Historical Time Series Analysis:
An Introduction and Some Applications

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Abstract
This article sketches some developments in historical time series analysis, i.e. the application of sophisticated statistical and econometric techniques to historical time series. After that, we present five applications on the economic development of the Netherlands over the last two centuries, and discuss implications for research in economic history.

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1. INTRODUCTION

One of the main research areas in quantitative economic history concerns the analysis of the determinants of long-term economic growth. Why do growth rates differ over time and across countries? Why are the rich countries rich, and the poor countries poor? Special attention is paid to the transition to modernity. To what extent is it justified to distinguish pre-modern from modern economic growth? And if this distinction is valid, then which factors have been responsible for the transition of (western) economies to modernity?

In order to find answers to these ‘big questions’, economic historians devote much time and energy to constructing databases on long-run economic growth and structural change. Especially important in this respect is the work on historical national accounting. This framework serves as an important and powerful tool for historians, as historical data are often scattered; the model of historical national accounts with its system of checks and balances, i.e. by means of a comparison of income, output and expenditure estimates, can shed light on the reliability and plausibility of such estimates. The construction of such datasets is extremely time-consuming, however due to huge research investments of several generations we now have reasonable accurate historical national accounts for the majority of western countries.

Of course, economic historians do not confine themselves to building time series. Also due attention has been paid to interpreting the new data series in the light of the ‘big questions’ raised above. However, more often than not this research has been rather descriptive by nature. Good examples of seminal studies in the tradition of descriptive, empirical economics
concern the growth accounting studies of Denison\(^1\) and Maddison\(^2\), as well the study of Broadberry\(^3\) into the interpretation of productivity differentials of the United States, the United Kingdom and Germany during the nineteenth and twentieth century, and the textbook on the economic development of the Netherlands by Van Zanden and Van Riel.\(^4\)

However the data constructed by economic historians can also be used for other purposes and analysed with other methods. This article focuses on one such alternative: *Historical Time Series Analysis* (HTSA), i.e. the analysis of historical time series by means of sophisticated statistical and econometric techniques. We present four applications of HTSA on the Netherlands, one of the few countries for which a complete set of historical national accounts covering income-, output- and expenditure estimates is available for the period 1815-2000.\(^5\)

In the basis of these applications we discuss what kind of insights HTSA may yield for economic historians.

There are not many studies in which modern time series techniques are applied to historical time series. One of the reason for this may be the somewhat delicate relationship between “data constructors” (historians) and “data users” (econometricians). A student of Milton Friedman once went to Chili to do field research. After he returned to Chicago he proudly came to show his results, estimates for a money demand equation, to the Nobel laureate. Friedman was not surprised at all: ”Your estimates merely reproduce the way I constructed the money series years ago!” The phenomenon that the econometrician finds the way the data

\(^1\) See e.g. *E.F. Denison*, Why do growth rates differ: Post war experience in nine western countries, Washington 1967.

\(^2\) See e.g. *A. Maddison*, Monitoring the World Economy, Paris 1995.


\(^5\) For the Dutch data see: *J.P. Smits/ E.Horlings/ J.L. van Zanden*, Dutch GDP and its Components, Groningen Growth and Development Centre Monograph no. 5 2000. For a survey of other European national accounts projects see the special issue of the *Scandinavian Economic History Review* XLII, 1995, no. 1.
maker constructed his data happens more often.\footnote{It also illustrates the double meaning of the expression data generating process. In time series analysis the data generating process is the mechanism behind the data, whereas in economic history it is the way the data maker constructed his data.} This pitfall should, of course, be avoided.\footnote{\textit{J.P.A.M. Jacobs/ J.E. Sturm/ P.D. Groote}, Data Constructors and Data Users Can Cooperate: An Illustrative Case Study, Heerlen 1999.}

In the ideal case the econometrician should know the historical context of his data and the historian should be familiar with modern techniques. This is perhaps too ambitious. Our cooperation is a typical example of a second best option, an econometrician and a historian joining forces.

The articles is structured as follows. After a brief introduction of HTSA in section two, we present five applications in section three. The first application deals with the periodisation of economic development in the Netherlands. We show the outcomes of a sequential structural break analysis. The second application identifies different technology regimes, and their relation with differences in economic growth rates. In the third application, following the debate sparked off by Gilboy in the 1930s, we ask to what extent demand factors can be held responsible for the beginning of a process of modern economic growth in the Netherlands from the 1860s onwards. Subsequently, the fourth application focuses on business cycle analysis, as it is often claimed that only in the modern era regional and national economies are that well integrated that the different patterns of fluctuation will converge into one, international business cycle. The final application focuses on the importance of infrastructural investments on economic growth, using a multivariate analysis and working with the concept of Granger non-causality. In the concluding section we discuss the implications of HTSA for economic history.
2. HISTORICAL TIME SERIES ANALYSIS

Time series analysis typically does not belong to the tool kit of economic historians. The standard textbook of Feinstein and Thomas\(^8\) only discusses some basic aspects.\(^9\) We begin our introduction with concepts from univariate time series analysis, i.e. the analysis of a single series. Thereafter we discuss topics in multivariate time series analysis, involving more than one series.

**Univariate time series analysis**

Classical time series analysis assumes that an observed time series can be decomposed into

\[ \text{Observed series} = \text{trend} + \text{cycle} + \text{season} + \text{irregular component}, \]

where the trend represents the long-run development in the series, the cycle the cyclical component arising from business cycle fluctuations, the season the seasonal pattern which repeats itself more or less every year, and the irregular component reflects non-systematic movements in the series.\(^10\) After an observed series is filtered for irregular components (and the season, if appropriate), advanced techniques are available to filter the trend and to carry out business cycle research.\(^11\) The third application in section three below presents an example.

Many historical time series exhibit trends. Recent work in econometrics has shown that it is important to determine the nature of the trend before carrying out any estimation. In

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\(^11\) See for example Mills, Modelling Trends, Chapter 4.
particular, it is crucial to know whether a trend is deterministc or stochastic. An example of a series $y_t$ with a deterministic trend is

$$y_t = \alpha + \beta t + \epsilon_t, \quad t = 1, \ldots, T,$$

where $\alpha$ and $\beta$ are parameters, $t$ is a linear trend and $\epsilon_t$ is white noise.\textsuperscript{12} Random shocks only have a temporary effect on the trajectory of the series. Generally, if the effects of a random disturbance die out over time, the series is stationary. A series is defined weakly or covariance-stationary if it has a finite mean, finite variance, and finite covariance, which do not depend on the date $t$. The series $y_t$ of Equation (1) grows along a trend and is hence called trend-stationary.

A variable that does not exhibit a tendency to return to its original level following a shock is non-stationary. A simple example of such a series is the random walk with drift

$$y_t = \beta + y_{t-1} + \epsilon_t. \quad (2)$$

Repeated substitution reveals the nature of the stochastic trend and the correspondence to the process of Equation (1)

$$y_t = \alpha + \beta t + \sum_{i=1}^{t-1} \epsilon_{t-i} + \epsilon_t, \quad (3)$$

assuming $y_0 = \alpha$. In Equation (3) $\alpha + \beta t$ is the deterministic trend and $\sum_{i=1}^{t-1} \epsilon_{t-i}$ is the stochastic trend.

A stationary process will be called integrated of order zero, denoted $y_t \sim I(0)$. The simplest example of a stationary process is a white noise process. A more general example of a stationary process is an autoregressive process of order one or AR(1) process

\textsuperscript{12} White noise is a series whose elements have mean zero and variance $\sigma^2$, and for which the elements are uncorrelated across time.
\[ y_t = \gamma y_{t-1} + \varepsilon_t, \quad |\gamma| < 1. \]

If \( \gamma \) equals one in this equation, series \( y_t \) is non-stationary and has a unit root. However, the first difference of this series, \( \Delta y_t = y_t - y_{t-1} \), is stationary. If a series becomes stationary after differencing once, it is called integrated of order one, denoted \( I(1) \).

Testing for time series properties has become standard practice in applied economic research. The most popular Augmented Dickey Fuller (ADF) test regresses the first difference of a series on its lagged level, supplemented with a constant, a trend and/or lagged first differences to ensure that the residuals become white noise. The null hypothesis is that the series is non-stationary or that the parameter of the lagged level equals zero. The test is implemented through the usual \( t \)-statistic for the estimate of this parameter. Under the null hypothesis this statistic does not follow the usual Student \( t \)-distribution, but critical values of the asymptotic distributions are available in standard statistical packages. If the null hypothesis is not rejected, the series is non-stationary and needs to be differenced at least once to become stationary. If the null hypothesis is rejected, the variable is stationary.

To label a series either deterministic (stationary) or stochastic (non-stationary) is overly restrictive. Unit root can hardly distinguish one from the other, especially when structural breaks occur in the series, as is the case for many historical time series. Hansen\(^{13} \) distinguishes three important issues in the econometric analysis of structural breaks: (i) testing the nature of the trend (stochastic or deterministic); (ii) testing parameter constancy with respect to an unknown structural break; and (iii) estimation and testing of the timing of the structural break. Recently, a further refinement has been added: testing for a change in

persistence, i.e. a change in the nature of the trend over time.\textsuperscript{14} Especially this last development seems promising for economic history. We postulate that the most important property of the transition of a pre-modern, agricultural society to a modern society might well be that series evolve from (trend-)stationary into non-stationary processes. Unfortunately, as shown in the first application in section three below, shocks around the first and the second World War are so large that other structural breaks and possible change in persistence cannot come to the fore.

**Multivariate time series analysis**

The statistical concept of *Granger (non-)*causality is often used to provide empirical evidence on the question of causality between variables. The basic principle of Granger (non-)causality analysis is to test whether or not lagged values of one variable help to improve the explanation of another variable from its own past. This interpretation of causality or antecedence should be intuitively appealing to historians, because they are aware of time as an explanatory variable. Nevertheless the term ‘causes’ in Granger-causality should be interpreted with caution. Granger-causality has nothing to say about contemporaneous causality between variables, so we cannot use the technique to determine for example whether a variable in a system is exogenous or endogenous.

Granger (non-)causality is usually analysed in a *Vector AutoRegression (VAR)* system, i.e. a multivariate model in which each variable is explained by its own lags and lags of the other variables. In some cases a constant and/or a trend enters the system, but we omit these deterministic variables here without loss of generality. The basic form of a VAR system is

\[
    z_t = A_1 z_{t-1} + A_2 z_{t-2} + \ldots + e_t , \tag{4}
\]

where $z_i$ is the vector of endogenous variables, $A_i$, $i=1,2,\ldots$ are matrices of parameters and $e_t$ is an error vector. In the context of a VAR, the first variable, $z_{1t}$, may be said to Granger-cause the second one, $z_{2t}$, if any lagged value of $z_{1t}$ is significant in the equation for $z_{2t}$. On the other hand, $z_{1t}$ does not Granger-cause $z_{2t}$ if all lagged values of $z_{1t}$ are jointly insignificant in the equation for $z_{2t}$. After having decided how many lags should be included in the VAR system, the non-causality hypotheses can be tested by Wald type tests. The fourth application below uses Granger non-causality tests.

In a VAR system any contemporaneous link between the endogenous variables runs through the errors, which implies that the errors may be correlated. Therefore it is not possible to make direct statements about the size of the estimated effects. We can analyse the behaviour of the system by means of impulse responses, i.e. the reaction of the system following a shock. To that purpose the VAR system must be converted into its corresponding Vector Moving Average representation, in which the endogenous variables are expressed in terms of current and past shocks (or innovations). To convert a VAR system into its vector moving average representation, the system must be stable, a necessary condition for which is (trend-) stationarity of the series. Because the innovations are contemporaneously correlated, shocks that hit the economy affect all variables in the current period. Consequently, it is not possible to single out the effects of a separate shock. A standard solution for this identification problem is to impose restrictions of some kind. Often the solution of a causal ordering is employed, i.e. to rank the variables from the most exogenous to the most endogenous.

As a general rule non-stationary variables should not be used in regression models to avoid the problem of spurious regressions. There is an exception to this rule. If variables $z_{1t}$ and
are non-stationary $I(1)$ variables, whereas there exists a linear combination that is a stationary $I(0)$ process, then $z_1$ and $z_2$ are said to be cointegrated. Cointegration analysis is considered beyond the scope of this article.\(^\text{15}\)

3. APPLICATIONS

Periodisation of economic development

The top panel of Figure 1 shows the economic development of the Netherlands over the last two centuries as measured by the natural logarithms of real Gross Domestic Product (GDP) per capita. The bottom panel shows corresponding growth rates. Eyeballing the graphs leads already to the impression that the series is dominated by World War II and to a lesser extent World War I. This is confirmed by Van Eijkel en Romp\(^\text{16}\) using sophisticated sequential structural breaks tests, in which the whole sample is tested for all possible break dates.\(^\text{17}\) Analyzing the whole series they indeed find that the war periods dominate. Only by interpolating series for the war years, structural breaks can be detected in other periods.

\(^{\text{15}}\) Interested readers are referred to e.g. W. Enders, Applied Econometric Time Series, New York 1995, Chapter 6.

\(^{\text{16}}\) R. van Eijkel/ W.E. Romp, Multiple Structural Breaks in Economic Development of the Netherlands over the Last 190 Years, unpublished paper Groningen 2005.

Figure 1. Real gross domestic product per capita 1800-2000

Levels (natural logarithms)

First differences (growth rates)

Source: Van Eijkel and Romp, Multiple Structural Breaks.
A striking conclusion from this analysis is that there is no evidence of a structural change around 1870, contrary to the notion of economic historians. However, it may be that the focus at a macro level obscures important underlying changes in the economy. One of the main features of economies in transition is the decline of ‘old’ sectors, and the strong growth of ‘new’ industries. Structural changes at the sector level might be invisible at a macro level. We therefore argue that HTSA methodologies should also be applied to series at a meso level, which can be found in many datasets on historical national accounting.

**Technology regimes and economic growth**

The building of historical national accounts and the construction of growth accounts goes virtually hand in hand. And also in the case of the Netherlands, economic growth has been analysed on the basis of such an aggregate production function. However, technology – one of the main driving forces in the growth process – remains largely exogenous. This notion led Smits, de Jong and Van Ark to try to establish a more direct link between changes in technological regimes and rates of GDP and productivity growth. First, time series on output, labour productivity and total factor productivity (for manufacturing as well as economy-wide) were tested for structural breaks with recursive tests for parameter constancy, i.e. by looking for parameter constancy expanding the sample one year at the time instead of the sequential test as applied in the first application. After that, the different sub-periods of growth were linked to technology-related phenomena.

According to the recursive test outcomes World War II was not a significant breaking point in the long-run development of the Dutch economy, whereas the year 1917 was. This outcome substantiated the view that where the Netherlands had performed quite poorly in the era of

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steam, it was able to rapidly adopt the new technologies of the second industrial revolution and that it was able to ‘translate’ this technological diffusion in high rates of (productivity) growth. Indeed, seen in an international comparative perspective the 1920s as well as the period 1950-1973 can be identified of strong productivity growth in the Netherlands. In addition the marked slow-down after the 1970s that came out their time series analysis, can be explained by problems in the area of technology diffusion (especially the slow and unsuccessful diffusion of ICT in services).

Even though the analysis of how technological change translates into productivity growth is far from simple and straightforward, Smits et al. identify and date two structural breaks (1916 and 1975) which indeed mark periods in which ‘old’ technologies were replaced by ‘new’ ones. Moreover, the rate of diffusion (rapid in case of electricity, slow and limited in the case of steam and ICT) correlates strongly with rates of (productivity) growth.

**Demand factors and the transition to modern economic growth**

Nowadays economic growth in general, and the transition to modern economic growth in particular, is primarily explained in terms of supply factors. Capital accumulation and technological change, often identified by means of growth accounting exercises, are seen as the main determinants of economic growth. Demand factors are hardly ever mentioned in literature, whereas in the past authors such as Gilboy forcefully argued to include demand in the analysis of growth.

Especially after Mokyr’s forceful critique on the Gilboy thesis, not many authors have attempted to view demand as a structural factor in the growth process. However, in the Dutch case there may be good reasons to do so. Due to drastic tax reforms in the period 1850-1870, real incomes of the lower income brackets increased substantially. And as the main part of Dutch industry was geared towards consumer products (food and textiles), this exogenous demand shock may have had an impact on growth. Smits, for example, demonstrated that Dutch industrialisation suffered from serious scale constraints in the period up to 1870. At the prevailing lower levels of production, steam technology was not viable. However, due to higher levels of demand, from the 1870s onwards steam became much cheaper, and diffused rapidly in the consumer good industries. Horlings and Smits strongly pointed at the importance of demand, but did not back their hypothesis of demand-led growth with an econometric analysis.

Bonenkamp, Jacobs and Smits apply a modern technique, a counterfactual VAR analysis, to compare the dynamics of consumption and its determinants before and after the Industrial Revolution. A VAR system generates the unexpected shocks in a period, $e_t$ in Equation (4), and the propagation mechanism by which these shocks feed through the system, the $A_i$, $i=1,2,...$ matrices of the same equation. By combining the shocks in one period with the propagation mechanism of the other period, one can answer questions like what would have happened if the demand shocks of the period before the Industrial Revolution also occurred in the period after the Industrial Revolution.

The results of the counterfactual VAR analysis indeed point to the possibility that changes in consumer demand spurred economic growth, substantiating the views of Horlings and Smits which were based on a more descriptive analysis of the data material. Perhaps the most intriguing result concerns the radical different characteristics of the time series of consumption and its determinants before and after 1865. Until 1865 the series are trend-stationary, whereas for the later period they become non-stationary $I(1)$, i.e. they go through a process of a change in persistence.

**Business cycles and modern economic growth**

Another way to analyse the transition to modernity is to focus on business cycles. As the degree of regional integration in the world economy is still quite weak in the pre modern era, we cannot expect different countries to follow one and the same business cycle. Even the existence of national cycles can be doubted. In the case of the Netherlands, Brugmans argued that before 1870 – according to him the date at which the Dutch economy started to modernise – no business cycle could be detected.\(^\text{24}\) Literature gives several reasons for this lack of cyclical behaviour. The lack of sector integration in the economy serves as an impediment for the occurrence of stable, wavelike patterns of development. Besides, the absence of large-scale production (due to rather primitive technologies) as well as the lack of well-developed capital goods industries and a modern banking system, explain why the modern type of business cycle cannot be expected. According to the conventional view as expressed by Brugmans, it was only from the 1870s onwards that the Netherlands started to follow the international business cycle, even though the fit was far from perfect. As was

stressed by Ridder, the Dutch economy showed strong growth in periods of international recession and grew slowly when the international economy was booming.\textsuperscript{25}

Jacobs and Smits\textsuperscript{26} compare the business cycle in the Netherlands to the international business cycle (UK and US), where the business cycle is defined in terms of fluctuations in the level of economic activity, i.e. the classical business cycle concept. In the case of business cycle research the combination of new data and modern research techniques worked out nicely. Already before 1870 a clear Dutch business cycle can be discerned which is closely related to that of the United Kingdom and the United States. This observation partly stems from the fact that Brugmans could only use partial indicators, whereas Jacobs and Smits had the disposal of a complete set of historical national accounts enabling a much more precise analysis. In addition, already in the 1850s and 1860s Dutch economic development seems to be influenced by the international business cycle. And the hypothesis put forward by Ridder that Dutch economic development is inversely related to this international business cycle could indeed be substantiated. Modern literature explains this pattern of development from huge levels of domestic demand in a context of scale-constraints to industrial production. In periods of high domestic demand, export demand could not be met. From the 1890s onwards the peaks and troughs in the Dutch and the foreign business cycle series are moving more and more along parallel lines, although the synchronicity is still not perfect.

A new finding of the analysis concerns the period of the 1870s and the 1880s. Contrary to what has been stated previously in the literature, Dutch economic development is hardly if at all linked to movements abroad. This is quite surprising as these decades are the period in which the Dutch economy modernised at light speed (see the diffusion of steam technology

\textsuperscript{25} J. Ridder, Een Conjunctuur-Analyse van Nederland 1848-1860, Amsterdam 1935.
\textsuperscript{26} J.P.A.M. Jacobs/ J.P. Smits, Business cycles in the Netherlands, 1815-1913. SOM research report 01C52, Groningen 2004.
and the rising levels of labour productivity in the industrial sector). Jacobs and Smits argue that this relatively autonomous pattern can be explained from the fact that the Netherlands in this period went through a growth phase driven by mainly domestic factors, such as the revision of the system of taxation and huge infrastructural investments which allowed for a substantial speeding-up of the spatial integration of the Dutch economy. It is precisely for these reasons that Horlings and Smits characterised developments in this period as ‘growth through size-effects’.²⁷

Viewing the entire period 1850-1914 from a business cycle perspective we arrive at a new interpretation of Dutch economic development. Scale constraints and under-demand in the Dutch economy resulted in a growth pattern that was inversely related to that of countries such as the United Kingdom and the United States. It was only during the 1870s and 1880s, a period in which many of the scale constraints in (industrial) production were being removed, that Dutch firms could meet domestic as well as export demand. After the removal of these constraints, Dutch economic development conformed more and more to the international business cycle.

**Infrastructure and economic development**

Economic historians have always assigned a large role to infrastructure in the process of economic growth. For instance, it is commonly agreed that infrastructure endowments made the Netherlands the economic superpower in the preindustrial era²⁸, but depressed economic

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²⁷ E. Horlings/ J.P. Smits, Private consumer expenditure.
²⁸ J. de Vries/ A.M. van der Woude, Nederland 1500-1815: de eerste ronde van moderne economische groei, Amsterdam 1995.
growth in the first half of the nineteenth century, and then again enabled modern economic growth in the second half of the nineteenth century.

To assess the effect of infrastructure on economic development in the Netherlands for the second half of the nineteenth century, Groote, Jacobs and Sturm analyse a VAR system consisting of GDP, machinery investment and infrastructure investment. Granger (non-)causality tests and impulse responses lead to the conclusion that infrastructure indeed exerted a positive effect on GDP. Their second conclusion is heavily influenced by the outcomes of the unit root tests. Since the series appeared to be trend-stationary in the second half of the nineteenth century, infrastructure investments only have a temporary effect on economic development, and cannot bring GDP to a permanently higher level.

4. CONCLUSION

In this contribution we have introduced Historical Time Series Analysis and showed five applications to time series originating from historical national accounts. Of course the applications as presented by us only scratch the surface of what can be done with the information that has become available over the last few years. Nevertheless, we conclude that the applications do provide statistical backing of insights previously derived by more descriptive research methods.

30 J.A. de Jonge, De Industrialisatie in Nederland tussen 1840 and 1914, Nijmegen 1976; Smits, Economische Groei.
One fundamental problem we encountered deals with periodisation and structural breaks. It is difficult to date structural changes precisely. As seen in Figure 1, the two World Wars have a profound impact on the economic development over the last two centuries, and dominate possible other structural changes like for example the transition from a premodern to a modern society towards the end of the nineteenth century. A possibly related observation concerns the properties of the time series. Unit root test outcomes are to some extent period-dependent, which implies that conflicting conclusions can be drawn regarding (non-)stationarity of e.g. GDP in the second half of the nineteenth century.

One of the options is to `adapt’ the data: to consider e.g. the World Wars as atypical events and to skip, or to smooth the series for, the war periods. Then still we might not be able to find the dates of structural changes. Structural changes might have occurred gradually, and not necessarily at the same date in all sectors. Therefore a second option is to analyse meso (sector) or perhaps even micro (firm) data in order to validate claims about structural changes, which might involve the construction of even more data – and does not necessarily solve the problem of the high impact of the World Wars. Especially in case of economies in transition, it is important to distinguish the downfall of old sectors, from the upsurge of the so-called ‘new’ industries. Besides, when trying to assess the importance of technological changes, specific time series such as labour productivity in the manufacturing sector needs to be investigated.

The use of the many sub series which can be derived from historical national accounts databases, may enable us to explore the wealth of such datasets more appropriately. Other forms of econometric modelling (structural models, general equilibrium analysis) should not
be ruled out a priori. Economists and historians should join forces to get the maximum of information out of data that is stored in the various historical national accounts databases.