DISCUSSION PAPER SERIES

No. 4319

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Guido Friebel, Marc Ivaldi
and Catherine Vibes

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ISSN 0265-8003

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Guido Friebel, Université de Toulouse (EHESS, IDEI) and CEPR
Marc Ivaldi, Université de Toulouse (EHESS, IDEI) and CEPR
Catherine Vibes, Université de Toulouse

Discussion Paper No. 4319
March 2004

Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

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CEPR Discussion Paper No. 4319

March 2004

ABSTRACT

Railway (De)Regulation: A European Efficiency Comparison*

Many European countries have sought to increase the efficiency of national railroad companies through a range of reforms: separating infrastructure and operations, creating independent regulatory institutions and providing access to the network to third parties. To estimate the effects of reforms on railroad efficiency, we investigate a new World Bank panel dataset that covers many EU countries over a period of 20 years. We compare the passenger traffic efficiency of national railroad companies by means of a production frontier model and evaluate the effects of reforms on efficiency. We find that reforms have efficiency-increasing effects but that the effect of reforms depends on sequencing: the introduction of multiple reforms in a package has at best neutral effects, but sequential reforms improve efficiency. Using the LISREL technique, we find that our results are robust against potential problems of endogeneity.

JEL Classification: C23, D24, L51 and L92
Keywords: network industries, panel data analysis, passenger and freight traffic and production frontier

Guido Friebel
EHESS, IDEI
Université des Sciences Sociales
Place Anatole France
31042 Toulouse Cédex
FRANCE
Tel: (33 5) 61 12 86 05
Fax: (33 5) 61 12 86 37
Email: friebel@cict.fr

Marc Ivaldi
EHESS, IDEI
Université des Sciences Sociales
Place Anatole France
31042 Toulouse Cédex
FRANCE
Tel: (33 5) 61 12 85 92
Fax: (33 5) 61 12 86 37
Email: ivaldi@cict.fr

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Catherine Vibes
GREMAQ and MPSE
Université des Sciences Sociales
Place Anatole France
31042 Toulouse Cédex
FRANCE
Email: catherine.vibes@univ-tlse1.fr

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*This Paper is produced as part of a CEPR-managed Research Training Network on 'Competition Policy in International Markets', funded by the European Community's Human Potential Programme under EC contract HPRN-CT-2002-00224 (CPIM). We thank Lou Thompson for providing us with the dataset and his generous help in using it. We are also grateful for comments of participants at a seminar in Toulouse, at the 8th European Workshop on Efficiency and Productivity Analysis in Oviedo, the 1st Conference on Railroad Industry Structure, Competition and Investment, Toulouse 7th and 8th November 2003, and at a workshop at Humboldt University Berlin. We also thank Tim Coelli, Markus Ksoll, Paul Seabright and Klaus Vestner. IDEI receives research grants from a number of corporate sponsors including Deutsche Bahn. The views expressed in the Paper and any remaining errors are solely the ones of the authors.

Submitted 01 March 2004

1. Introduction

By the end of the 20th century, railroads were in dire straits. Most national railways companies were heavily subsidized (Crozet et al., 2000, Friederiszick et al. 2003), but railway market shares in total (intermodal) transportation were, at best, stable. In many European countries, rail market shares decreased throughout the nineties (European Commission, DG Energy and Transport, 2002). Moreover, surveys show that customer satisfaction with railway services was low in many countries (INRA, 2000).

The European Commission, in its White Paper (EC, 2001), declared the development of the European railway system a priority for achieving sustainable development in Europe with the explicit goals of promoting railways, increasing their market share, and reducing subsidies. Based on the experience in a number of countries throughout the 1980s and 1990s, the cornerstones of the EC reform model (EC, Directive 91/440) were: a) to unbundle infrastructure from operations, that is, to separate them fully or, at least, create separate organizations and accounts within one holding, b) to create independent regulatory institutions for railways, c) to open access to national railway markets for competitors ("third party access").

There is a firm believe among many policy-makers, on both EU and national level, that these reforms ought to increase efficiency. But, while there is a substantial literature on efficiency in the railway industry (Cantos et al. 1999, Cantos et al. 2000, Coelli and Perelman, 1999, Cowie and Riddington, 1996, Gathon and Perelman, 1992, Oum and Yu, 1994), little is known about how regulatory reforms have affected railway efficiency. We are only aware of two papers. Cantos et al. (1999) analyze the impact of four types of reforms on different dimensions of railway efficiency. They look at separation between infrastructure and operations, changes in the legal constitution of companies, degree of regulation of prices, and degree of government influence over investment. They find that vertical separation appears to have had the strongest impact. However, construction of their regulatory variables does not allow using variations over time, but only across countries. Gathon and Pestieau's (1995) cross-sectional study indicates that constraints on managerial autonomy may reduce the efficiency of railway firms.

In this study, we investigate systematically to what extent third-party access, independent regulation, and separation of infrastructure have affected railway performance. This is not only interesting to better understand the determinants of railroad performance, but also to learn more about the effect of deregulation on industry performance in more general terms. To our knowledge there exist no comparable studies for other network industries.

One reason is that it is rare that there is enough cross-country variation and variation over time to disentangle reform effects from other influences. But, in railroads, different countries have implemented the reforms to different degrees and at different times. It is hence possible to identify the impact of regulatory regimes on railway performance by applying the production frontier approach, pioneered by Farrell (1957), on a new Worldbank (2001) panel dataset that provides input and output data for twelve European countries, over the period 1980-2000. We match this dataset with information about regulatory reforms in these countries and look at the impact of reforms on the efficiency in passenger traffic.

The paper has contributions on different levels. The first two are of rather technical nature: We, first, control for the congestion effects of freight traffic on the efficiency of passenger traffic, and second, for the potential endogeneity of explanatory variables and reforms by investigating the structure of the variance-covariance matrix, using the LISREL technique.[5] Third, we look at the effects of reforms and fourth, present efficiency measures for the twelve countries in our panel.

The main results are as follows: First, on average, if freight traffic increases by one percent, passenger traffic decreases by two and half tenth of a percent, a value larger than what is usually assumed in comparable studies. Second, there does not seem to be endogeneity of the explanatory variables. Third, reforms increase efficiency, that is, railroad performance would have, *ceteris paribus*, been lower in the absence of reforms. In particular, we find that while it is always efficiency enhancing to implement one reform, the effect of a larger number of reforms depends on sequencing. The introduction of multiple reforms in a package has at best neutral effects, but sequential reforms improve efficiency. It is also noteworthy that our regressions cannot identify that full separation of infrastructure from operations is a *conditio sine qua non* for railroad efficiency. Fourth, the development of efficiency overtime has been quite different across different countries. In general, smaller country railroads have had a more favorable efficiency development than larger countries. (Small and large are here measured in terms of network length). Among larger countries, only Sweden and Germany have been able to increase their railroad efficiency, both concerning passenger and total (that is, passenger and freight) traffic, throughout the period of observation (1980-2000).

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[5] This technique was introduced by Jöreskog (1973) and used in a similar context before by Ivaldi et al (1995).

Section 2 presents the data. Section 3 introduces the econometric model and looks at endogeneity. Section 4 presents results, constructs and compares efficiency measures. Section 5 discusses why sequencing may matter and how our results relate to experience from other network industries. Section 6 concludes.

2. The Data

The Worldbank (2001) data set comprises coherent and complete input and output information on railway industries of twelve EU countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden. Data cover 1980 to 2000, the period in which all reforms in the railroad sector have occurred in Europe.

Unfortunately, data for United Kingdom are not complete. In particular, as a result of the reforms, there is no consistent information about staff of railroad firms for the period from 1995 to 2000. National statistics in UK after the reform of the railways changed: People who formerly were counted as railway staff since then belonged to other industries like the construction industry or consulting. Therefore the official number of employees in the railway industry is much lower than it would be on a comparable basis. This makes it hard to evaluate railroads efficiency in the most interesting period and we will thus have to exclude UK from many of our regressions.

Table 1 provides an overview of the data. In terms of output we will look at *passenger kilometers* and *freight ton kilometers*. Table 1 reports means per country over the investigation period, showing that, in most countries, both outputs have increased in absolute values.

In the case of railroads, it is difficult to identify the correct input measures. Railroads are often integrated firms. The intermediate input "network" is produced by the inputs labor and land. This intermediate input network, additional labor, and rolling stock are then used in the production of the final outputs, *passenger-kilometers* and *freight-ton-kilometers*. The last column represents the measure for labor, *staff*, employed by railway carriers. In the regression this variable will be labelled L_{it}.

To find the right measure of capital input is not so easy a task. There are two problems: First, rolling stock can be interpreted both as input or output. At given labor and finance input, for instance, a company can decide to produce more passenger kilometers with old rolling stocks or higher quality traffic with new rolling stock. Similarly, a company can decide to build new faster or better tracks. In order to avoid this potential confusion between inputs and outputs, we focus on *route kilometers* as the second input besides *staff*. Route kilometers measure the total size of the network without taking into account whether a given connection has single, double or multiple tracks. They thus have the convenient feature to be clearly inputs, not outputs: In the mature networks of European countries, only few new routes are built. Actually, throughout the period we are interested in, route kilometers have decreased rather than increased in most countries. In the regressions, route kilometers are labelled K_{it}.

We have matched these physical data with information about reforms. Table 2 presents these deregulation data. It reports the year in which regulatory reforms were introduced and stems from a variety of documents: Erasmus University (1999), SORT-IT (1999), OECD (1998), Stoffaes et al (1995), Prognos (1998). The data have the advantage to capture the effects of regulatory changes both over time and across countries. They have the disadvantage that they report the state of national laws, and not the implementation of these laws. Moreover, there are many reform specificities across countries. There are thus certain limits concerning the extent to which one can interpret the results. We discuss these issues further in the next section.

3. Econometric specification and endogeneity

The frontier production function specifies what output can be achieved, if all decisions were taken according to "best practice". As the frontier production function defines a theoretically achievable optimum, all empirical observations must lie below it. Consider the Cobb-Douglas function:

$$y = AK^{\alpha_K} L^{\alpha_L}.$$

In our regressions, output *y* is either passenger kilometers, or the weighted sum of passenger and freight kilometers. Inputs are route kilometers (*K)* and staff (*L*). The production function is linear in the logs of the inputs. Thus, the log of the output variable can be expressed as the following function:

$$\ln y = A + \alpha_K \ln K + \alpha_L \ln L.$$

As we use a panel data set, we account for individual (country-) fixed effects and time trends through the introduction of effects of railway deregulation. Thus, for country *i* at time *t*, we assume that:

$$A_{it} = \alpha + (\gamma_i + \theta_0 Deregulation_{it})t + \varepsilon_{it}$$

The term $(\gamma_i + \theta_0 Deregulation_{it})$ represents technological progress. It may differ across countries (and is thus indexed by i). Moreover the country specific trend may depend on whether or not a country has reformed its railroad industry. We here introduce a dummy variable $Deregulation_{it}$ that takes value 1 if a country has introduced (and maintained) at least one of three reforms we look at. At this stage we do not distinguish types or intensity of reform, which we will do in other specifications, below.[6] The other components of the expression are an intercept and a normally distributed noise term.

The equation we estimate is then:

$$\ln y_{it} = \alpha + \alpha_K \ln K_{it} + \alpha_L \ln L_{it} + (\gamma_i + \theta_0 Deregulation)t + \varepsilon_{it}. \qquad (1)$$

3.1 Output measures: total traffic versus passenger traffic

We are mainly interested in the efficiency of passenger transport. Nonetheless, as we have no information about how capital and labor are allocated for the production of passenger and freight traffic, we must control econometrically for the effect of freight transportation on passenger traffic efficiency. In order to do so, we estimate Equation (1), using an aggregate output measure defined as

$$\ln y_{it} = \ln passkm_{it} + \lambda \ln tonkm_{it} \qquad (2)$$

In what follows, we use $\hat{\lambda}$, the estimate of λ that provides the best fit of the model, or to be more precise, the $\hat{\lambda}$ that minimizes the fit function for Equation (1). For different specifications, $\hat{\lambda}$ lies between 0.24 and 0.27. That is, on average, if freight traffic increases by one percent, passenger traffic decreases by two and half tenth of a percent. The advantage of our method is that we receive an empirical measure for the congestive effects of freight on passenger traffic, rather than using *ad hoc* measures. Other studies

[6] One could, alternatively, use a different type of specification in which deregulation would not enter multiplicatively with time, but, rather, a term $\theta_0 Deregulation_{it}$ would be added to the constant. This, however, would not take into consideration that the effects of reforms shift the slope of the trend and not only the level.

have assumed, for instance, that each passenger equals a certain fixed weight of freight, specifically 80 kilograms. According to our estimate, the congestion effect owing to freight is higher.[7]

3.2 Endogeneity and LISREL estimates

In our data set and with the specification we use, there is a potential problem of endogeneity: while we control for individual (country-level) effects, we can *a priori*, not exclude correlations of these individual effects with inputs (capital, labor). If there were such correlations, the regression results and the measure for efficiency, which is based on the error terms of the regression, would be biased.

We use the LISREL ("Linear Structural Relations")[8] method to verify whether or not this type of correlation is present in the data. LISREL has the convenient feature of estimating all possible correlations between inputs and individual effects and hence, for our case, between input quantities and individual technical efficiency levels. In Appendix 2, we briefly discuss the method.

Table 6 summarizes the results of the LISREL analysis. By looking at the covariances of different variables and at their associated t-values, it becomes clear that there is no correlation between variables. The results of our regressions are thus unbiased.

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[7] It should be noted that while our method has advantages over using *ad hoc* aggregation weights, there are some methodological issues associated with aggregating multi-product outputs to a single output (see Alvarez and Orea (2001) for a discussion of the caveats of aggregation to a single output). Note that it is however not our objective to estimate the full production possibility set (PPS), and that equation (2) is not an approximation of this PPS. Rather it is a point on the "true" unobserved PPS at which we investigate inefficiency. By using eq. (2), we are only able to compute inefficiency level of the passenger service conditional on the actual level of freight service. Identifying the full PPS is a research topic beyond the scope of this paper.

[8] See Jöreskog (1973, 1996).

4. Regression results and efficiency comparison

In what follows we present and discuss OLS estimates. These are also used to construct efficiency measures.

4.1 Results

Table 3 presents the regression results. We have run the regression both including and excluding United Kingdom. The dependent variable is aggregated output as defined in Equation (2). The parameter estimates for labor and capital are in line with what could be expected for a network industry like railroads. As $\alpha_K + \alpha_L > 1$, there are increasing returns to scale. Note also that in all countries except Finland, the productivity trend is positive. The regression shows that, excluding United Kingdom, deregulation increases the productivity trend of a country at the 7% level of statistical significance.[9] In terms of magnitude of output changes, this corresponds to an additional output of on average 0.4 percent per year after deregulation.[10]

These effects are less significant when one includes United Kingdom. This points to the problem with United Kingdom data. With the beginning of reforms, data quality for United Kingdom has declined, and data for staff since 1995 are missing. In what follows we thus run most regressions without United Kingdom.

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[9] As an example, total productivity for Austria changes from 0.01 to 0.014, for Germany from 0.02 to 0.024, and for France from 0.05 to 0.054, after introduction of deregulation.

[10] To compute the magnitude, we first write output as $y = AK^{\alpha_K} L^{\alpha_L} e^{\theta Deregulation t} e^{\gamma t} e^{\varepsilon}$. To measure of the effect of deregulation dummy on output, we compute $E(y / Deregulation = 1, t+1) - E(y / Deregulation = 1, t)$. Notice that as $\hat{\theta}_0$ is normally distributed with mean θ_0, $e^{\hat{\theta}_0}$ follows a lognormal distribution with mean: $E(e^{\hat{\theta}_0}) = \exp(\hat{\theta}_0 + \frac{1}{2}\hat{\sigma}_{\hat{\theta}_0}^2)$.

The first regression shows that reforms have affected railroad productivity in a positive way. In order to see whether more reforms are better than one reform, we have constructed a second set of reform variables: $DeregulationOneAspect_{it}$, which takes the value 1 when one and only one aspect of the deregulation is implemented, whatever happens later, and 0 otherwise. $DeregulationTwoAspects_{it}$, which takes the value 1 when exactly two aspects of the deregulation are implemented and 0 otherwise. Both inter multiplicatively with time, as for *Deregulation* before.

The results presented in Table 4 show that the implementation of only one aspect of the deregulation has a positive effect on the productivity trend of a country, whereas the effect of the implementation of two aspects is neutral.

The fact that two reforms do not improve productivity compared to no reform is discomforting. However, it is important to notice that the group of countries with two reforms is very heterogeneous. In some countries (Austria, Finland, Italy, Spain, Sweden), the two reforms (not necessarily the same across countries) were implemented sequentially. In other countries (France, Germany, The Netherlands, Portugal), both were implemented at the same time, as a "package". To get some idea of whether sequencing matters, we define a new set of variables that allows to distinguish the types of reform: $DeregulationPartial_{it}$ takes the value 1 if a reform is implemented, and no further reforms take place, and 0 otherwise. $DeregulationSequential_{it}$ takes the value 1 if a reform is implemented, and it is followed by further reforms, and 0 otherwise. $DeregulationPackage_{it}$, takes the value 1 if more than one reform are implemented by the same time, 0 otherwise.

The results in Table 5 indicate that there is a difference in implementing a given number of reforms in one blow or gradually. Both partial and sequential reforms have a positive sign, while package reforms are dominated.

Two comments arise. First, package reforms have a neutral effect when one excludes United Kingdom, but the effect becomes negative under inclusion of United Kingdom. This does not only stress again that the lacking United Kingdom data are complicating our analysis, it also points to a more important limitation of interpreting the parameter estimates of the reform variables. The results must be taken with a grain of salt, as the variable *DeregulationPackage* entails countries that have quite different models of reforms and different railroad specificities. For instance, while both France and Germany introduced the same reforms into their law books (some unbundling of infrastructure and operations, third party access), the implementation of these reforms have differed largely. In Germany the possibility of third-party access has led to entry of many new competitors, while no new competitors have entered the French market. To a similar extent, the implementation of infrastructure separation has been quite different in Germany from the one in France. While Germany chose an organizational solution in which infrastructure and operations remain in the same holding, France decided to create a separate infrastructure company that is not under the purview of SNCF. However, track allocation and management have been contracted back to SNCF. This example illustrates how difficult it is to operationalize empirically different types of reform implementation.

Second, to investigate the effect of different types of implementation of infrastructure separation, we have regressed output on these two different types of implementation. We use institutional work (Prognos, 1998) that classifies countries according to organizational or institutional types of infrastructure separation (see Table 9). Countries that have opted for organizational separation have created separate bodies and separate accounting, but retain them under the umbrella of one holding infrastructure. Other countries have created two (or more) independent institutions.

Controlling for these two different types of reform and looking at efficiency (results are available on request), we find that there is no significant difference between no separation at all and organizational separation. Full (or institutional separation) has a positive effect on efficiency, but only when one excludes UK. Our model can thus not identify that institutional separation of infrastructure from operations is a *conditio sine qua non* for railroad efficiency.

With the current data, one can unfortunately not go much further in investigating the role of different types of implementation of reforms. The regression results do, however, indicate that there is a need to measure implementation in order to evaluate policy reforms in a comprehensive way.

4.2 Efficiency

Using the regression results, we now investigate the development of railway efficiency in Europe. We construct the efficiency (performance) measure for total (passenger and freight) traffic as follows.[11] Using $\hat{\alpha}, \hat{\alpha}_K, \hat{\alpha}_L, \hat{\lambda}, \hat{\theta}_0, \hat{\gamma}_i$, the parameter estimates, the logarithm of the observed values for capital, labor, and the values for deregulation and time for each country, we compute the estimate of the logarithm of output for country *i* at time *t*. Deducting this estimate from the realized value for the respective country yields

[11] The method is explained in more details in Gathon (1991).

the residual of the regression, ε_{it}. We then rank the residuals and denote as $\varepsilon_t^{\max}$ the highest residual in year t.[12] We then express the performance of all other countries compared to the country with the highest performance by the following measure:

$$Eff_{it} \equiv \exp(\varepsilon_{it} - \varepsilon_t^{\max}) \qquad (3)$$

The residual here measures the part of the output of a country *i* at time *t* that cannot be captured by the estimates of the productivity parameters of the Cobb-Douglas function. Notice that these productivity parameters do not vary over time. Variations of output that cannot be explained by variations of inputs or productivity trends can in principle be owing to regulatory regimes. We control for these influences. Variations may also be owing to different types of implementation of reforms, and, in particular, to different degrees of managerial efficiency, both of which we do not control for. Notice that the efficiency measure takes the value 1 (or 100%) for the country with the highest performance in the year *t*.

Tables 7a and 7b present the results for smaller and larger countries separately, taking into account total railways transportation, that is, both freight and passengers. Tables 8a and 8b show the efficiency for passenger traffic only, computed as follows:

$$PassEff_{it} \equiv \exp(\varepsilon_{it} - \varepsilon_t^{\max}) + \hat{\lambda}(\ln tonkm_{it} - \ln tonkm^{\max}) \qquad (4)$$

The first term on the right hand side represents total traffic efficiency, and the second term represents the impact of freight transportation. As the value in the parenthesis is negative, we thus correct total efficiency by the relative level of freight efficiency of a

[12] The residual here measures the part of the output of a country *i* at time *t* that cannot be captured by the estimates of the productivity parameters of the Cobb-Douglas function. Notice that these productivity parameters do not vary over time. Variations of output that cannot be explained by variations of inputs or productivity trends must thus be either due to regulatory regimes, which we control for, or different degrees of efficiency.

country. Thus, only if a country is both most efficient in terms of freight *and* passenger traffic, it shows a 100% efficiency degree in Tables 7a and 7b.

We have plotted country efficiency levels in different ways. Figures 1 and 2 look at the efficiency development of countries over time, for total and passenger traffic, respectively. The depicted efficiency levels are computed relative to the period in which the country reached its highest efficiency level.

It appears that the development is quite similar for both types of traffic (efficiency levels across the two types of traffics turn out to be highly correlated). While smaller countries, except for the Netherlands, have been able keep or raise their efficiency levels, among larger countries only Sweden and Germany have been able to increase their efficiency, and Spain has been roughly stable.

In Figures 3 and 4 we normalize the sum of all country efficiency levels to 100%. The graph allows comparing the efficiency level of different countries. The component on top of each bar represents the sum of efficiency levels of all small countries. The following components of the bar represent the shares of Sweden, Spain, Italy, Germany and France in the sum of all country efficiency levels. For example, we notice that in 1999, Germany is relatively more efficient than the other countries. Moreover, we see that the relative efficiency of Germany increased from 1993 to 1999, and decreases in 2000. This does not necessarily mean that Germany starts to become "less efficient" in 2000: Germany may continue to be more and more efficient, but other countries efficiency gains may be stronger than the ones of Germany.

Figures 5 and 6 show the relative efficiency levels of large countries only, while figures 7 and 8 present the same information, but by averages of five-year periods.

5. Discussion

Our regressions results show that reforms have increased railroad efficiency. This is in line with what has been found in studies on other network industries, in particular airlines. Ng and Seabright (2001) find that in the period from 1990 to 1995, European airline costs could have dropped by as much as 26%, had European airlines been privately owned and subject to the same degree of competition as US carriers. Baltagi et al. (1998) report that airline deregulation in the US resulted in substantial cost savings and a shift towards more efficient technologies.

However, the result needs some qualification. In particular, the effect of reforms depends how they are packaged. When a number of reforms were introduced by the same time, efficiency did not increase. Sequential reforms, however, did improve efficiency. The literature on gradual versus shock reforms (see, for instance, Dewatripont and Roland, 1995) argues that gradual reforms allow a government to learn about the desirability of further reforms in intermediate stages. This is consistent with our finding that gradual reforms have a stronger and statistically more significant effect than partial reforms and that both are better than package (shock) reforms. This ranking is consistent with the theory, in which a government may decide to halt reforms when intermediate signals are not encouraging, an option that does not exist when several reforms are implemented in one blow.

Our regressions (see the discussion on page 12) also seem to indicate that reforms "in the books" are not all that matters and that the implementation of reforms is important. This is particular true regarding the separation of infrastructure and operations. Ivaldi and McCullough (2002) present empirical evidence about the potential costs of separation in railroads, and theoretical work, for instance, Vickers (1995) and King (1999) points out that vertical separation in network industries may have both costs and benefits. The experience in Britain has shed further doubt on vertical separation as the centrepiece of reforms in the sector. The separation of infrastructure from operations was motivated on grounds of the experience in the energy industry, but in the meantime, there are doubts that experience can easily be transferred across sectors. As David Willett, the Conservative Party's policy chief put it in an interview with *The Daily Telegraph* (see Rail News and Vies, 2003): "I would not defend the way we carried out the railway privatisation. Rail privatisation was a classic example of taking a model that had worked for one industry and wrongly applying it to different circumstances."

Hence, while our paper shows that the railroad sector seems to be quite sensitive to changes in the regulatory framework, building reform of the railroad industry on a one-size-fits-all model of separation of infrastructure from operations may not be a fruitful way to enhance efficiency.

6. Concluding remarks

This paper has investigated a new panel data set, which we have enriched by information about changes in regulatory regimes over the last twenty years. We find that reforms have had positive impact on output. The efficiency development of European carriers has been quite heterogenous. The LISREL analysis of the variance/covariance structure shows that the results are *not* subject to endogeneity issues. An additional contribution lies in the fact that we have controlled for the effect of freight traffic on passenger traffic efficiency without relying on ad-hoc weights given to freight versus passenger traffic.

Some limitations of our study should be noted. First, owing to data problems, we have not been able to include UK data in most of the regressions. Second, we have to date only been able to look at reforms in the law book, and cannot control for different types and intensity of implementation. Better data are needed to come to a final conclusion about the effect of different policies solution for the deregulation of railways. Third, we have not taken into account that the degree of subsidization is quite different across European countries as Friederiszick et al (2003) have shown. This may have an important impact on our measure of efficiency. Finally, we have only used quantitative measures of output. Quality is an equally important issue and would allow taking into account the effects of reforms on a multi-dimensional set of outcomes.

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APPENDIX 1: Tables

Table 1: Summary statistics

	period	*pass-km (millions)*	*ton-km (millions)*	*route (km)*	*number of employees*
Austria	1980-1989	7410	10770	5751	68976
	1990-2000	8856	13558	5625	59414
Belgium	1980-1989	6565	7709	3742	58017
	1990-2000	7008	7948	3428	42272
Denmark	1980-1989	4489	1656	2318	21908
	1990-2000	4906	1825	2293	15785
Finland	1980-1989	3185	7899	5972	25470
	1990-2000	3243	9182	5867	16253
France	1980-1989	59507	57274	34559	234564
	1990-2000	62058	50858	32378	186959
Germany	1980-1989	63368	115886	41933	534424
	1990-2000	61714	74304	39828	314748
Italy	1980-1989	40148	17649	16225	218337
	1990-2000	47078	21336	16086	142302
The Netherlands	1980-1989	9293	3194	2776	27188
	1990-2000	13970	3062	2773	26417
Portugal	1980-1989	5738	1253	3555	22598
	1990-2000	4906	1908	2113	14831
Spain	1980-1989	15061	10893	13094	65184
	1990-2000	16398	10294	12473	40514
Sweden	1980-1989	6385	16413	11367	32577
	1990-2000	6363	18801	10145	20316
United Kingdom	1980-1989	31816	16972	17013	183637
	1990-94[13]	33096	15612	16551	

[13] ÙK data are missing from 1995 to 2000.

Table 2: Deregulation events (three main aspects)[14]

	separation infra-structure, operations	*third party access*	*independent regulatory entity*
Austria	1997	1995	
Belgium	1998		
Denmark	1997	1999	
Finland	1995	1999	
France	1997	1997	
Germany	1994	1994	
Italy	1998	1999	
The Netherlands	1995	1995	
Portugal	1997		1997
Spain	1996	1995	
Sweden	1988	1989	
United Kingdom	1993	1993	1993

Table 3: OLS regression estimates: global deregulation

	Without United Kingdom		***With United Kingdom***	
Variables	***Parameter estimate***	***t-value***	***Parameter estimate***	***t-value***
Intercept	-1.327^{***}	-4.92	-1.271^{***}	-4.92
Logarithm (Capital)	0.526^{***}	9.77	0.520^{***}	9.89
Logarithm (Labor)	0.737^{***}	15.53	0.728^{***}	15.91
Deregulation Productivity trend	0.004^{*}	1.76	0.003	1.52
Productivity trend Austria	0.009^{**}	2.03	0.010^{**}	2.16
Productivity trend Belgium	0.020^{***}	4.40	0.020^{***}	4.55
Productivity trend Denmark	0.038^{***}	7.75	0.038^{***}	7.98
Productivity trend Finland	-0.002	-0.39	-0.002	-0.43
Productivity trend France	0.049^{***}	9.62	0.050^{***}	10.09
Productivity trend Germany	0.024^{***}	4.42	0.025^{***}	4.79
Productivity trend Italy	0.050^{***}	11.57	0.051^{***}	12.23
Productivity trend The Netherlands	0.081^{***}	16.47	0.082^{***}	16.99
Productivity trend Portugal	0.032^{***}	6.28	0.032^{***}	6.52
Productivity trend Spain	0.039^{***}	7.15	0.040^{***}	7.43
Productivity trend Sweden	0.026^{***}	3.85	0.026^{***}	3.92
Productivity trend United Kingdom	-	-	0.031^{***}	4.98

$\lambda = 0.26$
$R^2 = 0.9798$
Number of observations: 231.
*: significant at a 10% level, **: significant at a 5% level, ***: significant at a 1% level.

[14] Defined according to discussion p 1.

Table 4: OLS regression estimates, intensity of reforms

Variables	*Parameter estimate*	*t-value*
Intercept	-1.251^{***}	-4.63
Logarithm (Capital)	0.505^{***}	9.34
Logarithm (Labor)	0.739^{***}	15.57
DeregulationOneAspect Productivity trend	0.008^{**}	2.33
DeregulationTwoAspect Productivity trend	0.002	0.83
Productivity trend Austria	0.009^{**}	2.00
Productivity trend Belgium	0.018^{***}	3.86
Productivity trend Denmark	0.036^{***}	7.34
Productivity trend Finland	-0.003	-0.55
Productivity trend France	0.051^{***}	9.75
Productivity trend Germany	0.026^{***}	4.68
Productivity trend Italy	0.051^{***}	11.73
Productivity trend The Netherlands	0.082^{***}	16.53
Productivity trend Portugal	0.033^{***}	6.46
Productivity trend Spain	0.040^{***}	7.36
Productivity trend Sweden	0.028^{***}	4.04

$\lambda = 0.25$
$R^2 = 0.9797$
Number of observations: 231.
*: significant at a 10% level, **: significant at a 5% level, ***: significant at a 1% level.

Table 5: OLS regression estimates, sequencing of reforms

Variables	*Parameter estimate*	*t-value*
Intercept	-1.133***	-4.23
Logarithm (Capital)	0.518***	9.53
Logarithm (Labor)	0.711***	14.93
DeregulationPartial Productivity trend	0.008*	1.59
DeregulationSequential Productivity trend	0.011**	3.05
DeregulationPackage Productivity trend	-0.005	-1.28
Productivity trend Austria	0.004	0.89
Productivity trend Belgium	0.018***	3.63
Productivity trend Denmark	0.035***	6.98
Productivity trend Finland	-0.009	-1.48
Productivity trend France	0.054***	10.15
Productivity trend Germany	0.031***	5.31
Productivity trend Italy	0.049***	11.04
Productivity trend The Netherlands	0.085***	16.98
Productivity trend Portugal	0.034***	6.87
Productivity trend Spain	0.034***	5.80
Productivity trend Sweden	0.017**	2.25

$\lambda = 0.24$
$R^2 = 0.9801$
Number of observations: 231.
*: significant at a 10% level, **: significant at a 5% level, ***: significant at a 1% level.

Table 6: LISREL estimates

	Estimates	***t-values***
Logarithm (Capital)	0.4790***	8.967
Logarithm (Labor)	0.7840***	16.552
Cov(γ_i,LogCapital)	-0.0010	-0.438
Cov(γ_i,LogLabor)	-0.0005	-0.156
Var(γ_i)	0.0005***	2.18
σ^2	0.0370***	10.00
Ridge constant	0.001	

*: significant at a 10% level, **: significant at a 5% level, ***: significant at a 1% level.

Remarks:

The endogenous variable here is aggregate output. We report here an experiment with global individual effects, not controlling for deregulation. Covariances between capital and individual effects and between labor and individual effects are constrained to be constant over time. To avoid "near multi-collinearity" among predictors, LISREL automatically applies a ridge estimation (Jöreskog, 1996).

We have also run a model with $\delta_{it} = \gamma_i + \theta_0 Deregulation_{it}$. Because of their time pattern and structure, the deregulation dummies creates a problem because the matrix is not invertible. This imposes to restrict the panel to the period 1995 to 1999. In this regression we find similar results: covariances between individual effects and inputs are not significant.

Table 7: Relative efficiency measures, total traffic

a) Smaller countries

	Austria	*Belgium*	*Denmark*	*Finland*	*The Netherlands*	*Portugal*
1980	0.43	0.49	0.54	0.37	1.00	0.51
1981	0.41	0.48	0.56	0.39	1.00	0.51
1982	0.45	0.49	0.66	0.39	1.00	0.51
1983	0.49	0.54	0.63	0.45	1.00	0.54
1984	0.53	0.60	0.64	0.47	1.00	0.61
1985	0.58	0.64	0.68	0.50	1.00	0.66
1986	0.66	0.68	0.80	0.47	1.00	0.78
1987	0.69	0.74	0.79	0.59	1.00	0.82
1988	0.74	0.77	0.74	0.64	0.97	0.80
1989	0.78	0.81	0.73	0.68	0.94	0.82
1990	0.87	0.88	0.80	0.79	0.99	0.78
1991	0.87	0.87	0.75	0.74	1.00	0.76
1992	0.86	0.86	0.68	0.70	1.00	0.77
1993	0.93	0.90	0.71	0.81	1.00	0.89
1994	0.96	0.91	0.76	0.90	0.96	0.99
1995	0.93	0.86	0.82	0.92	0.79	0.95
1996	0.98	0.87	0.77	0.94	0.71	0.85
1997	0.80	0.85	0.90	1.00	0.68	0.79
1998	0.80	0.88	0.92	1.00	0.64	0.85
1999	0.72	0.67	0.79	0.90	0.50	0.61
2000	0.61	0.57	0.82	0.80	0.42	0.68
Mean	0.72	0.73	0.74	0.69	0.89	0.74

b) Larger countries

	France	*Germany*	*Italy*	*Spain*	*Sweden*
1980	0.76	0.50	0.62	0.50	0.52
1981	0.75	0.52	0.61	0.50	0.52
1982	0.78	0.54	0.62	0.53	0.50
1983	0.86	0.58	0.60	0.60	0.57
1984	0.89	0.61	0.67	0.63	0.61
1985	0.90	0.68	0.63	0.72	0.66
1986	0.96	0.76	0.77	0.78	0.72
1987	0.97	0.75	0.79	0.82	0.63
1988	1.00	0.76	0.77	0.88	0.61
1989	1.00	0.77	0.77	0.82	0.61
1990	1.00	0.72	0.82	0.87	0.73
1991	0.91	0.62	0.84	0.78	0.62
1992	0.85	0.60	0.86	0.76	0.61
1993	0.82	0.67	0.89	0.84	0.75
1994	0.86	0.78	1.00	0.81	0.82
1995	0.76	0.77	1.00	0.79	0.81
1996	0.79	0.84	1.00	0.80	0.87
1997	0.70	0.87	0.92	0.88	0.89
1998	0.69	0.90	0.78	0.85	0.97
1999	0.61	1.00	0.57	0.75	0.92
2000	0.50	0.90	0.49	0.68	1.00
Mean	0.83	0.72	0.76	0.74	0.71

Table 8: Relative efficiency measures, passenger traffic

a) Smaller countries

	Austria	*Belgium*	*Denmark*	*Finland*	*The Netherlands*	*Portugal*
1980	0.23	0.24	0.18	0.18	0.40	0.15
1981	0.22	0.24	0.18	0.20	0.40	0.15
1982	0.24	0.24	0.22	0.20	0.39	0.15
1983	0.26	0.26	0.21	0.23	0.39	0.16
1984	0.29	0.31	0.21	0.23	0.39	0.19
1985	0.31	0.32	0.23	0.25	0.39	0.20
1986	0.36	0.33	0.27	0.23	0.39	0.24
1987	0.37	0.36	0.26	0.29	0.39	0.26
1988	0.39	0.38	0.25	0.32	0.38	0.26
1989	0.42	0.40	0.24	0.34	0.36	0.27
1990	0.50	0.46	0.28	0.42	0.40	0.26
1991	0.54	0.48	0.28	0.40	0.43	0.28
1992	0.55	0.51	0.26	0.39	0.43	0.30
1993	0.60	0.53	0.27	0.49	0.44	0.35
1994	0.62	0.52	0.30	0.54	0.42	0.37
1995	0.61	0.48	0.32	0.55	0.35	0.38
1996	0.65	0.48	0.30	0.55	0.32	0.33
1997	0.52	0.47	0.33	0.60	0.31	0.32
1998	0.52	0.49	0.34	0.59	0.30	0.34
1999	0.48	0.37	0.31	0.54	0.23	0.25
2000	0.41	0.32	0.32	0.47	0.19	0.27
Mean	0.43	0.39	0.27	0.38	0.37	0.26

b) Larger countries

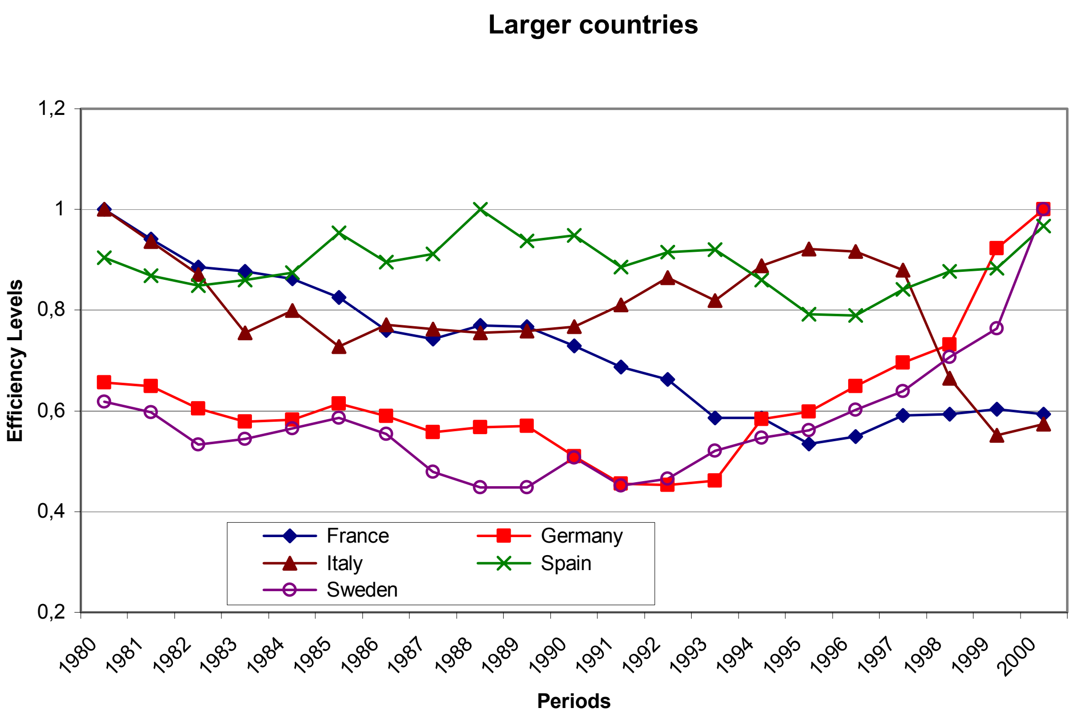
	France	*Germany*	*Italy*	*Spain*	*Sweden*
1980	0.66	0.50	0.38	0.26	0.31
1981	0.65	0.52	0.37	0.26	0.30
1982	0.67	0.54	0.38	0.29	0.29
1983	0.74	0.58	0.37	0.32	0.34
1984	0.75	0.61	0.41	0.35	0.37
1985	0.73	0.68	0.38	0.39	0.40
1986	0.77	0.76	0.47	0.42	0.44
1987	0.78	0.75	0.49	0.44	0.39
1988	0.81	0.76	0.47	0.48	0.38
1989	0.81	0.77	0.48	0.45	0.38
1990	0.84	0.72	0.53	0.48	0.47
1991	0.81	0.62	0.58	0.45	0.42
1992	0.77	0.60	0.63	0.45	0.44
1993	0.75	0.67	0.66	0.50	0.55
1994	0.78	0.78	0.72	0.47	0.58
1995	0.69	0.77	0.74	0.48	0.58
1996	0.72	0.84	0.74	0.48	0.62
1997	0.65	0.87	0.68	0.50	0.63
1998	0.64	0.91	0.57	0.52	0.69
1999	0.57	1.00	0.41	0.46	0.65
2000	0.46	0.80	0.36	0.42	0.70
Mean	0.72	0.72	0.52	0.42	0.47

Table 9: Types of separation of infrastructure from operations

	Organisational	***Institutional or Full***
Austria	From 1997	
Belgium	From 1998	
Denmark		From 1997
Finland		From 1995
France		From 1997
Germany	From 1994	
Italy	From 1998	
The Netherlands	From 1995	
Portugal		From 1997
Spain	From 1996	
Sweden		From 1988
United Kingdom		From 1993

APPENDIX 2: Figures

Figure 1: Efficiency development over time by country, total traffic



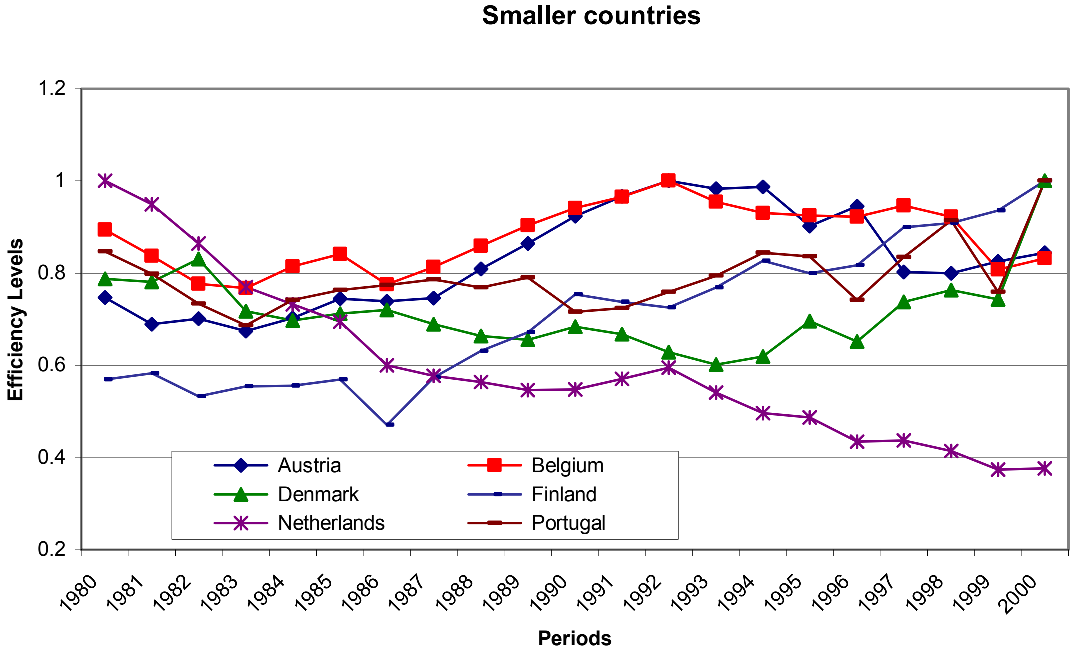
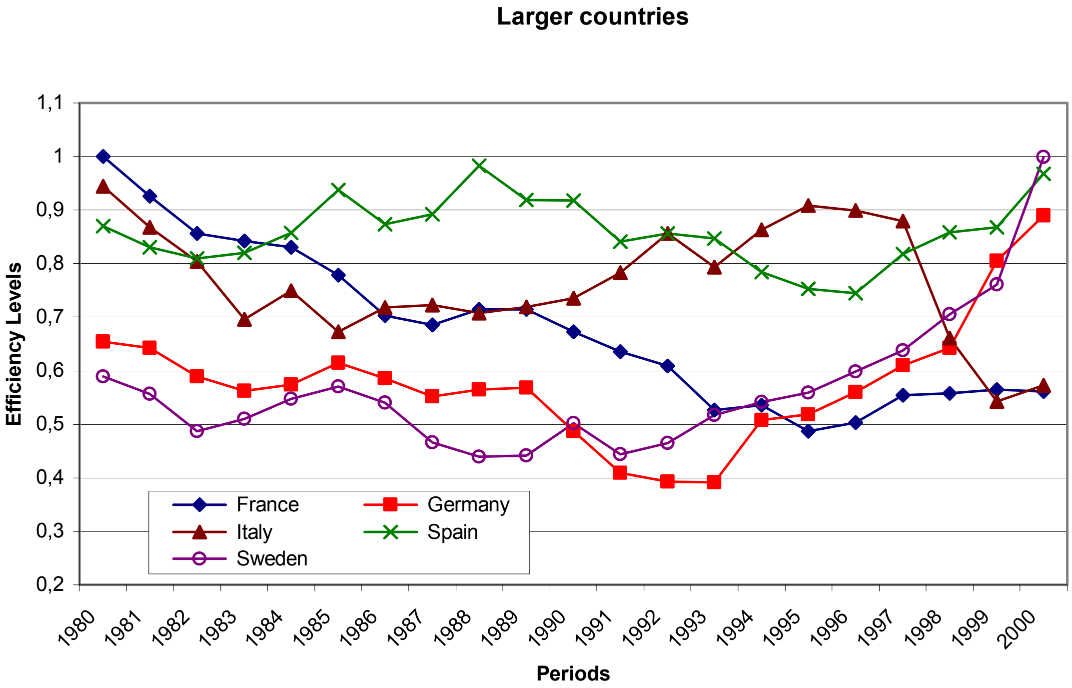


Figure 2: Efficiency development over time by country, passenger traffic



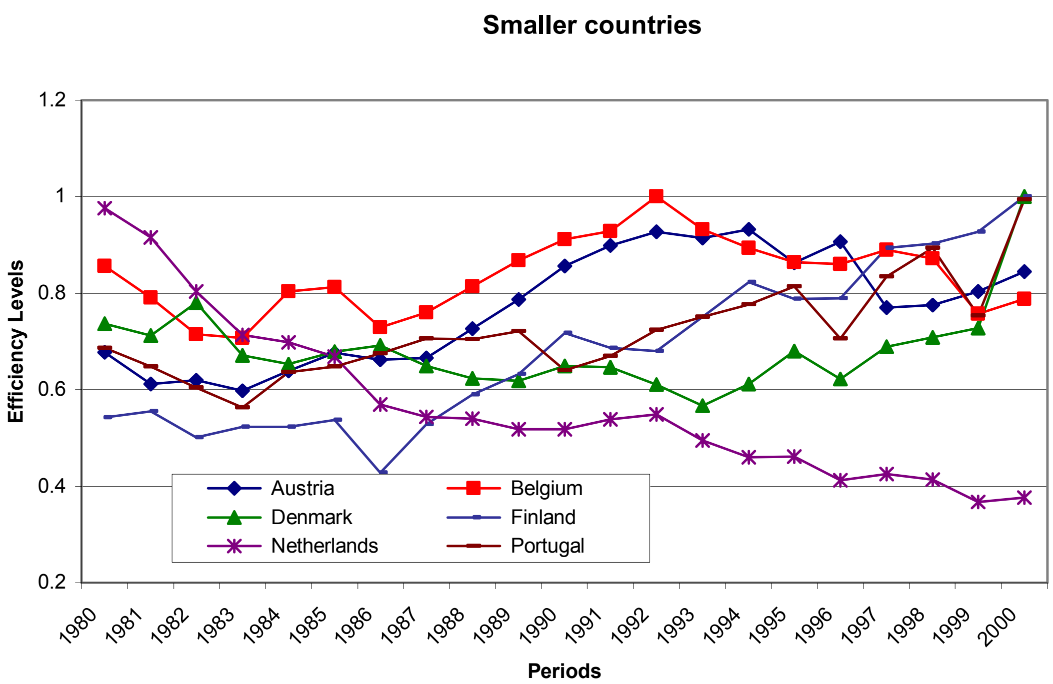


Figure 3: Normalized relative efficiency comparisons, total traffic

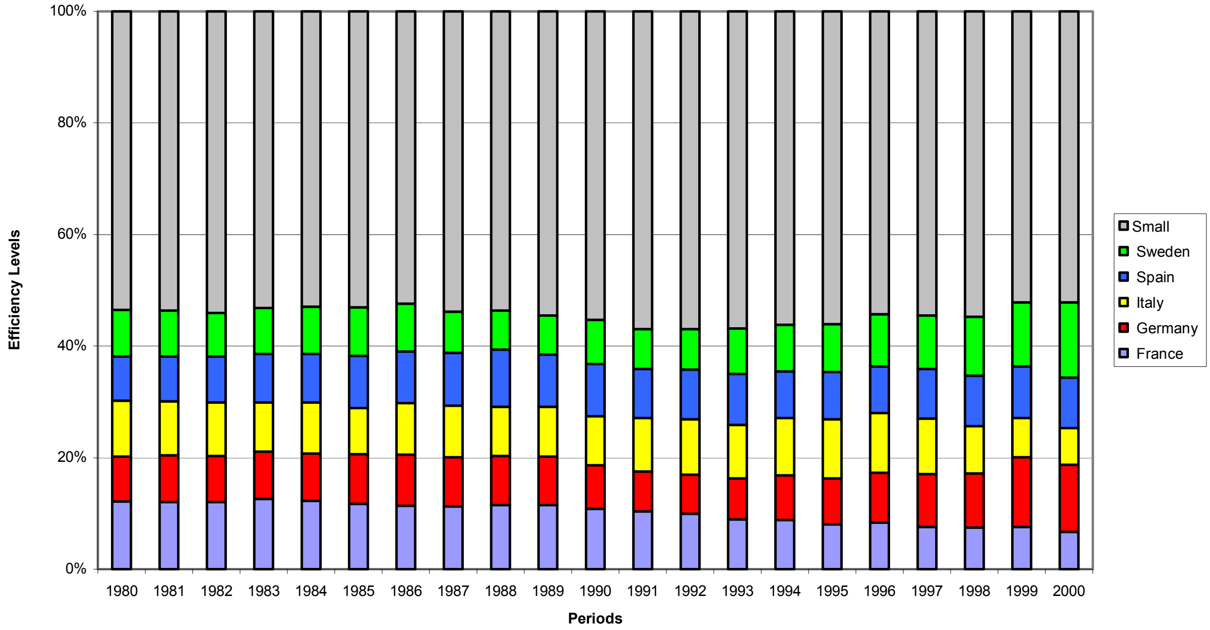


Figure 4: Normalized relative efficiency comparisons, passenger traffic

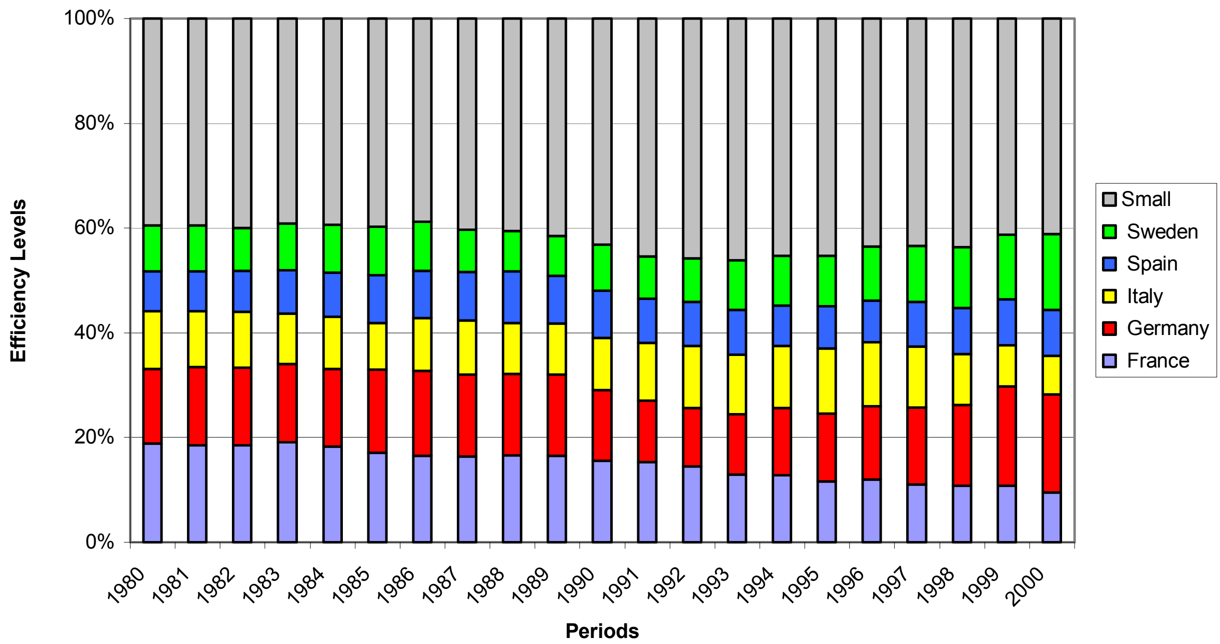


Figure 5: Normalized relative efficiency comparisons, larger countries, total traffic

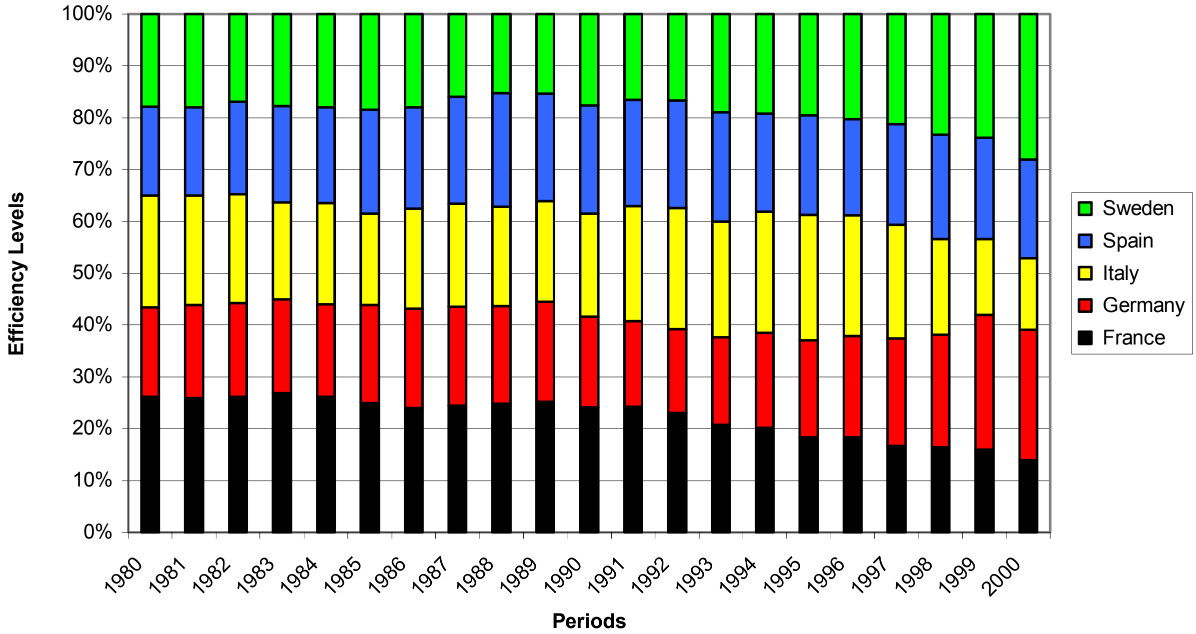


Figure 6: Normalized relative efficiency comparisons, larger countries, passenger traffic

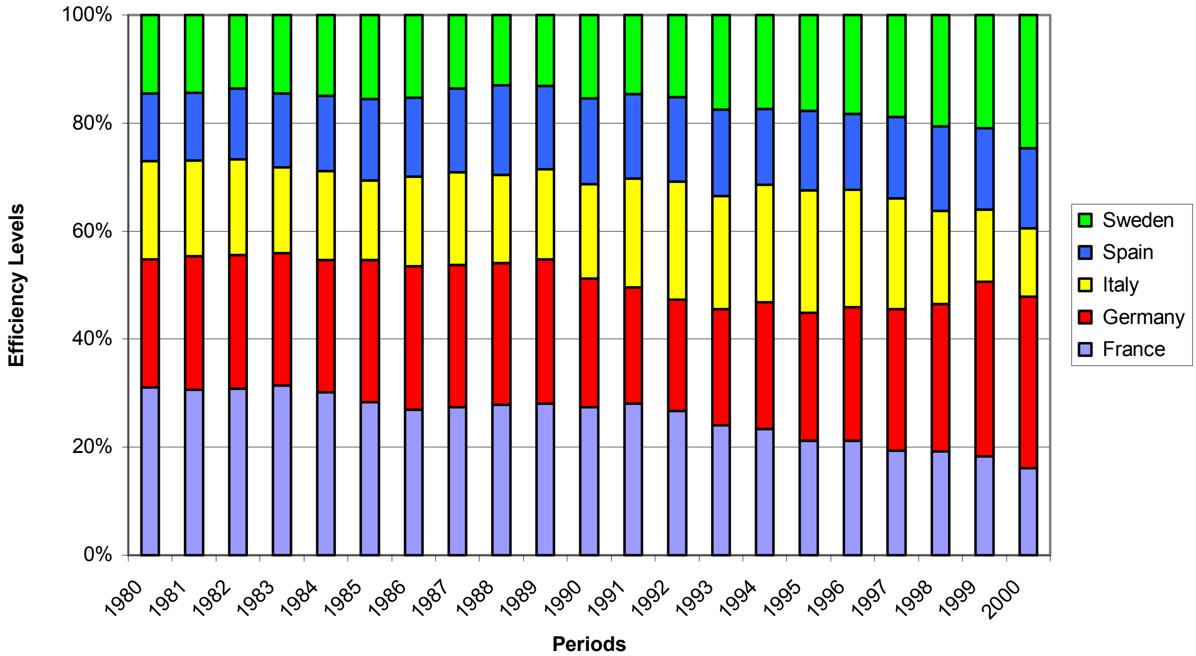


Figure 7: Relative efficiency comparisons, larger countries, by average of five-year periods, total traffic

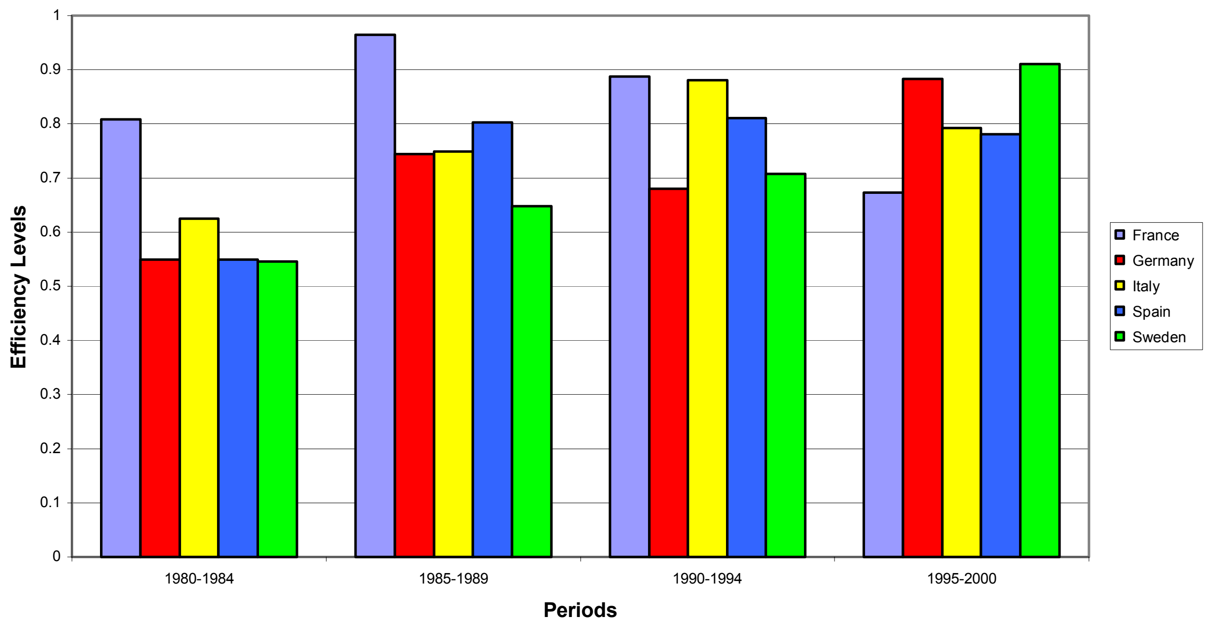


Figure 8: Relative efficiency comparisons, larger countries by average of five-year periods, passenger traffic

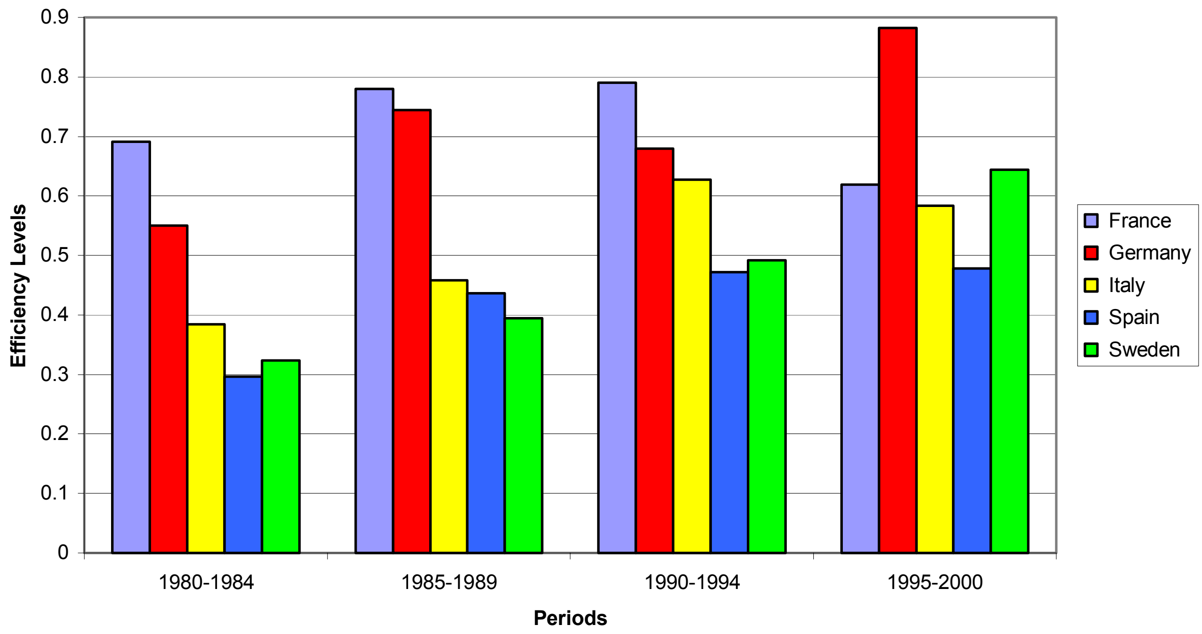
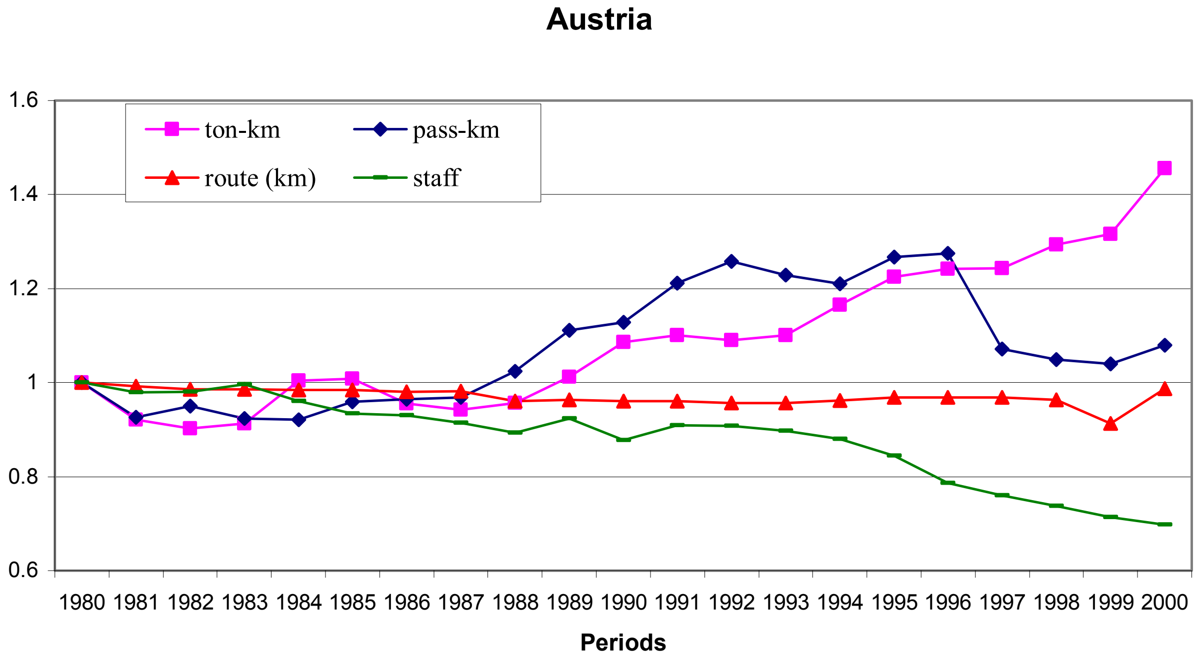
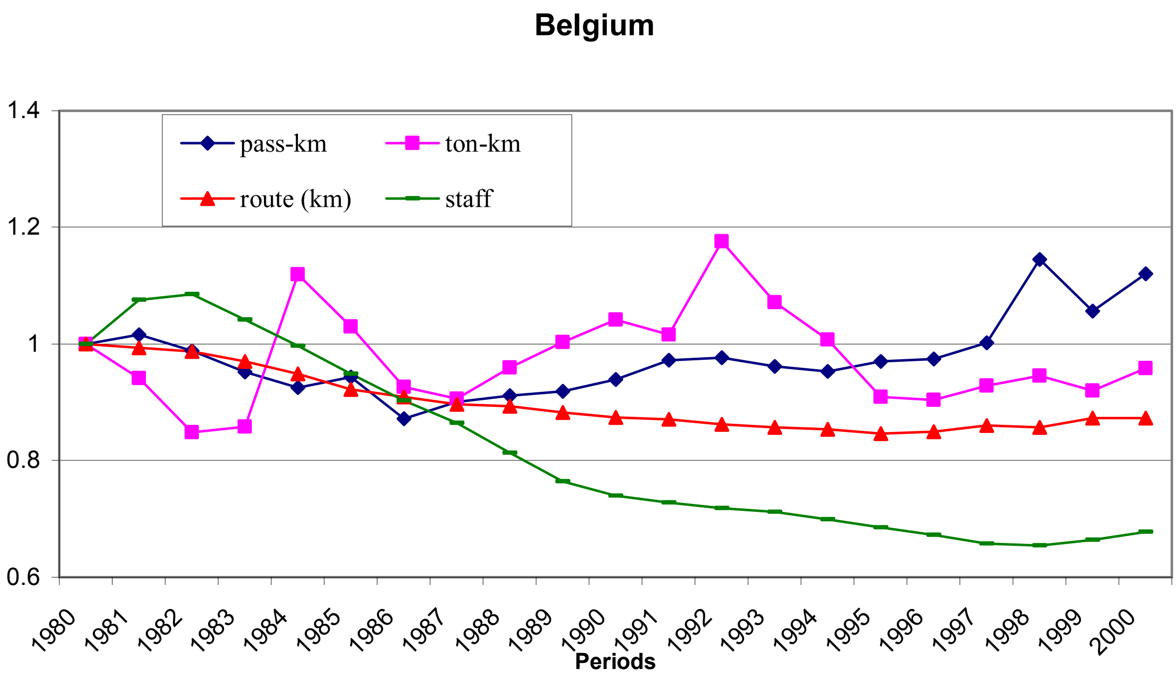
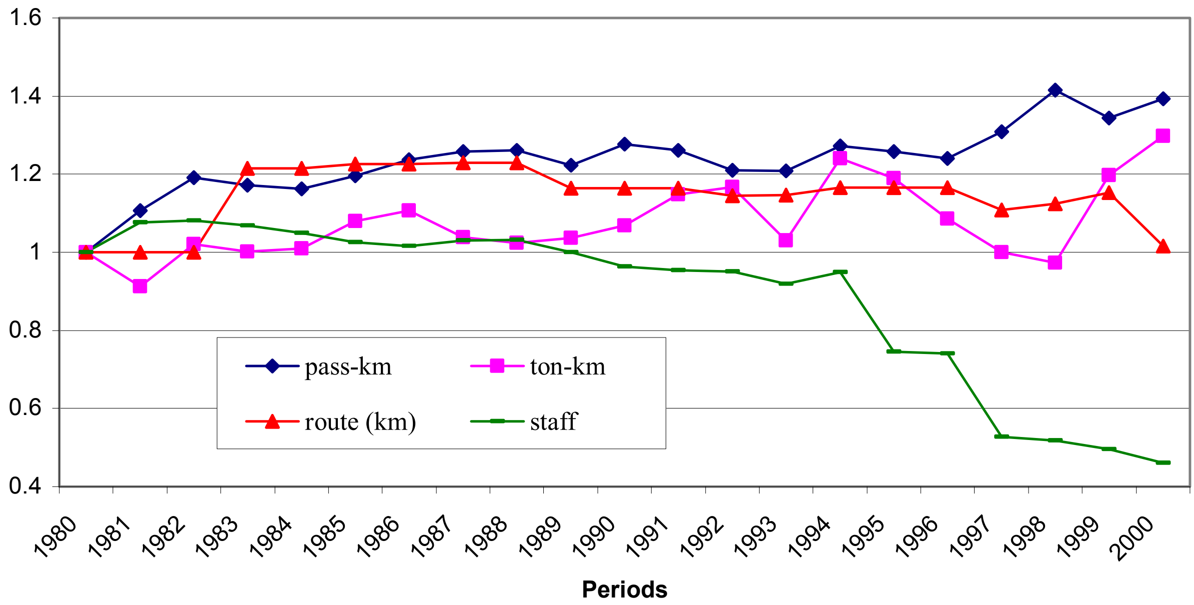


Figure 9: Input and output development of twelve countries over time.

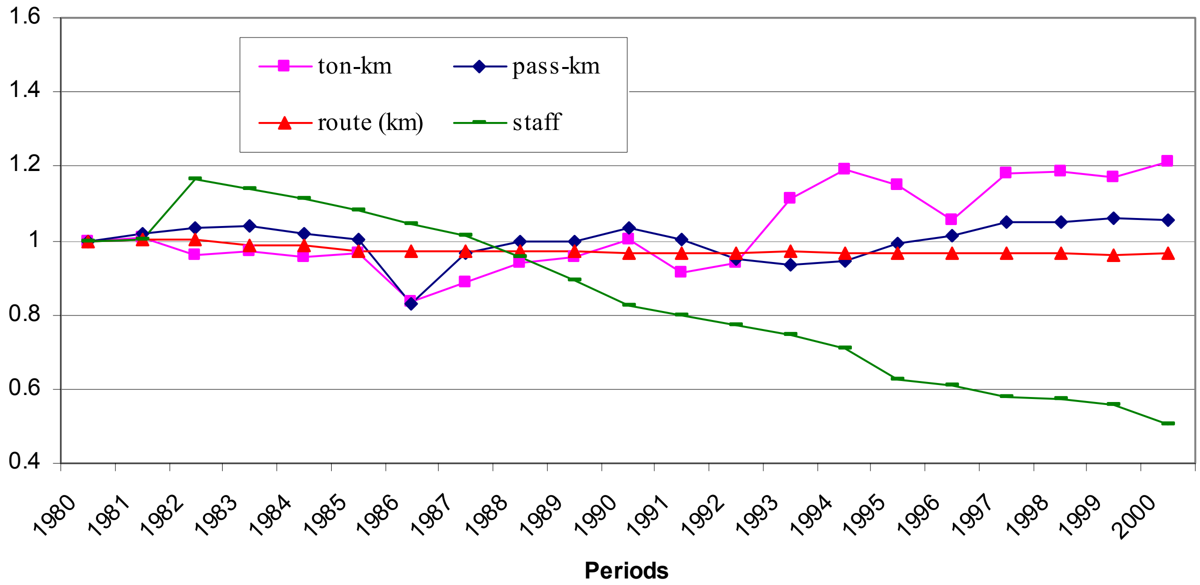


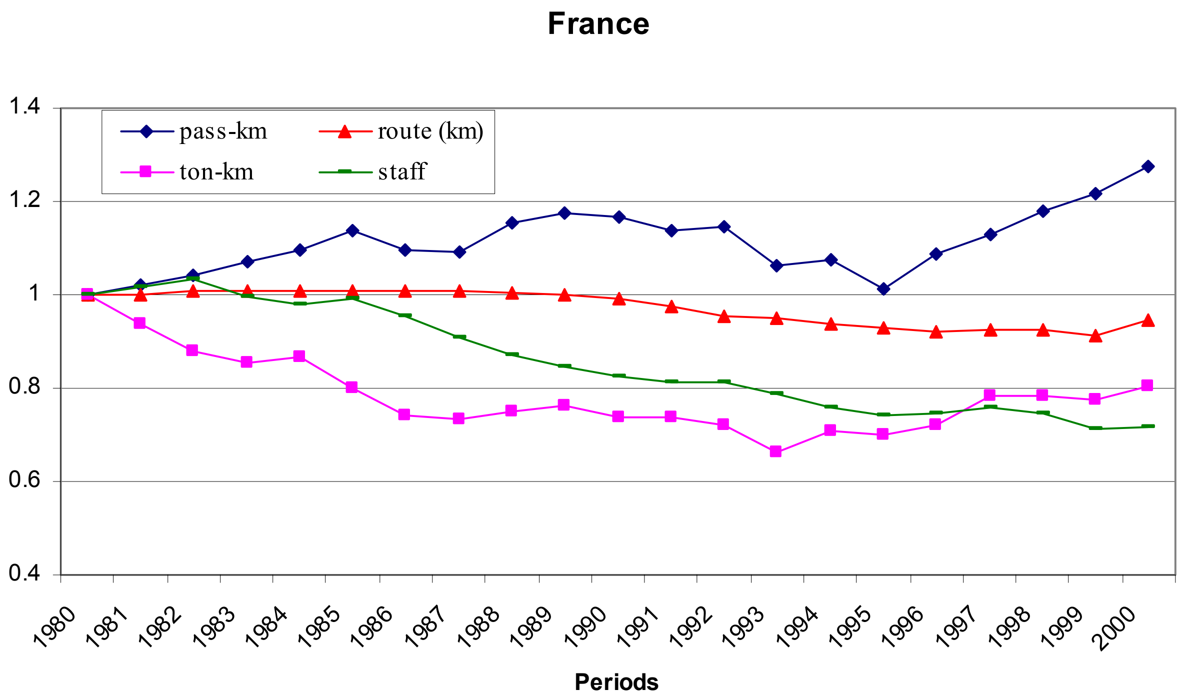


Denmark



Finland




France
1.4
1.2
1
0.8
0.6
0.4
pass-km
route (km)
ton-km
staff
1980
1981
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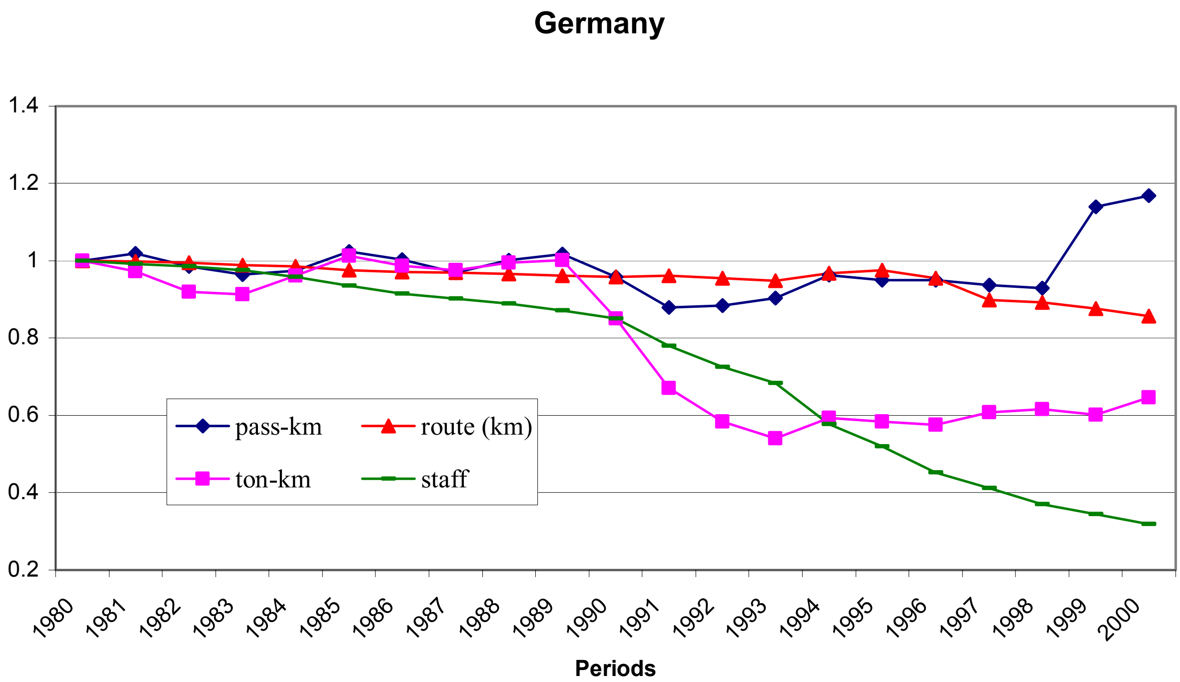
2000
Periods


Germany
1.4
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pass-km
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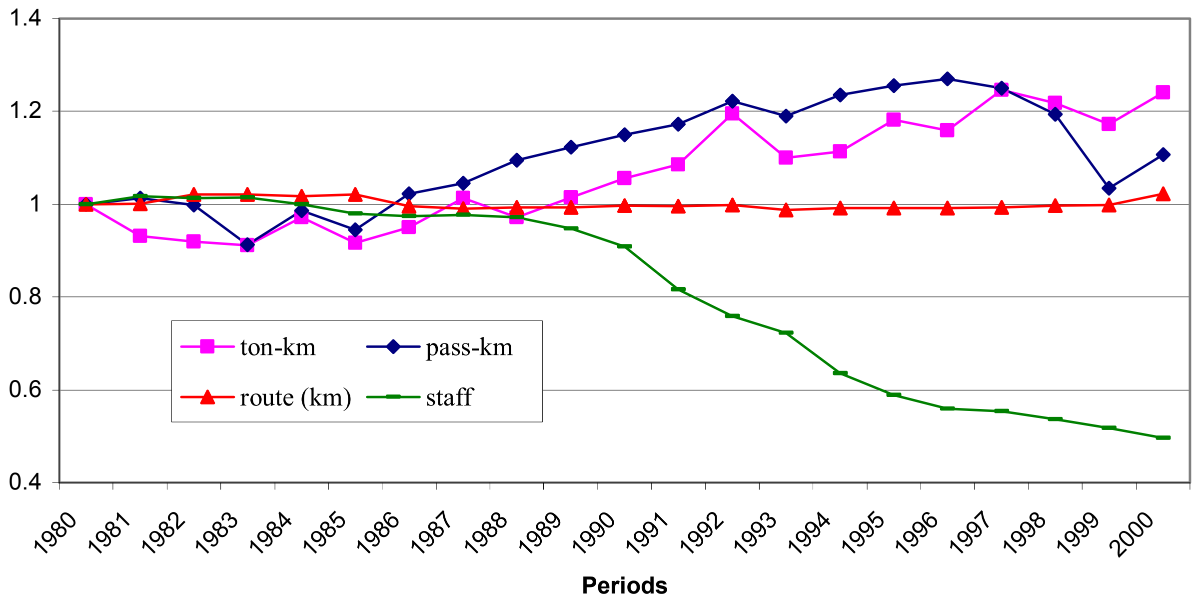
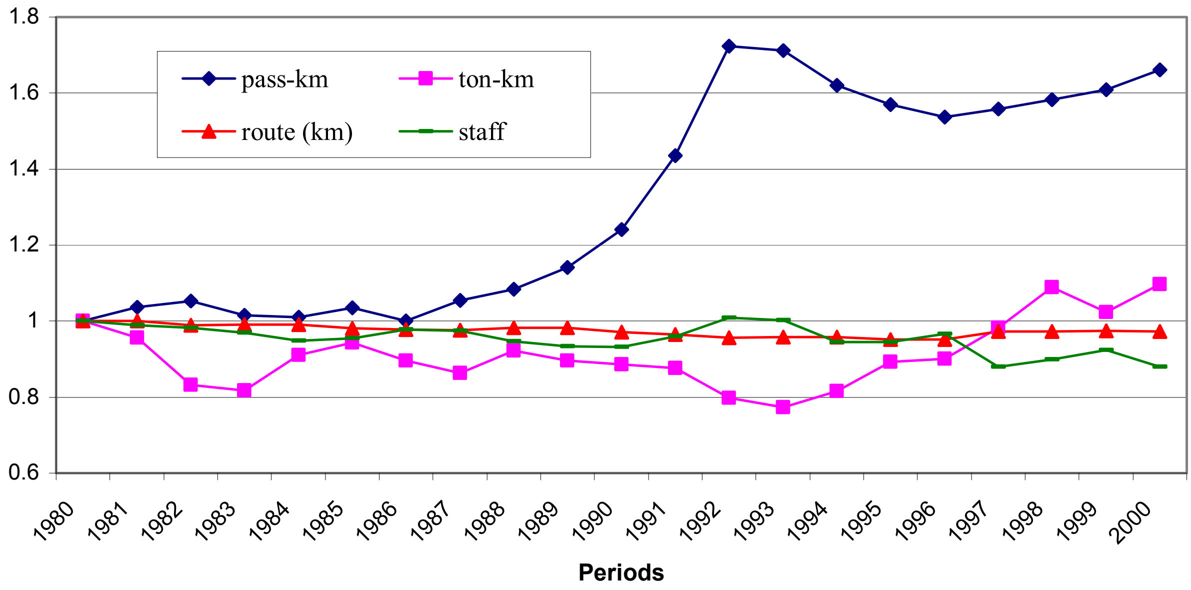
Periods

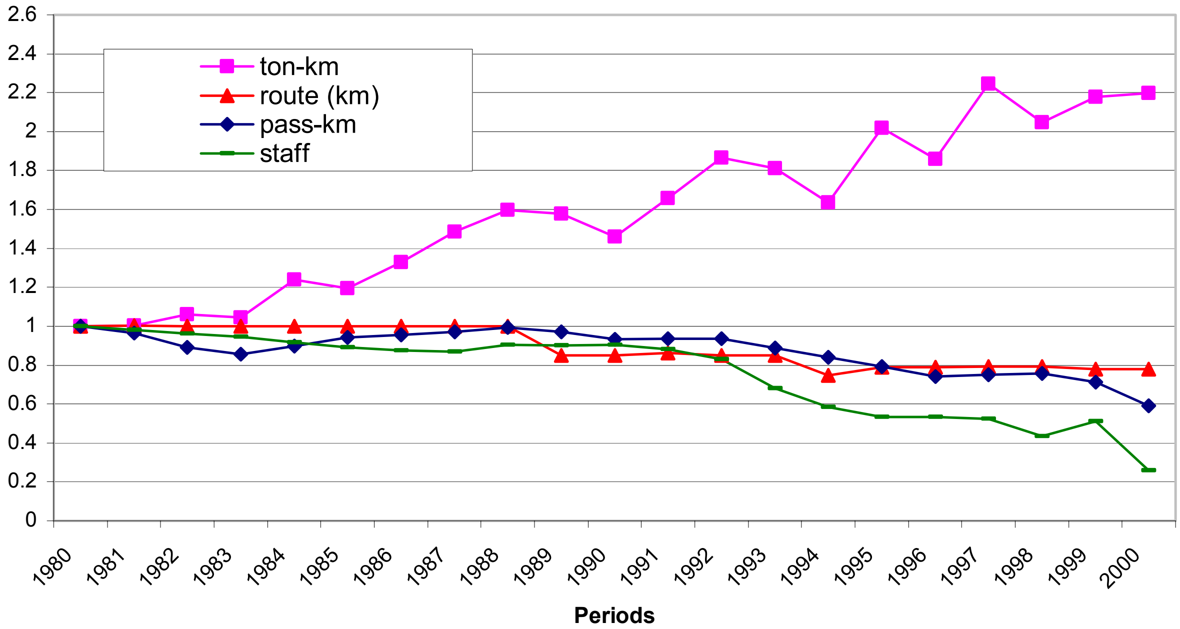
Italy



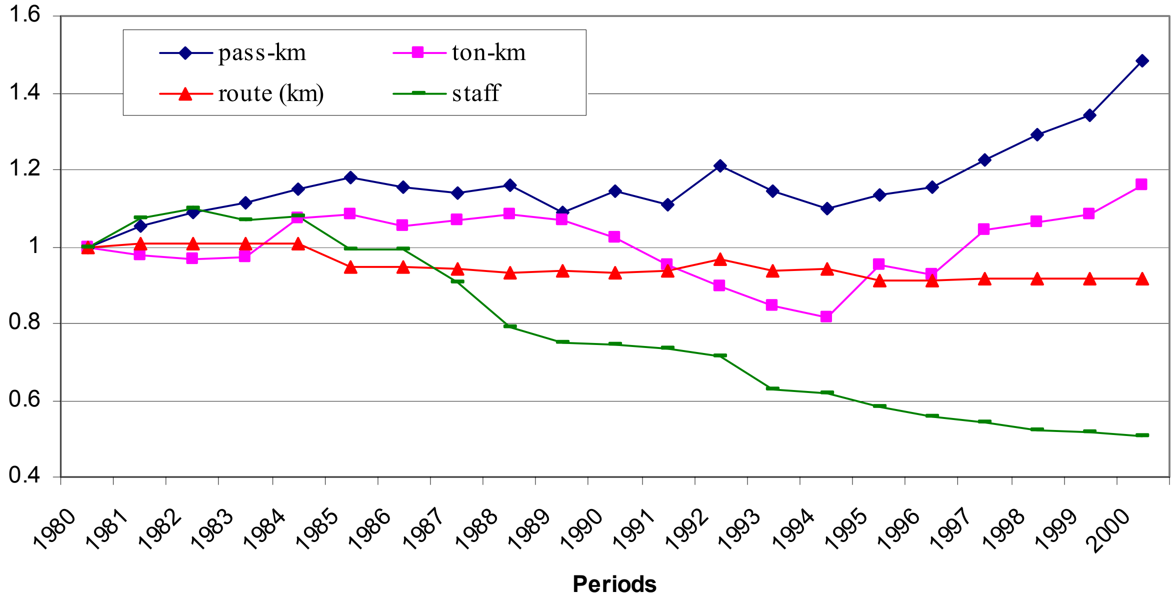
The Netherlands



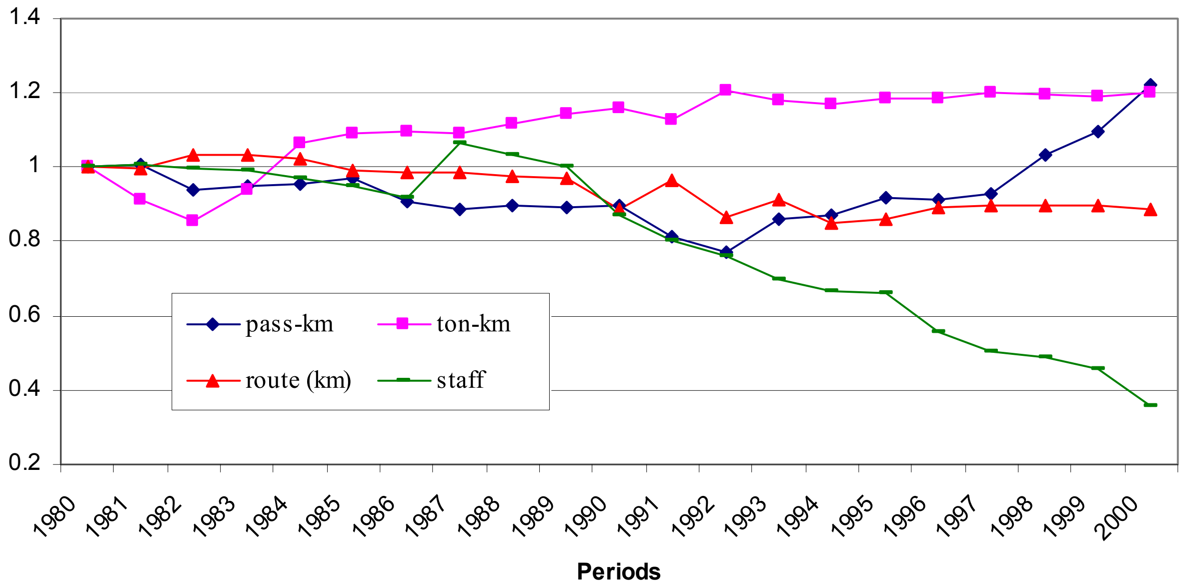
Portugal



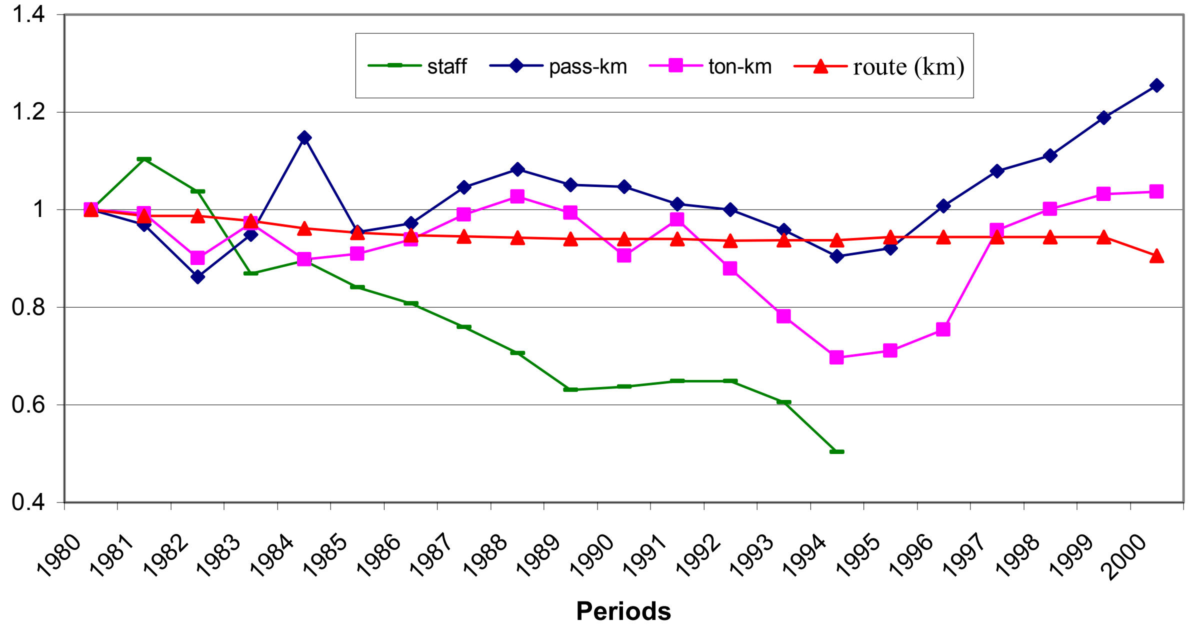
Spain



Sweden



United Kingdom



APPENDIX 3: The mean-and-covariance structure analysis

Estimation of our model is complicated by the fact that individual effects and inputs are often correlated in empirical studies. The method proposed here has the convenient feature of estimating all possible correlations between inputs and individual effects, and hence between input quantities and individual technical efficiencies. The correlation problem is directly addressed by treating individual effects as latent variables. Another advantage of this method is that contrary to the usual instrumental variable estimation, it does not require additional information.

Definition of the LISREL method (Jöreskog (1973), "Analysis of covariances structures"):

There are:

A structural equation system of the form:

$\eta = B\eta + \varsigma$ (a)

Here η is the vector of latent variables (individual effects), B the coefficient matrix of the regression of the latent variables on themselves, and ς are disturbances with zero means.

Measurement equations which link the latent variables η to the observed variables z according to:

$z = \Lambda\eta + \varepsilon$ (b)

Λ is the coefficient matrix of the regression of the observed variables z on the latent variables η, and ε disturbances with zero means. It is assumed that: $E(\varsigma\varepsilon') = E(\eta\varepsilon') = 0$.
Let the variables z be measured as deviations from their respective means. The moment matrix of z can be expressed as:

$$\Sigma = \Lambda(I - B)^{-1}\Psi(I - B')^{-1}\Lambda' + \Theta$$

where $\Psi = E(\varsigma\varsigma')$ and $\Theta = E(\varepsilon\varepsilon')$.

The elements of Σ are functions of the elements of B, Λ, Ψ, and Θ, which can be referred to as fixed parameters or free parameters.

Estimation of the model entails choosing values for the free parameters so that the predicted moment matrix Σ fits the empirical moment matrix, denoted by S, in different ways depending on the estimation method used. All common fit functions are special cases of a general family (see Browne (1984)):

$$F(\Sigma, S) = (s - \sigma)'\Omega^{-1}(s - \sigma),$$

where $s = vec_*(S)$, $\sigma = vec_*(\Sigma)$.
F(.,.) is a twice differentiable continuous function which maps S and Σ into a non-negative scalar. It requires positive definitiveness of the weight matrix Ω.

The estimation we use here consists in maximizing the likelihood of the parameters. Under the assumption of a multivariate normal distribution of the observed variables, the fit function becomes:

$$F(\Sigma, S) = \log\det(\Sigma) + trace(S\Sigma^{-1}) - \log\det(S) - p$$

Minimizing this function is equivalent to maximizing the log-likelihood of the sample.

Application to our framework:

The system of equations defining a production function with individual effects can be equivalently formulated as:

$$\begin{cases} y_{it} = \beta x_{it} + \varepsilon_{it} \\ \varepsilon_{it} = w_t \gamma_i + v_{it} \end{cases} \quad i=1, \ldots, N, \; t=1, \ldots, T$$

Here, w_t represents our previous t and γ_i is the individual random parameter, called individual effects. v_{it} is an error-term which is identically and independently distributed with variance σ^2.

This system can be reconstructed as a multivariate system by stacking the *T* equations for each individual. The system becomes:

$$\begin{cases} y_i = (I_T \otimes \beta) x_i + \varepsilon_i \\ \varepsilon_i = W\gamma_i + v_i \end{cases} \quad i=1, \ldots, N$$

y_i, ε_i, and v_i are $(T \times 1)$ vectors, x_i is a $(KT \times 1)$ vector and W is the $(T \times 1)$ matrix resulting from stacking the *T* vectors w_t.

Our model in matrix form becomes the following structural equation system (page 37 Equation (a)):

$$\begin{bmatrix} 1 \\ y_i \\ x_i \\ \gamma_i \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ e_T\alpha & 0 & I_T \otimes \beta & W \\ \bar{x} & 0 & 0 & 0 \\ \bar{\gamma} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ y_i \\ x_i \\ \gamma_i \end{bmatrix} + \begin{bmatrix} 0 \\ \xi_i \\ x_i - \bar{x} \\ \gamma_i - \bar{\gamma} \end{bmatrix}$$

$$with \quad \eta \equiv \begin{bmatrix} 1 \\ y_i \\ x_i \\ \gamma_i \end{bmatrix}, \quad B \equiv \begin{bmatrix} 1 & 0 & 0 & 0 \\ e_T\alpha & 0 & I_T \otimes \beta & W \\ \bar{x} & 0 & 0 & 0 \\ \bar{\gamma} & 0 & 0 & 0 \end{bmatrix}, \quad \varsigma \equiv \begin{bmatrix} 0 \\ \xi_i \\ x_i - \bar{x} \\ \gamma_i - \bar{\gamma} \end{bmatrix}$$

We can now interpret the stochastic production frontier model through the mean-and-covariance structure analysis.

The vector γ_i is treated as a vector of latent variables, and the moment matrix of ζ has the following form:

$$\Psi = E(\varsigma\varsigma') = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \sigma^2 I_T & 0 & 0 \\ 0 & 0 & \Sigma_{x,x} & \Psi'_{\theta,x} \\ 0 & 0 & \Psi_{\theta,x} & \Delta \end{bmatrix}$$

where $\Sigma_{x,x}$ is the $KT \times KT$ covariance matrix of vector x_i, $\Psi_{\theta,x}$ is the $1 \times KT$ covariance matrix between the vector γ and the vector x_i. Δ is the covariance matrix (here a scalar) of the vector γ_i.

The measurement equations which link the observable variables y_i and x_i to the latent variable η take the following form:

$$z \equiv \begin{bmatrix} 1 \\ y_i \\ x_i \end{bmatrix} = \Lambda \begin{bmatrix} 1 \\ y_i \\ x_i \\ \gamma_i \end{bmatrix} = \Lambda\eta \quad \text{with} \quad \Lambda \equiv \begin{bmatrix} I_{T(K+1)+1} & 0 \end{bmatrix}$$