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Development blocks and the second industrial revolution – Sweden 1900-1970

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Abstract

The paper explores development blocks around electrification at a 14 sector level in the Swedish economy 1900-1974. We suggest that long-run cointegration relations in combination with mutually Granger-causing short-run effects form a development block. One block centred on electricity that comprises five more sectors is found. In addition we demonstrate that increasing its electricity share makes a sector grow faster, and by testing the electricity share versus the growth rates we find another development block around electricity, party overlapping the first one.

Keywords: development block, electricity, GPT, second industrial revolution

1. Introduction

The aim of this paper is to explore the development block around electricity and its impact upon growth during the second industrial revolution. There have been two major empirical studies of Swedish industry using the development block approach. One is Erik Dahmén's (1950) formative study of Swedish entrepreneurial activity in the interwar period performed primarily on a micro and branch level. The other is Lennart Schön's (1990) study of electricity and industrial development that *inter alia* connects the use of electricity to innovative structural change and to the growth of relatively knowledge intensive industries. The links within development blocks are complex, however. Our ambition is to bring this kind of analyses one step further by investigating growth patterns and electrification in Sweden to assess the options of identifying such development blocks and their importance for growth quantitatively.

Development blocks should in principle be possible to identify with the means of cointegration analyses. A *first* reasonable expectation is that sectors that form a development block would be cointegrated, i. e. their *long-run* growth would be driven by a common stochastic trend. This stochastic trend could be seen as consisting of the specific technology of that block in a wide sense, but it might be influenced by business fluctuations driven by demand and export as well. Still, if electricity is an important component of that new technology, the electricity-producing sector should be cointegrated with every other sector of the block. *Second*, the direction of causation in the *short-term* of the production of the sectors should be marked by many mutually reinforcing connections within the development block, rather than one sector Granger causing another, since a basic idea of the development block is that activities are complementary.

Third, if electrification is a central kernel in a development block that drives growth it should be possible to detect a correlation between the electricity use of an industry and its growth rate. However, energy play very different roles in the production of sectors, some being heavy energy users and others light users. Thus it is not the electricity intensity (electricity divided by value added) but rather the electricity share of total energy use that would affect the growth rate of the sector.

Recently Moser and Nicholas (2004) have used historical patent citations in order to evaluate whether electricity was a general purpose technology. The method used here is also quantitative, but rather than tracing patent links it traces the links between the value added of sectors, and is thus a different method, but with the aim of answering a related question to that of general purpose technologies: are there any development blocks around electricity?

The outline of the paper is as follows:
Section 2 is a theoretical and historical section around development blocks and the second industrial revolution, with growth implications. Section 3 describes the data that we use to test the idea of development blocks centred on electrification. Section 4 explains the method of cointegration analyses. Section 5 shows the results of our testing of development blocks. Section 6 sums up the discussion.

2. Theory

2.1 Development blocks and growth

The concept of development blocks was first formulated by Dahmén (1950, 1988) and was influenced by the Schumpeterian idea of creative destruction (Carlsson and Henriksson 1991). It is part of an evolutionary approach to economic growth, according to which growth is not an even process over time, but takes place due to transformations and leads to structural change of the GDP composition. Early on the basis for development blocks was said to be new technologies, especially in the fields of communication and transportation that widened into broad societal impact (Schön: 1990, 1991, 1994, 2000a, 2000b).

Electrification of industry provides a good starting point for an analysis of industrial growth in the long-term perspective. Electricity has been central to Swedish industrial development and electrification constitutes a development block with strong potentials and complementarities. In addition, the electrification of industry required large simultaneous efforts in the generation and distribution of electrical power and in the development of the electro-technical industry and of industries consuming electricity and stimulated and was stimulated by urbanization with the concentration of goods, labor and knowledge. Thus, the concept of development block provides the framework for the analysis of this pattern of electrification, focusing on the inter-relations of power generation, the electro-technical industry and the industrial development, leading to shifts in supply and demand functions for electricity.

With the advent of the IT-revolution, many economists noticed the occurrence of radical innovations and technological shifts and in the mid-1990s the concept of General Purpose Technologies, GPTs, was launched (Helpman, 1998, Bresnahan, T. F., E. Brynjolfson, and L. M. Hitt 1999). Radical innovations tend to develop into GPTs. That is however a drawn-out process that may stretch over generations. The concept development block, that combines the characteristics of the innovation with economic relations, captures the main dynamics of this process. The basic innovation enters into different development blocks over time on its path to becoming a GPT. The innovation creates new complementarities – i.e. dependencies between specific functions or properties within the production process or between production and infrastructure or institutions that take time to bring forth and when accomplished the complementary factors mutually increase their marginal returns. Fulfilling a development block with radically new complementarities is a time consuming investment process. Breakthrough periods of new important development blocks – periods of industrial revolutions really qualify in this respect – are characterised by severe imbalances in growth, bottlenecks that may direct investments and strong tendencies towards divergence between branches and regions in growth performance.

Furthermore, in the breakthrough period, or period of structural transformation, the positive contribution on productivity from technical change tends to be hampered by the imbalances or bottlenecks in the economy. Complementarities are insufficiently provided for (Schön 1991, 1998). A productivity paradox, i.e. rapid technical change coinciding with slow productivity growth, appeared not only with the computer in the 1980s but also with the breakthrough of electricity in industry (David 1990, Schön 1990).

The GPT as drastic innovations characterized by pervasiveness in use and innovational complementarity has recently been integrated in endogenous growth models, for instance by Petsas (2003) and Carlaw and Lipsey (2006).

The evolutionary growth perspective, with some branches taking the lead and interacting with others in a complementary way, has been examined for Sweden for the period 1968 and onwards (Lundquist, Olander and Svensson Henning: 2005, 2006). Strong empirical support for the idea of complementarities in growth processes in time and space has been found simply by characterizing the growth rates of value added in a broad number of branches in different periods.

This paper takes on the challenge of investigating Swedish economic growth according to the development block ideas in an earlier period (1900-1970) and uses advanced time series analyses, called cointegration analyses, to trace such linkages in the economic growth process with specific emphasis on the role of electrification. The period under investigation here is the period of the second industrial revolution.

2.2 The second industrial revolution

Sometimes it is stressed that there are three main clusters of technologies that characterize the economic development, profound enough in socio-economic impact to be referred to as the first, second and third industrial revolution. All three industrial revolutions centered on innovations in the field of energy systems.

The *first industrial revolution* centred on an innovation in the field of inanimate power: the steam engine. Steam engines replaced traditional energy sources but also provided power for new fields of usage. They had several advantages, compared to traditional prime movers that affected substitution patterns. The main advantage compared to animate power was that the steam engine was more powerful. Compared to waterwheels its main advantage was that it was site-independent. Steam engines not only replaced other prime movers; they also opened up new application possibilities for prime movers. For instance steam powered railways revolutionized land transportation.

The *third industrial revolution* can be dated to the Mid 1970s, when the growth phase for microelectronics took off with the miniaturisation of hardware for information treatment, manifested in the microprocessor.[1] It was a revolution in information treatment and exchange relying on low-tension electricity just like the previous profound breakthroughs in communication: the telegraph and the telephone.

The *Second Industrial Revolution* (or the Big Wave, Gordon 1999) was to structure economic growth from the 1890s up until the late twentieth century. Thus, the concept of the Second Industrial revolution can, as every industrial revolution, be understood in two ways that do not exclude each other. In one perception it was a discontinuous event that within a short time-span (a few decades) created new conditions technically, structurally and institutionally for economic growth. In another conception it represented a set of forces that unfolded itself during almost a century. In recent decades, much research has focussed on this chain of events, allegedly giving birth to the modern industrial society.

At the heart of the Second Industrial Revolution there was a series of innovations that went through a marked acceleration in their diffusion during the 1890s with far-reaching repercussions on growth and society. And in the midst of this bunch of innovations were new power-machines – the electric motor and the combustion engine. As is usually the case, the basic innovations were born some decades earlier but complementary innovations (such as three-phase alternate current and new transmission technique in the technology of electricity) and economic expansion after the Baring crisis made diffusion more discontinuous and compressed in time.

The breakthrough of the electrical motor and the combustion engine liberated economic growth from a set of constraints that in the course of the nineteenth century had become more inhibiting with industrial expansion. These constraints concerned the supply and price of energy, the localisation of industry and the organisation of the industrial work process (Schön 1990). From the 1870s the relative price of coal and firewood rose significantly. There was a fear that industrial growth would be stifled by a shortage of energy. The breakthroughs of the electrical dynamo and the combustion engine as forceful power technologies widened energy supply and fear turned into new optimism. Running water had for centuries been utilised as power source, transmitted mechanically to the working machines at site. By the late nineteenth century, however, almost all reasonably available hydropower was taken into use. There were large unutilised resources but in more remote areas such as mountainous regions disfavoured by high transport costs. With a new transmission technology, enabled by the three-phase alternating current, the supply of hydropower became much more elastically available. Thus resources increased. Furthermore, with long-distance transmission of electricity – irrespective of primary energy source - the location of industries could be selected from a new basis of rationality, where markets were close at hand and where labour-power or skills were plentiful. This gave rise to broader industrial environments, where crucial knowledge, competence and skills could be utilised more efficiently and flexibly. The innovating capacity was enhanced. For different reasons, also the combustion engine gave a greater flexibility in choice of location. As a liquid fuel, petroleum was comparatively easy to transport and handle. In regions or countries of plentiful petroleum resources, the combustion engine became a prime mover. In every corner of the modern or modernising world, however, it became prominent in transportation.

Also within the plants a new flexibility was created through the electrical motor or the combustion engine. Mechanised factories driven by steam engines or direct waterpower was constructed around the power machine from which the motive power was transmitted mechanically via belts, cables and rotating shafts. Apart from all environmental damages – the working site was noisy, dirty and dangerous – the mechanical transmission meant certain constraints and indivisibilities in industrial organisation. The returns to increased mechanisation or to division of labour between specialised machinery units were diminished by these constraints. With small powerful motors and more sophisticated specialised machinery a new organisation based on unit drive, i.e. one motor on each working machine, developed during the first decades of the twentieth century

The power machines did not stand alone, though. The appearance of a radically new steel technology in the last decades of the 19th century created other prerequisites for new industrial growth. For one thing, the use of steel of higher qualities and in larger quantities made machine technology more competitive and pervasive, particularly in conjunction with new power machines. Steel also became the new material in constructions, in infrastructures, in vehicles and vessels – i.e. there were wide potentials in power machines and steel as kernels in new development blocks. Alongside with the new steel technology a new organic chemistry, mainly based on coal, arose. Scientific knowledge in chemistry became input in the production of steel and paper as well as of fertilisers, dyes, pharmaceutical drugs etc. And in information technology, the advent of the telephone and the wireless radio made communications much more flexible than before. In all, this swarm of innovations strengthened modern economic growth and industrialisation became a more encompassing social adventure and a more attractive path to follow.

To assess the full economic impact of these new technologies in quantitative terms is impossible, because they are so complex. The direct growth effects that stem from the growth of industries and branches involved with production of the new engines and related systems of energy and communication may not justify the term industrial revolutions, but the indirect effects on growth are substantial.

The indirect growth effects of the technologies of the second industrial revolutions were at least fourfold. First, the new engines in sea, land and air transportation implied increasing market integration with concomitant specialisation and economies of scale, which increased overall economic efficiency and growth. Second, the new engines established a growing production apparatus that augmented the motive power at the workers' disposal. The stock of machinery grew incrementally and brought about a long-term growth of industrial production. Third, the new engines enabled more efficient organisations of production. This was particularly so with electric engines when applied to group-drive or unit-drive. Fourth, the new technologies went hand in hand with human capital development, since there was a skill-technology complementarity especially in the electricity production and manufacturing of electro-technical equipment (Goldin and Katz: 1986).

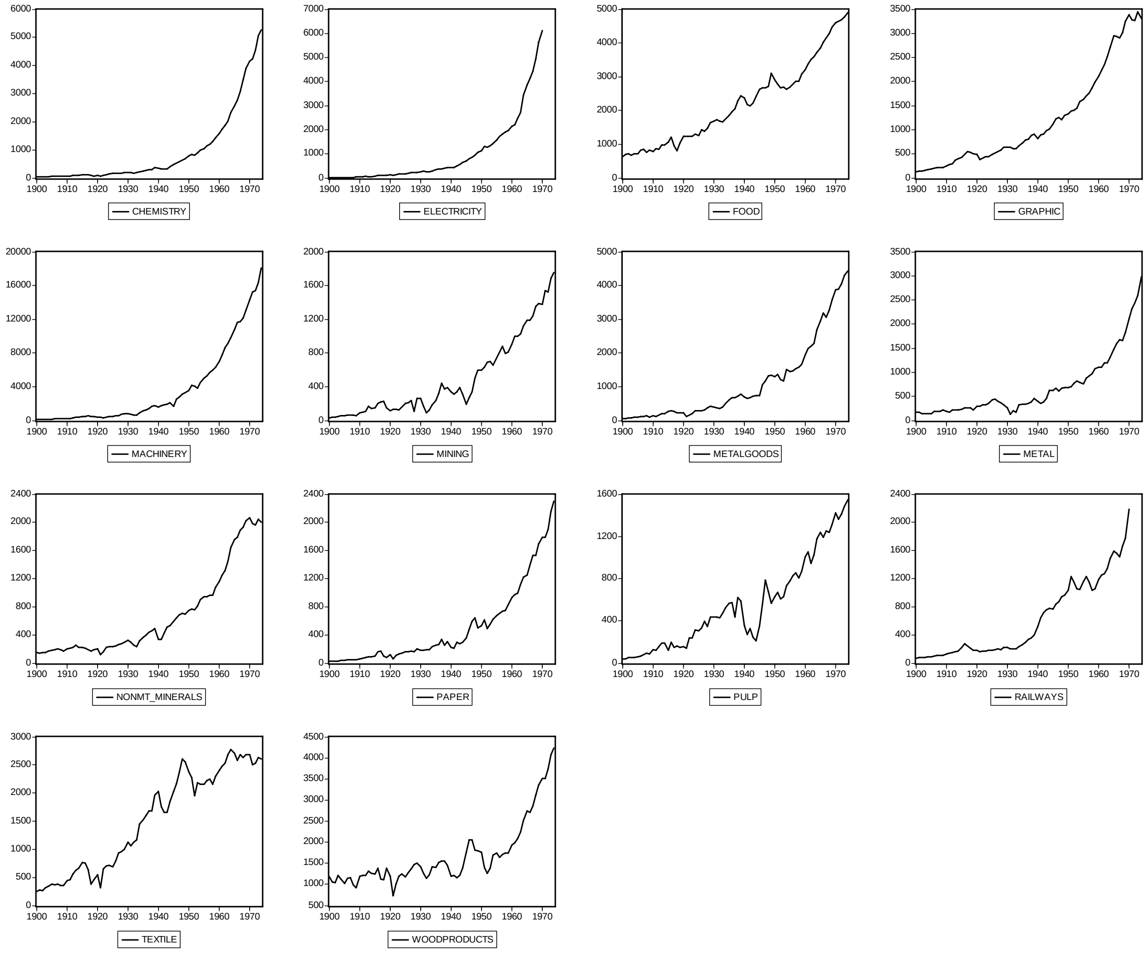
Diverging effects can be discerned from the Second Industrial Revolution in the midst of the Gold Standard period. Growth pattern changed from 1890 (Schön: 2006, *forthcoming*). Convergence became weaker and there was rather divergence in growth with different responses to the revolutionary transformation of industry. In the period 1870-1890 convergence was much more pervasive and growth rates much more even among countries. Growth was especially strong in the 1890s in a belt down from Scandinavia through Germany, Austria, and Switzerland to northern Italy. Germany had an industrial structural change similar to Sweden (or vice versa). Engineering industries and new chemical industries expanded. Engineering industries or new knowledge intensive industries – with electro technology as one outstanding part – were important also in the rest of the countries in this group.

This paper focuses on one of the two radical innovations of the second industrial revolution: electricity and we thus leave the combustion engine and oil aside for a later occasion. Our aim is to analyse how specific development blocks form at the sectoral level, and we expect that sectors that were early adopters and producers of electricity should take a lead of the evolution and be mutually connected within certain development blocks. If electricity was an important factor in driving growth in Sweden, Germany and Italy after 1890 we should be able to find evidence of strong development blocks around electricity and fast growth of electrifying sectors.

3. Data

The data set we use consists of a total of 14 time series of value added for 12 industrial sectors plus the railway sector and the electricity-producing sector from 1900 to 1974 in Sweden. In addition it consists of annual electricity consumption and fuel consumption for all the industrial sectors from 1936 to 1974. For the railway sector we have energy series from 1915 to 1974. Series of production volumes and energy use in the industrial sectors were constructed and presented in Schön (1990). All industrial series are measured as gross value added, whereas the electricity and railway sectors are measured in gross production expressed in 1969/70 constant prices (millions of SEK).

Figure 1. Value added in all 14 sectors, millions of SEK, constant prices, price level 1969/70.



4. Methods

We use cointegration analyses to trace long-run relations between sectors and variables and Granger causality to trace the short-run relations. We define a development block as consisting of a number of sectors that share a common long-run trend (i.e. are cointegrated) and are linked to each other by mutually reinforcing Granger causality. The expectation of mutually reinforcing linkages in the short term is due to one of the main ideas in the theory of development blocks: that of complementarity. This econometric approach to studying sectoral linkages is different from the conventional input-output method that assumes an instantaneous relationship between the sectors of the economy (Leontief: 1957). Instead we use time series data to capture the dynamic relations between various industrial sectors, both in the long and in the short-run. This econometric approach has been utilized in earlier studies to assess the linkages from particular sectors, such as the financial sector (Odedokun: 1996) or the construction sector (Chan: 2001) to the rest of the economy. To the best of our knowledge, this approach has not yet been used as a mean to identify development blocks among several sectors.

4.1 Cointegration

The concept of cointegration can be defined as a systematic co-movement between two or more non-stationary variables over the long run. A variable is said to be non-stationary when its mean, variance and covariance are time dependent, meaning that any shock to the variable will have a permanent effect, as the variable does not revert back to its mean. If two non-stationary variables are regressed upon each other, the result is likely to be spurious (Granger and Newbold: 1974), and therefore the econometricians used to opt for taking differences and logs in order to transform non-stationary variables into stationery ones that can enter into traditional regressions. A variable that becomes stationary after taking its first differences is said to be integrated by order one, I(1). The problem with this approach is that the differencing procedure removes all long-run properties from the series. However, Engle and Granger (1987) showed that there can be a linear combination between two non-stationary variables that produce a series which is stationary. If we are able to detect such a linear combination, the two non-stationary time series are cointegrated, which means that they may drift from their original means, but that that they follow the same stochastic trend so that they never drift too far apart from each other in the long-run. Thus, if X_t and Y_t are non-stationary but cointegrated, there exists some value, β, such that $Y_t - \beta X_t$ is stationary.

In order to find out whether our variables are cointegrated we use the Vector Auto Regression (VAR)-based trace test for cointegration developed by Johansen (1988, 1991). Since this test is sensitive to the choice of length of the time lag in the original VAR, we use a combination of information criterias and lag exclusion tests to determine the appropriate lag length, before testing for cointegration.[2] Since the asymptotic distribution of the test statistic for cointegration depends on the assumptions made with respect to deterministic trends in the data series and in the cointegration relations, an assumption regarding the underlying trends in our data needs to be made. All specifications includes intercept in the cointegration relation, but we only include trends if the variables appear to be trend stationary and if the trend turns out to be significant. [3]

4.2 Vector Error Correction (VEC)

The Granger representation theorem (Granger: 1983, Engle and Granger 1987) states that if a set of variables are cointegrated, there exists a valid error correction representation of the data. If X_t and Y_t are cointegrated we can therefore write the following Vector Error Correction Model (VECM) of lag order *p*:

$$\Delta Y_t = \sum_{i=1}^{p} \Phi_{1,i} \Delta Y_{t-i} + \sum_{i=1}^{p} \Phi_{2,i} \Delta X_{t-i} + \alpha_1 (Y_{t-1} - \beta_1 X_{t-1}) + \varepsilon_{1,t}$$

$$\Delta X_t = \sum_{i=1}^{p} \theta_{1,i} \Delta X_{t-i} + \sum_{i=1}^{p} \theta_{2,i} \Delta Y_{t-i} + \alpha_2 (Y_{t-1} - \beta_2 X_{t-1}) + \varepsilon_{2t}$$

Where Δ is the first-difference operator, Φ and θ are the coefficients of the first-differenced terms (the short-run parameters) and the α:s measure the speed of adjustment of each variable to the cointegration relationship. The cointegration relationship is represented by the expression within brackets, in which the β:s are the cointegration coefficients. The ε:s are serially uncorrelated error terms.

[2] Additional information about VAR-specification is provided in the appendix.

[3] We also check the robustness of our findings for different specifications, and it turns out that our tests are robust to alternative specifications.

In order to discern short-run linkages between industrial sectors we use the Granger causality test. The test was proposed by Granger (1969) and is a general approach to detect whether past values of a series X can be used to determine current values of Y. The test is usually carried out in a VAR-framework, but in the presence of a cointegration relationship between X and Y, Granger causality can be determined within the framework of the VEC as specified in the above equations. With respect to this system, there is one-way Granger-causality running from X to Y if the Φ_2's are jointly significantly different from zero in the first equation, but the θ_2's not jointly significantly different from zero in the second. In parallel, there is one-way Granger causality from Y to X if the θ_2's are jointly significant from zero in the second equation, but the Φ_2's in the first equation are not. Mutually short-run links are defined as the two-way Granger causality that occurs when the Φ_2's in the first and the θ_2's in the second equation both are jointly significant from zero. The two-way Granger causality describes a scenario in which past values of X determine current values of Y and past values of Y simultaneously determine current values of X, which means that the two series are mutually reinforcing each other. The tests are carried out using the Wald-test for the joint null hypothesis of the above-specified parameters being equal to zero in each equation.

In the absence of a long-run relationship between X and Y, there may still exists short-run linkages. In that case we have employed the Granger causality test in a VAR with variables in their differenced form to investigate these linkages.

5. Results

5. 1 Long-run relations

The Phillips-Perron test show that the value added-series in all 14 sectors are non-stationary and I(1).[4] Therefore we proceed by investigating whether we can find any long-run relationships between pairs of sectors during the second industrial revolution. Since there are 14 sectors, each one can maximally share long-run relationships with all of the other 13 sectors. The results are presented in table 1. In general, there are quite many long-run relationships between the sectors, which perhaps is not very surprising given that they are part of the same macroeconomic system. The highest number of cointegration relationships is found between the graphic industry and 12 other industries and most industries show 9 to 12

[4] All unit root tests are reported in the appendix

common trends with other industries, indicating strong long-run linkages between most industries in the Swedish economy. However, the exceptions are the textile and the food industry that only share 6 and 4 long-run relations with other industries respectively and consequently seem to be less integrated in the economic system.

As we discussed in section 2.2, the electric motor, three-phase alternate current and new transmission technique in the technology of electricity were core innovations in a series of innovations that went through a marked acceleration in their diffusion during the Second Industrial Revolution. Our prior knowledge about the nature of technologies driving the Second Industrial Revolution makes us focusing on development blocks around the particular industry that supplied the new technology: the electricity industry. The identification of development blocks and especially what constitutes the core of such blocks in this paper is thus not a random search, but driven by our previous understanding. We test the hypothesis that the electricity industry is at the core of one or more development blocks and that it interacts with several other industries in a mutually reinforcing way. In the electricity industry, we detect 9 cointegration relationships, namely between the electricity industry and the metal; chemistry; pulp; metal goods; graphic; machinery; railways; paper and wood products industries. This seems intuitively correct as all of these industries are dependent on electricity to a high extent, whereas the industries that do not share long-run relations with electricity (non-metal minerals, food and textile) are not. The only exception is the mining and quarrying industry which does not share a long-run trend with electricity, although we know that it is both energy intensive and was early in adopting electricity as a new technology.

Table 1 The number of cointegration relationships for each sector

Graph.	**Chem.**	**Pulp**	**Metal goods**	**Mach-inery**	**Paper**	**Rail-ways**	**Elect-ricity**	**Mining**	**Metal**	**Non-Met. Min.**	**Wood Prod.**	**Textile**	**Food**
12	10	10	10	10	10	10	9	9	9	9	9	6	4

It seems that electricity is an integrated part of the Swedish economic system during the second industrial revolution, but the number of long-run relationships per se cannot help us in identifying specific development blocks between sectors. To be able to identify such inter-linkages we must investigate the short-run relationships and possible complementarities between the industries.

5.2 Short-run linkages

Short-run Granger causality is tested either by running the bivariate VAR in differenced form or, in the presence of cointegration, by running VEC-regressions between all possible pairs of variables. Since there are 14 variables in the system, we start by running 91 regressions to test if lagged values of any variable in the system can significantly explain the current dependent variable. If a sector's past values can be used to explain another sectors current value, we define this relationship as a forward linkage. In parallel, we define a backward linkage as a sector whose current value added is significantly adjusting to the past values of another sector. If both variables past values can be used to mutually explain each other we consider this an indicator of short-run complementarity between the two industries. The fact that we are running a large number of tests obviously risks leading us into mass significance, since testing on the 5 % level theoretically means that every 20th test can be significant even under a correct null hypothesis, so some caution should be adopted when interpreting the results.

In table 2 we have ranked the industries with the most significant forward and backward linkages to other sectors. As there are 14 variables in the system, each variable can at most Granger cause 13 variables and be Granger caused by 13 variables, meaning that the maximum number of linkages for each sector is 26.

Table 2. Number of total, forward and backward linkages

	TOTAL	**Forward**	**Backward**
Machinery	17	7	10
Chemistry	14	5	9
Electricity	13	8	5
Metal goods	12	4	8
Wood products	12	8	4
Mining	10	3	7
Metal	10	9	1

Railways	10	3	7
Non-metal minerals	9	5	4
Pulp	9	6	3
Paper	9	5	4
Graphic	7	3	4
Textile	7	6	1
Food	2	0	2

The sector with the highest number of total linkages is the machinery industry, followed by the chemical industry and the electricity industry. At the level of 12 linkages, we find the metal goods and the wood products industry. The railways, mining and quarrying and the metal industry share 10 short-run linkages to other industries. The only branch that is an outlier at the bottom of the scale is the food industry, with only two linkages.

If we look at the relative distribution of industries with many forward linkages (Granger-causing other variables) it appears that the metal industry is outstanding in this respect. It Granger-causes 9 other variables and is only adjusting to 1 other variable. The machinery and the electricity industry Granger-causes 7 other variables each, but whereas the machinery industry adjusts to 10 other variables, the electricity sector only adjusts to 5 other variables. If we look at railways we find that its main linkages run through the adjustment to other variables, as it shows a total of 10 linkages with other industries, but only 3 of them being forward linkages. This could be interpreted as the railway industry is mainly responding to the short-run fluctuations of other industries, rather than causing them. It is also clear that the resource based industries: the metal industry and the wood product industry, Granger-cause growth in other sectors, but are not being Granger-caused by other sectors. Both these industries are dominated by exports and tend to lead the Swedish business cycles. It is however typical that linkages in these industries rather run one-way than being mutual, since the metal and wood products industries are primarily influenced by the timing sequence of the business cycle rather than forming a core of mutual complementarity in any development block.

5.3 A development block formed around electricity

In order to further explore the linkages between certain sectors, we look for dependencies between sectors that we expect to be closely interlinked in so called development blocks. As stated earlier, we expect that industries that form a development block should be driven by the same long-run stochastic economic trend (i.e. that they are cointegrated with each other). But in addition to sharing the same long-run trend, we also expect strong short-run mutually reinforcing linkages within the development block. Although the electricity industry does not have the most forward linkages in total, the electricity industry actually Granger causes all industries that it is in turn adjusting to (apart from non-metal minerals and wood products). This suggests that there are strong mutual short-run dependencies between the electricity industry and the other sectors and that the electricity industry is likely to form a core in a development block.

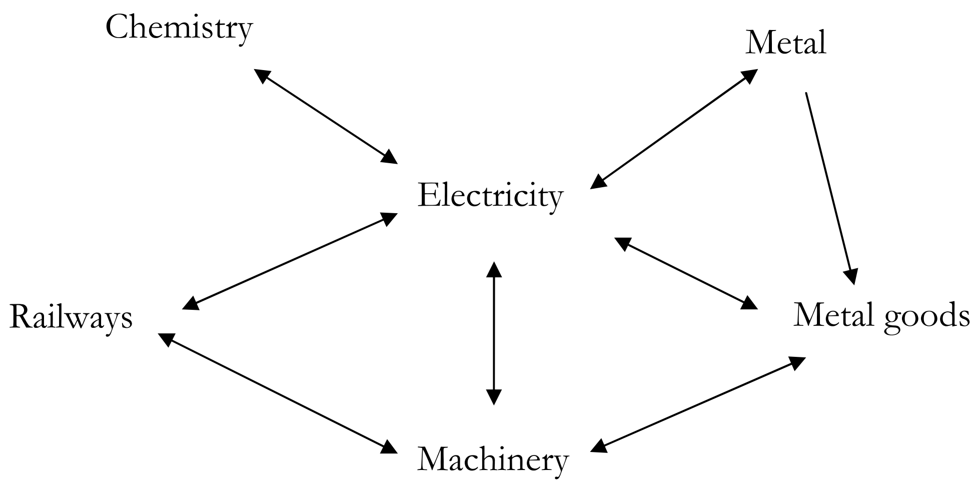
Table 3. P-values for Granger tests on short-run linkages. P-values below 0.05 suggest a significant short-run linkage. Dependent variable on horizontal axis.

	El	Mining	Metal	Non-met.	Chem	Food	Pulp	Mt goods	Graph	Mach.	Paper	Rail-ways	Wood Prod.	Textile
El		0.41	**0.00**	0.86	**0.00**	0.26	0.46	**0.02**	**0.00**	**0.00**	0.06	**0.02**	**0.02**	0.78
Mining	0.77		0.08	0.18	**0.00**	x	0.14	0.31	0.81	0.08	**0.00**	**0.00**	0.17	x
Metal	**0.01**	**0.04**		**0.00**	**0.02**	0.13	0.36	**0.00**	**0.00**	**0.00**	0.71	**0.05**	**0.03**	0.79
Non-met.	**0.00**	**0.01**	0.57		0.21	**0.00**	0.25	0.12	0.55	0.17	0.51	**0.03**	0.48	0.81
Chem	**0.04**	0.56	0.16	**0.01**		0.07	0.07	**0.00**	**0.01**	**0.04**	0.27	0.77	0.20	0.31
Food	0.95	x	0.41	0.65	0.09		0.39	0.43	0.81	0.59	0.52	x	0.85	0.12
Pulp	0.15	0.26	0.73	**0.00**	**0.05**	0.05		**0.00**	0.27	**0.03**	**0.00**	**0.01**	0.74	0.76
Mt goods	**0.00**	**0.02**	0.70	0.60	**0.02**	0.10	0.21		0.70	**0.01**	0.07	0.10	0.48	0.63
Graph.	0.29	0.21	0.91	0.74	0.51	0.59	0.07	**0.01**		**0.00**	0.14	**0.00**	0.40	0.74
Mach.	0.07	**0.01**	0.94	0.51	**0.01**	0.28	**0.05**	**0.02**	0.11		**0.00**	**0.02**	**0.00**	0.89
Paper	0.31	**0.00**	0.16	0.39	**0.00**	**0.00**	0.64	0.21	0.56	**0.01**		0.00	0.02	**0.02**
Rail-ways	**0.00**	**0.04**	0.07	0.35	0.11	x	0.07	0.08	0.53	**0.04**	0.26		0.25	x
Wood prod.	0.81	**0.01**	0.10	**0.00**	**0.01**	0.07	**0.00**	**0.00**	**0.04**	**0.00**	**0.00**	0.06		0.15
Textile	0.85	x	0.28	0.05	**0.02**	0.43	**0.02**	**0.00**	0.21	**0.02**	0.14	x	**0.03**	

Table 3 summarizes the p-values from the Granger causality tests in the VEC or the VAR as explained in section 4.2 between the 14 sectors. The dependent variable is displayed on the horizontal axis, and a value below 0.05 indicates that the null hypothesis of the sector on the vertical axis *not Granger causing* the sector on the horizontal axis can be rejected. When the null hypothesis is rejected we conclude that there is a significant forward linkage running from the sector on the vertical axis to the sector on the horizontal axis.[5]

The short-run linkages between the electricity industry and the other 13 industries are found in the first column and row of the table. Since our main interest is to identify the development that arose around electricity during the second industrial revolution, we start by examining the 9 industries that formed long-run relationships with the electricity sector (metal, chemistry, pulp, metal goods, graphic, machinery, railways, paper and wood products). We find mutually reinforcing short-run linkages between electricity and the following sectors: metal, chemistry, metal goods, machinery (at 7 % significance) and railways. In addition to being interlinked with electricity, these sectors show a large number of mutual linkages between each other, which further strengthens our hypothesis that these industries are signified by strong complementarities.

Figure 3 Development Block around Electricity



The development block displayed in figure 1 confirms earlier research that has shown a close timing in the development of the infrastructure of electricity and in the structural transformation of industry (Schön: 1990). Thus, great advances were made in the electricity infrastructure during the 1910s and from the late 1930s to the 1950s. A national grid was

[5] The VAR or VEC specifications and choices of lag lengths can be found in the appendix.

integrated and the technology of high voltage transmission developed that made it possible to supply industries with electricity at lower prices, in large quantities and with great regularity. Furthermore, this development of the infrastructure was simultaneous with a more rapid growth of new sectors. In particular, the machinery industry supplied new generations of electrical motors and machinery as a complement to the supply shift of electricity and the motors were in turn dependent upon new qualities of metal and metal goods. This is certainly relevant also for the electrification of railways. Electrification was first introduced in the 1910s, but it was more forcefully followed from the 1930s. In this connection the Swedish company ASEA (ABB), as a main supplier of equipment to electricity utilities, also developed the electricity traction technology in new locomotives. These linkages between electricity, machinery, metal, metal goods and railways have been traced quantitatively using our proposed methodology, but in addition we also detect a strong mutual relationship between electricity production and the chemical industry that calls for further analysis.

5. 4 Linkages between electricity use and growth of an industry

In order to explore the role of the electricity share and the effect on growth in value added of the sectors we first use a basic linear trend analysis to see whether sectors of high electricity shares have grown faster than sectors with low electricity share. Next we use cointegration analyses to detect long and short-run inter-linkages between electricity shares and growth patterns. Last we use the results to modify our previous understanding of development blocks around electricity.

Since energy plays different roles in different sectors, some being heavy energy users and others light users, we do not use the electricity intensity (electricity divided by value added) but rather the electricity share of total energy use as the hypothesized driving force of growth in the industrial sectors. In table 4 we have ranked all 13 industrial sectors (after 1936 we are able to split up the metal industry into non-iron metal and iron/steel industries, thus increasing the number of industrial sectors to 13) according to their electricity share in 1970.

As seen from table 5 railways, followed by non-iron metal industry have the largest electricity share in 1970 and also display the highest growth of the electricity share since 1936. The non-iron metal is the energy intensive part of the metal industry, since it contains the aluminum industry. The chemical industry started off with one of the highest electricity shares in 1936 but still managed to increase this share substantially until 1970. Mining and quarrying and the graphic industry were relatively dependent on electricity already in 1936, but did not increase this share so dramatically until 1970, whereas paper, pulp, wood products and metal goods start from rather low levels but nearly doubled their electricity shares. The machinery industry shows a similar development, although it initially started from a higher share. The iron / steel, textile, non-metal minerals and food industry were not very dependent on electricity in 1970 although some of these industries increased their shares from very low levels in 1936.

We find that all sectors that were part of the development block identified in section 5.3 show strong increases in their electricity shares from 1936 and have among the highest electricity shares in 1970 (railways: 0.78; non-iron metal 0.61; chemistry: 0.43; metal goods 0.29 and machinery 0.26). Besides these industries, paper and pulp also exhibit strong electricity growth and high electricity shares, which make them interesting from the point of view of development blocks around electricity. From table 4 it can also be found that value added in paper and pulp is mutually interlinked with each other as well as with the chemical industry, which further strengthens our belief that the paper and pulp industries may form a part of a development block around chemistry.

Table 4. Sectors ranked according to their electricity share (of total energy use) in 1970

	1936	**1970**	**Change in electricity share 1936-70**
Railways	0.15	0.78	4.20
Non-iron metal	0.09	0.61	5.70
Chemistry	0.23	0.43	0.90
Mining	0.24	0.32	0.33
Wood products	0.11	0.31	1.82
Paper	0.17	0.31	0.90
Metal goods	0.12	0.29	1.39
Machinery	0.18	0.26	0.43
Pulp	0.14	0.25	0.74
Graphic	0.21	0.23	0.08
Iron / steel	0.12	0.19	0.62
Textile	0.09	0.15	0.58
Food	0.05	0.15	2.01
Non-metal minerals	0.03	0.09	2.44

In table 5 we show the ranking of these industries in terms of growth of value added and we see that the linear economic growth trends coincide rather well with the electrification. In general sectors with high electricity shares and large increases of that ratio between 1936 and 1970 also grow substantially in value added. To explore whether this is only a coincidence we turn to long-run cointegration analyses and short-run Granger causality.

Table 5 Industries ranked according to their growth of value added

	Growth of Value Added 1890-1936	Average annual growth 1890-1936		Growth of Value added 1936-1970	Average annual growth 1936-1970
Machinery	84.95	0.09	Non-iron metal*	18.22	0.08
Pulp	72.31	0.09	Chemistry	14.91	0.08
Paper	36.76	0.08	Machinery	10.61	0.07
Metal goods	32.77	0.07	Railways	9.6	0.07
Graphic	27.06	0.07	Paper	5.71	0.05
Mining	20.71	0.07	Metal goods	4.81	0.05
Textile	11.12	0.05	Iron / Steel*	4.28	0.05
Railways	10.46	0.05	Non-met. min	4.14	0.05
Chemistry	8.26	0.05	Graphic	3.31	0.04
Non-met. min	6.52	0.04	Mining	3.3	0.04
Food	5.44	0.04	Pulp	1.49	0.03
Metal*	2.73	0.03	Food	1.34	0.02
Wood products	0.70	0.01	Wood products	1.31	0.02
			Textile	0.68	0.01
Value added total industry	**5.09**	**0.04**	**Value added total industry**	3.6	0.04

*Note that the metal industry was split up into non-iron metal and iron/steel after 1936.

5.5 Long-run relations between value added and electricity

In order to investigate whether electrification is a central force that drives industrial growth, we proceed by using the Granger test as explained in section 4.2. Our hypothesis is that we should be able to detect a long-run (cointegration) relationship between value added of electricity dependent industries and their electricity share. We also expect that increasing the electricity share should drive increases in value added in the short-run and not the other way round. We use data from 1936 to 1974 for all industries apart from railways where we have access to data from 1915 to 1974.

Table 6. VAR:s and VECM:s between the 13 sectors and the electricity share

Industry 1936-74	Specification	EL → VA	VA → EL
Chemistry	VEC (3)	**0.04**	**0.00**
Non-metal minerals	VAR(0)	x	x
Food	VAR(0)	x	x
Graphic	VAR(0)	x	x
Iron / Steel	VAR(3)	**0.00**	0.17
Machinery	VEC(5)	**0.04**	0.20
Metal goods	VEC (0)	x	x
Mining	VAR(0)	x	x
Non iron metal	VAR(1)	0.73	**0.02**
Paper	VAR(3)	**0.02**	0.22
Pulp	VEC(3)	**0.01**	0.72
Textile	VAR(0)	x	x
Wood products	VAR(1)	0.98	0.26
Railways ***1915-74***	VEC(0)	x	x

Comment: Values within the brackets of the VAR or VEC specification refer to the number of lags in first-differenced specifications.

The second column in table 6 displays the bivariate VAR specification in first differences between the electricity share and value added in the 13 industries. Whenever we find a cointegration relationship between electricity share and value added, we proceed by estimating a VEC. Again we find cointegration relationships between the electricity share and four of the five industries in the development block defined in section 5.2: chemistry. machinery, metal goods and railways. However, we cannot find any long-run relationship between electricity use and the metal industry (which we have now divided into non-iron metal and iron and steel) that also are part of the development block, which is at odds with our expectations. We do however find a fifth long-run relationship between the electricity share and value added in the pulp industry, which was not part of the pervious development block.

5.6 Short-run linkages between value added and electricity

In addition to finding long-run cointegration between electricity shares and value added in five industries, we also discover that electricity use seems to have short-run relationships with several industries apart from the above-mentioned. The third column in table 6 exhibits the probabilities from testing the null hypothesis of the electricity share *not Granger causing* value added growth, whereas the fourth column refers to the null hypothesis of value added growth *not Granger causing* increases in the electricity share. Whenever the lag length was determined to 0 and we do not have a short-run relationship between the variables, the column in denoted with an x. Table 6 displays that short-term changes in the electricity share Granger causes fluctuations in iron/steel, paper and pulp while we find mutual linkages between the electricity share and value added in the chemical industry. In the non-iron metal industry we find that fluctuations in value added seem to drive the short-term evolution of the electricity share. Increased production in this heavy electricity using industry may have led to bottle necks that caused expansionary investments in the electricity supply with further price reductions - such links are basic to the development block approach.

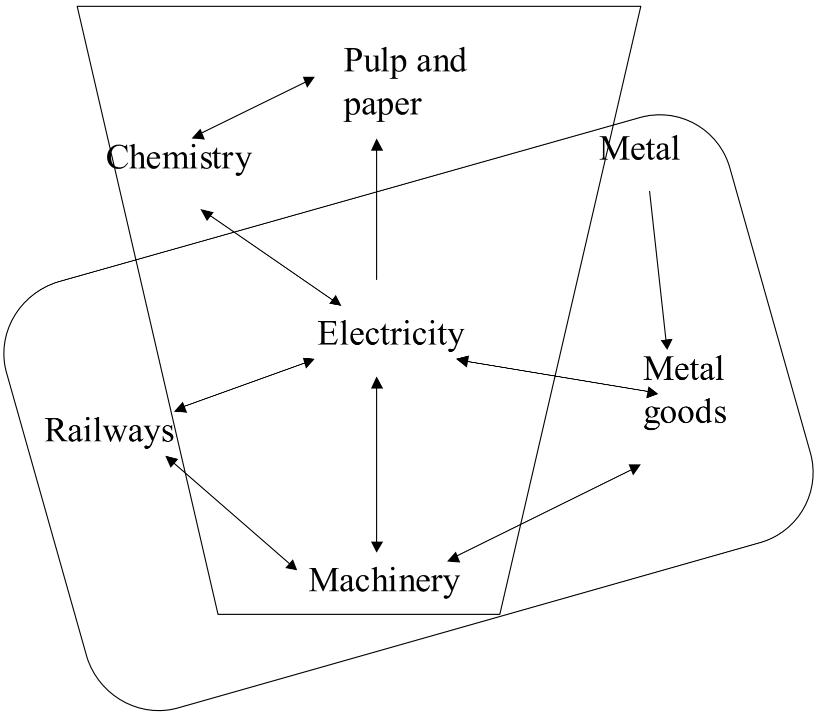
None of the industries with low electricity shares (i.e. food, textile, non-metal minerals) show any long-term or short-term relationship between value added and electricity shares. Industries that were rather electricity dependent all ready in 1936 (graphic industry, mining and quarrying), but had fairly constant electricity shares up until 1970, do not exhibit any short or long-run relationship either. This could be explained by the fact that both mining and quarrying and the graphic industry were early in adopting electricity as a source of energy and have adapted well to the electricity using technology already in 1936, therefore exhausting the major growth advantages from increasing the electricity share that lay ahead of the majority of the other industries.

5.7 A modified development block

With the additional information obtained from the cointegration and Granger causality tests between the electricity share and value added, we may modify our initial development block somewhat. It seems that the qualities of complementarity between electricity and innovative behaviour in the leading sectors of the second industrial revolution (machinery, chemistry, metal products and railways) were a driving force behind long-term growth. In addition, the cointegration relationship between the electricity share and value added in the pulp industry suggests that this sector should be added to the development block around electricity. The pulp industry is likely to be more closely related to the parts around the development block formed around electricity and the chemical industry, since the production of pulp developed in close connection with the chemical industry.

In addition to confirming the long-term structure in the development block found in section 5.3, the short-term analysis showed that changes in the electricity share also drove short-term fluctuations in those sectors that increased their electricity share during the time period (machinery, chemistry, paper, pulp and iron/steel). It therefore seems that we could also add the paper industry to the second development block formed around electricity, chemistry and pulp, especially since we found close mutual short-run linkages between paper and pulp and pulp and chemistry in section 5.3, indicating complementarities between these sectors.

Figure 4 *Two development blocks around electricity*



With this additional information we find it possible to discern two partly separate and partly overlapping development blocks, portrayed in figure 4. Thus, we have been able to discern two development blocks involving electricity at this level of industrial sectors. Apart from the main block around metal, machinery and railways, there is also one with a main link between electricity, chemistry and pulp and paper. Both chemical industries and pulp and paper mills used large amounts of electricity. Electrolytical processes were e.g. important in chemical industries from the early 20th century onwards, while electricity was important in driving the machinery of pulp and paper mills. These industries were early in constructing power sites of their own and could later on take advantage of their integration into a national grid. Furthermore there was a close link between chemical industry and the explosive expansion of the pulp industry in the 20th century since mostly chemical pulp was produced stimulating the production of chemical ingredients in the process, such as chlorine. Both industries are likely to be interlinked also with the machinery industries through the adoption of the new technology introduced with electricity. This macro-level picture conforms very well to prior micro-level analyses (Dahmén: 1950) and analyses of industrial innovative transformation and electricity use as well as to more qualitative interpretations of the role of development blocks in long-term Swedish economic growth (Schön 2000a).

6. Concluding discussion

The contributions of this paper are twofold. First, we have proposed a method for quantitatively tracing the existence of development blocks in time series data that can be used by other scholars for other countries, datasets and periods. We suggest that cointegration analyses combined with short-run Granger causality tests are appropriate for such investigations. Sectors within a development block should share common long-run stochastic trends *and* be linked to each other with mutually reinforcing bonds (that is, the direction of Granger causality should go in both ways). This definition comes naturally from the theory of development blocks, which states that sectors within a development block are strongly dependent on each other so that complementarities are a basic feature. This complementary aspect is captured by the mutually reinforcing linkages of Granger causality. The long-run common trend consists of everything that unites the sectors, and thus captures common technologies as well as influences from the external world (business cycles). For a small open economy like Sweden certainly the export markets play a fundamental role for the evolution of those common trends. We therefore find that most sectors share many common trends with other sectors, and thus the long-run common feature is not a sufficient criteria for a development block. It must be complemented by the short-run mutually reinforcing linkage.

Second we have empirically discerned two development blocks around electricity, allegedly one of the general purpose technologies of the second industrial revolution. The period we study is 1900-1974 and we use 14 sectors for our analyses. Those are the electricity production, mining and quarrying, metal, metal products, manufacturing of non-metal minerals, chemical, food, pulp, paper, graphic, machinery, wood products, textiles and railways.

A first development block was discovered by using data of value added in constant prices comprised of electricity production (center of the system), metal, metal products, machinery, chemistry and railways. A complementary analysis was performed which used data of electricity and energy consumption of the sectors and related the electricity share (electricity/total energy) to the value added. This analysis showed that pulp and paper qualified to be part of the bigger development block around electricity and that it is possible to discern two partly overlapping development blocks around electricity: A first block with metal, metal goods, machinery and railways; and a second block with pulp and paper, chemistry and machinery. These results give a new formulation of development blocks that booth deepens and confirms the earlier analysis of the role of development blocks and electricity in Swedish economic growth.

We have demonstrated that sectors that adopt the electricity technology grow faster than others and that they reinforce each other's growth. This supports the idea of electricity being a general purpose technology with wide growth implications.

Appendix A:

Unit root tests

A1. Value added in 14 sectors 1900-1970

Level			**1st diff**				**Conclusion**
	PP t-stat	**P-value**	**PP t-stat**	**P-value**	**Trend**	**Intercept**	
Electricity	20.259	1.000	-3.811	0.022	0.005	0.104	I(1) trend stationary
Mining	-0.325	0.988	-7.253	0.000	no	0.025	I(1)
Metal	6.998	1.000	-6.506	0.000	0.000	0.090	I(1) trend stationary
Non-metal minerals	1.512	1.000	-6.561	0.000	0.001	0.223	I(1) trend stationary
Chemistry	38.540	1.000	-4.093	0.000	0.013	0.162	I(1) trend stationary
Food	-0.668	0.971	-6.843	0.000	no	0.002	I(1)
Pulp	1.609	0.999	-7.744	0.000	no	0.056	I(1)
Metal Goods	9.574	1.000	-6.988	0.000	0.001	0.162	I(1) trend stationary
Graphic	2.813	1.000	-6.258	0.000	0.001	0.399	I(1) trend stationary
Machinery	12.123	1.000	-5.904	0.000	0.000	0.028	I(1) trend stationary
Paper	1.963	1.000	-8.896	0.000	0.000	0.156	I(1) trend stationary
Railways	0.488	0.999	-3.789	0.023	0.020	0.389	I(1) trend stationary
Wood prod.	-0.492	0.982	-6.204	0.000	no	no	I(1)
Textile	-2.688	0.245	-7.683	0.000	no	0.040	I(1)

McKinnon one-sided p-values to the hypothesis of a unit root.

A2. Electricity share in 14 sectors 1936-1974

Level			**1st diff**				**Conclusion**
	PP t-stat	**P-value**	**PP t-stat**	**P-value**	**Trend**	**Intercept**	
Mining	-2.009887	0.2815	-10.37816	0.0000	no	0.3632	I(1)
Iron/steel	-2.168294	0.2207	-9.147958	0.0000	no	0.3953	I(1)
Non-iron metal	-2.194909	0.2113	-5.533455	0.0000	no	0.0805	I(1)
Non-metal minerals	-1.015243	0.7384	-4.654000	0.0006	no	0.1190	I(1)
Chemistry	-0.682947	0.8390	-9.206948	0.0000	no	0.0163	I(1)
Food	0.736094	0.9915	-12.06838	0.0000	no	0.0001	I(1)
Pulp	-1.255065	0.6405	-7.266335	0.0000	no	0.2734	I(1)
Metal Goods	0.317429	0.9762	-11.76169	0.0000	no	0.0103	I(1)
Graphic	-4.670999	0.0005					I(0)
Machinery	0.818891	0.9931	0.818891	0.9931	no	0.0752	I(1)
Paper	-1.163171	0.6805	-8.479996	0.0000	no	0.2661	I(1)
Railways 1915-1974	-0.076391	0.9450	-4.061294	0.0031	no	0.0263	I(1)
Wood products	-1.095314	0.7081	-6.247771	0.0000	no	0.0590	I(1)
Textile	1.256897	0.9980	-9.890581	0.0000	no	0.0349	I(1)

McKinnon one-sided p-values to the hypothesis of a unit root.

Specifying the VAR:s

Before applying the Johanssen's test for cointegration we need to specify the appropriate number of lags in the VAR. Since the cointegration test is sensitive for the specification of lags in the VAR, information criteria such as Akaike, Schwarz and Hannan-Quinn were all used to find the appropriate number of lags. We also used the Final Prediction Error and the LR-test for lag exclusion. When different information criterion and tests suggested conflicting number of lags, we have followed the number suggested by most indicators and thereafter checked the robustness of our results to different lag specifications. All VAR:s were specified with the variables appearing in their differenced form in order to avoid spurious results.

Table A3. bivariate VAR lag specification (in differences) and the presence of cointegration between the variables (Y=yes, N=no)

	EL		**Min**		**Metal**		**Non-mt min.**		**Chem.**		**Food**		**Pulp**		**Mt prod**		**Graph**		**Mach**		**Paper**		**Railw**		**Wood prod.**	
EL																										
Min	4	N																								
Mt	5	Y	4	Y																						
Nm	5	N	1	Y	5	N																				
Che	6	Y	6	Y	4	Y	1	Y																		
Fo	4	N	0	N	4	N	1	N	4	N																
Pu	4	Y	1	Y	4	Y	2	Y	4	Y	2	N														
Mtp	4	Y	3	Y	5	N	1	Y	6	N	1	Y	2	Y												
Gra	4	Y	1	Y	4	N	1	Y	4	Y	1	Y	1	Y	1	Y										
Mac	5	Y	5	N	6	Y	5	Y	3	Y	1	Y	5	Y	4	Y	2	Y								
Pap	4	Y	3	Y	1	Y	3	Y	5	Y	3	N	3	Y	3	Y	2	Y	5	N						
Rail	6	Y	1	Y	4	Y	5	Y	4	Y	0	Y	2	Y	5	N	5	Y	5	N	4	Y				
Woo	5	Y	3	Y	4	Y	2	Y	5	Y	3	N	2	N	1	Y	2	Y	5	Y	5	Y	5	N		
Text	4	N	0	N	1	Y	1	N	4	N	1	N	1	N	1	Y	1	Y	1	Y	4	Y	0	Y	3	N

Table A3 displays the different VAR-lag specifications that were chosen using the information criterias next to a letter indicating whether we were able to detect a cointegration relationship between the two variables (Y/N). Since the specification was made in differences the maximum dependence between two variables is 7 years; however the usual dependence seems to be around 2-3 years.

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