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In Defense of Electricity as a General Purpose Technology

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In Defense of Electricity as a General Purpose Technology

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Abstract

Electricity has been regarded as a typical example of a general purpose technology and important for the surge both in energy productivity and overall productivity in the American economy in the 1920s. This view was challenged by Nicholas and Moser (2004) based on patent statistics. We argue that other methods are required for studying productivity effects and propose cointegration analyses. We demonstrate a clear impact from electrification on energy productivity in those broad Swedish industrial branches that used electricity for multiple uses. This effect goes beyond mere book-keeping effects and indicates the existence of dynamic effects.

Keywords: electricity, GPT, productivity, cointegration, dynamic effects

Disclaimer: All the opinions expressed in this paper are the responsibility of the individual author or authors and do not necessarily represent the views of other CIRCLE researchers.

In defense of electricity as a General Purpose Technology

Electricity has long been regarded as a general purpose technology (GPT), but this notion was recently attacked by Moser and Nicholas (2004) in an analysis of the patent citations in the electricity industry compared to other industries. Our aim is to defend the role of electricity as one of the most important GPTs so far. We question Moser and Nicholas' method and propose a new method for statistically identifying productivity effects from electrification.

A GPT is characterized by pervasiveness and innovational complementarities and is marked by its wide economic impact in society, driving whole eras of growth. "As a GPT evolves and advances it spreads throughout the economy, bringing about and fostering generalized productivity gains." (Breshanan & Trajtenberg 1995, p 84). When Breshanan & Trajtenberg (1995) launched the concept of GPT they used electricity (or rather the electric motor) as an obvious, clear-cut example of a GPT. The relation between electricity and productivity has primarily been investigated in the breakthrough period of the electrical motor from the 1890s to the 1920s. Schurr and Netschert (1978) had noticed that not only was there a general productivity surge in the 1920s, but this was accompanied by a steep increase in the energy productivity, which they conjectured was related to the electrification of industry. Devine (1983) connected the general productivity growth with the energy productivity growth. He explicitly explained the productivity effects that arose from electrification of industry, when steam and water powered prime movers were substituted with electric motors that first drove groups of machines and later individual machines. Not only did this mean that energy was saved, because of reduced losses in the transmission of power within the industrial factories; it also improved the working conditions, the control of

machines and enabled the gradual expansion of plants. Together this improved the productivity of labour and capital. The productivity effects were further emphasized by David (1990) in a discussions of "productivity paradoxes" when he regarded the productivity increase in the first decades of the 20th century as a delayed effect from the introduction of the electric dynamo in the 1880s.

Electrification was also central in the acceleration of Swedish industrialization from the 1890s onwards. Sweden was one of the early adopters of the new technology. The development of electrical utilities and electrical engineering industries was stimulated by the demand from energy intensive industries as well as by ample hydro power resources. In the Swedish context, the relationship between electricity, productivity and structural transformation of industry was studied by Schön (1990, 1991, 2000). His study indicated that electrification was part of a broader structural transformation of industry and that the productivity effects were delayed until the industrial organization was rationalized and the share of electricity stabilized, hence a productivity paradox effect. Furthermore, electrification in Sweden was part of a technological upgrading in the sense that human capital increased in sub-branches that electrified (a case of technology/skill complementarity, cf Goldin and Katz 1995) and in that sense electricity was a force behind long term productivity growth.

The view on the electrical motor as a GPT has largely remained unchallenged until Moser and Nicholas (2004) used patent statistics to empirically test the importance of electricity. They question the reasons for the surge in US productivity growth in the 1920s that hitherto had been attributed to effects from electrification. Based on the patent statistics they find that electricity do not stand out as exceptional in comparison

with other technology fields. Moser and Nicholas (2004) should certainly have credit for their effort to make the existence of a GPT testable and for conducting an empirical study that goes more into certain details than previous studies. They claim that since a GPT is marked by originality, generality and by its importance for further technological progress it is possible to use patent citations to compare technologies in these three respects. Patents are required to cite previous patents of importance for their own inventions. This means that backward citations (citations to previous patents of importance) can be used as a measure of originality (fewer citations means more original) and forward citations (citations that the patent will receive later on) can be used as a measure of generality, especially if these future citations are widely spread among technological sectors. They use a sample of American patents in the 1920s to check which of four industry categories (electricity, chemicals, mechanical and other) most closely fit with the concept of GPT, by analyzing the citations these patents make themselves to previous patents and by analyzing the citations that these patents receive much later: in the period between 1976 and 2002. They find that although electricity patents were broader in scope and more original at their grant date, they had lower generality scores than other sectors (demonstrated in fewer forward citations per patent and lower range of different industries that cite the patents) and shorter impact period (the mean time between the grant date of a patent and the date of all its forward citations). Hence Moser and Nicholas argue that electricity does *not* qualify as a GPT and that inventions in other industries, such as chemicals, fulfill the criteria for GPTs at least as well as those in electricity. They conclude their article by suggesting that it was not electricity alone, but more generally scientific advances of the late 19th century that caused the productivity increases in the 1920s.

There are, however, two main problems with the analyses by Moser and Nicholas (2004). One is that they do not address productivity issues at all in their empirical investigation, and yet place it within the economic growth debate and interpret their findings in productivity terms. They make no attempt to measure the economic impact of the patents in their material, but restrict their analyses to technical properties of these patents, implicitly assuming some connection. The second problem is their operationalization of the concept "generality". In our opinion patent citations are unsuitable for testing whether electricity is a general technology or not. This is simply because when something is general enough it becomes part of common knowledge, so there are no longer any requirements of citations by subsequent patents. This means that all machines today that use electricity as a power source, or all present day lighting equipment, or heating by means of electricity do not cite electricity patents from the 1880s. Neither do all micro-electronic patents of the 1970s until today cite basic electricity patent, although the integrated circuits make use of low current electricity. Electricity is so deeply embedded in our society that hardly anything functions without it, exactly because it is a general purpose technology, and to paraphrase Solow (1987): "We find electricity everywhere but in the patent statistics".

The connection between electricity diffusion and productivity improvements is certainly not simply direct, bearing the productivity paradox and the broader structural changes in mind. In this article we make a new contribution to this analysis of long term growth. We use the time- series method of cointegration to investigate the impact from electrification on energy productivity in some broad Swedish industrial sectors. We find a strong impact from electrification on energy productivity in the

sectors of machinery and chemicals. In a second step we test whether all these energy productivity gains from electrification are due to book-keeping effects (electricity is a secondary energy carrier and the energy losses in its production are taken in the electricity generating sector) or if it is possible to also identify dynamic effects, as suggested by earlier analyses like Devine (1983). We do find dynamic effects from electrification on energy productivity.

Theory and conceptualization

Book-keeping versus dynamic effects

There are two principal ways that electricity may affect energy productivity within a certain industrial sector: book-keeping effects and dynamic effects. The book-keeping effects are due to electricity being a secondary energy carrier, produced from primary sources, which has high technical efficiency in its final use compared to fuels. To use increasing amounts of electricity leads to lower energy demands and increased energy productivity in a specific sector, per se. This gain from electricity is however not a real gain in terms of energy requirements in relation to output on the GDP level, since the transformation losses of converting the primary energy to the secondary energy are taken by the electricity generating and transmitting industry. Such energy savings are in one sense illusionist and may thus be perceived as “book-keeping” gains.

A second possibility is that there are “dynamic” impacts from electricity on energy productivity within the electricity using sectors, impacts that go beyond the book-

keeping gains. The dynamic effects have to do with new organizations of production, better working conditions for the workforce etc. Schurr & Netschert (1978) held forward this interpretation of the energy productivity development in the US and Devine (1983) claimed that there were also total factor productivity (TFP) gains in industry from electrification. Furthermore, Schön identified TFP gains through the complementarity between electricity and skills in more sophisticated technology within Swedish industry 1890-1990 (Schön 1990, 2004). These dynamic effects are likely to be more prevalent within industrial sectors with multiple and extensive use of electricity, such as machinery, than in sectors of single-use, such as railways. The size of the dynamic effects should depend on whether electricity adoption entails the total transformation of the organization of motive power and work within a factory, or if it mainly means that one fuel driven engine is substituted for a electricity driven one.

We conceptualize the electricity generating sector and the electricity using sectors as forming development blocks that drive growth (Dahmén 1950, 1988). The existence of two partly overlapping development blocks in Swedish industry centered on electricity was quantitatively identified in Enflo, Kander and Schön (2007). Moser and Nicholas (2004) play down the role of electricity inventions by only counting technical inventions within the electricity producing sector as "real" electricity inventions and neglect the inventions within electricity using sectors. They state that of the top ten general patents only two are electricity inventions, and then add that two more use electricity as a power source. However, in a discussion of electricity in an economic growth perspective it is absolutely essential to look at the productivity effects from *using* electricity.

We hypothesize that the relationship between electricity consumption and energy productivity is an indicator of the gains that electricity adoption brought about by virtue of being a GPT. If this is the case, we expect to find a common stochastic trend between time series of electricity consumption and energy productivity within the industries that were likely to ripe the dynamic benefits from electricity as a GPT. This common stochastic trend can be seen as the technology shocks affecting both electricity consumption and energy productivity. In addition, since electricity is a technology with the virtues of a GPT, we expect electricity consumption to affect energy productivity rather than the other way around.

Methods and Data

Energy productivity versus TFP

We choose to focus the analyses on the relation between electricity and energy productivity rather than on the relation between electricity and TFP. There is yet no consensus on how to model energy in a full production function approach where output and labour are also included. One major complicating fact for such modeling is that energy is highly complementary with capital. Adopting the production function approach means including restrictive assumptions concerning the nature of the production process and the linkages between the production factors that are all the more unsuitable when taking into account the length of the time period encompassed

in our study. We argue that the impact of electricity on productivity can be made more compelling by investigating the more restricted issue of the role of electricity for energy productivity.

Book-keeping versus dynamic effects

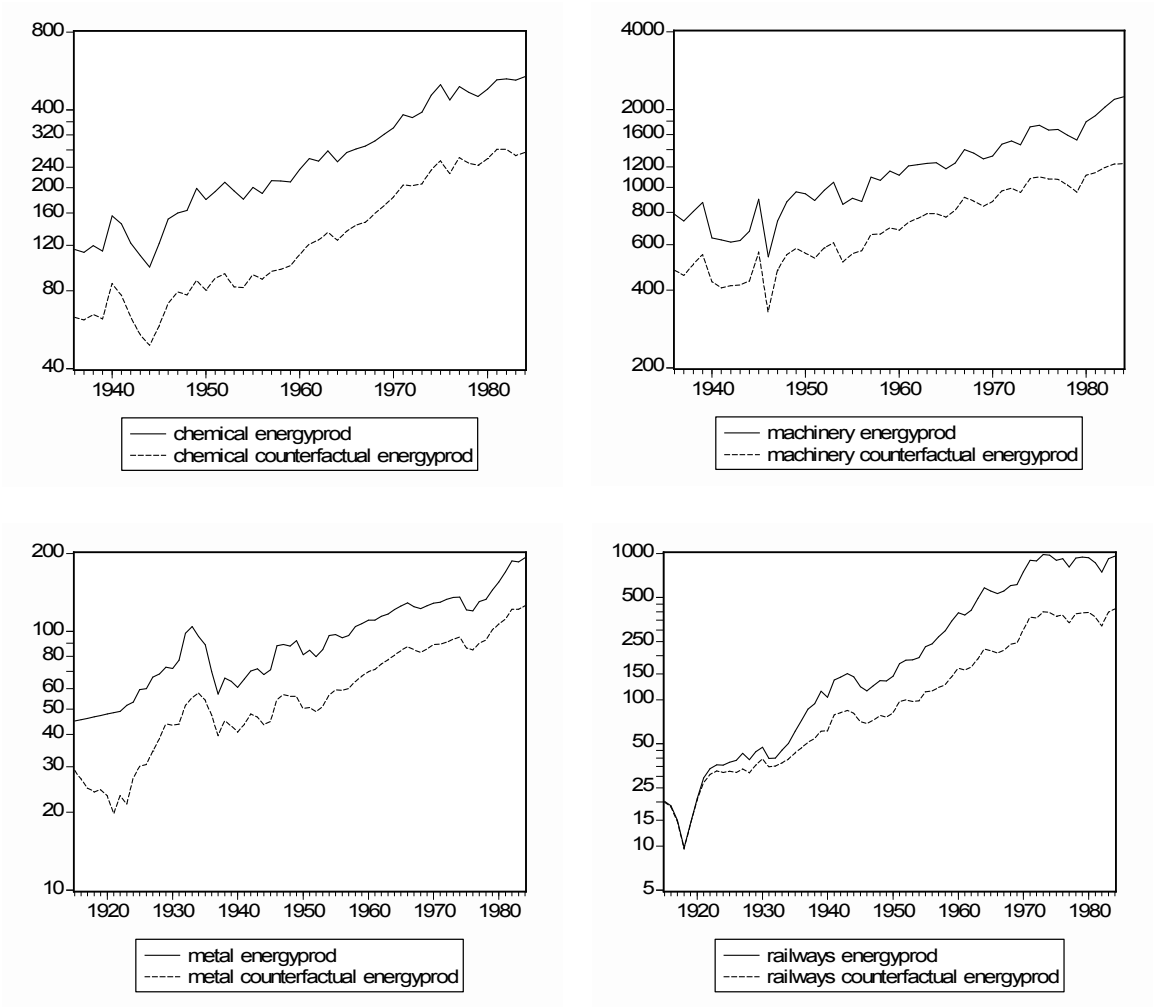
The basic method we use for identifying energy productivity effects from electricity use in an industrial sector is cointegration (see below). In order to single out pure book-keeping effects from the more dynamic effects we construct a counterfactual energy productivity measure and investigate whether this too is cointegrated with electricity use. If that is so we consider to have dynamic effects from electricity. The counterfactual energy productivity is based on the assumption that the electricity consumed in one sector is also produced within that sector, thus the energy value of electricity is calculated as the energy value of the fuels required for its production - also counterfactually assuming that all electricity was produced from fuels. Since electricity generation and transmission has become substantially more efficient over time, it is necessary to use a historically founded factor for converting primary energy into electricity. The conversion factor we have used is taken from Kander (2002) and based on Etemad & Luciani (1991).

Thus, by our method we translate the energy value of electricity to the heat content of fuels necessary for its production for each and every year (according to the technology of the time). In the counterfactual energy productivity measure we have in fact deducted the book-keeping gains by transferring the energy that was needed for the production of electricity to the electricity using sector. This means of course that the

level of energy use will be raised and hence that the level of energy productivity will be lowered (see figure 1).The important characteristic is however not the level but the rate of change in energy productivity in relation to electricity use. In principle, the difference between the growth rates of the original energy productivity and the counterfactual energy productivity will be the net effect of two opposing forces that take place over time: the growing electricity shares that raises the counterfactual energy use and the declining transformation losses that lowers the counterfactual use. Over this period the electricity share of total energy increases substantially, but at the same time the transformation losses of energy decreases a lot (which is expressed in the changing conversion factor).

If the electricity use is cointegrated with the counterfactual energy productivity, an effect from electrification on energy productivity is indicated, which reaches beyond book-keeping gains, and thus is of a dynamic character.

Figure 1. Energy productivity (Value added in 1969/70 SEK) divided by total energy use in MWh, logarithmic scale on the y-axis



Sources: Schön (1990), SOS Järnvägar.

In figure 1 we have depicted the actual energy productivity and the counterfactual energy productivity in four main sectors of Swedish industry that were important electricity users. We have access to data for the period 1915-1987 for metal industry and railways, and the period 1936-87 for machinery and chemical industries. 1936 is the earliest year for which there is a complete set of energy statistics at the industrial sector level in Sweden, and after 1987 the statistics change, so creating consistent time series after that year is much more laborious. To have longer time series would be beneficial for the cointegration test in general, but the test of dynamic versus book-

keeping effects would not change, since the conversion factor stabilizes in the early 1990s.

Figure 2. Total electricity consumed in MWh (left) and the electricity share of total energy used (right) in four industries

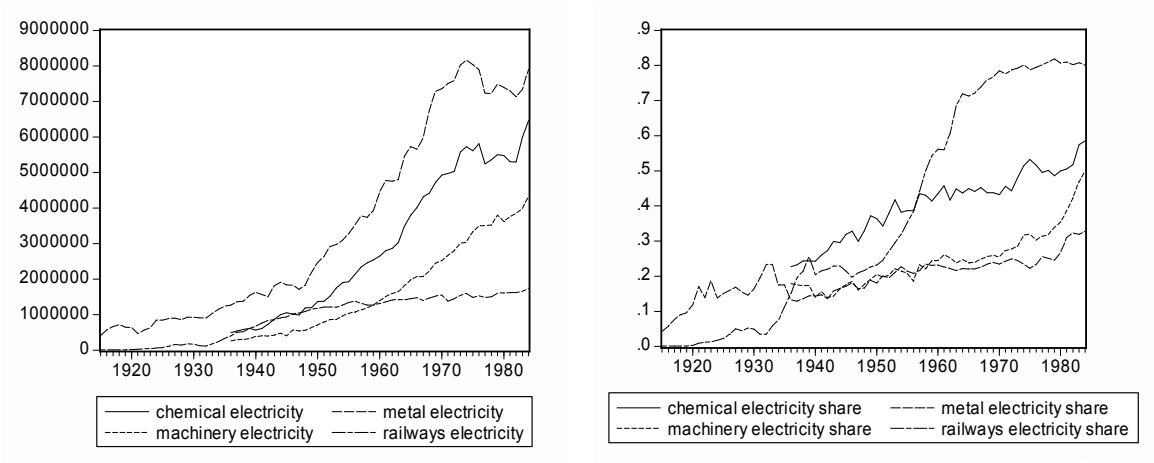


Figure 2 displays electricity diffusion throughout Swedish industries after 1915 for metal and railways and after 1936 for chemicals and machinery. The left panel in the figure shows the total energy consumed and the right panel shows the share of electricity in total energy for the same industries. As seen from the figures electricity consumption grew substantially during the 20th century. Total electricity consumed grew rapidly in the post-war period, foremost in the energy-intensive industries metal and chemistry. The share of electricity in total energy consumed penetrated the branches in Swedish industry to varying degrees, showing the highest growth with the electrification of the railways. The chemical industry relied on electricity for more than half of its energy consumption in the 1980s. The machinery industry converged to similar levels after a rapid electrification during the 1970s. The lowest and most stable electricity share is found for the metal industry for which electricity stood for roughly 30 percent of total energy consumption at the end of the period. In this latter sector fuel based thermal processes dominated production.

Cointegration and VECM:s

We use cointegration methods to identify the long-term relationships between electricity use and energy productivity in the chemical, machinery, metal industries and the railways during the 20th century. 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 non-stationary when its mean, variance and covariance are time dependent. This implies that any shock to the variable will have a permanent effect, as the variable does not revert back to its mean. We find that electricity consumption and energy productivity are non-stationary variables when testing for this property using the ADF-test (p-values are found in the appendix).

If two non-stationary variables are regressed upon each other, the result is likely to be spurious (Granger and Newbold: 1974). However, Engle and Granger (1987) showed the existence of a linear combination of two non-stationary variables that produces a stationary time series. If we are able to detect such a linear combination, the two non-stationary time series are cointegrated, which means that they may drift away from their original means, but that they follow the same stochastic trend, so 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 criteria and lag exclusion tests to

determine the appropriate lag length, before testing for cointegration (the p-values from the lag length tests are found in the appendix). Since the asymptotic distribution of the test statistics for cointegration depends on the assumptions made with respect to deterministic trends in the data series and in the cointegration relations, we need to make an assumption regarding the underlying trends in our data. All specifications include 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.

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 VECM has the property of estimating the short-term relationship, denoted by the differenced terms separately from the long-term cointegration relationship and its adjustment parameters separately. In the case of two variables, X_t and Y_t , their long-term relations are estimated by the β:s in the cointegration relation, within brackets. Note that the specification of the cointegration relation states that a negative sign of the β:s signifies a positive long term relation. The α:s in both VECM measure the speed of adjustment of each variable to the cointegration relationship. If one α is not significantly adjusting to the cointegration

relation, it can be said to be weakly exogenous to the variables in the system. This means that it is rather driving than responding to the shocks in the system. Finally, the ε:s are serially uncorrelated error terms.

Results

Electricity and energy productivity

When testing for cointegration between electricity and energy productivity in our four industries, we detect significant relationships for the machinery and chemical industries. This result is in line with our expectations, since electricity in these sectors are used for multiple purposes so the productivity enhancing effects from electrification is especially large here. In railways and the metal industry, where electricity was used for fewer purposes (merely motive power and heating respectively) we do not find any systematic long-term relations.

Since we use longer time series for railways and the metal industries than for machinery and chemicals, we need to rule out that the sample size affects the outcome. Therefore we also test for cointegration in railways and the metal industry using a shorter sample from 1936 to 1984. We do not find any cointegration relationship in the railways and metal industries for the shorter time period either and conclude that the results seem robust to changes in sample size.

The p-values of the Johansen Trace test for cointegration between electricity and energy productivity are summarized in the upper part of table 1. The null hypothesis

of no cointegration relationships was first tested against the alternative hypothesis of at least one cointegration relationship. If this null hypothesis was rejected, the procedure continued by testing the null hypothesis of at most one cointegration relationship against the alternative hypothesis of more than one relationship. P-values lower than 0.05 indicate that we can reject the null hypothesis at the 5 percent significant level, and here draw the conclusion that electricity and energy productivity are related. The bottom rows of table 1 display the p-values from Trace tests for cointegration between fuels and energy productivity and indicates that we cannot reject the null hypothesis in any of our four industries. Thus, fuels did not affect energy productivity in the same apparent way as electricity did.

The number of lags in the differenced VAR:s is determined on the basis of information criterias and the log likelihood lag exclusion tests (details can be found in the appendix). In general we find a rather long dependence between the series; between 2 and 7 lags in differenced terms. This is perhaps not so surprising, since several of the productivity effects from electrification takes time to mature.

Table 1. Johansen Cointegration Trace Test

		Machinery 1936-84	Chemistry 1936-84	Railways 1915-87	Metal 1915-87
A. Electricity and Energy productivity		p-values	p-values	p-values	p-values
Hypothesized no. of CE:					
	none	*0.03*	*0.00*	0.28	0.47
	at most one	0.95	0.10	0.95	0.58
B. Fuel and Energy productivity					
Hypothesized no. of CE:					

	none	0.85	0.74	0.40	0.84
	at most one	0.39	0.93	0.62	0.69

Note: p-values are calculated from critical values in MacKinnon-Haug-Michelis (1999).

Tests were performed with linear deterministic trend specification in VAR and intercept in CE.

Trends in CE were only included when significant.

The finding of a long-term cointegration relationship in the machinery and chemical industry requires further analysis using statistical methods. This relationship can be modeled econometrically using the Vector Error Correction Model (VECM). The VECM is a useful way to establish the nature of the long-term relationship between the cointegrated variables. As outlined in the methodology section, the nature of the long-term cointegration vector is such that a negative sign of the β-coefficient in the cointegrating vector indicates that the relationship between the cointegrated variables is positive in the long run, i.e. that an increase in one variable gives rise to an increase in the other. In addition to determining the nature of the cointegrating relationship, the VECM also models how the variables adjust to a shock to the long-term relationship, for example an exogenous technology shock. If one variable is less likely to adjust to restore the long-term relationship, this is an indicative sign that it is driving the system, whereas the other one merely responds to the shocks. If the cointegration relationship between electricity and energy productivity truly is a relationship determined by technology shocks, we would expect electricity to play such a driving role in relation to energy productivity.

In table 2 we report the estimated values from the VECM, where the first two columns give the values for the machinery industry and the last two columns report

values for the chemical industry. Starting with the cointegration relationship in the machinery industry, we find that the β-coefficient displays the expected negative sign and that it is significant. The α-coefficients of the error correction show how the differenced terms of the two VECM:s adjust to the long-term cointegration relationship and are only significantly different from zero in the equation where energy productivity is the dependent variable. In line with our expectations, this indicates that energy productivity is adjusting to restore the positive long-run relationship whenever the system is hit by a shock, whereas there is no significant adjustment in the electricity variable to shocks in energy productivity. Thus electricity is driving energy productivity rather than the other way around. The explanatory power of the VECM:s can be considered high, judging from the adjusted R-squares of 0.4 in both VECM:s.

The last two columns report the VECM estimated for the chemical industry. Again we find that electricity is driving energy productivity. The adjusted R-squares are high in the case of the Energy productivity VEC-equation (0.39) but turn negative (due to high number of insignificant lags) in the Electricity equation. The negative sign indicates that this model (trying to explain electricity by energy productivity) does a worse job than a horizontal line! Since we expect that electricity is driving energy productivity and not vice versa, the negative R-square of the chemical Electricity equation is actually nothing strange.

Table 2. Bivariate Vector Error Correction Models (VECM)

	Machinery 1936-84		Chemical Industry 1936-84	
	Electricity	Energy prod.	Electricity	Energy prod.
CE				

β	1.00	-7394.59	1.00	-14193
		[-3.01]***		[-35.43]***
Trend		197408.30		
		[2.73]***		
Constant		-7255896.00		1059502
Error correction				
α	0.0026	0.0001	-0.0117	0.0001
	[0.14]	[4.63]***	[-0.06]	[3.17]***
Adj R-sq	0.40	0.40	-0.16	0.39
No. of lags (diff. terms)	5		7	
N	43		41	

Note that t-values are given in parenthesis below the estimated coefficient values

More than book-keeping gains?

Our second ambition was to single out the mere book-keeping effects from electricity on energy productivity and to see if there were also dynamic effects, as described by Devine (1983) and others. In table 3 we report the test for cointegration between our counterfactual energy productivity (where the pure thermal efficiency gains from electricity are omitted) and electricity use in the machinery and chemical industry. We find that the null hypothesis of no cointegration relationship was rejected at the 5 percent level for both the machinery and the chemical industries, which we take as an indication of dynamic effects from electricity on energy productivity.[1]

[1] Again, details of the lag length choice can be found in appendix.

In order to test that the observed cointegration between electricity and the counterfactual energy productivity is not spuriously related to the introduction of the conversion factor when recalculating the electricity shares, we also tested for cointegration between electricity use and the conversion factor. The results are found in the lower part of table 3 and show no sign of cointegration between electricity and the conversion factor. Thus, we may conclude that the long-term relationship between electricity and energy productivity is due to dynamic effects that go beyond the mere book-keeping gains from adopting electricity.

Table 3. Johansen Cointegration Trace Test

A. Electricity and Counterfactual Energy productivity		Machinery 1936-84	Chemistry 1936-84
Hypothesized no. of CE:			
	none	*0.04*	*0.03*
	at most one	0.29	0.51
B. Electricity and the Conversion factor			
	none	0.09	0.77
	at most one	0.59	0.93

Table 4 displays the VECM:s for the relationship between electricity and the counterfactual energy productivity in the machinery (the first two columns) and the chemical industry (the last two columns). In the machinery industry the β in the CE are again indicating a positive and statistically significant long-term relationship. The α:s show that the counterfactual energy productivity is significantly to to the long-run equilibrium, whereas the opposite is not the case, indicating that electricity is the driving force again. The adjusted R-squares are again high in both VECM:s (0.48 and 0.52).

The β-coefficient in the chemical industry also shows the expected negative and statistically significant sign, indicating positive relation in the long run. The adjustment coefficients again show that there is only significant adjustment to equilibrium in the energy productivity variable. R-squares indicate again that electricity does a better job in explaining energy productivity (0.52) than the other way around (0.01).

Taken together, the VECM indicates that there is a positive and significant long-term relation between electricity and energy productivity, even after controlling for the obvious book-keeping gains. Adjustment coefficients and R-squares seem to suggest that electricity is the exogenous variable in the system that energy productivity is adjusting to.

Table 4. Bivariate Vector Error Correction Models (VECM)

	Machinery 1936-84		Chemical Industry 1936-84	
	Electricity	Energy prod. (C)	Electricity	Energy prod. (C)
CE				
β	1.00	-7552.58	1.00	-18866.11
		[-8.58]***		[-7.91]***
Trend		45140.86		-29644.54
		[2.73]***		[-2.25]***
Constant		621749.9		1636271
Error correction				
α	-0.1384	0.0003	-0.4243	0.0004
	[-1.42]	[3.86]***	[-1.80]	[4.13]***
Adj R-sq	0.48	0.52	0.01	0.52
No. of lags (diff. terms)	6		6	
N	42		42	

Conclusions

We have argued that Moser and Nicholas (2004) were wrong in suggesting that electricity was not a GPT. They do not address productivity effects in their article, but

draw conclusions as if they were. This article has demonstrated that electricity use had a significant impact on long term energy productivity in those broad industries that used electricity for multiple uses (machinery and chemical industry). In addition we have shown that this positive effect from electrification on energy productivity was not confined to “book-keeping” effects (electricity being a secondary energy carrier with low energy losses at the point of consumption), but entails dynamic effects with a time lag of typically 2 to 7 years. We have used Swedish industry as our case, because Swedish industries were early adopters of electricity, but we believe the same results could be obtained for other economies as well. That however remains to be seen, if anyone will follow the methodological path we have shown here.

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Appendix A

Table A1. Phillips-Perron test for a unit root in energy productivity series

Level					**1st diff**				**Conclusion**	**N**
	T-stat	**P-val.**	**Trend**	**Const.**	**T-stat**	**P-val.**	**Trend**	**Const.**		
MACHINERY	2.37	1.00	x	x	-6.26	0.00	x	x	I(1) trend	49
	1.00	1.00	x	0.84	-6.74	0.00	x	0.05		
	-2.00	0.59	0.02	0.02	-7.09	0.00	0.09	0.30		
CHEMISTRY	4.48	1.00	x	x	-5.22	0.00	x	x	I(1) trend	49
	1.20	1.00	x	0.44	-6.66	0.00	x	0.00		
	-2.01	0.58	0.02	0.08	-6.92	0.00	0.12	0.77		
RAILWAYS	1.10	0.93	x	x	-7.71	0.00	x	x	I(1)	72
	-0.26	0.93	x	0.14	-8.10	0.00	x	0.20		
	-1.94	0.62	0.05	0.13	-8.28	0.00	0.17	0.97		
METAL	2.51	1.00	x	x	-5.69	0.00	x	x	I(1) trend	97
	0.91	1.00	x	0.93	-6.06	0.00	x	0.06		
	-1.77	0.71	0.06	0.76	-6.17	0.00	0.26	0.97		

Table A2. Phillips-Perron test for a unit root in electricity series

Level					**1st diff**				**Conclusion**	**N**
	T-stat	**P-val.**	**Trend**	**Const.**	**T-stat**	**P-val.**	**Trend**	**Const.**		
MACHINERY	7.58	1.00	x	x	-3.81	0.00	x	x	I(1) trend	49
	3.48	1.00	x	0.10	-6.82	0.00	x	0.00		

	-1.24	0.89	0.04	0.10	-8.62	0.00	0.00	0.18		
CHEMISTRY	3.41	1.00	x	x	-4.12	0.00	x	x	I(1) trend	49
	0.58	0.58	x	0.08	-5.47	0.00	x	0.00		
	-2.20	0.48	0.03	0.08	-5.55	0.00	0.34	0.87		
RAILWAYS	2.62	1.00	x	x	-5.92	0.00	x	x	I(1)	72
	-0.60	0.86	x	0.01	-7.18	0.00	x	0.00		
	-1.16	0.91	0.34	0.07	-7.13	0.00	0.72	0.04		
METAL	2.89	1.00	x	x	-5.69	0.00	x	x	I(1) trend	97
	0.54	0.99	x	0.06	-6.06	0.00	x	0.06		
	-1.76	0.71	0.05	0.91	-6.17	0.00	0.26	0.97		

Table A3. Specification of the VAR in the Johansen Cointegration Trace Test

	Machinery	**Chemistry**	**Railways**	**Metal**
	1936-84	**1936-84**	**1915-87**	**1915-87**
Electricity and Energy productivity				
Trend in CE	Y	N	N	N
No of lags (diff. terms)	5	7	7	4
Fuel and Energy productivity				
Trend in CE	Y	N	N	N
No of lags (diff. terms)	2	4	7	4
Electricity and Counterfactual Energy productivity				
trend in CE	Y	Y		
no of lags (diff. terms)	6	6		
Electricity and Conversion factor				
trend in CE	N	N		
no of lags (diff. terms)	3	1		

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