Productivity Impacts of Infrastructure Investment in the Netherlands 1853-1913

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Abstract

The effects of infrastructure investment on production are usually studied with post-war data. This paper finds strong evidence of a positive impact of infrastructure investment on the Netherlands'GDP in the second half of the 19th century. A brand new historical data set is exploited that allows the distinction between basic and complementary infrastructure investment. Whereas the effect is significantly positive for basic investment, it is absent for complementary investment.

Rather than estimating production functions as in the well-known model of Aschauer (1989a), data-oriented econometric techniques are employed, particularly Granger-causality tests in a Vector AutoRegression (VAR) framework. The VAR model is analysed with impulse response analyses and variance decompositions.

Keywords: infrastructure investment; Granger causality; VAR.

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1 Introduction

Recent years have witnessed a remarkable swell of interest in public infrastructure spending as a strategy to promote economic development. While specialists in regional and local economic development have long recognized infrastructure investment as a possible growth policy,[1] the genesis of this new attention is David Aschauer's (1989a) research on the impact of government investment on private sector productivity. This author hypothesized that the decrease in productive government services might be an explanation for the productivity slowdown in the United States (US) in the 1970s. He tested this hypothesis by running regressions derived from a standard Cobb-Douglas production function augmented by public capital. His empirical findings are impressive: over the period 1949 to 1985 a 1 percent increase in the public capital stock raised the level of output (all other things equal) by 0.39 percent.

Unlike previous regional/metropolitan studies, Aschauer's results lead to the conclusion that public capital is productive and not just a possible inducement to business location. Aschauer's timing could not have been better. Bill Clinton and his advisors were advocating public investment to revive the economy, thereby furthering research on this topic in the US. With some delay, the debate reached Europe, and many politicians now advocate a rise in public capital outlays.

Summarizing the economic literature, both Gramlich (1994) and Sturm and De Haan (1995) write that various economists found output elasticities with respect to public capital of around 0.3.[2] These implausible large elasticities have in turn generated a raft of criticisms from authors as for example Aaron (1990), Hulten and Schwab (1991) and Munnell (1992).

Our econometric approach in examining the effect of infrastructure on production differs from previous studies. Most authors derive single-equation regressions from first principles, run these regressions and base their conclusions on the elasticity

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1. See, e.g. Hirschman (1958), Mera (1973), Blum (1982), Helms (1985), Eberts (1986), Nijkamp (1986), and Silva Costa, Ellson and Martin (1987).

2. See, e.g. Ram and Ramsey (1989), Munnell (1990), and Ford and Poret (1991).

estimates. Because of the lack of theory and the empirical controversy over the effect of infrastructure on the private sector, we choose to use as little economic theory as possible. We apply Granger-causality tests in a multi-equation setting to find relationships between the variables. Granger-causality tests are typically carried out within the framework of Vector AutoRegression (VAR) models as propagated by Sims (1980). In a VAR model a limited number of variables is distinguished that are explained by their owns lags and lags of the other variables, meaning that all variables are treated as jointly determined. This implies that no a priori causality directions are imposed. For instance, the causality might run from output to infrastructure, which is the opposite of what is usually assumed. An additional advantage is that infrastructure might indirectly influence output by raising the return to machinery capital. Some authors, like Aschauer (1989b) and Erenburg (1993), report evidence for this complementary relationship between infrastructure and machinery investment.

We explicitly use the time series properties of our data set to construct the VAR model. Previous studies as, e.g. Aschauer (1989a) and Munnell (1990), often do not test for stationarity and obliviously use their data to analyse the effect of infrastructure on production. Furthermore, the effects of the different variables on each other are also examined by the computation of impulse response functions and variance decompositions.

As far as we know, only McMillin and Smyth (1994) used a VAR framework to examine the effect of government capital on private output.[3] This might stem from the fact that standard VAR methodology is not undisputed. For instance Cooley and LeRoy (1985) and more recently Duggal et al. (1995) note that in order to calculate impulse response functions and variance decompositions, restrictions with regard to ordering are needed. These restrictions can only be derived from theoretical consideration, thereby nullifying the advantage of VAR analysis. However, as we will show in section 4.2, the ordering of the variables is of minor importance in our model.

A further innovation of this paper is the exploitation of a new long run data set on infrastructural capital formation in the Netherlands in the nineteenth century. Only the post World War II period has been extensively explored in the literature. Mayer

3. Their small VAR model covers the 1952-1990 period for the US. No evidence of a significant effect of government capital is found.

(1980) argues that in applied econometrics one should seek to replicate previous results using a different data set. Groote's (1995) thesis on capital formation in infrastructure in the Netherlands in the previous century allows us to study the relation for the second half of that period. In the Netherlands not only the industrial revolution took place during this period, but also large infrastructure projects were carried out. For example, the construction of a national railway network started in 1860, and the existing system of natural and artificial waterways was enlarged, integrated, and modernised after 1850. It seems plausible that these infrastructural investments have induced, or at least enabled, the integration of markets that before were regionally and functionally separated. Our finding that investments in basic infrastructures, such as railways, roads and canals, have had large positive long-run effects on the production level of the Dutch economy in the previous century, gives a quantitative underpinning of this belief.

Gramlich (1994) noticed that data limitation forces economists to use public investment expenditures as a proxy for total infrastructure outlays. This may not be optimal. First of all, in many countries part of the infrastructure is financed and constructed by the private sector. Secondly, public investment often consists of much more than infrastructure investment alone. For instance, many governments are responsible for residential investments and spend on public buildings. Our data set solves both problems by capturing public as well as private infrastructure investment spending.

The paper is structured as follows. The next section gives a brief description of the Dutch economy in the previous century. Section 3 describes the data and their time series properties, whereas the fourth section presents our estimation results for the Netherlands. That section will be subdivided into three subsections, each capturing a topic in our estimation procedure. Finally, the paper ends with some discussion.

2 The Netherlands in the second half of the 19th Century

In the first half of the nineteenth century the foundations of Dutch wealth came under increasing pressure from foreign competition, thereby continuously losing ground on neighbouring countries (Maddison 1995). Infrastructural deficiencies hold a key position in explaining this slackness of Dutch relative economic performance. For instance, Griffiths (1979) argues that the impact of the high costs of raw materials, especially coal and iron, due to the lack of natural resources, was aggravated by high costs of transport and communications due to the lack of a modern infrastructure.[4] Therefore, the main breakthrough in the Netherlands took place after the 1860s when transport costs could be reduced thanks to a large scale rehabilitation of the country's infrastructure.

In 1860 the first Railway Act passed parliament. As a consequence, the central government started with the construction of a national railway network. Before, Dutch railways consisted of four separated lines with a total length of only 350 kilometres. In 1885 the Netherlands had 1250 kilometres of government railway lines. As government construction induced several private railway companies to participate as well, the total length rose to 2280 kilometres of well-integrated railway lines.

At the same time, the existing system of natural and artificial waterways was enlarged, integrated, and modernised. Until the 1820s, the country still 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). Unfortunately, these became unsuited for increasing demands on the scale and reliability of transport. For instance, the country's main rivers, which linked the Amsterdam and Rotterdam harbours with the German hinterland, were improved after 1850. At the same time, these main harbours got new direct links to the North Sea.

Transaction costs in the Dutch economy were further reduced by the construction of a national telegraph network. Relative to other forms of infrastructure, however, this did not ask for large sums of money. As Field (1992) argues, its macroeconomic

4. Other growth retarding factors mentioned are the high and sticky real wages, the national government wrestling to pay off an enormous debt (Mokyr 1976), and institutional rigidities on the local level squeezing entrepreneurial initiatives (Olson 1982).

impact may be regarded as much greater than shown by the sums spent. This is exemplified by the 6.4 million telegrams being sent in 1913 against a mere 6,000 in 1850.

It seems plausible that these infrastructural investments have induced, or at least enabled, the integration of regionally and functionally separated markets. Indeed, historically this has often been implicitly assumed, without any qualitative or quantitative testing (see, e.g. De Jonge 1968). After 1890 the main characteristics of the Dutch economy began to differ fundamentally. Sectors that are generally regarded as modern came to the forefront: metal working, machinery construction, chemicals. Investments in machinery became of more importance than those in structures.

3 The Data

3.1 Description

This paper builds on three relatively new data sets regarding Dutch economic development in the nineteenth century. These are the outcome of research efforts of participants in the project on "*The Reconstruction of Dutch National Accounts, and the Analysis of the Development of the Dutch economy, 1800-1940*", which has been under way since 1989 at the universities of Utrecht and Groningen. For the series on GDP (*y*) and on investment in machinery and equipment (*m*), we refer to Buyst et al. (1995) (1995), and Clemens et al. (1995). Both series are displayed in constant prices in figure 1. Because series for machinery investment are only available for the second half of the previous century, we consider the sample period 1853-1913 throughout the paper.

The data on infrastructural investments (*i*) are taken from Groote (1995). He gives annual time series on capital formation in current and constant prices, and subdivided by sector or type of asset.[5] Only the truly infrastructural aspects of these

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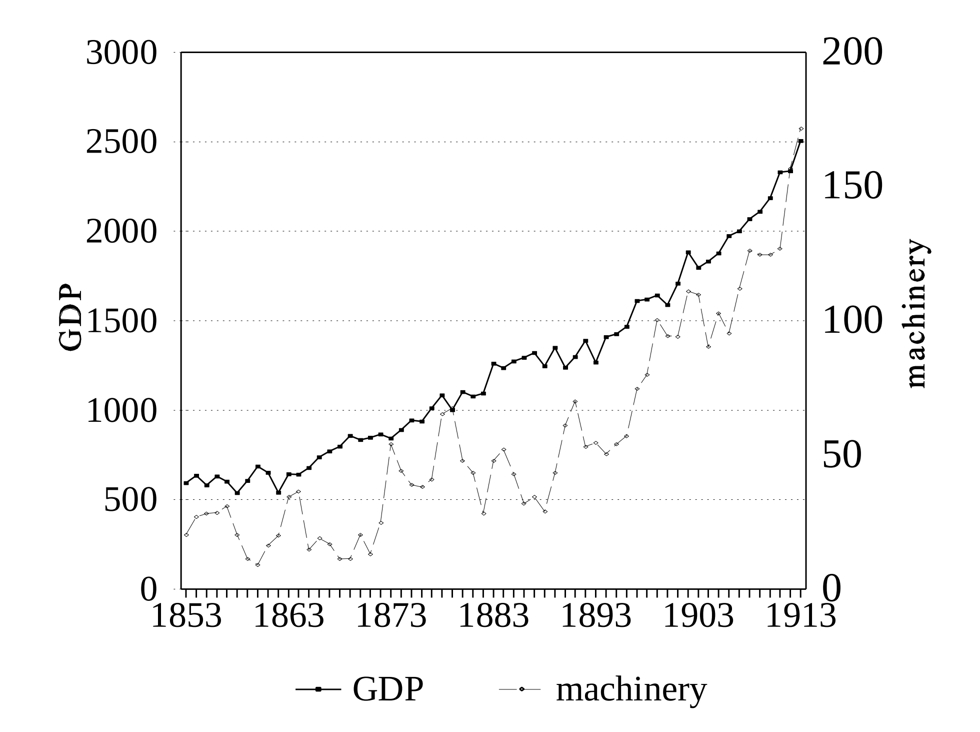
5. The data series will also become available in the English version of Groote's dissertation, which is due to appear in Spring 1996. Groote also gives long run series on capital stocks and the physical development of infrastructural works, e.g. the length of the networks of rail- and tramways, or the number of electrical power stations.

sectors are included. Thus, the permanent way and works of railways are included, but rolling stock is not.

Figure 1: Gross Domestic Product and investments in machinery in millions of constant 1913 guilders for the Netherlands, 1853-1913.



Because the definition of machinery and equipment is based on the definition of infrastructure, both series are complements: the summation of investments in infrastructure and in machinery and equipment gives total capital formation. Agricultural capital formation, including livestock, changes in stock and work in progress are all included in machinery investment, but investment in dwellings and other buildings are not.

For analytical reasons, we will divide infrastructure investments into, what we will call, basic infrastructure (i^B) and complementary infrastructure (i^C). Basic infrastructure investments consist of the 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 include: light railways, (urban) tramways, gas, electricity, and water supply, (local) telephone networks.

Figure 2: Investments in infrastructure subdivided into basic and complementary infrastucture in millions of 1913 guilders for the Netherlands, 1853-1913.

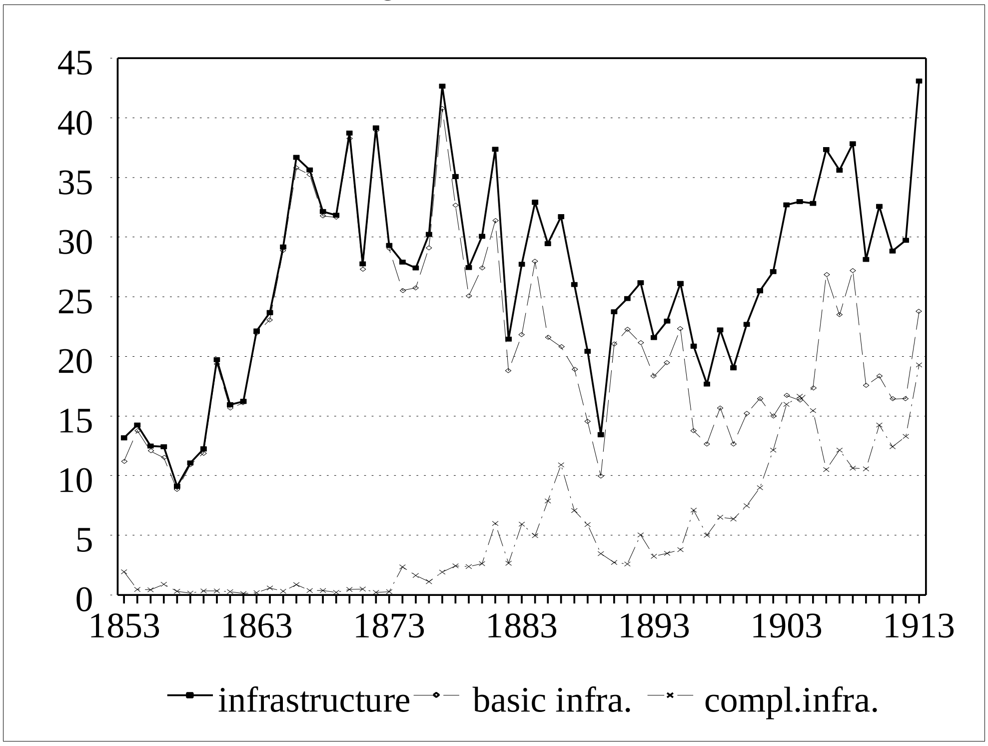


Figure 2 displays these two series and their sum, i.e. total infrastructural investments, in constant 1913 prices. As can be seen from this figure, investment in complementary infrastructure took off in 1874, before that year it was negligible. Except for 1904, basic infrastructure investments exceeded complementary infrastructure investments.

Prior to the analysis, natural logarithms are taken from all series.

3.2 Stationarity

The asymptotic distributions of causality tests are sensitive to unit roots and time trends in the data series (Sims, Stock and Watson, 1986). The finite sample distribution of these tests will also depend on these time-series properties (Stock and Watson, 1989). The rewriting of our original model, necessary to conduct impulse response analysis and variance decomposition analysis, assumes stability of the model. This condition prevails in case of stationary series. Therefore, non-stationary variables must be transformed into stationary ones before using them in our regression analysis.

To determine whether series are stationary, we follow the testing strategy suggested by Dolado *et al.* (1990) and use the Augmented Dickey Fuller (ADF) test. Dickey and Fuller (1981) consider the problem of testing the null hypothesis of non-stationarity versus stationarity, suggesting Ordinary Least Squares (OLS) estimation of:

$$\Delta z_t = \eta_0 + \eta_1 t + \eta_2 z_{t-1} + \sum_{j=1}^{p} \eta_{2+j} \Delta z_{t-j} + \varepsilon_t \ , \qquad (1)$$

where z_t is the series being tested, t represents the trend variable, p is the number of lags included, and ε_t is an independent identically distributed residual term.

The test is implemented through the usual t-statistic of the estimated η_2, denoted as τ_t. Under the null hypothesis the τ_t will not follow the standard t-distribution; adjusted critical values are computed by MacKinnon (1991). If τ_t is significant, the null of non-stationarity is rejected, and the series are stationary. If τ_t is insignificant, we estimate the same equation without a trend ($\eta_1 \equiv 0$) and again test for the unit root.

The number of lags used in the estimated equations is determined in a similar way as in Perron (1989). We started with five lags. If the last lag is insignificant at a ten percent level (using the standard normal distribution), it is omitted. Now four lags are included. Again it is tested whether the last lag is significant or not. This is repeated until the last lag is significant (or there are no lags left, in which case the test is called the Dickey-Fuller (DF) test). We took this large significance level because as Perron (1989, p. 1384) pointed out “including too many extra regressors of lagged firstdifferences does not affect the size of the test but only decreases its power. Including too few lags may have a substantial effect on the size of the test." Furthermore, Molinas (1986) noticed that "a rather large number of lags has to be taken in [the ADF test] in order to capture the essential dynamics of the residuals."

Table 1: (Augmented) Dickey-Fuller tests for non-stationarity, 1853-1913.

Series	Trend	Lags	*t*-statistic[a]
GDP	yes	0	-4.98**
Machinery Investment	yes	1	-4.49**
Infrastructure Investment	yes	0	-3.70*
Basic Infrastructure	yes	0	-3.80*
Complementary Infrastructure	yes	0	-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 (τ_t).
*Significant at a 5 percent level.
**Significant at a 1 percent level.

Table 1 reports the outcomes of the ADF tests. Except for '*Machinery Investment*', no lagged dependent variables have to be included. Comparison of the *t*-statistics resulting from these tests, and the corresponding critical values show that all our time series are trend-stationary. In our estimations we will therefore include a trend variable.[6] Filtering the trend from the individual series instead of including a trend in the regressions does not change the qualitative outcomes presented below.

6. McMillin and Smyth (1994) also include a trend in their model.

4 VAR analysis

4.1 Granger Causality Testing

In order to test whether infrastructure influences GDP we perform Granger causality analysis. We have to restate our main hypothesis to make it testable: infrastructural capital formation is said to ‘Granger-cause’ a rise in GDP, if the time series prediction of GDP from its own past improves when lags of infrastructural capital formation are added to the equation. This interpretation of causality is, of course, intuitively attractive. It has therefore become widely accepted, although some of its implications are still under debate.[7]

Simple Granger-causality analysis may be obstructed by simultaneity effects: infrastructural capital formation may Granger-cause GDP, while at the same time GDP Granger-causes infrastructural capital formation. To avoid this problem, we analyse Granger-causality in a so-called ‘Vector AutoRegression’ (VAR) model. VAR methodology resembles simultaneous-equation modelling in that several endogenous variables are considered together. In a VAR only endogenous variables enter: each variable is explained only by its own lagged, or past, values and the lagged values of the other endogenous variables. If necessary, deterministic variables, such as a constant or a trend, are included. An advantage of this solution to the simultaneity problem, is that *a priori* no identifying conditions, to be derived from economic theory, are needed. Beforehand, the only decision that should be made concerns which variables to include, and not their causal relationship. If the direction of causality is debatable, this is a clear advantage.

We have opted to include, apart from GDP and capital formation in infrastructure, capital formation in machinery and equipment.[8] The reason for this is obvious: private investments in machinery are made to increase profits by increasing output or productivity. This gives the following VAR model:

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7. For an early overview of pros and cons of Granger-causality, see Granger (1980).

8. The model in which total infrastructure investment is taken up will be described. By subdividing infrastructure the model can be expanded in a trivial way.

$$\begin{pmatrix} y_t \\ m_t \\ i_t \end{pmatrix} = \begin{pmatrix} a_{10} \\ a_{20} \\ a_{30} \end{pmatrix} + \begin{bmatrix} A_{11}(L) & A_{12}(L) & A_{13}(L) \\ A_{21}(L) & A_{22}(L) & A_{23}(L) \\ A_{31}(L) & A_{32}(L) & A_{33}(L) \end{bmatrix} \begin{pmatrix} y_{t-1} \\ m_{t-1} \\ i_{t-1} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{pmatrix}, \qquad (2)$$

where a_{j0} are the 1×2 vectors containing a constant and a time trend, A_{jk} are polynomials of order p in the lag operator L, and e_{jt} are independent and identically distributed disturbance terms such that $E(e_{jt}e_{kt})$ for $j \neq k$ is not necessarily zero.

In case the order p is known, each equation in the system can be estimated by OLS. Moreover, OLS estimates are consistent and asymptotically efficient. Even though the errors are correlated across equations, system estimators do not add to the efficiency of the estimation procedure since the regressions have identical right-hand-side variables (Harvey 1990, p. 68).

A practical disadvantage of VAR is that the number of parameters to be estimated can easily become large. In our case - with three endogenous variables - each extra lag that is incorporated in the model brings in nine extra parameters. This fastly chews up degrees of freedom in the estimation procedure. Often, however, a substantial number of parameters hardly differ from zero. Moreover, Ahking and Miller (1985) and Thornton and Batten (1985) have shown that imposing common lag lengths has no basis in theory and can distort the estimates and lead to misleading inferences concerning causality if lag structures differ across variables. To avoid this problem, we combine the multivariate Granger-causality tests with Akaike’s (1969, 1970) Final Prediction Error (*FPE*) criterion in order to select the appropriate lag specification for each explanatory variable in each equation. As Hsiao (1981) indicates, choosing the appropriate order of a model by using Akaike’s *FPE* criterion is equivalent to applying an approximate *F*-test with varying levels of significance.

To determine the appropriate lag length, each of the dependent variables is regressed on its own lags. A series of autoregressions is estimated by varying the order of the lag p from zero to our predetermined maximum lag length of seven years. The lag that minimizes the following *FPE* value is considered the appropriate own lag, which we designate as p^o:

$$FPE(p^o) = \frac{T+p^o+1}{T-p^o-1} \frac{SSR(p^o)}{T} , \tag{3}$$

where T is the number of observations, and SSR is the sum of squared residuals. The *FPE* criterion is appealing because it balances the risk due to increased variance when selecting a longer lag against the risk due to bias when a shorter lag is selected.

Once the appropriate own lag (p^o) is determined, the equation is expanded by adding lags of each of the remaining variables separately one at a time. For each additional variable, one varies again the lag order p^r and calculates the following modified *FPE*:

$$FPE(p^o,p^r) = \frac{T+p^o+p^r+1}{T-p^o-p^r-1} \frac{SSR(p^o,p^r)}{T} . \tag{4}$$

The appropriate lag length (p^r) is that which minimizes this *FPE*.

At this point, we determine the order in which the variables are added to the equation. To do that, we add first, to the appropriate own lag (p^o), the variable with the least minimum *FPE* among all equations with its appropriate lag determined in the previous step. Each of the remaining variables is then added, one at a time, with different lag lengths. The appropriate lag length for each of the additional variables is again determined by the above *FPE* procedure. We proceed in a similar fashion as above until all variables under consideration have been added to the first equation. Then the same steps are used to determine the specification for the other equations.

Application of the *FPE* criterium reduces the complexity of the model itself, but increases the complexity of its estimation. As the right-hand-side variables in each equation may now differ, a gain in efficiency can occur by using the Seemingly Unrelated Regression (SUR) estimator (Zellner 1962). This two-stage technique explicitly takes into account correlation between the error terms. At the first stage all equations are estimated with OLS, and the variance-covariance matrix of the residuals is constructed. In the second round the parameters are estimated with generalized least squares using the estimated variance-covariance matrix.

In this setting, the analysis of a Granger-causal relation from infrastructure on GDP boils down to testing whether the sum of the A_{13}-elements in equation (2) differs from zero. However, we cannot use ordinary F-tests, which apply to the individual equations, because the error terms may be correlated over the equations, and i affects *y* through these correlated error terms. Following Geweke et al. (1983), who indicate that the Granger procedure conducted using a Wald chi-square test statistic outperforms other causality tests in a series of Monte-Carlo experiments, we apply Wald tests on the system as a whole.

Table 2: VAR model using the FPE criterium to reduce the number of coefficients, 1853-1913.

Equation:	*GDP*			*Mach.Inv.*			*Infra.Inv.*		
Variable:	lags	sum	χ^2	lags	sum	χ^2	lags	sum	χ^2
GDP	1	0.17	2.21	0			4	-0.59	0.94
Mach.Inv.	2	-0.01	0.11	2	0.43	14.58**	0		
Infra.Inv.	5	0.09	15.55**	0			1	0.67	57.80*
adj. R^2		0.99			0.87			0.58	

**Significant at a 1 percent level.

Table 2 displays our results. For each equation we first report the number of lags that are included for each variable. Secondly, we give the sum of the parameters of these lags, and finally the table displays the outcomes of the Wald tests whether these sums are significant. Links between the equations hamper interpretation of individual coefficients. Therefore, we do not report the individual coefficients. Of course the same holds for the sums, but the signs of the sums give information on whether there is a positive or a negative relationship between the variables.

Interestingly, the combined coefficient of lagged GDP in the GDP equation is not significant, whereas the individual coefficients are. The same holds for machinery investment in the GDP equation. The effect of infrastructure investment on*y* is positive and significant at the 1% level. So our main hypothesis is confirmed: infrastructure investment is a significant explicand of GDP.

Besides infrastructure, only GDP enters the infrastructure equation. The negative sign of GDP indicates that a rise in GDP lowers infrastructure investment. However, and more important, the sum does not significantly differ from zero. Therefore, we only find evidence for an unidirectional relationship between infrastructure and GDP; infrastructure Granger-causes GDP without any feedback.

The most striking fact from the machinery equation is that no relationship seems to exist between machinery investment and infrastructural investment. This does not confirm the hypothesis that infrastructure positively influences GDP indirectly through machinery outlays. Also business cycles, as indicated by changes in GDP, do not influence investment decisions in machinery. Only machinery investments in previous years affect this year's investments.

Table 3: VAR model using the *FPE* criterium to reduce the number of coefficients, 1853-1913.

Equation:	*GDP*			*Mach.Inv.*			*Basic Infr.*			*Compl.Infr.*		
Variable:	#	sum	χ^2	#	sum	χ^2	#	sum	χ^2	#	sum	χ^2
GDP	1	0.18	2.66	0			0			5	2.35	2.35
Mach.Inv.	2	-0.01	0.09	2	0.48	18.39**	0			1	0.54	10.77**
Basic Infr.	5	0.08	15.84**	0			1	0.67	63.94**	1	0.28	2.58
Compl.Infr.	0			1	-0.10	2.98 '	0			1	0.52	28.16**
adj. R^2		0.99			0.88			0.56			0.91	

'Significant at a 10 percent level.
**Significant at a 1 percent level.

Summarizing, we find evidence of three relationships in table 2: machinery investment and infrastructural investment both Granger-cause themselves, and infrastructure Granger-causes GDP.[9]

Splitting up the infrastructure series into basic and complementary infrastructural capital spending allows some further conclusions. As table 3 shows, only basic infrastructure Granger-causes GDP. Between machinery investment and complementary infrastructural investment exists a two-way relationship; machinery

9. When using five lags for all variables, these conclusions do not alter.

investment has a positive influence on complementary infrastructure, whereas there is a slightly negative relationship the other way around. So again, no evidence is found that infrastructure might indirectly influence GDP through machinery investments.

As already noticed, the values of the coefficients cannot be interpreted as indicators of the size of the effects. Sims (1980) therefore proposed the so-called impulse response analysis, which we will discuss in the next section.

4.2 Impulse Response Analysis

Sims (1980) proposed to analyse a VAR model by observing the reactions over time of different shocks on the estimated system. Just as an autoregression has a moving average representation, a VAR can be written as a Vector Moving Average (VMA). The VMA representation is an essential part of Sims' (1980) methodology in that it allows to trace out the time path of various shocks on the variables contained in the VAR system. To get the VMA of equation (2) we have to iterate it backward to obtain:

$$x_t = b_0 + \sum_{j=0}^{\infty} B_j e_{t-j} \ , \qquad (5)$$

where $x_t = (y_t, m_t, i_t)'$, b_0 is the matrix containing constants and a trend, B_j are matrices filled with parameters, and e_t is the vector of residuals. A sufficient condition that makes this conversion possible is that the series are stationary. As section 3.2 has shown, this prerequisite prevails.

There are many equivalent representations for model (5): for any non-singular matrix G, B_j can be replaced by B_jG and e by $G^{-1}e$. A particular version is obtained by choosing some normalization. Without the use of such a G-matrix, i.e. $B_0=I$, each component of e_t is the error that results from the one step forecast of the corresponding component of x_t. These are the **non-orthogonal innovations** in the components of x; non-orthogonal because, in general, the covariance matrix $\Sigma=E(e_te_t')$ is not diagonal.

There are two principal advantages of orthogonalized innovations over non-orthogonal ones. First, because orthogonalized innovations are uncorrelated, it is very simple to compute the variances of linear combinations of them. Secondly, and more importantly, it can be rather misleading to examine a shock to a single variable in isolation when historically it has always moved together with other variables. Since the equations in the VAR contain only lagged values of the system's variables, any contemporaneous relations among the variables are reflected in the correlation of the residuals across equations. The cross-equation residual correlation is removed by orthogonalization.

If we choose matrix G so that $G^{-1}\Sigma G'^{-1}=I$ then the new innovations $\varepsilon_t=G^{-1}e_t$ satisfy $E(\varepsilon_t\varepsilon_t')=I$. These **orthogonalized innovations** have the convenient property that they are uncorrelated both across time **and** across equations. Matrix G can be any solution of $GG'=\Sigma$. There are many such factorizations of a positive definite Σ. We use those based on the Choleski factorization, where G is chosen to be lower triangular with positive elements on the diagonal (Graybill 1969, p. 299).

The Choleski decomposition implies an ordering of the variables from the most pervasive - a shock to this variable affects all the other variables in the current period - to least pervasive - a shock does not affect any other variable in the current period. In this manner some economic structure is imposed on the computation of the impulse response functions and the variance decompositions. Unfortunately, there are many ways to order the variables, and as, e.g. noted by Cooley and LeRoy (1985) and Duggal et al. (1995), the choice of one particular ordering might not be innocuous.[10] The key point is that the factorization forces a potentially important asymmetry on the system. We have to decide which is appropriate.

The importance of the ordering depends on the magnitude of the correlation coefficient between the e_{jt}'s. In case the estimated correlations are almost zero, the ordering is immaterial. However, if a correlation coefficient is almost unity then a single shock in the system contemporarily affects two variables. In that case, the usual procedure is to first obtain the impulse response functions using a particular ordering. Subsequently, these results are compared to the impulse response functions obtained

10. In case of k variables there are $k!$ ways of ordering them.

by reversing the ordering of the two variables. If the implications are quite different, additional investigation into the relationships between the variables is necessary. Fortunately, the largest absolute correlation in our first model, which is between total infrastructure and GDP, equals only 0.15, implying that the ordering of the variables is of minor importance.[11]

The ordering we will employ is '*infrastructure*', '*machinery*', '*output*'. Placing GDP last is consistent with the single-equation studies cited earlier. As in single-equation studies, the other variables in the model directly affect GDP. Thus placement of GDP last facilitates comparison of our results to single-equation studies. Placement of '*infrastructure*' first is based on the assumption that contemporaneous shocks to infrastructure investment stem mostly from government decisions, which we see as less endogenous than the other variables.

Orthogonalization allows us to rewrite equation (5) to the following VMA:

$$\begin{pmatrix} y_t \\ m_t \\ i_t \end{pmatrix} = \begin{pmatrix} b_{10} \\ b_{20} \\ b_{30} \end{pmatrix} + \sum_{j=0}^{\infty} \begin{bmatrix} \phi_{11}(j) & \phi_{12}(j) & \phi_{13}(j) \\ \phi_{21}(j) & \phi_{22}(j) & \phi_{23}(j) \\ \phi_{31}(j) & \phi_{32}(j) & \phi_{33}(j) \end{bmatrix} \begin{pmatrix} \varepsilon_{1,t-j} \\ \varepsilon_{2,t-j} \\ \varepsilon_{3,t-j} \end{pmatrix}, \qquad (6)$$

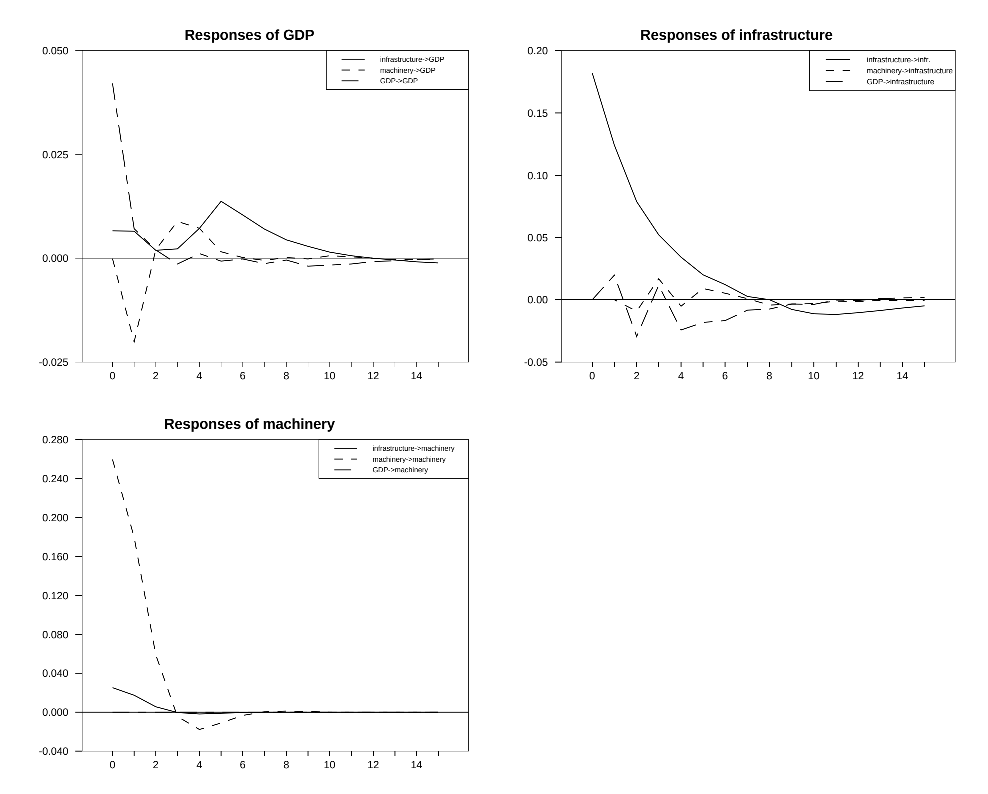
where $\Phi_j = B_j G$ and $\varepsilon_t = G^{-1} e_t$. The coefficients $\phi_{kl}(j)$ of Φ_j can be used to generate the effects of ε_{jt} shocks on the entire time paths of y_t, m_t and i_t. The four elements $\phi_{kl}(0)$ are instantaneous impact multipliers. For example, the coefficient $\phi_{13}(0)$ is the instantaneous impact of a one-unit change in ε_{3t} on y_t. The imposed ordering of the variables implies $\phi_{21}(0)=\phi_{31}(0)=\phi_{32}(0)=0$. In the same way, the element $\phi_{13}(1)$ is the one period response of unit changes in ε_{3t} on y_{t+1}.

The nine sets of $\phi_{kl}(j)$-coefficients are called the impulse response functions. Plotting the impulse response functions, i.e. plotting the coefficients of $\phi_{kl}(j)$ against j, is a practical way to represent the behaviour of the series in response to the various shocks. Figure 3 displays these impulse response functions for the estimated equations in table 2. The graph allows several conclusions. Investments in infrastructure have an important and long-lasting effect on GDP, as can be seen from

11. Nevertheless, we changed the ordering in several ways. As expected, the outcomes stay roughly the same.

the upper-left part of the figure. This part shows the responses of the GDP-equation to the various shocks.

Figure 3: Responses of various shocks on the model with total infrastructure investments.



The course of the solid line, which displays the responses of GDP to a shock on infrastructure, might be interpreted as evidence that it takes time to adapt to the system to changes in the infrastructural environment. The initial small positive effect may be caused by backward linkages, or direct impulses on the economy through the demand for labour, raw materials and other capital goods in the construction of the infrastructural works. In this interpretation, the real effects of infrastructural investment on the economy, or the forward linkages, would pay off only in the long run.

Evidently, infrastructural investments cause changes in the economic system to which economic agents need time to adapt to. Large technical systems as, e.g. railways and telephone, have complementary relationships with the rest of the economy. Externality effects of these large technical systems set in motion an incremental trajectory of technological and organizational improvements in other sectors of the economy. Before economic agents are able to join in on this trajectory, they need time to adapt both their behavioural strategies, and their durable physical assets.[12] In several 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, e.g. ship building, brewing, and dairy industries in the Netherlands (Clement, 1994 pp.204-206; Van der Knaap, 1978; Passchier and Knippenberg, 1978).

The responses of y_t on shocks in infrastructure and machinery, respectively, differ in three ways. First, a growth impulse of machinery investment dies out much faster than an infrastructure impulse. After six years already, machinery investment ceases to have any effect. Obviously, the economy adapts more easily to changes in machinery capital. Secondly, the responses of machinery investments are on average lower than the responses of infrastructure, which indicates that the aggregate effect of infrastructure investment on GDP in the period under study has been much larger. From this it is tempting to conclude that investing in infrastructure has been a rational decision in the nineteenth century. Thirdly, GDP decreases remarkedly in the first period after a machinery shock. Apparently the economy needs one period to adapt to the changed stock of machines.

As can be seen from the upper-right panel of figure 3, growth of GDP has on average a negative effect on investment in infrastructure. This again supports the view of infrastructure as a basic prerequisite for growth, and as a large technical system, characterized by indivisibilities. When, after heavy initial investment, a certain threshold in the level of infrastructure is attained, the economy starts to grow. By then, indivisibilities will have generated an overcapacity in infrastructural services.

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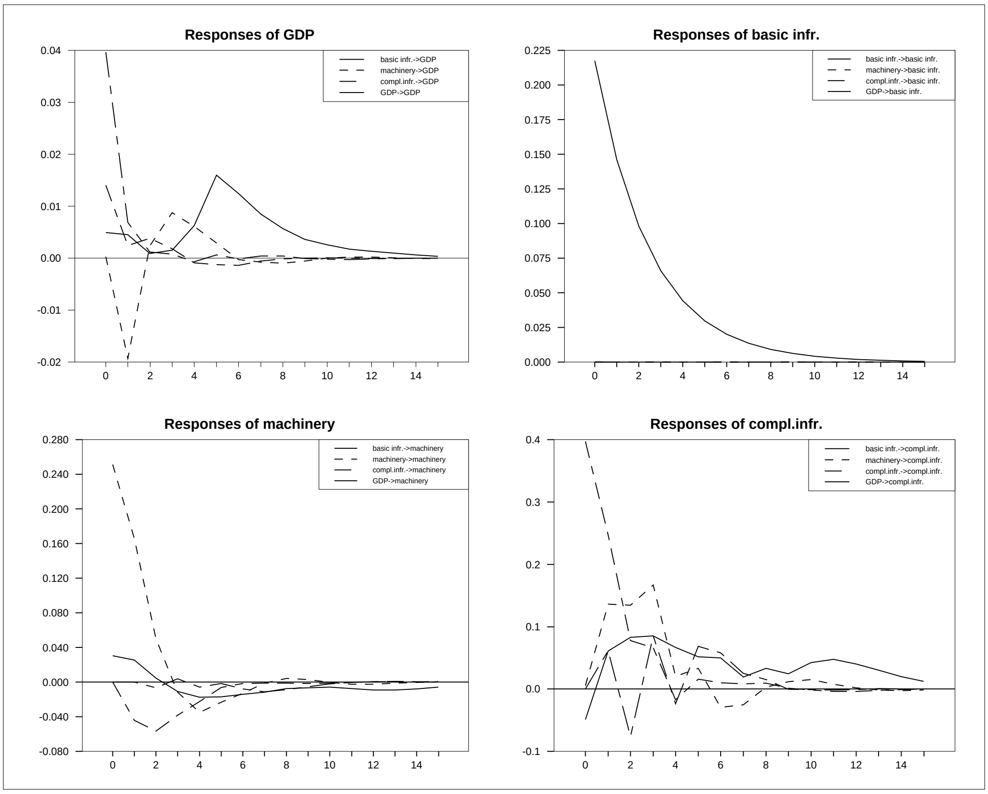
12. For an elaboration on this see, e.g. David (1985, 1990).

Infrastructural investment needs are thus much smaller and will taper off, whereas GDP can continue to grow.

Figure 4: Responses of various shocks on the model with basic and complementary infrastructure investments.



In the model in which infrastructure investment is subdivided, the largest absolute correlation of 0.31 is between GDP and complementary infrastructure investment. Therefore, the relative ordering of y and i^C can have a significant effect on our results. Figure 4 displays the results if the ordering employed is '*basic infrastructure*', '*machinery*', '*complementary infrastructure*', '*output*'. As we expected from the causality analysis before, basic infrastructure causes a large rise in GDP and peaks after five years. The instantaneous impact of total infrastructure can largely be attributed to complementary infrastructure. Of course, this is exactly what was to be expected beforehand.

Because the *FPE* criterion did not allow other explanatory variables in the basic infrastructure equation beside the lagged dependent variables, shocks of other variables do not influence basic infrastructure investment. However, complementary infrastructure investment is affected by any shock. As expected from table 2, the biggest hump in the right-below panel of figure 4 is attributed to machinery investment. What did not prevail from the previous subsection is the long-lasting positive effect of basic infrastructure on complementary infrastructure outlays. The solid line, depicting the effects of a i^B shock even peaks again after eleven years. Investments in basic infrastructure increases the needs for complementary infrastructure for a long time.

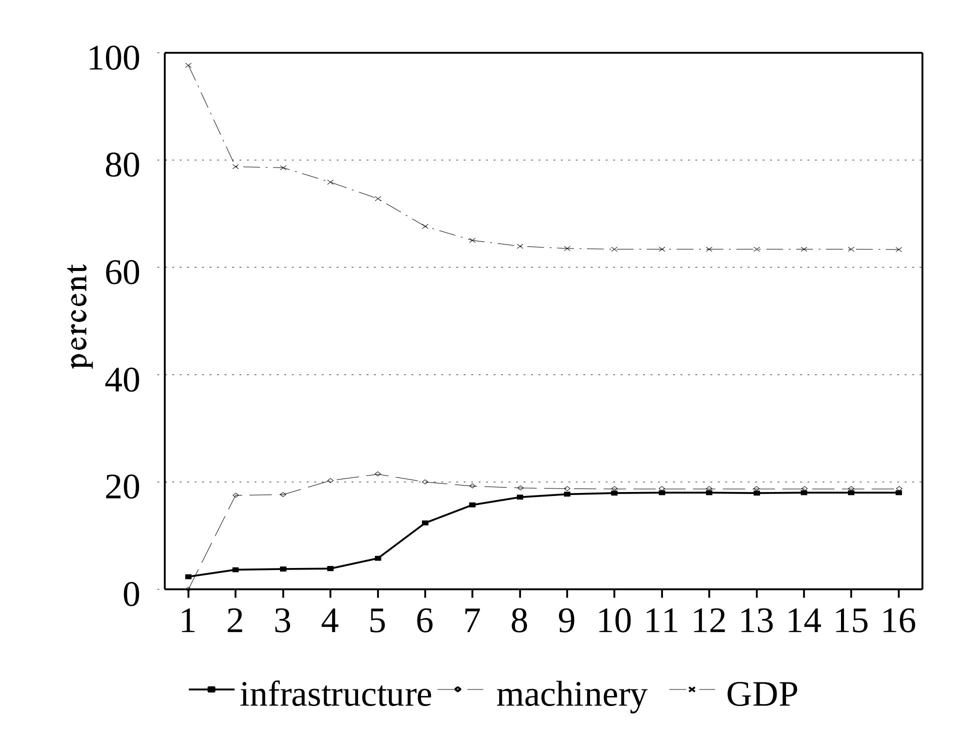
Despite the significant correlation between y and i^C, interchanging complementary infrastructure and GDP in the ordering hardly changes figure 4. Of course, the instantaneous effect of complementary infrastructure on GDP disappears by assumption. However, after one period, the responses are approximately the same as in figure 4. For the same reason, GDP now has a large positive instantaneous effect on complementary infrastructure investments. But again, the effects are similar after the first period.

4.3 Variance decomposition

In this subsection we will decompose the forecast error variance due to each one of the shocks. The forecast error variance decomposition tells us the proportion of the movements in a sequence due to its ‘own’ shocks versus shocks to the other variables. If, for example, ε_{3t} shocks explain none of the forecast error variance of y_t at all forecast horizons, we can say that y_t is exogenous. In that case, y_t evolves independently of the ε_{3t} shocks and the i_t sequence. At the other extreme, ε_{3t} shocks could explain all the forecast error variance in y_t at all forecast horizons, so that y_t would be entirely endogenous. It is typical for a variable to explain almost all its forecast error variance at short horizons and smaller proportions at longer horizons.

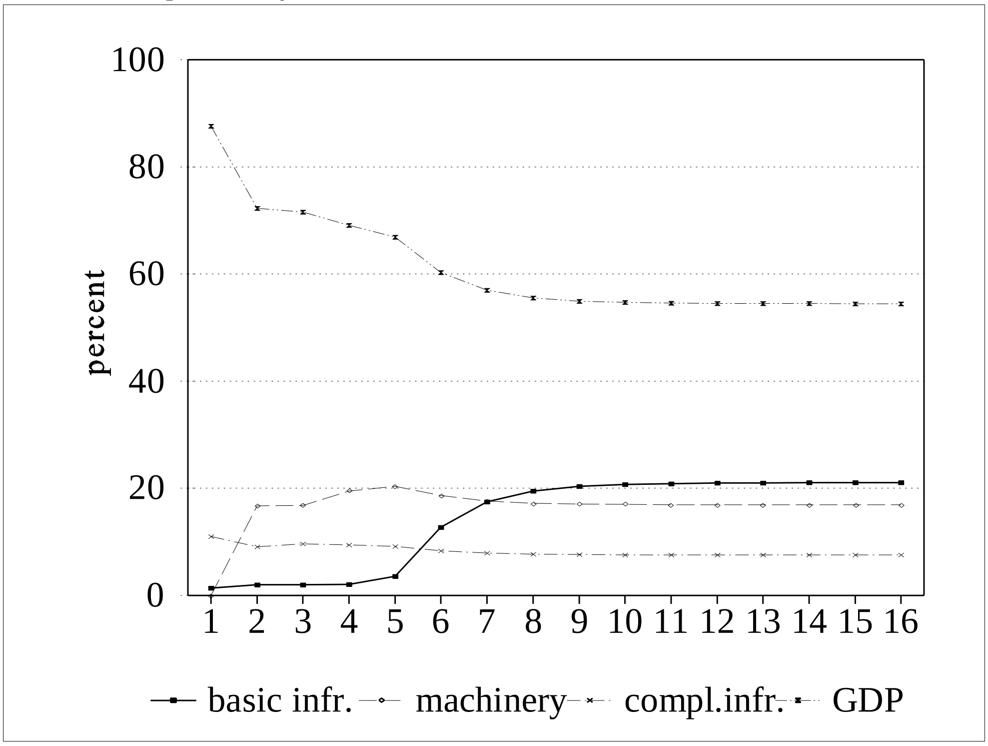
We would expect this pattern if ε_{3t} shocks had little contemporaneous effect on y_t, but acted to affect y_t with lag.

Figure 5: Variance decompositions of the forecast error of GDP in the model with total infrastructure investments.



Note that the variance decomposition analysis contains the same problem inherent in impulse response function analysis. In order to identify the ε_{jt}, it is necessary to impose some restrictions. The Choleski decomposition used in the previous subsection necessitates that all the one-period forecast error variance of i_t is due to ε_{3t}. If we use the reverse ordering, all the one-period forecast error variance of y_t would be due to ε_{1t}. The effects of these alternative assumptions are reduced at longer forecasting horizons. In practice, it is therefore useful to examine the variance decomposition at various forecast horizons. As the horizon increases, the variance decompositions should converge.

Figure 6: Variance decompositions of the forecast error of GDP in the model with basic and complementary infrastructure investments.



To decompose the standard error of forecast we assume that the coefficients of the model are known, so the standard error of forecast is lower than the true uncertainty with estimated coefficients. We ignore this sampling error term, which depends upon the squares of the coefficients and becomes extremely complicated as the size of the model and the number of forecast steps increases. We concentrate upon the ones due to the effects of the innovations.

Because the forecast errors of infrastructure and machinery investment both are mainly due to their own shocks, we only show the decompositions of the GDP forecast error in figure 5. Again, a large part is accounted for by the own GDP shocks, but not all. In the long run almost 40 percent of the variance is explained by machinery and infrastructure investments shocks, both capturing somewhat more than 18 percent. Conspicuously, machinery investment shocks already explain a large part after the first period, whereas infrastructure only significantly starts to contribute to the explaining the forecast error after five lags. Again, infrastructural investments take almost five periods to have an effect.

In figure 6, the variance decomposition for our four-variable model again shows that the effect of infrastructure is mainly due to basic infrastructure. Nevertheless, the contribution of complementary infrastructure with somewhat less than 10 percent is not neglectable. Similar figures for the decomposition of complementary infrastructure investment show that after four periods almost 20 percent of the forecast error is explained by shocks in machinery investment (not shown). Almost 11 and 7.3 percent are explained by respectively basic infrastructure and GDP. The forecast error variance decompositions of machinery investment reveal that around 7 percent of the movements is due to complementary infrastructure shocks.

5 Discussion

In this paper we have shown infrastructural investments to have a significant positive effect on GDP in the Netherlands in the second half of the nineteenth century. Our four-variable VAR model showed that mainly basic infrastructural projects have contributed to the Dutch industrial revolution. Complementary infrastructure only seems to induce short-run demand effects.

Furthermore, only the complementary part of infrastructure investments seems to be related to machinery investment. The thesis that infrastructure positively influences GDP indirectly through machinery outlays is not confirmed; we find a slightly negative effect on machinery. Machinery and basic infrastructure investments both have a positive effect on the level of complementary infrastructure outlays. Especially investments in basic infrastructure increases the demand for complementary infrastructure for a long time.

Of course, one has to be careful translating these findings into policy recommendations. However, if one assumes that public investment nowadays mainly consists of complementary infrastructure investments some tentative conclusions can be drawn. First of all, infrastructural investment might not have the long-run effects on production as is often assumed by politicians nowadays. Aggregate demand impulses, however, are not ruled out beforehand. In this way, the disappointing results of McMillin and Smyth (1994) for the post World War II period can also be brought into conformity with our findings; the positive long-run effects of basic infrastructure are missing nowadays, and so public capital hardly affects output anymore.

Finally, our findings corroborate the positive effect of private investment on public investment found by De Haan et al. (1996) for 22 OECD countries in the 1980s and early 1990s. In the nineteenth century investments in machinery in the Netherlands had large positive effects on complementary infrastructure investments. It remains to be seen if this and the other conclusions are an artifact of the period under consideration or hold more generally.

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