

**Output Responses to Infrastructure
Investment in the Netherlands, 1850-1913**

Research Memorandum GD-24

Peter Groote, Jan Jacobs and Jan Egbert Sturm

December 1995

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Peter Groote, Jan Jacobs, Jan Egbert Sturm*

Faculty of Economics, University of Groningen

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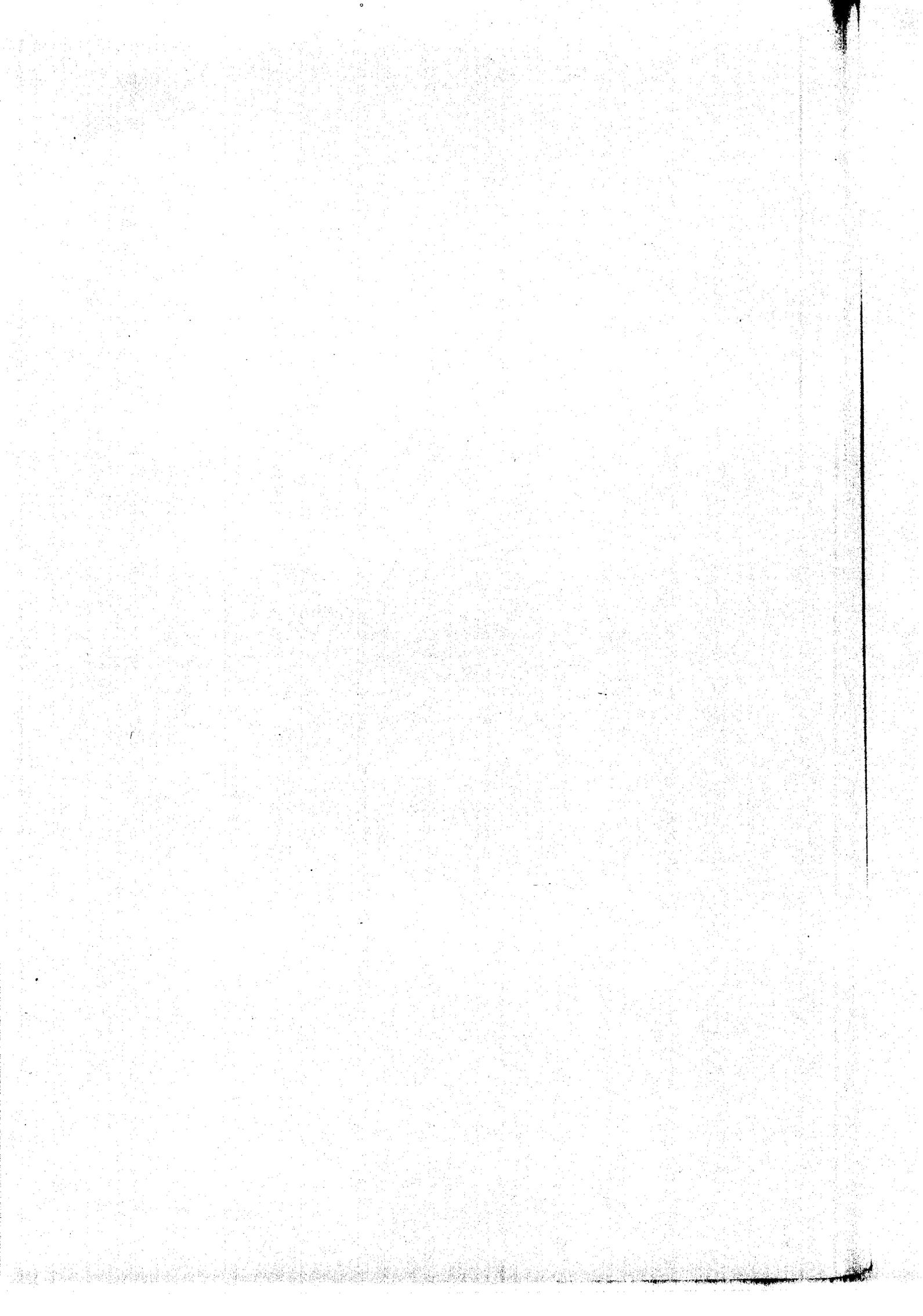
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Abstract

This paper combines a new historical data set regarding capital formation in infrastructure in the Netherlands in the nineteenth century with data-oriented econometric techniques aimed at testing the causal relationship between these infrastructural investments and economic growth. The resulting vector autoregression (VAR) model is analysed further with impulse response analysis. The results show that the time series characteristics of both capital formation and GDP are trend stationary, which is a fundamental difference with their twentieth century counterparts. The paper finds strong evidence of both a long term and a medium term or short term impact. In the short run, positive expenditure effects are partly offset by negative transitional dynamics. To fine tune the analysis we have exploited the possibility to disaggregate the data set in basic and complementary infrastructure investment. Whereas the effect on output is significantly positive for basic infrastructure investment, it is absent for complementary infrastructure investment.

Keywords: infrastructure; Granger-causality; VAR.

* Peter Groote: Groningen Growth and Development Centre and Netherlands Organisation for Scientific Research (NWO); Jan Jacobs, Jan-Egbert Sturm: Centrum voor Conjunctuur en Structuuronderzoek. This article is based on research sponsored by the Faculty of Economics of the University of Groningen, and by the Foundation for Economic, Social, and Spatial Sciences (ESR), which is part of NWO. All correspondence is welcome. Please direct to Peter Groote, University of Groningen, Faculty of Economics (AE/ESG), P.O. Box 800, 9700 AV Groningen, the Netherlands; e-mail: P.D.Groote@eco.rug.nl. We would like to thank Jan Willem Drukker, Rainer Fremdling, Jakob de Haan and members of the Economic History Seminar and the SOM-Seminar of the University of Groningen, especially Eric Dietzenbacher, for helpful comments and suggestions.



OUTPUT RESPONSES TO INFRASTRUCTURE INVESTMENT IN THE NETHERLANDS 1850-1913

Infrastructure is traditionally a focal point in the debate on economic growth, which periodically rises to prominence. In recent years interest in public infrastructure spending as a strategy to promote economic growth has swollen again. Both politicians and macro-economists have placed infrastructural investment back on their agendas. The renewed attention in mainstream economics was triggered by the startling productivity impact of public investment as reported by Aschauer (1989). He tested whether the productivity slowdown of the USA in the 1970s may have been caused by a lack of public investment in infrastructure. Aschauer's empirical findings are impressive: over the period 1949 to 1985 a 1 percent increase in the public capital stock raised the level of output, *ceteris paribus*, by 0.39 percent. Many economists consider this size of the output elasticity with respect to increased public infrastructure as implausibly large (see e.g Gramlich [1994], Sturm and De Haan [1995]). Aschauer's method of deriving these results, via an augmented Cobb-Douglas production function with public capital as an additional factor of production, met with critique. In his production function he was forced to treat technical progress as a constant. Econometricians also point out that in many Aschauer-type analyses, time series properties of the variables are not explicitly taken into account.

In the back of their minds, economic historians, development economists, and regional scientists have always held some notion of the role of infrastructure in paving the road to economic progress (for example Hirschman [1958], Rostow [1960], Blum [1982], Nijkamp [1986], David [1990]). Rostow (1960) regards investment in infrastructure, or social overhead capital, as one of the preconditions for economic take off. Only after a certain threshold level of social overhead capital was reached, sustainable economic growth per capita would in his view be possible. Although Hirschman (1958) treats infrastructure more delicately, he still sees a possibility for inducing economic development through a surplus of social overhead capital.

Ville (1990, 10-12) rightly stresses the possibility of complementary negative instead of only positive effects stemming from improvements in (transport) infrastructure. Many forms of transport infrastructure are exploited under natural monopoly. This can render social costs larger than private benefits. Also, transport improvements often have negative externalities, such as pollution, noise, and congestion. These, however, are not —yet— priced. Thus, they have no economic value, and are not discounted from national income. Finally, the diffusion of transport innovations may reinforce, rather than resolve, regional disparities. Depressed regions may well lose their last economic strongholds as soon as natural

protection through the friction of distance is reduced. Firms may move away from the region in order to supply it from other regions with better factor endowments.

David explicitly points to such growth retarding externalities of innovations. In his view the “large technical systems characteristic of network industries” may lead to path dependency or hysteresis in economic development (David [1990], 355).¹ His central idea is that network industries have complementary relationships with the rest of the economy. These may start an economy-wide, incremental process of technological and organizational improvement. Before economic agents are able to join in on this process, they must adapt their behavioural strategies, their durable physical assets, and the geographical location of their activities. This takes time and other scarce resources. Therefore, once they have done so, it becomes even more costly to switch again to a different path. As such, hysteresis caused by infrastructural investments, may shape behavioural patterns of economic agents on the micro level, and the path of economic development on the macrolevel.

Infrastructure is traditionally assigned a major causal role in three important phases of Dutch economic development. Firstly, it has become a stylized fact that the Netherlands were the economic superpower of the preindustrial era, and that this was for a considerable part thanks to its infrastructural development (De Vries and Van der Woude [1995], 27-36). Secondly, infrastructural deficiencies, partly to be seen as the penalty of the pioneer of the preceding period, are often blamed for the retarded economic development in the first half of the nineteenth century (for example Griffiths [1979]; Horlings [1995]). Thirdly, a costly large scale rehabilitation of the country’s infrastructural endowments is regarded one of the causes of the take off of Dutch economic growth in the second half of the nineteenth century (for example De Jonge [1968], Smits [1996]).

Because of the peculiar relationship between its infrastructural endowments and its economic development in different phases of its history, the Netherlands are well suited for empirically testing the belief that infrastructure is an important factor in explaining economic growth. As the quality of available data is clearly the best for the last of the three periods mentioned above, i.e. the second half of the nineteenth century, we will focus on this period. Our main hypothesis reads as follows: “In the Netherlands increased investment in infrastructure in the second half of the nineteenth century has played the mayor role in economic development in the same period, and has enabled a Kuznetsian process of modern economic growth to take off.” In this paper we add quantitative evidence, based on econometric techniques, to the existing qualitative and sometimes merely intuitive ideas on this topic. The main innovations of the paper are the exploitation of a new long run data set on infrastructural capital formation, the application of data oriented econometric

1 Historians of technology use various definitions of “large technical systems.” The one we adopt here is from Gökalp (1992), and is geared towards the physical characteristics of network industries. It closely resembles the definition of basic infrastructure as given later in this paper.

techniques, and the combination of these in a modern analysis of historical economics. Thus, we will try to amalgamate the rhetorics of history, economics, and econometrics.

NEW DATA ON DUTCH ECONOMIC DEVELOPMENT IN THE NINETEENTH CENTURY

Although general agreement on the details of Dutch macroeconomic development in the nineteenth century is still not reached, some stylized facts are widely accepted by now. Both the stylization of these facts, and our contribution to the discussion in this paper owe much to new data sets regarding Dutch economic development in the nineteenth century. These are the outcome of joint research efforts of participants in a project on "*The Reconstruction of Dutch National Accounts 1800-1940*", which has been under way since 1989 at the universities of Utrecht, Groningen, and Amsterdam (see Van Ark 1995). Below we will elucidate in detail on the sources and methods applied in constructing the series on infrastructural capital formation. For the series on Gross Domestic Product we refer to Buyst, Smits, and Van Zanden (1995), for the series on investment in machinery and equipment to Clemens, Groote and Albers (1995).

Van Zanden, who is one of the initiators of the research project mentioned above, has recently concluded that Dutch economic development must not be judged by any standard moulded on the British Industrial Revolution (Van Zanden 1995). Although in the first half of the nineteenth century industrialisation in the Netherlands lagged behind most other European countries, this should not be regarded as a token of backwardness, but rather as the penalty of the pioneer. Industrialization was late in the Netherlands because agriculture and services modernized very early. Industrialization would only have subtracted scarce resources from these more productive sectors.

At the beginning of the nineteenth century, the Dutch economy was still firmly rooted on the strongholds upon which the wealth of the former Dutch Republic was once built: high levels of productivity in international services, especially transport and finance, in agriculture, and in the industrial processing of colonial foodstuffs. An abundance of financial capital and human capital (Drukker and Tassenaar [1990]) complete the picture of a nation that was still living off the resources accumulated in former times. Results of the *Dutch Historical National Accounts* project published so far, confirm the existing view that in the first decades of the nineteenth century these foundations of Dutch wealth came under increasing pressure from foreign competition. In 1820 Gross Domestic Product of the Netherlands was already surpassed by that in the United Kingdom. It was still a lot higher than for example in the German area (Maddison 1995, table D-1a). Table 1 clearly

shows that afterwards the Netherlands were continuously losing ground to Germany, albeit without being overtaken before the start of the First World War.

Table 1 Levels and annual compound growth rates of GDP per head in The Netherlands, the UK, and Germany, 1820 and 1850; in 1990 Geary Khamis dollars; percentages

	Netherlands	United Kingdom	Germany		Netherlands	United Kingdom	Germany
1820	1561	1756	1112				
1850	1888	2362	1476	1820-1850	0.64%	0.99%	0.95%
1890	3113	4099	2539	1850-1890	1.26%	1.39%	1.37%
1913	3950	5032	3833	1890-1913	1.04%	0.90%	1.81%

source: Maddison (1995), table D-1a

Griffiths (1979) and Mokyr (1976) argue that the main reasons for the relatively slow development during the nineteenth century were the opposites of the former advantages. Mokyr mentions, for example, high and sticky real wages as a growth retarding factor.² Griffiths focuses on high costs of raw materials, especially coal and iron, because of the lack of natural resources. The impact of these causal factors was aggravated by high costs of transport and communications due to the lack of a modern infrastructure. These infrastructural deficiencies hold a key position in explaining the slackness of Dutch relative economic performance in the first half of the nineteenth century.

In the course of the nineteenth century, small signs of a gradual transformation appeared. Government finance was reorganized, mainly thanks to surpluses drawn from the East Indies. This made it possible to abolish the heavy taxes on daily foodstuffs, which increased domestic demand, and decreased income inequality. The latter phenomenon is also clear from recent anthropometric studies (Drukker and Tassenaar [1996]). This development was strengthened by the agricultural sector being able to enter the home markets of the industrializing neighbouring countries, prominent among which the United Kingdom (Griffiths 1979, 25). A token of these modest positive developments was the completion in 1852 of an important public infrastructural project: the reclamation of the *Haarlemmermeer*, a 45,000 acre lake increasingly threatening the city of Amsterdam.

The completion of this project marks the major breakthrough, and consequently the beginning of our period of analysis. Afterwards transaction costs in the economy could be substantially reduced thanks to a large scale rehabilitation of the country's infrastructure. This view is based on one of the new data sets referred to above, concerning Dutch infrastructural development. In his dissertation on capital formation in Dutch infrastructure in the period 1800-1913, Groote gives annual time series on capital formation and capital stocks, both in current and constant prices, and subdivided by sector and type of asset

2 Mokyr (1976) also mentions the huge government debt, and institutional rigidities on the local level that squeezed entrepreneurial initiative (cf. Olson 1982) as growth retarding factors.

(Groote 1995).³ The United Nations' *System of National Accounts (SNA 1968)*, and Raymond Goldsmith's Perpetual Inventory Method provided a framework that was strictly kept to. "Infrastructure" is defined as equivalent to the categories "other construction" and "land improvement" in the *System of National Accounts* (1968, 114). It consists of 18 sectors in the fields of transport, telecommunications, utilities, and water management. Included are rail- and tramways, roads, shipping canals, docks and harbours, telegraph and telephone, gas, water, and electricity, water management, dikes, land reclamation, and impolderings. Only the truly infrastructural aspects of these sectors are included. Thus, the permanent way and works of railways are included, but rolling stock is not.

The time series were built up from the micro level, starting from individual companies' accounts, government reports and archival records. This historical handicraft proved once again that it is possible to give historical economics time series not only a more thorough base than is often thought beforehand, but also one that matches its modern counterparts (Goldin 1995). The detailed figures were aggregated in sectoral gross fixed capital formation series. The subdivision made it possible to apply specific deflators and perpetual inventory assumptions on lifetime and depreciation pattern, which contributes to maintaining transparency. It also means that the final series may be disaggregated again at will.

In this paper we subdivide aggregate infrastructure for analytical reasons into basic infrastructure and complementary infrastructure.⁴ Although a subdivision like this is always debatable, it serves our purpose. Basic infrastructure consists of those sectors that exhibit (nearly) all of the elementary characteristics of infrastructure (public character and fundamental importance for other economic sectors; non-tradable and lumpy character of investments; technical and spatial indivisibilities). These sectors are: main railways, roads, canals, harbours and docks, the electromagnetic telegraph, drainage, dikes, and land reclamation. Complementary infrastructural sectors have enough of these characteristics to label them as infrastructure, but not all, or not as intense as basic infrastructural sectors: light railways, (urban) tramways, gas, electricity, and water supply, (local) telephone networks. Of course this division in basic and complementary infrastructure is time-dependent. Whereas we regard for our period of study, for example, electricity as complementary infrastructure, this became of fundamental importance to the economy in the twentieth century, and must be labelled basic infrastructure nowadays. No one will deny, however, that main railways and shipping canals (including harbours) belong to basic infrastructure in the period under study. In the main period of investment, 1866-1888, these accounted for 60% of total infrastructural capital formation.

3 The data series will also become available in the English version of this dissertation, which is due to appear in Spring 1996. It also contains long run series on the physical development of infrastructural works, for example the length of the networks of rail- and tramways, or the number of electrical power stations.

4 We will also take a brief look at the effects of railway and canal building on economic growth.

Figure 1 GDP, infrastructure investment, and machinery investment in the Netherlands, 1850-1913, constant prices; in millions of 1913 guilders. Note: GDP on left axis, investment on right axis.

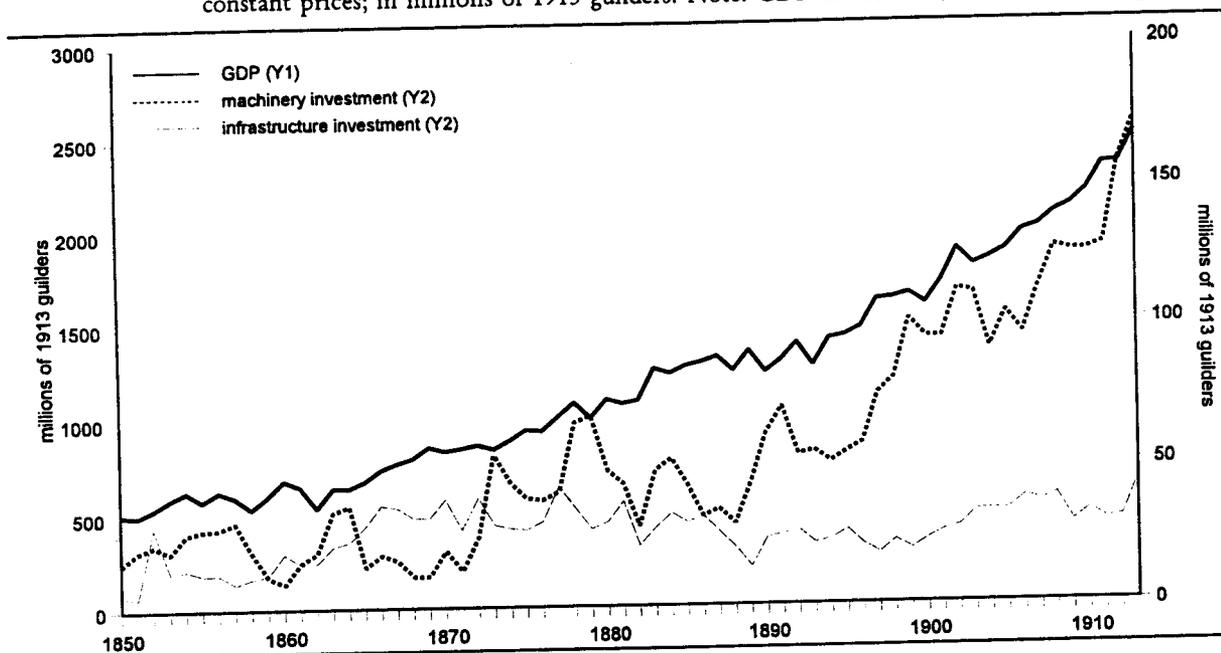


Figure 1 shows the development of infrastructural capital formation in the Netherlands in the study period. Apart from the outlying peak in 1853, due to the reclamation of the *Haarlemmermeer* mentioned before, a boom in infrastructural activity started around 1860 and lasted until approximately 1885. In 1860 a Railway Act passed Parliament, which authorized the central government to construct a national railway network, as a supplement to the existing privately owned lines. Before 1860, the latter measured just 350 kilometres of not interlinked lines.⁵ Upto 1885 the government had built 1250 kilometres of railway lines, and the private sector had also jumped in with the construction of 700 additional kilometres. Public and private lines were well interconnected. On average, annual gross fixed capital formation in railways amounted to 11.5 million guilders of 1913 (average of 1860-1885), with a peak of 20.5 million guilders in 1866.⁶ These activities asked for more than 1 percent of national income (weighted average 1860-1885).⁷ At the same time, the existing system of natural and artificial waterways was enlarged, integrated, and modernized. Until the 1820s, the country had relied on its natural and historical endowment with rivers, barge canals dating from the seventeenth century, and coastal and estuary waters (De Vries 1981; De Jong 1992). These had, however, become unsuited for increasing demands on the scale and reliability of transport. Entrance from the

5 These and all following data on infrastructure in the Netherlands are taken from Groote (1995).

6 If not otherwise stated, all value figures are given in constant 1913 prices.

7 Data on national income were kindly supplied by Edwin Horlings & Jan Pieter Smits (Buyst, Smits, and Van Zanden (1995); see also Maddison (1995)).

sea to the main harbours retrogressed as tidal estuaries silted up. The main rivers coped with the same problems, causing shallows waters in summer, ice drifts in winter, and regular flooding in spring. Many small rivers and barge canals needed enlargement and interconnection, but particularism in the organization, which was in the hands of local administration, prevented this. In the 1820s a number of canals were constructed in a first try to overcome these problems, but these proved not very successful.

After 1850 the country's main rivers, which linked the Amsterdam and Rotterdam harbours with the German hinterland, were improved in order to make them navigable all year. In this, the Treaties of Mainz (1831) and Mannheim (1868), in which Rhine shipping was liberalized, played an important role. The country's main harbours got new direct links to the North Sea. In Amsterdam work on this was begun by a private, London based, company. Private investors originally thought canal construction could be made profitable in conjunction with land reclamation in the Amsterdam region. This proved to be a mistake, as the project turned out to be more expensive than planned. The central government stepped in to complete the project. Capital formation in shipping canals and harbours peaked in 1870, when it amounted to over 15 million guilders.

Transaction costs in the Dutch economy were reduced further by the construction of a national telegraph network. Relative to other forms of infrastructure this did not ask for large sums of money, but as Field (1992) argues, its macroeconomic impact will have been much greater than shown by the sums spent.

Historians have often implicitly assumed that these huge infrastructural investments fundamentally changed the character of the Dutch economy. They were not able to quantitatively test this belief, however, as they did not have at their disposal the data nor the techniques to do so. Now that we do have these, in this paper we can give quantitative evidence confirming the belief.

In the econometric analysis in this paper, we use capital formation figures instead of capital stocks because of the inherent problems of making capital stock estimates for infrastructural works using the standard perpetual inventory method. Feinstein (1968) has convincingly argued that the 'awkward' life cycle of infrastructural works, often without a clear date of 'birth' and nearly always without a clear moment of retirement, makes them less suited for application of the perpetual inventory method.

The data on capital formation in aggregate, basic, and complementary infrastructure are reproduced in the appendix to this paper. Data on infrastructural investment are available from 1800 onwards, but data on GDP and machinery investment only from 1850. Our sample period starts in 1853, in order to exclude from the analysis the outlying peak in infrastructural investment in 1852, caused by the reclamation of the *Haarlemmermeer*. As this was a public project unprecedentedly large in scale, we do not want it to influence our

results. We feel confident to do so, as any bias caused by the exclusion of this outlier in the series will probably work against our main hypothesis.

We do not use per capita figures in the analysis. A reason for this is that infrastructure is by definition characterized by (technical) indivisibilities and constant or increasing returns to scale. Therefore, the economic effects of infrastructural investment will pay off on the aggregated macrolevel. These aggregate effects would only partially be taken into account, if population growth would be used as a scaling factor.⁸

Regarding the time series characteristics of the data, the major distinction is between stationary and nonstationary processes, the latter normally containing unit roots (see Mills [1992] for "An economic historians' introduction to modern time series techniques in econometrics"). A process is called stationary if its first two moments, the mean and (co-

Table 2 Unit root test outcomes: Augmented Dickey Fuller t-statistics on the time series of levels of (natural logarithms of) GDP, machinery investment, and infrastructure investment, 1853-1913, with trend, constant, and appropriate number of lags included

series	t-statistic ^a
<i>GDP</i>	-4.98**
<i>machinery investment</i>	-4.49**
<i>infrastructure investment</i>	-3.70*
<i>basic infrastructure</i>	-3.80*
<i>complementary infrastructure</i>	-3.72*

^a At a 5 (1) percent significance level the MacKinnon critical values are -3.49 (-4.13) when a trend and a constant are included
* Significant at the 5 percent level
** Significant at the 1 percent level

)variance, are time independent. The asymptotic distributions of the causality tests that we will apply are sensitive to the existence of such unit roots. We first test whether our variables have unit roots by running Augmented Dickey Fuller tests (see Dolado *et al.* [1990]). Comparison of the t-statistics resulting from these tests, and the corresponding critical values as calculated by MacKinnon (1991), shows that all our time series are trend stationary (table 2). Trend stationarity implies that first-differencing of the time series is not necessary, and that we can build our model in levels of (the natural logarithms of) the original data. This in itself is a remarkable result. Post World War II economic time series are almost without exception difference stationary, being integrated, mostly of order 1, and necessitating first-differencing. Although corresponding (nineteenth century) time series for the United Kingdom (based on Feinstein 1972, and Feinstein 1988) proved to be trend stationary as well, it would require another paper to test whether this is a general

8 Experimentation with population scaled variables did not alter our basic conclusions.

characteristic of nineteenth century economic time series. Recently, Crafts (1995b) has paid attention to the trend stationary character of British economic growth in the eighteenth and nineteenth centuries.

At first sight, the trend stationarity characteristic of our series only facilitates the mathematics. The normal procedure in business cycle analysis is to remove the trend from the series, and plug the detrended series directly in the econometric technique. Doing so, however, would preclude the analysis of long term effects, as these make up the trend! One would compare fluctuations around the trend of the one series with fluctuations around the trend of the other series. In the analysis of long term effects, we opt for the less common, but still valid procedure of incorporating the trend in our model. In the analysis of short and medium term effects, we do things in the usual manner by first detrending our series. In the formulas in the remainder of this article we will refer to our (detrended) series with underscore letters: y is gross domestic product, i is investment in infrastructure, and m is investment in machinery and equipment.

A GRANGER-CAUSALITY ANALYSIS IN A VECTOR AUTOREGRESSION MODEL

In order to test our main hypothesis of a significant effect of infrastructural investment on GDP, we apply the concept of Granger-causality, and the combined techniques of vector autoregression- and impulse response analysis. In essence Granger-causality is a statistical concept of antecedence, or predictability. The results address the question of whether one variable helps to explain the subsequent time path of another (Eichengreen 1983, 154; Mills 1992, 39-40). This interpretation of causality is intuitively appealing to historians, conscious as they are of the importance of time as an explanatory factor. In Granger-causality terms, our main hypothesis reads as follows: infrastructural capital formation causes a rise in GDP, if the time series prediction of GDP from its own past improves when lags of infrastructural investment are added to the equation.

Simple Granger-causality analysis may be obstructed by simultaneity, or feedback effects: infrastructural capital formation may Granger-cause GDP, while at the same time GDP causes infrastructural capital formation. To avoid this analytical problem, we analyse Granger-causality in a vector autoregressive or VAR model. VAR methodology resembles simultaneous equation modelling in that several variables are considered together, but in a VAR model do only endogenous variables enter. Each variable is explained by its own lagged, or past, values and the lagged values of the other endogenous variables. An advantage of VAR as a solution to the simultaneity problem is that VAR imposes no restrictions based on supposed *a priori* knowledge of the dynamic linkages in the model (see

Knot 1995, 17). The only decision that must be made beforehand concerns which variables to include, not their causal relationship.

We opt to add machinery investment to the analysis as a control variable, apart from gross domestic product and infrastructure investment as the key variables. The reason for including machinery investment is obvious: private investments in machinery are made to increase profits and by this will generally increase output. It would be hard to believe that only infrastructural investments would raise output.

If p lags are included, our basic VAR model would look like this:

$$\begin{pmatrix} y \\ m \\ i \end{pmatrix}_t = A_1 \begin{pmatrix} y \\ m \\ i \end{pmatrix}_{t-1} + A_2 \begin{pmatrix} y \\ m \\ i \end{pmatrix}_{t-2} + \dots + A_p \begin{pmatrix} y \\ m \\ i \end{pmatrix}_{t-p} + \begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix}_t$$

The A_i -terms ($i=1, \dots, p$) are 3×3 matrices with parameter values. The first column in the A_p matrix gives the effects of the p -th lag of y on respectively y itself, m , and i . In the same manner, the second and third columns give the parameters for the effects of m and i on y , m , and i . On the diagonal of each matrix are the effects of each variable on itself, whereas, for example, the upper right cell gives the effect of infrastructure investment on output. The u 's are error terms. In this setting, the analysis of Granger-causal effects of investment in infrastructure boils down to testing whether the sum of the parameters for lags of i differ from zero. For statistical reasons, we apply likelihood ratio tests to do this.

A disadvantage of VAR modelling is that the number of parameters to be estimated can easily grow large. If every variable is allowed to influence every other variable, the number of parameters that must be estimated increases with the square of the number of variables. In our case, with three endogenous variables, each extra lag that is incorporated in the model, brings in one extra A_i matrix with 9 extra parameters. This chews up degrees of freedom and renders interpretation of test statistics based on asymptotic distribution theory dubious. Often, however, a substantial number of parameters hardly differs from zero, and can be omitted from the model. Therefore we combine Granger multivariate causality tests with the Final Prediction Error (FPE) criterion (Akaike 1969, 1970) in order to select the appropriate lag specification for each explanatory variable in each equation. FPE makes it possible to judge whether the inclusion of an extra lag significantly diminishes the error term in the final prediction of the model. Application of FPE reduces the complexity of the model and preserves degrees of freedom in the data. It increases, however, the econometric complexity of the estimation of the model. In the current paper we will not digress on the details of the FPE procedure, but we may refer to a complementary paper wherein we treat the subject extensively (Sturm, Jacobs & Groote [1995]).

Results of Granger-Causality Tests

The estimated parameter values of our long term VAR model are summarized in table 3. For each equation we report on three aspects. First, we give the number of lags to be included for each variable, as determined by the FPE procedure. Second, we give the sum of the coefficients of these lags. Finally, the table displays the outcomes of Wald tests on the significance of these sums. We did also derive the coefficients for each individual lag, but we do not report these, as interpretation of the values of the coefficients is dubious, due to contemporaneous links between the equations. Of course, the same holds for their sums. These do enter in the table, however, because their signs tell whether or not there is a significant positive or negative long run relationship between the variables.

As shown in table 3, we find evidence for five statistically significant Granger-causal relationships: GDP, machinery investment and infrastructural investment all Granger-cause themselves, infrastructure also causes GDP, and GDP causes machinery investment. It comes as no surprise that for each endogenous variable most explanatory power is held by

Table 3 VAR model parameter estimates aggregated over all lags, model with aggregated infrastructure, 1853-1913

Effect of:	Effect on:	GDP				machinery investment				infrastructure investment			
		#	sum	χ^2	p	#	sum	χ^2	p	#	sum	χ^2	p
GDP		3	0.96	688.44	0.00	1	0.73	16.97	0.00	0			
machinery investment		2	0.02	1.44	0.23	1	0.58	34.99	0.00	0			
infrastructure investment		1	0.06	6.55	0.01	0				1	0.69	73.08	0.00
R^2			0.98				0.86				0.55		

Legend:
= number of lags of the relevant parameter included in the model after application of the FPE-criterion
sum = sum of coefficients for all lags of the relevant parameter
 χ^2 = value of Wald test statistic
p = significance level, indicating the chance that H_0 (sum of coefficients=0) is true

its own lagged values. More relevant is that our main hypothesis is confirmed. The values in the second to fifth columns of the fifth row, show that the effect of infrastructure investment on GDP is positive and significant at the 1% percent level ($\chi^2=6.55$, with a corresponding p-value of 1%, and thus a 99% probability that the coefficient differs significantly from zero). In contrast, machinery investment is not a significant explanatory variable of GDP ($\chi^2=1.44$). The individual coefficients for machinery investment after 1 and 2 lags, which are both significant and included in the model, have different signs and seem to counteract each other. No Granger-causal relationships exist between infrastructure and machinery investment.

As we have defined infrastructure as rather a hotchpotch of capital assets, which all share some basic characteristics, but still may have different effects on the economy, it may be illuminating to disaggregate it. We have done so in various ways. The most rigorous one

shows that it is railways that accounts for the larger part of the effect on GDP (table 4). With 99% confidence we can say that railway investment Granger-causes GDP. The effect of machinery investment on GDP is not significant and investment in other infrastructure is removed from the model by the FPE criterium. Again, the lagged values of all variables are the most significant explanatory factors of the variables themselves. GDP explains not only machinery investment, but also both forms of infrastructure. Interestingly, the sum of the coefficients on railway investment has a negative sign, indicating that a rise in GDP would bring about a decline in railway investment. Below, we will argue that this may be explained by the economy transcending to a different technology. Railway infrastructure has a positive effect on other forms of infrastructure. This is not surprising, as complementary relations between railways and other forms of transport infrastructure, for example tramways and turnpikes may be expected, the latter serving as feeders to the former. No Granger-causal relation running from railways or other forms of infrastructure to machinery investment could be detected.

Table 4 VAR model parameter estimates aggregated over all lags, model with disaggregated infrastructure (railways and other infrastructure), 1853-1913

Effect of:	GDP				machinery investment				infrastructure investment							
	#	sum	χ^2	p	#	sum	χ^2	p	railways				other			
Effect of:	#	sum	χ^2	p	#	sum	χ^2	p	#	sum	χ^2	p	#	sum	χ^2	p
GDP	3	0.97	928.07	0.00	1	0.67	11.66	0.00	4	-0.58	6.47	0.01	3	0.34	13.13	0.00
mach. inv.	2	0.03	2.61	0.11	1	0.56	37.55	0.00	0				0			
railways	4	0.03	7.80	0.01	0				4	0.46	16.40	0.00	5	0.18	14.04	0.00
other	0				1	0.15	0.66	0.42	1	0.59	4.11	0.04	2	0.36	6.65	0.01
\bar{R}^2		0.98				0.87				0.56				0.69		

Legend:

= number of lags of the relevant parameter included in the model after application of the FPE-criterium

sum = sum of coefficients for all lags of the relevant parameter

χ^2 = value of Wald test statistic

p = significance level, indicating the chance that H_0 (sum of coefficients=0) is true

The empirical evidence presented thus far shows that infrastructure investment has a significant positive influence on GDP. It is mainly the basic forms of infrastructure, in essence railways, that underlie this relationship. The generally held thesis that it is indirectly through machinery outlays that infrastructure influences GDP is not confirmed by our analysis of the nineteenth century

Impulse Response Analysis

In basic VAR analysis it is not possible to use the estimated coefficients to make direct statements about the *size* of the estimated effects. Sims (1980) proposed to work around this problem, and to analyse a VAR model by observing the reactions over time of shocks on

the estimated system. Following Sims (1980), we have rewritten the autoregressive process in its moving average representation (see Sturm, Jacobs, and Groote [1995] for econometric details). This allows us to trace the time path of the various shocks on the variables contained in the VAR system in a so-called impulse response analysis (see Eichengreen 1992).

Unfortunately, the possibility of correlation between the error terms renders it impossible to measure the total impact—direct and indirect via the other variables—of a shock on any specific variable directly. To overcome this problem, we must introduce a causal ordering in the variables (Sims 1980). By doing so, one of the strengths of VAR analysis—the possibility to abstain from imposing *a priori* theoretical restrictions to the model—is lost. It must be stressed, however, that this causal ordering is only concerned with the instantaneous response, thus at time $t=0$, to the shock imposed. Later responses are all derived from the estimated model, and not imposed upon it.

From our main hypothesis, it is clear that infrastructure must be at the basis of our causal scheme. This is backed by the fact that infrastructure investment decisions are often taken by the government. This makes infrastructure investment the most exogenous of our variables. It is logical to place GDP at the other end of the causal scheme, as we are interested in the reactions of GDP to infrastructure investment. This also facilitates comparison with single equation studies. We assume therefore that shocks in i influence y and m in the same period, and shocks in m influence y . Shocks in y do not have any instantaneous impact, but do induce responses in later periods. Experiments with other causal schemes did not lead to substantially differing results. For an overview of the effect of changes in the underlying causal scheme on the analysis, we may refer to Sturm, Jacobs, and Groote (1995).

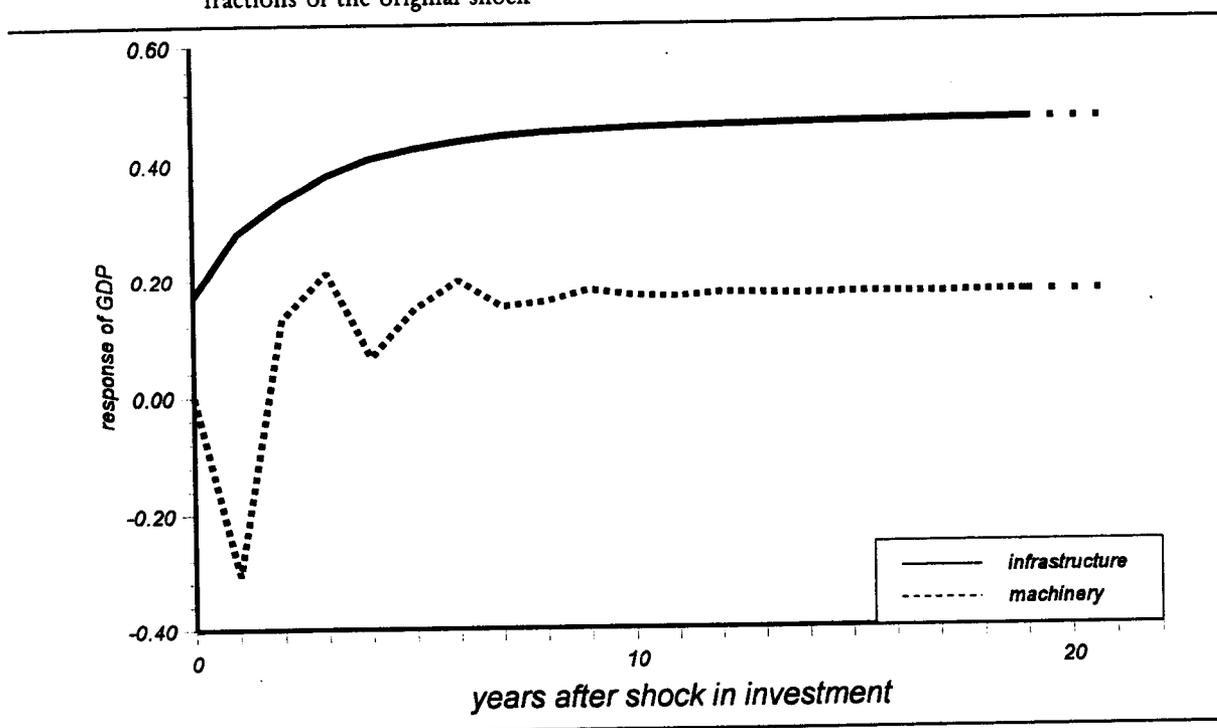
Response of GDP to Shocks in Infrastructure Investment

Figure 2 shows both the size and the duration of the calculated response of GDP to shocks in total infrastructure investment and in machinery investment. The size of the response is measured in fractions of the original shock, which we gave a size of one standard deviation. The duration of the response is set out on the horizontal axis of the graph, and is measured in years. The impulse response curve for machinery investment is drawn in the same graph to provide a standard for comparison. It must be kept in mind, however, that the aggregated effect of machinery on GDP is not statistically significant (table 3).

Obviously, our main hypothesis is again confirmed: investments in infrastructure have an important and long lasting effect on the level of GDP. The response of GDP to a shock in machinery investment is clearly lower. It takes a considerable time for GDP to fully realize the growth opportunities offered by the impulse in initial infrastructure investment.

Therefore it might be interesting to take a closer look at the short and medium term effects, leaving aside the long term effects analysed thus far.

Figure 2 Long-term response of GDP to shocks in infrastructure respectively machinery investment; in fractions of the original shock



Medium and Short Term Effects: VAR and Impulse Response

If we want to take a closer look at the short and medium term effects of investment on GDP growth in our period of study, we must remove the trend from our time series, which above were shown to be trend stationary. For each series we removed the trend, including the constant, by estimating an OLS regression consisting of a constant, a trend, and an error term. The residuals represent the new, detrended series.

Table 5 VAR model parameter estimates aggregated over all lags, detrended model with aggregated infrastructure, 1853-1913

Effect of:	Effect on:	GDP				machinery investment				infrastructure investment			
		#	sum	χ^2	p	#	sum	χ^2	p	#	sum	χ^2	p
	GDP	1	0.22	3.66	0.06	0				4	-0.69	1.22	0.27
	machinery investment	2	0.00	0.02	0.89	2	0.46	16.49	0.00	0			
	infrastructure investment	5	0.09	12.46	0.00	0				1	0.70	66.46	0.00
	R^2		0.33				0.36				0.57		

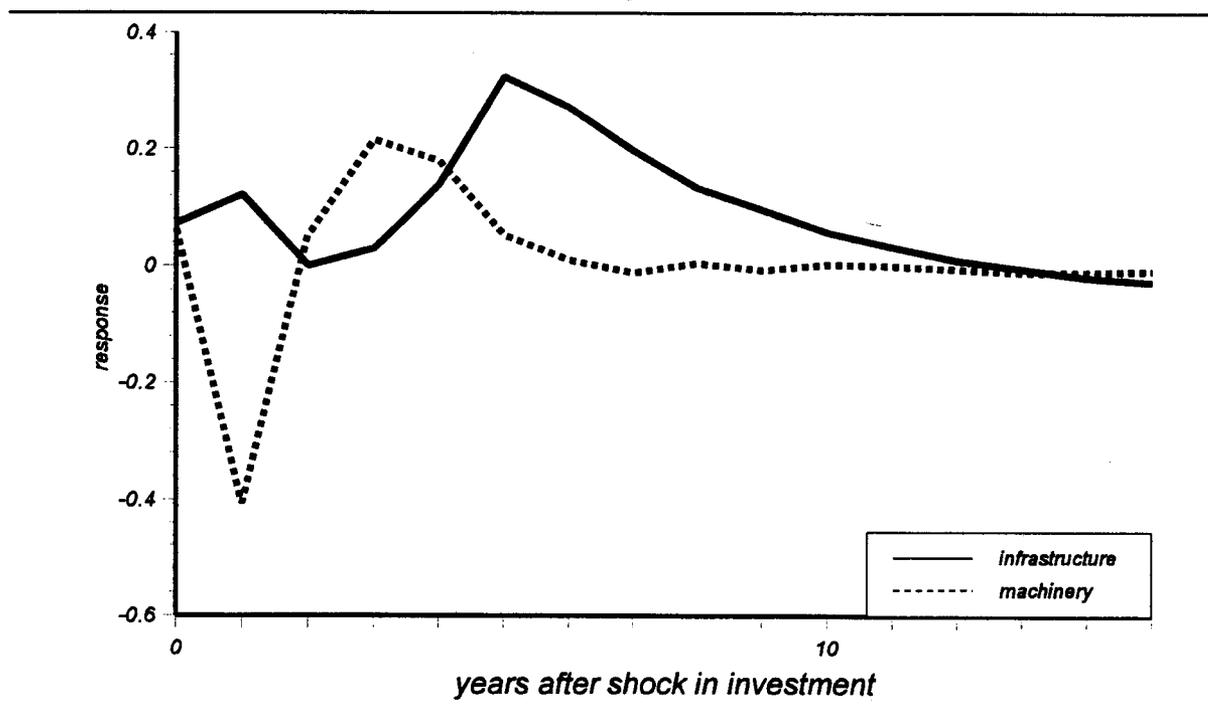
Legend:

= number of lags of the relevant parameter included in the model after application of the FPE-criterion
sum = sum of coefficients for all lags of the relevant parameter
 χ^2 = value of Wald test statistic
p = significance level, indicating the chance that H_0 (sum of coefficients=0) is true

The results of the Granger-causality tests and the estimated parameter values of our VAR model are given in table 5 in the same manner as the earlier results in tables 3 and 4. In essence, the results are the same as for the long term model. All variables Granger-cause themselves, although the χ^2 statistic of 3.66 for GDP is not very convincing. The other important Granger-causal relation is between infrastructure investment and GDP, which is significant at more than the 99% level. That our main hypothesis is confirmed again may seem reassuring, but not very spectacular. It suggests, however, that the long run effects demonstrated earlier are built up from short and medium term effects. With this, it becomes interesting how the latter do substantiate through time. Above, we have already introduced impulse response analysis as a means to tackle this question.

Figure 3 gives the short and medium term response of (detrended) GDP to a shock in (detrended) infrastructure investment. The time pattern of the response of y to a shock in i this does not gradually build up to its peak. At first the response of GDP to infrastructure investment is positive, although not very substantial. Then it gradually diminishes to come

Figure 3 Response of GDP to a shock in infrastructure investment, short and medium term model with detrended series; in fractions of the original shock



close to zero after the second year. Next, it regains momentum again, to peak after six years. Thereafter the response dies out gradually, and even gets negative.⁹ Unfortunately, we can only speculate on the plausibility and underlying reasons of this peculiar time

9 As only trend stationary time series that have been detrended before analysis are included in this model, no permanent effects can exist. Therefore, the response curve must eventually approach zero.

pattern of the response of GDP to a shock in infrastructure investment. It is impossible to quantitatively test any underlying hypothesis on our original data set, because the data were used to build the model in the first place. No degrees of freedom are left to do any formal testing. Therefore, we can only go so far as to make our hypothesis as convincing as possible by transparent reasoning and comparison with stylized facts from the literature (see Eichengreen (1992), 62-73, for a similar approach).

Our hypothesis is that the time pattern of the response curve may be seen as the resultant of three underlying processes, which are all known from the literature: forward linkages, backward linkages and transitional dynamics. We are of the opinion that decomposition of the aggregate response function as described underneath is convincing, without denying the possibility of other hypotheses. As far as we know, up to now no methodology exists to econometrically decompose the aggregate response function. In Sturm, Jacobs and Groote (1995) we have taken some steps in this direction by introducing a variance decomposition of the response functions. It would require a separate, and more econometrically oriented paper to further develop a suitable methodology for the decomposition of the response function itself.

The first process we discern in the aggregate response curve has to do with regular forward linkages, or cost reductions to sectors using infrastructural services as an input in their process of production. The improvement of transport infrastructure obviously reduces transport costs. These are captured by entrepreneurs and consumers in the transport sector itself, and through the price mechanism passed on to other sectors. The improvement in communications infrastructure gives economic agents more and better knowledge of the market and reduces transaction costs. The improvement in water management and hydraulics infrastructure reduces risk and uncertainty. The improvement in utilities infrastructure, finally, reduces production costs through the availability of cheap and reliable sources of energy, and increases the value of human capital through sanitary improvements. It is clear that through these forward linkages infrastructural investments generate a positive response from GDP. As a chain of reactions from economic agents, influencing each other's behaviour, is needed to capture the forward linkage effects completely, the response will not subsume immediately, but will be stretched out over some period of time. Due to ordinary decreasing marginal returns, the response curve is downward sloping, probably concave.

The second process also produces a positive and downward sloping response curve, but on a much shorter time scale, and with a much steeper slope. It is driven by direct backward linkages, or expenditure effects. Since the construction of infrastructure itself is an economic activity, it stimulates the demand for labour, raw materials, other capital goods, entrepreneurship, technology, and institutions. This will generate additional income that

circulates through the economy for some time. Below, where we subdivide infrastructure, we will go deeper into the backward linkages. It will suffice here to give a measure of the exact size of the backward linkage effects. Groote (forthcoming) contains a calculation of the annual demand for labour which was induced by the construction of infrastructure. By dividing the total wage sum by the average earnings per worker in the year concerned, it is possible to estimate the total number of workers employed. In 1877 almost 3 per cent of the total Dutch labour force was employed in the construction of infrastructural works, comprising 43,000 working years. About a third was directed towards railway construction (Albers and Groote 1994, 366).

The third response curve is perhaps the most interesting, although the most controversial and speculative as well. It is negative, but upward sloping. Thus, it induces an initial *decline* in relative economic performance. From the graph it is clear this decline is almost strong enough to fully absorb positive forward and backward linkage effects two years after the initial shock. The negative response is caused by what we already referred to in the introduction: the costs of adapting the economic system to changes in its fundamental characteristics. Infrastructure is by definition of fundamental importance to the rest of the economy. Therefore, infrastructural investments cause changes in the basic economic system that economic agents need time and money to adapt to. On several occasions Paul David has elaborated on this (for example David 1985; David 1990). David (1990) gives an explanation of the surprising absence in the economic statistics of the 1980s of a productivity boost thanks to the breakthrough of the computer. In his view, this problem must be approached (1) from a perspective offered by the economic history of *large technical systems characteristics of network industries*, and (2) from a time scale appropriate for thinking about transitions from established technological regimes to their respective successor regimes. David then draws a parallel with the effects of the introduction of the electric dynamo after 1900, which to our opinion can be extended to the large scale infrastructural breakthrough half a century before (see Foreman-Peck (1991) and Crafts (1995b, 757), for similar points of view). It is the young, relatively small sectors that most easily overcome transitional problems. Older industries, which are firmly rooted in the preceding *large technical system*, will need more time. As these more inert industries normally have a larger share in output, this will further delay the showing up of any productivity effects in aggregate economic indicators.

As such, this story resembles recent ideas about the response of economic agents—and as a consequence national income—to technological shocks. Mokyr (1990) makes the distinction between “macroinventions” and “microinventions.” He defines the former as “...technological breakthroughs that constitute discontinuous leaps in the information set and create new techniques” (Mokyr 1990, 351). Crafts (1995b, 756-757) describes macroinventions as “...essentially exogenous and unpredictable ...” It is widely accepted

nowadays that growth of output and productivity in for example, the British industrial revolution, was not as fast as was to be expected from a simple technological point of view. The economy obviously needed a long time to really catch the new potential by developing a chain of microinventions following the macroinventions, before finally evolving to a situation of increased output and productivity (Mokyr 1990; Mokyr 1992; Mokyr 1993; Crafts 1995a). “‘Microinventions’ come through improvement, adaptation, and diffusion of a technology and notably involve learning by doing and learning by using” (Crafts [1995b], 757). If one reads “infrastructural transformation” for “macroinventions” —Mokyr himself frequently refers to types of basic infrastructure, such as gaslighting and the electromagnetic telegraph— Dutch economic development in the second half of the nineteenth century is reminiscent of this story. The economic system needed time to adapt to the profound changes in the infrastructural environment that had been brought forward in large part through political decisions that can be regarded both ‘exogenous’ and ‘unpredictable’ (Groote 1995, 84-85).

This is exemplified most clearly by changes in the geographical dispersion of economic activities. In numerous studies, infrastructural improvements, especially railways, canals and port facilities, are shown to have had a gradual, but eventually no less profound, effect on the locus of, for example ship building, brewing, and dairy industries in the Netherlands (Clement 1994, 204-206; Van der Knaap 1978; Passchier & Knippenberg 1978). This relocation of industries itself is one of the outcomes of regional specialization, which can again be seen as a behavioural response to the infrastructural improvements discussed. Regional specialization will have positive effects on the aggregated (national) economy, through economies of scale and economies of agglomeration (Lloyd and Dicken (1979), 260-300). On the regional level, however, it may very well have negative effects. These are caused by increased competition from outside regions with comparative advantages in the production of specific goods or services. Market integration, caused by infrastructural improvements, reduces the friction of distance and the natural protection stemming from this. Regions may be opened up for outside competition and local suppliers may be driven out of a more competitive market. In the geographical literature this phenomenon is noticed most often for developing countries. In the colonial era transport improvements were often explicitly directed to exploiting these so-called backwash effects to the advantage of the colonial power, but to the detriment of the local economy (see for example Taaffe, Morrill, and Gould 1963). Local and regional historians have repeatedly described the same phenomenon, with some regions within the national territory winning from market integration, but others losing from increased competition (see for example Kooij 1988). The same story can be told for countries winning and losing from becoming integrated in the world market through infrastructural improvements.

The aggregation of the three response processes described above —forward linkages, backward linkages, and transitional dynamics— may explain the larger part of the time pattern visible in Figure 2. One interesting aspect remains, however: the response curve does not only decline after 6 years, but even turns negative. It is tempting to again seek the explanation for this phenomenon in Paul David's concept of large technical systems characteristics of infrastructure, as discussed above. The line of thought would run as follows.

Large technical systems do not develop in a vacuum. Emerging systems are superimposed upon the systems they replace (Gökalp 1992). Railroad engineers have, for example, originally used existing land or canal based transport networks. This superimposition is not merely imitation, it also has elements of complementarity. Often, competition from the emerging system may lead to the adoption by the old system of characteristics of the new one (Fremdling 1990). Thus, outdated systems are not simply replaced by modern ones when the latter are the more profitable. Instead, a more subtle process evolves, in which the old system resists being overtaken. Large sunk costs, and close relations with the rest of the socio-economic system, may make this 'struggle for life' of the old system more successful than would have been expected from a static analysis. This is exactly the explanation put forward for the slow diffusion of the railways in the Netherlands in the first half of the nineteenth century (De Vries 1981). De Vries' thesis is that in the 1830s and 1840s the costs of changing the economic, geographical, and social environment that surrounded the network of barge canals were higher than the profits expected from building railways. In David's terms, switching from a navigation based regime to a railway regime was costly and therefore postponed until expected profits were able to cover these extra transitional costs. As such, infrastructure can play an important and long lasting role in shaping hysteresis or path dependency in economic development (David 1985).

From our analysis it might be concluded that in the second half of the nineteenth century this may have been the case. However attractive and appealing this argument may sound, to our opinion it would probably stretch the available evidence too far. For the time being, our data and the available econometric techniques do not preclude the possibility of mere statistical chance being responsible for the negative offshoot of the response curve. Also, one must keep in mind that this is only the case for the medium term response curve, based on detrended time series. In the long run analysis, the response curve approaches a constant level.

In our opinion, the explanation for the impulse response function as given above is a plausible, even persuasive, story. We would like to see it enhanced, however, by more quantitative evidence. Fortunately, some admittedly circumstantial, evidence can be supplied. In the first place, we can to subdivide aggregate infrastructure. This makes it

possible to test whether the negative response curve is indeed to be ascribed to transitional effects, and the initial positive response curve to backward linkages. In the second place, we can investigate what a shock in GDP will do to aggregate and disaggregated infrastructure investment. This will give another approach to our ideas on the role of infrastructure in shaping path dependency in economic development.

Disaggregated Infrastructure: Basic Infrastructure and Railways

As a starting point, we apply the subdivision in basic and complementary infrastructure as defined earlier. As an impulse in basic infrastructure must by definition have the more fundamental impact, we expect it to account for the larger part of the transitional costs. Complementary infrastructure, on the other hand, is expected to react more directly, but with less durability. Fortunately, this is exactly what happens when the response of y to shocks in basic and complementary infrastructure are compared.¹⁰ Basic infrastructure causes a large rise in GDP with a peak after five years, whereas the instantaneous impact of aggregate infrastructure on GDP can largely be attributed to complementary infrastructure (table 6).

Table 6 Short and medium term response of GDP to shocks in infrastructure (total, basic, railways and canals combined, railways only) investment; in fractions of the original shock in each component

Years after Shock	Total Infrastructure	Basic Infrastructure	Railways and Canals	Railways
0	0.072	0.083	0.033	0.316
1	0.132	0.065	0.007	0.133
2	0.013	0.009	-0.024	0.044
3	0.019	0.038	0.022	-0.087
4	0.129	0.097	0.230	0.431
5	0.317	0.328	0.354	0.308
6	0.268	0.279	0.260	0.203
7	0.195	0.198	0.187	0.263
8	0.131	0.136	0.130	0.078
9	0.094	0.079	0.094	0.117
10	0.057	0.053	0.066	0.075
11	0.031	0.028	0.047	-0.067
12	0.009	0.016	0.033	-0.021
13	-0.004	0.007	0.024	-0.046
14	-0.018	-0.003	0.017	-0.042
15	-0.026	-0.008	0.012	0.002

10 On statistical grounds, we have applied the following causal ordering: basic infrastructure investment, machinery investment, complementary infrastructure investment, GDP.

It is possible to continue on this path and strip basic infrastructure of any remaining more or less 'complementary' parts. We have done so rather rigourously, and analysed the impulse response functions of GDP on shocks in, firstly, railways plus canals, and, secondly, in railways only. It is not as easy as it would seem, however, to formulate a hypothesis regarding the expected results, as railways are generally accepted to have lacked the central position in the Dutch economy as they had in, for example, the British, Belgian or German economies. In these countries it was the demand for coal and iron by the railway sector that created huge backward linkages (Fremdling 1985, 5-85; Fremdling 1977). No less than 39 per cent of total pig iron output in Britain in the period 1844 to 1851 was delivered to the railways (Mitchell 1964, 327-328). In Germany this was between 22 and 37 per cent (1840-1859) (Fremdling 1985), and in Belgium 20 to 60 per cent (Laffut 1983, 220-221). The central position of the railways in the German coal-iron-steel industrial complex makes Fremdling (1977, 1985) conclude that railways were the leading sector in Germany's industrial revolution. Due to the absence of a large scale domestic coal-iron-steel industrial complex, this part of the story does not apply to the Netherlands. Almost all rails delivered for the railways in the Netherlands were imported directly. Forty-two per cent of the total was imported from Germany, twenty per cent from Belgium, and eighteen per cent from the United Kingdom (Albers and Groote 1994, 367). The remaining twenty per cent was delivered through Dutch intermediaries, which made it impossible to trace the origin. From this, it must be concluded that the demand for labour was the main backward linkage of railway construction in the Netherlands in the nineteenth century. In this, railways did not differ from other sectors of infrastructure in the Netherlands as they did in the neighbouring countries.

In spite of this, the initial response of GDP to a shock in railway investment is still much higher than the response to total infrastructure. This suggests that backward linkages from railway construction, although lower than those in the United Kingdom, Germany, or Belgium, were still higher than those created by other infrastructural investments. This results from the fact that railway construction was more sophisticated and capital intensive than, for example, canal digging. It asked for more skilled labour, resulting in a higher wage sum, and higher expenditure effects. Although a large share of the capital goods used were imported, this still created backward linkage effects, namely in the trade and transport sectors. However, these linkage effects were more volatile than the ones in the countries that were able to build an industrial complex on railway induced demand.

Other Impulse Response Functions: Machinery Investment as a Cause of GDP Growth

To put the impulse response analysis of infrastructure investment in a broader perspective, we also look at the response of GDP to a shock in machinery investment (see figures 2 and 3). Both response curves differ in two ways, both of which are supportive of our main

conclusions. In the first place it remains on a lower long-run level, and in the second place it dies out earlier. The long-run response curve of machinery stays below the infrastructure curve, indicating that the aggregate effect of infrastructure investment on GDP in the period under study has been much larger (figure 2). From this it is tempting to conclude that investment in infrastructure in the nineteenth century has indeed been rational from a macroeconomic point of view. This deduction deserves, however, a more thorough foundation, which can only be delivered in a separate paper.

The short- and medium-run growth impulse of machinery investment dies out about twice as fast as infrastructure's (figure 3). After 7 years already, machinery investment ceases to have any significant effect on GDP-growth. Like the response of GDP to infrastructure investment, the response to machinery investment is characterized by an initial negative effect, albeit with a length of only one period. One might suggest that this must, again, be interpreted as transitional costs. It is not very plausible, however, that these would be as important for machinery as for infrastructure. It is a tautological truth that machinery is by definition not as fundamental to the economy as infrastructure. If it were, it would be labelled infrastructure. To our opinion a better explanation lies in the time lag of labour market adjustments, combined with learning by doing effects. In order to operate new machines effectively, an entrepreneur needs an experienced and large enough work force. It might easily take a year to hire and train the operators of the machinery, and to let them get acquainted with it. It may also be the case that it is not so much the transitional dynamics that explain the negative response for machinery after one lag, but rather a lack of backward linkage effects. In an open economy as the Netherlands, backward linkages from machinery investment will easily leak away to foreign countries through imports of machinery.

Without going into too much detail, the conclusion may be that it is possible to explain the response of GDP to shocks in machinery investment in the same vocabulary as we used earlier for the response of GDP to infrastructure investment. This may be regarded as evidence, albeit it circumstantial, of the tenability of the latter.

A Reversed Impulse Response Analysis: GDP growth as a Cause of Infrastructure Investment

Growth of GDP has the expected positive effect on investment in machinery (table 5). It has a negative effect, however, on investment in infrastructure. This can be interpreted as infrastructure being a large technical system, characterized by indivisibilities. The line of thought is reminiscent of the one put forward as an explanation for the eventual negative response of GDP to a shock in aggregate infrastructure investment. When, after heavy initial investment in infrastructure, a certain threshold in the level of infrastructure is attained, the economy starts to grow, mainly through investments in machinery. By then, indivisibilities ascertain an overcapacity in infrastructural services. Further infrastructural

needs are thus small and infrastructural investment will taper off. In other words: growth of GDP (through machinery investment) will go hand in hand with a (temporary) reduction in infrastructural investment.

After some time investment in machinery has gradually filled up the existing growth potential, and eaten up the initial infrastructural overcapacity. Often, technical progress in the infrastructural sector will by then have caused other forms of infrastructure to be the norm. As a result, a new large technical system will have to be superimposed upon an outdated one. In our data set, which describes the period 1850-1913, such an infrastructural regime switch is not included, although with the benefit of hindsight it is easy to point at the growth of electricity as an indication of such a regime switch to come. Therefore, we only find evidence for the negative relationship between GDP growth and infrastructural investment, and not the consecutive positive one.

If we consider the response of complementary infrastructure investment to a shock in the other variables, machinery investment and GDP turn out to have the largest short run impact. The medium-term response to shocks in basic infrastructure is not very impressive in size, but at the same time remarkably long-lasting. The response curve concerned even reaches a new peak after no less than eleven years. This will mainly be caused by complementary relations between national and regional network components, for example main railways and light railways, or the national telegraph system and local telephone networks. The latter serving as feeders for the former.

In the above manner, the results of all additional impulse response analyses performed can well be brought in line with our main interpretation of the response curve of GDP to shocks in infrastructure investment. As this interpretation is, at least to our opinion, intellectually appealing, relatively simple, rather convincing, and not yet falsified, we put it forward as for the moment the best explanation of the rather idiosyncratic short- and medium-term pattern of the effect of investment in infrastructure on GDP growth in the nineteenth century.

CONCLUSIONS

In this paper we have shown modern time series econometrics to be applicable and useful to the analysis of the evolution of the Dutch economic system in the second half of the nineteenth century. The length of the time series available and their statistical

characteristics enabled us to estimate the parameters of vector autoregression models describing both the long run and the short run dynamic links between investment in infrastructure and gross domestic product, with investment in machinery added as a control variable. The VAR model showed that in the period 1853-1913 annual investments in infrastructure Granger-caused GDP. The relation between machinery investment and GDP was not as unequivocally.

In this manner we have given a firm quantitative and statistical basis to intuitive conclusions drawn earlier from the description of the infrastructural system in the Netherlands in the nineteenth century.

Impulse response analysis revealed the time pattern of the relation between infrastructure investment and GDP. The medium and short run aggregate response of GDP to a sudden increase in infrastructural capital formation seemed to consist of three partial response curves. Initially, positive forward and backward linkage effects are partly rebutted by negative transitional dynamics. The latter correspond to well known patterns described by Paul David in terms of regime switches between large technical systems, and hysteresis, or path dependency in economic development.

APPENDIX 1: DATA

Gross fixed capital formation in infrastructure, the Netherlands, 1850-1913, constant prices; in millions of 1913 guilders

	Total	Basic	Complementary		Total	Basic	Complementary
1851	4.403	4.286	0.117	1881	37.366	31.365	6.001
1852	29.211	29.102	0.109	1882	21.451	18.790	2.661
1853	13.178	11.230	1.948	1883	27.708	21.775	5.933
1854	14.255	13.787	0.468	1884	32.909	27.940	4.969
1855	12.473	12.048	0.425	1885	29.452	21.572	7.880
1856	12.417	11.512	0.905	1886	31.701	20.795	10.906
1857	9.121	8.812	0.309	1887	26.019	18.955	7.065
1858	11.067	10.921	0.146	1888	20.432	14.536	5.896
1859	12.251	11.896	0.355	1889	13.434	9.984	3.450
1860	19.729	19.390	0.339	1890	23.725	21.014	2.711
1861	15.935	15.645	0.290	1891	24.846	22.253	2.593
1862	16.232	16.094	0.138	1892	26.167	21.123	5.044
1863	22.123	21.943	0.180	1893	21.564	18.313	3.251
1864	23.672	23.089	0.582	1894	22.968	19.487	3.481
1865	29.168	28.871	0.298	1895	26.105	22.307	3.798
1866	36.674	35.799	0.875	1896	20.860	13.743	7.117
1867	35.623	35.237	0.386	1897	17.667	12.675	4.992
1868	32.147	31.766	0.381	1898	22.212	15.697	6.514
1869	31.848	31.646	0.202	1899	19.024	12.658	6.366
1870	38.725	38.256	0.469	1900	22.686	15.216	7.470
1871	27.753	27.265	0.488	1901	25.487	16.486	9.001
1872	39.159	38.950	0.209	1902	27.116	14.961	12.155
1873	29.292	29.016	0.277	1903	32.690	16.712	15.978
1874	27.894	25.536	2.358	1904	32.973	16.308	16.665
1875	27.404	25.750	1.653	1905	32.826	17.371	15.455
1876	30.233	29.122	1.111	1906	37.336	26.832	10.503
1877	42.661	40.759	1.902	1907	35.603	23.468	12.135
1878	35.074	32.635	2.439	1908	37.836	27.192	10.644
1879	27.447	25.054	2.393	1909	28.122	17.561	10.561
1880	30.080	27.453	2.628	1910	32.565	18.318	14.247
				1911	28.833	16.405	12.428
				1912	29.735	16.459	13.277
				1913	43.076	23.782	19.293

Note: basic infrastructure consists of main railways, roads, canals, harbours and docks, telegraph, drainage and water management, dykes, land reclamation
complementary infrastructure consists of light railways, tramways, gas, electricity, water supply, telephone

Source: Groote (1995)

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