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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, carbon monoxide, nitrogen monoxide, nitrogen dioxide pollution and infant mortality. 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. An analysis of household behavior shows that the effects of railway services on outcome variables are driven by substitution from road to rail.

JEL: Q53, R41, R48

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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, tramways 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) 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, road accidents and most types of local pollution declined. Yet clearly, this simple before-and-after comparison says little about the causal effect of expanding regional passenger services. The concentrations of many local pollutants have declined in the last decades in many industrialized countries. To a large extent, this 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), 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 substantial differences across lines in the evolution of passenger service frequency. We ask whether areas with greater improvements in railway services also experienced a more favorable evolution of environmental quality. Our findings suggest there is no such effect. Clearly, this may reflect endogeneity of increases 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

[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.

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. We argue that this reform serves as an instrument for frequency of service. 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 2008a, 2011).[3] Second, 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 service quality which could have independent effects on the demand for passenger railways. Third, 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. Fourth, 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. Finally, we find that environmental quality improved similarly in the four years prior to the reform (1990 to 1994) along lines that were procured competitively as along lines that were procured in direct negotiations with the incumbent supplier. Taken together, these reasons imply that procurement mode is a valid instrument for growth of frequency of train service.

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 (2008a) 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 are also negative, but 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.

As a robustness exercise, we show that our results survive the introduction of additional instruments that are based on frequencies of long-distance trains in 1939 and 1994. Finally, we analyze the mechanisms behind the improvements in environmental quality. Data on travel mode indicates that car and motorcycle use for commuting to work and leisure activities has grown less strongly along lines that were served more frequently with regional passenger trains. These results indicate that expansions of local passenger railways enhances the environment due to substitution from cars and motorcycles to trains and increases in income. This yields even more direct support of hypothesis (C1) than the observation that improved passenger transportation reduces road accidents.

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 provides rough estimates of the monetary value of the improvements. Section 8 concludes.

2 Related Literature

A large literature deals with the effects of transportation policies on the environment.[4] To relate our contribution to this literature, note that our paper tests (C1) and (C2) hold jointly. Moreover, our results with survey data suggest that (C1) holds individually. Existing papers deal with (C1) and (C2) as follows.

(C1) Many papers attempt 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 estimate short-term elasticities, ignoring the long-term adjustments. Evans (2004) reviews evidence on the elasticities of public transport ridership with respect to service frequency. For railways, the elasticities are between 0.5 and 0.9.[5] Evans (2004) contains evidence for 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. – a context in which bus service is marginal.

(C2) 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 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

[4]See Schmutzler (2011) for a recent survey.

[5]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. The elasticities are higher when initial service levels are low.

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.

Existing studies therefore support the notion that each of the statements (C1)-(C2) holds individually. A recent contribution by Chen and Whalley (2012) tests (C1) and (C2) jointly. The paper shows how the introduction of a Mass Transportation System in Taipei in 1996 led to a significant drop in CO emissions (by 9-14 %), with similar yet insignificant effects for NO_x. There were no clear-cut effects on O_3 formation, which reflects the complexities of the chemistry of ozone.[6]

Another important strand of literature investigates the claim that pollution reductions actually have positive health effects. For instance, 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. Currie and Walker (2011) 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).

Our paper contributes to the existing literature in four 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 procure-

[6]See the discussion in the introduction. Also note that Davis (2008) studies the effects of direct driving restrictions on air pollution in Mexico City – a related but different context. He finds that weekday limitations to driving a car had no effects on air quality.

ment 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. Finally, it directly identifies substitution from road to rail as the mechanism leading to reductions of externalities.

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 German states. They can use the money to procure passenger services on the non-profitable part of the network.[7] Second, the states assign responsibility for planning and procurement to agencies which act on the basis of state law.[8] 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.[9]

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

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

[9] In other cases, the firms can submit bids that contain not only transfer payments, but

Competitive procurement auctions have been used quite often between 1994 and 2004. 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. 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.[10] Between 1994 and 2004, the average frequency of service on the lines with competitive procurement grew from 10,888 trains in 1994 to 16,466 in 2004, that is, by 51 %. The corresponding figures for lines without competitive procurement were 15,090 in 1994 and 18,738 in 2004 (24 %). Thus, not only was there a 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. Figure 2 plots a kernel density estimate of the growth in service quality from 1994 to 2004, again differentiating between competitively procured lines and others. Most lines 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

also some aspects of quality, which are then weighted in a suitable scoring rule.

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

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 ticket prices. Neither of these concerns appears to be justified. First, where the incumbent is free to set its price, the ticket 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 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 Ministry of Transportation (BMVBS) is responsible for motorways (*Bundesautobahnen*) and other major roads (*Bundesstrassen*).[11] The state governments set priorities for roads of intermediate importance.[12] They also define the duties of the local governments which typically decide on the policy towards smaller roads, parking policies, etc.[13] Second, the taxes that are most likely to affect road transportation (vehicle

[11]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.

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

[13]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.

taxes and gasoline taxes) are set at the federal level. Third, safety regulations are also typically set at the federal level.[14] 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, infant mortality and travel modes.

Main explanatory variable: The explanatory variable of primary interest is (the log of one plus) the 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).[15]

Instruments: Following Lalive and Schmutzler (2011), we define a line as competitive if at least 20 % of the services were procured competitively. The overwhelming majority of these cases correspond to competitive tenders which were wither won by *DB Regio* itself or some competitor, but we also included cases where an ownership change took place for other reasons.[16]

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

[15] 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.

[16] We are grateful to Felix Berschin for providing us with a list of competitve tenders;

Railway timetables were included as sources for the instruments that rely on long-distance transportation. Specifically, we used the timetables for 1939 (*Deutsche Reichsbahn*) and 1994 (*Deutsche Bahn*) to obtain the number of long-distance passenger trains that run on at least 25 % of the line under consideration on Monday to Friday.[17]

Outcome variables: 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. We have information on the concentration levels of six air pollutants, namely CO, NO, NO_2, SO_2 and O_3. The data are from the *Umweltbundesamt* (UBA), 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.[18] 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.[19] We then aggregate interpolated values to the county level.

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 reflect all local pollution that matters for infant health.

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in addition, we could obtain information on ownership chages from the *Deutsche Bahn* timetables.

[17]In 1939, we included trains of the categories D, FD and L; in 1994, we included ICE trains.

[18]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.

[19]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).

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.[20] 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.[21] We use the three year average 1993-1995 to estimate infant mortality in 1994 and the three year average 2003-2005 to assess infant mortality in 2004.[22]

The German Socio Economic Panel (SOEP) contains individual information on the type of travel mode normally used for commuting, leisure activities (cinema, soccer game, etc.), shopping, week-end trips and bringing children to school (see Wagner et al. 2007). Individuals choose between the following travel modes: public transport, car, motorcycle, bicycle, or by foot. We aggregate individual responses to the county level and calculate the probability of travelling by car or motorcycle conditional on using at least one of the travel modes. The closest information available on travel mode around the reform date is 1998. Travel mode information is also available in 2003.

All measures of road traffic externalities, travel mode, and economic performance 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.

Controls: The data also include controls for important line-level characteristics (distance to nearest large city, length of line and information on electrification).

[20]Hamburg and Schleswig-Holstein share one agency.

[21]The German Youth Institute, an independent research institute on children and families, compiled and courteously provided the data.

[22]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.

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 different 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.

Let Y_{it} capture 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.[23] 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. This means

[23] We do not explicitly model the sources of the level of transport demand. These could be plausibly related to gross domestic product per capita and population. 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.

that outcome variable s is

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

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

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

For accidents, the outcome variable is interpreted as the total (log) number. Our other outcomes are pollution concentrations and infant mortality rate. Since in a constant volume of air an increase in emissions leads to a proportionate increase in pollution concentration and since infant mortality rates depend on prevailing concentration levels, (2) can still be applied.[24]

In the empirical analysis, we will rely on the following log-linear approximation to equation (2)[25]

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

This log-linear specification (3) is only an approximation to the true specification (2). Yet this approximation provides important information on the

[24]To see this divide 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. 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.

[25]Note that this 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. Moreover, the log-linear approximation (3) provides an estimate of how expanding regional passenger services translates into improvements of environmental quality. This is the relevant policy parameter.

relative contribution of cars and trains to environmental quality s. In particular, it is possible to show that

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

which is 0 if trains and cars contribute equally, and it is 1 if trains do not contribute at all. 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 % 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. Moreover, it follows 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

$$\Delta logY_i = -\delta\gamma\Delta log(1 + FOS_i) + \Delta logT_i + \Delta\tau_j + \Delta\varepsilon \qquad (4)$$

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.[26]

[26] 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-

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. Arguably, procurement auctions affect train service frequency monotonically and positively. Lalive and Schmutzler (2011) show 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.[27]

However, for competition to be a valid instrument, it must also be unrelated to the evolution of environmental quality. This requirement cannot be tested. What can be tested is whether procurement of a train line is related to trends in environmental quality before the reform. We discuss this below and find no differences in the evolution of environmental quality before the railway reform in 1994. Moreover, we also test whether competitive procurement is related to environmental quality in 1994. Our analysis in the appendix uncovers two main findings (Table A.1). First, regressions that do not control for line characteristics suggest that lines with low frequency of service, few accidents, high CO and NO_2 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.) and state effects, these partial correlations drop to a level that is not distinguishable from zero (except for infant mortaility). This suggests that choice of procurement mode is not related to the initial level of environmental quality conditional on line characteristics. In

linearized versions of estimating equations are biased if the error term in the original 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.

[27]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.

this sense, the mode of procurement is as good as randomly assigned.

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, competition for the market affects does not seem to affect 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 left-wing parties in the state government elections in 1997 (see Table A.1 below).

As a robustness exercise, we use two other instruments, relating to the frequency of long-distance train service. The railway reform was introduced soon after the German reunification. It is thus plausible that growth of regional passenger services in the period we consider reflects adjustments to pre World-War II transportation patterns to some extent. We thus introduce a measure of the frequency of express trains (D-Züge and FD-Züge) in 1939 to capture the potential for traffic growth after re-unification. In addition, it is highly plausible that, the growth potential of regional passenger traffic may be curtailed if a line is heavily utilized for competing usages. We thus took the frequency of long-distance trains (ICE) in 1994 as another instrument.

6 Results

6.1 Descriptive Statistics

Sections A and B of Table 1 provide 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 % ($100\,(\exp(-0.108) - 1) = -10.237$). Air quality has improved substantially for all measures except O_3. For instance, the median reduction of CO was 35.6 %. For SO_2, which is essentially unrelated to road transportation, the reduction was 66.1 %. In particular this last figure strongly suggests that the improvements cannot completely be attributed to public transportation, thus 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 1C 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 large standard deviation suggests the possibility that differences in the evolution of service quality may have contributed to the different developments in the outcome variables. Below, we will investigate whether this is indeed true.

Moreover, Table 1C also shows that train lines differ with respect to traction, length and distance to large cities. About 45 % of all railway lines are electrified. The mean length of a line is 3.8 log kilometers, which translates to 45 kilometers. Distance to city measures the remoteness of a line. Distance to city is zero if the line runs through a city of at least 100,000 inhabitants in 1994. For railway lines that do not run through a city the distance is the length of the shortest passenger railway connection between a city and one of the stations on the line. The average distance is 17 kilometers, the median is 0.

Table 1D shows that 25 % of the railway lines were classified as competitive. In 1939, on about 20 % of the lines, at least six long-distance trains per day used at least part of the line. In 1994, on about 5 % of the lines, at least six express trains per day used at least part of the line.

6.2 Econometric results

We first discuss naive regressions that do not account for endogeneity of service frequency growth. We then focus on the results that rely on procurement status as an instrument. After that, we discuss robustness to our alternative IVs. Finally, using survey data, we investigate the mechanisms by which public transport affects outcome variables.

6.2.1 Basic results

Table 2 provides OLS regressions of the differences in the log of the outcome variables on the differences in the log of the frequency of railway services, with different controls. The table shows no effect of service quality on outcome variables.

— Table 2 about here —

The absence of clear effects may signal endogeneity problems. If passenger railways systematically obtain more support where the outcome variables are expected to deteriorate because of increasing transport volumes, a beneficial effect may be obscured in an OLS regression. Indeed, Section 16 in LNVG (2010) clearly indicates that favorable demand projections are decisive for supply increases. We address this issue with an IV approach that uses the procurement mode of the railway line as an instrument.

Table 3 presents first stage results. Column 1, which uses information on electrification, length, and distance to city, shows that the frequency of service grew more strongly on lines that were competitively procured than on lines that were not. This result is both quantitatively important and statistically significant. The F-statistic on the instrumental variable is 10.256, suggesting that procurement mode is not a weak instrument. Service frequency increases 14.4 % more strongly on comparatively procured lines than under direct negotiations.

— Table 3 about here —-

Column 2 in Table 3 uses the procurement status of the line along with two measures of the frequency of long-distance train service used in the robustness analysis. Historical frequency of service in 1939 measures whether a line was served by more than six long-distance trains per day in 1939. Interestingly, lines that were frequently served by long-distance trains in 1939 also grow 9 % more strongly between 1994 and 2004 than train lines that were not as frequently served by long-distance trains in 1939. In contrast, lines that are frequently served by long-distance trains in 1994 grow 12 % less strongly over the 1994 to 2004 period, consistent with the intuition that long-distance trains act as a capacity constraint. Historical service of train lines therefore predicts service growth over the 1994 to 2004 period. Note, however, that the F-statistic testing the joint significance of the three instruments is 6.940, signalling the presence of weak instruments. We therefore use limited information likelihood (LIML) in estimates that rely on all three instruments.

Table 4 presents the reduced form estimates of procurement mode on the change in environmental quality between 1994 and 2004. Results indicate significantly negative effects on all measures of environmental quality. Accidents decrease by 6.3 percentage points more strongly on competitively procured lines than on lines that were procured in direct negotiations. A similar decrease effect is found for infant mortality and NO concentration. Concentration of CO and NO_2 also decreases, but to a lower extent.

— Table 4 about here —-

Table 5 discusses whether the outcome variables evolved more favorably before the railway reform, in the 1990 to 1994 period. The analysis focuses on the evolution of NO, NO_2 and infant mortality because data on the other measures of environmental quality were not available.[28] Results indicate that the 1990 to 1994 change in NO and NO_2 concentration was the same along lines that were procured competitively in the 1994 to 2004 period as along lines procured in direct negotiations. Results for infant mortality are similar. These results suggest that there was no differential change in environmental quality by procurement status of the line – consistent with the main identifying assumption that environmental quality would have improved in the same fashion on competitively procured lines as on the remaining lines.

— Table 5 about here —-

Table 6 presents the IV results with the procurement instrument. 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

[28] CO data is not available before 1997 and there are no local data on road accidents before 1995.

for accidents where we find an elasticity of -0.46, suggesting that road accidents are reduced by 4.6 % if the frequency of service increases by 10 %. This estimate reflects the fact that road accidents are entirely the result of road transportation (Section 5). Table 6 also shows substantial and significant effects 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 % and NO_2 by 1.7 %. As for accidents, this finding is likely to reflect reductions in road traffic, which is a substantial source of NO_x emissions. Although road traffic is also an important source of CO pollution, our results for CO are weaker and less precisely estimated (Table 6, column 2). A potential explanation is data quality.[29]

— Table 6 about here —-

Results suggest that expanding rail service reduces air pollution. Does this improvement in air quality matter for infant mortality (Table 6, column 5)? We find a significantly negative elasticity. 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_x pollution. While our estimates of the service elasticity are not directly comparable to existing pollution elasticities of infant mortality, the magnitude of the frequency of service elasticity is certainly in the range of the elasticities that have been documented.[30] Nevertheless, the results for infant mortality need to be qualified. Improvements in infant mortality could, for instance, also be due to improvements in health care due to GDP growth.[31]

[29]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.

[30]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.

[31]We have explored regressions that condition on population and GDP growth (results not shown). Note that population and GDP growth are potentially endogenous to expanded regional passenger service. Nonetheless, estimates of frequency of service on accidents, CO, NO and NO_2 remain robust. Estimates of the effects of frequency of service

Table 7 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. Columns 1 and 2 contain results that use procurement status of each line as an instrument. The placebo regression for SO_2 shows no effect of railway transportation. Also, in line with the complexities of the chemistry of ozone formation, there is no significant effect for O_3. These results reinforce the plausibility of the main result that supporting railway services reduce road traffic externalities.

— Table 7 about here —

6.2.2 Robustness

Table 8 presents IV results that use procurement status and historical frequency of service in 1939 and 1994 as instruments. The Kleibergen-Paap (2006) weak identification statistic rejects the null of weak instruments at the 10 % level but not at the 5 % level.[32] Multiple IV results are estimated using LIML. The overidentification test does not reject the null that the instruments are valid in all cases except for accidents. In the cases where the multiple IVs are valid, results are more precise than the baseline results with just one instrument (Table 6). The additional precision is important for the service elasticity of CO concentration which is negative and significantly different from zero (at the 10 % level). In contrast, the service elasticity of infant mortality turns insignificant. The null of the overidentification test is rejected for accidents. This signals that the supplementary instruments are not exactly orthogonal to the model errors. The service elasticity of accidents is not quantitatively different with several instruments compared to the single instrument case. This means that the resulting bias is quantitatively

on infant mortality turn insignificant with a point estimate slightly lower than the one we report. We take this as evidence that expanding frequency of service is beneficial both due to direct improvements in air quality and indirect improvements in health care due to GDP growth. Results are available upon request from the authors.

[32] The statistic follows a χ^2 distribution with three degrees of freedom.

small. Overall, the multiple IV results suggest that our results are robust to adding historical frequency of service to instrument for service growth.

— Table 8 about here —

6.2.3 Effects on modal choice

The analysis so far suggests that increasing the frequency of service on regional passenger train lines is beneficial for the environment. We have interpreted this as evidence of substitution from cars to trains. In this section, we provide direct evidence for this. Table 9 therefore presents IV estimates of the effect of increasing frequency of regional passenger train service on the change in the probability of using cars or motorcycles for commuting, leisure activities, shopping, week-end trips or taking children to school. Results indicate strong negative effects of service frequency on the probability of using cars or motorcycles to commute to work or leisure activities (e.g., watch a movie or soccer game). A 10 % increase in the frequency of service (an increase by 0.1 log points) reduces car or motorcycle use by 2.7 percentage points in commuting to work and by 2.8 percentage points in leisure activities. Point estimates are also negative but less strong for shopping, week-end trips, or taking children to school. These activities are arguably also those where trains are not a good substitute for cars or motorcycles.

— Table 9 about here —

Evidence in Table 9 strongly suggests that adding regional passenger trains does induce substitution from cars and motorcycles to trains for two key activities. 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.[33] Such strong demand effects are necessary conditions for the substitution effects of supporting public transport.

[33]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 %.

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 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 Valuation of Benefits from Public Transportation

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 6 provide estimates of the elasticity of each outcome with respect to regional train service. We combine the 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 10 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.[34] The second step assesses

[34]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

the economic value of 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 10 about here —

Table 10 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 13.2 %. This amounts to preventing almost 70 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 1.11 billion EUR.[35]

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 10.8 %, and NO_2 concentration by 4.7 %. These reductions translate into a reduction of 2.29 $\mu g/m^3$ for NO, and a reduction of 1.37 $\mu g/m^3$ 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 876 million EUR for NO and approximately 524 million EUR for NO_2.[36] Nitrogen is primarily emitted as NO and then ox-

service z. Table 10 column 3 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 $y - z$.

[35]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.

[36]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 10.

idizes to NO_2. Therefore, effects on NO and NO_2 inherently related and should not be double counted.

Finally, consider the economic value of reduced infant mortality. The expansion of regional passenger rail service between 1994 and 2004 reduced infant mortality by 13.1%, or 446 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 2.29 billion EUR (range 1.72 billion to 2.87 billion EUR).

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 1.98 billion EUR using estimates for accidents and air pollution or of 3.39 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. 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.[37]

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 infant 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.

[37] Moreover, as argued for instance by Gibbons and Machin (2005) for the UK using housing data, improved public transport also has private benefits. These benefits result from travel time spendings and better access to jobs.

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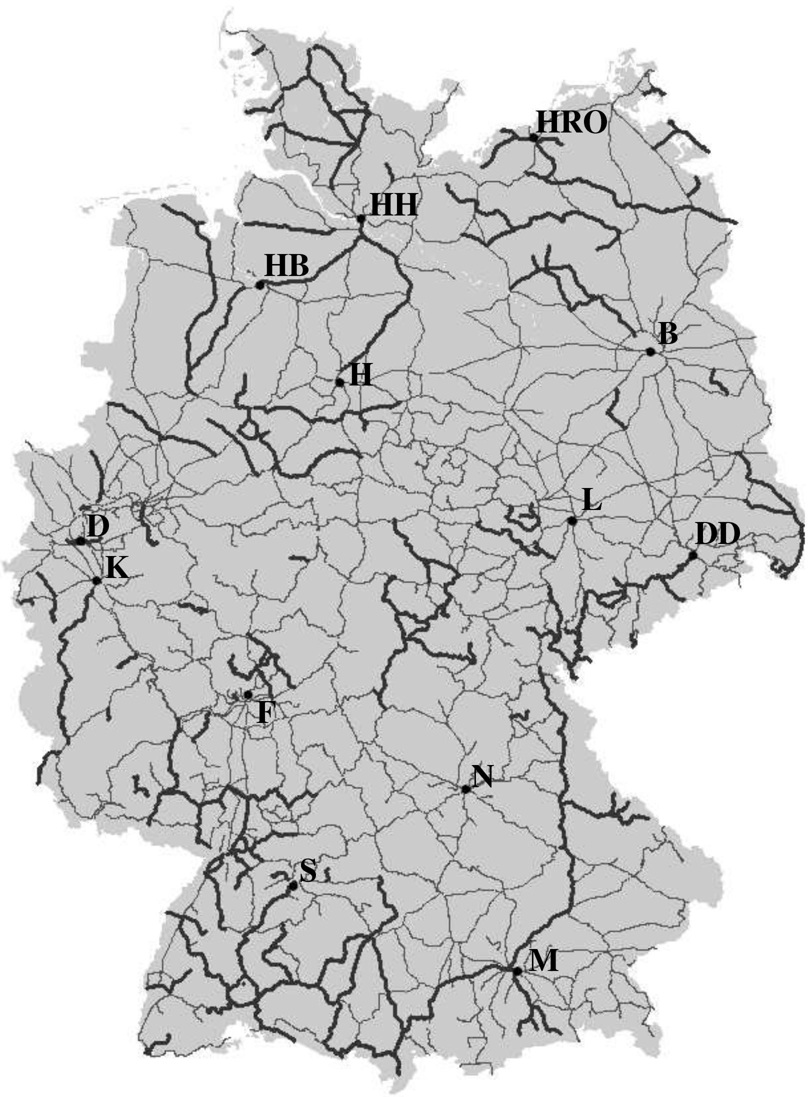
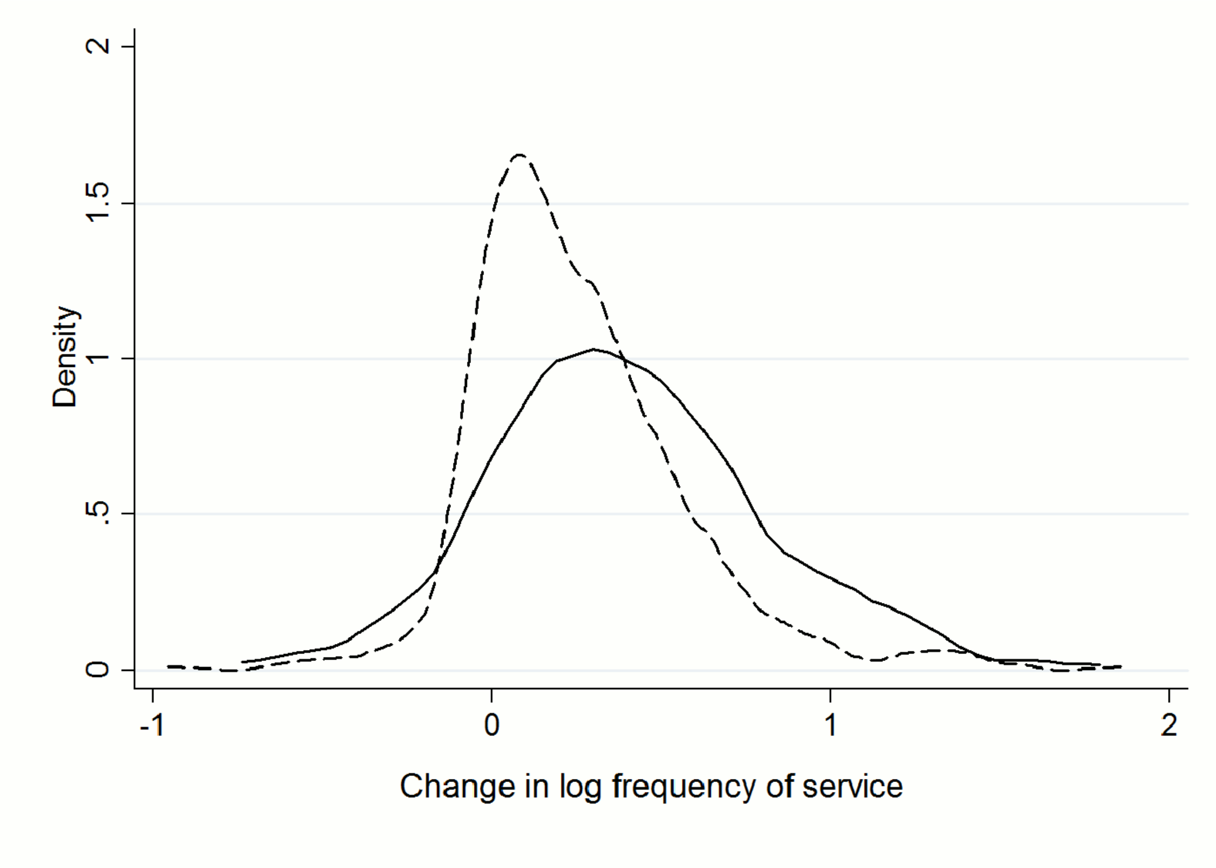
A Figures and Tables

Figure 1: Map of regional railway lines



Notes: Thin lines denote non-competitively procured train lines, bold lines competitively procured train 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: Descriptive Statistics

	N	Mean	Median	Std. Dev.
A. Outcomes				
Accidents	544	-0.1807	-0.1076	0.3073
CO	551	-0.4230	-0.4407	0.2320
NO	551	-0.0583	-0.1295	0.4246
NO2	551	-0.1077	-0.1095	0.1240
Infant mortality	551	-0.2963	-0.2855	0.3225
B. Placebo Outcomes				
SO2	551	-1.2910	-1.0831	0.6081
O3	551	0.0861	0.0880	0.0729
C. Train Lines				
Frequency of service	551	0.2838	0.2364	0.3683
Electrification	551	0.4537	0.0000	0.4983
Length (log km)	551	3.8071	3.8286	0.7975
Distance to city (/100 km)	551	0.1781	0.0000	0.2928
D. Instruments				
Auction	551	0.2505	0.0000	0.4337
Long distance trains in 1939	551	0.2087	0.0000	0.4068
Long distance trains in 1994	551	0.0526	0.0000	0.2235

Notes: This table reports descriptive statistics. A and B and frequency of service in C present differences in the log of the variables in 2004 and 1994. Electrification is 1 if the line has electric traction, 0 if it has diesel traction. Length (log km) is the log of length of the line in kilometers. Distance to city is 0 if the line runs through a city of at least 100,000 inhabitants in 1994. Train lines that do not run through a city have a positive distance to city that is equal to the air distance to the nearest city with at least 100,000 inhabitants ("as the crow flies"). Auction takes the value 1 if the line was procured using an auction rather than in direct negotiations with the incumbent between 1994 and 2004. Long distance trains in 1939 takes the value 1 if line shared track with long-distance lines served by more than 6 long-distance trains per day in 1939. Long distance trains in 1994 takes the value 1 if the line shared track with long-distance lines served by more than 6 long distance trains (=ICE trains) per day in 1994.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.

Table 2: Do Trains Matter for the Environment? OLS Results

	Accidents	CO	NO	NO2	InfMort
Frequency of service	0.011	-0.024	0.010	0.004	0.021
	(0.030)	(0.016)	(0.024)	(0.010)	(0.047)
Electric traction	0.031*	-0.004	0.037*	0.025***	-0.054**
	(0.018)	(0.014)	(0.021)	(0.008)	(0.027)
Length (log km)	0.009	-0.004	-0.019	-0.009*	-0.013
	(0.013)	(0.010)	(0.013)	(0.005)	(0.017)
Distance to city (100 km)	-0.088**	0.040	-0.095**	-0.046**	0.017
	(0.034)	(0.026)	(0.043)	(0.019)	(0.068)
Adj. R-squared	0.601	0.629	0.701	0.459	0.097
Train Lines	544	551	551	551	551

Notes: This table reports the results of OLS regressions of the change in the log of the outcome variables in 2004 and 1994. All regressions control for fixed effects of federal states. See notes to Table 1 for definition of control variables. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.

Table 3: Do Auctions and Track Sharing Predict Changes in Regional Service Frequency?

	IV	IVmult
Auction	0.134***	0.133***
	(0.042)	(0.042)
Long distance trains in 1939		0.090**
		(0.040)
Long distance trains in 1994		-0.116**
		(0.046)
Electric traction	-0.014	-0.034
	(0.034)	(0.039)
Length (log km)	-0.070***	-0.075***
	(0.023)	(0.023)
Distance to city (100 km)	-0.049	-0.045
	(0.068)	(0.067)
F-stat instruments	10.256	6.940
Adj. R-squared	0.060	0.066
Train Lines	551	551

Notes: This table reports the results of OLS regressions of the change in the log of frequency of service of regional passenger trains between 2004 and 1994 on three instruments. Auction takes the value 1 if the line was procured using an auction rather than in direct negotiations with the incumbent between 1994 and 2004. Long distance trains in 1939 takes the value 1 if line was served by more than 6 long distance trains per day in 1939. Long distance trains in 1994 takes the value 1 if the line was served by more than 6 long distance trains (=ICE trains) in 1994. All regressions control for fixed effects of federal states. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables.

Table 4: Do Auctions Predict Future Changes in Environmental Quality? Reduced Form Estimates

	Accidents	CO	NO	NO2	InfMort
Auction	-0.063***	-0.023*	-0.051**	-0.022**	-0.062*
	(0.019)	(0.013)	(0.026)	(0.010)	(0.032)
Electric traction	0.018	-0.008	0.027	0.020**	-0.067**
	(0.018)	(0.014)	(0.021)	(0.008)	(0.028)
Length (log km)	0.009	-0.003	-0.019	-0.009*	-0.014
	(0.012)	(0.010)	(0.012)	(0.005)	(0.017)
Distance to city (100 km)	-0.082**	0.043*	-0.091**	-0.044**	0.023
	(0.035)	(0.026)	(0.043)	(0.019)	(0.068)
Adj. R-squared	0.608	0.630	0.703	0.465	0.102
Train Lines	544	551	551	551	551

Notes: This table reports the results of OLS regressions of the change in environmental quality between 2004 and 1994 on whether the line was auctioned between 1994 and 2004 or not. Auction takes the value 1 if the line was procured using an auction rather than in direct negotiations with the incumbent between 1994 and 2004. All regressions control for fixed effects of federal states. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.

Table 5: Do Auctions Predict Past Changes in Environmental Quality? Analyzing Pre-Trends

	NO	NO2	InfMort
Auction	0.012	0.009	0.034
	(0.023)	(0.010)	(0.023)
Electric traction	0.006	-0.006	-0.012
	(0.020)	(0.009)	(0.019)
Length (log km)	-0.023*	-0.009*	0.023*
	(0.012)	(0.006)	(0.014)
Distance to city (100 km)	-0.123***	-0.046**	-0.007
	(0.046)	(0.023)	(0.044)
Adj. R-squared	0.639	0.680	0.032
Train Lines	551	551	551

Notes: This table reports the results of OLS regressions of the change in the log of outcomes between 1994 and 1990 on whether the line was auctioned between 1994 and 2004 or not, and line characteristics. CO data is not available before 1997 and we have not been able to locate data on road accidents going back to 1990. All regressions control for fixed effects of federal states. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables, the federal environmental agency and state statistical agencies.

Table 6: Do Trains Matter for the Environment? IV Estimates

	Accidents	CO	NO	NO2	InfMort
Frequency of service	-0.464**	-0.171	-0.382*	-0.167*	-0.462*
	(0.197)	(0.109)	(0.222)	(0.090)	(0.273)
Electric traction	0.011	-0.010	0.021	0.018*	-0.074**
	(0.026)	(0.015)	(0.026)	(0.010)	(0.032)
Length (log km)	-0.024	-0.014	-0.046**	-0.021**	-0.046*
	(0.021)	(0.013)	(0.022)	(0.008)	(0.026)
Distance to city (100 km)	-0.102**	0.035	-0.109**	-0.053**	0.000
	(0.047)	(0.028)	(0.052)	(0.023)	(0.073)
F-stat (p-value)	0.000	0.000	0.000	0.000	0.000
Train Lines	544	551	551	551	551

Notes: This table reports the results of IV regressions of the change in the log of outcomes between 2004 and 1994 on the frequency of service, instrumented with the procurement status of the line. All regressions control for fixed effects of federal states. The F-stat (p-value) reports the p-value on the joint test of significance of the regressors. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.

Table 7: Do Trains Matter for the Environment? Placebo Estimates

	SO2	O3
Frequency of service	0.173	0.059
	(0.159)	(0.041)
Electric traction	0.005	0.001
	(0.022)	(0.005)
Length (log km)	0.046***	-0.000
	(0.017)	(0.004)
Distance to city (100 km)	0.071	-0.010
	(0.046)	(0.012)
F-stat (p-value)	0.000	0.000
Train Lines	551	551

Notes: This table reports the results of IV regressions of the change in the log of placebo outcomes between 2004 and 1994 on the frequency of service. Frequency of train service is instrumented with the procurement status of the line. F-stat is the p-value on the joint test of significance of regressors in the 2nd stage regression. All regressions control for fixed effects of federal states. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables and the federal environmental agency.

Table 8: Do Trains Matter for the Environment? Using Multiple Instruments

	Accidents	CO	NO	NO2	InfMort
Frequency of service	-0.528**	-0.178*	-0.425**	-0.178**	-0.340
	(0.253)	(0.092)	(0.190)	(0.077)	(0.219)
Electric traction	0.008	-0.010	0.020	0.018*	-0.069**
	(0.028)	(0.015)	(0.026)	(0.010)	(0.029)
Length (log km)	-0.028	-0.015	-0.049**	-0.021***	-0.038*
	(0.024)	(0.012)	(0.020)	(0.008)	(0.023)
Distance to city (100 km)	-0.104**	0.035	-0.111**	-0.053**	0.004
	(0.050)	(0.028)	(0.054)	(0.023)	(0.070)
Overid. (p-value)	0.072	0.992	0.800	0.944	0.446
KP F-stat (1st stage)	7.029	6.940	6.940	6.940	6.940
F stat (p-value, 2nd stage)	0.000	0.000	0.000	0.000	0.000
Train Lines	544	551	551	551	551

Notes: This table reports limited information maximum likelihood (LIML) estimates of the effect of the change in frequency of service on the change in the log of outcomes between 2004 and 1994. Frequency of service is instrumented with the procurement status of the line and historical data on track sharing with long-distance trains in 1939 and 1994. All regressions control for fixed effects of federal states. Overid. (p-value) is the p-value on the overidentification test. KP F-stat (1st stage) is the first stage Kleibergen-Paap statistic. F-stat (p-value, 2nd stage) is the p-value on the joint test of significance of regressors in the 2nd stage regression. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.

Table 9: Do Trains Reduce Car or Motorcycle Use?

	Work	Leisure	Shop	Weekend	KidsSchool
Frequency of service	-0.266**	-0.275**	-0.083	-0.039	-0.064
	(0.130)	(0.124)	(0.081)	(0.087)	(0.111)
Electric traction	0.003	-0.011	0.023**	0.003	0.003
	(0.015)	(0.014)	(0.011)	(0.013)	(0.014)
Length (log km)	-0.021	-0.051***	-0.012	-0.019**	-0.003
	(0.013)	(0.012)	(0.008)	(0.009)	(0.012)
Distance to city (100 km)	0.100***	-0.088***	-0.031	-0.058**	0.013
	(0.035)	(0.027)	(0.024)	(0.026)	(0.031)
F-stat (p-value)	0.000	0.000	0.000	0.000	0.000
Train Lines	547	548	548	548	546

Notes: This table reports the results of IV regressions of the effect of the frequency of service on regional passenger trains on the change of the probability of car or motorcycle use for various purposes between 2003 and 1998. Trains are instrumented with the procurement status of the line. All regressions control for fixed effects of federal states. Robust standard errors in parentheses. The variables 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.

Sources: Own calculations based on data from published railway timetables and the SOEP.

Table 10: 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	-13.2	454113	-69059	0.016	-1105
B. Valuing NO concentration					
	Percent	Micrograms	Micrograms	Microgram [b]	
Average	-10.8	18.91	-2.29	382.60	-876
Minimal	-10.8	18.91	-2.29	22.84	-52
Maximal	-10.8	18.91	-2.29	742.36	-1700
C. Valuing NO2 concentration					
Units	Percent	Micrograms	Micrograms	Microgram [b]	
Average	-4.7	27.79	-1.37	382.60	-524
Minimal	-4.7	27.79	-1.37	22.84	-31
Maximal	-4.7	27.79	-1.37	742.36	-1017
D. Valuing infant mortality					
	Percent	Infant deaths	Infant deaths	Infant death [c]	
Average	-13.1	2957	-446	5.14	-2293
Minimal	-13.1	2957	-446	3.86	-1720
Maximal	-13.1	2957	-446	6.43	-2866

Notes: Average refers to the average valuation, Minimal refers to minimal valuation, and maximal refers to maximal valuation. [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.

Source: Own calculations, based on estimates in Table 6.

Table A.1: Explaining Procurement Mode

	base	controls
Frequency of service in 1994	-0.056**	0.003
	(0.028)	(0.031)
Left vote share in 1994	-0.146	-0.470
	(0.260)	(0.466)
Accidents in 1994	-0.042*	-0.042
	(0.023)	(0.034)
CO in 1994	0.209*	0.240
	(0.122)	(0.175)
NO in 1994	-0.126	-0.072
	(0.099)	(0.145)
NO2 in 1994	-0.416*	-0.001
	(0.246)	(0.343)
Infant mortality in 1994	0.251***	0.268***
	(0.083)	(0.083)
SO2 in 1994	-0.134***	-0.020
	(0.050)	(0.101)
O3 in 1994	-0.526**	0.045
	(0.267)	(0.377)
Electric traction		-0.188***
		(0.043)
Length (log km)		0.021
		(0.032)
Distance to city (100 km)		0.056
		(0.087)
State Effects	No	Yes
F-test for pollutants (p-value)	0.019	0.784
Adj. R-squared	0.049	0.118
Train Lines	547	547

Notes: This table reports linear probability models of procurement choice. Left vote share in 1994 is the vote share (secondary vote) of social democrats (SPD), green party (Gruene), and the left party (Linke) in the 1994 federal election. Pollutants, accidents, and infant mortality are measured in logs.

Sources: Own calculations based on data from published railway timetables, the federal agency for road transportation, the federal environmental agency and state statistical agencies.