JOURNAL OF NORTHERN STUDIES **2 • 2010**, PP. 55–78

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Household Firewood Consumption in Sweden during the Nineteenth Century

ABSTRACT Household firewood consumption underwent significant changes during the industrial breakthrough. Recent literature on Sweden makes the case that greater energy efficiency drastically reduced rural household fuel consumption, while coal substituted for firewood in cities. This article shows that although coal substituted for wood in some urban areas, rural firewood consumption was not reduced. Higher standards of living indicate contrary to previous results that fuel consumption increased during the industrialisation process. The study shows that households with higher standard of living consumed more fuel and that rural households, due to lower fuel prices, consumed relatively more fuel than urban households. The result shows contrary to previous research that the total energy intensity decreased more rapidly after and not before the industrial breakthrough.

KEYWORDS energy, firewood, economic history, Sweden, biofuels, household consumption, energy intensity

Introduction[1]

In this study we use hitherto unexplored household budget data to estimate the determinants of household firewood demand in the early twentieth century and, in a second step, estimate the development of firewood during the nineteenth century. Firewood was a key energy carrier in Sweden and most other European countries during the pre-industrial era. The pre-industrial energy system was dependent on photosynthesis for its fuel supply, and it has been recognised that the introduction of coal into this energy system was a key component, or at least a necessary precondition for the emergence of high and sustained economic growth. Already in the 1960s Tony Wrigley (1962; 1988; 2006) stressed that the industrial revolution itself was fundamentally related to a transformation of the energy system, since an energy system based on photosynthesis imposes limits to growth. This limit depends on fundamental scarcity related to the area of land, because solar radiation is appropriated and processed into a useable form by plants, which implies that the supply of energy is restricted to the available fertile land area. Since energy in the form of heat is complementary to machinery and buildings, in the economist terminology known as real capital, and energy in the form of foodstuff is complementary to human and animal labour, this means that the energy supply limits the growth of the factors of production, which puts limits on economic growth. Only with fossil fuels did it become possible to substantially increase the energy supply and accordingly overcome the limits to growth. This idea was later further explored by scholars such as Wilkinson (1973), Pomeranz (2000) and Sieferle (2001).

Estimates of energy supply, including traditional energy carriers during the pre-industrial era, are therefore essential for understanding the broad patterns of economic development and industrialisation (Kander & Lindmark 2004). Lately, a number of articles have been published aiming to assess long term energy consumption for a number of countries (Gales *et al.* 2007). International research has pointed at a steady decline in the long-term development of the Energy-to-Gross Domestic Product (GDP)-ratio, or energy intensity, as a common feature in several countries. It is, however, more or less pronounced and Sweden stands out as the country with the largest reduction in energy intensity and also as the most energy intensive economy in the early nineteenth century. A common problem is, however, that the historical source material is often weak regarding traditional energy carriers such as firewood. This setback is even more pronounced when household consumption is concerned. This is certainly challenging due to the sheer size of household energy consumption in relation to other sectors.

In this paper we will argue that new and fully plausible approaches to estimating Swedish firewood consumption will lower the early nineteenth century consumption levels as compared to what has been previously suggested. As a consequence of this, the reduction of the energy intensity is also reduced.

Theoretical Framework

A crucial factor for estimating household firewood consumption is how demand is affected by technical change. At first glance, the effects may appear straightforward. An improved technology, resulting in less firewood being required for a certain space heating service, may be expected to result in a decreased demand for firewood. Critique of this simplified analysis was first proposed by the British economist Stanley Jevons in the 1860s (Jevons 1865). Jevons discussed why coal consumption had increased in Britain while steam engines had undergone significant technological improvement efficiency. He explained the paradox as an effect of efficiency and prices. Improved efficiency would in effect lower the price for the heating service. In our case this is so, since the efficiency improvement implies that less firewood is required for producing one unit of heating energy. The price for heat falls. The lower price, following Jevons's reasoning, would in turn lead to an increased demand for firewood, which could fully or partly offset the technical improvement. Thus, the economy may experience increased consumption of fuels as a direct consequence of technical improvement, not despite technical change.

Jevons's paradox has been further developed by contemporary economists and is today known as the rebound effect or the Khazzoom-Brookes postulate (Saunders 1992). For readers in economics a more elaborated presentation of the rebound effect is found in Appendix 1. The rebound effect is an important point of departure for the present investigation. This is because previous estimates of Swedish firewood consumption have overlooked the role of prices. Shortly, they have either relied on obviously crude estimates or on methods that are biased towards large effects of technical improvement, such as tiled stoves. By incorporating prices into the analysis this issue is addressed in the following analysis.

The following section provides an overview of previous estimates in order to show that nineteenth century sources are scattered, based on crude estimates and drawing on a few common sources. Secondly, the overview describes in more detail the household firewood survey of 1924, which remains an important benchmark. Thirdly, the section presents an overview of the techniques used in the latest estimates of the historical development of household firewood consumption in Sweden. This serves the purpose of providing the reader with a fair opportunity to evaluate our approach. Our new estimates are elaborated in the following sections, while the last section concludes.

Previous Research

A relevant starting point for any historical estimate is certainly records and assessments from the historical period in question. As this survey will show, the nineteenth century reports are for various reasons inappropriate as benchmarks (see also Egelrud 2005). One of the earliest attempts to estimate the Swedish household firewood consumption was made by Carl af Forsell in his Swedish statistics from 1833 (Forsell 1833). The figures were, however, rough guesswork originating from Israel af Ström's (1837) free-hand adjustment of consumption figures for Copenhagen. The next record was published by Carl Ludwig Obbarius in 1851 and implies a doubling of Forsell's estimate. Obbarius argued that this figure was more representative of an ordinary Swedish rural household as compared to Forsell's estimate. In contrast to Forsell it is evident that Obbarius had based his estimate on proper investigations of household consumption at iron works (Obbarius 1851: 5).

Victor Magnus Thelaus (1865) did, however, criticise Obbarius' estimates, which he considered only applicable to certain forest rich areas. In 1865 Thelaus therefore presented an alternative estimate based on firewood consumption data for Germany and Denmark. On the basis of the lower average temperatures in central Sweden as compared to Saxony, Berlin and Copenhagen, Thelaus proposed an annual Swedish consumption of 150 cubic feet per person corresponding to four cubic metres of loose measure or three cubic metres of solid measure.[2]

Yet another estimate appeared in 1882, as Forest officer Johan Olof af Zellén (1882) argued that the national consumption amounted to roughly 6.75 million fathoms of firewood. It is very likely that Zellén simply used Thealus's estimate of 150 cubic feet per capita and adjusted the figure with the population growth.

This shows that the nineteenth century figures of firewood consumption were merely educated guesswork based on empirical material from other countries and generalisations of very limited studies.

The first comprehensive wood consumption survey was undertaken in 1884 at the *AB Finspongs styckebruk* iron works (Ekman 1906). According to the survey, each farm consumed on average 50 m^3 of wood per year, of which 79 per cent was firewood, roughly corresponding to 4.7 m^3 of firewood per person. It is not stated whether this figure relates to solid or loose measure. A loose measure is, however, likely since the solid measure to our knowledge was only introduced in twentieth century consumption surveys as a means to assure compliance with the national forest survey practice to report standing timber volumes in solid measure. For the nineteenth century investigations, we use the conversion factor 0.65 for transformation from loose to solid measure (sm^3) giving 1.9 sm^3 per capita according to Forsell, 2.56 sm^3 according to Thelaus, 3.56 sm^3 according to Obbarius and 3 sm^3 at the *AB Finspongs styckebruk.*

These figures may be compared with the twentieth century surveys. The first one was undertaken at the Västernorrland countryside located in Northern Sweden during the season 1913–1914 (Ödman 1920). The sample was, however, not representative. The average household size was between 6 and 7 individuals, making the investigated farms twice as large as the average countryside household.

It is also worth noticing the Västernorrland survey reports that highly ineffective open stoves were still common and that fodder for the cattle was boiled during the winter (in so-called *murpannor*) (Ödman 1920: 12–13, 17–19). The report also states that rotten fuel was often used for this purpose. Since the energy content of such wood is low, the amount of wood consumed also increases. At richer farms most of the rooms were heated, while poorer farms only heated the kitchen and sometimes one additional room. In all 364 farms were investigated. It is worth noticing that the farmers were sceptical to the survey, since they suspected new taxes. The report also tried to compensate for this suspected underreporting. Thus, we cannot be sure whether the compensation led to exaggerations or not. On the basis of the investigation the project leader, Per Ödman, later estimated the average firewood consumption per farm to 52 sm^3 in Northern Sweden, 35 sm^3 in Central Sweden and 26 sm^3 in Southern Sweden.

The most comprehensive investigation was undertaken in 1924, surveying firewood consumption in the County of Värmland located in the central part of Sweden (SOU 1924:42). This study covered 613 farms, comprising 716 households and 3,422 individuals. Table 1 summarizes the main results.

Table 1.
Annual firewood consumption in solid cubic metres (sm^3), Värmland countryside 1920–1921.

Area in Värmland	Firewood per farm	Firewood per household	Firewood per capita
North	22.30 sm^3	21.30 sm^3	3.65 sm^3
Central	15.97 sm^3	15.00 sm^3	3.19 sm^3
South	17.96 sm^3	13.11 sm^3	2.83 sm^3

Source: SOU 1924:42: 37.

A few years later, Professor Tor Jonson (1923), one of the experts in the Värmland survey, was appointed to estimate the national firewood consumption on the basis of the Värmland survey. Table 2 summarizes Jonson's estimates for the countryside:

Table 2.
Jonson's estimates of rural firewood per capita consumption and total firewood consumption 1923.

Region	sm^3 per capita	Million sm^3
1. Northern Sweden to northern Värmland	5	1.23
2. The Norrland coast and Jämtland	4	2.59
3. Bergslagen	2.5	2.17
4. Southern Sweden	1.7	4.07
5. Sweden	2.4	10.06

As seen from table 2, the countryside average amounted to 2.4 sm^3 per capita, a reduction by approximately 0.6 m^3 compared to the mid-nineteenth century countryside figures. If this is a factual reduction or just an improvement of the educated guesses is an open question.

A simplification of Jonson's estimates was used in the National Income project, a pioneering and very ambitious effort to estimate the development of incomes since the 1860s (Lindahl *et al.* 1937). The National Income project stated a per capita consumption of 2 sm^3 per person in southern Sweden and 3 sm^3 in northern Sweden around 1915. For estimating the nineteenth century consumption, the project stressed several changes that may have affected the firewood consumption. These included improved stoves and the increased use of coal. The overall standpoint was that technical changes and substitution had induced a substantial decrease in the firewood consumption per capita during the period 1860 to 1930. Accordingly, the scholars behind the National Income project did not believe in the rebound effect. For a nineteenth century benchmark, references were made to Zellén and Thelaus and an estimate between 3.90 sm^3 and 4.00 sm^3 was stated for the nineteenth century. However, one should bear in mind that Zellén had based his estimate on Thelaus's educated guess, for which reason the nineteenth century firewood consumption assessments made in the National Income project rely entirely on one person's extrapolation of German and Danish figures. This is the state of art when we look at the contemporary historical estimates.

The figures used today for analyses of long-term energy use and growth were pioneered by Astrid Kander (2002). The approach used in her thesis may be characterised as a back-casting approach based on Jonson's countrywide estimates as a benchmark. Back-casting is a reverse-forecasting technique that starts with a specific outcome, here the 1924 benchmark, and then works backwards to model the historical development leading to this outcome.

In Kander's work the reverse-forecasting is underpinned by an educated reasoning about five semi-quantifiable factors. The first one is increased firewood consumption due to more heated rooms and higher requirements of indoor temperature (Kander 2002: 28). Kander notices that it was common practice during the early nineteenth century to only heat the kitchen during the winter, a claim that is verified by various sources (Socialstyrelsen 1938). Furthermore, Kander argues that it gradually became more common to heat additional rooms as the household economy improved (Kander 2002: 26–28).[3] This is indeed a reasonable assumption, while it is difficult to assess with any precision the exact income effect on the firewood consumption without appropriate data. It is for instance reported that children, when they grew older, often slept in unheated rooms (*Bygd och vildmark* 1944). Furthermore, the number of stoves did not necessarily correspond to more heated rooms. In an eighteenth century report, Magnus Nordenström ([1894] 1990) points out that even though a farm may have had several rooms equipped with stoves, most of the indoor work was done either in the morning or in the evening by "one and the same fireplace." Accordingly, it seems that most additional stoves were not fired on a regular basis.

Kander's second factor is reduced firewood consumption due to improved insulation. Nordberg reports that it was common practice in Norrland to insulate house ceilings with earth and material from ant heaps during the 1850s. Accordingly, these measures tend to lower the firewood consumption, given a constant indoor temperature. For the back-cast, Kander assumes that insulation precisely balanced increased indoor temperature. Thus, the net increase of firewood consumption in Kander's estimates originates from more rooms being heated. It is therefore essential to assess the number of heated rooms and how they increased in number. This is again an income issue. Kander assumes an average of 2.5 heated rooms per household, including the kitchen, in 1920. Furthermore, she assumes that 30 per cent of the households had two heated rooms in 1800. The number of households with two heated rooms is furthermore assumed to have increased by 50 per cent between 1800 and 1850. For 1800 it is assumed that most of the population inhabited comparatively well-built houses, with glass windows and dampers and so forth, with an exception of approximately 20 per cent of the Norrland population, who were assumed to have lived in simple cottages. This assumption, boldly, we dare to say, draws on assessments of living conditions in western Finland (Kander 2002: 27).[4] It is worth noticing that the characterisation of the poor conditions in Norrland is apparently contradicted by Jon Engström's (1834) report, in which he remarks that the Norrland farmhouses often resembled manor houses, "with two floors and high windows."

In all cases this translates to an increase of heated rooms by 15 per cent between 1800 and 1850, and an increase by 67 per cent between 1850 and 1920. Since these rooms assumingly were only heated half the year, the effect from additional heated rooms is a 7.5 and a 33.5 per cent increase during each period.

Kander's third factor is a reduction of firewood consumption due to more efficient stoves and the increased use of dampers. Dampers were foremost used for conserving heat during the night, when the stoves were not fired. Kander reports that open stoves had a heat efficiency of 10 per cent while the most important space heating innovation of the period, the Cronstedt tiled stove, had reached 50 per cent efficiency by 1800 (Larsson 1979). Furthermore, Kander assumes that 20 per cent of the stoves in the year 1800 were of the effective Cronstedt type. By 1850 she assumes that the efficiency had reached 60 per cent and that the efficient stoves were found in 60 per cent of the households. For the 1920s, the efficiency is assumed to have reached 70 per cent, while at the same time 80 per cent of the household stoves were of the efficient Cronstedt type (Kander 2002: 28–29).[5] Kander states that the combined effect of diffusion and efficiency corresponds to decreased firewood consumption by 41 per cent between 1800 and 1850 and a further decrease by 51 per cent between 1850 and 1920 (Kander 2002: 32). In order to arrive at the combined effect of more rooms and improved efficiency, Kander adds the percentage effects from the two factors. Thus, for the period 1800 to 1850 the reduction is 33 per cent, calculated as the sum of 8 and –41 per cent. For 1850 to 1920 the net effect is calculated as the sum of more additional rooms (+34 per cent), improved efficiency (–51 per cent), increased use of coal (–20 per cent) and effects from a higher population growth in northern Sweden (4 per cent), thus a 33 per cent increase of household firewood consumption.[6]

Certainly, any estimate of nineteenth century household firewood consumption is necessarily approximate due to a lack of solid historical data. Kander's estimate is one attempt. It does, however, suffer from not considering actual observations of household behaviour. The floor should therefore be open for alternative interpretations.

New Estimates of Household Fuel Consumption

To overcome the problems associated with scattered nineteenth century data, we will instead estimate the determinants of household energy demand in the early twentieth century. Applying the parameters with corresponding time-series variables provides a historical projection and estimate of household fuel consumption. In short, we are building the historical interpretation upon the earliest recorded data of consumer behaviour.

In both Kander's and in the National Income estimates it is implicitly assumed that consumer behaviour is known, for which reason estimating energy demand is foremost a question of assessing technical change. Our approach, on the contrary, assumes that consumer behaviour is not known, for which reason it is only the first observations of consumer behaviour that may form the basis for educated guesses of nineteenth century demand for fuels. In short: our estimate depends on the assumption that nineteenth century households behaved as households did in early twentieth century.

Information of consumer behaviour is found in the early twentieth century household budget surveys. These data are, as previously stated, used for analysing the determinants for household fuel demand. This is done through an ordinary regression model. The second step is to use time series data corresponding to the variables (a) foodstuff share (b) persons in household (c) coal port (d) fuel price in order to estimate the nineteenth century fuel consumption by applying the estimated parameters and corresponding time series variables. Thirdly, the household coal consumption is estimated directly *on the basis of* the Household Budget Survey (HBS) data. Historical household coal consumption is estimates *on the basis of* this benchmark and projected backwards by the coal imports. When the coal consumption is deducted from the fuel consumption we arrive at a residual estimate of the household firewood consumption. The household budget surveys provide information on the households' expenditures distributed on services and goods. The latter include fuel consumption.

Table 3 presents the fuel consumption per household. According to the Stockholm survey 1907–1908 and the surveys for a number of other towns 1913–1914 (merged in table 3), the fuel consumption was on average 6.6 sm^3 of firewood (all fuels have been converted to birchwood equivalents) per household. The surveys focused on working-class and lower middle-class households in urban centres (Stockholm, Eskilstuna, Uppsala, Hälsingborg, Jönköping, Gävle, Malmö and Göteborg) located in southern and central Sweden. In 1920 the cities covered in the surveys held close to one million inhabitants of totally six million people.

It is important to recognise that the household budget surveys did not provide a representative picture of the Swedish population. When attempt-

Table 3. Descriptive statistics of household budget surveys. Calculations based on Socialstyrelsen (1922); Socialstyrelsen (1938); SOS (1967); SOS:S (1933).

Variable		Mean	Std. Dev.	Min	Max
Coal port	1 if coal port, 0 otherwise	0.46	0.50	0.00	1.00
Days with frost	number	114.52	32.35	76.00	173.00
Individuals per household	number	4.51	0.96	3.00	8.50
Food expenditure share	per cent	47.35	4.22	38.13	55.84
Consumption of fuel	Cubic metre birch wood	6.56	2.22	3.07	11.28
Relative fuel price	Fuel price / food price	10.96	1.39	7.80	14.09
Observations	number	54.00			

Note: All fuels (wood, coal, coke and gas) are converted to birchwood equivalents. The fuel price and food prices respectively are weighted by consumption baskets for each observation to avoid bias due to differences in consumption baskets among different households. The measure of birchwood is based on stacked cubic metre wood (CMSW). This measure may be converted to a solid cubic metre (SCM) [1 CMSW=0.65 sm^3]. See SOU 1923:57. The summarized values are unweighted.

ing to use the surveys as a benchmark for a national estimate, it is necessary to address the sample bias, in other words the focus on working-class households. The national energy consumption would for instance be incorrectly estimated, if the demand for household energy turns out to be sensitive to income changes and income distribution among households. In order to avoid this potential sample bias it is necessary to control for effects on demand from various factors. As previously suggested it is also these variables that are later used for the back-cast. We therefore use a regression model for estimating how income, prices and spatial factors have affected the consumption behaviour. The income effect is obvious and is here measured as the expenditure share of foodstuffs (food expenses/total expenditure).[7] Using the expenditure share of foodstuffs offers some advantages as compared to direct measurement of incomes. Simply put, regional variations in money wages and consumer prices cause the purchasing power to vary among towns. We notice research that shows that income elasticity of foodstuffs is particularly stable over time, and hence the consumption share of foodstuffs is a reliable indicator of real incomes (Costa 2001; Hamilton 2001). But there are also other factors apart from incomes that must be considered. Spatial differences in relative prices are certainly expected to affect household fuel consumption. These differences could be considerable by the early twentieth century too. Prices are measured as the fuel price in a specific town in relation to the price of foodstuffs.

Furthermore, it is likely that household size is positively correlated with fuel demand. A larger household is, *ceteris paribus*, expected to require more energy both for the preparation of food and for space heating. Another common sense factor is differences in outdoor temperature, which are expected to be correlated with fuel consumption, that is lower temperature implies higher fuel consumption. Outdoor temperature is measured as the number of days with frost. A less obvious factor drawn from observation of the surveys is that the consumption of fossil fuels such as coal, coke and gas seems to have been limited to towns with seaports. In the model we will test for a specific seaport factor that is not captured by any of the other variables.

Table 4 shows how household fuel consumption is affected by household size, standard of living, temperature and proximity to coal ports respectively. Household size has, as expected, a positive effect on fuel consumption, that is large households consume more fuel than small ones. The standard of living, measured by the food expenditure share, also has a significant and negative effect on fuel consumption. Households with a higher standard of living consume more fuel than households that are less well off. Concerning prices, the relationship is also the expected one; as fuels become relatively more expensive the consumption of fuels decreases. However, it is worth noticing that the model does not lend support to the notion that a longer winter causes higher fuel consumption. Several explanations may however be considered. For instance, both temperature and firewood prices could be correlated. If so, the effect may already have been captured by the price variable. Another possibility is that people living in colder climate might have mitigated low temperatures with warmer clothes rather than consuming more fuel. Due to the lack of significance, days with frost along with the time dummies were excluded in the second model. All variables are significant at the one per cent level and because the adjusted R-squared (explanatory power) is 0.76 in model 2.

Table 4. Factors explaining the fuel consumption per household in Sweden 1907–1913.

Variable	Model 1	Model 2
1913=1 (year dummy)	1.75*	(dropped)
1907=1 (year dummy)	(dropped)	(dropped)
Coal port	2.60**	1.54***
Days with frost	.007	(dropped)
Persons in household	1.47***	1.48***
Food expenditure share	–0.47***	0.47***
Relative fuel price	–0.83***	–1.01***
Constant	31.36***	36.04***
Adj R-squared	0.76	0.76
Observations	54	54

Note: * denotes significant at the 10 per cent level, ** denotes significant at the 5 per cent level, *** denotes significant at the 1 per cent level.

Back-Casting Fuel Consumption 1800–1920

For the back-cast we first estimated time series for the food expenditure share, fuel prices and household sizes. Before proceeding it is important to consider that the rural firewood consumption was higher than in the cities. A drawback is therefore that the model draws entirely on urban data. Given that the model is valid also for rural areas, that there is no unknown rural factor, it is reasonable to assume that the higher rural consumption is primarily explained by lower fuel prices. While the food expenditure share is assumed to have been equal across the country, we have estimated separate fuel price and household size series for urban centres and rural districts (see also Lindmark & Andersson 2010).

Concerning the food expenditure share, consumption of food stuffs with domestic origin was obtained from the Swedish Historical National Accounts (SHNA) as the sum of direct domestic consumption with origin in agriculture, horticulture and food stuffs industries (Krantz & Schön 2007). Use of imports for final consumption is missing in SHNA, which unfortunately is necessary for estimating the foodstuff consumption share. The problem was addressed by using unpublished foreign trade series (Schön 1984), which cover imports with both agriculture and food stuff industries as foreign sectors of origin during the period 1830 to 1871. Schön's series are directly followed by corresponding series according to Johansson's (1967) Historical National Accounts.

For estimating the shares of imports for final consumption we used the 1920 foreign trade statistics and divided imported agricultural goods and foodstuffs on final and intermediate consumption. Using import statistics from 1924, we divided the agriculture goods and foodstuffs among investments, intermediate consumption and final consumption. The share of final consumption is 24 per cent for agricultural goods and the share of final consumption is 54 per cent for foodstuffs. We assume that the share of final consumption is constant during the period 1830–1950. The estimated food expenditure share is very similar to the weight of foodstuffs in Myrdal's consumer price index (CPI). For instance, in 1830 the weight of foodstuffs is 0.65 in Myrdal's CPI while it is 59 per cent in our estimate.

Prices for fuels were obtained from SOS's *Detaljpriser och indexberäkningar åren 1913–1930* ['Consumer prices and index calculations, 1913–1930'] from the year 1830. Prior to 1830 prices from Jörberg (1972) were used. While it is difficult to obtain rural firewood prices, the previously quoted Västernorrland study does, however, provide a price for 1913–1914. Generalising from this observation we assumed that rural prices were approximately 60 per cent of urban prices. It is worth noticing that even though firewood could be obtained for free, especially in the Norrland countryside, it still meant an opportunity cost in terms of labour. For the back-cast we calculated the fuel relative prices as fuel prices in relation to CPI and weighted with the actual fuel price in 1913 to ensure compatibility with the model (2). For estimating rural firewood consumption, the price series was divided by 2.

The urban and rural populations were obtained from SOS: *Historisk Statistik för Sverige. Del 1 Befolkning* ['Historic statistics of Sweden. Part 1 Population']. The size of the population is readily available for the full period, while household size is only accessible from 1860 and onwards. For the period 1800 to 1860 estimates of the rural household sizes were obtained from Lundh (1995), while we assumed that urban household sizes developed in proportion to this. Table 5 summarises our assumptions of average household sizes along with Lundh's estimates.

Table 5. Household size in Sweden 1800, 1850, 1900 and 1920.

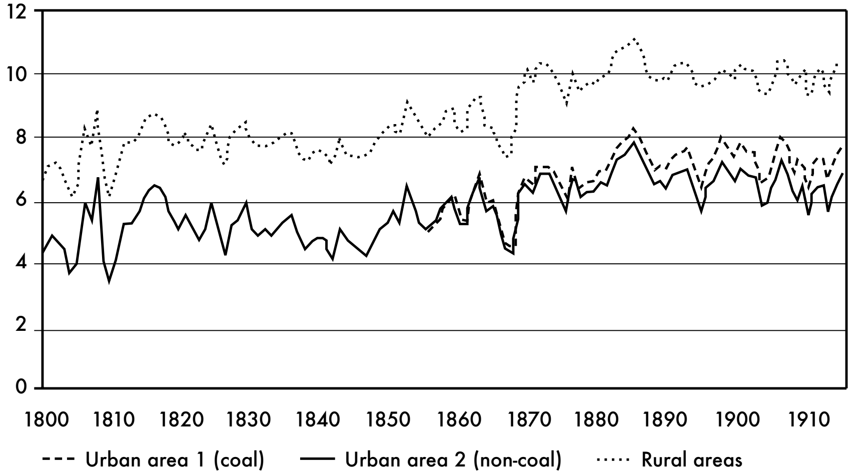
	Rural	Urban	National	Lundh
1800	5.8	4.6	5.7	5.8
1850	4.9	3.9	4.8	4.9
1900	4.0	3.2	3.8	3.8
1920	4.0	3.1	3.7	3.7

Source: Lundh 1995; SOS 1967.

According to the HBS coal, coke (and gas made of coke) replaced 5 per cent of the firewood consumed in the household sector around 1913. In the southern port cities the substitution rate was, however, close to 75 per cent of the total fuel consumption. Firewood was the totally dominating energy carrier in rural areas. Thus, for 1910 we estimate that 218,000 tons of coal were consumed by households. We use coal imports as a variation index for estimating the historical coal consumption, which is assumed to have been zero in 1850.

Fig. 1 outlines the long-term development of fuel consumption per household using the back-casting procedure. The consumption in a rural household was estimated at approximately 8 sm^3 in the early nineteenth century. A pronounced increase is also revealed from approximately 1850 to

Fig. 1. Estimated household fuel consumption (sm^3 per household) in urban and rural areas in Sweden 1800–1920. Source: See table 1.



1890, during which period the fuel consumption per household increased by roughly 15 to 20 per cent.

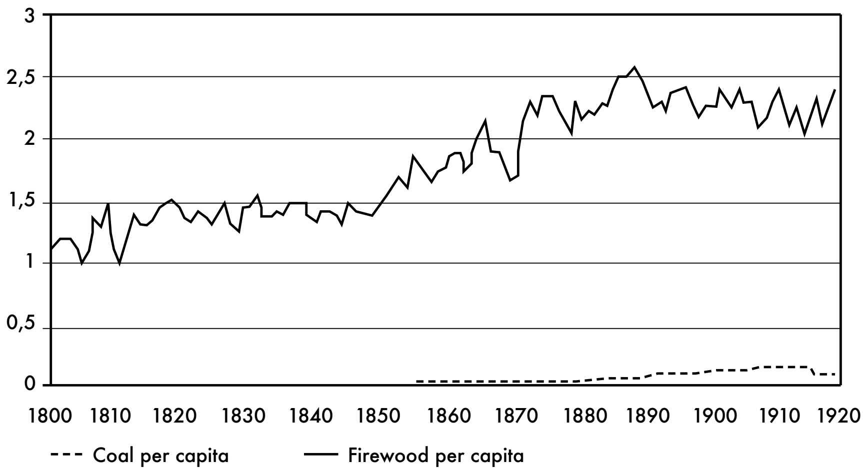
In the back-cast this increase is mainly driven by an improved standard of living, although higher fuel prices somewhat keep down the growth in fuel consumption after the 1890s.

Expressed in per capita terms, the back-cast suggests an even stronger increase due to the declining household size (see Fig. 2). The reason is that each extra household adds more to the aggregated fuel consumption than an additional member to an existing household. It is important to recognise that it is the household, not the individual, that is the relevant unit for accounting for fuel consumption. When the household size decreases, this will, according to the model, lead to larger per capita consumption.

As the household size dropped by one third during the nineteenth century, the per capita growth in fuel consumption also became much stronger than the growth in per household consumption.

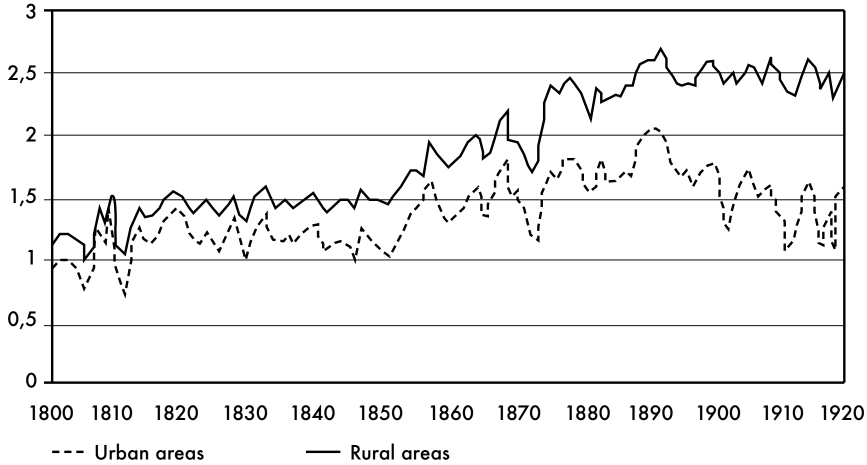
In the twentieth century, the per capita and per household developments are fairly similar.

Fig. 2. Estimated household fuel consumption (sm^3 per capita) 1800–1920. Source: See table 1.



The back-cast shows differences between urban and rural areas (see Fig. 3). Due to lower fuel prices, the consumption of firewood was higher in rural areas. When coal imports started to increase in the second half of the nineteenth century, firewood consumption developed even more slowly in urban areas. Especially in the late nineteenth century and early twentieth century firewood was replaced with coal in urban areas.

Fig. 3. Estimated per capita firewood consumption (sm³ per capita) 1800–1920.
Source: See table 1.



In 1920 the per capita firewood consumption was 2.6 sm^3 in rural areas and 1.9 in cities. These figures are close to Jonson's rural estimate presented in table 2. Jonson estimates the rural consumption to 2.4 sm^3 in 1923. For urban areas Jonson assumes a consumption of 1.25 sm^3 per capita. Taken together, our estimate of firewood consumption in 1920 is somewhat higher than that suggested by Jonson. However, the main differences from the previous estimates are not the 1920 level, but the development in the pre-1920 period.

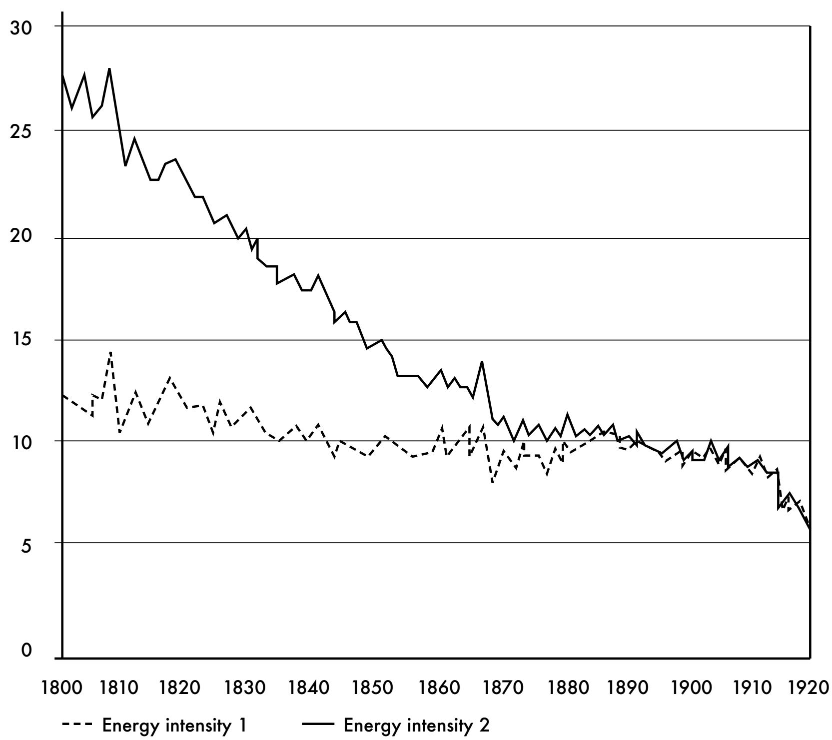
The previous back-cast technique applied (Kander 2002) indicates that household fuel consumption has decreased over time. The reduction of fuel is believed to have been driven by technological effects (improved heating efficiency and insulation), assuming that the efficiency gains were exclusively used to reduce fuel. One obvious shortcoming of the latter assumption is that the efficiency gains were attributed to the improvement and diffusion of Cronstedt tiled stoves, but these were mainly used for heating *additional* rooms. Cronstedt stoves are rarely, if ever, found it the kitchen, which was the original heated room in a typical homestead. This means that even though an efficient Cronstedt tiled stove implies an improvement of the average household heat efficiency, it happens at the same time as the total household energy increases. This is exactly what we would find if we compared a modern household with an early twentieth century household.

The second major technological improvement during the period of study was insulation. When sawn battens became cheaper from the 1840s, it also became more common to equip the timber-log house with a weatherboarding. Due to the reduced airflow through the walls and the floor, the weatherboarding helped to improve the insulation. Without weatherboarding it would have been difficult to increase the indoor temperature given the airflow through the walls and the floor. Unless insulation had improved during the nineteenth century, higher fuel consumption would have given a poor, if any, pay-off in terms of indoor temperature.

Given the reasoning of the rebound effect and the result from the regression estimate in table 4, the increasing technical energy efficiency would yield an increase in fuel consumption rather than a decrease. As improved energy efficiency results in a lower fuel per indoor temperature ratio, it will have a similar effect as a lower relative price on fuel. Unless the improved energy efficiency is counteracted by an equal increase in fuel price, the household utility function would imply an increase in the physical fuel consumption, as shown in Fig. 1.

The increase in household fuel consumption gives a rather different picture than the previous estimate of the nineteenth century development. As households tend to increase fuel consumption along with improving living standard, the new estimate gives a significant effect on the total energy

Fig. 4. Energy intensity (energy use /GDP) in Sweden 1800–1920. Both energy series excludes human energy.
Source: Kander 2002, table 1 (Energy intensity 1) and this study (Energy intensity 2).



use. By adding the household fuel consumption to that for other institutional sectors, we can arrive at a new estimate for the total energy consumption (excluding human energy).

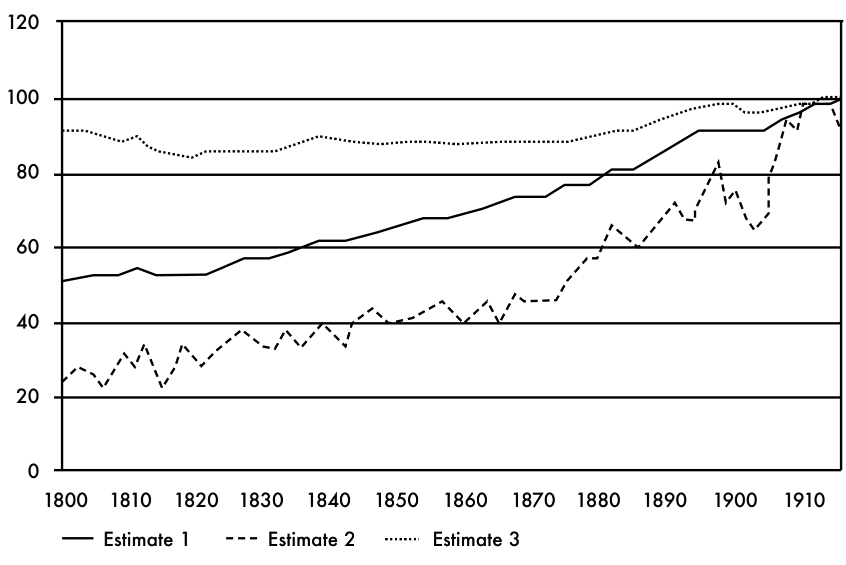
Fig. 4 shows the development of the Swedish energy intensity according to the old estimate (energy intensity 1) and the new estimate (energy intensity 2). Please notice that Kander's energy series is only adjusted with the household firewood consumption. This means that the manufacturing industry fire wood consumption is left unaffected.

The two estimates give a rather similar picture of the early twentieth century development, but a rather different view of the nineteenth century. The old estimate shows that the energy intensity decreased by more than one per cent annually during the pre-industrial period 1800 to 1870. During the early stage of the industrial breakthrough in the late nineteenth century, the energy intensity remained fairly unchanged, while a slow decrease is seen to be evident after 1890.

The new estimate does not lend support for a rapid decoupling process between energy and income during the pre-industrial phase. The energy intensity does not seem to be decreasing more rapidly before the industrial breakthrough than after.

The estimates of household firewood consumption also have implications for the historical estimates of GDP. This is because the logging

Fig. 5. Estimated household firewood consumption and household wood consumption in Sweden 1800–1870. Indices (1880=100).
Source: Schön 1995: 121–123 (Estimate 1), this study (Estimate 2), Kander 2002: 219–221 (Estimate 3).



and transportation of wood for household purposes, of which firewood is a part, are economic activities that are recorded under agriculture and forestry (Schön 1995). Firewood estimates that differ substantially from the SHNA figures therefore call for revision of either SHNA or the firewood estimate. Fig. 5 shows the estimated household consumption of firewood in Sweden between 1800 and 1870 along with the SHNA estimates of household wood consumption.

The first estimate is the SHNR household wood consumption (Schön 1995). This estimate includes final consumption of wood in household and input in services (private services, public services, transport, and building).[8] The consumption figure does not distinguish among different purposes such as firewood, building materials or other purposes. The second estimate is the household firewood consumption according to this study, while the third is the estimate according to Kander.

The first and second estimates show that the consumption of firewood (and wood for other purposes) increased substantially during the nineteenth century. Despite the larger scope of the SHNR figures it shows roughly the same development as the new estimate. The differences that exist could be attributed to other uses (input in services) or other purposes (building materials) in the SHNR figures. The new estimates of firewood do not suggest a major revision of the SHNR figures. However, the figures on firewood consumption according to estimate 3 would provide reason to revisit SHNR. This further means that Kander's figures should not be used for calculating nineteenth century energy intensity without appropriate adjustment of forestry output and GDP.

Conclusion

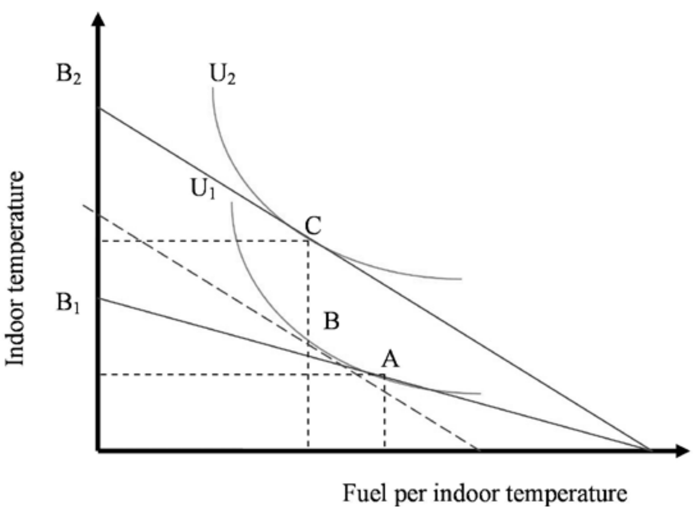
This study shows that Swedish household fuel consumption increased over time due to higher standard of living, although rising fuel prices kept down the growth rate. Given the high price elasticity of demand and the efficiency improvements, a rebound effect is likely to have been at hand. On a national scale, the study shows that higher standards of living indicate that per capita fuel consumption increased during the industrialisation process. It is therefore likely that the per capita firewood consumption was considerably lower in the early nineteenth century in comparison with previously reported estimates. This implies that the role of technical progress inducing a lower demand for household firewood during the nineteenth century may be mistaken. The new estimate shows that the energy intensity decreased more slowly before the industrial breakthrough than after.

APPENDIX 1

The dynamics of the rebound effect are basically the following (the outline is based on Vikström 2008). An initial increase in energy efficiency leads first to an increased marginal productivity of energy. This is to say that the energy service flow from each physical unit of energy increases. If the price per physical unit of energy remains constant, this implies falling energy service unit prices. The falling energy service price makes it profitable to buy more energy services until the marginal productivity corresponds to the new lower price per energy service unit. Besides the size of the efficiency increase, this process is affected by how easy it is to integrate additional energy in the production process or by the elasticity of substitution. From a macro economic perspective, the process of adding energy services to the production process will in turn increase the marginal productivity of the other factors, capital and labour. This is because each unit of capital and labour is now working with more energy service units than before. The process will continue until marginal productivities again correspond to factor prices. This is because the relative price of energy in terms of energy services has decreased.

In this case, when space heating is concerned, it is reasonable to assume that increasing energy efficiency was caused by technical changes such as improved stoves and housing insulation. For the household, increasing energy efficiency (given an unchanged energy unit price) will have a similar effect as a lower relative price on fuel. Depending on the price elasticity, the household may decide to leave the physical fuel consumption unchanged

Fig. A1. Demand schedule for indoor temperature (energy) and fuel efficiency (fuel per indoor temperature) showing income and substitution effects.



or increase the physical fuel consumption. The two different options will ultimately depend on how space heating is valued relative to the cost saving through fuel efficiency. The rebound effect may therefore be seen as a combination of substitution and income effects. Fig. A1 shows a demand schedule with fuel efficiency and indoor temperature.

B1 represents the original budget line and U1 is the corresponding indifference curve. Maximum utility is found in point A. If a technical shift is assumed, implying that a higher indoor temperature is available at a given fuel consumption, the budget line shifts to B2. This is effectively the same as an exogenous price fall in indoor temperature. Maximum utility is now found at the point C where U2 has the same curvature as U1. The substitution effect is the leftward move from A to B, which is a tangency between U1 and the dashed hypothetical budget line, which only takes into account the technical change. The upward shift from B to C is the income effect, which is caused by the technical change implying falling prices for indoor temperature. A falling price for indoor temperature can be attributed to both higher energy efficiency and/or an exogenous fall in fuel price (which also implies a falling price for indoor temperature). A key issue is therefore to examine the price elasticity of demand. An equally important issue is how an exogenous increase in income affects fuel consumption.

APPENDIX 2

Total household firewood consumption (CONS) in Peta Joule (PJ)

Year	CONS_PJ	Year	CONS_PJ	Year	CONS_PJ
1800	18	1840	29	1880	72
1801	19	1841	31	1881	68
1802	19	1842	32	1882	71
1803	18	1843	32	1883	70
1804	16	1844	30	1884	73
1805	17	1845	34	1885	73
1806	22	1846	33	1886	80
1807	21	1847	33	1887	82
1808	24	1848	33	1888	83
1809	18	1849	33	1889	86
1810	16	1850	36	1890	83
1811	20	1851	38	1891	79
1812	23	1852	40	1892	75
1813	22	1853	42	1893	78
1814	22	1854	41	1894	77
1815	23	1855	47	1895	82
1816	25	1856	46	1896	83
1817	26	1857	44	1897	84
1818	26	1858	43	1898	80
1819	25	1859	46	1899	76
1820	24	1860	48	1900	80
1821	24	1861	51	1901	81
1822	26	1862	52	1902	85
1823	25	1863	48	1903	84
1824	24	1864	49	1904	82
1825	25	1865	56	1905	87
1826	28	1866	59	1906	85
1827	25	1867	52	1907	85
1828	24	1868	53	1908	78
1829	28	1869	49	1909	79
1830	29	1870	47	1910	85
1831	31	1871	49	1911	91
1832	28	1872	62	1912	89
1833	28	1873	67	1913	82
1834	30	1874	65	1914	88
1835	29	1875	70	1915	79
1836	30	1876	71	1916	87
1837	31	1877	70	1917	93
1838	32	1878	67	1918	85
1839	30	1879	64	1919	94
				1920	98
				1921	85

NOTES

[1] Financial support from the Swedish Energy Authority (STEM) and The Swedish Research Council (Vetenskapsrådet) is gratefully acknowledged.

[2] Thelaus estimated a population of 4 million people.

[3] No specific sources are mentioned here, apart from the general income growth.

[4] Probably the information on the Finnish houses refers to fishermen's cottages. Such cottages were used for temporary housing also by loggers, but seldom for entire households.

[5] Kander does not exactly show how she does this.

[6] This is unfortunately erroneous algebra, which causes an overestimate of early nineteenth century firewood consumption. Let us consider the operation with a simple numerical example. Assume that a car drives 100 km the first year and 150 km the next year. Thus, the mileage increases by 50 per cent. Also assume that the fuel consumption is 1 litre per km the first year but only 0.5 litres per km the next year. This is an improvement. or efficiency gain by 50 per cent, or minus 50 per cent. If we were allowed to add the per cent changes this would leave us with a zero per cent change in total fuel consumption. However, the correct total effect is calculated as 100 km times 1 litre per km for the first year, leading to 100 litres of consumed fuel, and then 150 km times 0.5 litres per km for the second year, leaving us with 75 litres of consumed fuel. This means that the total effect is a reduction by 25 per cent.

[7] This method finds support in the research showing that income elasticity and foodstuff are stable over time; the expenditure share of food.

[8] This is because total output is divided into consumption, exports and intermediate consumption in the manufacturing industry (mainly iron works and sawmills).

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