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Analyzing the Efficiency of County Road Provision – Evidence from Eastern German Counties*

Abstract

This study analyzes the efficiency of the road provision of the local governments of eastern German counties using data envelopment analysis. The provision of roads is a costly public service, which makes an efficiency analysis in this field an interesting subject. I enhance the previous literature by first, examining the differences in the efficiency of eastern German counties; I consider the age of the foundations of roads, which previous studies have not considered due to data limitations. Second, I use a unique dataset on road quality for my efficiency analysis and show that efficiency levels differ from studies that apply proxies, such as the number of accidents, to analyze the quality of roads. These findings indicate there is a great need to develop suitable proxy variables to describe government services. Additional, I show that the correlations between efficiency levels and county characteristics vary greatly depending on the quality indicator used.

JEL-Codes: H41, H72, R51.

Keywords: DEA, technical efficiency, public services, roads.

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1. Introduction

In this paper, I highlight the data limitations of previous studies on the efficiency of the provision of roads and propose a method to overcome them: I enhance the previous literature by first, examining the differences in the efficiency of eastern German counties; I consider the age of the foundations of roads, which previous studies have not considered due to data limitations. Second, I use a new data on the quality of roads to calculate efficiency scores. The general population is highly interested in the efficient provision of public goods and services because, as tax payers, they provide the funds for these public expenditures. Public expenditures on roads represent a considerable portion of total building investments in public budgets. More specifically, county roads, which are the research object of this study, are very important for rural economic activity and for residents living in rural areas, as these roads connect them to agglomeration centers and the respective services they provide.

The results of my study indicate that there are substantial efficiency differences and efficiency reserves in the provision of roads in eastern German counties. In a comparison of the results of this study to those of previous studies, the importance of data accuracy becomes apparent. As highlighted by Narbón-Perpiñá and De Witte (2017a), some of the input and output variables in other studies are not sufficiently specific, and there is a great need to develop better proxy variables for local government services. I show that efficiency scores differ greatly depending on the quality indicator used. Furthermore, I relate these differences in efficiency to county characteristics and show that the correlations between efficiency and county characteristics also vary depending on the road quality indicator used. This finding is highly relevant when seeking to identify the source of these inefficiencies.

I begin this paper with a short overview of the existing literature and detail my own contributions to the literature. Next, I discuss the institutional background of the public provision of county roads in Germany. Then, I present the method and data and provide a detailed discussion of the results related to the technical efficiency of road provision in eastern German counties. Finally, I show how the results differ depending on the quality measure used and perform a robustness exercise.

2. Literature review and contributions made by the author

My research adds to the literature on "sector-specific" efficiency, where only a particular public service, such as street cleaning, water supply or road maintenance, is evaluated.[1] The advantage of a sector-specific efficiency analysis is that it is more straightforward to identify a certain public good and study the relationship between the provision of that good and the respective expenditures. However,

[1] Another possibility is to evaluate the overall efficiency of local governments by considering not only one but a variety of services (i.e., a "global" efficiency analysis). Numerous studies have followed this approach (for a recent literature review, see Narbón-Perpiñá and De Witte 2017a and 2017b). However, these studies face difficulties defining an accurate and comprehensive set of reasonable input and output variables that can fully describe all of the local government's activities.

data on the inputs and outputs related to the efficiency of a sector-specific public good are rarely available. Therefore, the empirical literature on each sector is very limited. In the following, I briefly discuss studies concerning the provision of public roads (see Table 11 in the appendix for a summary of the results of previous studies).

The efficiency of road provision is an excellent case in point: Roads are an important public good that should be provided by authorities in countries all over the world. Usually, expenditures related to the investment in and maintenance of roads are quite high; therefore, they represent a considerable portion of public budgets (see Table 12 in the appendix). County roads are especially important for people living in rural areas, as they maintain connections to agglomeration centers and the respective services and amenities they provide. Further, country roads play an important role in rural economic activity. The first generation of literature on the efficient provision of roads incorporated only the “quantity” of roads (e.g., the length of the road network) as the relevant output indicator: Deller and Nelson (1991) investigate rural municipalities in Illinois, Minnesota and Wisconsin using four input variables (expenditures for full-time employees, road graders, single axle trucks and surfacing materials) and one output variable (road length). Deller and Nelson (1991) identify considerable efficiency reserves and find that larger townships tend to be more efficient in the provision of rural roads. Deller and Halstead (1994) investigate various municipalities in New England and as input variables, they use the annual operating expenditures on town roads, including the wages of people employed in road maintenance and the depreciation rates for motorized graders and single axle dump trucks. The authors also use the length of the town roads as the output variable. Similar to Deller and Nelson (1991), the authors find considerable differences in efficiency and a great potential to enhance efficiency. While these early studies provide a good foundation for research on the efficiency of road provision, they did not consider the quality of the road network as an output variable and mainly focused on the quantity of roads (i.e., the length of the road network). However, quality differences may influence the efficiency scores of public services (Balaguer-Coll et al. 2007): Often, the decisions regarding the expenditures of local governments are not concerned with a change in the quantity of the outputs but rather their quality. Further, performance decisions may impact the quality of goods rather than their quantity; therefore, studies incorporating quality indicators are especially informative for local governments (Narbón-Perpiñá and De Witte 2017a).

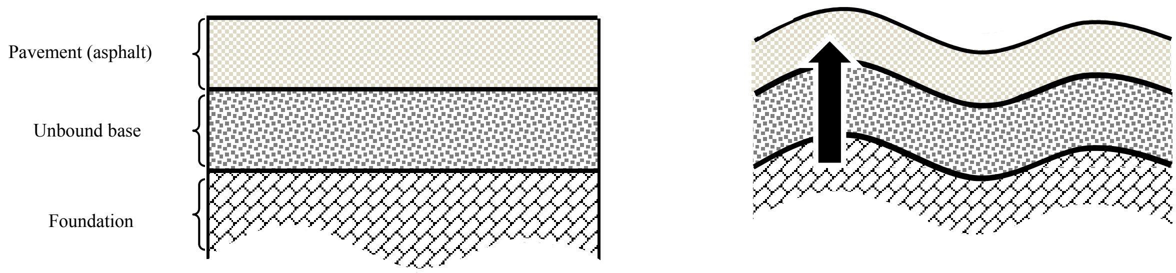
A second generation of studies enhanced the previous literature by considering this idea and incorporating the quality of public goods as an output variable. Rouse et al. (1997) were the first to do so in their study on highway provision in New Zealand. The authors use the expenditures of highways as the input variable and the length of the highway network (quantity) as an output variable. To measure the quality of the highways, the authors calculate an index based on recorded defects (such as potholes, cracks and digouts) observed in the road network. Rouse et al. (1997) find considerable scale effects and some efficiency reserves. Kalb (2014) examines differences in the efficiency of the road provision of counties in the German state of Baden-Württemberg. He uses total expenditures on county roads as the input variable. In addition, he employs the area of county roads as a quantity output and the number of accidents due to poor road conditions as a quality output. Similar to Rouse et al. (1997), he finds efficiency reserves. Although the quality variable enriched the efficiency analysis, the author admits that he uses a proxy for true road quality that rests on the assumption that an increase in the number of accidents due to poor road conditions is negatively correlated with the quality of the roads. Therefore, he implies that driving behavior is independent of road quality. However, as highlighted by Mankiw (2017), people might change their behavior when the costs and benefits change:[2] Drivers operate their cars more carefully when the benefit of increased safety is high, such as when the road is in bad condition. A road that is in good condition reduces the benefits of careful driving and therefore induces people to drive faster, which may result in more accidents. Thus, an increase in the number of accidents could also be caused by good road conditions (see Kalb 2014). Studies on the causes of accidents find that the quality of the road does not have a high impact on the number of accidents.[3] Therefore, it would be more effective to measure the quality of the roads with an index that measures actual road conditions, as proposed by Rouse et al. (1997). However, data constraints did not allow Kalb (2014) to perform such an analysis.

I propose the development of a third generation of efficiency analyses that also consider the age of the foundation of the road network. The mechanical process that describes the deterioration of pavements (and thus the quality of roads and increasing maintenance costs) can be separated into two categories (Habiballah and Chazallon 2005): First, the short-term mechanical process (horizontal stress), which is activated by vehicle use (the effect of this process is usually very small and is reversible) and second, the long-term mechanical process (vertical stress), which is caused by ground water flows, creep processes in the clay, or long-term settlement after a large amount of vehicle use. Regarding vertical stress, any permanent deformation in the foundation leads to a modification of any layer above it (the unbound base and the pavement) and eventually results in a deformation (also permanent) of the surface (see Werkmeister 2003, Habiballah and Chazallon 2005 and Figure 3). Pavement tests show that 30 to 70% of surface rutting is attributed to this long-term mechanical process (Little 1993).

[2] Mankiw (2017) describes a situation where the introduction of a seat belt law causes people to drive faster and less careful; therefore, its net effect on the number of deaths from driving is ambiguous: Drivers wearing a seat belt are more likely to survive any given accident, but they are also more likely to be in an accident.

[3] For example, Butterwegge (2001) finds that the quality of a road (in terms of the number of cracks, patches or other types of road damage) does not have an impact on accidents. Bräuninger (2007) shows that only 20% of roads on which accidents have occurred have a significant number of cracks and patches. A study conducted by Tenzinger (1989) provides evidence that only the grip of the road affects the number of accidents. The quality of the roads was only slightly correlated with accidents in metropolitan areas. However, it is considered to be very difficult to assess the causes of accidents in metropolitan areas. Furthermore, Gruner (2009) finds that low road quality leads to fewer accidents.

FIGURE 1. ILLUSTRATION OF THE DEFORMATION OF ROAD PAVEMENT DUE TO ITS FOUNDATION



Notes: This figure illustrates the possible deformation of road pavement due to a deformation in its foundation. The picture on the left illustrates a case with no deformation because the underlying layers of the foundation are even. The picture on the right illustrates the deformation of all the layers due to a deformation in its foundation. *Source*: Author's own illustration, which aligns with Voigt (2013).

Generally speaking, foundations slowly deteriorate with age (Beckers et al. 2009 and Voigt 2013). As a result, an old road network may result in higher maintenance costs because its pavement is deteriorated due to vertical stress.

Therefore, it is possible that governments with an older road network in their region could be identified as less efficient even if they do not actually employ their financial resources in a less efficient manner. To my knowledge, there is no available data on the extent of the deformation of the foundation of roads and data on the age of roads in Germany is not available. However, I believe it is highly necessary for an efficiency analysis to consider the foundation of a road network, I suggest – as a third generation of efficiency analyses – comparing only regions for which the road networks are of the same age.

My study adds to the previous literature by overcoming the limitations of previous studies, as highlighted above, and has two major differences related to the data: First, I follow the second generation of studies examining the efficiency of road provision by using a unique dataset on the quality of county roads in Germany. Second, I enhance the previous literature by conducting a study that represents the first of a third generation of efficiency analyses. In this analysis, I compare the expenditure decisions of local governments in eastern German counties where the age of the road networks is similar.

3. Institutional background

Germany provides an excellent setting for an empirical efficiency analysis. First, German counties are a good research subject because they rely on the same institutional framework but differences in expenditure decisions are to be expected (see also Kalb 2014):[4] Counties constitute the third layer of government beneath the federal and the state levels and are distinguished as either rural (*Landkreise*)

[4] Please note that the county functions may differ to some extent, e.g., urban counties combine county functions and municipal functions.

or urban (*Kreisfreie Städte*) counties. Urban counties simultaneously represent a county and a (one) municipality, while rural counties represent several municipalities. Eastern Germany[5] consists of 76 counties of which 58 are rural and 18 are urban. Counties differ in size and demographic structure: The size of rural counties range from roughly 56,800 to 347,700 inhabitants and their population density ranges from 37 to 348 inhabitants per square kilometer (as of 31/12/2012, Statistic Departments of the Federation and the Federal States 2017). Labor agreements and access to capital markets are the same across all counties. Furthermore, counties are guaranteed the right to local self-government according to the German constitution, and they exhibit considerable autonomy regarding expenditures, particularly, those for road construction/maintenance, social security and youth welfare and certain expenditures for education and public transport (see Table 1).[6] As in other countries, the investments of local governments in Germany in "roads" represent a considerable portion of their total building investments (see Table 12 and Figure 3 in the appendix).

TABLE 1. VARIOUS EXPENDITURES ON AND THEIR SHARE OF TOTAL EXPENDITURES (ONLY CONSTRUCTION AND PERSONNEL EXPENDITURES) AT THE (RURAL) COUNTY LEVEL, 2014

Expenditure Category	*Expenditures in 2014 (m €)*	*Share of Total Expenditures*
General administration[a]	4,295.4	35%
Social security and youth[b]	2,805.9	23%
Shaping the environment[c]	2,696.4	22%
... of roads	*1,050.6*	*8%*
Schools[d]	1,763.7	14%
Health and sports[e]	1,613.2	5%
Culture and science[f]	236.4	2%
Total Expenditures	12,396.4	100%

Notes: This table shows the expenditures for various categories in mill. € and their percentage of total expenditures for construction and personnel at the rural county level (eastern and western German counties) in 2014. a) *Zentrale Verwaltung*. b) *Soziales und Jugend*. c) *Gestaltung der Umwelt*. d) *Schulen und Schulträgeraufgaben*. e) *Gesundheit und Sport*. f) *Kultur und Wissenschaft*. *Data*: Federal Statistical Office (2016).

Second, public roads in Germany are classified into four different types, and a different government level (federal, state, county and municipality) is responsible for each type. Thus, public expenditures on roads for each government level can be clearly attributed to a specific road type. This classification is as follows: (1) Highways (*Autobahnen*), (2) state roads (*Landesstraßen*), which are mainly used for transit traffic, (3) county roads (*Kreisstraßen*), which are used for traffic between neighboring counties

[5] Because my sample includes eastern German counties, I provide supporting information only on institutions in Eastern Germany.

[6] Due to extensive tax sharing and fiscal equalization payments, counties' budgetary autonomy is somewhat limited, and the degree of fiscal autonomy varies across states. Counties do not receive taxation income, and finance their expenditures through the contributions of municipalities within the county, transfers from the states they are in and by borrowing.

or to connect municipalities with supra-local traffic routes[7], and (4) municipality roads (*Gemeindestraßen*), which are mainly used for traffic within metropolitan areas.[8] In Eastern Germany, the length of the county road network in 2015 was approximately 92.000 km. Table 2 shows that both state and county roads represent a considerable share the total road network outside of metropolitan areas in Eastern Germany (36%).

TABLE 2. ROAD CLASSES AND THEIR SHARE OF THE TOTAL ROAD NETWORK IN EASTERN GERMANY, 2015

Road Class	*Share of Total Road Network*
Highways	5%
Federal roads	19%
State roads	39%
County roads	36%

Notes: This table shows the road classes and their share of the total road network outside of metropolitan areas in Eastern Germany for 2015. Municipal roads are not included. *Data*: Federal Statistical Office (2017a).

Third, the case of the eastern German road network is unique: In 1990, the capital stock of county roads was equal to zero, which implies that almost all roads are roughly the same age; therefore, the foundations of county roads in eastern German counties are quite similar. In the former German Democratic Republic (GDR), investments in the road infrastructure were very low and a significant portion of the existing structure in 1990 had not been maintained since 1945 (Heilemann and Rappen 2000). In the 1970s, the condition of roads was so poor that many roads could only be used to a limited extent; nevertheless, expenditures and investments on roads further decreased from 1977 to 1983 (Lorbeer 1990). Enderlein and Kunert (1992) note that even the very limited expenditures on maintenance cannot be described as "serious measures but rather provisional patchwork". In 1990, the German Council of Economic Experts (Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung 1990) described the road network in the former GDR as "extremely poor" due to insufficient maintenance and the use of sub-standard materials. Roads at the local level were in very poor condition (Zimmermann et al. 1993): The share of district roads[9] with ruined surfaces and partly ruined foundations increased from 28% to 41% between 1980 and 1990 (Lorbeer 1990). Studies and reports cited in this study indicate that the capital stock of county roads was basically depreciated to zero at the time of the German Reunification. In addition, it may be assumed that since that time, any major reconstruction of roads has not been necessary because roads usually last for about 30 years

[7] County roads are supposed to end at either a federal highway, a state road, or another county road.
[8] In addition, roads that connect municipalities (*Gemeindeverbindungsstraßen*) are also used to connect municipalities to supra-regional road networks. However, this special type of road plays only a minor role in the total road network.
[9] In the former GDR, regions were divided into districts rather than counties. Most district roads were classified into state roads after the German reunification.

(see, for example, Federal Ministry of Finance 2000, Kommunale Verwaltung Sachsen 2007 and Bayrische Staatskanzlei 2008).[10] As a result, the age of the county roads in Eastern Germany can be considered as quite similar, providing an excellent framework for efficiency analysis.

Fourth, county governments collect data on the quality of their county roads, which allows me to include a quality indicator in my empirical analysis. Each county in Germany must assess the value of its assets prior to the public disclosure of their local budget.[11] These assets include county roads. The value of the roads depends on their condition, which can be determined using a standardized scheme that considers cracks, patches, general unevenness, road safety and future maintenance. These defects are recorded and used to construct an index indicating the condition of the total road network, which usually uses a range from 1 (very good condition) to 4 (poor condition).[12] An example of such a classification scheme is presented in Table 3. This index seems to be very similar to the one applied by Rouse et al. (1997), which also included recorded defects in the road network.

TABLE 3: STANDARDIZED SCHEME TO CLASSIFY THE CONDITION OF COUNTY ROADS IN GERMAN COUNTIES

Grade	Description
1.0-1.4	*Very good condition* The structural stability, safety and sustainability of the road are apparent. Ongoing maintenance is necessary
1.5-1.9	*Good condition* The structural stability and safety of the road are apparent. The sustainability of the road might be slightly affected in the long run. Ongoing maintenance is necessary.
2.0-2.4	*Satisfactory condition (bumps, small amount of damage to the pavement, and bitumen are visible)* The structural stability and safety of the road are apparent. The sustainability of the road might be affected in the long run. It is possible, that in the long run, the damage or consequential damage may spread to significantly affect the structural stability and safety or may lead to an increase in deterioration. Ongoing maintenance is necessary. Restoration will be necessary in the medium run.
2.5-2.9	*Still sufficient condition (cracks, pot holes, and patches are visible)* The structural stability of the road is apparent. Safety might be compromised. The sustainability of the road might be considerably compromised. In the medium run, it is expected that the damage or consequential damage may spread to significantly affect the structural stability and safety of the road or may lead to an increase in deterioration. Ongoing maintenance is necessary. Restoration will be necessary in the medium run. Measures to address damage or warning signs to maintain road safety might be necessary in the short run.
3.0-3.4	*Critical condition (cracks, large potholes, patches, portions of old pavement, and bumps are visible)* The structural stability and/or the road safety of the road are affected. The sustainability of the road is under some circumstances not met anymore. In the short run, the damage or consequential damage may spread to significantly affect the structural stability and safety of the road or may lead to an increase in deterioration. Ongoing maintenance is necessary. Immediate restoration is necessary. It may necessary to immediately address road safety or institute usage restrictions.
3.5-4.0	*Insufficient condition* The structural stability and/or the safety of the road are compromised. In certain aspects, the sustainability of the road has been compromised. In the short run, the damage or consequential damage may spread to significantly affect the structural stability and safety of the road or may lead to irreparable road damage. Ongoing maintenance is necessary. Immediate restoration or renewal is necessary. It is necessary to immediately address road safety or institute usage restrictions.

[10] Of course, new county roads have been constructed over the course of time; however, these new roads represent a relatively small share of the total road network.
[11] The assessment of the asset value is only necessary for the double-entry accounting system. In 2012, the local governments in Brandenburg, Mecklenburg-Western Pomerania, Saxony and Thuringia applied this system. Saxony-Anhalt did not finish the transition to this system; therefore, it cannot be included in my empirical analysis.
[12] A few counties use a classification scheme from 1 to 5. In these cases, I adjusted this scheme to a 1 to 4 scale with the help of information provided by the respective building authority (*Bauamt*) on the condition to which the respective grade is applied.

Notes: The table shows the standardized scheme for which the condition of county roads in German counties should be classified. The standards comply with DIN 1076 (for building surveys). Some building authorities utilized specialized vehicles to monitor the condition of roads automatically, while others visited their roads in person. *Source*: The author's own translation based on DIN 1076 and information provided by building authorities (*Bauämter*) in eastern German counties (2015).

4. Estimating differences in the provision of roads

In the following section, I assess differences in the provision of county roads in eastern German counties. First, I discuss the method used in this analysis. Then, I present my dataset and perform my analysis.

4.1 Method

Technical efficiency refers to the use of economic resources in the most technologically efficient manner to produce a certain amount of output (Woodbury and Dollery 2004).[13] The empirical measurement of technical efficiency involves the estimation of a production frontier: For a given technology, it indicates either the maximum possible output for a given input or the minimal input needed to produce a given output. A decision-making unit (such as a local government) is considered to be efficient when it reaches a specific point on this production frontier. The relative efficiency of governments below this frontier can be identified by measuring the deviation from the frontier. The production frontier is unknown; therefore, it must be estimated.

Two main methods have been employed in the literature on efficiency analyses to estimate the production function: the non-parametric data envelopment analysis (DEA) (see Farrell 1957, Charnes et al. 1979 and Banker et al. 1984) and the parametric stochastic frontier analysis (SFA) (see Aigner et al. 1977, Meeussen and Van Den Broeck 1977 and Battese and Corra 1977). Parametric approaches assume that the production frontier has a certain functional form, usually a Cobb-Douglas or a translog production function, and estimate the function with the given observations. Non-parametric approaches define the efficiency frontier with the help of linear optimization and estimate the production frontier by identifying a set of linear estimates that bind (or envelop) the observed data (Woodbury and Dollery 2004). Therefore, the production frontier consists of the most relatively efficient unit in the sample. Then, each observation is compared with the piecewise linear surface of the most efficient observation derived (with optimal values of inputs and outputs), and an efficiency score is generated for each county. If the efficiency score of a country is below 1, the it is considered to be technical inefficient, i.e., there is another county that is able to provide more services with the same amount of inputs or vice versa. The best performing (efficient) counties receive an efficiency score of 1.

[13] Technical efficiency, in this context, can be interpreted as managerial efficiency, which refers to the efficient use of economic resources that are directly overseen by management (Deller and Halstead 1994).

To determine whether the parametric or non-parametric approach should be used, unfortunately, there is no diagnostic test associated with regression estimation that can be applied (Webster et al. 2000). The non-parametric DEA can be used when realistic price data are not available for the inputs and outputs (Webster et al. 2000). Another advantage of DEA is that it is better suited for small samples, such as that used in this study (Maudos et al. 2002). In addition, DEA does not require the functional form or distributional form of the error term to be specified (Gupta et al. 2012). Because the form of the production function is not obvious when considering public units, I use a non-parametric approach.

DEA requires some fundamental decisions regarding the properties of the points in the production set. First, the efficiency frontier can be calculated by considering either an input orientation or an output orientation. When using the input orientation, the production frontier represents the point where the the highest level of input is used to produce a given level of outputs. In contrast, when using the output orientation, the production frontier represents the point where the highest level of output is achieved with a given level of inputs. Both approaches yield the same frontier, but the calculation of the derived efficiency scores is different (Coelli 1996). All previous studies on the efficiency of road provision use input-oriented models (see Table 11 in the appendix). This seems appropriate since a decrease in the input factors employed in the process (given a constant output) is always feasible, whereas an increase in the output may not be possible, (for instance, the construction of additional roads comes at a very high cost).In addition, local governments usually seek to optimize their budgets and specifically, German counties possess considerable autonomy in their expenditure decisions (see Section 3). Thus – and in alignment with previous literature – the input orientation seems to be the most appropriate for this analysis.

Second, the economies of scale in the production process must be identified. DEA was initially designed for a constant return-to-scale-production process (Charnes et al. 1978). Banker et al. (1984) refined this method so it can be used for processes with variable returns-to-scale. It is not entirely obvious whether constant returns-to-scale are applicable to the production of roads. Studies have measured the economies of scale for public road expenditures (see Table 13 in the appendix) and found constant, increasing and decreasing returns-to-scale. Therefore, – and again in alignment with previous studies (see Table 11 in the appendix) – I use the method developed by Banker et al. (1984) that considers variable returns-to-scale.

4.2 Dataset and results

Following Kalb 2014, the input necessary to construct and maintain county roads is approximated by the total expenditures for county roads.[14] I develop the input indicator by calculating the average of total expenditures on county roads for each county from 2011 to 2013 for each county.[15] Table 4 shows that in the study sample, there are substantial variations in the expenditures for county roads. I exclude urban counties from the analysis because these counties are not comparable to rural counties, as there are great differences in terms of their functions and expenditures (see Section 3). Outliers have been removed and generally, each state is equally represented in the sample.[16] The data covers only counties in Eastern Germany to allow for a comparison of counties for which the foundations of the road networks are roughly the same age. This study excludes counties from Saxony-Anhalt (due to reasons highlighted in Section 3). In summary, the empirical analysis is based on data from 2012 (the most recent year for which data is available for all my variables) and includes 47, 40 and 23 observations depending on the input or output variable used.

TABLE 4. SUMMARY STATISTICS OF INPUTS AND OUTPUTS

Variable	*Year*	*Obs.*	*Mean*	*Std. Dev.*	*Min*	*Max*
Input						
Expenditures on county roads[a]	2011-2013	47	6,353,496	5,333,281	425,763	21,770,330
Output						
Area of county road network[b]	2012	47	1,743,684	1,236,875	301,600	5,241,600
Number of accidents[c]	2012	40	24.01	15.32	1	59
Condition of county roads[d]	2012	23	2.86	0.57	1.52	3.84

Notes: The table describes the data set and urban counties are excluded. a) The mean of construction and maintenance expenditures on county roads in € from 2011 to 2013. b) The area of the county road network in square meters; when data were available only on the length of the county roads, the calculation used the average width of country roads, which is 5.2 m. c) The number of accidents due to poor road conditions. d) The condition of the county roads is classified by a grading system from 1 to 5, where 1 constitutes the best condition; the data have been inverted to match the setting of the efficiency analysis (the higher the variables, the higher the efficiency). *Data*: Statistical Offices in Saxony, Brandenburg, Mecklenburg-Western Pomerania and Thuringia (2017), IÖR (2017), and Building authorities (*Bauämter*) in eastern German counties (2015).

The main challenge for my analysis is determining how to measure output. In alignment with the second generation of efficiency analyses of road provision, I separate my outputs into quantity and quality

[14] As roads are public goods (i.e., indivisible and non-excludable), there is no need to relate expenditures to the population in each county.

[15] A focus on only operational expenditures would have been desirable as high investment costs in one year could skew my results. However, expenditures on roads can be considered as either investment costs or operational costs, and there is no definite rule regarding the classification of these costs. Therefore, to compare the expenditures of the counties, I included expenditures from capital budgets as well as administrative budgets. I try to overcome this problem by calculating average expenditures over three years and excluding outliers. As a robustness exercise, I calculate the estimated capital stock of county roads, and perform my analysis using these data (see Section 6).

[16] For more descriptive statistics and more information on the differences among the subsamples used in each model and the eliminated outliers, see Table 15 and Figure 6-8**Fehler! Verweisquelle konnte nicht gefunden werden.** in the appendix.

measures.[17] For this study, the quantity output is measure by the area of the county road network in each county. Thus, I capture both road length and road width. The data on the area of the county road network is provided by the statistical offices in each state. In cases were only the length of the county road network was available, the area of the road network is calculated using the average road width, which is used by the IÖR (2017) (i.e., 5.2 m for a two lane road that is not a highway). Regarding the quality output, unfortunately, data on the quality of public goods and services are scarce.[18] Kalb (2014) uses the number of accidents on county roads due to poor road conditions to describe the quality of roads, but he admits that this proxy might be problematic. I obtained actual data on road conditions from some of the local public construction authorities of the counties in my sample to overcome this problem. I describe how these data are captured in Section 3. When correlating these data with data on the number of accidents on county roads due to poor road conditions, the relationship between the condition of county roads and the number of accidents is positive but to a much weaker extent (and statistically not significant) than reported by Kalb (2014) (see Table 5 and Figure 4 in the appendix).

TABLE 5. CORRELATION COEFFICIENTS FOR THE CONDITION OF COUNTY ROADS AND NUMBER OF ACCIDENTS AT THE COUNTY LEVEL, 2012

	Number of accidents due to poor road conditions	*Accidents due to poor road conditions as a share of all accidents*	*Accidents due to poor road condition to total population*
Condition of county roads[a]	0.0475	0.006	0.141

Notes: This table shows the Pearson correlation coefficients for the condition of county roads and the number of accidents due to poor road conditions (as used in Kalb 2014) and the correlation between the condition of county roads and the number of accidents due to poor road condition on all accidents for the year 2012. Due to data constraints, the sample includes only observations in Saxony, Brandenburg and Thuringia. The p-values of all correlation coefficients are higher than the 10% significance level; therefore, I cannot conclude that the correlation is different from 0. a) The condition of county roads is classified by a grading system from 1 to 5 where 1 constitutes the best condition. *Data*: State Statistical Offices in Saxony, Brandenburg and Thuringia (2017), Building authorities (*Bauämter*) in eastern German counties (2015).

To increase the reliability of the efficiency frontier, I test for different combinations of inputs and outputs and multiply the outputs with each other to use as few input and output variables as necessary, as recommended by Illy (2015).[19] Additionally, I compare my results with those reported by Kalb (2014),

[17] Rouse et al. (1997) argue that a low correlation between quantity and quality outputs highlights the necessity to include both measures in the evaluation of efficiency in road provision. I show the correlations between the quantity and quality outputs in Table 14 in the appendix.
[18] Even Rouse et al. (1997) who had access to data on the quality of roads needed to adjust their output variable as data has not been available for unsealed roads.
[19] The more inputs and outputs are used, the higher the number of dimensions enabling a comparison of decision-making units. As a result, the number of suitable reference points decreases, leading to more efficient units. Formally the increasing number of dimensions leads to slower convergence rates. Therefore, this phenomenon is known as the “curse of dimensions”.

who uses similar data.[20] Table 6 shows my specifications (i.e., models) as well as the respective results for the input orientation with variable returns-to-scale.

TABLE 6. RESULTS OF THE EFFICIENCY ANALYSIS

Model	*Obs.*	*Min.*	*Median*	*Std. Dev.*	*Efficient*	*% efficient*
A: Output area	47	0.116	0.359	0.239	3	6%
B: Output area and accidents[a]	40	0.147	0.519	0.286	8	20%
C: Output area*accidents[b]	40	0.089	0.301	0.268	3	8%
D: Output area and condition	23	0.135	0.498	0.269	4	17%
E: Output area*condition[c]	23	0.128	0.456	0.263	3	13%
Results by Kalb (2014): Output area and accidents[d]	660	0.05	0.64	0.24	121	18%

Notes: This table shows the results of the efficiency analysis (DEA) with input orientation and variable returns-to-scale using different outputs and only counties with a similar foundation of their road structure. a) The number of accidents due to poor road conditions. b) Only one output is used, namely, the product of the output area and the number of accidents. c) Only one output is used, namely, the product of the output area and the road condition. d) The results reported by Kalb (2014), who applied DEA with input orientation and variable returns-to-scale for the state of Baden-Wurttemberg.

As presented in Table 6, the minimum efficiency level (column "*Min.*") is very low but greater than those reported by Kalb (2014). As shown in the fourth column, the median efficiency for the different specifications ranges from 30 to 52%, which means that in the median county, the same level of output could be achieved using 48 to 70% fewer inputs. Compared to the results of previous studies on the efficiency of road provision, the results of this study imply that eastern German counties have considerable efficiency reserves (see Table 11 in the appendix). When more than one output variable is included in the model, the efficiency scores improve, and more counties in the sample attain the efficiency frontier (which refers to the "curse of dimensions" identified by Illy 2015). The percentage of efficient counties in models A, C and E (only one output variable) lies between 6% and 13%, while models B and D respectively indicate that 17% and 20% of the counties are fully efficient. Variations in efficiency scores (column "*Std. Dev.*") slightly increase when a quality output is included, as shown by an increase in the standard deviation, which ranges from 23.9 to 28.6. Considering the range of output proxies and the differences in sample sizes, the difference between the minimum and median efficiency levels and the variations in the efficiency scores for each model seem to be small and similar to those reported by Kalb (2014). However, Table 6 does not show the differences in efficiency rankings. It is possible that the efficient counties are not the same in all the models. Therefore, I use

[20] The only differences between data used for this study and Kalb's (2014) study are the observed regions (counties in Eastern Germany vs. Baden-Württemberg) and the time frame (2012 vs. 1990-2004).

Spearman's rank correlation coefficient to measure the correlation among the efficiency ranks for the different specifications (see Table 7).[21]

TABLE 7. CORRELATIONS OF THE EFFICIENCY RESULTS USING DIFFERENT OUTPUTS

Model	B	C	D	E
B: Output area and accidents	1.00			
C: Output area*accidents	0.84	1.00		
D: Output area and condition	0.64	0.44	1.00	
E: Output area*condition	0.32	0.06	0.93	1.00

Notes: This table shows the Spearman's rank correlation coefficients of the efficiency ranks for the different specifications. The efficiency scores were recalculated for the respective sample sizes.

Models D and E have almost identical rankings; these models have a correlation of 0.93. The efficiency ranks between the model with the number of accidents (B and C) and the model with the road condition as an output variable (D and E) are not very similar. Counties that were identified as more efficient in the model using the number of accidents as the quality variable appear to be less efficient in the model using the road condition as the quality variable. The results indicate that the use of the number of accidents as a proxy variable for road quality might be problematic. It is therefore desirable to use indices that measure true road quality.

I conclude for an efficiency analysis, it is crucial to use accurate data, as the results are very sensitive and depend on the dataset that is used. Therefore, it is important to, first, not rely on vague input and output variables but rather develop a suitable proxy for local government services (see Narbón-Perpiñá and De Witte 2017a). Second, this should hold true for the selection of the sample data in general; therefore, the study should consider other peculiarities of the government service under study (such as the age of the road foundation).

5. Correlation with county characteristics

The efficiency analysis does not clearly identify the source of inefficiencies. Therefore, many studies that conduct efficiency analyses are also concerned with the determinants of local governments' performance (see Narbón-Perpiñá and De Witte 2017b). Local governments face different conditions that are beyond the control of political decision makers but yet affect the efficiency scores. Such conditions may be socio-economic (such as the population density) or geographical (such as the climate). To examine the nexus between these conditions and the efficiency of road provision, a second-stage anal-

[21] I use Spearman's rank correlation coefficient to measure the differences among the rankings of the efficiency scores because the differences within each rank do not matter.

ysis is often conducted (see Narbón-Perpiñá and De Witte 2017b).[22] However, this type of analysis cannot be conducted here because my sample is too small. To highlight the importance of data accuracy once again, I simply analyze the correlations between the efficiency scores and population density, which, in the German literature, has been considered to have a considerable influence on the efficient provision of roads (see Suter et al. 2000, Seitz 2008, Kalb 2014 and Deilmann et al. 2016).[23]

I correlate the efficiency scores of models B and D with the population density and the total population in the respective county (see Table 8).[24]

TABLE 8. CORRELATION BETWEEN EFFICIENCY SCORES AND POPULATION DENSITY

Model	Population density
B: Output area and accidents	0.28*
D: Output area and condition	-0.55***

Notes: This table shows the Pearson's correlation coefficients between the efficiency scores of different specifications and population density (inhabitants per square meter) as of 12/31/2012. Significance levels: *** 0.01, * 0.1. *Data*: Statistic Departments of the Federation and the Federal States (2017) and statistical offices in Saxony, Brandenburg, Mecklenburg-Western Pomerania and Thuringia (2017).

When using the area of the road network and the number of accidents as output variables (model B), I find (similar to Kalb 2014) that a positive relationship exists between the efficiency scores and population density; i.e., more densely populated counties appear to be more efficient. However, when using the condition of county roads as an output variable (model D), I find quite the opposite relationship. While these findings do not allow me to explore the actual sources of inefficiency, they highlight, once again, the need to choose a specific and suitable proxy variable for local government services when conducting an efficiency analysis, as highlighted by Narbón-Perpiñá and De Witte (2017a).

[22] DEA can be extended into a two-stage approach, where first, the frontier is derived without considering exogenous effects (as in the previous section) and second, a regression model for the efficiency is formulated (i.e., the calculated efficiency scores are explained by indicators of potential determinants through regression analysis). These methods are subject to some criticism: First, the results crucially depend on the efficiency scores that are determined in the first stage. Second, the two-stage approach assumes that the determinant variables do not influence the input or output levels but only the efficiency of the decision-making unit (Narbón-Perpiñá and De Witte 2017b). Many scholars interpret their results in a causal way, which neglects these endogeneity issues. Third, some variables are often omitted due to data limitations or methodological reasons. Therefore, deviations in policy implications may not be applicable (Narbón-Perpiñá and De Witte 2017b).

[23] Seitz (2008) emphasizes the importance of population density when analyzing public expenditures for roads. He finds that as population density decreases, per capita expenditures on county road provision and maintenance increase. Suter et al. (2000) find only very moderate additional costs in road provision for areas with lower population density in Switzerland. Kalb (2014) conducts an efficiency analysis and considers (among other variables) the population density of the counties in his sample. He finds mixed results regarding the relationship between efficiency and population density depending on the specification used. Deilmann et al. (2016) also evaluate the relationship between population density and efficiency scores and find that German municipalities with a moderate population density tend to be the most efficient.

[24] For a graphical illustration of the differences between the models, see Figure 8 in the appendix.

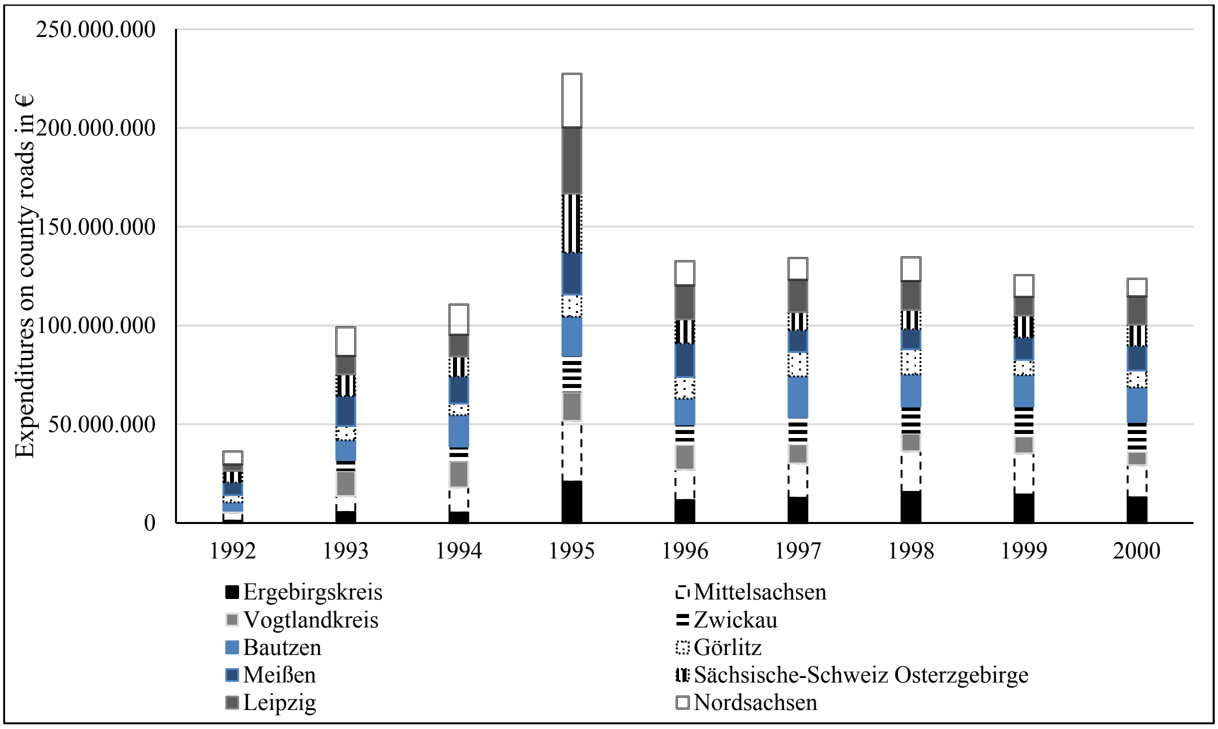
6. Robustness exercise

In my estimation technique, I worked diligently to replicate the approaches undertaken in previous studies. However, as investments in roads follow a rather cyclical pattern, the usage of total expenditures (both operational expenditures and investments) on county roads is subject to some criticism: If a county invested heavily in one year (e.g., due to the construction of a new road), it receives a lower efficiency score than a county with the same outputs that did not build a new road. However, it is not always clear whether expenditures on roads are considered as investments or operational costs. Therefore, I needed to include expenditures from the capital budget as well as the administrative budget to compare expenditures between counties. I account for large differences in investments in my baseline analysis in Section 4 by including the average of total expenditures from 2011 to 2013. An alternative method is to calculate the sum of all previous (discounted) expenditures.[25] I estimate the discounted sum of expenditures for each county since the German reunification and compare the results to those when using the average of expenditures between 2011 and 2013.

Data on the expenditures on county roads are only available since 1995 for most counties included in my sample, and there is no information on investments before 1995. Thus, I first assume that the "capital stock" of roads before the German reunification is zero because the roads in Eastern Germany were entirely depreciated in 1990 (see Section 3). Second, I assume that the majority of investments occurred after 1995; therefore, the investments the occurred between the German reunification and 1995 can be neglected. In 1995, the Federal Office for Building and Regional Planning (1995) observed that the majority of the county roads in Eastern Germany were in relatively poor condition. Between 1991 and 1998, the majority of investments focused on highways and bypasses to provide connections across the former inner-German border (Eckey and Horn 2000 and Komar 2000). However, by the end of the 1990s, there were still very few connections between rural areas and agglomeration centers (Komar 2000). As a result, in 1998, the road network was in need of considerable investments (Snelting et al. 1998). Furthermore, for one state included in my sample (Saxony), data on expenditures on county roads are only available from 1992 to the present. The data show that investments increased steadily with a considerable wave of investments in 1995 (see Figure 2). It can also be assumed that there is a time lag of several years between the investments and the actual completion of the roads.

[25] By doing so, I estimate a fictitious "capital stock" of county roads.

FIGURE 2: DEVELOPMENT OF EXPENDITURES ON COUNTY ROADS IN SAXON COUNTIES FROM 1992 TO 2000



Notes: This figure shows the development of the expenditures on county roads in counties in the Free State of Saxony (excluding urban counties) from 1992 to 2000 in real prices of 2012 using the price indices of the construction industry for underground construction (excluding value added taxes) for Germany. *Data*: Federal Statistical Office (2017) and statistical office in Saxony (2017).

I assume that county roads have an average service life of 30 years (see, for example, Federal Ministry of Finance 2000, Kommunale Verwaltung Sachsen 2007, and Bayerische Staatskanzlei 2008). To calculate the capital stock, I follow the same mathematical model as the official national accounts in Germany (see Schmalwasser and Schidlowski 2006), which derives the consumption of fixed capital from gross capital and the service life of the fixed asset. The German national accounts use the density function of the gamma distribution to calculate the depreciation, which provides the best approximation of the depreciation of assets, distributed around the average service life. Capital stock K_t is the sum of the non-depreciated investments of all prior periods $\tau < t$ given by

$$K_t = \sum_{\tau=1}^{t-1} I_\tau * (1 - F(\tau)),$$

where I_τ is the investment in year τ. Because roads have an average service life of 30 years, I define the depreciation function for county roads, $F(\tau)$, by

$$F(\tau) = 9^9(8!)^{-1}30^{-9}\tau^8 e^{(-\frac{9\tau}{30})}.$$ [26]

[26] This function assumes a lower depreciation rate during the early years than a linear depreciation rate would. For more details on the depreciation function, see Schmalwasser and Schidlowski (2006).

Table 9 summarizes the results of my calculation of the capital stock of county roads in 2012.

TABLE 9. SUMMARY STATISTICS OF INPUT

Variable	*Year*	*Obs.*	*Mean*	*Std. Dev.*	*Min*	*Max*
Input						
Capital stock of county roads in Mill. €[d]	2012	40	87.54	68.29	7.41	278.93

Notes: This table shows the alternative input variable, namely, the capital stock of county roads. Data on counties in Mecklenburg-Western Pomerania were not available before 2008; therefore, those counties were excluded. *Data*: State Statistical Offices, Statistical Offices in Saxony, Brandenburg, Mecklenburg-Western Pomerania and Thuringia (2017).

Next, instead of using the total expenditures on county roads as the input variable, I use the capital stock of county roads to calculate the efficiency scores. Table 10 presents the results along with a comparison of the results when using total expenditures.

TABLE 10. RESULTS OF THE EFFICIENCY ANALYSIS USING AN ALTERNATIVE INPUT

Model	*Obs.*	*Min.*	*Median*	*Std. Dev.*	*Efficient*	*% efficient*	*Correlation with three-year average results*[b]
I: Output area	40	0.112	0.413	0.265	4	10%	0.76
J: Output area and accidents[a]	40	0.112	0.464	0.285	9	23%	0.82
K: Output area and condition	21	0.112	0.562	0.270	4	20%	0.78

Notes: This table shows the results of the efficiency analysis (DEA) with input orientation and variable returns-to-scale using the estimated capital stock of county roads as the input variable and different outputs. a) The number of accidents due to poor road conditions. b) Spearman's rank correlation coefficient.

Again, the overall results do not differ much from my baseline analysis. The minimum efficiency scores are very similar to the respective models using the three-year average (2011-2013) of expenditures as the input variable. The median efficiency scores, which are between 0.41 and 0.56, still suggest large efficiency reserves. The share of efficient counties is somewhat higher when using the discounted sum of expenditures. The reported Spearman's rank correlation coefficient shows a relatively high correlation with the results using the three-year average of total expenditures, indicating that counties that were identified as more efficient in the model using the alternative input variable are about the same as in by baseline model. To summarize, the results in this section suggest that my approach (which aligns with previous studies) is fairly robust when using an alternative input variable.

7. Conclusion

I show that the definition of an appropriate set of input and output variables plays an integral role in an efficiency analysis, particularly when evaluating sector-specific efficiency and the data are not widely available. First, I suggest considering the differences in the foundations of roads, which has not been done by previous studies. Second, I apply a unique variable to measure the quality of county roads, namely, road condition, which differs from other quality variables. Overall, I find considerable variations in the efficiency scores for the provision of county roads and large efficiency reserves in eastern German counties. I observe very different results when applying quality outputs that were used in other studies. The differences in efficiency rankings are substantial and highlight the sensitivity of the data to the definitions of the input and output variables. When simply analyzing the correlations between efficiency scores and potential determinants of efficiency, such as population density, I find opposite relationships (positive vs. negative) depending on the quality variable that is used. This finding is highly relevant for studies that seek to identify sources of inefficiencies.

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Appendix

TABLE 11. OVERVIEW OF THE SPECIFICATIONS APPLIED AND RESULTS OBTAINED BY PREVIOUS STUDIES ON THE EFFICIENCY OF PUBLIC ROAD PROVISION

Study	*Country*	*Government layer*	*Inputs*	*Outputs*	*Generation*[a]	*Returns-to-scale*[b]	*Input/output orientation*[b]	*Efficiency reserves*[c]
Deller and Nelson (1991)	United States	Municipality	Expenditures on roads	Road length	1^{st}	Variable	Input	65%
Deller and Halstead (1994)	United States	Municipality	Expenditures on roads	Road length	1^{s}	Variable	Input	41%
Rouse et al. (1997)	New Zealand	County	Expenditures on roads	Road length, quality index	2^{nd}	Varia-ble/constant	Input	32%
Kalb (2014)	Germany	County	Expenditures on roads	Road area, accidents	2^{nd}	Variable	Input	36%

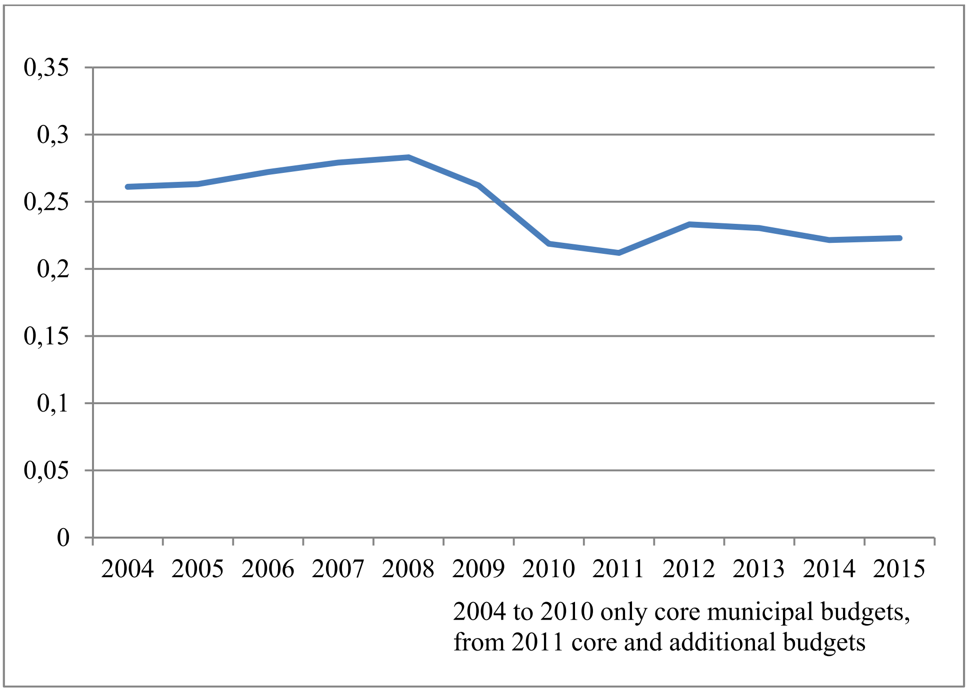
Notes: This table presents a summary of the previous literature on the efficiency of public road provision and includes the methods applied and results obtained. a) The generation of the study according to the classification outlined in section 2. b) The specification used DEA; see section 4.1. c) The efficiency reserves identified by the studies for the median decision-making unit (same output level could be achieved using x% fewer inputs; see also section 4.2. *Source*: The author's representation.

TABLE 12. ROAD INFRASTRUCTURE INVESTMENT AND MAINTENANCE SPENDING IN MILL. EURO (AND SHARE OF TOTAL GOVERNMENT EXPENDITURES) IN EUROPEAN COUNTRIES, 1995 TO 2015

	Year									
Country	1995		2000		2005		2010		2015	
Austria	989	1.0%	983	0.9%	1,130	0.9%	949	0.6%	1,147	0.7%
Belgium	218	0.2%	208	0.2%	236	0.1%	532	0.3%	1,235	0.6%
Estonia	31	2.7%	36	1.6%	127	3.3%	175	2.9%	224	2.7%
Finland	1,056	1.8%	1,022	1.6%	1,195	1.5%	1,557	1.5%	1,743	1.5%
France	10,983	1.7%	11,168	1.5%	14,060	1.5%	14,574	1.3%	10,877	0.9%
Germany[a]	10,216	1.0%	11,967	1.3%	10,200	1.0%	11,240	0.9%	11,690	0.9%
Greece[a]	-	-	1,402	2.1%	1,080	1.2%	1,394	1.2%	-	-
Ireland	-	-	998	3.0%	1,818	3.2%	1,579	1.4%	694	0.9%
Italy	9,836	1.9%	16,650	3.0%	21,718	3.1%	9,826	1.2%	-	-
Latvia	12	0.8%	37	1.4%	209	4.5%	244	3.0%	374	4.1%
Luxembourg	137	2.1%	192	2.2%	163	1.2%	216	1.2%	260	1.2%
Netherlands	-	-	2,251	1.2%	2,361	1.0%	3,509	1.2%	-	-
Portugal	862	2.3%	1,089	2.0%	2,289	3.1%	1,613	1.7%	-	-
Slovak Republic	78	0.8%	294	1.8%	460	2.3%	517	1.8%	1,335	3.7%
Slovenia	-	-	451	5.2%	549	4.2%	358	2.0%	228	1.2%
Spain[a]	4,263	2.1%	4,792	1.9%	8,580	2.4%	7,854	1.6%	4,183	0.9%
Lithuania	26	1.0%	170	3.2%	290	4.1%	582	4.9%	417	3.2%

Notes: The table presents the expenditures on road infrastructure and road maintenance in mill. Euro and this amount as a percentage of the total government expenditures in European countries for 1995, 2000, 2005, 2010 and 2015 in European countries. a) Data were only available on road infrastructure investment. *Data*: OECD (2017).

FIGURE 3: SHARE OF INVESTMENTS IN THE CATEGORY "ROADS" TO TOTAL CONSTRUCTION INVESTMENTS IN GERMAN STATES AND MUNICIPALITIES FROM 2004 TO 2015



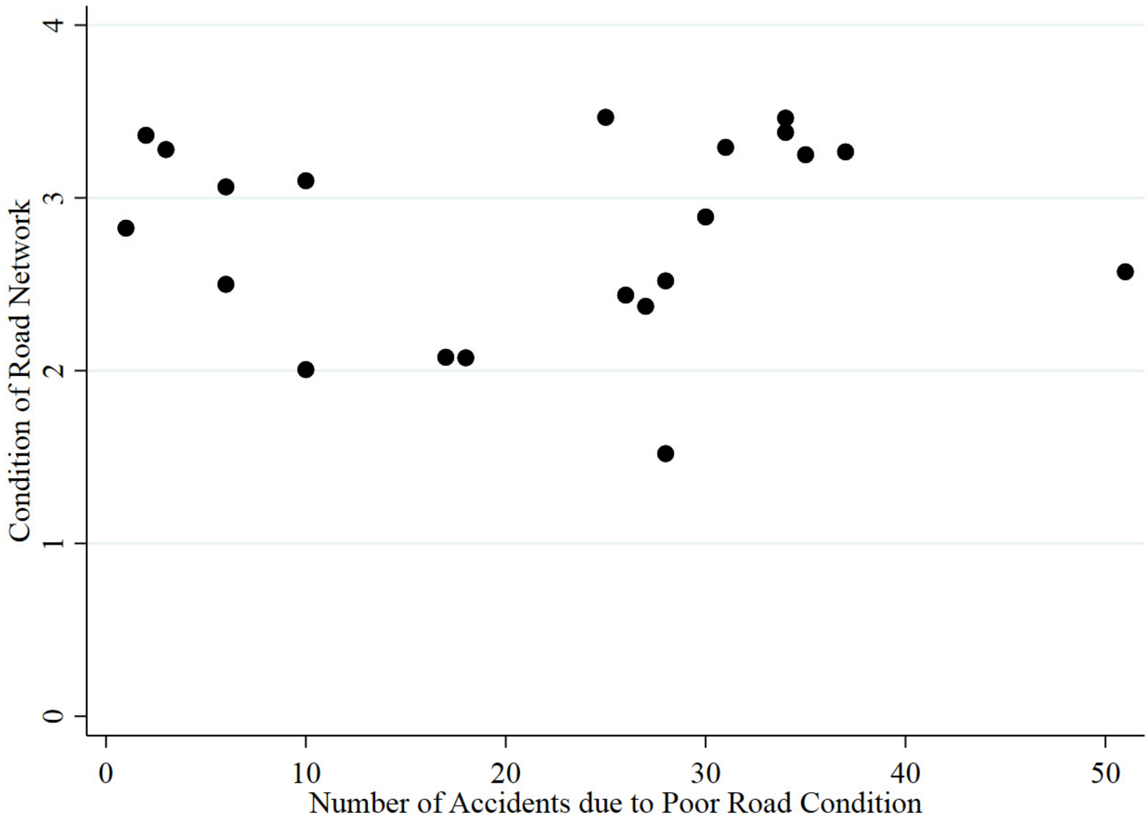
Notes: This figure shows the development of the share of investments in the category "roads" to total construction investments in German states (excluding city states and municipalities from 2004 to 2015). The slight decrease in the share of investments on roads might be explained by the overall completion of road infrastructure projects and tighter budgets. Unfortunately, data on expenditures at the county level for all of Germany was not available but can be assumed to follow a similar pattern. *Data*: Federal Statistical Office (2017b).

TABLE 13. OVERVIEW OF EMPIRICAL STUDIES ON THE ECONOMIES OF SCALE IN PUBLIC ROAD PROVISION

Study	*Country*	*Government Layer*	*Returns-to-scale*[a]
Borcherding and Deacon (1972)	United States	State	+ / 0
Deller and Nelson (1991)	United States	Municipality	+
Deller and Halstead (1994)	United States	Municipality	+
Kraus (1981)	United Kingdom	State	+
McGreer and McMillan (1993)	Canada	Municipality	-
Pommerehne (1978)	Switzerland	Municipality	-
Pommerehne and Frey (1976)	Switzerland	Municipality	-
Santerre (1985)	United States	Municipality	0

Notes: This table presents an overview of empirical studies measuring the economies of scale in the provision of public roads. a) + indicates increasing returns-to-scale were identified; 0 indicates constant returns-to-scale were identified; and - indicates decreasing returns-to-scale were identified. *Source*: The author's own representation, following Reiter and Weichenrieder (2003).

FIGURE 4: SCATTER PLOT FOR DIFFERENT QUALITY VARIABLES



Notes: This figure shows the scatter plot for two quality variables, namely, the condition of the road network and the number of accidents due to poor road conditions.

TABLE 14. CORRELATION COEFFICIENTS BETWEEN QUALITY AND QUANTITY OUTPUTS

	Quantity output area	Quality output accidents	Quality output condition
Quantity output area	1.00		
Quality output accidents	0.35	1.00	
Quality output condition	-0.30	0.05	1.00

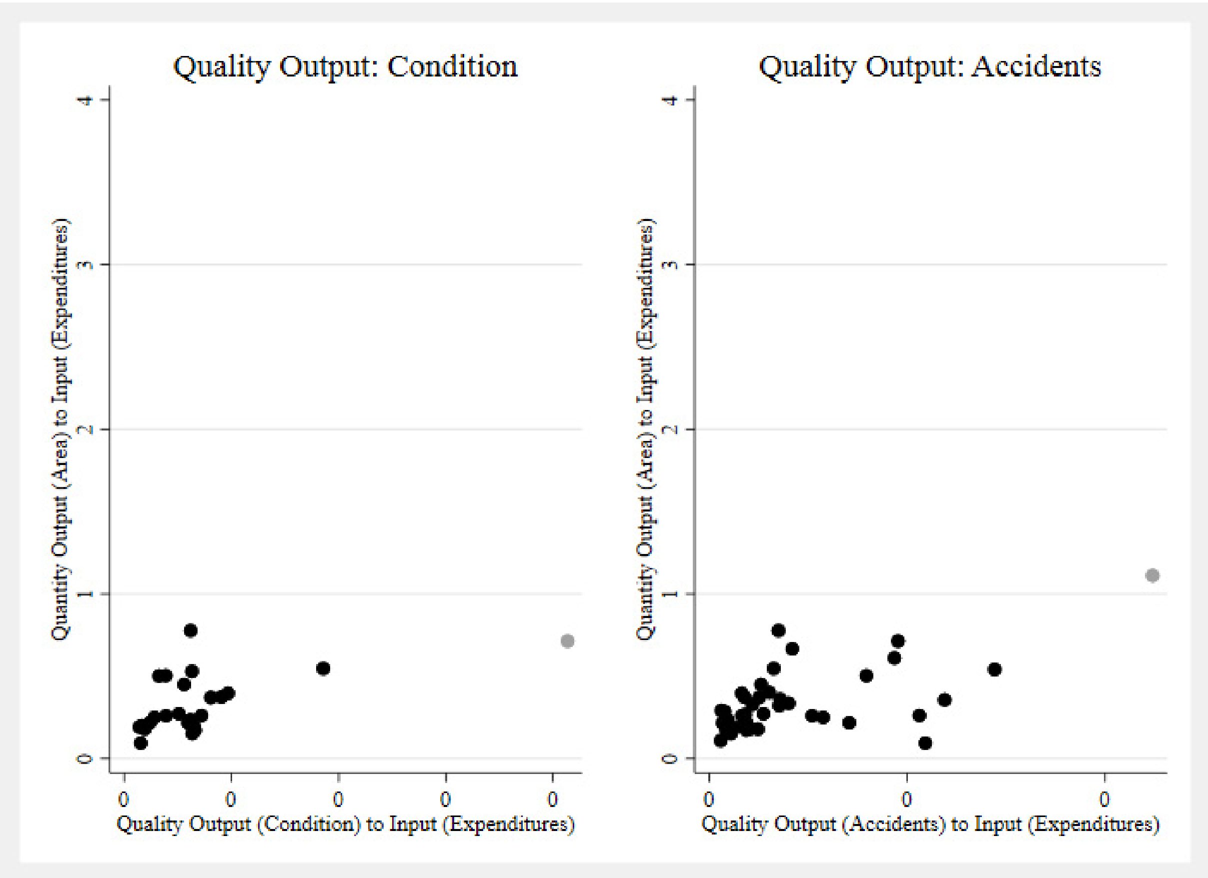
Notes: This table shows the Pearson correlation coefficients between the output variables used. The low correlation between quantity and quality outputs highlights the need for the inclusion of both in efficiency analyses (see Rouse et al. 1997).

TABLE 15. DESCRIPTIVE STATISTICS OF THE SUBSAMPLES USED IN EACH MODEL

Model	*Number of observations*	*Mean population*	*Mean population density*[b]	*Mean expenditures on county roads*[c]	*Mean area of road network*[d]	*Mean number of accidents*[e]	*Mean condition of county roads*[f]
A: Output area	47	164,966	105	6,353,496	1,743,684	(24)[e]	(2.9)[e]
B: Output area and accidents[a]	40	158,557	112	6,323,384	1,499,816	24	(2.8)[e]
C: Output area and condition	23	178,003	117	7,545,816	2,019,189	(22)[e]	2.9

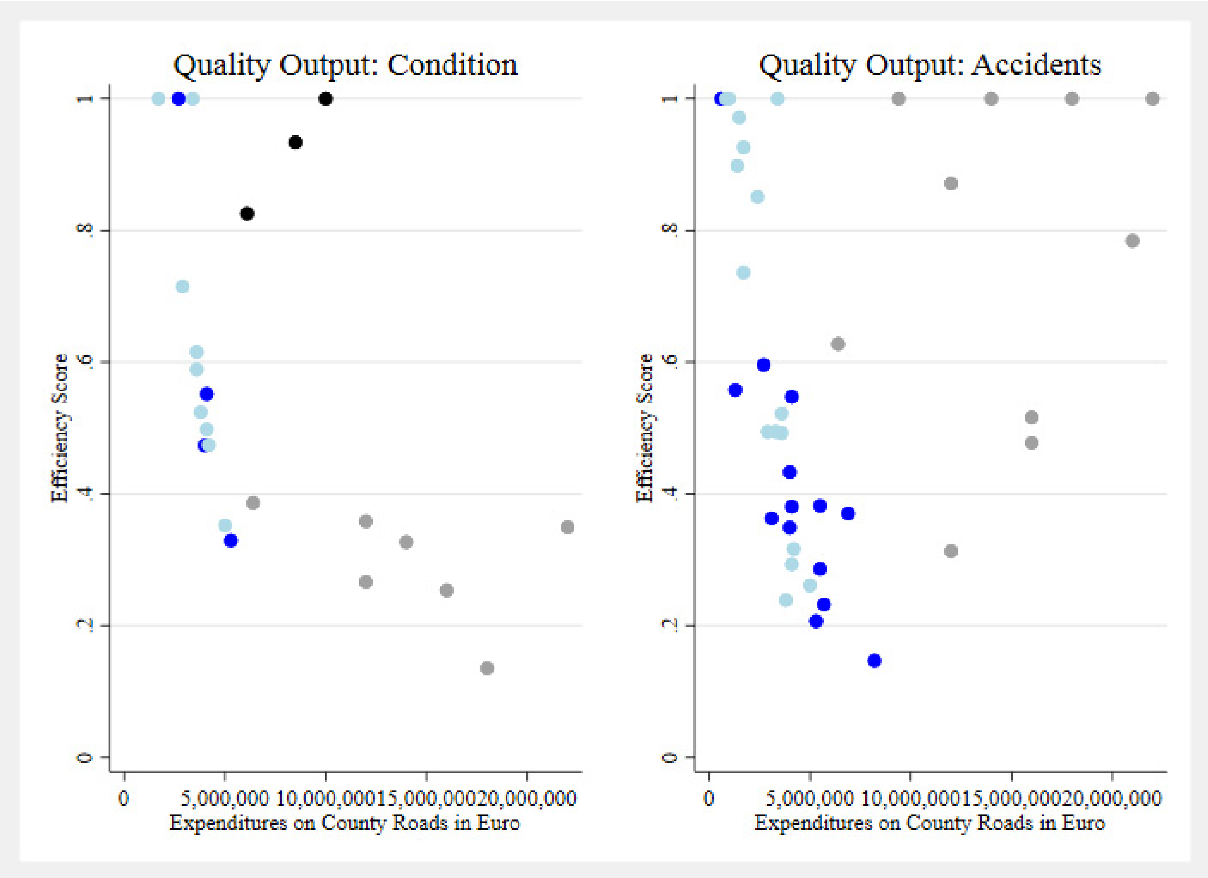
Notes: This table describes the data set. Urban counties are excluded. a) The number of accidents due to poor road conditions. b) The average inhabitants per square kilometer. c) The mean construction and maintenance expenditures on county roads in € from 2011 to 2013. d) The area of the county road network in square meters; some data were calculated using the average width of country roads (5.2 m) when data were only available on the length of county roads. e) The condition of county roads is classified by a grading system from 1 to 5 where 1 represents the best condition; the data have been inverted to match the setting of efficiency analysis (the higher the variables, the higher the efficiency). f) This includes only counties for which data were available. *Data*: Statistical Offices in Saxony, Brandenburg, Mecklenburg-Western Pomerania and Thuringia (2017), Statistic Departments of the Federation and the Federal States (2017), and Building authorities (*Bauämter*) in eastern German counties (2015).

FIGURE 5: SCATTER PLOTS OF SAMPLE WITH OUTLIERS



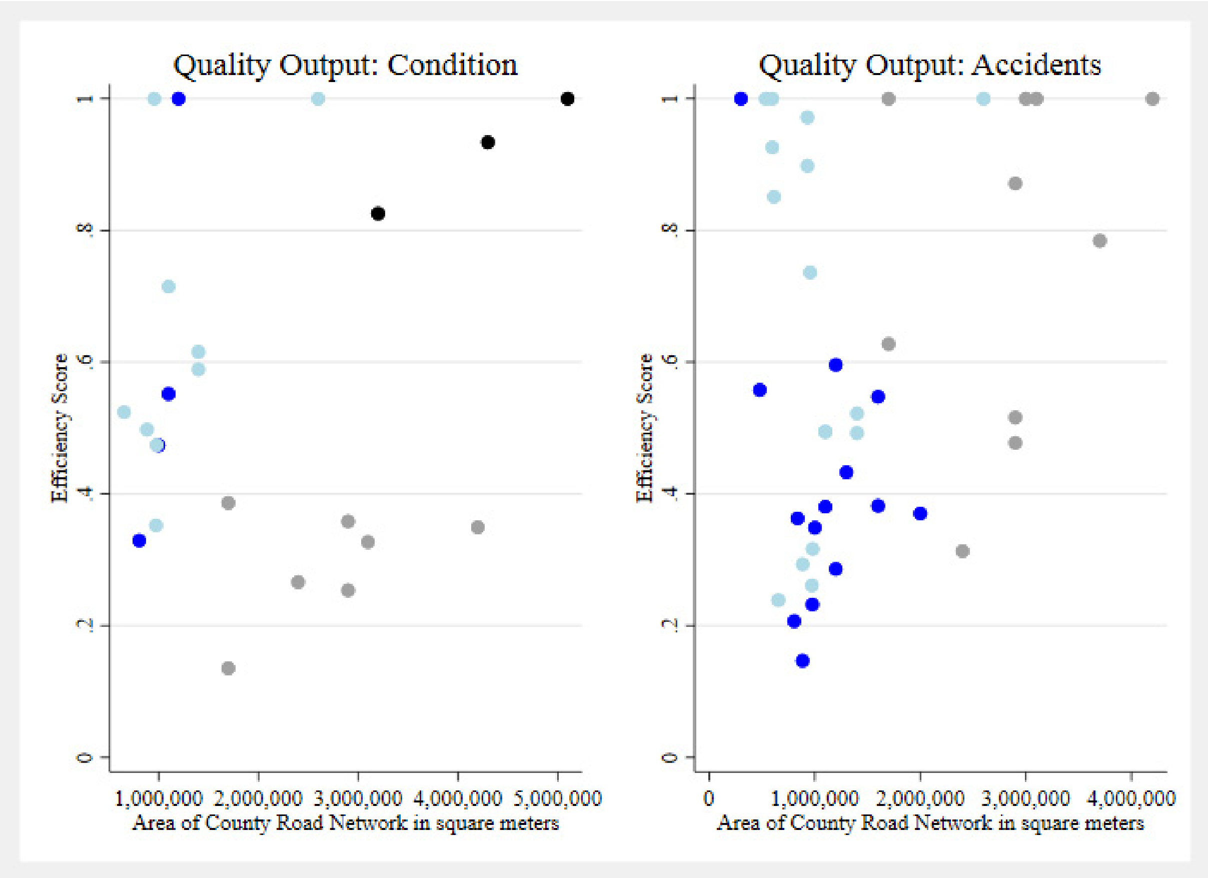
Notes: This figure shows the distribution of counties included in the sample when outliers are excluded. The left figure shows the ratio of the area of the road network (quantity output variable) to the expenditures on county roads (input variable) in relationship to the ratio of the condition of the road network (quality output variable) to expenditures. The right figure does the same but uses the number of accidents as the quality output variable. Black data points are included in my empirical analysis, and gray data points have been eliminated.

FIGURE 6: COMPARISON OF EFFICIENCY SCORES RELATIVE TO EXPENDITURES WHEN USING DIFFERENT QUALITY OUTPUTS



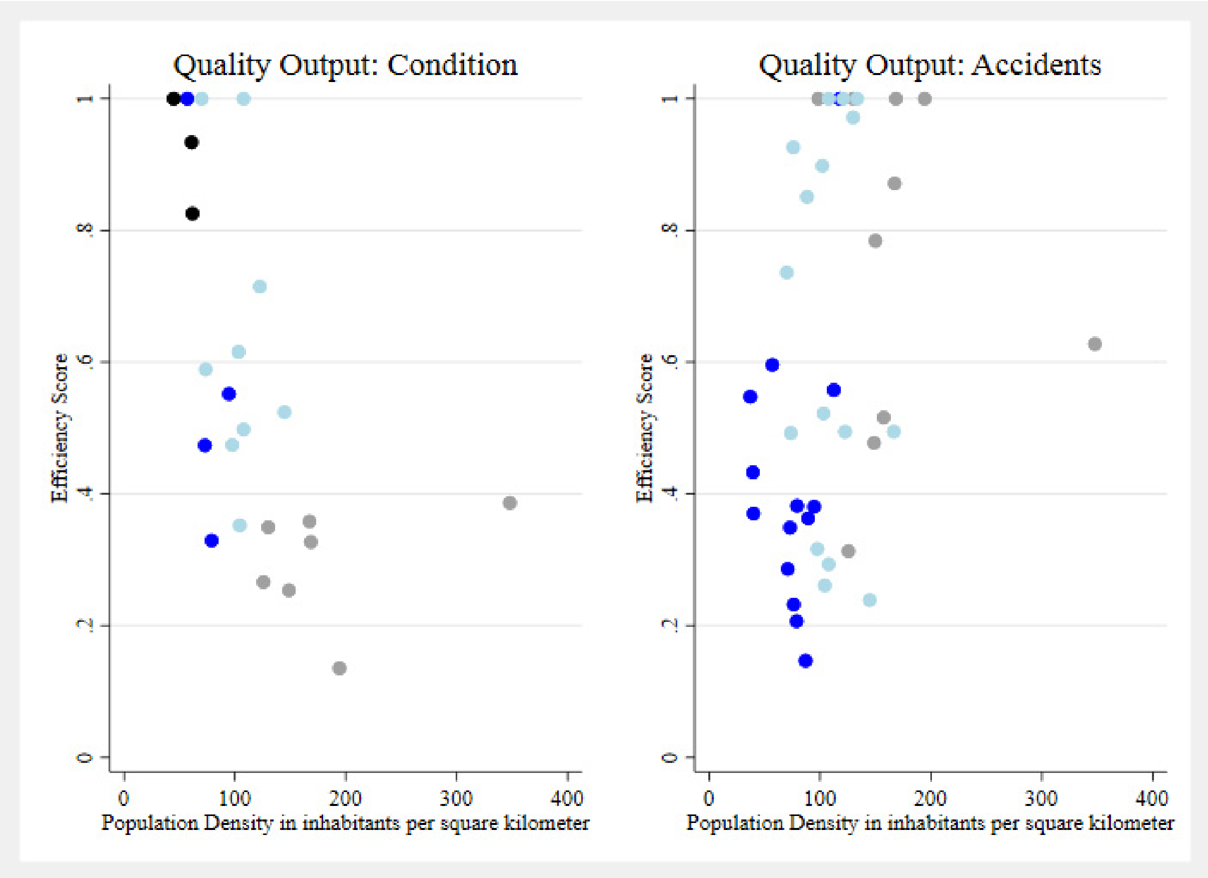
Notes: This figure shows the distribution of counties included in the sample when using either the condition of the road network (left hand side) or the number of accidents as one output variable (right hand side). Black data points represent Mecklenburg-Western Pomerania, gray data points represent Saxony, light blue data points represent Thuringia and dark blue points represent Brandenburg.

FIGURE 7: COMPARISON OF THE EFFICIENCY SCORES RELATIVE TO THE AREA OF THE ROAD NETWORK WHEN USING DIFFERENT QUALITY OUTPUTS



Notes: This figure shows the distribution of counties included in the sample when using the either the condition of the road network (left hand side) or the number of accidents as one output variable (right hand side). Black data points represent Mecklenburg-Western Pomerania, gray data points represent Saxony, light blue data points represent Thuringia and dark blue points represent Brandenburg.

FIGURE 8: COMPARISON OF THE EFFICIENCY SCORES RELATIVE TO POPULATION DENSITY WHEN USING DIFFERENT QUALITY OUTPUTS



Notes: This figure shows the distribution of counties included in the sample when using the either the condition of the road network (left hand side) or the number of accidents as one output variable (right hand side). Black data points represent Mecklenburg-Western Pomerania, gray data points represent Saxony, light blue data points represent Thuringia and dark blue points represent Brandenburg.

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