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WHAT IS DRIVING ENERGY INTENSITY DECLINE IN SWEDISH MANUFACTURING? A DECOMPOSITION ANALYSIS

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ABSTRACT

This paper uses decomposition techniques to analyse factors influencing electricity intensity in Swedish manufacturing over the period 1993-2012. The results of the analysis show that both changes in the composition of the sector (the structure effect) and technological change *within* manufacturing industries (the technology effect) have contributed to an aggregate decline in electricity intensity. The decomposition results indicate that the technology effect has increased in relative importance over time. In a modified decomposition, I distinguish between two kinds of technological change: technological change that leads to an adjustment of the relative factor employment (the factor mix effect) and technological change in the form of general productivity changes and scale effects (the adjusted technology effect), following Wenzel & Wolf (2014). The results of the modified decomposition indicate that considerable factor substitution from labour to electricity has dominated any energy-saving technological change, and led to a net increase in electricity intensity from the factor mix effect. General productivity improvement and scale effects have instead driven the intensity decline. Combined, the results challenge current energy, climate and environmental policy in Sweden and abroad. In particular, the effectiveness of subsidising research directed at energy efficient technologies may be questioned.

Keywords: Energy intensity; Log Mean Divisia Index (LMDI) decomposition; Structural change; Induced technological change; Swedish manufacturing
JEL: D24, Q40, L60, L16

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INTRODUCTION

Aggregate energy intensity, defined as the ratio between final energy consumption and value added, is commonly used as an indicator of industrial energy efficiency. However, two main factors influence energy intensity when measured on an aggregate level: technological changes *within* sectors of the economy (the technology effect), and structural changes *between* sectors (the structure effect).[1] The issue of which effect that dominates has important implications for the appropriate choice of policy. The manufacturing sector is typically among the most energy intensive sectors of an economy. In the context of manufacturing, the technology effect captures changes in sectoral energy intensity that may result from technological and organisational improvements, such as the use of more efficient production processes and the implementation of less wasteful practices. It could also reflect substitution between factors of production. In contrast, the structure effect arises when resources move between industries that are more or less energy intensive. Structural changes result in lower aggregate energy intensity in the manufacturing sector when resources are allocated from energy intensive sectors, such as the primary metals industry, towards less energy intensive sectors, such as the textile industry. The purpose of this paper is to investigate to what extent the decline in energy intensity in Swedish manufacturing is the result of structure effects or technology effects.

As a key input in the production of goods and services, energy is a prerequisite for global prosperity. Since the industrial revolution, energy has fuelled economic growth and development. At the same time, it has become clear that traditional energy sources are finite and that their use is associated with considerable environmental and social costs (Kander & Stern, 2011). Climate change and energy security concerns have put energy issues high on the political agenda and efforts focus on increasing the use of renewable energy and reducing overall energy consumption.[2] Another important policy objective is to increase the efficiency of energy use with improved technology. In 2007, the European Union (EU) set a target to increase energy efficiency by 20 per cent until 2020, compared to the levels in 1990, which was followed by corresponding national targets in many member countries.[3] Increasingly, improving energy efficiency is viewed as one of the most cost-effective ways to counteract the growth in energy consumption associated with economic growth, and therefore as a major component of sustainable development.[4]

Energy efficiency improvements are particularly important in industrial activities, which account for around one third of global energy demand and almost 40 per cent of carbon dioxide emissions worldwide (IEA, 2009). The pattern of energy use in energy-intensive

[1] The energy decomposition literature uses slightly varying terminology. The technology effect is also known as the real intensity effect, the efficiency effect, or the within-sector effect. The structure effect is also known as the compositional effect or the between-sector effect.

[2] The United Nations (UN) estimates that the global population will reach 9.2 billion people by 2050. This demographic development, coupled with urbanisation and growing average per capita income, will inevitably have repercussions on energy demand and use. The US Energy Information Administration forecasts that energy consumption in OECD and non-OECD countries will grow by 14 per cent and 84 per cent respectively, between 2007 and 2035 (Wolfram, Shelef, & Gertler, 2012).

[3] The energy efficiency target is part of the energy and climate objectives of the EU's growth strategy ”Europe 2020”, which also includes a 20 per cent cut in greenhouse gas emissions and increasing the share of renewable energy in the EU to 20 per cent from 1990 levels (Europe 2020, 2007).

[4] The IEA projects that energy efficiency could achieve 31 per cent of the reduction in greenhouse gas emissions necessary to halve emissions by 2050 compared to levels in 2009 (IEA , 2012).

industries such as manufacturing has consequently received special attention in energy research. In Europe, energy efficiency gains have come primarily from technological change *within* manufacturing sectors, while structure effects have been dominating during certain periods (see for example Wenzel & Wolf (2014); Unander (2007)). Kander & Henriques (2010) conclude that the manufacturing sector has been the major driver of the energy intensity decline observed in Sweden over the period 1971-2005. There is, however, only limited evidence regarding the extent to which the energy intensity decline in the Swedish manufacturing sector is the result of technology or structure effects (a recent contribution is Inés Pardo Martínez & Silveira (2013)) and applications focusing completely on electricity use are particularly scarce. The provision of such evidence is therefore relevant from a policy perspective.

There is considerable literature that uses decomposition techniques to identify and separate out structure effects from more fundamental changes in our use of energy (Ang & Zhang, 2000). The aim of this paper is to contribute to the energy decomposition literature by decomposing the decline in aggregate electricity intensity in the Swedish manufacturing sector over the period 1993-2012. The decomposition analysis is divided into two parts. In the first part, a two-factor decomposition is performed. The period studied is of particular interest since it includes the deregulation of the Swedish electricity market, and the subsequent marked and sustained increase in wholesale electricity prices of the early 2000s (Swedish Energy Agency, 2015). Since electricity prices have historically been low and stable in Sweden, this development has significantly changed the conditions for the manufacturing sector, which is one of the most electricity-intensive in the world (Stenqvist & Nilsson, 2011). The decomposition results indicate that both the structure effect and the technology effect has contributed to the aggregate decline in electricity intensity, to similar degrees, but that the relative contribution of the technology effect have increased over time. It should be emphasised that this development coincides with the increase in electricity prices.

Another main development within the Swedish manufacturing sector is increasing levels of automation.[5] During the five-year period 2006-2011 alone, it is estimated that every tenth job or around 450,000 vacant jobs have been lost due to automation, especially in industry and administration, and the forecast is that around 54 per cent of Swedish jobs may be automated within the next 20 years (SFF, 2014). Automation is likely to have had an impact on both labour and electricity intensity of production. As pointed out by Wenzel & Wolf (2014), the energy decomposition literature fails to take into account the effect of changes in the demand for complementary factors like labour, which in the Swedish case may have strong implications for the conclusions drawn. For this reason, the second part of the decomposition analysis incorporates labour use, following Wenzel & Wolf (2014). This approach assumes that technological change can take two different directions: a change in relative factor employment (the factor mix effect) or general productivity improvements (the adjusted technology effect), which could also indicate pure scale effects.[6] The result of this modified decomposition suggests a significant substitution from labour to electricity over the period studied, which has countered the decline in aggregate electricity intensity. Notably, it appears that general

[5] Swedish industry is considered one of the most automated in the world (Inés Pardo Martínez & Silveira, 2013).
[6] A scale effect is defined here as an increase in output resulting from a parallel increase in productivity of all factors. Scale effects can arise when some part of the electricity use is fixed and thus independent of business fluctuations, for example electricity used for lightning in buildings (Wenzel & Wolf, 2014).

productivity improvements rather than energy-saving technological change have driven the decline in aggregate electricity intensity.

The structure of the rest of this paper is as follows. Section 1 introduces basic concepts used in the energy literature and shows how this study relates to previous work in the area. Section 2 provides a background to the manufacturing sector in Sweden and gives an overview of policies related to industrial energy use. Section 3 describes the data used and highlights some key trends observed. Section 4 describes how to implement the decomposition method and introduces the two parts of the decomposition analysis. Section 5 presents the results. Finally, section 6 discusses the results and presents the conclusions of the paper.

1. ENERGY INTENSITY DECOMPOSITION

This section will introduce some basic concepts used in the energy decomposition literature. It will then relates to previous work on the relative contribution of technology and structure effects to changes in aggregate energy intensity in manufacturing in general, and in Swedish manufacturing in particular.

Energy intensity

There are various indicators that may be examined to better understand the different dimensions of energy use. Energy intensity (I_t) is commonly used to explore the relationship between energy consumption and economic growth (Kander, Malamina, & Warde, 2012). Energy intensity measures the amount of energy required to produce a given output [7]. It may be defined on different levels of sector disaggregation (economy-wide, sector, sub-sector) and in terms of either physical or economic output. A *physical* energy intensity indicator relates energy use in production to physical units of output, and is most accurately measured at the level of individual technologies and processes (for example, units of energy input per ton of steel produced, given a particular type of technology and process). It is a reliable and precise measure in the sense that the influence from price-related and structural changes is limited, but it may be difficult to aggregate since production units differ both within and across sectors (Reddy & Ray, 2010). An *economic* energy intensity indicator instead relates energy use to output expressed in monetary units, such as GDP or value added, which simplifies aggregation. An example of an economic energy intensity indicator is the amount of megajoules per euro of value added. A general expression is:

$$I_t = \frac{E_t}{Y_t} \qquad (1)$$

E_t Final or primary energy consumption in year *t*

[7] Although often used interchangeably, *energy efficiency* is the reciprocal of energy intensity. An energy efficiency improvement is achieved when more services can be delivered from the same amount of energy input, or the same services can be delivered for less energy input. For example, modern lighting technologies such as the light-emitting diode (LED) are more energy efficient than traditional incandescents; they typically use about 25-80 % less energy.

Y_t Measure of economic activity, such as GDP or value added (depending on the level of aggregation), in year *t*

When defined on an aggregate level, changes in energy intensity not only captures real efficiency improvements and substitution between factors of production, but also the effect of changes in the sectoral composition of the aggregate unit. For example, if the economy reallocates resources towards less energy-intensive sectors, aggregate energy intensity will decrease. This is an important consideration when examining energy intensity in the manufacturing sector, since there is significant variation in production processes, and therefore in energy intensity, between manufacturing sub-sectors. A common approach to tackling this measurement issue is to use decomposition techniques to separate out structural shifts in the economy from more fundamental improvements in the use of energy that may result from technological progress or factor substitution.

Energy intensity decomposition

Energy decomposition enables the breakdown of changes in indicators such as energy or electricity intensity into various components. Changes in these components are in turn driven by underlying factors such as environmental regulations, changing preferences and changed foreign trade patterns. According to Kander & Lindmark (2004), there are three principal causes of energy intensity change: (1) changes in the output mix (structural changes), (2) changes in the factor or input mix (movement along the isoquants of a neoclassical production function), and (3) technological changes in (a) overall productivity, and (b) in specific production processes.

In its basic form, energy decomposition analysis only distinguishes between structural and technological changes, where technological changes are defined in a broad sense to include changes in the input mix, general productivity improvements, and specific improvements in processes (Kander & Lindmark, 2004). Industry can work to improve energy efficiency in production processes through for example technical energy efficiency, load management and utilisation of excess heat (Thollander, Rohdin, & Moshfegh, 2012). In general, technological changes are identified as within-sector variation in energy intensity, whereas structural changes are tracked using the sector's share in total economic activity. A common extension when decomposing overall energy intensity is to include an energy or fuel mix effect to take into account qualitative differences among energy carriers (Enflo, Kander, & Schön, 2009).[8] By focusing on only one energy carrier, the energy mix effects may be removed. It is still necessary, however, to take into account that energy carriers to some extent are substitutes, and that the decreased consumption of one energy carrier can be due to it being replaced by another. For example, in a decomposition analysis of electricity intensity, a fuel shift towards electricity translates into an increase in intensity, without there being an actual reduction in the efficiency

[8] For example, studies indicate that electricity is more productive than other fuels. This is partly a result of electricity being a secondary energy carrier, produced in one sector (which carriers most of the energy transformation losses) and consumed in another (which receives the benefits). However, it has been shown that there are productivity effects beyond these so-called "book-keeping effects". In particular, these productivity effects are related to the fact that electricity can be used in a wider set of activities, and for activities that are more valuable.

of energy use (Steenhof, 2006). Structural changes refer to the reallocation of resources from one sector to another, and can be measured in terms of changes in the share of sectors or sub-sectors in total value added. A typical example is the service transition of economies as they develop. It can take the form of offshoring and closing of factories, triggered by trends such as higher energy price or globalisation. Aggregate energy intensity is affected by structural changes only to the extent that intensity differs between sectors that comprise the aggregate unit. A complicating factor is that structural and technological changes often occur simultaneously in an economy over time. In addition, they are often interrelated. Technological changes may for example lead to unbalanced productivity changes that in turn affect relative production costs, output prices, and both the final demand and output structure. It is also likely that technological changes lead to increases in income, and since income elasticities differ among goods, such changes may again affect the structure of final demand and output (Kander & Lindmark, 2004).

Ang & Zhang (2000) provide a comprehensive survey of different energy decomposition methods. An early approach to decomposition analysis was to compute energy intensity in a given year, while holding constant the sectoral energy intensities. Any difference between this measure and the actual energy intensity was attributed to structural change. A main shortcoming of this approach from an economic perspective was that technological effects and structural effects did not add up to the aggregate change in energy intensity, which resulted in often large residuals, making interpretation difficult.[9] In 1987, Boyd, McDonald, Ross & Hansson were first to implement a decomposition based on index number theory. They used the Divisia index, developed by Divisia (1925) and later adapted by Törnqvist (1935), which was originally developed to decompose changes in expenditures into price and quantity effects. The method has been refined in several steps, with an important adjustment being made by Ang & Choix (1997) that allowed for a perfect decomposition.[10] The novelty of their approach was to use the logarithmic mean function to compute the Divisia index, which is why it is referred to as Log Mean Divisia Index (LMDI) decomposition (Montgomery, 1937) .[11] In particular, the log mean Divisia index is a weighted sum of logarithmic growth rates, weighted by the components share in total value added (or a similar economic activity measure). [12] It has become one of the standard tools in energy decomposition analysis (Ang & Zhang, 2000). This paper employs the LMDI method, and section 4 describes how it is implemented.[13]

Empirical findings and research contribution

In the energy and environmental fields, decomposition analysis is used widely to identify and separate change in indicators such as energy consumption, energy intensity or carbon dioxide emissions. Applications within the decomposition literature that focus on the manufacturing

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[9] The indexes also did not fulfil the desirable properties of time and factor reversibility.

[10] A perfect decomposition leaves no unexplained residual term. This is viewed as a desirable property since the presence of a residual can lead to problems with interpretation.

[11] There are two versions of the LMDI decomposition: the LMDI (1) and the LMDI (2). In this paper, LMDI refers to the former version.

[12] The log percentage change is suitable as an indicator of relative change since it is symmetric, additive and normed (Törnqvist, Vartiab, & Vartia, 1985). The symmetric property means that it is independent of the point of comparison, and the additive property means that it is possible to add successively related changes.

[13] The rationale behind the choice of method is included in appendix B.

sector are extensive, with an emphasis on the energy intensive industries. A common conclusion in this strand of literature is that structural change plays an important role in determining aggregate energy intensity in the sector, although results are heterogeneous depending on the country and time-period analysed. Reddy & Ray (2010) find that improvements in energy intensity in Indian manufacturing are mainly the result of structural changes, and Weber (2009) reports similar findings for the manufacturing sector in the USA. Unander (2007) examines energy use and intensity in ten IEA countries and finds that structural change has almost completely determined energy intensity over the period 1973-1998.

Applications of decomposition analysis that focus entirely on electricity use are, however, relatively scarce. Alghandoor *et al* (2008) introduce the use of multivariate regression analysis to identify the structural effect of aggregate energy intensity changes. In contrast to decomposition analysis based on economic index numbers, this approach does not require detailed disaggregated energy data. The proposed model is tested in an empirical analysis using data on the US manufacturing sector over the period 1977-1998. The results indicate that structural changes have contributed to around 41 per cent of the decline in aggregate electricity intensity. Hankinson & Rhys (1983) examine the significance of structural changes and sectoral intensity changes on aggregate electricity consumption in the UK, during the period 1968 to 1980. They find that both structural and intensity changes have contributed to changes in consumption and, based on this finding, they emphasise the effect of industry composition when using econometric techniques for electricity forecasting. Steenhof (2006) performs a decomposition analysis of electricity consumption in China's industrial sector. The decomposition is performed over the period 1998-2012 and is based on the Laspeyres index. He investigates the influence of four economic processes: (1) changes in the total activity level, (2) changes in sectoral electricity intensity, (3) structural changes, and (4) energy-mix changes. The decomposition results show that the level of industrial activity level (the activity effect) is the main driver of increasing electricity demand. Decreasing electricity intensity was found to be the most important factor counteracting the activity effect; in 2002 electricity intensity was 83 per cent of its value in 1998. Structural shift had only a minor influence. Considering the importance of electricity in manufacturing, there is reason to expand this strand of energy decomposition literature.

The energy decomposition literature have previously failed to take into account the effect of changes in the demand for labour and other complementary factors of production. Wenzel & Wolf (2014) contribute in this regard. They analyse the pattern of electricity intensity in the manufacturing sector of 20 European countries (Sweden is not included), over the period 2000-2011, using the LMDI decomposition method.[14] The analysis suggests that around 10 per cent of the decline in electricity intensity is due to a shift towards less energy intensive sectors. They furthermore argue that technological change may be due to both changes in relative factor use (the factor mix effect) and general productivity increase (the adjusted intensity effect), and

[14] The 20 countries included in the analysis are: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Great Britain, Greece, Italy, Lithuania, Netherlands, Portugal, Romania, Slovak Republic, and Slovenia.

extend the analysis by incorporating labour use in the decomposition to reflect this.[15] The results indicate that factor substitution from labour to electricity has countered the decline in electricity intensity. They also find that this effect has been steadily increasing in most countries during the early 2000s. The fact that electricity prices in general have increased relative to workers' compensation over the same period leads the authors to conclude that factor prices have not been driving the substitution from labour to electricity. The results show that the adjusted intensity effect is an important contributor to electricity intensity decline. However, the authors note that this effect need not reflect only technological improvements, but could also be the result of pure scale effects. Combined, the results leave the authors sceptical about the usefulness of macroeconomic energy measures as indicators of technological progress.

There are several historical accounts of Swedish energy use, some of which use decomposition analysis to examine the development of indicators such as energy consumption and energy intensity. An important contribution in this area is Kander (2002), who provides a decomposition analysis of energy use in Sweden over a period of 200 years. The results show that efficiency effects are dominating structural effects on the economy-level. Kander & Henriques (2010) investigate to what extent the transition to service sectors in Sweden has contributed to changes in aggregate energy intensity on the economy-level, and find that previous studies tend to overstate its effect due to the influence of price inflation. For this reason, the importance of using constant prices when computing structural changes is emphasised. They conclude that the manufacturing industry has been the major driver of the energy intensity decline in Sweden over the period 1971-2005, but there is no further analysis of energy use in manufacturing. Clara Inés Pardo Martínez & Semida Silveira (2013) use both decomposition and econometric techniques to analyse the effects of energy efficiency improvements and other variables on energy consumption and carbon dioxide emissions in Swedish manufacturing, during the period 1993-2008. The decomposition results indicate that the effect of structural change has been minor, compared with the effect of technological change and fuel substitution.

The contribution of this paper is to decompose electricity intensity in manufacturing industries in Sweden into a structure effect and a technology effect, over a longer period covering also more recent years. In a second stage, the modification suggested by Wenzel & Wolf (2014) is implemented to see to what extent the observed technology effect is driven by changes in the factor mix, or more general productivity improvements and scale effects. The Swedish case is particularly relevant to study in light of both considerable electricity price increases for industrial consumers, and high and increasing levels of automation.

2. THE SWEDISH MANUFACTURING SECTOR

This section will provide a brief background to the Swedish manufacturing sector and the surrounding policy environment.

Sweden is a country rich in natural resources such as wood, iron and hydropower, and consequently, the Swedish economy has traditionally been organised around the industry sector

[15] The modification consists of the introduction of two new terms in the decomposition analysis: one term expressing labour intensity and one the ratio between electricity and labour use. I will use this modification and explain its implementation in section 4.

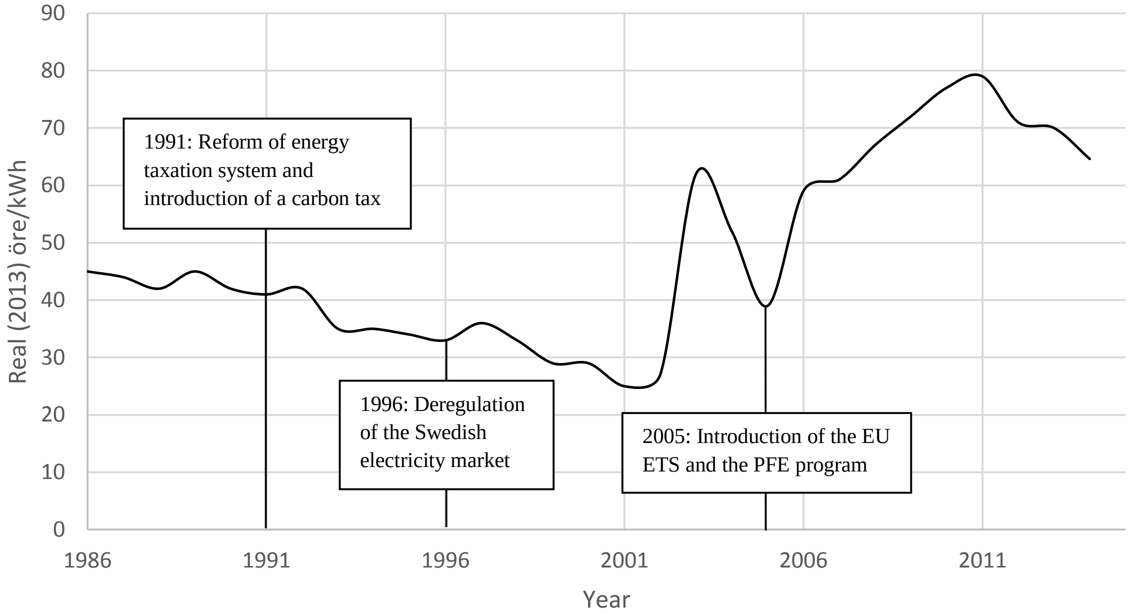
as a result. The wide accessibility to hydropower created low energy prices over long periods and led to a favourable environment in particular for energy intensive industries, such as manufacturing industries processing natural resources (for example wood and iron ore) (Kander & Lindmark, 2006). During the 20th century, Swedish industry has moved away from traditional sectors with lower value added, towards engineering industries with a higher input of skill and technology. In the 1990s, another wave of the transition consisted in a move towards more research-intensive industries such as information technology and pharmaceuticals.

Even with structural changes, the manufacturing sector has remained important for the Swedish economy. In 2012, it consisted of around 54,615 manufacturing companies and accounted for roughly 20 per cent of the economy's value added. Around one third of total energy use in Sweden may be traced to industrial activities, with the most energy intensive industries belonging to the manufacturing sector. Consequently, the industry sector is also responsible for a large share of greenhouse gas emissions (Statistics Sweden (SCB)).[16] Since electricity prices in Sweden have been low historically, the industry has, to a greater extent than in other European countries, chosen electricity as energy provider. Electricity accounted for 35 per cent of total energy consumption in manufacturing industries in 2012 (Kander & Lindmark, 2006).[17]

The deregulation of the electricity market in 1996 and increasing fuel prices internationally, have led to a general increase in electricity prices since the early 2000s; between 2000 and 2012, prices more than doubled. Other factors that have driven higher electricity prices are the introduction of the European emission trading system (EU ETS) (SEA, 2005) and price convergence resulting from a system increasingly integrated with continental Europe (Trygg, 2006).[18] The Swedish Energy Agency forecasts that electricity prices will remain relatively low until 2020. In the lead up to 2030, however, increasingly stringent climate policies and the shutdown of nuclear reactors in Sweden are expected to result in a 30 per cent increase in electricity prices from current levels (Andersson & Gustafsson, 2014). This development is significantly changing the conditions for Swedish manufacturing for which cheap energy is an important comparative advantage.

[16] Around one third of total Swedish carbon emissions originates from industrial activities.
[17] Biomass is another main energy carrier used in manufacturing, and accounts for around 40 per cent of total energy use.
[18] The European emission trading system is intended to increase the costs for the use of fossil fuels.

Figure 1: Electricity prices for industrial customers in Sweden, 1986-2014



Note: The graph includes a selection of historical policy changes that have had an influence on electricity prices. *Source:* Author's graph based on the Swedish Energy Agency.

Several policy instruments affect industrial energy use and efficiency, particularly policies with an influence on energy prices, such as energy and environmental taxation.[19] Initially, energy taxation in Sweden was driven by public financing reasons. A tax on petrol and motor alcohol was introduced in 1929, followed by a tax on electricity in 1951 and a general energy tax in 1957. Energy taxation was further expanded in the wake of the oil crisis in the 1970s, in an attempt to reduce oil consumption and increase the capacity of electricity production. In the 1980s, environmental considerations also influenced energy policy and strengthened the arguments in favour of energy taxation. The general tax system reform during 1990-1991 also included energy and environmental taxation, and led to the introduction of the Swedish carbon tax, which was one of the first of its kind.[20] In 1993, both energy and carbon taxes were substantially increased. The manufacturing industry, however, was completely exempt from the energy tax and taxed at only 25 per cent of the carbon tax rate. The tax exemption lasted until 1997 when the European Commission deemed it incompatible with the common market and it was transformed into a 50 per cent reduction of the statutory tax rate. In the subsequent years, the statutory tax rate was increased, and in 2004, the manufacturing industry was no longer exempt from the tax on electricity use in production.[21] The EU ETS was introduced in 2005, with the purpose of increasing the costs for the use of fossil fuels. Another indirect effect, however, was to increase electricity prices and provide increased incentives for industry to

[19] Johansson, Modig and Nilsson (2007) conclude that the, at the time, renewed interest in improving energy efficiency was almost exclusively driven by higher energy prices.

[20] The carbon tax was set to SEK 0.25 per kilo of carbon emitted. Simultaneously, the energy tax was reduced by a corresponding amount.

[21] A tax rate in line with the minimum requirement of the Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity was implemented (0.5 Euro/MWh).

improve electricity efficiency (Lundgren, Marklund, & Zhanga, 2014). Following the introduction of the EU ETS, the Swedish government introduced the voluntary Programme for Energy Efficiency (PFE) that gave energy intensive companies the opportunity to obtain an electricity tax exemption if they implemented certain measures to improve energy efficiency.[22] The carbon tax was gradually phased out for manufacturing industries covered by the EU ETS in the years leading up to 2011, when it was completely removed.[23]

The history of special tax reductions and exemptions for manufacturing industries reflects another prioritised political goal, that of maintaining industrial competitiveness. Therefore, the political challenge is to provide economic incentives for improving energy efficiency, but at the same time take into consideration effects on competitiveness (Stenqvist & Nilsson, 2011). Although energy taxation of the industry remains at low levels, the general trend seems to be towards higher tax rates and energy price increases. The national target for energy efficiency in Sweden is a 20 per cent reduction in energy intensity between 2008 and 2020, and the contribution from the manufacturing sector in this regard is crucial. It is uncertain if higher energy prices will influence industry in this direction, and if change will primarily be in the form of structural or technological changes. Historical energy data can provide valuable clues.

3. DATA

Data sources and industry classification

For this study, I use data from two main sources: the Odyssee Database and Statistics Sweden (SCB). I also use complementary data from the Swedish Energy Agency and EU KLEMS Growth and Productivity Accounts.

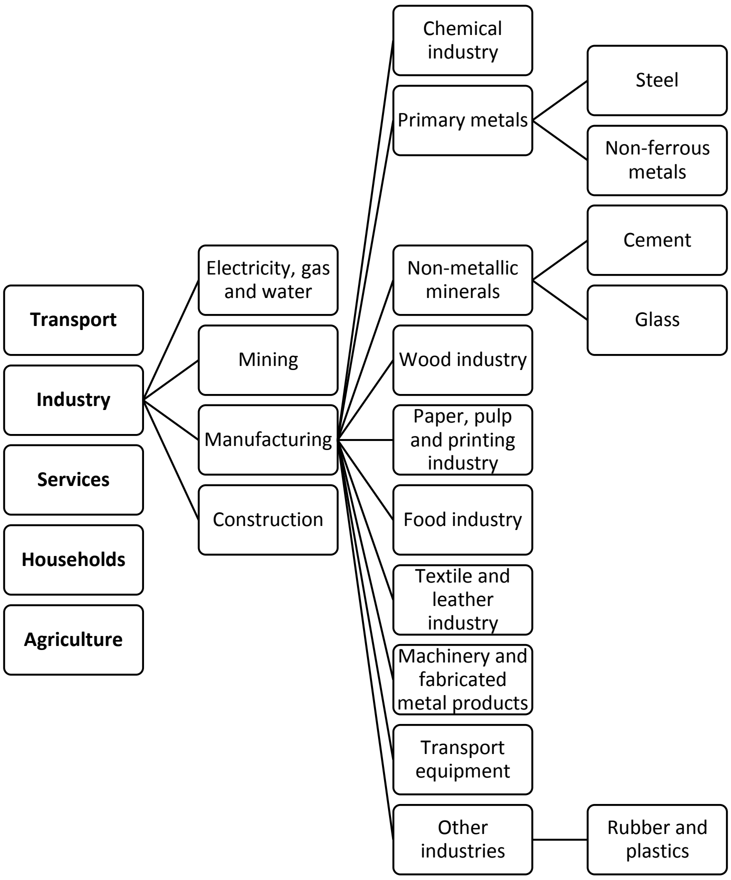
The European programme Odyssee is dedicated to energy use and efficiency data and indicators. It is coordinated by the independent research and consulting firm Enerdata with the aim of monitoring energy efficiency trends and policy measures. Its database contains detailed energy and economic data for 28 EU member states and Norway, and is annually updated by national representatives, such as energy agencies or statistical organisations. The Swedish data provider is SCB. The data is in the form of annual time-series, covering the period 1990-2013, and is reported on both aggregate and sectoral levels based on the International Standard Industrial Classification (ISIC) of economic activity. The main sectors of the economy are Industry; Transports; Households; Services and Agriculture. Industry in turn is divided into the four sub-sectors Mining; Manufacturing; Electricity, gas, and water; and Construction, where Manufacturing is defined in terms of ten manufacturing industries at the two-digit level of

[22] The program started in 2005 and the first five-year period was concluded in 2009. The initial phase of the program consisted of energy use monitoring, with the purpose of identifying measures for energy efficiency improvements. Companies were expected to implement a standardised energy management system and other routines. Several evaluations of the PFE have been made, generally suggesting that the program has been successful in improving efficiency. The gross impact, in terms of electricity savings, has been estimated to around 1450GWh annually.

[23] The phase-out was initiated in 2008.

disaggregation.[24] Figure 2 presents an overview of the industrial classification as described here, and industry descriptions are provided in appendix A, Table A 2.

Figure 2. Industrial classification in the Odyssee Database



Note: The main sectors of the economy are in bold. Industry descriptions can be found in appendix A.
Source: Author's own model based on the Odyssee Database.

The decomposition analysis of electricity intensity requires a matching set of data on final electricity consumption and value added (or other measures of economic activity), partitioned into different manufacturing sub-sectors.[25] The Odyssee Database provides such data consistently for a period of 20 years, between 1993 and 2012, for the following eight manufacturing industries: Chemical industry; Primary metals; Non-metallic minerals; Wood industry; Paper, pulp and printing industry; Food industry; Textile and leather industry; and Rubber and plastics. Consequently, for the analysis of this paper I define the manufacturing sector as the sum of these eight industries. Data for the remaining industries, Machinery and fabricated metal products, Transport equipment, and Other industries (except Rubber and plastics), was not available.[26] Since industry classifications and definitions vary according to

[24] Energy consumption data is also given separately for the energy-intensive industries Steel and Non-ferrous metals (primary metals), and Glass and Cement (Non-metallic minerals).
[25] Final electricity consumption is the electricity used by final or end-use consumers. It is defined as primary electricity consumption minus electricity consumed and lost in transformation processes and distribution. Value added measures the net output of a sector in monetary units. It is defined as the gross output minus the value of inputs.
[26] Rubber and plastics account for around two thirds of energy consumption in Other industries.

data source, and in order to achieve an internally consistent dataset, the option of using another source was discarded. The literature in general suggests that a minimum of five to six sectors are required to identify structural changes in decomposition analysis, and that these should include the most energy-intensive sectors, Paper and pulp, Chemical industry, and Primary metals (Boyd e*t al.*, 1987; Howarth *et al*, 1991).[27] The dataset compiled fulfils these requirements. An important limitation, however, is that the decomposition results are sensitive to the level of sectoral detail in the sense that structural changes on lower levels of aggregation, within manufacturing sub-sectors, may be incorrectly interpreted as technological change (Weber C. , 2009).

The Odyssee Database uses the general energy unit tonne of oil equivalent (toe) to describe the energy content of different energy carriers.[28] The energy content of electricity is converted in oil equivalents based on coefficients that are specific to the primary energy source used in electricity generation.[29] Value added is measured in euros at the constant exchange rate of the year 2005. It is important that the value added data used in decomposition analysis be defined in terms of constant prices, since there is otherwise a risk that price inflation skews the results (Kander & Henriques, 2010).

The modified, three-factor decomposition analysis incorporates labour use in terms of working hours per year, following Wenzel & Wolf (2014). I retrieved data on annual working hours for the period 1993-2012, by manufacturing sub-sector, from SCB. Annual electricity prices for industrial customers were obtained from the Swedish Energy Agency. Prices are in terms of real (2013) öre per kWh and include taxes computed based on tax rates, with a general reduction for the industry sector. Finally, data on labour compensation, in million Swedish Krona, are obtained from the EU KLEMS Growth and Productivity Accounts.

A number of computations and adjustments to the data have been made. As indicated above, I have defined the manufacturing sector as the sum of eight industries and adjusted aggregate measures include only these. Electricity intensity was computed as the ratio between final electricity consumption and value added, both on aggregate and sub-sectoral levels, expressed in terms of kilograms of oil equivalents per value added in euros, at constant exchange rate of 2005 (koe/€2005). Similarly, labour intensity was computed as the ratio between working hours and value added, expressed in terms of millions of working hours per value added in euros, at constant exchange rate of 2005 (€2005). Table A 1 in the appendix provides summary statistics of the main variables used in the decomposition analysis, for the manufacturing sector as a whole and by manufacturing sub-sector.

[27] In terms of electricity use and the data employed here, the highest intensities can be found in the Paper, pulp and printing industry, the Primary metals industry and the Wood industry.

[28]A tonne of oil equivalent (toe) measures the energy generated by burning one tonne of crude oil and is equal to 41.868 gigajoules (GJ). A joule (J) is an energy unit of the International System of Units (SI). Its definition is not related to any specific fuel, and it is for this reason sometimes referred to as a basic energy unit (a calorie is another example of a basic energy unit). Other units are source-specific in the sense that their definition is related to the properties of a specific fuel, for example a barrel of oil or a ton of coal. Since energy content can vary considerably between different energy products, however, energy statistics are typically converted to a common unit, such as oil equivalents.

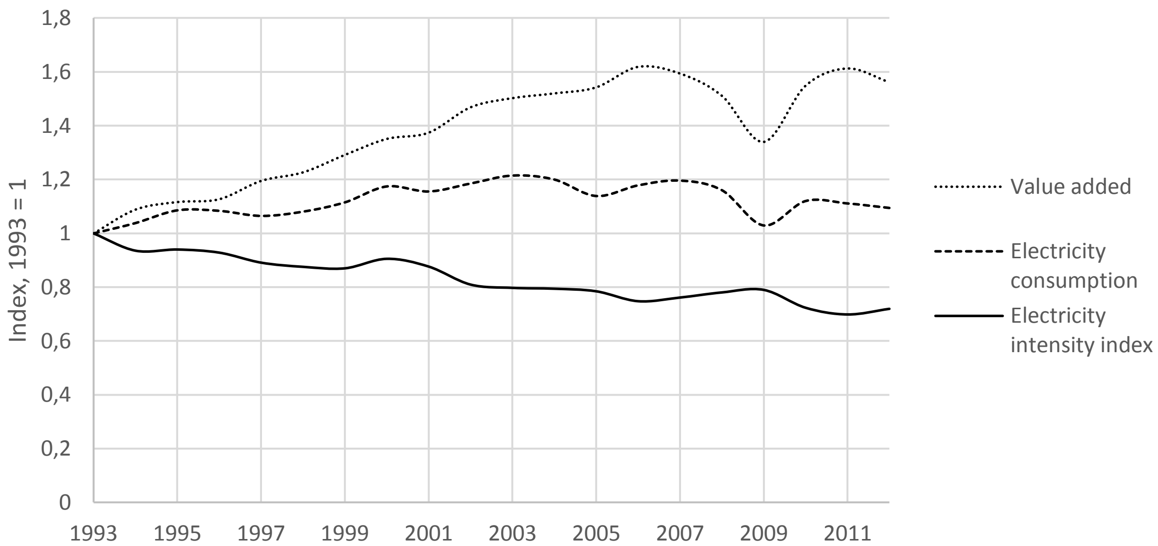
[29] Nuclear: 1TWh = 0.26 Mtoe; hydroelectricity: 1TWh = 0.086 Mtoe; geothermal: 1TWh = 0.86 Mtoe – total production: 1TWh = 0.086 Mtoe; imports, export: 1TWh = 0.086 Mtoe; consumption: 1TWh = 0.086 Mtoe

Trends in electricity consumption, value added, and electricity intensity

This section will proceed to highlight a number of trends in the data that may have a bearing on the decomposition results. A first indication of the role of structural effects will be presented. In particular, the data reveals considerable variation in electricity intensity across manufacturing sub-sectors and shows that structural changes have been significant during the time period studied. These results combined suggest that the decline in aggregate electricity intensity may at least partially be attributed to structural change. At the same time, there is variation in sectoral electricity intensity over time, suggesting that technological changes have also contributed to changes in electricity intensity. Labour use in manufacturing has been steadily declining and it is therefore possible that a considerable portion of technological change is in the form of direct substitution between factors of production, in this case, substitution from labour to electricity.

Electricity intensity in the Swedish manufacturing sector has been declining since the early 1990s, by around 28 per cent over the period 1993-2012. Figure 3 shows the relative decoupling between the trends in electricity consumption and value added that lies behind this decline; the growth of production, in terms of value added, has not required a proportional growth in electricity inputs. Both electricity consumption and value added experienced a significant slump in connection with the financial crisis in 2008 and 2009. The decline in electricity consumption was less severe than that in value added. A possible explanation is that some electricity consumption constitutes a fixed cost component that is independent of economic activity, such as the electricity used for lighting in buildings. The consequence is that electricity intensity increased slightly in the years of the crisis. In general, it is reasonable to assume that similar short-term fluctuations in electricity intensity are not the result of technological changes, but are rather demand-driven.

Figure 3. Trends in electricity consumption, value added, and electricity intensity in the Swedish Manufacturing sector, 1993-2012



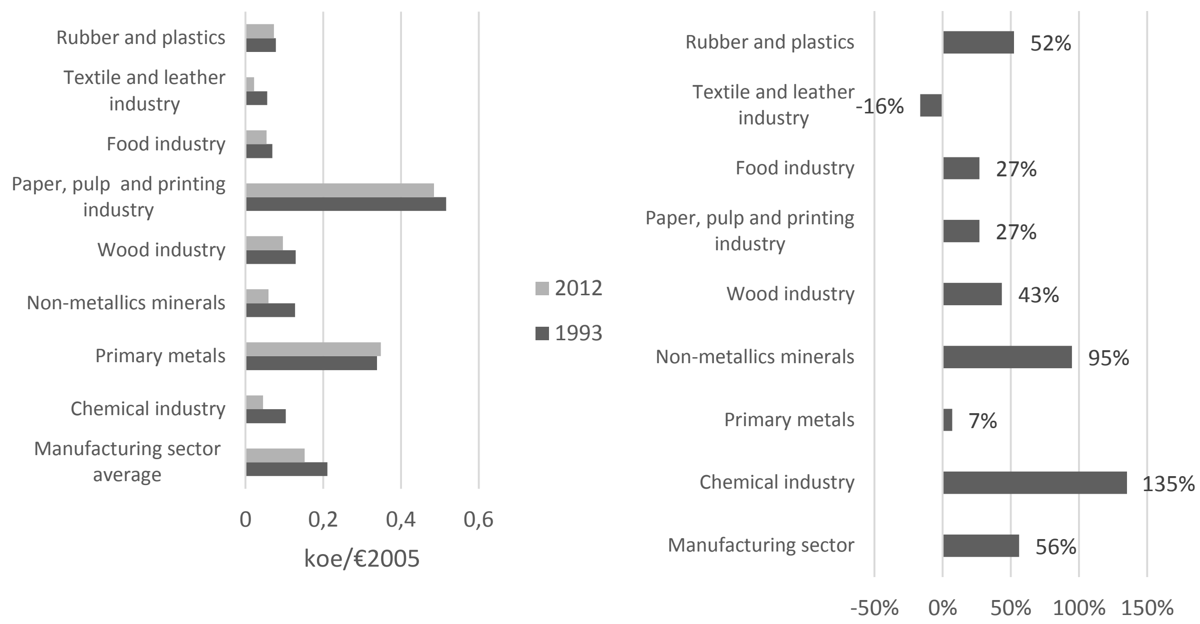
Note: The index base year is 1993.
Source: Author’s calculations based on the Odyssee Database.

Manufacturing industries are recognised as heterogeneous in terms of both production processes and output and the observed variation in electricity intensity confirms this variation.[30] As resources move between industries that have different sectoral intensity, the aggregate intensity measure changes. The variation in intensity therefore implies that structural changes, if present, may have influenced the development of aggregate electricity intensity. The average growth rate of value added across the industries analysed, evidences such structural change. All industries, and in particular the Chemical industry, have increased in economic importance over the period studied, with the exception of the Textile and leather industry. There is also evidence of technological change since electricity intensity in all industries, except the Primary metals industry, has been declining over the period studied. The decomposition analysis serves to determine the relative contribution of these two effects. Figure 4 provides a summary of the observations above. Another key trend in the manufacturing industry is revealed by looking at the development of labour use, Figure 5, in terms of the number of working hours per year. Increased automation has contributed to a steady decline in labour use, of about 20 per cent between 1993 and 2012, and consequently an adjustment of the factor mix used in production. It is likely that automation has had an influence also on electricity intensity.

The main conclusions from this brief exploration of the data is that in addition to being an indicator of industrial energy efficiency, it is possible and likely that the observed changes in aggregate electricity intensity also reflect the influence of structural changes. Furthermore, in light of considerable automation in the manufacturing sector over the studied period, there is reason to investigate the effect of the incorporation of the relative demand for labour in the decomposition analysis.

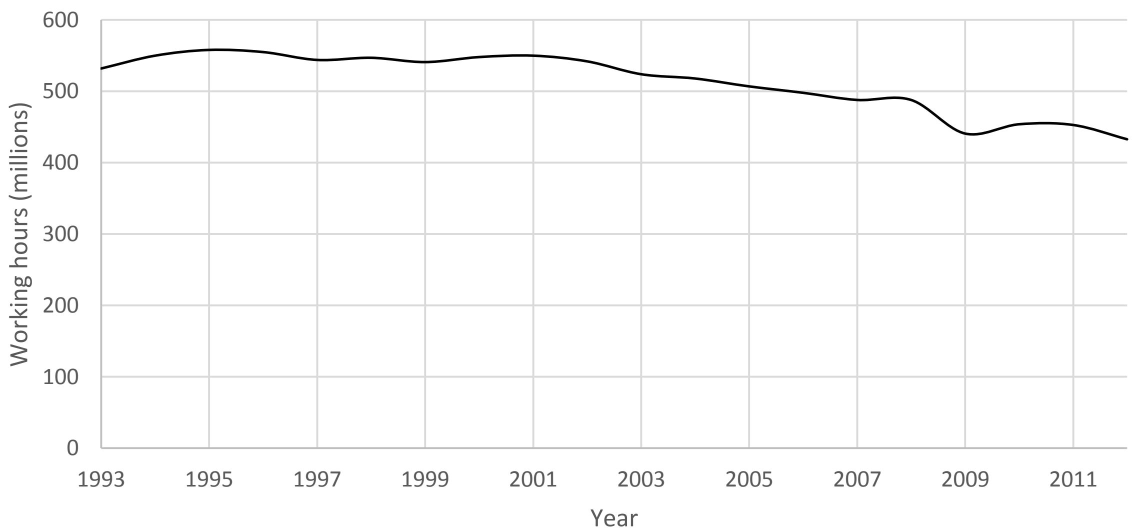
[30] Electricity intensity is typically high in industries involved in the processing of primary commodities. In the primary metals industry, for example, the smelting and pressing of ferrous and non-ferrous metals requires a lot of electricity (Steenhof, 2006). Among the industries analysed in this paper, the *Paper, pulp and printing industry* (0.49 koe/€2005) as well as the *Primary metals industry* (0.35 koe/€2005) have the highest electricity intensity. Less electricity per unit of value added is required in the *Textile and leather industry* (0.02 koe/€2005).

Figure 4. Electricity intensity in 1993 and 2012, and percentage change in value added, 1993-2012, by manufacturing sub-sector



Source: Author's calculations based on the Odyssee Database.

Figure 5. Working hours per year in Swedish manufacturing sector, 1993-2012



Source: SCB

4. METHODS

Two-factor LMDI decomposition

The data presented in the previous section indicates that electricity intensity varies *within* manufacturing sub-sectors over the time-period studied, and therefore suggests that there has been some degree of technological change. However, there is also evidence of parallel changes in the composition of the manufacturing sector. Since electricity intensity varies on a sectoral level, such structural changes may be part of the explanation to the aggregate decline in electricity intensity. Furthermore, the high and increasing level of automation in Swedish manufacturing is likely to have implications for the composition of the technology effect, which motivates the incorporation of labour use in the decomposition.

To investigate what factors drive electricity intensity, this paper employs the Log Mean Divisia Index (LMDI) decomposition method using the version of (Ang & Zhang, 2000) and (Ang B. W., 2005) to analyse energy patterns. The decomposition scheme consists of the following elements, where the subscript *i* is the sub-category of the energy intensity aggregate for which structural change is studied, in this case one of eight manufacturing sub-sectors:

E_t	Final energy consumption in year *t*
E_{it}	Final energy consumption in manufacturing sub-sector *i* in year *t*
Y_t	Total value added in year *t*
Y_{it}	Total value added in manufacturing sub-sector *i* in year *t*
I_t	Final energy intensity in year *t* (E_t/Y_t)
I_{it}	Final energy intensity in manufacturing sub-sector *i* in year *t* (E_{it}/Y_{it})
S_{it}	Share of manufacturing sub-sector *i* in total value added in year *t* (Y_{it}/Y_t)
D_{tot}	Total change in aggregate energy intensity
D_{str}	Change in aggregate energy intensity (I_t) due to the structure effect (changes in the composition of economic activities in the manufacturing sector)
D_{tech}	Change in aggregate energy intensity (I_t) due to the technology effect (technological changes influencing energy use)

The energy intensity in the manufacturing sector is an aggregate indicator that can be expressed in terms of energy intensity and economic activity on the level of manufacturing sub-sectors. The economic activity in this case is measured as the share of sub-sector *i* in total value added.

$$I_t \equiv \frac{E_t}{Y_t} = \sum_i \frac{E_{it}}{Y_{it}} \frac{Y_{it}}{Y_t} = \sum_i I_{it} S_{it} \tag{2}$$

This expression forms the decomposition identity. In its multiplicative form, the LMDI decomposes the change in aggregate energy intensity (I_t) between two consecutive periods *t-1* and *t*, expressed as a ratio, into a technology effect (D_{tech}) and a structure effect (D_{str}):

$$D_{tot} = \frac{I_t}{I_{t-1}} = D_{tech} D_{str} \tag{3}$$

The formulae for the technology and structure effects, respectively, are:

$$D_{tech} = exp\left(\sum_i w_i \, ln\left(\frac{I_{it}}{I_{it-1}}\right)\right) \tag{4}$$

$$D_{str} = exp\left(\sum_i w_i \, ln\left(\frac{S_{it}}{S_{it-1}}\right)\right) \tag{5}$$

where, w_i is a weighting function, defined as:

$$w_i = L(I_{it}, I_{it-1}) \tag{6}$$

L is a logarithmic mean function that for two positive numbers a and b, is given by:

$$L(a,b) = \frac{(a-b)}{ln(a/b)} \tag{7}$$

The decomposition is first performed for the complete time-period (*period-wise decomposition*) and on a rolling, year-by-year basis, where changes are chained to form a time series (*chained decomposition*). The value in a selected base year is normalised to one. In this case, the resulting time-series stretches from 1993 to 2012. Although chain-weighting the index makes the choice of base year arbitrary, care was taken to select a base year that was not under the immediate influence of a recession or oil shock (Liu & Ang, 2007). I selected the first year in the sample, 1993, as base year. The results of the multiplicative LMDI has the following additive property (Ang B. W., 2005):

$$ln(D_{tot}) = ln(D_{tech}) + ln(D_{str}) \tag{8}$$

Three-factor LMDI decomposition

The aim of the modified decomposition is to distinguish between two kinds of technological change: technological change that causes an adjustment of the relative factor employment and technological change in the form of general productivity changes or scale effects, leaving relative factor use unchanged. For this purpose, a number of new elements are introduced to the decomposition scheme:

F_{it} Electricity-to-labour ratio (E_{it}/L_{it}) in manufacturing sub-sector *i* in year *t*

$\hat{I}_{it}$ Labour intensity in manufacturing sub-sector *i* in year *t* (L_{it}/Y_{it})

D_{mix} Change in aggregate energy intensity (I_t) due to the factor mix effect (adjustments in relative factor use in production)

$D_{\widehat{int}}$ Change in aggregate energy intensity (I_t) due to the adjusted technology effect (technological changes that leaves relative factor mix unchanged)

The modification consists of including the electricity-to-labour ratio and the labour intensity in the decomposition identity:

$$I_t \equiv \frac{E_t}{Y_t} = \sum_i \frac{E_{it}}{L_{it}} \frac{L_{it}}{Y_{it}} \frac{Y_{it}}{Y_t} = \sum_i F_{it} \hat{I}_{it} S_{it} \tag{9}$$

Using the modified decomposition identity, the change in aggregate energy intensity (I_t) is decomposed into three effects: a factor mix effect (D_{mix}), an adjusted technology effect ($D_{\widehat{tech}}$), and the usual structure effect (D_{str}):

$$D_{tot} = \frac{I_t}{I_{t-1}} = D_{mix} D_{\widehat{tech}} D_{str} \tag{10}$$

The structure effect is defined as in the two-factor decomposition. The formulae for the two new effects are:

$$D_{mix} = exp\left(\sum_i w_i \, ln\left(\frac{\hat{I}_{it}}{\hat{I}_{it-1}}\right)\right) \tag{11}$$

$$D_{\widehat{tech}} = exp\left(\sum_i w_i \, ln\left(\frac{F_{it}}{F_{it-1}}\right)\right) \tag{12}$$

The weighting function is defined as before, and the decomposition is again performed both period-wise and on a rolling basis. The additive property of the results are now expressed as:

$$ln(D_{tot}) = ln(D_{mix}) + ln(D_{\widehat{tech}}) + ln(D_{str}) \tag{13}$$

It should be noted that the adjusted technology effect also captures productivity changes in unobserved factors that are not part of the analysis. For example, potential improvements in the productivity of capital are reflected in this term (Wenzel & Wolf, 2014). Another comment on this note concerns the properties of the LMDI method. It was argued previously that one of the desirable properties of LMDI is that it leaves no unexplained residual and therefore is easier to interpret. According to Muller (2006), however, a residual term is to be expected in decomposition analysis when it involves integral approximation, which LMDI does. He argues that an optimal decomposition approach not necessarily requires a non-zero residual term. In fact, forcing the residual to zero could result in a less exact decomposition, and result in more difficult interpretation since there is no indication of how much of the approximation error that has been attributed to each term. He nevertheless concludes that the LMDI performs better than other popular decomposition approaches and notes that the strength of the LMDI method lies in its ability to provide exact decomposition for a wide range of different functions. When interpreting the results, the potential costs of a zero residual should be kept in mind. Another remark related to the interpretation of the results is that decomposition analysis gives only correlation, not causation, and any interaction among variables may be difficult to identify and track. This paper does not attempt to establish causality, but rather focuses on correlations. Finally, it is possible that the results are biased due to misinterpretation of structural changes *within* manufacturing industries as technological changes.

The chained decomposition results can be directly compared to Inés Pardo Martìnez & Silveira (2013), whose analysis covers the period 1993-2008. To enable a direct comparison with the results of Wenzel & Wolf (2014), both parts of the decomposition analysis are performed over the shorter time-period analysed in their paper, 2000-2011, using 2000 as base year. However, since decomposition analysis is sensitive to the scope of the analysis, in terms of the time-period studied and industries included, due care must be taken when comparing across studies.

5. RESULTS

The results of the decomposition of electricity intensity are in the form of indexes, or effects. Each effect represents the potential change in aggregate electricity intensity associated with changes in a given factor, holding all other factors constant. An index value less than one is interpreted as a reduction of aggregate electricity intensity, whereas a value above one is interpreted an increase in aggregate electricity intensity. If the index value is equal to one, changes in the given factor has not influenced aggregate electricity intensity (Ang & Zhang, 2000). The results of the two-factor decomposition are presented first, followed by the results of the modified, three-factor decomposition.

Two-factor LMDI decomposition

The two-factor decomposition results in two indexes: a structure effect and a technology effect. The structure effect measures the changes in aggregate electricity intensity that are due to a changing composition of economic activities, or structural changes, holding the level of technology constant. Similarly, the technology effect measures the change in electricity intensity that results from technological changes, holding the economic structure constant. It is common in the energy decomposition literature to attribute strong technology effects completely to energy efficiency improvements. However, this interpretation relies on the assumption that reductions in electricity intensity within industries only reflect improvements in the efficiency of energy use. This paper uses a broader definition of technological change that includes both specific energy efficiency improvements in production processes, general productivity changes and changes in the input mix. In this paper, these changes combined are assumed to influence aggregate electricity intensity.

In 2012, electricity intensity in the Swedish manufacturing sector was only 72 per cent of its level in 1993, implying a total reduction of 28 per cent. Table 1 presents the decomposition results and indicates that both technology and structure effects have contributed to this aggregate decline. More specifically, the technology effect in 2012 was 0.83. Thus, without any changes in the economic structure, technological changes would have led to a decline in aggregate electricity intensity of 17 per cent between 1993 and 2012. Similarly, the structure effect of 0.86 implies that structural changes would have led to a decline in electricity intensity of 14 per cent, given constant technology levels. The product of the structure and technology effect is the aggregate effect of 0.72.

A comparison with previous literature may give an indication of the extent to which results are biased by the exclusion of the two manufacturing sub-sectors Machinery and fabricated metal products; and Transport equipment. The economic importance of these industries has increased significantly over time, and since they are generally considered less energy-intensive than other manufacturing industries it is possible that their inclusion would have significantly altered the decomposition results (SOU 2008:90). To enable a comparison with the results from Wenzel & Wolf (2014), the decomposition analysis was repeated over the time-period 2000-2011. The results are qualitatively similar, indicating that the computed index values lies within a reasonable range. The overall decline in electricity intensity in Sweden was greater compared to the European country average (a total effect of 0.72 compared to 0.77). Wenzel & Wolf (2014) compute an average structure effect of 0.96 and a technology effect of 0.76, in their sample of 20 European countries. Compared to the European country average, the decomposition results for Sweden over the same period suggest a stronger structure effect (0.92), while the technology effect is weaker (0.84).[31] The results are also consistent with Inés Pardo Martìnez & Silveira (2013), who conclude that the technology effect is the main driver of overall energy intensity decline in the Swedish manufacturing sector over the period 1993-2008, although their results suggest weaker effects.[32]

Table 1. Results of electricity intensity decomposition for the Swedish manufacturing sector, 1993-2012

Structure effect (D_{str})	Technology effect (D_{tech})	Electricity intensity (D_{tot})
0.86	0.83	0.72
	$D_{tot} = 0.72 = D_{tech}D_{str}$	

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method over the time-period 1993-2012.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

To see how long-term changes have emerged over time, Table 2 and Figure 6 present the results of a chained decomposition of annual changes in electricity intensity between 1993 and 2012. The results confirm that electricity intensity during this period has decreased as a result of both structural and technological changes. There is also evidence of variation in the indexes over time.[33] The high volatility of both effects in 2008-2009 may be ascribed to the financial crisis in Europe, and it is reasonable to assume that such short-term fluctuations do not arise because of longer-term organisational or technological changes, but rather reflect demand-driven changes.[34] For example, the sharp increase in the technology effect during the crisis may reflect underutilisation of production capacity, and the fact that some parts of electricity costs are fixed and relatively insensitive to business cycle fluctuations. The rebound effect in the wake of the crisis, as the economy recovered, further support demand-driven changes.

The decomposition results indicate a trend-break in terms of what effect has been the main driver of electricity intensity decline. In the period before 2003, the structure effect contributed the most to decreasing intensity, whereas the technology effect increased in importance over subsequent years. The decomposition results over the period 1993-2000, presented in appendix C, suggest that the technology effect accounted for 11 per cent of the total decline in electricity intensity, whereas the structure effect accounted for 89 per cent. Over

[31] The decomposition results for the period 2000-2011 are provided in appendix C.
[32] Inés Pardo Martìnez and Silveira (2013) also employ the LMDI method, but use production values instead of value added as their measure for economic activity in the decomposition. Their analysis covers the period 1993-2008.
[33] Summary statistics of the decomposition results, presented in appendix C, suggests that the technology effect in general has been more volatile (standard deviation of 0.06) than the structure effect (standard deviation of 0.04). In other words, it appears that controlling for structural changes increases the volatility of changes in electricity intensity.
[34] Industrial production in Sweden was particularly hard hit by the crisis, especially the manufacturing sector.

the more recent period 2000-2011, the technology effect accounted for 68 per cent, whereas the structure effect accounted for only 32 per cent.[35] To some extent, previous findings indicate similar trends. For example, Unander (2007) finds that over the period 1973-1998, structural effects on average accounts for one third of the observed change in aggregate energy intensity in ten IEA countries. The analysis over the period 1994-1998, however, suggests that almost all change in energy intensity may be attributed to structural shifts in the economy.

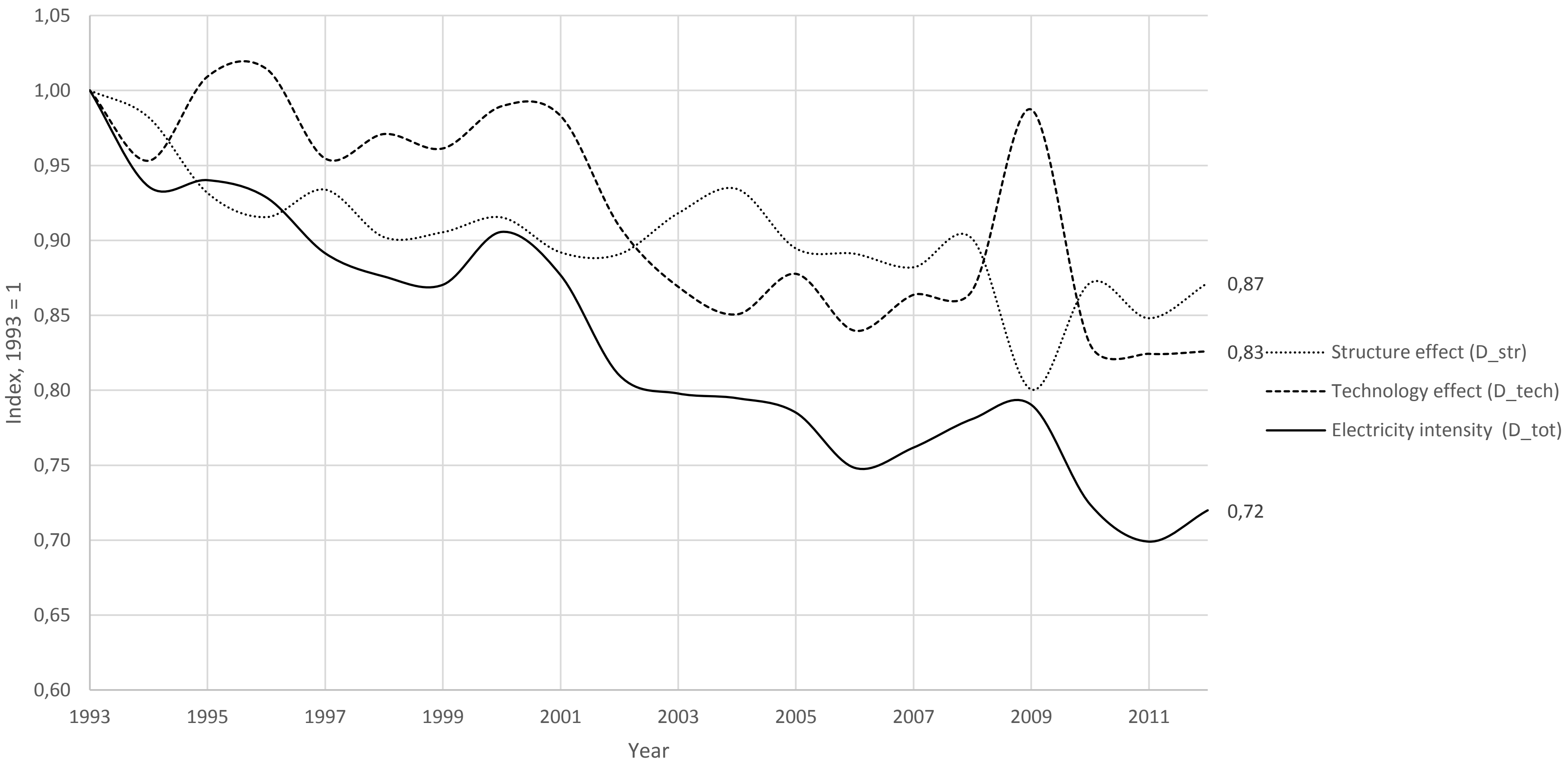
Table 2. Results of electricity intensity decomposition for the Swedish manufacturing sector, 1993-2012 (annual changes, chained)

Year	Structure effect (D_{str})	Technology effect (D_{tech})	Electricity intensity (D_{tot})
1993	1.00	1.00	1.00
1994	0.98	0.95	0.94
1995	0.93	1.01	0.94
1996	0.92	1.01	0.93
1997	0.93	0.95	0.89
1998	0.90	0.97	0.88
1999	0.91	0.96	0.87
2000	0.92	0.99	0.91
2001	0.89	0.98	0.88
2002	0.89	0.91	0.81
2003	0.92	0.87	0.80
2004	0.93	0.85	0.79
2005	0.89	0.88	0.79
2006	0.89	0.84	0.75
2007	0.88	0.86	0.76
2008	0.90	0.87	0.78
2009	0.80	0.99	0.79
2010	0.87	0.83	0.72
2011	0.85	0.82	0.70
2012	0.87	0.83	0.72

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 1993 to that year.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

[35] The relative contribution of the effects are computed using the additive property of the decomposition results, presented in section 4.

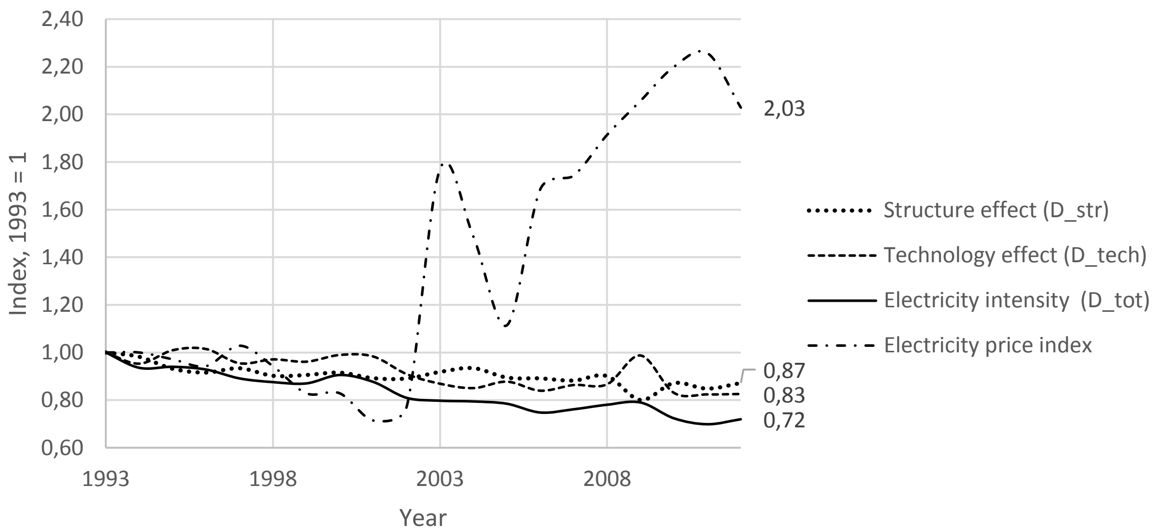
Figure 6. Results of electricity intensity two-factor decomposition for the Swedish manufacturing sector, 1993-2012 (annual changes, chained)



Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 1993 to that year. Note that the vertical axis has been shortened to make annual variations and relative effects more salient.
Source: Author's calculations based on the Odyssee Database. See section 4 for details on index design.

It is notable that the apparent increase in the relative contribution of the technology effect to electricity intensity decline coincides with the marked and sustained increase in electricity prices for industrial customers in Sweden during this period, see Figure 7. Economic theory predicts that higher electricity prices will lead to lower electricity consumption.[36] And given well-functioning markets, higher prices should also lead to lower electricity intensity, either through structural or technological changes (Song & Zheng, 2012). The observation above provides at least some indication that technological changes may be more sensitive to increasing electricity prices than structural changes.[37] This is in line with the hypothesis of induced innovation, first formulated by Hicks (1932), which suggests that an increase in the relative price of a factor of production may lead to technological change directed to economising the use of the factor that has become relatively more expensive. In other words, higher electricity prices may lead to energy-saving technological change. Inés Pardo Martìnez & Silveira (2013) suggests that this is the case in the Swedish manufacturing industry. In an econometric analysis, they show that energy prices have a significant and negative effect on energy intensity in Swedish manufacturing, over the period 1993-2008.

Figure 7. Results of electricity intensity two-factor decomposition for the Swedish manufacturing sector, 1993-2012 (annual changes, chained), and electricity price index



Note: An index value of 1.1 means a 10 per cent increase, a value of 0.9 means a 10 per cent, and a value of 1 means that there is no change. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 1993 to that year. Note that the vertical axis has been shortened to make annual variations and relative effects more salient.
Source: Author's calculations based on the Odyssee Database and the Swedish Energy Agency.

[36] This prediction hinges on the assumption of electricity price exogeneity.
[37] It should be noted, however, that the results presented only reflect correlations, and no attempt is made to establish a causal relationships.

Three-factor LMDI decomposition

The results of the modified electricity intensity decomposition are in the form of three indices: a structural effect, a factor mix effect, and an adjusted technology effect. The structure effect is defined as before. The technology effect is split into a factor mix effect and an adjusted technology effect.[38] The interpretation of the indices follows the same logic as before; the factor mix effect measures the change in aggregate electricity intensity that is due to changes in the electricity-to-labour ratio, holding both economic structure and sectoral labour intensity constant. For example, energy-saving technological change is likely to reduce electricity use per worker, whereas automation may lead to direct substitution between factors of production, also changing relative factor use. The adjusted technology effect measures the effect of changes in general productivity, holding all other factors constant. In fact, holding the factor mix effect constant implies that the adjusted technology effect captures both technological improvements that increase the productivity of all factors equally and pure scale effects.

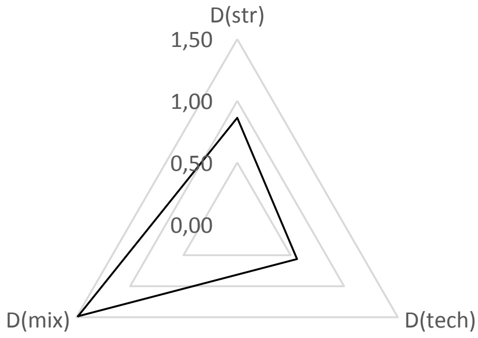
Table 3 presents the decomposition results for the complete time-period, and shows that technological change is in the form of both factor substitution and general productivity improvements. The factor mix effect has contributed to a substantial long-term *increase* in electricity intensity (1.49), while the adjusted technology effect has worked in the opposite direction, lowering electricity intensity (0.56). This illustrates the need to account for these two effects separately, and suggests that the positive effect of factor substitution outweighs the intensity reduction associated with specific energy efficiency improvements. The contribution from the structure effect is still towards a long-term decline in electricity intensity (0.86).[39] The radar diagram shows the relative effects graphically. The factor mix effect is the highest impact factor, whereas the adjusted technology effect has contributed the most to the decline in aggregate electricity intensity over the studied period. The results combined indicates that the evaluation of the technology effect is significantly biased when the factor mix effect is not accounted for.

[38] As pointed out by Wenzel & Wolf (2014), when taking on this descriptive approach, no assumption is made regarding the production technology.

[39] The structure effect is by definition the same as in the two-and three-factor decomposition.

Table 3. Results of electricity intensity decomposition for the Swedish manufacturing sector, 1993-2012

Structure effect (D_{str})	Adjusted technology effect ($D_{\widehat{tech}}$)	Factor mix effect (D_{mix})	Electricity intensity(D_{tot})
0.86	0.56	1.49	0.72



$$D_{tot} = 0.72 = D_{mix} D_{\widehat{tech}} D_{str}$$

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that the given factor has no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method over the time-period 1993-2012.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

Performing the decomposition on a rolling basis yields the results presented in table 4 and Figure 8. Changes in the factor mix have consistently contributed to increasing electricity intensity, with the exception of the years 1994, 2001, 2008 and 2009 when changes in the factor mix had a negative effect on electricity intensity.[40] In other words, there is an indication of a substantial substitution from labour to electricity in production that have countered any improvement in energy efficiency, which is in line with the observed trend of high and increasing automation. In addition, the factor mix effect has increased in importance over time. This finding confirms the results of Wenzel & Wolf (2014), and suggests that the decline in aggregate electricity intensity is mainly due to a combination of structural changes and general productivity improvements, captured by the adjusted technology effect, rather than more electricity efficient modes of production. A further comparison shows that the decomposition results are qualitatively similar.[41] Compared to the European country average, the results for Sweden suggests a slightly weaker factor mix effect and adjusted technology effect, whereas the structure effect was stronger in Sweden than the European country average.[42]

The period of the financial crisis is again associated with short-term fluctuations in all effects, most likely reflecting demand-driven adjustments. The factor mix, for example,

[40] Unchained annual effects are provided in appendix C.
[41] The decomposition was again repeated over the period 2000-2011. The results are presented in appendix C.
[42] Wenzel & Wolf (2014) compute an average structure effect of 0.98, an adjusted technology effect of 0.63 and a factor mix effect of 1.25, in their analysis of 20 European countries. The corresponding results for Sweden in this paper are 0.92, 0.72, and 1.17.

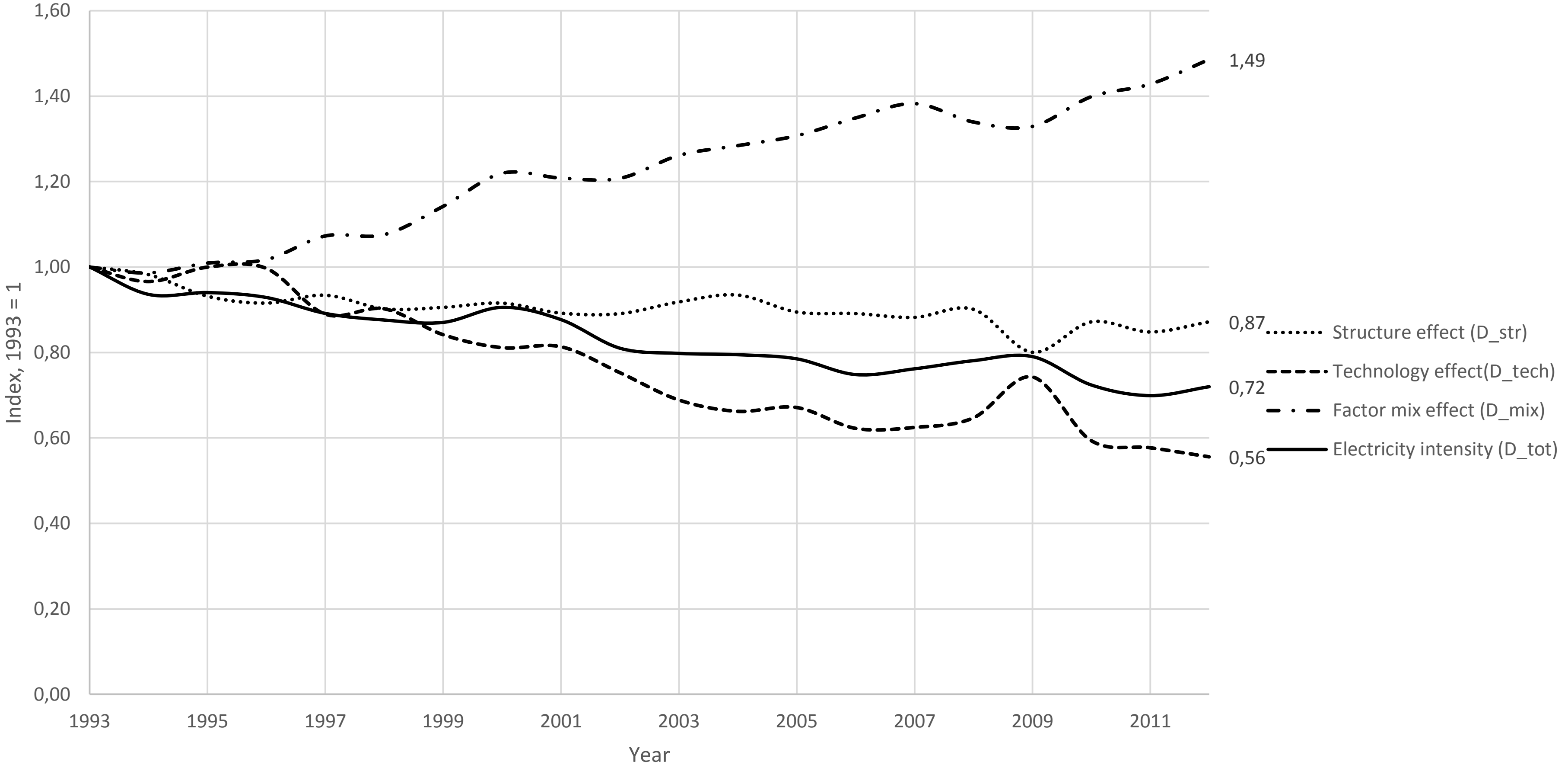
decreased during the crisis, indicating that electricity use was reduced relatively more than labour use as a response to the demand shock.

Table 4. Results of electricity intensity decomposition for the Swedish manufacturing sector, 1993-2012 (annual changes, chained)

Year	Structure effect (D_{str})	Adjusted technology effect ($D_{\widehat{tech}}$)	Factor mix effect (D_{mix})	Electricity intensity (D_{tot})
1993	1.00	1.00	1.00	1.00
1994	0.98	0.97	0.99	0.94
1995	0.93	1.00	1.01	0.94
1996	0.92	1.00	1.02	0.93
1997	0.93	0.89	1.07	0.89
1998	0.90	0.90	1.08	0.88
1999	0.91	0.84	1.14	0.87
2000	0.92	0.81	1.22	0.91
2001	0.89	0.81	1.21	0.88
2002	0.89	0.75	1.21	0.81
2003	0.92	0.69	1.26	0.80
2004	0.93	0.66	1.28	0.79
2005	0.89	0.67	1.31	0.79
2006	0.89	0.62	1.35	0.75
2007	0.88	0.62	1.38	0.76
2008	0.90	0.65	1.34	0.78
2009	0.80	0.74	1.33	0.79
2010	0.87	0.59	1.40	0.72
2011	0.85	0.58	1.43	0.70
2012	0.87	0.56	1.49	0.72

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 1993 to that year.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

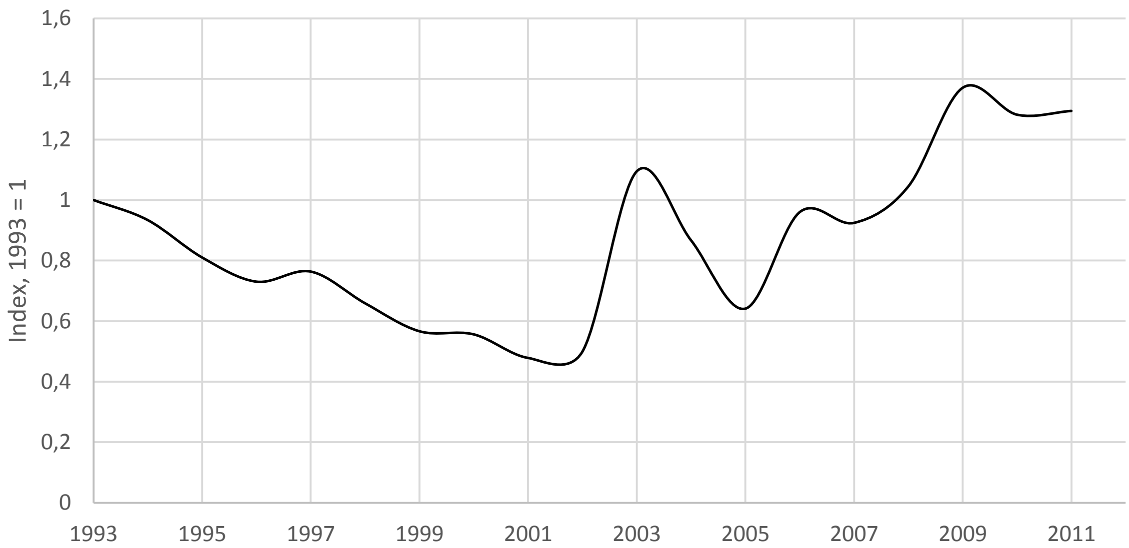
Figure 8. Results of electricity intensity three-factor decomposition for the Swedish manufacturing sector, 1993-2012 (annual changes, chained)



Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 1993 to that year. Note that the vertical axis have been shortened to make annual variations more salient.
Source: Author's calculations based on the Odyssee Database. See section 4 for details on index design.

To get an indication of whether the relative factor compensation has been driving the observed substitution from labour to electricity in Swedish manufacturing, Figure 9 shows the ratio between electricity prices and worker compensation. The relative price of electricity steadily decreased during the 90s. In 2002, it increased sharply to reach a peak around 2003. Interestingly, the relative electricity price has experienced a general increase during the 2000s, which would suggest factor substitution in the opposite direction, from electricity to labour. This is again in line with the conclusion of Wenzel & Wolf (2014), who further conclude that the adjusted technology effect also is unlikely to be driven by factor prices, since in their sample, countries having experienced relatively larger energy price increases do not necessarily show stronger technology effects. In this light, the nature of the relationship between energy prices and the overall technology effect is less clear.

Figure 9. Ratio of electricity price to worker compensation, 1993-2012



Note: The electricity price is for industrial customers and the labour compensation is for manufacturing industries, as defined in the EU KLEMS.
Source: Author's calculation based on the Swedish Energy Agency and EU KLEMS Growth and Productivity Accounts.

6. DISCUSSION AND CONCLUSION

This paper has used decomposition techniques to explore factors influencing electricity intensity in the Swedish manufacturing sector, over the period 1993-2012. The decomposition analysis was divided into two parts. In the first part, the decomposition yielded two effects: the technology effect and the structure effect. In the second part, the decomposition was modified to incorporate factor substitution, distinguishing between three effects: the adjusted technology effect, the factor mix effect and the structure effect. The decomposition was performed both for the complete period, capturing the long-term effects, and on a rolling basis. In addition, the decomposition was repeated for the shorter time-period 2000-2011 to enable a direct comparison with relevant other literature.

The total decline of aggregate electricity intensity in Swedish manufacturing between 1993 and 2012 was slightly lower compared to the country average in Europe, as computed by

Wenzel & Wolf (2014). The total effect was 0.72 for Sweden, compared to the European average of 0.77. The first part of the decomposition analysis resulted in the following findings. First, both the technology effect and the structure effect have contributed to the long-term decline of electricity intensity between 1993 and 2012 in the Swedish manufacturing industries. The decomposition results suggest a structure effect of 0.86, and a slightly stronger technology effect of 0.83, over the complete time-period. The variation in the effects over time suggests that the technology effect has increased in relative importance since the early 2000s. The parallel trend of increasing electricity prices is highlighted, and may suggest that the technology effect is more sensitive to price changes than the structure effect. From a policy perspective, these results indicate that a focus on promoting technological improvements in the manufacturing sector may be more effective in terms of decreasing aggregate electricity intensity, than strategic planning of the composition of the sector in the direction of less energy intensive industries. The second part of the analysis, however, makes these seemingly straightforward implications more complicated.

The second part suggests a need to distinguish between two kinds of technological change in Swedish manufacturing industries: the kind that results in an adjustment of the factor mix used in production, and the kind that is constituted by general productivity changes. The results show that a factor mix effect of 1.17 has contributed to increased electricity intensity over the complete period, suggesting that a substitution from labour to electricity has countered the effect of any specific energy efficiency improvements. The long-term decline in electricity intensity has instead been driven by general productivity improvements, which is indicated by a low value of the adjusted technology effect (0.56), while the structure effect has contributed relatively less to aggregate changes (0.86). The short-term volatility of all effects in reaction to external demand shocks indicates that general productivity changes may be partly in the form of pure scale effects. In summary, the modified decomposition indicates that interpreting the technology effect in Swedish manufacturing as only the result of direct efficiency improvements may be misleading. From a policy perspective, it suggests a critical view of the effectiveness of public support directed towards the development of energy efficiency technologies. The results of this paper confirm previous findings by Wenzel & Wolf (2014).

In this context, another comment related to the interpretation of the technology effect should be made. Several studies have shown that improved technical energy efficiency will not necessarily lead to reduced energy intensity. This is because efficiency gains may make energy services cheaper, leading to increased consumption. A concept explaining this phenomenon is the so-called rebound effect, which in a decomposition analysis will manifest itself as a structural change in the economy. The rebound effect may hamper energy intensity reductions, but since energy services are also provided by capital it is unlikely that the price of energy services decreases proportionally with energy costs. It is also unlikely that all of the cost savings associated with improved efficiency will be used to consume more energy services (Kander & Lindmark, 2004). The rebound effect implies that it may be hard to accurately capture technical energy efficiency improvements in a decomposition analysis, and it should be emphasised that this paper does not cover those aspects, which require another level of technical detail.

The main limitation of this study is that structural changes may be hidden at lower levels of aggregation. Several studies have shown that the level of detail is a crucial factor for an accurate identification of structural changes (Weber, 2009). For example, if the composition of the Primary metals industry (the relative share in value added of Steel and Non-ferrous metals) has changed over the time-period analysed, it is possible that the effect of this change on electricity intensity has been misinterpreted as part of the technology effect. The decomposition results are, however, in the range of findings both for other European countries and for Swedish manufacturing industries, which provides some confidence. The comparison with previous findings is made difficult because of two reasons. First, this paper only covers eight of the manufacturing industries, whereas the other relevant papers include two main additional sub-sectors. The qualitative similarity between the results does suggest that the inclusion of the complete set of sub-sectors would neither alter the direction of the effects, nor the relation between them. Second, decomposition studies use varying measures of economic activity, depending on what measure is considered the best reference for, in this case, energy intensity. Inés Pardo Martìnez & Silveira (2013), for example, use the production value instead of the value added, as several studies indicate that this may be a better choice, particularly when analysing manufacturing industries. The reason is that value added as an output measure tends to be more sensitive to economic change. Again, this may have affected the precision of the decomposition results, but the main conclusions should remain. Ideally, production values should have been employed also in this paper, but due to data limitations, this was not possible.

Finally, it should be noted that the conclusions of the paper are limited by the choice of empirical approach. Since decomposition analysis is a statistical exercise, which is descriptive in nature, it is ultimately not possible to identify what fundamental factors determine variation in energy intensity and its underlying components. For example, additional methods are needed in order to determine the relative effect of energy prices on technology, structure and other effects. Possible avenues for further research therefore include an econometric analysis of the decomposition results, which is the approach used in a relatively new strand of the energy decomposition literature (see for example Metcalf, 2008). Since energy intensity may respond to energy prices with a lag, a partial adjustment model would be suitable in such an analysis. Finally, to achieve a more accurate decomposition and gain additional insight the three-factor decomposition could be extended further to include other production factors, such as capital.

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APPENDIX A

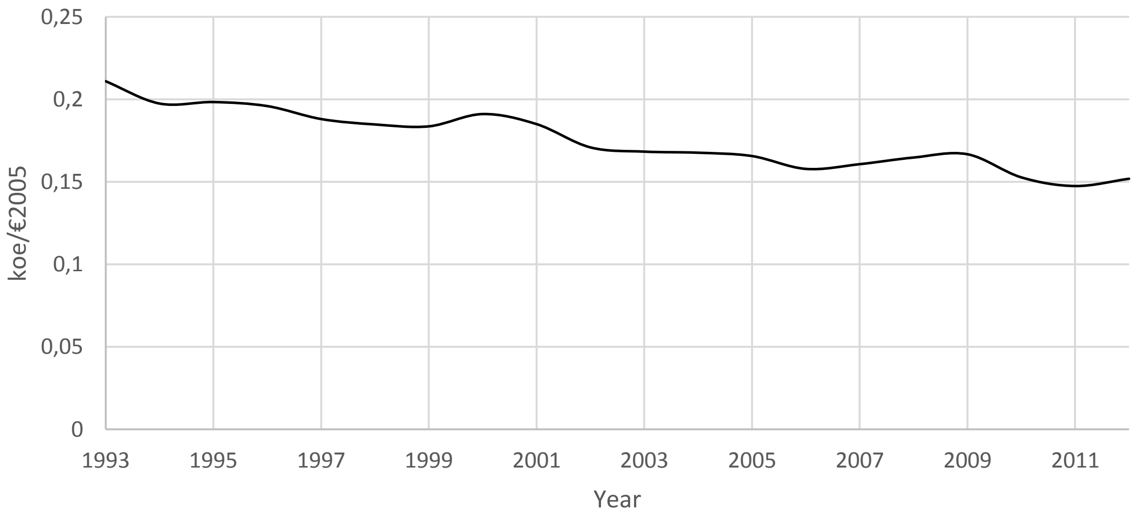
Data and summary statistics

Table A 1. Summary statistics: main variables of decomposition analysis, by manufacturing sub-sector

	Value added (M€2005)		Electricity Intensity (koe per €2005)		Labour intensity (million working hours per €2005)	
Sector/sub-sector	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Manufacturing sector	21,049	3,002	0.181	0.016	0.025	0.005
Chemical industry	6,464	1,623	0.076	0.014	0.010	0.003
Primary metals	2,375	557	0.274	0.035	0.027	0.008
Non-metallic minerals	1,023	246	0.109	0.020	0.034	0.007
Wood industry	1,934	338	0.099	0.018	0.036	0.007
Paper, pulp and printing industry	3,520	360	0.559	0.030	0.033	0.008
Food industry	3,816	307	0.058	0.006	0.029	0.005
Textile and leather industry	538	47	0.048	0.010	0.041	0.007
Rubber and plastics	1,378	199	0.073	0.007	0.033	0.005

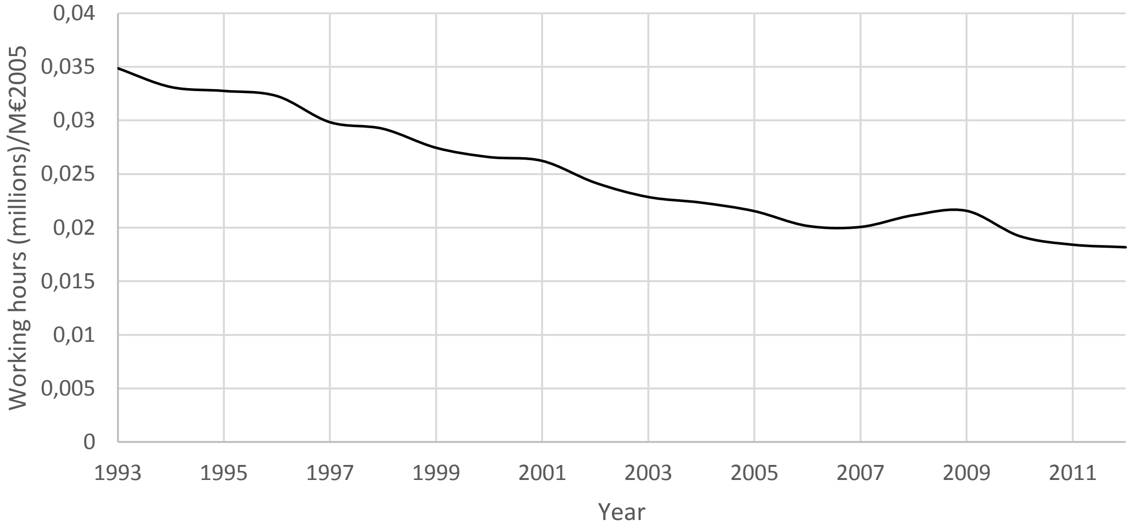
Note: Data is from 1993-2012.
Source: Author's calculations based on the Odyssee Database and SCB

Figure A 1. Electricity intensity in the Swedish manufacturing sector, 1993-2012



Source: Author's calculations based on the Odyssee Database

Figure A 2. Labour intensity in the Swedish manufacturing sector, 1993-2012



Source: Author's calculations based on the Odyssee Database.

Industry classification

Table A 2. Classification of industrial sectors and corresponding ISIC codes (Revision 3)

Odyssee name	**ISIC Revision 3 code**	**Description**
Manufacturing	15-37	The physical or chemical transformation of materials or components into new products, performed either by power-driven machines or by hand, in a factory or in the worker's home. Products can be sold at wholesale or retail.
Food industry	15	Manufacture of food products and beverages
	16	Manufacture of tobacco products
Textile and leather industry	17	Manufacture of textiles
	18	Manufacture of wearing apparel; dressing and dyeing of fur
Wood industry	20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Paper, pulp and printing industry	21	Manufacture of paper and paper products
	22	Publishing, printing and reproduction of recorded media
Chemical industry	24	Manufacture of chemicals and chemical products
Non-metallic minerals	26	Manufacture of other non-metallic mineral products
Primary metals	27	Manufacture of basic metals
Machinery and fabricated metal products	28	Manufacture of fabricated metal products, except machinery and equipment
	29	Manufacture of machinery and equipment n.e.c.
	30	Manufacture of office, accounting and computing machinery
	31	Manufacture of electrical machinery and apparatus n.e.c.
	32	Manufacture of radio, television and communication equipment and apparatus

Transport equipment	34	Manufacture of motor vehicles, trailers and semi-trailers
	35	Manufacture of other transport equipment
Others	25	Manufacture of rubber and plastics products
	33	Manufacture of medical, precision and optical instruments, watches and clocks
	36	Manufacture of furniture; manufacturing n.e.c.

Note: n.e.c. = not elsewhere classified.

Source: United Nations Statistical Division

APPENDIX B

Choice of decomposition method

There are two main approaches to energy decomposition analysis: Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA). IDA builds on index number theory, whereas SDA is based on energy Input-Output Analysis (IOA). Studies in the field of energy overwhelmingly employ IDA, which provides a number of advantages over SDA. These include allowing for both multiplicative and additive decomposition, as well as decomposition of different kinds of aggregates, such as values, ratios and elasticities. From a practical perspective, IDA is the preferred method mainly because of its lower data requirements (Hoekstra & van der Bergh, 2003). Also in this paper, IDA is considered the most appropriate approach.

There is a range of different indexing methods that are used in IDA, and these are primarily linked to the Laspeyres index (weights based on values in a base year) or the Divisia index (weights allowed to change over time) (Ang B. W., 2004). These methods may also be categorised according to whether they are multiplicative or additive. An additive method decomposes absolute changes, whereas a multiplicative method decomposes relative changes, that is, a change in an aggregate expressed as a ratio. Since the aggregate indicator used in this paper is given as a ratio (energy consumption/GDP), a multiplicative decomposition is suitable.

Another consideration is whether to decompose changes using a rolling or fixed base year. The advantage of using a fixed base year approach is that it is computationally simple in the sense that it only compares data from two points in time. However, results become sensitive to the choice of base year. This problem can be overcome, and more information can be extracted from the data, by using a rolling or chained base year, where comparisons are made on a year-by-year basis. For the purpose of this paper, the latter approach is more useful since decomposition results are in the form of a time-series, showing the emergence of long-term trends over time.

Studies that compare different index decomposition methods use a number of criteria, the most common being: (a) theoretical foundation (b) adaptability (c) ease of use and (d) ease of result interpretation. The theoretical foundation can be evaluated by testing for factor reversal, time reversal, proportionality and consistency in aggregation. A desirable property is for example perfect decomposition in the sense that the decomposition results do not contain a residual term. Neither the conventional Laspeyres approach, nor the Divisia method has this property, and leave a sometimes large portion of aggregate change unexplained. A range of decomposition approaches has been developed to improve these methods.

In the literature on energy intensity decomposition, the Log Mean Divisia Index (LMDI) has been identified as a favourable approach (Ang, 2004; Liu and Ang, 2007). The LMDI achieves perfect decomposition and has a number of other desirable properties, including an ability to handle zero and negative values, ease of calculation and consistency in aggregation. Proportionality and invariance under time and factor reversal are other properties of LMDI. The method was introduced by Ang and Liu (2001) and is a weighted sum of relative changes expressed as logarithmic growth rates. LMDI has been identified as a preferred approach in energy use studies (Ang B. W., 2004), and is employed in this paper.

APPENDIX C

Table C 1. Results of electricity intensity two-factor decomposition, 1993-2012 (annual changes, chained)

Year	Structure effect (D_{str})	Technology effect (D_{tech})	Electricity intensity (D_{tot})
1993	1.00	1.00	1.00
1994	0.98	0.95	0.94
1995	0.95	1.06	1.00
1996	0.98	1.01	0.99
1997	1.02	0.94	0.96
1998	0.97	1.02	0.98
1999	1.00	0.99	0.99
2000	1.01	1.03	1.04
2001	0.97	0.99	0.97
2002	1.00	0.92	0.92
2003	1.03	0.96	0.99
2004	1.02	0.98	1.00
2005	0.96	1.03	0.99
2006	1.00	0.96	0.95
2007	0.99	1.03	1.02
2008	1.02	1.00	1.03
2009	0.89	1.14	1.01
2010	1.09	0.84	0.92
2011	0.97	0.99	0.97
2012	1.03	1.00	1.03

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the result yielded for each year represents the given effect's impact from the previous year.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

Table C 2. Summary statistics: two-factor decomposition

	Mean	Standard deviation	Min	Max
Structure effect	0.99	0.04	0.89	1.09
Technology effect	0.99	0.06	0.84	1.14
Energy intensity	0.98	0.03	0.92	1.04

Note: Data are from 1993-2012.
Source: Author's calculations based on the Odyssee Database.

Table C 3. Results of electricity intensity three-factor decomposition, 1993-2012 (annual changes, chained)

Year	Structure effect (D_{str})	Adjusted technology effect ($D_{\widehat{tech}}$)	Factor mix effect (D_{mix})	Electricity intensity (D_{tot})
1993	1.00	1.00	1.00	1.00
1994	0.98	0.97	0.99	0.94
1995	0.95	1.03	1.02	1.00
1996	0.98	1.00	1.01	0.99
1997	1.02	0.89	1.05	0.96
1998	0.97	1.01	1.00	0.98
1999	1.00	0.93	1.06	0.99
2000	1.01	0.96	1.07	1.04
2001	0.97	1.00	0.99	0.97
2002	1.00	0.93	1.00	0.92
2003	1.03	0.92	1.04	0.99
2004	1.02	0.96	1.02	1.00
2005	0.96	1.01	1.02	0.99
2006	1.00	0.93	1.03	0.95
2007	0.99	1.00	1.02	1.02
2008	1.02	1.04	0.97	1.03
2009	0.89	1.15	0.99	1.01
2010	1.09	0.80	1.05	0.92
2011	0.97	0.97	1.02	0.97
2012	1.03	0.96	1.04	1.03

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method and the result yielded for each year represents the given effect's impact in relation to the previous year.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

Table C 4. Summary statistics: three-factor decomposition

	Mean	Standard deviation	Min	Max
Structure effect	0.99	0.04	0.89	1.09
Technology effect	0.97	0.07	0.80	1.15
Factor mix effect	1.02	0.03	0.97	1.07
Electricity intensity	0.98	0.03	0.92	1.04

Note: Data are from 1993-2013.
Source: Author's calculations based on the Odyssee Database.

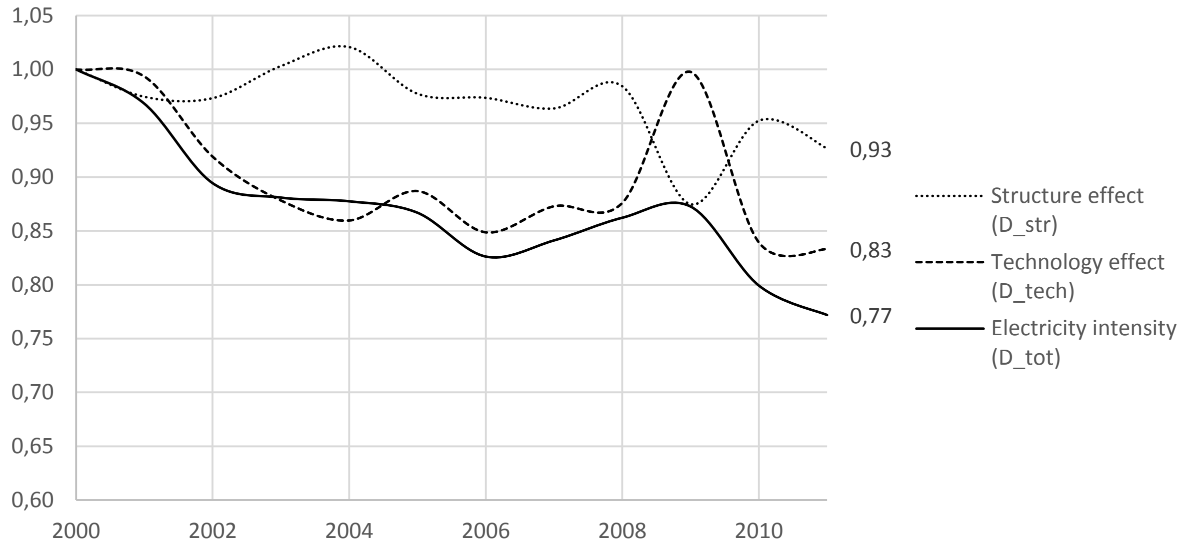
Table C 5. Results of electricity intensity decomposition for the Swedish manufacturing sector, 2000-2011

Structure effect (D_{str})	Technology effect (D_{tech})	Electricity intensity(D_{tot})
0.92	0.84	0.77

$$D_{tot} = 0.77 = D_{mix} D_{\widehat{tech}} D_{str}$$

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that the given factor has no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method over the time-period 2000-2011.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index design.

Figure C 1. Results of electricity intensity three-factor decomposition, 2000-2011 (annual changes, chained)



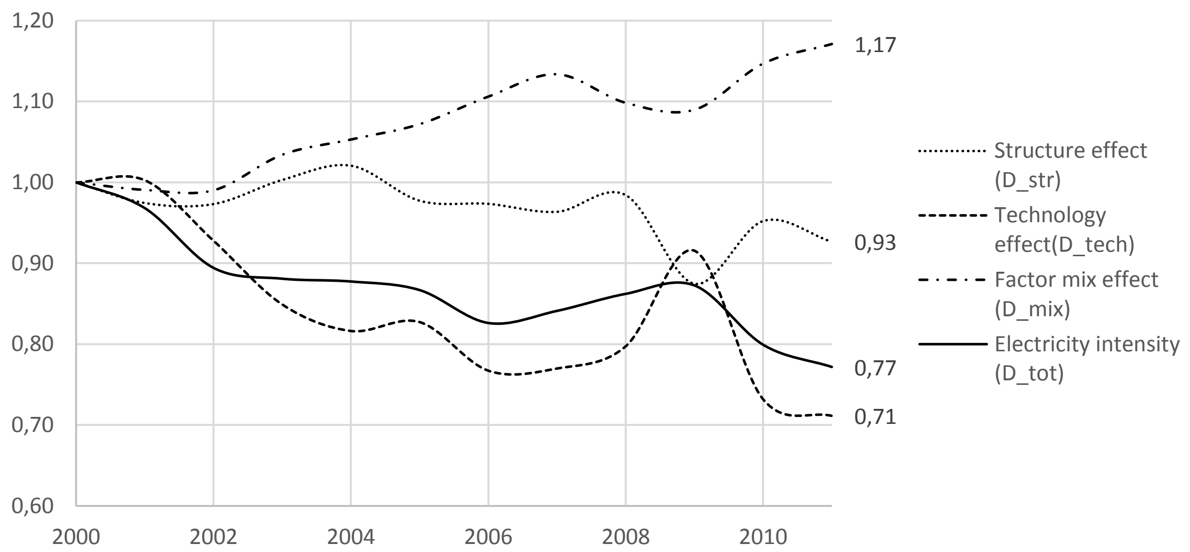
Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 2000 to that year. Note that the vertical axis have been shortened to make annual variations more salient.
Source: Author's calculations based on the Odyssee Database. See section 4 for details on index construction

Table C 6. Results of electricity intensity decomposition for the Swedish manufacturing sector, 2000-2011

Structure effect (D_{str})	**Adjusted technology effect ($D_{\widehat{tech}}$)**	**Factor mix effect (D_{mix})**	**Electricity intensity(D_{tot})**
0.92	0.72	1.17	0.77
$D_{tot} = 0.77 = D_{mix} D_{\widehat{tech}} D_{str}$			

Note: An index value of 1.1 means a 10 per cent increase in aggregate electricity intensity, a value of 0.9 means a 10 per cent reduction in aggregate electricity intensity, and a value of 1 means that the given factor has no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method over the time-period 2000-2011.
Source: Author's own calculations based on the Odyssee Database. See section 4 for details on index construction.

Figure C 2. Results of electricity intensity three-factor decomposition, 2000-2011 (annual changes, chained)



Note: An index value of 1.1 means a 10 % increase in aggregate electricity intensity, a value of 0.9 means a 10 % reduction in aggregate electricity intensity, and a value of 1 means that there is no effect on aggregate electricity intensity. The decomposition has been performed using the multiplicative version of the LMDI method, and the results have been chained. The result yielded for each year thus represents the given effect's impact from 2000 to that year. Note that the vertical axis have been shortened to make annual variations more salient.
Source: Author's calculations based on the Odyssee Database. See section 4 for details on index construction