

Kriedel, Norbert

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## Long waves of economic development and the diffusion of general-purpose technologies: The case of railway networks

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# Long waves of economic development and the diffusion of general-purpose technologies – the case of railway networks

Norbert Kriedel

**HWWI Research**

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**Norbert Kriedel**  
Hamburg Institute of International Economics (HWWI)  
Neuer Jungfernstieg 21 | 20354 Hamburg | Germany  
Tel +49 (0)40 34 05 76 - 35 | Fax +49 (0)40 34 05 76 - 76  
kriedel@hwwi.org

HWWI Research Paper  
Hamburg Institute of International Economics (HWWI)  
Neuer Jungfernstieg 21 | 20354 Hamburg | Germany  
Tel +49 (0)40 34 05 76 - 0 | Fax +49 (0)40 34 05 76 - 76  
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# Long waves of economic development and the diffusion of general-purpose technologies – the case of railway networks

Norbert Kriedel\*

## Abstract

**The possible existence of long waves in economic time series has long been an important subject of debate for economists, statisticians and historians. Recent empirical evidence for these long-term fluctuations is found in the literature of structural time series models. One empirical method for detecting long waves which seems to be particularly compatible with their theoretical explanation is the band pass filter. Applying the band pass filter to data from six European countries demonstrates the presence of wave-like fluctuations with a length of between 30 and 50 years. Their turning points show quite strong similarities across the six countries examined. Moreover, there is evidence for a stable lead-lag structure for two countries. The dominant theoretical explanation for long waves stresses the diffusion of general-purpose technologies. The diffusion of the railway system as one example of a general-purpose technology was analysed by means of logistic regression. The results are quite striking, as there seems to be evidence for a temporal sequence, implying that the turning points of railway diffusion occurred before the turning points of long waves.**

\* Hamburg Institute of International Economics (HWWI); kriedel@hwwi.org  
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## 1. Introduction

The debate on the existence of long waves started with the Russian economist and statistician Nikolai Kondratieff, who observed long-term fluctuations with a duration of about 56 years in economic time series for prices, interest rates and a variety of other economic variables. His statistical methodology was criticised, as his assumptions for the trend component of a time series were considered to be arbitrary. Though Reijnders (1990, 1992) found evidence for long waves using the more sophisticated spectral analysis approach, the problem of arbitrariness in the estimation and elimination of the trend component remained.<sup>1</sup> Metz (1992) used a digital filter and found approximately the same mean duration of long waves (56 years) as Kondratieff.<sup>2</sup> The results produced by Goldstein (1999), who detected long waves with an average length of about 56 years, are based on a structural time series model, which has attracted much attention in business cycle research.<sup>3</sup>

The use of a band pass filter seems to be a particularly appropriate method for long wave analysis. The reason for this view is that both the band pass filter and the dominant theoretical explanation for long waves, Schumpeter's theory of innovation, exhibit a kind of 'decomposition principle' as a core feature. For the band pass filter, this 'decomposition principle' is inherent in its structure, as the filter treats an economic time series as an overlay of many cyclical components of different lengths and frequencies. The filter decomposes a time series into existing frequencies, and can be specified in a way that eliminates certain frequencies in order to show the isolated impact of others. Hence, if long wave components are to be found, all high frequency components have to be eliminated.

The decomposition principle is also a core feature of the most important theoretical explanation for long waves, stressing the importance of general-purpose technologies acting as long run 'engines of growth'.<sup>4</sup> This theoretical explanation is based on Schumpeter's decomposition of economic development into a number of cyclical processes of different lengths and frequencies, each reflecting the diffusion of a corresponding innovation. The length of a cyclical component is determined by the importance of a particular innovation, so that long waves are explained by very important innovations or general-purpose technologies. As the

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<sup>1</sup> The reason is that the application of spectral analysis requires the stationarity of the time series, so that the trend has to be estimated and eliminated. As there seems to be no common understanding about the 'true' trend model, the results of trend elimination can always be criticized as being more or less arbitrary.

<sup>2</sup> Metz, R. (1992), p. 92; Kondratieff, N. (1984), p. 61.

<sup>3</sup> Goldstein, J. P. (1999), p. 87; for the use of structural time series models, see also: Flaig, G. (2003)

<sup>4</sup> See for example: Aghion, P. and Howitt, P. (1998); Helpman, E. and Trajtenberg, M. (1998); Li, C. (2001).

band pass filter seems to be an appropriate empirical method when analysing long waves, one aim of this paper is to identify long waves within the time series of aggregate production for six European countries by using a band pass filter of the Baxter-King type.

The second aim consists in tracing an empirical relationship between the diffusion of the general purpose technology ‘railway’ and the shape of the 2<sup>nd</sup> long wave, which according to Kondratieff lasted from the late 1840s until the late 1880s and had its upper turning point around the year 1873. The idea behind this second aim is based on Schumpeter’s theory that railways can be regarded as the general-purpose technology behind the second long wave.<sup>5</sup> Also, in the recent literature of long waves and endogenous growth, the railway is considered to be an important general-purpose technology of the 19<sup>th</sup> century.<sup>6</sup> Growth accounting results suggest that railways contributed significantly to economic growth in the middle of the 19<sup>th</sup> century.<sup>7</sup> The construction of railway systems is often seen as an endogenous reaction to a ‘transport bottleneck’ which existed in the first half of the 19<sup>th</sup> century and was a major hindrance to growth at that time.<sup>8</sup> In this respect, railways seem to have played a similar role to electricity in the second half of the 19<sup>th</sup> century, as this general purpose technology might be said to have solved an ‘energy bottleneck’ for the industrial countries at that time.

Because of the importance of railways for the growth in the middle of the 19<sup>th</sup> century, the diffusion curves of the railway system should show a certain correspondence with the 2<sup>nd</sup> long wave. Correspondence will be analysed by a comparison between the position of the turning points of the long waves and the technology diffusion curves respectively.

## 2. Methods and data

An important example of a band pass filter widely used in business cycle and growth research is the Baxter-King-filter. This filter alters the spectral shape of an original time series according to:<sup>9</sup>

$$y_t = \int_{-\pi}^{+\pi} \alpha(v) \cdot \xi(v) dv \quad (1)$$

In equation (1),  $y_t$  represents the filter output (or the filtered series),  $\alpha(v)$  measures the weight

<sup>5</sup> Schumpeter, J. A. (1961), p. 355 and p. 343-346.

<sup>6</sup> The three other general purpose technologies of the 19<sup>th</sup> century are electricity, steel and chemistry. See: Nefiodow, L. (1996), p. 3; Lipsey, R.; Bekar, C.; Carlaw, K. (1998), p. 21-29 and Perez, C. (2002), p. 11.

<sup>7</sup> According to Crafts, N. (2002), railway and steam contributed to 23.6% of the growth rate of Great Britain in the period 1830-1860. See Crafts, N. (2002), p. 20-22.

<sup>8</sup> O’ Brian, P. (1983), p. 7.

the filter gives to the cyclical component  $\xi(v)$  of the original series,  $v$  stands for the frequency. In order to find long waves in a time series, all cyclical components of a relatively short duration - and therefore of a relatively high frequency - have to be eliminated or removed. The remaining filter output should then include all 'low frequency' components within the range of long waves. Acknowledging the possibility of a certain variance in the duration of Kondratieff cycles, a frequency interval ranging from 1/35 to 1/200 was chosen for this study. This means that all cyclical components with a duration outside the interval [35 years; 200 years] should be removed by the filter. If long waves exist, they should thus show up within the frequency band (or frequency interval) [1/35; 1/200]. Given that sufficiently long time series were not always available for gross national or gross domestic product, an index for industrial production had to be applied for two countries. The following table shows the data used for the filtering process:

Table 1: Data used for time series filtering

<b>Country</b>	<b>Time series</b>	<b>Period</b>
Germany	Net national product in constant prices of 1913 (in million marks at market prices)	1850-1938
France	Index of industrial production (1913 = 100)	1815-1913
Great Britain	Gross national product in constant prices of 1900 (in million pounds at factor costs)	1830-1913
Italy	Gross national product in constant prices of 1938 (in thousand million lire at market prices)	1861-1919
Russia	Index of industrial production (1913 = 100)	1860-1913
Sweden	Gross national product in constant prices of 1913 (in million swedish kroner at market prices)	1861-1950

Source: see appendix A1

As an indicator for the diffusion of the general-purpose technology 'railway', the length of the transport network (measured in km) was chosen. The available data contain the length of the railway system in Great Britain (1825 - 1930), France (1828 - 1913), Italy (1839 - 1900), Belgium (1835 - 1930), Germany (1835-1913) and Russia (1838-1913).<sup>10</sup> For Great Britain, no data were available for the period 1868-1870 and 1914-1918. The missing values had to be calculated by linear interpolation.

<sup>9</sup> Baxter, M. and King, R.G. (1999), p. 577.

<sup>10</sup> The data source for the diffusion of the railway is listed in the appendix A2.

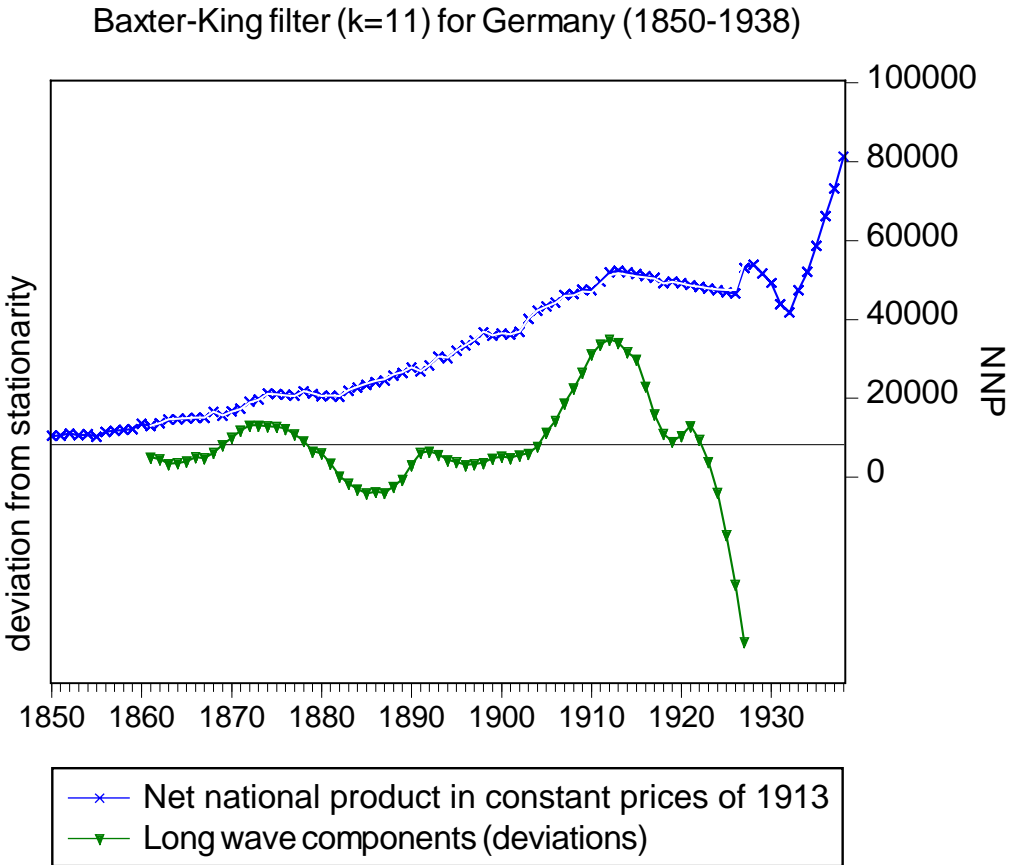
The empirical results show S-shaped diffusion paths for the indicator ‘length of railway line open’, so that a logistic function was fitted to the data. This was achieved by a non-linear regression technique called ‘logit transformation’.

**3. Results**

3.1. Time series analysis

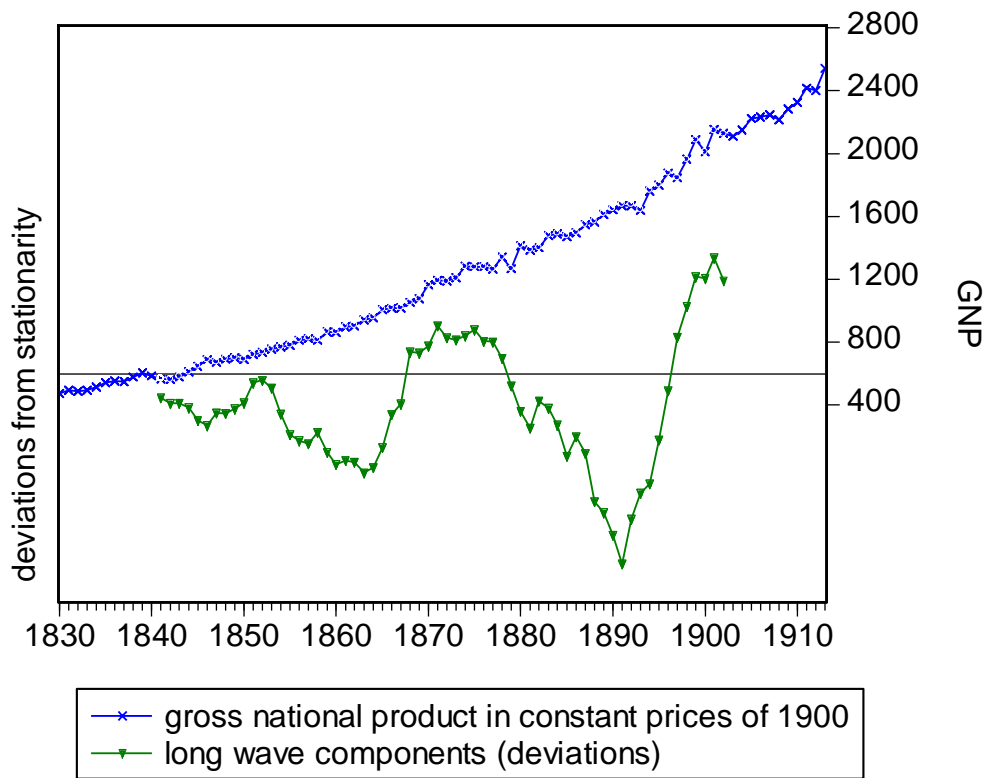
The results of the Baxter-King-filter according to the frequency band [1/35; 1/200] and the smoothing value  $k = 11$  are shown in the following graphs, with each graph containing two different series:

- 1) the original time series exhibiting an upward trend
- 2) the filter output ('long wave components')

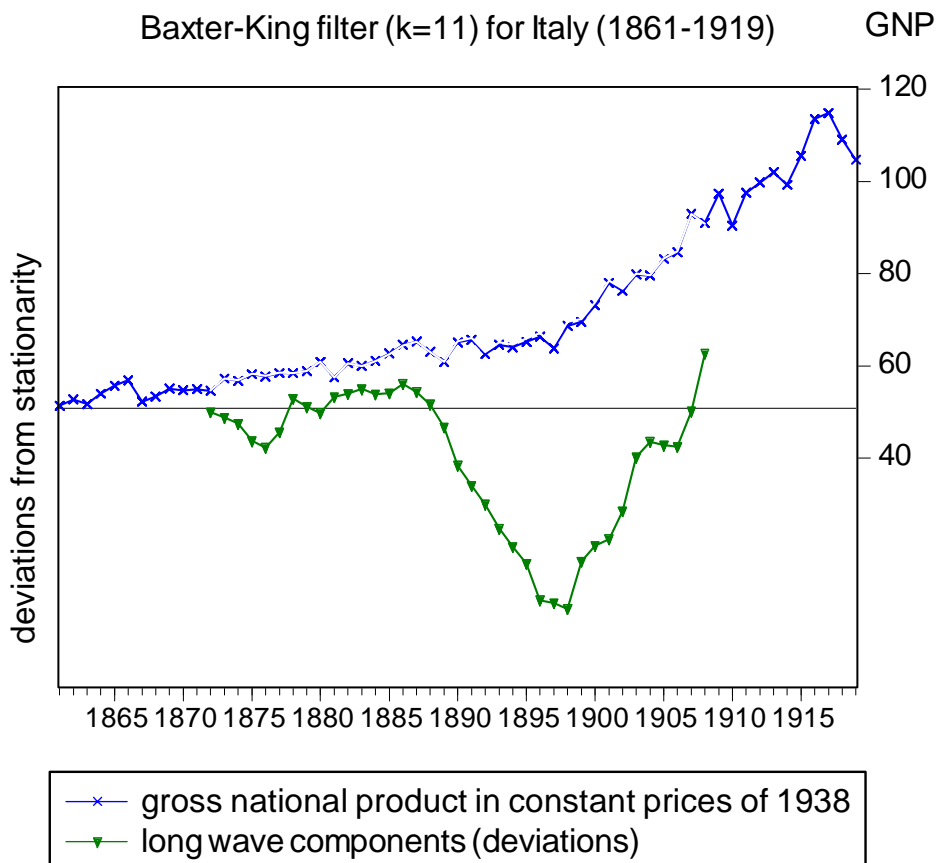




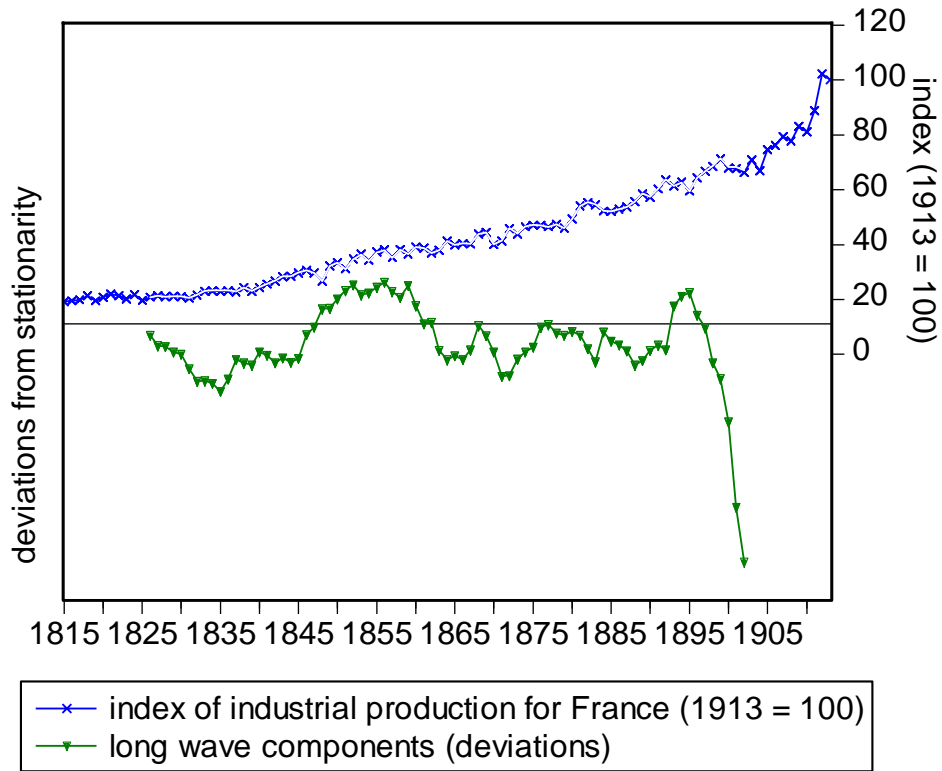
Baxter-King filter (k=11) for Great Britain (1830-1913)



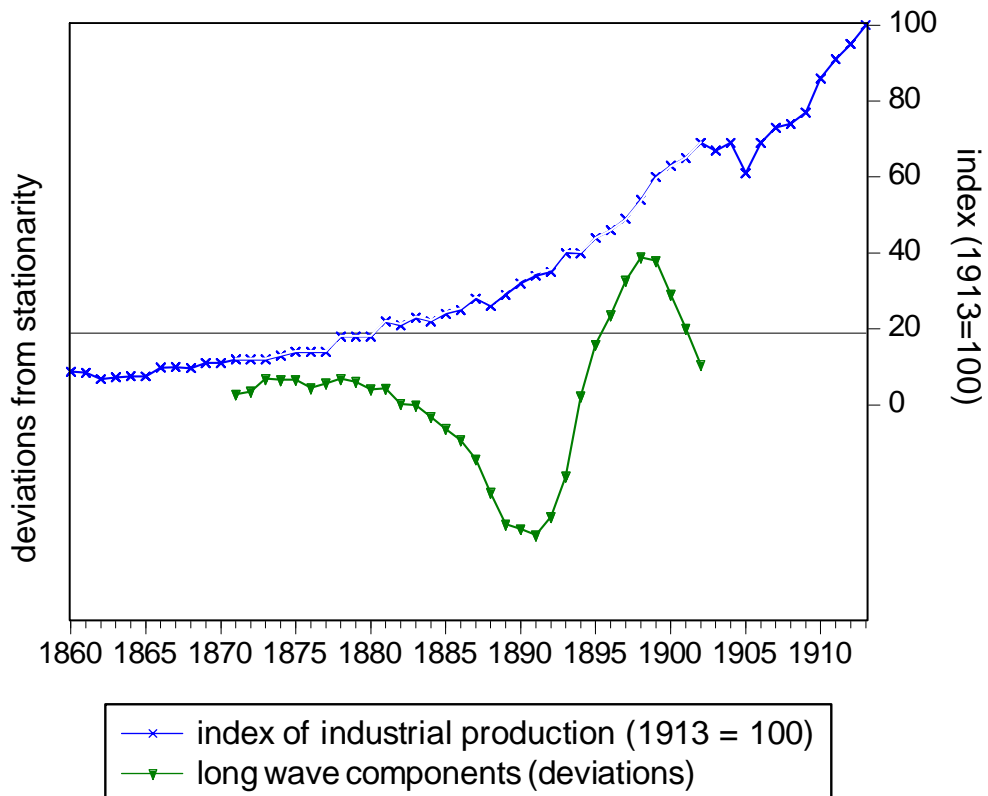
Baxter-King filter (k=11) for Italy (1861-1919)

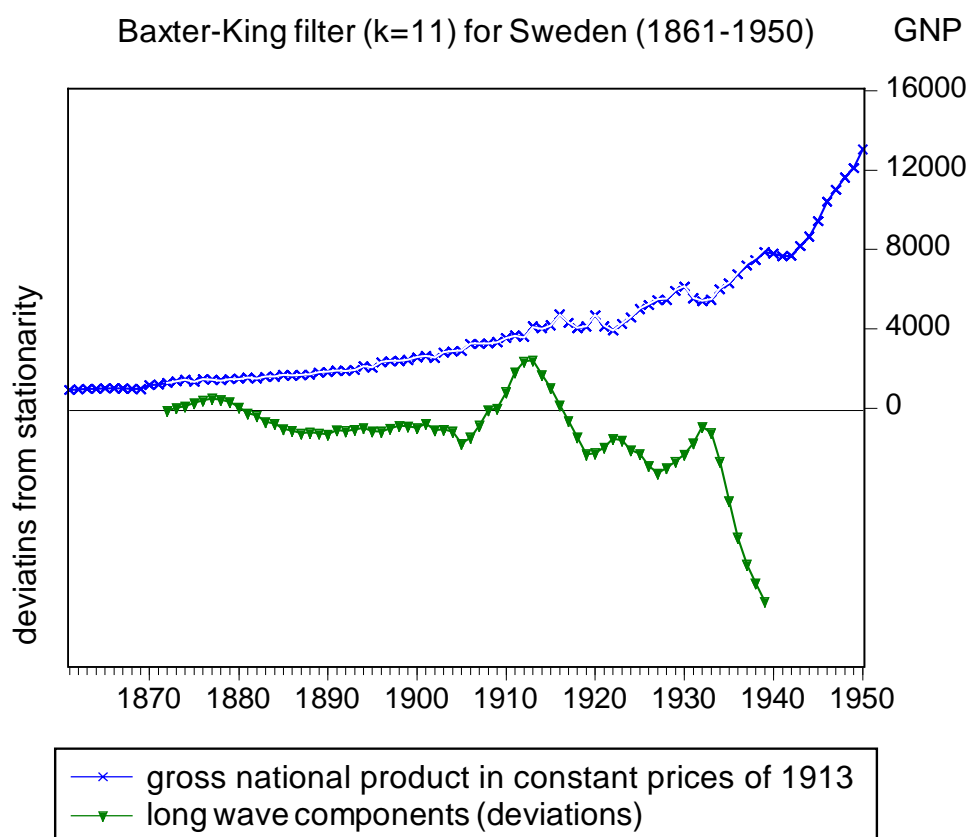


Baxter-King filter (k = 11) for France (1815-1913)



Baxter-King filter (k=11) for Russia (1860-1913)





The results for the different countries do show wave-like fluctuations, although their length seems to be shorter than 56 years, the period found by Kondratieff. Before the length of these waves is discussed in detail, the turning points observed shall be analysed. These turning points are summarised in the following table:

Table 2: Upper turning point (peak) and lower turning point (trough) of the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> long waves (filtering with smoothing parameter  $k = 11$ ):

Country	1 <sup>st</sup> wave / trough	2 <sup>nd</sup> wave / peak	2 <sup>nd</sup> wave / trough	3 <sup>rd</sup> wave / peak	3 <sup>rd</sup> wave / trough
Germany	-	1872	1885	1912	-
France	1835	1856	1871	1895	-
Great Britain	1860	1871	1891	-	-
Italy	-	1886	1898	-	-
Russia	-	1873	1891	-	-
Sweden	-	1877	1890	1913	1939

Before reporting the results, it is important to note that a missing value in the table for a cer-

tain peak or trough is due to a lack of data and to the shortening effects of the filtering process, and cannot be interpreted as the non-existence of a certain turning point for a particular country.

The lower turning point of the first long wave appears for France in the year 1835 and for Great Britain in the year 1860. For Germany, Great Britain, Sweden and Russia, the upper turning point of the second long wave is located in a (quite short) time interval between 1871 and 1877. France leads the way, having reached this turning point relatively early, in the year 1856. In contrast, Italy exhibits a time lag as it did not attain the upper turning point until the year 1886. This lead-lag structure is also observed for the lower turning point of the 2<sup>nd</sup> long wave. Germany, Great Britain, Sweden and Russia are again close together concerning their lower turning point, which in these countries occurred during a short time span between 1885 and 1891. In contrast, France again reached this turning point much earlier (in 1871) and Italy much later (in 1898).

Due to the shortening effect of the filtering process, which leads to a reduction in the length of a time series under study, the upper turning point of the subsequent third long wave can only be detected for three countries. However, the results are again in line with the above-mentioned lead-lag structure, as France shows its upper turning point much earlier (in 1895) than Germany and Sweden (1912 and 1913).

If the duration of a Kondratieff cycle is measured from one lower turning point to another, then the second long wave extends from 1835 to 1871 for France and from 1860 to 1891 for Great Britain. This would imply a duration of 36 years in the case of France and 31 years in the case of Great Britain. Another complete Kondratieff cycle showing a length of 49 years is the 3<sup>rd</sup> long wave for Sweden (1890 to 1939). The 3<sup>rd</sup> long wave for Germany is incomplete, as it begins in the year 1885, reaches its upper turning point in 1912 and then continues in the direction of a depression phase. Due to the strong economic upswing in the 1950s, and on the basis of earlier long wave calculations for this country, this would imply an approximate length of 50 to 60 years.<sup>11</sup> A possible explanation for the relatively short duration in the cases of France and Great Britain concerns the smoothing parameter of the Baxter-King-filter. Though increasing its value would improve the accuracy of the filter, this would shorten the filter output at the beginning as well as at the end of the time series. Therefore, a certain trade-

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<sup>11</sup> Metz's results suggest the year 1942 as the trough of the 3<sup>rd</sup> long wave for Germany [See also: Metz, R. (1992), p. 92]. Based on the calculated beginning of the 3<sup>rd</sup> long wave in the year 1885, this would imply a length of 57 years for Germany.

off has to be accepted between the aim of optimising the smoothing effect and that of obtaining a long enough filter output.<sup>12</sup>

Overall, the results are mostly in line with those of other empirical studies on long waves conducted by Goldstein (1999) and Metz (1992). In particular, Goldstein obtained the year 1831 as the lower turning point of the 1<sup>st</sup> wave for France, while Metz found the year 1832.<sup>13</sup> Goldstein detected the upper turning point of the 2<sup>nd</sup> wave in the year 1864 for France, 1872 for Denmark, 1873 for Sweden and 1866 for Italy. With the exception of Italy, these results match those in Table 2 quite well. The results obtained by Metz show an upper turning point in the year 1863 for France, 1867 for Sweden and 1869 for Great Britain. Both Metz and Goldstein place the lower turning point of the 2<sup>nd</sup> wave around the year 1890. Finally, the results of these authors are also similar with regard to the upper turning point of the 3<sup>rd</sup> long wave.<sup>14</sup>

### 3.2. Diffusion of the general-purpose technology ‘railway’

The following figures show the empirical diffusion process of the general purpose technology ‘railway’, together with the logistic functions which were fitted to the observed data.<sup>15</sup> The logistic function was chosen as a theoretical model because the empirical diffusion of the railway networks exhibits an S-curve pattern, which is a typical feature of technology diffusion and expresses a logistic growth process.<sup>16</sup> The following mathematical model can be used to describe the growth process according to a logistic function:<sup>17</sup>

$$m(t) = \frac{\lambda}{1 + \eta \cdot t^{-\omega}} \quad , \quad (2)$$

where  $m(t)$  indicates the state of diffusion at time  $t$ , the parameter  $\lambda$  represents the saturation level of the diffusion process, and  $\eta$  and  $\omega$  are parameters which influence the extension of the resulting S-curve. In order to estimate the parameters  $\eta$  and  $\omega$  of a logistic growth curve,

<sup>12</sup> The setting of a value for the smoothing parameter always implies a certain trade-off. On the one hand, increasing this value improves the accuracy of the filter. This means that the results of filtering reflect the chosen frequency band better if the value of the smoothing parameter is increased. On the other hand, raising the value shortens the filter output, so that it is not possible to increase the smoothing parameter indefinitely.

<sup>13</sup> Metz, R. (1992), p. 92 and Goldstein, J. P. (1999), p. 87.

<sup>14</sup> Goldstein, J. P. (1999), p. 87: Belgium 1913; Canada 1915; Denmark 1911; France 1913; Italy 1923; Sweden 1907; Great Britain 1899. Metz (1992), p. 92: Belgium 1920; Denmark 1928; France 1927; Germany 1912; Italy 1921; Sweden 1913; Great Britain 1909.

<sup>15</sup> The data source is listed in the appendix A2.

<sup>16</sup> See for example: Andersen, B. (1999) and Marchetti, C. (1998).

<sup>17</sup> Moosmüller, G. (2004), p. 55.

the ‘logit transformation’, a non-linear regression technique, is applied.<sup>18</sup> Before these calculations can be carried out, a saturation level  $\lambda$  for the relevant diffusion processes has to be specified. For Germany, France, Great Britain, Italy and Sweden, the maximum length of the railway network was chosen as an indicator for the saturation level. All of these five countries reached this maximum value in the first half of the 20<sup>th</sup> century, which means that the length of their railway networks decreased during the second half of the 20<sup>th</sup> century.<sup>19</sup> The exception is Russia, a country that does not exhibit a saturation level until the end of the 20<sup>th</sup> century, so that it had to be left aside as a special case. After the specification of the saturation level, the variable  $m(t)$  is divided by this level, so that an expression for the degree of diffusion is formed:

$$\lambda^* = \frac{m(t)}{\lambda} = \frac{1}{1 + \eta \cdot t^{-\omega}} \quad (0 < \lambda^* < 1) \quad (3)$$

From this term expressing the degree of diffusion, the following logarithmic ratio (called ‘logit’) can be derived:

$$\log \frac{1 - \lambda^*}{\lambda^*} = \log \eta \cdot t^{-\omega} = \log \eta - \omega \cdot \log t \quad (4)$$

This equation can be used to calculate ordinary least squares estimates for the parameters  $\eta$  and  $\omega$ . After inserting the estimated values into the logistic function of equation (2), the estimated logistic growth curve can be plotted for each country, with the exception of Russia. The following figures show these results as well as the original, empirically measured diffusion curves for each country except Russia.<sup>20</sup>

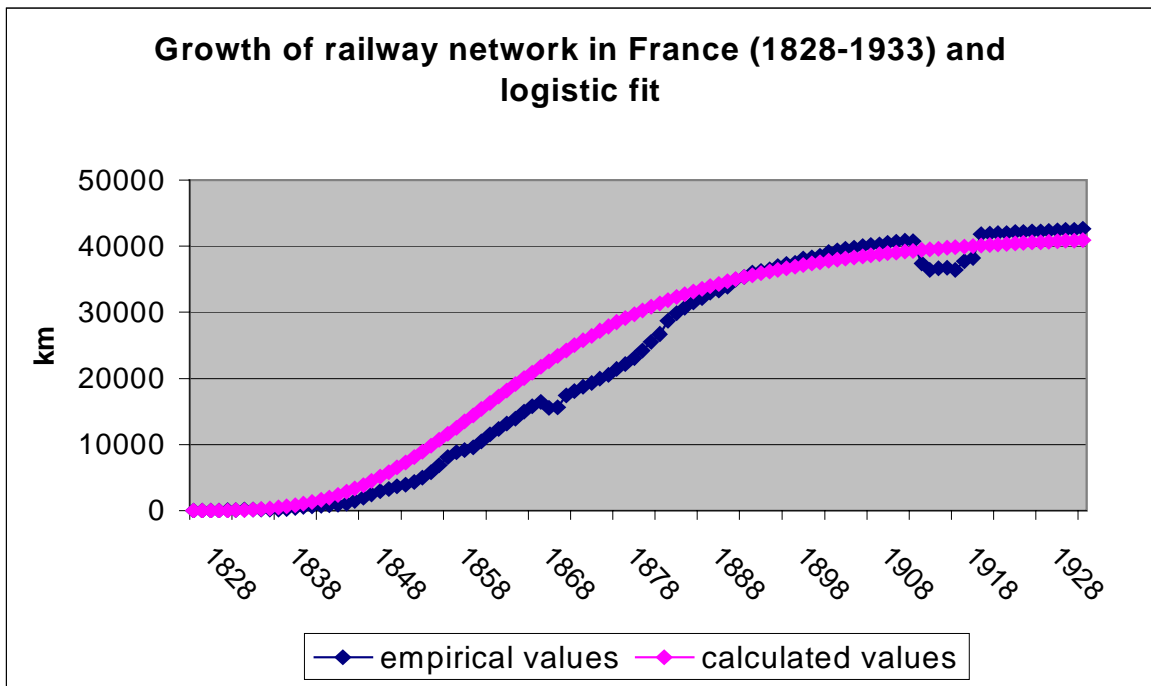
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<sup>18</sup> See for example Moosmüller, G. (2004), p. 56-60 or Schaich, E. and Schweitzer, W. (1995), p. 129.

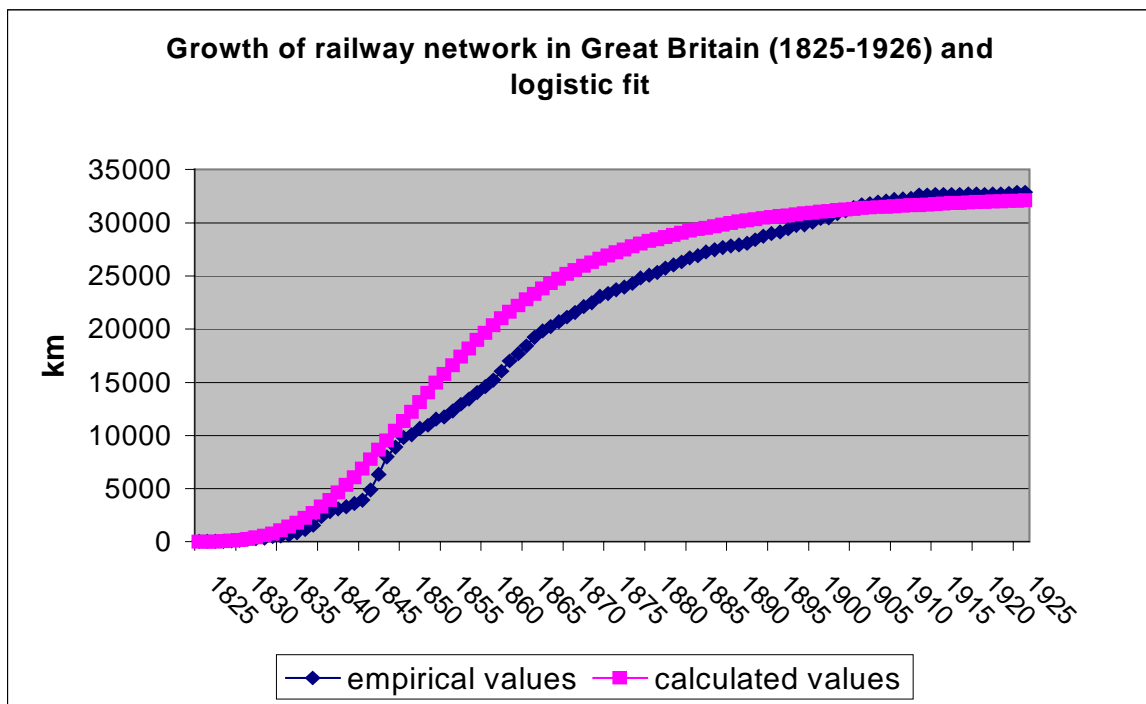
<sup>19</sup> Mitchell, B. R. (1980), p. 609-615.

<sup>20</sup> For details concerning the estimation results see table 4 in appendix A3.

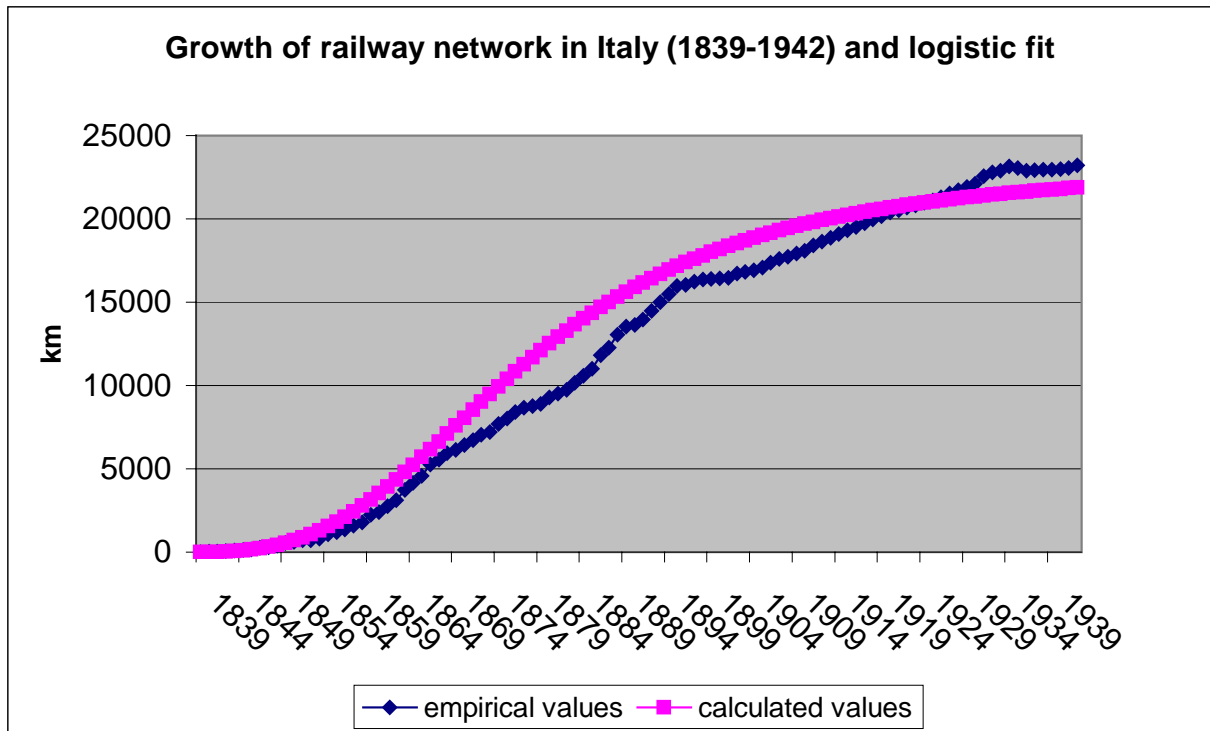
1) France



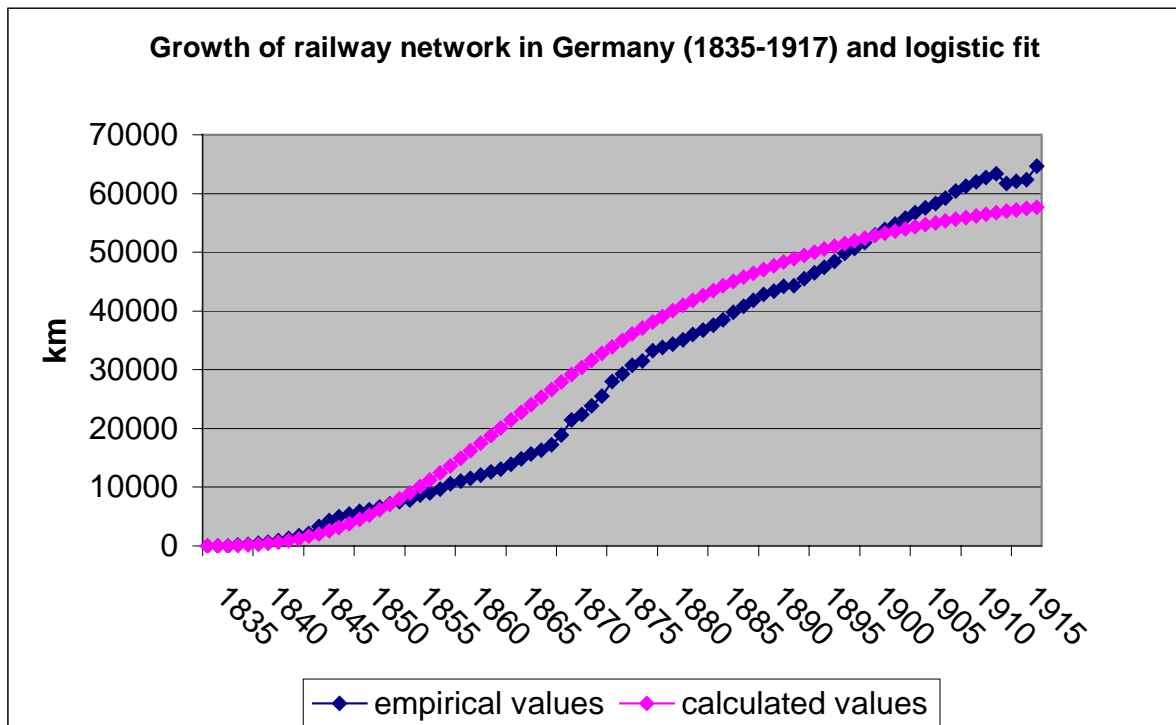
2) Great Britain



3) Italy

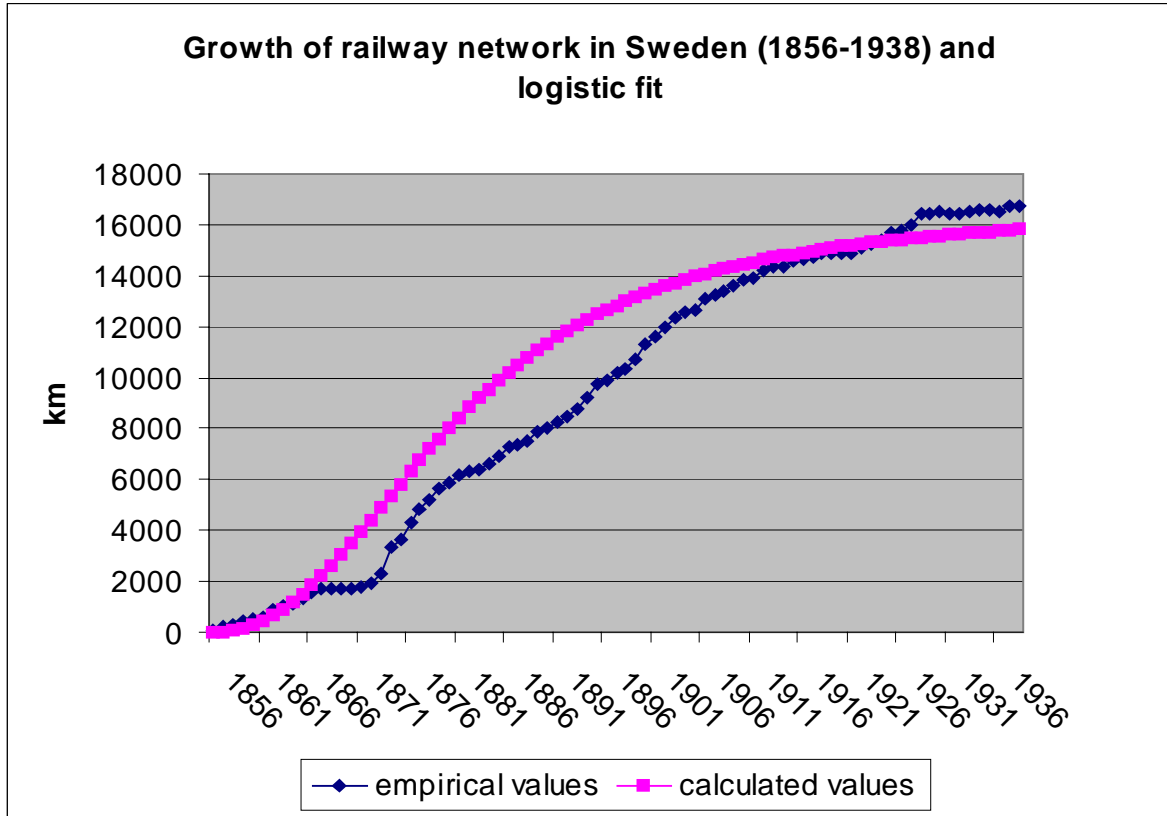


4) Germany





5) Sweden



Based on the numerically specified logistic regression functions, the turning points  $[t^*; m(t^*)]$  of these logistic functions were obtained according to the following formula:<sup>21</sup>

$$[t^*; m(t^*)] = \left( \eta^{\frac{1}{\omega}} \left( \frac{\omega - 1}{\omega + 1} \right)^{\frac{1}{\omega}} ; \frac{\lambda}{1 + \frac{\omega + 1}{\omega - 1}} \right) \quad (5)$$

The turning point of a logistic function marks a fundamental shift in the underlying growth process, from a period of exponential growth to a period of decreasing absolute growth. The importance of the S-shaped diffusion of a general-purpose technology is due to the relationship between a logistic growth curve (S-curve) and a cyclical process. This relationship can be identified if attention is focused on the change of the variable  $m(t)$ . If the absolute value of  $m(t)$  follows a logistic growth curve, then the change of  $m(t)$  per unit of time exhibits the form of a wave.<sup>22</sup> Therefore, the point of inflection of the logistic curve becomes the upper turning point of the resulting wave. From this simple relationship, the importance of a correlation between the upper turning point of a long wave and the point of inflection of an S-curve,

<sup>21</sup> Moosmüller, G. (2004), p. 56; see also: Schaich, E. and Schweitzer, W. (1995), p. 127.

<sup>22</sup> Marchetti, C. (1998), p. 60.

which represents the diffusion of a general-purpose technology, becomes apparent. An additional indicator for the diffusion of an innovation is the point of time when half of the saturation level is attained. This point of half saturation is denoted by  $[t^{**}; \lambda/2]$  and was calculated using the empirical values of railway diffusion.

The following table shows the calculated points of inflection, the empirically observed points of half saturation and the turning points of the long waves calculated with the band pass filter.

Table 3: Comparison of the turning points for the 2<sup>nd</sup> long wave with the turning points of railway diffusion and points of half saturation

Country	Time of half saturation	Turning point / diffusion	Upper turning point / 2 <sup>nd</sup> long wave
Germany	1878-1879	1866	1872
Great Britain	1862-1863	1855	1871
France	1877-1878	1863	1856
Italy	1885-1886	1870	1886
Sweden	1891-1892	1874	1877
Russia	-	-	1873

The table shows that - with the exception of France - all diffusion turning points appear before the turning points of the relevant long wave. Concerning the length of this time lag, there seems to be no common ground among the countries analysed above. The time lag ranges from three years in the case of Sweden to six years in Germany and sixteen years in Great Britain and Italy; its average value - when France is excluded - is 10,25 years. In three out of five cases, the point of half saturation occurs later than the two different turning points. The exceptions are Great Britain, where half of the saturation level is attained before the upper turning point, and Italy, where the level of half saturation is exactly matched by the upper turning point of the second long wave. The time lags between the turning point of a long wave and the point of half saturation are quite different. In general, it has to be accepted that the construction of a railway network can have very specific characteristics in different countries, for which Russia is the best example. Altogether, the results of Table 3 can be interpreted as tentative evidence for the observation of a certain sequence, implying that the turning points of railway diffusion appear earlier than the turning points of the second long wave.

#### 4. Summary and Outlook

The application of a band pass filter to historical time series of aggregate and industrial production for Great Britain, France, Germany, Russia, Italy and Sweden demonstrates the presence of wave-like fluctuations with a length of between 31 and 49 years. Their turning points exhibit a strong correlation for a group of four countries, namely for Great Britain, Sweden, Russia and Germany. Concerning the turning points for the second and third long waves, France leads the field while Italy lags behind the other countries in the group. It is not easy to explain this empirical lead-lag behaviour, although it might be due to institutional factors which were similar for the four countries Great Britain, Sweden, Russia and Germany and more or less different for France and Italy.

Based on the theory of Schumpeter, who saw railways as the main driving force for the development of the 2<sup>nd</sup> Kondratieff cycle, a possible empirical relationship between the diffusion of the general purpose technology ‘railway’ and the second long wave was observed. This observation concerns the position of the turning points of railway diffusion and long waves respectively. There seems to be evidence for a kind of sequence, implying that the turning points of railway diffusion generally occurred before the turning points of the second long wave. This relationship was observed for four of the five countries for which all types of turning points could be calculated. Of course, it is not possible to establish a causal relationship from this finding, but at least it does not contradict Schumpeter’s theory.

An important task in further research will be to trace such empirical relationships for other general-purpose technologies like electricity in the case of the third long wave and the automobile in the case of the fourth long wave. This appears promising, as the diffusion of electricity and automobiles also shows S-shaped diffusion curves.<sup>23</sup> Establishing a more stable empirical relationship between the diffusion of major basic innovations and long waves would also be helpful for predicting long term growth and could then possibly be applied to today's general-purpose technology, information technology.

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<sup>23</sup> Kriedel, N. (2005), p.188 and p. 225-227.

### **Appendix A1: Data used for the Baxter-King filter:**

For France and Russia: Mitchell, B.R. (1981), *European Historical Statistics 1750-1975*, p. 375-379; for Germany, Italy and Sweden: Mitchell, B.R. (1981), *European Historical Statistics 1750-1975*, p. 817-823; for Great Britain: Mitchell, B.R. (1988), *British Historical Statistics*, p. 837ff.

### **Appendix A2: Data used for the growth of railway network:**

For Italy and France: Mitchell, B.R. (1980): *European Historical Statistics 1750-1975*, S. 609-614; for Germany: Mitchell, B.R. (1980): *European Historical Statistics 1750-1975*, p. 609-611; for Sweden and Great Britain: Mitchell, B.R. (1980): *European Historical Statistics 1750-1970*, p. 610-615.

### **Appendix A3: Results of the logistic regression for the diffusion of railways**

In the following table, the estimation results for the parameters  $\eta$  and  $\omega$  of the regression function (4):

$$\log \frac{1 - \lambda^*}{\lambda^*} = \log \eta \cdot t^{-\omega} = \log \eta - \omega \cdot \log t$$

are depicted. Besides, for each country except Russia, the corresponding t-value, the coefficient of determination (R-squared), the adjusted coefficient of determination (adjusted R-squared) and the marginal significance level (p-value) is shown.

A note has to be made concerning the estimation results: The original coefficient estimations concern the variable  $\log \eta$  and  $\omega$ , as these variables appear in the regression function (4). The estimations for  $\eta$  have been derived from these original estimates by the simple retransformation  $10^{(\log \eta)}$ .

This transformation has to be applied, because EViews 5.0 (the software used for these calculations) applies the decadic logarithm when taking the logarithm of a variable. Of course, the t-values, and therefore also the p-values as well as the two different coefficients of determination were calculated for the variables  $\log \eta$  and  $\omega$ .

Table 4: Estimation results of the logistic regression

Country	coefficient estimation		t-statistic		p - value	R-squared	Adjusted R-squared
	$\eta$	$\omega$	$\log \eta$	$\omega$			
France	295.292,897	3,383	31,119	31,752	0,00	0.907	0,906
Great Britain	63.668,703	3,198	25,429	27,657	0,00	0,885	0,884
Italy	43.132,934	2,897	32,981	33,853	0,00	0,919	0,918
Sweden	2.897,837	2,453	16,975	18,612	0,00	0,812	0,810
Germany	36.697,12	2,856	42,298	40,966	0,00	0,954	0,954

As the t-statistics and the p-values show, the coefficients  $\eta$  and  $\omega$  are significantly different from zero. The estimation results for  $\eta$  and  $\omega$  were used to calculate the turning points of the logistic diffusion curves according to formula (5).

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Hamburg Institute of International Economics (HWWI)

Neuer Jungfernstieg 21 | 20354 Hamburg | Germany  
Tel +49 (0)40 34 05 76 - 0 | Fax +49 (0)40 34 05 76 - 76  
[info@hwwi.org](mailto:info@hwwi.org) | [www.hwwi.org](http://www.hwwi.org)