportation causes a large fraction of local and global pollution. Moreover, it leads to accidents and congestion. Countries all over the world have addressed these externalities with a wide range of policies, including support for public transportation. Based on the argument that buses, trams and railroads have favorable environmental properties, many governments subsidize public transportation. In the U.S., for example, President Obama recently justified plans to construct fast rail corridors on environmental grounds.

Even so, very little is known about the actual environmental effects of improvements in public transportation. For there to be a positive effect of such improvements, two conditions must be jointly satisfied:

(C1) The improvement must induce a substantial substitution of traffic from roads to public transportation.

(C2) Second, public transportation must involve lower externalities than road transportation per passenger transported.

Neither of these conditions needs to be fulfilled. First, even if improved public transportation increases ridership, this does not inevitably lead to a large reduction in road transportation. For instance, the inhabitants of large cities may move to the suburbs as public transportation becomes more attractive. While they may use public transportation for some of their trips (say, for commuting), they might still use the car more often than they would have done in the city, because public transportation in the countryside is still not a sufficiently good alternative for other activities.

Second, while public transportation is often said to perform better than road transportation with respect to many environmental externalities, such comparisons usually assume otherwise identical conditions (e.g., speed, capacity utilization, etc.). It is again not obvious that this assumption is adequate to evaluate concrete policy measures. For instance, in rural regions, the number of passengers per train may be so small that the emissions of most major pollutants could well be higher than if these passengers had traveled by cars. Hence, a public transport policy that targets rural regions might lead to increases in pollution.

This study measures the environmental effects of a specific public transportation program in such a way that (C1) and (C2) can be jointly tested. In Germany, regional passenger railway services expanded by 28 % between 1994 and 2004. During the same period, Germany improved substantially with respect to all the externality measures except for ozone. Yet clearly, this simple before-and-after comparison says little about the causal effect of expanding regional passenger service. The concentrations of many local pollutants have declined in the last decades in many industrialized countries. A large part of these improvements reflects changes in the vehicle park which are unrelated to improvements in public transport. Also, Germany witnessed changes in the economic and political landscape and the implementation of important environmental policies in the nineteen nineties.

To assess the environmental effects of expanding rail service, we collect data on the evolution of the service frequency on all regional passenger railway lines in Germany in 1994 and 2004.[1] We then combine this information on public transport capacity with county-level data on externalities: road traffic accidents, carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), particulate (TSP and PM), sulfur dioxide (SO_2), and ground-level ozone (O_3) pollution. We also consider infant mortality rates.[2]

To isolate the effects of passenger railway support on environmental quality, we first use differences across lines in the evolution of passenger service frequency. In spite of the overall increase in service frequency, some areas have seen no growth, whereas frequencies nearly doubled in other regions. We therefore ask whether areas that experienced greater improvements in the quality of railway services also fared better in terms of the evolution of environmental quality. These findings suggest there is no effect of service frequency on the environment. Clearly, this may reflect endogeneity of increases

[1] Lalive and Schmutzler (2011) also use these data to estimate the effects of procurement mode on frequency of rail service.

[2] Luechinger (2009, 2011) uses data on SO_2 pollution at the county level for Germany in the period 1985-2003 to estimate the general effects on well-being and infant mortality, respectively, without discussing the contribution of transportation.

in the regional passenger railway service capacity. Public transport may have been supported most in regions in which authorities expected an increase in traffic volume and, thus, a deterioration of environmental quality. The positive effects of an increase in the frequency in rail services on environmental quality would then be obscured by the adverse underlying trend.

To address such problems, we exploit a railway reform in 1994. This reform allowed regional passenger service agencies to choose between procuring the service competitively via public tenders or negotiating with the incumbent supplier. This reform serves as an instrument for frequency of service for several reasons. First, lines that were procured competitively between 1994 and 2004 exhibit much stronger growth of frequency of service than lines that were not procured competitively (Lalive and Schmutzler 2008, 2011).[3] Second, lines that were procured competitively do not differ from other lines once important characteristics of the line (remoteness, traction, etc.) are taken into account. Third, it appears likely that competitive procurement represents an exogenous shock that serves to increase the frequency of service without any direct effects on the environment. In particular, competition for the market seems to have little effects on ticket prices or aspects of service quality which could have independent effects on the demand for passenger railways. Fourth, decision makers who are in charge of local railway procurement usually do not have a say in environmental policy issues, which eliminates another source of correlation between procurement mode and outcome variables. Fifth, there is no correlation between procurement and voter preferences, which again makes it appear less likely that there is a correlation between procurement and other green policies (see Section 5).

Our analysis supports the hypothesis that improvements in the quality of local passenger transportation cause improvements in the outcome variables of interest. First, we find a substantial negative effect of improved passenger transportation on road accidents. Because road accidents are exclusively the result of road transportation, this finding suggests that increasing the

[3] Lalive and Schmutzler (2008) focuses on the state of Baden-Württemberg, Lalive and Schmutzler (2011) refines the analysis and extends it to the entire country. The authors argue that the correlation between the mode of procurement and the frequency of service can be given a causal interpretation.

frequency of regional passenger railway services reduces road traffic (C1). Second, we observe negative and significant effects of an increase in the frequency of service on NO and NO_2; the effects on CO and TSP/PM are negative, weaker and imprecisely estimated. Third, we test the validity of the instrument by placebo regressions on SO_2 pollution; SO_2 is mainly emitted from power stations. We find that improving the railway service frequency has no effects on the concentration of SO_2. Similarly, we do not find any effect of railway services on O_3. Again, this is not surprising. Even though road traffic is an important source of O_3 and CO, NO and NO_2 are precursors of O_3, the complex chemistry of ozone formation often leads to high O_3 concentrations far away from the emission sources. Fifth, we find some evidence that the increase in the frequency of rail services reduced infant mortality rates. Summing up, our analysis supports the idea that improvements in the quality of railway services can substantially reduce road traffic externalities.

The paper is organized as follows. Section 2 discusses related literature. Section 3 provides a brief account of the relevant institutions. Section 4 introduces the data. In Section 5, we introduce the framework for the empirical analysis. Section 6 contains the results. Section 7 discusses the results and concludes.

2 Related Literature

A large literature deals with the effects of transportation policies on the environment.[4] To put these contributions into perspective, note that our paper is motivated by the presumption that the following statements hold:

(1) Improvements in public transportation increase ridership and thereby reduce car transportation.

(2) Reductions in car transportation lead to reductions in air pollution, which dominate any possible increases in pollution resulting from additional public transportation. Similarly, reductions in road transportation lead to less road accidents.

[4] See Schmutzler 2011 for a recent survey.

(3) Finally, the reductions in pollution increase human health and well-being.

Most of our results are joint tests of the first two statements; our result that improved railway services help to reduce infant mortality support the idea that all three statements are correct. Existing papers deal with each of the three claims above.

(1) A large literature attempts to quantify the effect of public transport improvements on ridership and the induced reductions in car transportation. Typically, these studies either suffer from endogeneity problems, or they confine themselves to the calculation of short-term elasticities, ignoring the long-term adjustments. Evans (2004) provides an account of half a century of evidence on the elasticities of public transport ridership with respect to service frequency. For buses, the average service elasticity, the percentage change in ridership induced by a 1 % change in the frequency of service, is approximately 0.5. As one might expect, the elasticities are higher when initial service levels are low. For railways, the elasticities are larger, with values between 0.5 and 0.9. Evans (2004) contains evidence for such mode shifts from roads to public transport from experiments in the Boston area carried out in the nineteen sixties. He reports that 64 % of the riders attracted by increasing commuter rail frequency previously used their own car; 17 % a carpool and 19 % the bus. In a recent study, Duranton and Turner (2011) find no effects of expanding peak bus service on vehicle kilometers traveled on interstate highways across metropolitan statistical areas in the U.S. However, they look at traffic within metropolitan areas in the U.S. context – a context in which bus service is marginal.

(2) Many engineering studies provide "emissions coefficients" which give information on the emissions characteristics of cars and railways. Together with information on capacity utilization of cars and railways, such information allows to compare the emissions per passenger kilometer. For instance, IFEU (2010) provides such a comparison for Germany, while INFRAS (2010) provides a more detailed analysis for automobiles. The analysis broadly supports the view that, for most pollutants, the specific emissions for railways are lower than those for cars. It also shows, however, that there are substantial differences across pollutants and the relative advantage of railways

has been declining over time. The problem with these measures is that they depend highly on the specific context, such as the type of road, topography, traffic situation and driving behavior. Also, they are typically average measures and not the marginal measures that are relevant when policy effects are studied.

(3) Chay and Greenstone (2003a,b) used changes in TSP pollution induced by recession and regulation in the U.S. to document that TSP pollution increases infant mortality substantially. Similarly, Luechinger (2011) uses the natural experiment created by the mandated de-sulfurization at power plants in Germany to show that SO_2 pollution increases infant mortality. Currie and Neidell (2005) exploit within zip-code month by month variation in pollution levels and link it to individual data on infant survival in California. They find a negative effect of CO on infant survival, but no effects of PM and O_3. This finding is corroborated by Currie et al. (2009) with data for New Jersey that allow them to follow mothers over time. Currie and Neidell (2005) and Currie et al. (2009) also report that air pollution increases the incidence of low birth weight and stillbirths. Currie and Schmieder (2009) estimate the effect of a large range of toxic chemicals on infant mortality and adverse birth outcomes. Of particular interest are strong effects of chemicals (including gasoline additives benzene, dibromoethane, toluene and other volatile organic compounds) which are thought to negatively affect fetal and infant development. Most relevant for the present context is a the recent study by Currie and Walker (2012): They show how the introduction of electronic toll collection reduced traffic congestion and emissions and thereby improved the health of infants in the immediate vicinity. The evidence regarding adult mortality is less conclusive: While early cross-section estimates find a positive association between air pollution and adult mortality (Mendelsohn and Orcutt 1979), more recent and sophisticated studies fail to do so (Chay et al. 2003).

Existing studies therefore support the notion that each of the statements (1)-(3) holds individually. There is one recent contribution by Chen and Whalley (2012) that tests the first two claims jointly. The paper analyzes the effects of the 1996 introduction of a Mass Transportation System in Taipei, which made public transport much more attractive than before. The authors show that the new transportation system led to a significant drop in CO emissions (by 9-14 %), with similar effects yet insignificant effect for NO_x. There were no clear-cut effects on O_3 formation, which reflects the complexities of the chemistry of ozone.[5] This paper contributes to the existing literature in three ways. First, it considers a comprehensive set of (local) externality measures: road accidents, air pollution, and infant health. Second, the paper uses a different econometric approach than the previous studies, exploiting geographical variation of growth in railway services and instrumenting with the type of procurement to identify the policy effects. Third, this paper analyzes the effects of a nation-wide policy in a Western industrialized country with very low levels of air pollution. This setting makes it harder to find effects and is relevant for countries with similar levels of pollution.

3 Institutional Background

Until 1994, railways in Germany were run by two vertically integrated state monopolists (*Deutsche Bundesbahn* and *Deutsche Reichsbahn*), one in West Germany and one in East Germany. In 1994, a major railway reform became effective, which not only created *Deutsche Bahn AG* as a successor of *Deutsche Bundesbahn* and *Deutsche Reichsbahn,* but also led to measures that affected regional passenger transportation in several important ways.

First, the overall budget for regional passenger transportation increased. Starting in 1996, the central government has distributed approximately 6-7 billion EUR per year to the 16 states. They can use the money to procure passenger services on the non-profitable part of the network.[6] Second, the

[5]See the discussion in the introduction. Two related studies merit attentions. First, Davis (2008) studies the effects of direct driving restrictions on air pollution in Mexico City in a related but different context. He finds that weekday limitations to driving a car had no effects on air quality. Second, Fowlie et al. (2012) find that the marginal cost of reducing NO_x emissions from cars is half as large as the marginal cost of reducing NO_x emissions from power plants.

[6]The value for 2004 was approximately 6.8 billion EUR (SCI 2006). The funds are not used to procure long-distance passenger services (*Intercity* and *Intercity-Express*); it is expected that the dominant firm *DB Fernverkehr* supplies these services profitably.

states assign responsibility for planning and procurement to agencies which act on the basis of state law.[7] Third, the service level on a particular part of the network and the amount of state transfers that a railway company receives for its services is now pre-specified in a long-term contract. Fourth, this contract is not necessarily the result of negotiations between the agency and the supplier, but it can, in principle, also be procured in a competitive auction. In the simplest case, the agency pre-specifies the desired quantity of railway services and quality aspects such as properties of the vehicles; the bid submitted by the firm is the level of transfer payments they demand to procure the desired service.[8]

Competitive procurement auctions have been used quite often. Figure 1 displays a map of all regional passenger railway lines shaded according to procurement status. Bold lines were procured competitively (138 out of 551), whereas thin lines (413 out of 551) were procured in direct negotiations with the incumbent. The map reveals that competitive mechanisms were used to procure parts of regional passenger service networks. But there is no clear rationale that was followed in choosing the lines. Both lines that serve a regional center as well as lines that do not were procured competitively. Moreover, the map also shows that competitive and non-competitive lines co-exist within the same state. The empirical analysis will focus on using such within state variation.

— Figure 1 about here —

Competitive procurement has had a substantial impact on service frequency. The overall level of services has increased substantially.[9] Between 1994 and 2004, the average frequency of service on the lines with competitive procurement grew from 10888 trains in 1994 to 16466 in 2004, that is, by 51 %. The corresponding figures for lines without competitive procurement were 15090 in 1994 and 18738 in 2004 (24 %). Thus, not only was there a

[7]Almost all states have laws (*Nahverkehrsgesetze*) governing local public passenger transportation.

[8]In other cases, the firms can submit bids that contain not only transfer payments, but also some aspects of quality, which are then weighted in a suitable scoring rule.

[9]See also Lalive and Schmutzler (2008, 2011)

substantial overall growth, but this was more pronounced on the lines that were exposed to competition than on the remaining part of the network.

— Figure 2 about here —

This correlation between competitive procurement and growth in the frequency of services will play an important role in our identification strategy. The other important pillar of the approach is the observation that there is substantial variation in the growth rates on different lines. Figure 1 plots a kernel density estimate of the growth in service quality from 1994 to 2004, again differentiating between competitively procured lines and others. While few lines saw negative growth rates, most others enjoyed positive growth, some even a duplication of the frequency of service.

We shall argue below how we will use the positive correlation between competitive procurement and growth of service frequency for identification. However, one might argue that the mode of procurement could affect the extent of substitution from road to rail (and thereby our dependent variables) through other channels. This might happen either because the incumbent applies different tariffs in cases where it has to win the market in competitive tendering or because the competitors who win a market set lower prices. Neither of these concerns appears to be justified. First, where the incumbent is free to set its price, the price is based on distance, not on the specific line. Second, in many regions, local public transport organizations rather than railway companies set ticket prices which are identical regardless of the mode of procurement. Third, outside those regions, tenders usually require the application of the tariff of the incumbent by its competitors. Similarly, the mode of procurement could affect other dimensions of quality rather than just the frequency of service. While we are not aware of any systematic evidence on this, a recent ranking in Bavaria suggest that there is at least no systematic advantage of the competitors over the incumbent in this regard (BEG 2011).

Finally, it is important to collect some facts about the decision-making authority regarding policies that can potentially influence the outcome variables. First, decisions on the quantity and quality of roads are taken at all levels of the jurisdictional hierarchy, depending on the type of road under considerations. The federal Ministery of Transportation (BMVBS) is responsible for motorways (Bundesautobahnen) and other major roads (Bundesstrassen).[10] The state governments set priorities for roads of intermediate importance.[11] They also define the duties of the local governments which typically decide on the policy towards smaller roads, parking policies, etc.[12] Second, the taxes that are most likely to affect road transportation (vehicle taxes and gasoline taxes) are set at the federal level. Third, safety regulations are also typically set at the federal level.[13] Finally, while decisions regarding air quality are made both at the federal and at the state level, federal decisions dominate in conflicting cases.

Thus, while the decisions on railway procurement (in particular, on the mode) are made at the state level, the role of the states for other policies affecting transportation and the environment is much more limited. Also, even if the states are responsible, the agency in charge is not identical with the one that deals with procurement and effects of decisions are state-wide rather than local. All told, it seems unlikely that there is a substantial correlation between local railway procurement decisions and other determinants of local environmental quality arising because the same decision makers are in charge.

4 Data

We combine railway data with county-level data on road traffic accidents, air pollution and infant mortality.

The explanatory variable of primary interest is (the log of one plus) the

[10]For instance, the Ministry provides five-year plans for major investments (a recent example is the Investitionsrahmenplan bis 2010 für die Verkehrsinfrastruktur des Bundes) and decides on major projects.

[11]To this end, they use long-term plans (*Landesstrassenbedarfspläne*).

[12]Local governments typically formulate a long-term plan (*Verkehrsentwicklungsplan*) that identifies priorities for road infrastructure. They also lay down fee structures for parking, which are potentially of great importance for the development of passenger transportation. For instance paragraph 1(2) in the *Verordnung über Zuständigkeiten im Bereich Verkehr* of the State of Lower Saxony stipulates that local jurisdictions have the right to define parking fees.

[13]The relevant legal document is the Strassenverkehrsordnung of 1970 `http://bundesrecht.juris.de/stvo/`.

frequency of service, defined as the number of passenger trains per year on a line. In tedious work, we collected this information on the basis of published railway timetables for the years 1994 and 2004, i.e. the last year before and the year one decade after the start of the reform process (Lalive and Schmutzler 2011). The data also include controls for important line-level characteristics (distance to nearest large city, length of line and information on electrification).[14]

We have information on the concentration levels of six air pollutants, namely CO, NO, NO_2, TSP/PM10, SO_2 and O_3. The data are from the *Umweltbundesamt* (hereafter the UBA for short), the federal environmental agency. The UBA provides data on annual mean concentrations for each pollutant measured at monitors belonging to the monitoring networks of the 16 state environmental agencies and the UBA. CO monitoring started only in 1997, and around 2000 there was a gradual switch from TSP to PM10 monitoring.

Data are available for 310 (1997) and 207 (2004) monitors for CO, 323 (1994) and 410 (2004) monitors for NO, 404 (1994) and 410 (2004) monitors for NO_2, 513 (1994) and 265 (2004) monitors for SO_2, and 319 (1994) and 205 (2004) monitors for O_3. For TSP/PM10, there were 431 monitors for TSP in 1994, 325 monitors for PM10 in 2004.

In order to estimate the pollution concentrations at all other locations, we interpolate the monitor readings on a grid covering the whole area of Germany using inverse distance weighting.[15] We then aggregate interpolated values to the county level. For PM10, we use county-specific PM10/TSP ratios in 2000 and TSP values from 1994 to estimate PM10 concentration in

[14] We decompose the rail network following the classification of lines in the official timetables, with two exceptions. First, to avoid double-counting of trains, we deleted parts of lines that are also contained in other lines. Second, to have a clear assignment of a line to a state, we divided lines that do not lie completely within one state into several lines.

[15] The method of inverse distance weighting requires the choice of two parameters: the number of monitors used in the interpolation and the power parameter. We have chosen these parameters so as to get a large correlation between actual readings at each monitor and the pollution level that would be predicted by the interpolation if the monitor in question was not there (Currie and Neidell 2005 suggest this approach to assess the accuracy of the interpolation procedure).

1994.

Our data on air pollution refer to an important subset of pollutants associated to road traffic. We therefore also analyze whether infant mortality is affected by changes in the frequency of rail service. Infant mortality is an indicator that will pick up all changes in local pollution that matter for infant health. Infant mortality is reported as the number of deaths within one year after birth per 1000 live births. The data on infant mortality originally came from the 15 state statistical agencies.[16] The state agencies are required by federal laws to collect data on births and deaths in a standardized way. Aggregated values at the county level are then either published in state reports or available on request. The German Youth Institute, an independent research institute on children and families, compiled and courteously provided the data. For confidentiality reasons, states do not report infant mortality rates based on a small number of cases. In small counties with few births and infant deaths, infant mortality rates are missing in some years. Therefore, we use three year averages (1993-1995; 2003-2005).

The data on accidents refer to severe road accidents involving injuries or fatalities. This information is collected by the *Kraftfahrzeugbundesamt*, the federal agency for road transportation, for all of Germany at the level of individual counties. We used these data for 1995 and 2005, because data for 1994 and 2004 were not available.

All measures of road traffic externalities are available at the county level (for a total of 439 counties in Germany; *Landkreise*). As our data points correspond to lines which might run through several counties, we take the average value of the outcome variable in all counties to construct a measure of the outcome variable for the line under consideration.

5 Empirical Framework

We now introduce a simple model from which we derive hypotheses on the determinants of environmental quality and related outcome variables. We adopt a unified approach that emphasizes the similarities between the differ-

[16]Hamburg and Schleswig-Holstein share one agency

ent pollutants by relating pollution to a small number of identical explanatory variables. Thus, we do not address the differences in the spatial and temporal diffusion patterns across pollutants. Yet this unified approach enables us to provide the key estimate on the causal effects of expanding regional passenger rail service on emissions.

Our dependent variable Y_{it} captures environmental damage along a line i during a time period t. Our specification takes into account that the damage is affected by total passenger transportation, the modal split and potentially by other variables. Let T_{it} denote total transport demand.[17] We focus on the two main modes of regional traffic: cars and trains. We assume that an increased frequency of service of trains, FOS_{it}, reduces car traffic. Specifically, we suppose the share allocated to car traffic is

$$CAR_{it} = \frac{1}{(1 + FOS_{it})^{\gamma}}$$

where γ is a parameter to be estimated. Note that $CAR_{it} = 1$ if there are no train services, and CAR_{it} decreases in FOS_{it} if $\gamma > 0$.

The empirical analysis focuses on various outcome measures, including the concentrations of several pollutants, accidents and infant mortality. We index these measures by s. θ_s^C measures the contribution of one unit of car traffic to measure s, and θ_s^T is the corresponding parameter for train traffic. For instance, when referring to pollution, θ_s^C measures the pollution intensity of cars concerning pollutant s. Similarly, θ_s^C captures the risk of getting into a road accident when s corresponds to the number of accidents. We model outcome variable s as

$$Y_{it}^s = (\theta_s^C CAR_{it} + \theta_s^T (1 - CAR_{it})) T_{it} exp(\alpha_i + \tau_{jt} + \varepsilon_{it}) \quad (1)$$

where α_i is location specific unobserved effect, ε_{it} reflects other sources of

[17] We do not explicitly model the sources of the level of transport demand. These could be plausibly related to gross domestic product per capita (GDP_{it}) and population (POP_{it}). However, population and gross domestic product enter the analysis only via their (positive) effect on transportation, which also implies a positive effect on emissions. As will be discussed in more detail in Section 6, both variables may have independent effects on emissions, and there are also reasons why pollution might affect these variables, suggesting reverse causality.

emissions, τ_{jt} are time effects which we allow to differ across states j to capture changes in background pollution.

The (natural) logarithmic version of this equation is

$$logY_{it}^s = log\left(\theta_s^C CAR_{it} + \theta_s^T (1 - CAR_{it})\right) + logT_{it} + \alpha_i + \tau_{jt} + \varepsilon_{it} \qquad (2)$$

We now discuss why this specification is suitable to analyze the effects of railway service qualities on the outcome variables we are interested in.

As to accidents, we model the total number of (log) accidents, so that specification (2) is directly suitable.

Our pollution data are given as concentration levels. We take this into account by dividing both sides of (1) by a measure of the volume of air that is affected by emissions of type s. Denote this volume by A_i. Hence, $logA_i$ should be subtracted from equation (2). However as $logA_i$ does not change in time, it will cancel out after first differencing. Thus specification 2 can also be applied.

Infant mortality is measured as the number of infant deaths within one year after birth per 1,000 live births. This mortality measure is likely to be affected by concentration of pollutants along each line i. We therefore also use specification (2) to analyze infant mortality.

In the empirical analysis, we estimate the following log-linear approximation to equation (2).

$$\begin{aligned} logY_{it}^s &= \delta logCAR_{it} + logT_{it} + \alpha_i + \tau_{jt} + \varepsilon_{it} \\ &= -\delta\gamma log(1 + FOS_{it}) + logT_{it} + \alpha_i + \tau_{jt} + \varepsilon_{it} \qquad (3) \end{aligned}$$

The log-linear approximation (3) provides an estimate of how expanding regional passenger services translates into improvements of environmental quality. This is the key policy parameter.[18] The approximation (2) is exact, if the train-specific contribution to the outcome variable is zero ($\theta_s^T = 0$); which is the case for accidents. In this case, the elasticity of accidents with respect to the share riding by car, δ, is 1 (increasing the share riding by car by 1 %

[18] Note that the log-linear equation (3) can be studied using standard linear least squares or instrumental variables methods. Estimation of the non-linear equation (2) is challenging since the non-linear part of (2) contains three parameters, but only one regressor, that is, the equation is not identified.

also increases accidents by 1 %). This means that the coefficient associated with log frequency of service directly measures the substitution parameter γ. Analyzing road accidents is therefore crucial for two reasons. First, the analysis informs on externalities due to accidents. Second, accidents directly inform on whether substitution takes place.

In case train-specific emissions are not zero, the log-linear specification (3) approximates the true specification (2). This approximation provides important information on the relative contribution of cars and trains to environmental quality s. In particular, it is possible to show that

$$\frac{\partial logY_{it}^{s}}{\partial logCAR_{it}} = \delta = \frac{(\theta_s^C - \theta_s^T)CAR_{it}}{\theta_s^T + (\theta_s^C - \theta_s^T)CAR_{it}},$$

which is 0 if trains and cars contribute equally, and it is 1 if trains do not contribute at all. This means that the coefficient relating log outcome s with log frequency of service should be smaller than for accidents in all outcomes where trains contribute to generating the externality.

To remove the fixed region effect, we look at changes between $t-1 = 1994$ and $t = 2004$. Using $\Delta\tau_j \equiv \tau_{jt} - \tau_{jt-1}$ and $\Delta\varepsilon \equiv \varepsilon_{it} - \varepsilon_{i,t-1}$, the difference specification corresponding to (3) is

$$\begin{aligned} logY_{it} - logY_{i,t-1} = \\ -\delta\gamma\Delta log(1 + FOS_{it}) + \Delta logT_{it} + \Delta\tau_j + \Delta\varepsilon \end{aligned} \quad (4)$$

We estimate specification (4) directly in the empirical analysis. We also present estimates that add time invariant line characteristics to (4) to reflect changes in the evolution of unmeasured transport demand ($\Delta logT_{it}$) along lines with different characteristics. Note that frequency of service is endogenous as it is likely to be correlated with the change in transport demand $\Delta logT_{it}$, which we cannot observe. We therefore instrument it using the 1994 reform that allows German regional passenger service agencies to choose between auctioning a line and negotiating the service directly with the incumbent.[19]

[19]An additional problem with least squares estimation of this equation is due to log-linearizing. Santos Silva and Tenreyo (2006) show that the estimated parameters in log-linearized versions of estimating equations are biased if the error term in the original

The choice of the instrument is motivated by the strong positive correlation between the competitive procurement and service growth between 1994 and 2004 (Figure 2). This means that competitive procurement predicts service frequency growth. However, for competition to be a valid instrument, it must also be unrelated to the evolution of environmental quality. This requirement can not be tested. What can be tested is whether competitive procurement is related to environmental quality in 1994.[20] Our analysis in the appendix uncovers two main findings (Table A1). First, regressions that do not control for line characteristics suggest that lines with low frequency of service and low rates of pollution (but high infant mortality) in 1994 were more likely to be chosen for competitive procurement between 1994 and 2004. Second, once we condition on key line characteristics (traction, electrification, etc.), the partial correlations of service frequency and environmental quality drop to a level that is not distinguishable from zero. This suggests that choice of procurement mode is not related to the initial level of environmental quality conditional on line characteristics. This finding does, of course, not prove that procurement mode is unrelated to the evolution of environmental quality but it is consistent with this key untestable assumption. In this sense, the mode of competition is as good as randomly assigned. The analysis of Lalive and Schmutzler (2011) suggests that unobserved line characteristics of competitively procured lines do not influence the frequency of

equation (1) is heteroskedastic. This is because expectations of the log of the error term involves higher order moments of the error term itself. Note that this problem is unlikely to be relevant in the current application. We focus on instrumental variable estimates of (2) which are consistent as long as the instrument is mean independent of the error in the log-linearized version of the model.

[20]Table A1 presents two linear probability analyses of the determinants of competitive procurement. Results indicate that lines with low frequency of service were more likely to be competitively procured between 1994 and 2004. Moreover, lines that cross counties with high levels of NO_2, TSP/PM and SO_2 concentration were also less likely to be competitively procured. Interestingly, infant mortality is also positively associated to the probability of procurement. These correlations disappear entirely once controls for line location, electrification, GDP per capita, and population are added. Competitive procurement is orthogonal to frequency of service and environmental quality (p-value 0.49). The only externality measure that continues to predict competitive procurement is infant mortality.

service in 2004, thus eliminating one possible reason why the procurement mode might be directly correlated with the evolution of the environmental outcome variables.[21] Lalive and Schmutzler (2011) argue that the positive effect of competition on the frequency of services is the mirror image of a negative effect of competition on the procurement prices paid by the agencies: Where competitive procurement takes place, agencies expect to pay less than when there are direct negotiations with the incumbent. Accordingly, they are prepared to procure greater quantities.[22]

Moreover, though one might expect that competition affects the substitution from road to rail by other channels than the increase in the frequency of service, there is little evidence that this concern is justified. As discussed in Section 3, there is little evidence that competition for the market affects ridership via reduced ticket prices or improved quality. Moreover, Section 3 shows that the institutional structure also makes it unlikely that the decisions on procurement mode are directly related to environmental policy decisions. Finally, the procurement mode of a line is unrelated to voter preferences in the Kreis, as measured by the proportion of voters in favor of the Social-Democratic Party (SPD) in the state government elections in 1997 (Péchy 2009).

6 Results

6.1 Descriptive Statistics

Table 1A provides some simple descriptive statistics on our dependent variables. The first line indicates that the number of severe road accidents has decreased substantially over the period 1994 to 2004; the median reduction in accidents is 10.2 % ($100\,(\exp(-0.108)-1) = -10.237$). In terms of air

[21] Applying a switching regression framework, Lalive and Schmutzler (2011) find that unobserved determinants of procurement mode are neither related to the subsidy required to run the line nor to the frequency of service on the line. This finding reinforces the plausibility of the assumption that procurement mode is exogenous.

[22] There are two reasons why agencies nevertheless do not procure all lines competitively: first, the large administrative costs of auctions and second, the influence activities of the incumbent.

quality measures, we find that with the exception of O_3, there have been substantial improvements in all areas. For instance, the median reductions of CO and particulate pollution are 35.6 and 36.6 %, respectively. For SO_2, which is essentially unrelated to road transportation, the reduction has been 66.1 %. In particular this last figure strongly suggests that the improvements cannot completely be attributed to improvements in public transportation, thereby illustrating the need for a more careful econometric analysis. Finally, infant mortality also decreased by 25 %, a substantial improvement.

— Table 1 about here —

For all variables, the standard deviation is substantial, indicating large regional variation in the outcome variables.

Table 1B summarizes the independent variables. The first line contains our key variable of interest, namely the evolution of regional passenger railway services. It identifies a substantial overall increase, with a median growth of 26.6 %. The standard deviation is again substantial, at least suggesting the possibility that differences in the evolution of service quality may have contributed to the different developments in the outcome variables. In the following, we will investigate whether this is indeed true.

6.2 Econometric results

The broad research strategy is to identify whether regions where the growth of passenger services has been substantial have seen a more favorable development of the outcome variables. Table 2 is a first crude attempt. It provides OLS regressions of the log differences of the outcome variables on the log differences of the frequency of railway services, with different controls. The picture does not suggest the existence of favorable consequences of improved service quality on outcome variables, no matter which outcome is considered and controls are used.

— Table 2 about here —

A central issue is whether the absence of clear effects signals endogeneity problems. In particular, a beneficial effect might be obscured in an OLS regression if passenger railways systematically obtain more support where the outcome variables are expected to deteriorate without such support because of increasing transport volumes. Indeed, Section 16 in LNVG (2010) clearly indicates that favorable demand projections are decisive for supply increases. We address this issue with an IV regression. For reasons discussed in Section 5, we use the procurement mode of the railway line as an instrument.

— Table 3 about here —-

Table 3 presents the results of the IV regressions. The bottom panel B presents the first stage results. Results indicate that the frequency of service grew at least 14.4 % more strongly on lines that were competitively procured compared to lines that were not procured competitively. This result is both quantitatively important and statistically significant. The F-statistic on the instrumental variable is at least 12.56 suggesting that procurement mode is not a weak instrument.[23]

The top panel A of Table 3 displays two types of IV regressions. For each outcome variable, the first column reports a regression where we only control for state effects, which are in our first difference setting tantamount to state-specific time effects or state-specific trends. The second column for each outcome variable reports a regression where a set of control variables is added. These controls are line characteristics that might capture geographical heterogeneity that contributes to differences in the development of the outcome variables, even though there is no clear theoretical reason to expect specific signs for their effects.

For most outcome variables where better railway services should be expected to contribute to an improvement, this is indeed the case. The effect is strongest for accidents where we find an elasticity of -0.535 without controls (column 1), or -0.465 with controls (column 2). This estimate suggests that road accidents are reduced by 4.65 % if the frequency of service increases by 10 %. This estimate not only reflects the fact that road accidents are entirely the result of road transportation (Section 5). In addition, it appears likely that the substitution effect of better railway services is strongest where

[23]Estimates are based on IV which is identical to 2SLS or LIML in the present context (just identified equation).

congestion and thus the potential for accidents is particularly pronounced. The driving force behind this substantial substitution effect is not only the increase in the supply of passenger railways, but also in train ridership. This indeed has taken place: Consistent with the analysis presented here, Böttger and Pörner (2007) report an increase in the usage of local passenger railways in Germany from 30.3 billion passenger kilometers to 40.2 billion passenger kilometer. In a similar vein, LNVG (2010) reports growth rates of passenger transportation that are often substantially above the growth rates of supply, measured in train kilometers.[24] Such strong demand effects are necessary conditions for the substitution effects of supporting public transport.

Columns (5)-(8) show substantial and significant effects also for NO and NO_2. Point estimates for NO indicate that a 10 % increase in the frequency of service reduces NO concentration along the line by 3.8 % (column 6; significant at 10 %) and NO_2 by 1.7 % (column 8; significant at the 10 % level).[25] These results are consistent with our findings for accidents. Expanding frequency of service reduces road traffic. This leads to lower NO_x concentration because road traffic is a substantial source of NO_x emissions. However, a potential counter-effect has to be taken into account when railway transportation uses electricity that is generated by fossil fuels. Such electricity generation leads to air pollution elsewhere. This is is not captured by our analysis.

Although road traffic is also an important source of CO pollution, our results for CO are weaker and less precisely estimated (columns 3 and 4). A potential explanation is data precision.[26] We also find that expanding regional passenger rail service has a negative but insignificant effect on partic-

[24]For instance, on the Weser-Ems Netz run by Nord-West-Bahn, the number of passengers grew by 248 % between 1998 and 2006, with a concomitant growth in the number of passengers per train by more than 50 %.

[25]Reduced form results are more precise than IV results. The effect of public procurement on NO_x concentration is negative and significantly different from zero at 5 % level (Table A2, column (6) and (8)). Electric traction does not predict the evolution of most environmental quality measures. This is consistent with electric traction predicting the level of service frequency but not the evolution of service frequency (or demand for travel).

[26]CO pollution is only available from 310 monitors in 1997 and 207 monitors in 2004, whereas NO_x is measured by 400 monitors or more (except for NO in 1994) providing a more disaggregate picture of local air pollution.

ulate matter pollution (columns (9) and (10)). This result probably reflects the fact that both trains and cars generate substantial particulate matter emissions. It might also result from poor data quality since information on PM10 concentration in 1994 was imputed.

Results suggest that expanding rail service reduces air pollution. Does this improvement in air quality matter for infant mortality (columns 11 and 12)? Without controls, we find a negative but insignificant elasticity of infant mortality with respect to regional passenger rail service. Interestingly, the elasticity turns significantly negative once control variables have been added to the model (column 12). A 10 % increase in the frequency of service reduces infant mortality by 4.6 % (significant at the 10 % level), which could at least partly reflect reduced NO_xpollution. The link is less clear for CO and TSP/PM because the results are insignificant. Is the service elasticity of infant mortality large or small? The literature has documented a broad range of elasticities of infant mortality with respect to road traffic externalities. For instance, Currie et al. (2009) document an elasticity of 0.03 for CO whereas Currie and Schmieder (2009) document an elasticity of VOCs of 6.1. While our estimates of the service elasticity are not directly comparable to these pollution elasticities, the magnitude of the frequency of service elasticity is certainly in the range of the elasticities that have been documented. Nevertheless, the results for infant mortality need to be qualified in two respects. First, procurement mode is not orthogonal to the level of infant mortality in 1994. This suggest that using procurement mode as an instrument for changes in service frequency may not be valid for child mortality. Second, changes in infant mortality could also reflect changes in GDP triggered by increased frequency of service, a point we discuss further in Table 5.

— Table 4 about here —

Table 4 contains the results of placebo regressions that study measures of environmental quality that should not be related to road traffic on a priori grounds. These regressions allow testing whether competitive procurement was used more frequently in areas that are more environmentally friendly, a procurement choice that would invalidate our IV results. The placebo regression for SO_2 shows no effect of railway transportation, no matter whether the control variables are added or not. Also, in line with the complexities of the chemistry of ozone formation, there is no significant effect for this pollutant. These results reinforce the plausibility of the main result that supporting railway services reduce road traffic externalities.

— Table 5 about here —

As a sensitivity analysis, we also carried out regressions with potentially endogenous controls. In Table 5, we included GDP per capita and population as additional controls. These variables can affect accidents, pollution, and infant health through several channels. On the one hand, GDP per capita and population are both important determinants of demand for transportation. Hence, they should contribute to an increase in pollution and accidents via their impact on total transportation.

On the other hand, one can also argue for a negative effect of each control on the outcomes. High GDP growth might be associated with a high turnover in the vehicle fleet and, thus, reductions in specific emissions , increased car safety etc. It could, in principle, also be positively affected by improvements in public transportation, suggesting potential reverse causality. Similar concerns arise for population. It has been well-documented that local amenities, including environmental quality, attract population (Banzhaf and Walsh 2008). In spite of these concerns, we have included the regression results as a robustness check. Results indicate that the key results are robust with the exception of infant mortality. Thus, expanding frequency of rail service directly reduces severe road accidents and NO_x pollution. The situation is different for infant mortality. The marginally significant negative effect of railway services on infant mortality from Table 3 looses significance at the 10 % level (p-value is 15.6 %). This is because frequency of service increases GDP, and GDP has a strong negative effect on infant mortality.[27] Frequency of rail service matters for infant mortality not only directly (due to reductions in pollution), but also indirectly (via increases in GDP).

Summing up, while the OLS regressions show no effect of railway services on the outcome variables, in the IV regressions an increase in the frequency

[27]Results on the effects of frequency of service on GDP are not shown but available upon request from the authors.

of service tends to reduce those externalities to which trains contribute more than cars. This observation suggests that those lines with strong growth of the frequency of service have unobserved characteristics that would have made relatively bad outcomes likely in the absence of improved railway services. This seems to be consistent with the practice of the agencies to increase supply on those lines where demand increases are expected. Such expected demand increases will most likely go hand in hand with overall increases in expected transportation which would lead to worse outcomes without improvements in public transport.

7 Discussion

The empirical analysis shows that expanding the frequency of service on regional passenger lines reduces the number of accidents, the concentration of NO and NO_2, and infant mortality. This section discusses a back-of-the-envelope assessment of the economic benefits of supporting regional passenger train lines in two steps. The first step calculates the reduction in road traffic externalities due to increased frequency of regional train service. Results in Table 3 provide two sets of estimates of the elasticity of each outcome with respect to regional train service. We combine the (inverse variance weighted) average of the two elasticities and the observed increase in the frequency of passenger rail service between 1994 and 2004 to estimate the percentage reduction of each road traffic externality measure (Table 6 column 1). This percentage reduction due to regional passenger trains can be combined with data on the observed level of each externality measure in 2004 to estimate the number of prevented accidents, reduced concentrations of NO and NO_2, and prevented infant deaths.[28] The second step assesses the economic value of

[28]Specifically, let x be the percentage reduction in the outcome due to increased rail service (in absolute value). For instance, for severe road accidents $x = 14.2$. Let z be the counterfactual outcome in 2004 without increased rail service. The observed level of the outcome in 2004, y, is related to the hypothetical outcome without expanded service, i.e. $y = (1 - x/100)z$. This allows backing out the hypothetical situation without expanded service z. Table 6 column 2 reports the reduction in the outcome due to passenger trains contrasting the actual outcome y with the hypothetical outcome z, i.e. the reduction due to trains is $y - z$.

the prevented accidents, infant deaths and reductions in concentration based on estimates published in the literature. We provide minimal, maximal, and average valuations by considering the lowest, highest and intermediate unit value of reducing externalities.

— Table 6 about here —

Table 6 presents our back-of-the-envelope estimates of the economic value of reducing road traffic externalities. Consider first the economic value of preventing severe road accidents. The 28.4 % expansion of regional passenger train service between 1994 and 2004 reduced severe accidents by 14.2 %. This amounts to preventing almost 75 thousand of the total of 454 thousand accidents involving road traffic in Germany in 2004. The economic value of preventing one accident is in the order of 16,000 EUR according to BASt (2006). The overall value of the accidents prevented because of expanded regional passenger rail line service is in the order of 1.20 billion EUR.[29]

Next, consider the economic value of reducing the concentration of NO and NO_2. Our results indicate that expanding regional passenger train service by 28 % reduces NO concentration by 7 %, and NO_2 concentration by 5.6 %. These reductions translate into a reduction of 1.43 $\mu g/m^3$ for NO, and a reduction of 1.65 $\mu g/m^3$ for NO_2. Palmquist's (1982, 1983) studies of the role of NO_2 concentration for house prices suggest that a household would pay 10.35 EUR per year for a reduction of NO_2 concentration by one $\mu g/m^3$. A reduction of one NO_2 concentration by one $\mu g/m^3$is therefore worth 383 million EUR to the 37 million German households. We conclude that the value of reducing pollution due to supporting regional passenger railways is approximately 548 million EUR for NO and approximately 630 million EUR for NO_2.[30] Nitrogen is primarily emitted as NO and then oxidizes to NO_2. Therefore, effects on NO and NO_2 inherently related and should not be double counted.

[29]Note that BASt (2006) report the economic value of the average accident. Our elasticity values concern severe accidents. Our estimate is therefore a lower bound for the actual damage.

[30]The ranges for the willingness-to-pay in Palmquist's study range from 0.62 EUR to 20.1 EUR per year, which translate into the ranges given in Table 6.

Finally, consider the economic value of reduced infant mortality. The expansion of regional passenger rail service between 1994 and 2004 reduced infant mortality by 10.5%, or 346 infant deaths were prevented in 2004 because regional passenger rail service was expanded. Blomquist et al. (1996) estimate the value of a statistical life for children based on the use of safety equipment by their parents. These estimates of the value of the statistical life of a child range from 3.9 million EUR to 6.4 million EUR or an average of 5.1 million EUR. The value of reduced infant deaths due to expanded regional passenger railways is 1.78 billion EUR (range 1.34 billion to 2.23 billion EUR). These effects are quantitatively important,but need to be interpreted with care. For instance, according to the discussion in Section 6, they also contain indirect effects of frequency of service due to GDP rather than only direct substitution effects.

What is the total value of expanding regional passenger railway service as captured by the above calculations? The value of reducing air pollution and the value of preventing infant deaths cannot simply be added up since air pollution directly contributes to infant mortality. This means that the value of prevented infant deaths is already (partly) reflected in the benefit estimates for reduced air pollution. Yet adding the value of prevented accidents to the value of reduced air pollution or to the value of reduced infant deaths provides lower bound estimates on the total value of expanding regional train service. A lower bound on the total value of reduced externalities due to expanded regional passenger train services is in the order of 1.75 billion EUR using estimates for accidents and air pollution or of 2.92 billion EUR using estimates for accidents and prevented infant deaths. All told, our analysis suggests that the benefits from expanding railway transportation capacity are substantial. Taking the subsidies of 6-7 billion EUR spent for the entire provision of regional passenger services as a reference and assuming that the 28 % increase in railway services corresponds to a cost increase of similar size, the costs for the additional services are likely to be in the order of magnitude of 1.5 to 2 billion EUR. This compares favorably to the additional benefits.

Of course, these figures only refer to the types of externalities that we consider in our analysis. The substitution from cars to railways most likely has considerable effects on other externalities. For instance, the substitution should lead to less emissions of carbon dioxide, less noise and lower congestion externalities. As discussed above, increased emissions from electricity generation counterbalance some of these effects. However, because of strict environmental regulations for power plants and the predominance of diesel trains, this countervailing effect is likely to be small.

8 Concluding Remarks

This paper exploits regional variation in the supply of railway services to identify the effects of support for passenger railways on road traffic externalities. Our results suggest that supporting passenger railways provides substantial benefits in terms of reduced road traffic externalities. Results indicate that the elasticities are substantial. Severe road accidents decrease by 4.7 %, nitric oxide emissions decrease by 3.8 %, and child mortality decreases by 4.6 % for every 10 % increase in regional passenger railway service.

Regional passenger railway service is heavily subsidized in Germany. Is this a worthwhile cost to taxpayers? We provide estimates of the monetary benefits of the 28 % expansion in the capacity of regional railway services between 1994 and 2004. Our estimates indicate that these monetary benefits are in the same order of magnitude as the costs. While we do not have any precise figures on the additional subsidies required to finance this growth, it appears unlikely that these additional funds are much higher than the corresponding monetary benefits.

In principle, our empirical procedure is applicable to other countries with local variation in the development of railway services. We addressed endogeneity concerns by using the mode of procurement as an instrument. In some countries this approach cannot be applied, because procurement either relies exclusively on competition (as in Great Britain) or not at all (as in Switzerland). Yet Denmark and the Netherlands are gradually extending competitive tendering off their core networks (Nash 2008). The empirical approach may therefore become increasingly important.

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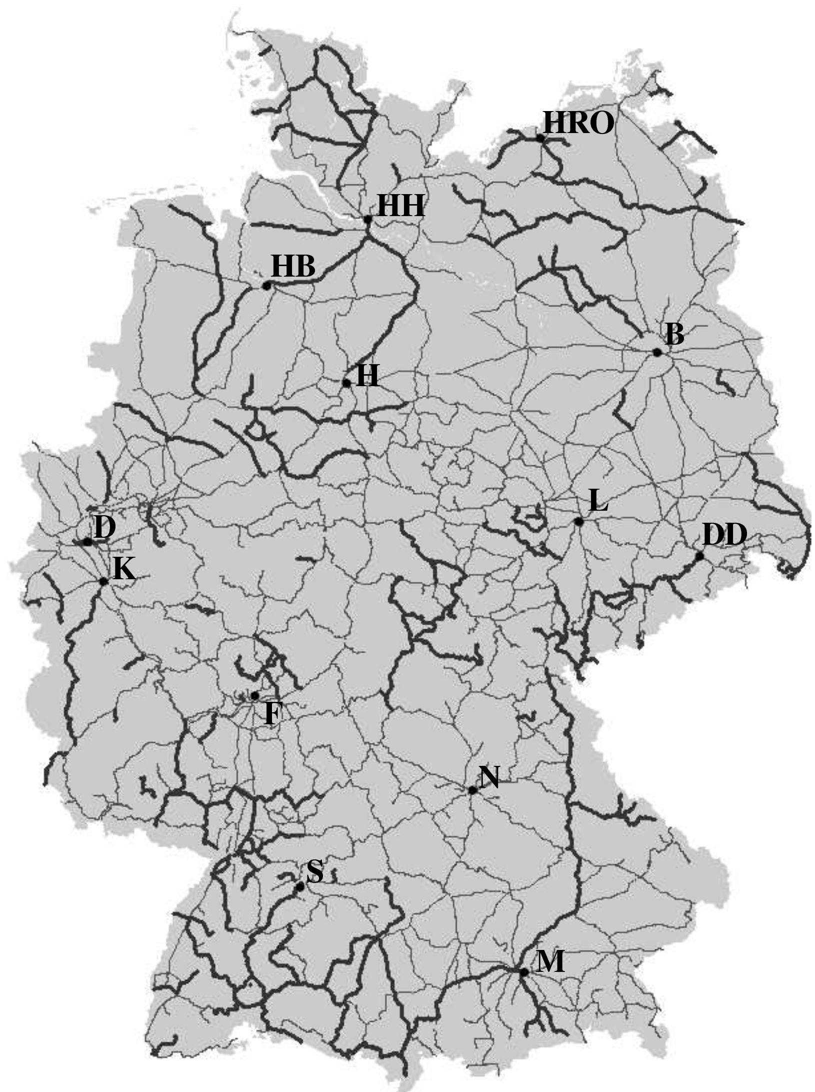
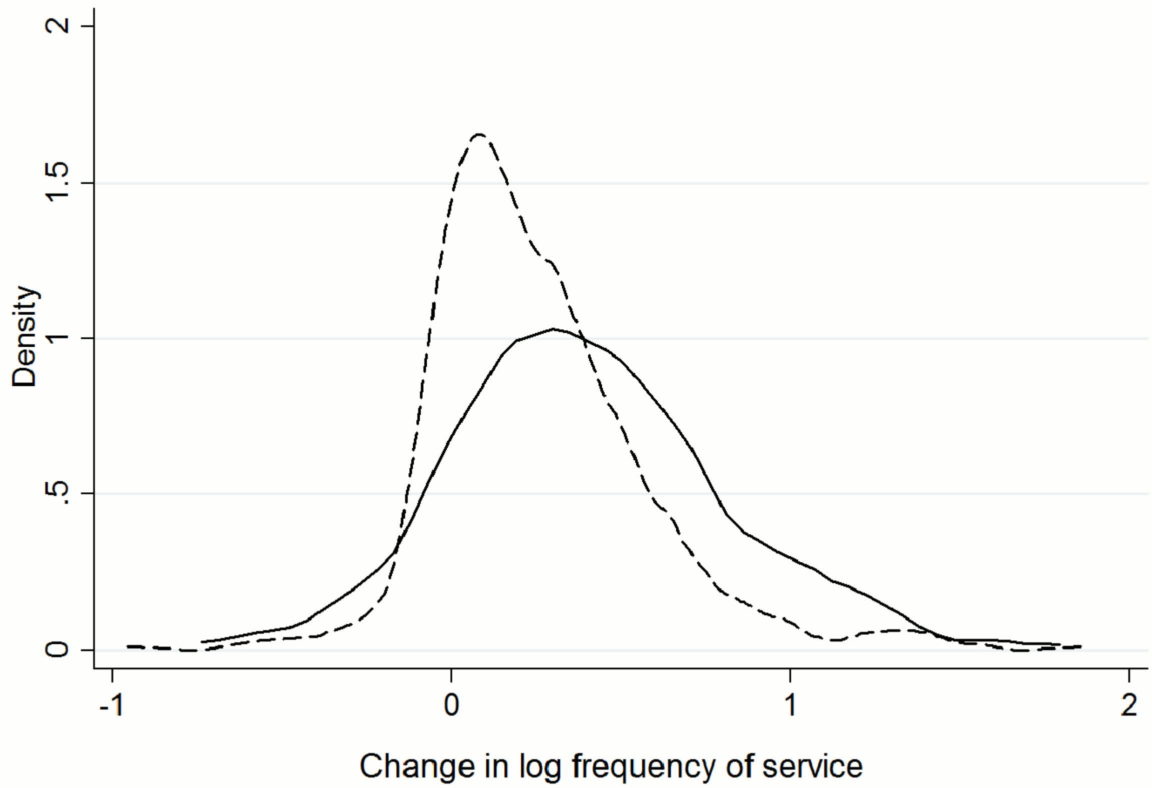
Appendix: Figures and Tables

Figure 1: Map of regional railway lines



Notes: Thin lines denote non-competitively procured lines, bold lines competitively procured lines, and point important cities: B: Berlin, D: Düsseldorf, DD: Dresden, F: Frankfurt (Main), H: Hanover, HB: Bremen, HH: Hamburg, HRO: Rostock, K: Cologne, L: Leipzig, M: Munich, N: Nuremberg, and S: and Stuttgart.

Figure 2: Variation in Service Growth



Notes: (1) Epanechnikov kernel with bandwith 0.122; (2) continuous line is for competitively procured lines, dashed line for non-competitively procured lines.

Table 1 . Summary statistics

	Obs	Mean	Median	Std. Dev.	Min	Max
A. Externality variables						
Acidents (log-difference 2004-1994)	544	-0.181	-0.108	0.307	-1.223	0.688
CO (log-difference 2004-1994)	551	-0.423	-0.441	0.232	-0.973	0.690
NO (log-difference 2004-1994)	551	-0.058	-0.130	0.425	-0.944	0.835
NO_2 (log-difference 2004-1994)	551	-0.108	-0.110	0.124	-0.445	0.260
TSP/PM10 (log-difference 2004-1994)	551	-0.429	-0.454	0.199	-0.879	0.007
SO_2 (log-difference 2004-1994)	551	-1.291	-1.083	0.608	-2.696	-0.448
O_3 (log-difference 2004-1994)	551	0.086	0.088	0.073	-0.110	0.271
Infant mortality (log-difference 2004-1994)	551	-0.296	-0.286	0.323	-1.519	1.046
B. Train and control varibales						
Frequency of service (log-difference 2004-1994)	551	0.284	0.236	0.368	-1.762	1.879
Electric traction	551	0.454	0.000	0.498	0.000	1.000
Track length	551	60.394	46.000	47.395	4.000	296.000
Distance to city	551	17.813	0.000	29.289	0.000	142.000
GDP per capita (log-difference 2004-1994)	551	0.131	0.120	0.083	-0.243	0.490
Population (log-difference 2004-1994)	551	-3.E-4	0.013	0.067	-0.343	0.334

Table 2 . Service frequency and raod traffic externalities: Conventional estimates

	Accidents		CO		NO		NO_2		TSP/PM		Infant mortality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Frequency of service	0.002	0.011	-0.021	-0.023	0.010	0.013	0.003	0.006	0.001	-1.E-4	0.030	0.023
	(0.023)	(0.023)	(0.017)	(0.017)	(0.028)	(0.028)	(0.011)	(0.011)	(0.012)	(0.012)	(0.036)	(0.037)
Electric traction		0.031 (*)		-0.004		0.037 (*)		0.025 **		0.003		-0.054 (*)
		(0.018)		(0.013)		(0.022)		(0.009)		(0.010)		(0.029)
Track length		2.E-4		-3.E-5		-2.E-4		-1.E-4		-1.E-4		-1.E-4
		(2.E-4)		(1.E-4)		(2.E-4)		(9.E-5)		(1.E-4)		(3.E-4)
Distance to city		-0.001 *		4.E-4 (*)		-0.001 *		-4.E-4 **		-2.E-4		2.E-4
		(3.E-4)		(2.E-4)		(4.E-4)		(2.E-4)		(2.E-4)		(5.E-4)
State effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	544	544	551	551	551	551	551	551	551	551	551	551
R^2	0.60	0.61	0.64	0.64	0.70	0.71	0.45	0.47	0.75	0.75	0.12	0.12

Notes : (1) OLS regressions; (2) dependent variables and the frequency of service variable are in log-differences for the years 2004-1994; the variable for electric traction, track length, distance to city, and state effects are time invariant and, thus, capture differential trends in the dependent variable across these line characteristics and states or characteristic- and state-specific time effects; (3) standard errors in parentheses; (4)(*) significant at 10%; * significant at 5%; ** significant at 1%.

Table 3 . Service frequency and road traffic externalities: IV estimates with procurement mode as instrument

A. Second stage	Accidents		CO		NO		NO_2		TSP/PM		Infant mortality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Frequency of service	-0.535 **	-0.465 *	-0.121	-0.171	-0.479 *	-0.378 (*)	-0.231 *	-0.165 (*)	-0.070	-0.053	-0.290	-0.459 (*)
	(0.199)	(0.197)	(0.107)	(0.117)	(0.216)	(0.211)	(0.093)	(0.085)	(0.077)	(0.080)	(0.242)	(0.273)
Electric traction		0.010		-0.010		0.022		0.018 (*)		1.E-3		-0.074 *
		(0.026)		(0.015)		(0.027)		(0.011)		(0.010)		(0.035)
Track length		-1.E-4		-1.E-4		-0.001 (*)		-2.E-4 (*)		-2.E-4		-5.E-4
		(3.E-4)		(2.E-4)		(3.E-4)		(1.E-4)		(1.E-4)		(4.E-4)
Distance to city		-0.001 (*)		4.E-4		-0.001 *		-5.E-4 *		-2.E-4		2.E-4
		(4.E-4)		(3.E-4)		(5.E-4)		(2.E-4)		(2.E-4)		(0.001)
State effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
B. First stage												
Competition	0.142 **	0.138 **	0.137 **	0.135 **	0.137 **	0.135 **	0.137 **	0.135 **	0.137 **	0.135 **	0.137 **	0.135 **
	(0.037)	(0.038)	(0.037)	(0.038)	(0.037)	(0.038)	(0.037)	(0.038)	(0.037)	(0.038)	(0.037)	(0.038)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	544	544	551	551	551	551	551	551	551	551	551	551
F test of excl. instruments	14.61	13.00	13.90	12.56	13.90	12.56	13.90	12.56	13.90	12.56	13.90	12.56
Uncentered R^2	0.41	0.47	0.91	0.91	0.54	0.61	0.42	0.56	0.95	0.95	0.45	0.37

Notes : (1) IV regression with procurement mode as an instrument for frequency of service growth; (2) dependent variables and the frequency of service variable are in log-differences for the years 2004-1994; the variable for electric traction, track length, distance to city, and state effects are time invariant and, thus, capture differential trends in the dependent variable across these line characteristics and states or characteristic- and state-specific time effects; (3) standard errors in parentheses; (3) standard errors in parentheses; (4) (*) significant at 10%; * significant at 5%; ** significant at 1%.

Table 4 . Placebo regressions: Service frequency and SO_2 and O_3 pollution.

A. Second stage	SO_2		O_3	
	(1)	(2)	(3)	(4)
Frequency of service	0.189	0.158	0.051	0.061
	(0.170)	(0.174)	(0.038)	(0.042)
Electric traction		3.E-3		9.E-4
		(0.022)		(0.005)
Track length		0.001 **		-5.E-5
		(3.E-4)		(6.E-5)
Distance to city		0.001 (*)		-1.E-4
		(4.E-4)		(9.E-5)
State effects	Yes	Yes	Yes	Yes
B. First stage				
Competition	0.137 **	0.135 **	0.137 **	0.135 **
	(0.037)	(0.038)	(0.037)	(0.038)
Controls	Yes	Yes	Yes	Yes
Number of observations	551	551	551	551
F test of excl. instruments	13.90	12.56	13.90	12.56
Uncentered R^2	0.97	0.98	0.79	0.78

Notes : (1) IV regression with procurement mode as an instrument for frequency of service growth; (2) dependent variables and the frequency of service variable are in log-differences for the years 2004-1994; the variable for electric traction, track length, distance to city, and state effects are time invariant and, thus, capture differential trends in the dependent variable across these line characteristics and states or characteristic- and state-specific time effects; (3) standard errors in parentheses; (4) (*) significant at 10%; * significant at 5%; ** significant at 1%.

Table 5 . Sensitivey analysis: Regressions with potentially endogenous controls

A. Second stage	Accidents	CO	NO	NO_2	TSP/PM	Infant mortality
	(1)	(2)	(3)	(4)	(5)	(6)
Frequency of service	-0.465 *	-0.132	-0.334 (*)	-0.162 (*)	-0.051	-0.365
	(0.195)	(0.108)	(0.202)	(0.084)	(0.079)	(0.253)
Electric traction	0.016	-0.015	0.024	0.018 (*)	0.001	-0.079 *
	(0.026)	(0.014)	(0.026)	(0.011)	(0.010)	(0.033)
Track length	-1.E-4	-1.E-4	0.000 (*)	-2.E-4 (*)	-2.E-4	-5.E-4
	(3.E-4)	(2.E-4)	(3.E-4)	(1.E-4)	(1.E-4)	(4.E-4)
Distance to city	-0.001 (*)	3.E-4	-0.001 *	-5.E-4 *	-2.E-4	-7.E-5
	(4.E-4)	(2.E-4)	(4.E-4)	(2.E-4)	(2.E-4)	(0.001)
GDP per capita	-0.045	-0.232 **	-0.295 (*)	-0.022	-0.014	-0.591 **
	(0.163)	(0.087)	(0.162)	(0.067)	(0.063)	(0.202)
Population	0.507 (*)	-0.806 **	-0.173	-0.069	0.021	-1.381 **
	(0.265)	(0.134)	(0.250)	(0.104)	(0.098)	(0.313)
State effects	Yes	Yes	Yes	Yes	Yes	Yes
B. First stage						
Competition	0.140 **	0.137 **	0.137 **	0.137 **	0.137 **	0.137 **
	(0.039)	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	544	551	551	551	551	551
F test of excl. instruments	13.17	12.80	12.80	12.80	12.80	12.80
Uncentered R^2	0.49	0.92	0.63	0.57	0.95	0.46

Notes : (1) IV regression with procurement mode as an instrument for frequency of service growth; (2) dependent variables, the frequency of service variable, GDP per capita and population are in log-differences for the years 2004-1994; the variable for electric traction, track length, distance to city, and state effects are time invariant and, thus, capture differential trends in the dependent variable across these line characteristics and states or characteristic- and state-specific time effects; (3) standard errors in parentheses; (4) (*) significant at 10%; * significant at 5%; ** significant at 1%.

Table 6. The monetary value of supporting regional trains

	Reduction due to trains (relative)	Level in 2004	Reduction due to trains (absolute)	Unit value (mil. EUR) per …	Total value (mil. EUR)
A. Valuing road accidents					
	Percent	Accidents	Accidents	Accident [a)]	
Average valuation	-14.2	454113	-75156	0.016	-1202
B. Valuing NO concentration					
	Percent	Micrograms	Micrograms	Microgram [b)]	
Average valuation	-7.0	18.91	-1.43	382.60	-548
Minimal valuation	-7.0	18.91	-1.43	22.84	-33
Maximal valuation	-7.0	18.91	-1.43	742.36	-1064
C. Valuing NO_2 concentration					
Units	Percent	Micrograms	Micrograms	Microgram [b)]	
Average valuation	-5.6	27.79	-1.65	382.60	-630
Minimal valuation	-5.6	27.79	-1.65	22.84	-38
Maximal valuation	-5.6	27.79	-1.65	742.36	-1223
D. Valuing infant mortality					
	Percent	Infant deaths	Infant deaths	Infant death [c)]	
Average valuation	-10.5	2957	-346	5.14	-1781
Minimal valuation	-10.5	2957	-346	3.86	-1336
Maximal valuation	-10.5	2957	-346	6.43	-2226

Notes: a) Value of prevented accident from BASt (2006), b) value of nitrogen reduction based on Palmquist (1982, 1983), annualized using 4 percent discount rate, aggregated for 37 million households (Germany), c) value of a statistical life of a child from Blomquist (1996). All monetary values in 2010 EUR.

Table A1 . Explaining procurement mode

	(1)		(2)	
Frequency of service in 1994	-0.075	**	-0.004	
	(0.029)		(0.033)	
Accidents in 1994	-0.013		0.026	
	(0.017)		(0.026)	
CO in 1994	0.174		0.679	
	(0.303)		(0.450)	
NO in 1994	0.101		-0.043	
	(0.129)		(0.151)	
NO_2 in 1994	-0.524	(*)	0.074	
	(0.268)		(0.388)	
TSP/PM in 1994	-0.336	**	-0.163	
	(0.125)		(0.198)	
SO_2 in 1994	-0.095	(*)	-0.070	
	(0.051)		(0.111)	
O_3 in 1994	-0.277		0.265	
	(0.308)		(0.402)	
Infant mortality in 1994	0.260	*	0.263	*
	(0.102)		(0.107)	
Population in 1994			-0.137	**
			(0.049)	
GDP per capita in 1994			0.088	
			(0.137)	
Electrification			-0.192	**
			(0.043)	
Track length			-0.014	
			(0.030)	
Distance to city			0.005	
			(0.014)	
State effects	No		Yes	
Number of observations	551		551	
F test for pollutants	0.001		0.490	
R^2	0.07		0.16	

Notes : (1) OLS regression; (2) explanatory variables are in logs - except dummy variables; (3) standard errors in parentheses; (4) (*) significant at 10%; * significant at 5%; ** significant at 1%.

Table A2 . Road traffic externalities and procurement mode: reduced form estimates

A. Second stage	Accidents		CO		NO		NO_2		TSP/PM		Infant mortality	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Competition	-0.076 **	-0.064 **	-0.017	-0.023	-0.066 **	-0.051 *	-0.032 **	-0.022 *	-0.010	-0.007	-0.040	-0.062 (*)
	(0.020)	(0.020)	(0.014)	(0.015)	(0.024)	(0.024)	(0.009)	(0.010)	(0.010)	(0.011)	(0.031)	(0.032)
Electric traction		0.017		-0.008		0.027		0.020 *		0.002		-0.068 *
		(0.019)		(0.014)		(0.022)		(0.009)		(0.010)		(0.030)
Track length		2.E-4		-1.E-6		-2.E-4		-1.E-4		-1.E-4		-1.E-4
		(2.E-4)		(1.E-4)		(2.E-4)		(9.E-5)		(1.E-4)		(3.E-4)
Distance to city		-0.001 *		5.E-4 (*)		-0.001 *		-4.E-4 **		-2.E-4		3.E-4
		(3.E-4)		(2.E-4)		(4.E-4)		(2.E-4)		(2.E-4)		(0.001)
State effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	544	544	551	551	551	551	551	551	551	551	551	551
R^2	0.61	0.62	0.64	0.64	0.71	0.71	0.46	0.48	0.75	0.75	0.12	0.13

Notes : (1) IV regression with procurement mode as an instrument for frequency of service growth; (2) dependent variables and the frequency of service variable are in log-differences for the years 2004-1994; the variable for electric traction, track length, distance to city, and state effects are time invariant and, thus, capture differential trends in the dependent variable across these line characteristics and states or characteristic- and state-specific time effects; (3) standard errors in parentheses; (4) (*) significant at 10%; * significant at 5%; **