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North versus South: Energy transition and energy intensity in Europe over 200 years

BEN GALES†, ASTRID KANDER‡,
PAOLO MALANIMA* AND MAR RUBIO¶
†*Faculty of Economics, Economic History, University of Groningen, The Netherlands*
‡*Department of Economic History, Box 7083, 220 07 Lund, Sweden*
**Institute of Studies on Mediterranean Societies (Italian National Council of Research) Italy*
¶*Department of Economics and Business, University Pompeu Fabra, Barcelona, Spain*

This article examines energy consumption in Sweden, Holland, Italy and Spain over 200 years, including both traditional and modern energy carriers. The analysis is based on totally new series of energy consumption including traditional carriers along with modern sources. Our main purposes are a closer examination of the process of the energy transition in Europe and a revision of the prevailing idea of there being, over the long run, an inverted U-curve in energy intensity. Changes in energy consumption are decomposed into effects from population growth, economic growth and energy intensity. The results on energy intensity challenge the previous suggestions of most scholars. An inverted U-curve does not exist whenever we include traditional sources of energy in our analysis.

1. Introduction

There is no consensus on precisely how important energy is for economic growth and human welfare. If energy is a crucial resource for the economy, inasmuch as economic growth cannot take place without more or less proportionate increases of energy, its availability could endanger economic behaviour in the near future. If, on the other hand, energy consumption shows high variability in relation to the economy, and especially if it tends to decline in relative terms, the prospects are more optimistic.

The proposition that energy consumption does not grow proportionately to GDP, but that the ratio between energy and GDP (energy intensity)[1]

[1] Energy measured by its heat content divided by GDP in constant prices.

shows a pattern that resembles an inverted U-curve, a curve with a relative increase in the early phases of industrialisation and subsequently a decline in the post-industrial phase, was widely accepted among energy scholars following an influential article in *Scientific American*, 1990.[2] Nevertheless, this proposition does not take into account traditional forms of energy exploited prior to the introduction of fossil fuels. It is reasonable to believe that the long-term pattern will look profoundly different from an inverted U-curve when traditional energy carriers, such as firewood, food intake by men and working animals, water and wind, are included in the calculation. In this case, the initial level of energy use would be higher and part of the increase of energy consumption would, as a consequence, appear only as a substitution of modern energy carriers for traditional ones.[3] Unfortunately, few long-term series of energy consumption have been elaborated including traditional sources. The use of historical series that only account for modern energy sources hinders the discussion of the dynamics of energy intensity in a long-term perspective. For two large economies, the US and Japan from 1900, the inclusion of one traditional energy source (firewood) made a difference for the long term energy intensity, but it is not clear how these series regarding firewood were compiled.[4] The four series presented in the Appendix for Sweden, the Netherlands, Spain and Italy, are, in fact, the first national series to include the full set of traditional energy carriers (manpower, firewood, wind and water) with the sources and methods well accounted for and thus setting the problem of energy consumption and energy intensity in a historical perspective of two centuries.[5]

The lack of long-term series is the reason why the ever-increasing literature on the environmental effects of growth typically deals with cross-section data referring to sets of countries with different levels of *per capita* GDP and energy consumption for the period after 1960. There is a vast literature relating environmental consequences and economic growth and referring to the so-called 'Environmental Kuznet's Curve' (EKC).[6] Although related

[2] Goldenberg and Reddy (1990). Smil (2003) discussed the trend in energy-intensity from a historical perspective. He concluded that 'a deeper understanding of underlying realities' and efforts to overcome 'serious data limitations' were needed (p. 71).

[3] For instance Schurr and Netschert (1978) and Humphrey and Stanislav (1979), who did not include any traditional energy carriers, obtain the result that energy intensity increases substantially with modernisation and industrialisation both in the US and the UK.

[4] Grübler (2004). Similarly an article by Martin (1988) lacks sources for firewood estimates; thus the quality of the graphs is hard to assess.

[5] Kander (2002), Malanima (2006), Rubio (2005, and forthcoming), Gales (2007).

[6] Stern (2004) gives an effective and well-structured overview of the encompassing EKC debate. More specifically related to the energy emission issues there are a couple of recent papers expressing doubts about the existence of an EKC for CO_2 emissions: Wagner-Fürstenberger (2004), Mazzanti *et al.* (2006). Holtz-Eakin and Selden (1995) found that it is only at extremely high income levels that a falling trend in CO_2 to GDP could be discovered.

to the topic of this article it is far beyond our intention to account here for the EKC literature and debate. Particularly since energy consumption does not translate straightforwardly into environmental consequences, we have chosen simply to discuss the inverted U-curve hypothesis for energy intensity.

The hypothesis about the lack of an inverted U-curve in the long-term ratio of energy to GDP was confirmed for Sweden, where, from the beginning of the nineteenth century, energy intensity declined, even though with some reversals in the trend.[7] Sweden, however, may present an unusual pattern because of the large nineteenth-century consumption of firewood for household heating. However, a similar trend was recently found for Italy, where energy intensity diminished as from the middle of the nineteenth century.[8] It seems reasonable to suppose that we could also discover a decreasing trend in the energy intensity for other European countries.

We have chosen two northern and two southern European regions to test our hypothesis because of the diversity of the pre-modern level and composition of energy consumption in the North and the South. The possibility of finding similar trends in different environments is much more rewarding than that of discovering similarities where homogeneous conditions already exist. These four countries represent regions of Europe with differences in climate, domestic sources of energy and economic development paths. The availability of new series of energy consumption data calculated according to the same criteria and including every primary energy source with an economic cost is the precondition for a comparative exercise like this.

In Section 2 we account for the different energy systems of our four countries.[9] In Section 3 we compare aggregate and *per capita* energy consumption. We find pair-wise similar results in *per capita* consumption for the northern and the southern countries. In Section 4 we analyse the changes in aggregate energy consumption. To this purpose we use a decomposition analysis, better suited in this case to our basic materials than other statistical procedures. On this basis we are able to distinguish the relative importance of population, *per capita* product and a residual representing the role of technology.[10] Section 5 contains a concluding discussion, which sums up the main results of the study and makes some overall comments on what has to be learnt from the previous analysis on the long term energy-economy relationship.

[7] Kander (2002), Kander and Lindmark (2004).

[8] Malanima (2006).

[9] Work on Germany, England and Wales, France, Portugal and Norway is ongoing by researchers in our EGP (Energy-Growth-Pollution) network.

[10] Commoner (1971a, b), Ehrlich *et al.* (1977), Ehrlich and Ehrlich (1990).

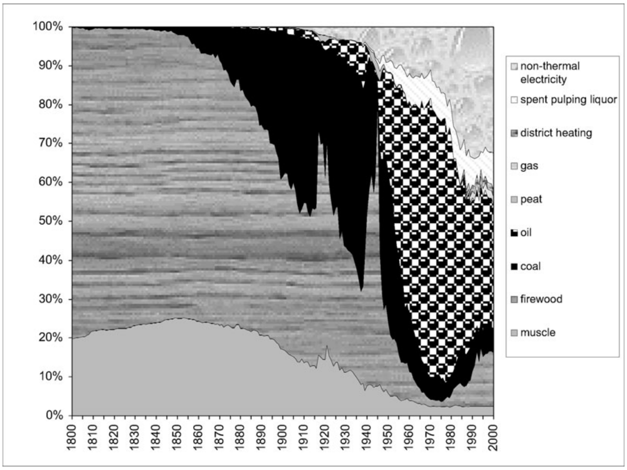

Figure 1. *The Swedish energy transition 1800–2000.*

Notes: District heating is hot wastewater from industrial processes used for heating houses. This is quite common in Sweden. *Spent pulping liquor* is an energy-rich waste product from the pulp manufacturing that is used as fuel in the pulp industry.

2. The energy transition: comparisons of the national energy systems

The common feature of all four countries is that traditional energy carriers made up a large part of energy consumption until rather late (Figures 1–4). If we classify food for men and working animals, firewood, wind and water and peat as traditional energy carriers, we find that their contribution to total energy input became less than 50 per cent only after 1864 in the Netherlands, from the late 1920s in Sweden, and immediately before World War II in Italy and Spain.

The relative importance of specific traditional energy carriers differed among our countries.[11] In Sweden the dominant energy source was firewood, with roughly 75 per cent of energy in 1850, whilst food and fodder made up the remaining part. Direct working water was less than 1 per cent. In 1850 the Spanish situation was almost the reverse: food and fodder made up 50 per cent, firewood 46, coal 1.7 and direct water 2. This means that Spain had relatively more motive power and less thermal energy at its disposal than

[11] The figures presented in these pages have been elaborated using the same methodology. These methods are fully explained in Kander (2002) and Malanima (1996 and 2006). Muscle energy corresponds to the input of food by men and working animals; firewood to the actual consumption; wind and water have been estimated from the power of water and wind engines – sailing ships included – and the time, per year, these engines were in use. On modern carriers we exploited the statistical national accounts, or OECD and IEA series (in The Netherlands from 1950 on).

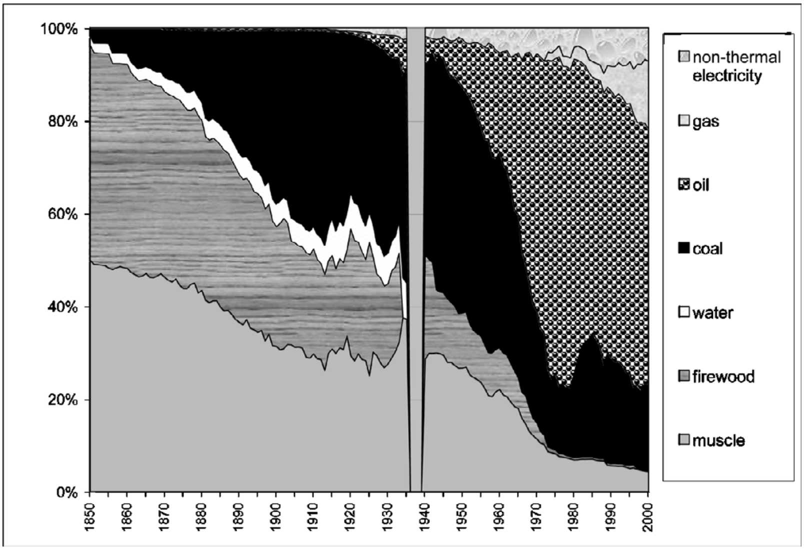

Figure 2. *The Spanish energy transition 1850–2000.*

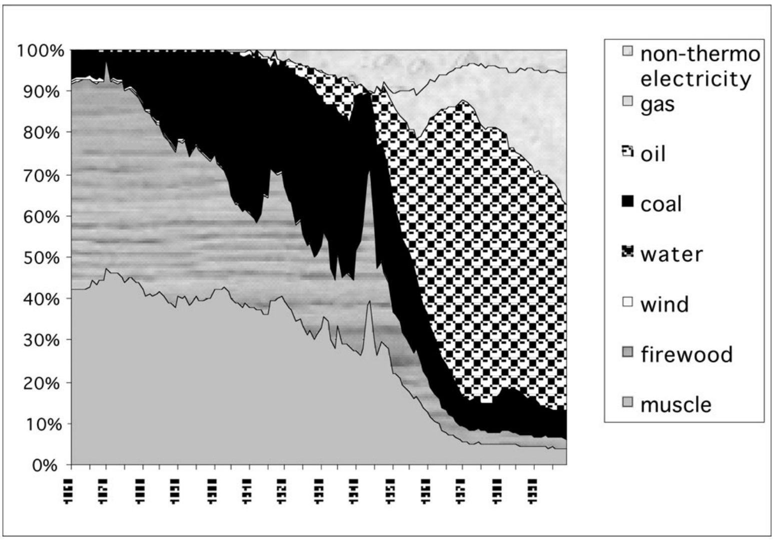

Figure 3. *The Italian energy transition 1861–2000.*

Sweden.[12] In Italy in 1861 the situation was similar to that of Spain, but food for men and fodder for draught animals played a minor role (about 20 per cent each), firewood made up 50 per cent and coal 7, while wind

[12] On Spain see Rubio (2005).

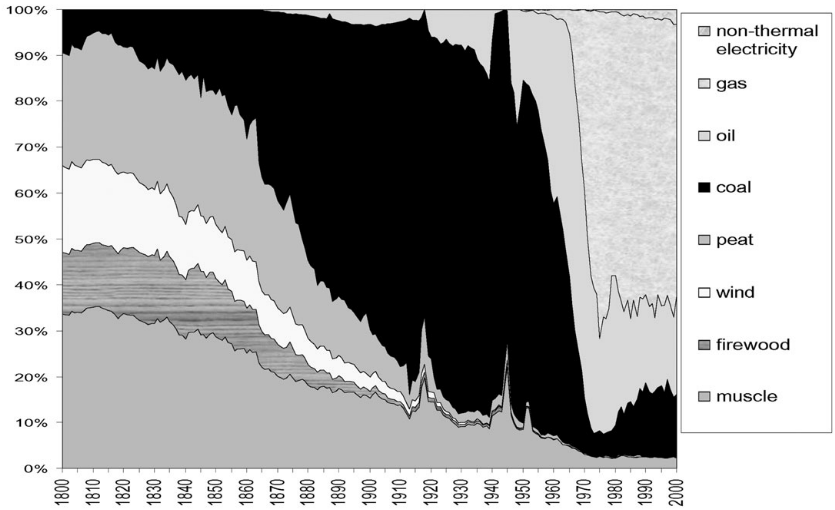

Figure 4. *The Dutch energy transition 1800–2000.*

Table 1. *Composition of energy consumption in 1850 Sweden, The Netherlands, Italy* and Spain (%).*

	Sweden	Netherlands	Italy	Spain
Food (men, animals)	25	28	41	50
Firewood	73	13	51	46
Wind, water	<1	12	1	2
Fossil fuels	2	47	7	2

*At 1861.

and water accounted for only 1 per cent.[13] In Holland the situation was remarkable in terms of the relative roles played by wind[14] and peat. Around 1850 peat represented 30 per cent and wind 10 per cent. The large pumping and drainage projects, needed in a country with half of its surface close to or below the sea level, were the main reason for the spectacularly high wind consumption. Firewood was, on the contrary, not very important, only accounting for 13 per cent, with coal 20 and food and fodder 28[15] per cent (Table 1).

The coal age arrived late in these countries, even though the age of fossil fuels was already in progress in Holland due to the widespread use of peat (Table 2). Coal was very much a phenomenon of the twentieth century.

[13] Malanima (2006), Bardini (1998), Bartoletto (2004).

[14] Albers (2002), pp. 103–14 and 200–02.

[15] Van Zanden (1997), p. 491. See also the remarks on firewood consumption in the Netherlands by Van der Woude (2003).

Table 2. *Composition of energy consumption in 1900 Sweden, The Netherlands, Spain and Italy (%).*

	Sweden	Netherlands	Italy	Spain
Food (men, animals)	17	15	39	31
Firewood	45	2	34	26
Wind, water	<1	3	1	5
Fossil fuels	38	80	26	38
Primary electricity	0.1	0	0.1	0

Note: Primary electricity is an abridged expression used for hydro- and nuclear electricity. Primary electricity does not actually exist, electricity being in any case a secondary form of energy. Electricity is here calculated by its heat content, and not by the energy content of the water or uranium used for its production.

Table 3. *Composition of energy consumption in 1950 Sweden, the Netherlands, Spain and Italy (%).*

	Sweden	Netherlands	Italy	Spain
Food (men, animals)	6	9	27	27
Firewood	21	0	17	12
Wind, water	<1	0	0	0
Fossil fuels	64	91	47	59
Primary electricity	9	0	9	2

The dominance of coal varied considerably. At its peak its share was 82 per cent in the Netherlands (1913),[16] but only 45 per cent in Sweden (1909). In Italy the maximum was around 40 per cent in 1935–40 and in Spain it peaked in the years 1927–30 with levels of 46–49 per cent (Table 3).

The fact that the Netherlands became more of a coal-based economy than the other countries is not due to its own stocks.[17] Domestic coal-mining did not take off until 1900, and essentially from World War I onwards.

All four countries showed greater similarity in the dependence upon oil. The major breakthrough for oil came after World War II in Italy, Spain and Sweden, but less so in the Netherlands, which remained coal-based for a longer period (Table 4).

Primary electricity is of different importance in our four countries. Negligible in the Netherlands for a long period, because of lack of waterfalls, nowadays it makes up 10 per cent of national energy consumption, where two-thirds comes from bio-fuels and one-third from nuclear power. In Spain its importance has increased steadily over time to its present 7 per cent.

[16] We consider here normal conditions. The dependence upon coal could be larger in times of war. The importance of coal, however, was not much bigger under abnormal conditions than in 1913. In 1941 the share of coal and lignite was 84 per cent.

[17] Gales (2000).

Table 4. *Composition of energy consumption in 2000 in Sweden, the Netherlands, Italy and Spain (%).*

	Sweden	Netherlands	Italy	Spain
Food (men, animals)	2	2	4	5
Firewood	23	0	2	0
Fossil fuels	40	88	88	88
Primary electricity	33	10	6	7

Note: In 2000 Sweden had 2 per cent of its energy supplied by district heating, therefore the figures for Sweden do not sum to 100 per cent! Primary electricity in the Netherlands is the sum of biomass electricity (7 per cent), international trade in electricity (more than 2 per cent) and nuclear electricity.

In Italy the relative share declined from its maximum in the 1950s (9–10 per cent) and is nowadays 6 per cent. Nearly all of this primary electricity is produced by hydropower. Nuclear energy has been negligible in Italy and nowadays no nuclear power plant exists.[18] Sweden has put most effort into the production of primary electricity. This presently constitutes around 30 per cent of the energy consumed in the country, half of which comes from nuclear energy and half from hydropower. Sweden today has ten active nuclear reactors, out of its original twelve.

Over 200 years, by the end of the twentieth century, a long energy transition had been accomplished with the almost total disappearance of traditional carriers such as wind, water and draft animals. Another traditional source, human muscle energy, was then relatively unimportant, whereas firewood remained of substantial importance in many countries until well into the twentieth century. The more recent decades, following the oil crises of the 1970s, show a proliferation of relevant energy carriers. The portfolio is less determined by one prime energy carrier than in the past. There is, however, some difference in the importance of the diverse carriers. The Netherlands became a gas-consuming country. In Italy gas consumption has increased rapidly since the oil crisis. Sweden opted for nuclear electricity and, again, wood. Spain in turn, reverted to coal-burning for electricity production. In the year 2000, about 90 per cent of the coal consumed in Spain was for thermal electricity production.

3. Aggregate energy consumption

While structures of the energy systems are different, there are clear similarities in the long-term patterns of total energy consumption in the four countries (Figure 5). There were modest rates of increase until the World War II, a period of faster growth rates in 1950–73 and declining

[18] Silvestri (1989), p. 175.

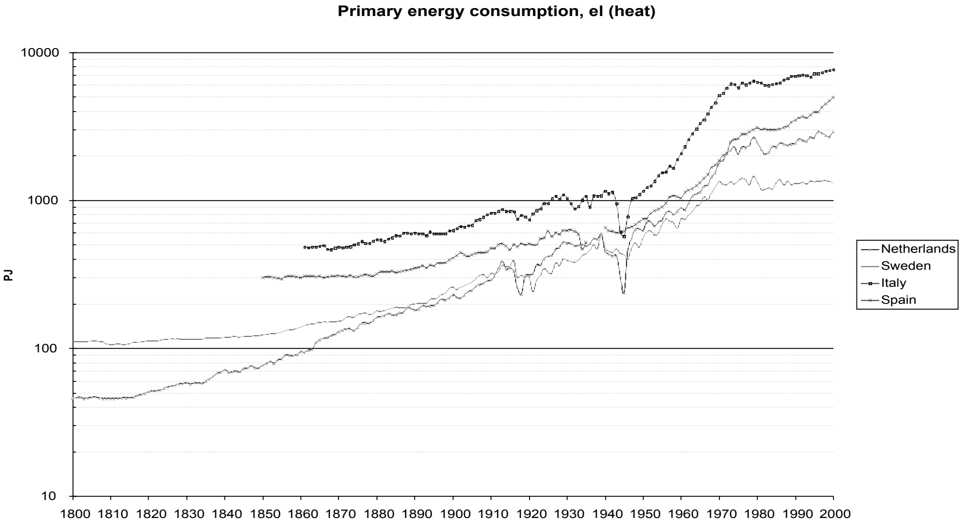

Figure 5. *Primary energy consumption in Italy, the Netherlands, Spain and Sweden (Petajoules, PJ).*

growth rates between 1973 and 2000. These facts integrate well the overall economic growth patterns and lend some credibility to the idea that more growth requires more energy and more energy allows for further growth. However some differences are obvious:

1. The response to crises such as the World Wars differed. The First World War produced similar effects in the Netherlands and Sweden, with a relatively large decrease in their energy consumption, while Spain and Italy witnessed more modest declines. Spain had its own civil war to cope with in the 1930s and for those years statistical data are lacking.
2. The interwar period was marked by strong growth in energy consumption in the Netherlands and Sweden, while energy requirements in Spain (which did not participate in World War II) and in Italy hardly increased at all.
3. Spain shows a stronger growth in energy consumption during the 1990s than the other countries, which continue to have modest growth rates.

To some degree the different levels of energy consumption are naturally connected to the size and population of the country. The levels of energy consumption, and the ordinal ranking of the countries in this respect, show that Italy is the clear leader. Spain is second, but challenged in that position by the Netherlands that catches up with Spain in the 1930s, after which the level of both countries stays very close. Sweden starts at a level higher than The Netherlands, but converges and reaches the same level in the 1880s, only to fall behind The Netherlands again from the 1920s onwards.

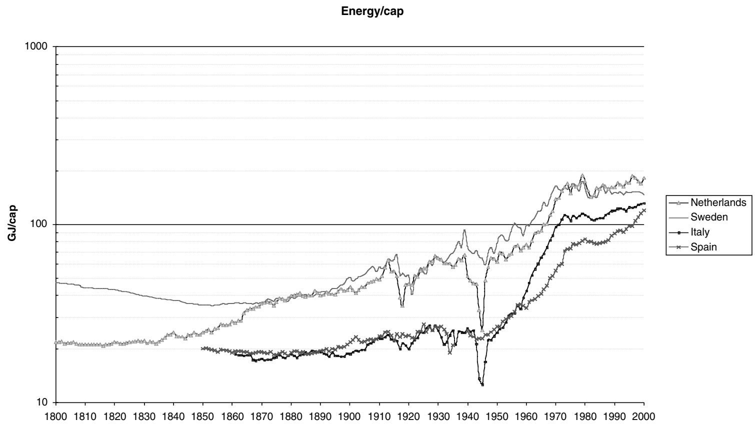

Figure 6. *Energy consumption* per capita *in Italy, the Netherlands, Spain and Sweden (Gigajoules, GJ).*

When examining the energy consumption *per capita* (Figure 6), we see more distinct developments in the northern and southern European countries, together with a completely different hierarchy: Sweden and Holland clearly overtake Italy and Spain. The Netherlands and Sweden also show remarkable resemblance in their long-term development, apart from the period before 1870, where Sweden actually reduces its *per capita* energy consumption thanks to impressive thermal efficiency developments, both in household heating and the iron industry, and in cultivation of new land, without proportionate increases in draught animals. Their development is thus one of convergence. Spain and Italy share almost the same level of energy *per capita* over the first 100 years (1860–1960), but then Italy witnesses a sharp increase and surpasses Spain. We see, however, that, while ever-important climatic conditions count relatively less in the long term, with the economic performance being more meaningful, a relative convergence takes place. The difference between Sweden-Holland on one hand and Italy-Spain on the other is much lower today than immediately after the Second World War and during the previous century.

4. Decomposing energy

A frequently used formula for decomposing the environmental impact into its main components is the Commoner-Ehrlich formula:[19]

$$I = P \cdot A \cdot T \tag{1}$$

[19] For an overview, see Ekins (2000), pp. 154–81. The formula has often been used in environmental research. Well known examples are Gowdy and Miller (1987) and Casler and Hannon (1989). On the decomposition analysis, see also Ang and Zhang (2000).

where:

I = environmental impact of a group or nation;

P = population size;

A = *per capita* affluence (measured by proxies such as income or product per capita);

T = a measure of the environmental impact from the technologies involved in supporting each unit of consumption.

A growth in P and A needs to be outbalanced by declines in T in order for I to stay constant. Technical change can imply shifts in production possibilities so that the environmental stress per produced unit is reduced. In other words, there is an ongoing race between productivity increases and growth and the winner determines the relationship between economy and environment.[20]

Translated into an energy context, the Commoner-Ehrlich formula becomes the following identity, where E stands for total energy consumption, Y for GDP (A in Equation (1), while the T-factor has been replaced by energy intensity (E/Y):

$$E = P \cdot \frac{Y}{P} \cdot \frac{E}{Y} \tag{2}$$

If we take the partial derivatives of the identity (2) with respect to time (represented by the dot in Equation (3), we get the following relationship for the relative current growth rates:

$$\frac{\dot{E}}{E} = \frac{\dot{P}}{P} + \frac{\left(\frac{\dot{Y}}{P}\right)}{\frac{Y}{P}} + \frac{\left(\frac{\dot{E}}{Y}\right)}{\frac{E}{Y}} \tag{3}$$

Then we compute annual continuous growth rate of any variable. The Equation (3) can be simplified in:

$$e = p + y + e_y \tag{4}$$

where e, p, y and e_y are the annual rates of increase of total energy consumption, population, *per capita* GDP and energy intensity (Table 5).

In our identity (4), whenever $p + y$ exceeds e_y, the consequence is an increase of total energy consumption e.

If we look at the overall trend from 1870 until 2000, we see that in any case the yearly rise in energy consumption increased until the end of the series, whilst a marked reduction in the rate of growth took place after 1973. During the period 1950–73, the fast rise in energy consumption was accompanied by an increase in energy intensity (with the exception of Spain).[21] The 1950s

[20] Grübler (1998).

[21] Because of the civil war, energy intensity did not diminish in Spain in 1920–40 as happened in the other three countries. Increases in efficiency took place (with some delay) only in 1950–73, especially in the agrarian sector which replaced much of the organic energy with fossil fuels in this late period. See Figure 11 below.

Table 5. *Yearly growth rates in Energy (total), Population, per capita GDP, Energy intensity in 4 periods (1870–2000) (%).*

		E	p	y	e_y
Sweden	*1870–1913*	2.00	0.70	1.90	−0.60
	1920–1938	2.30	0.37	3.00	−1.07
	1950–1973	4.01	0.63	3.03	0.35
	1973–2000	0.10	0.32	1.44	−1.66
Netherlands	*1870–1913*	2.56	1.26	0.89	0.41
	1920–1938	3.07	1.36	1.19	0.52
	1950–1973	5.41	1.24	3.40	0.77
	1973–2000	1.70	0.99	2.93	−2.22
Italy	*1870–1913*	1.39	0.65	1.24	−0.50
	1920–1938	2.09	0.84	1.44	−0.19
	1950–1973	7.16	0.61	4.85	1.70
	1973–2000	0.86	0.27	2.02	−1.43
Spain	*1870–1913*	1.60	0.56	1.21	−0.17
	1920–1940	1.49	0.96	−0.24	0.77
	1950–1973	5.13	0.96	5.43	−1.26
	1973–2000	2.61	0.59	2.47	−0.45

Note: Because of the lack of data on energy consumption in Spain during the civil war, we assume 1940 as the end of our second period instead of 1938.

and 1960s were a period of very low energy prices. In the decade 1962–72, the price of oil on the international markets was lower than ever before or since: less than 10 US dollars per barrel (in constant 1999 prices).[22] The forces of growth – population and GDP *per capita* – were stronger than the forces of the efficiency – energy intensity – in a period when industry and transport were rapidly increasing everywhere.

We see, however, that when we distinguish the period 1973–2000 within this half century, the forces of productivity and efficiency show their stronger impact on the overall trend of energy consumption. They have been able to reduce greatly the growth of energy consumption and finally, at the very end of the century, to neutralise it. In 1973–2000, the decline in energy intensity was faster than *per capita* GDP and population growth, seen separately, only in Sweden. In any case, taking into account the 27 years between 1973 and 2000, the combined effect of $p+y$ has been stronger than the decline in e_y. The whole result – the slower increase of e than before – has been more easily attained thanks to the slower growth rate of GDP and population. If we contrast the relative importance of any factor (p, y and e_y) in the determination of overall energy consumption in the whole period 1870–2000, with the average of our four countries in 1973–2000, we discover that

[22] The price refers to crude oil and the source is British Petroleum. The oil price on the international markets can be considered as a plausible proxy of the energy price as a whole.

Table 6. *The importance of any factor in determining the overall energy consumption in 1973–2000 in comparison with the average for the four countries in 1870–2000 (%).*

	P	y	e_y
4 countries 1870–2000	27.7	54.6	17.6
1973–2000			
Sweden	9.4	42.1	48.5
Netherlands	13.9	55.2	30.9
Italy	7.3	54.3	38.4
Spain	16.8	70.4	12.8

Note: The figures in the table represent the ratio between the absolute value of any factor (p, y and e_y) and the sum of p, y and e_y, multiplied by 100. The first line refers to the average values in 1870–2000.

Table 7. *Population in Sweden, the Netherlands, Italy and Spain 1800–2000 (thousands).*

	Sweden	Netherlands	Italy	Spain
1800	2,336	2,112	18,260	10,392*
1825	2,771	2,514	20,134	12,615
1850	3,482	3,098	24,603	14,894
1875	4,383	3,788	28,258	16,267
1900	5,136	5,133	33,343	18,594
1925	6,053	7,362	38,715	22,433
1950	7,041	10,113	46,768	27,976
1975	8,208	13,666	54,764	35,548
2000	8,882	15,925	57,844	40,933

**Note*: Year 1797.

the importance of energy intensity has been remarkable in our four countries and particularly strong in Sweden (Table 6).

A disaggregate analysis per country and per factor provides a clearer picture of the overall trend.

4.1. The P-factor

The P-factor (in Equation 3), or the population factor (Table 7), explains why the Netherlands overtook Sweden in energy consumption in the 1920s: after this point in time, the growth rate of the Dutch population was much higher than that of the Swedish. The Netherlands were a demographic outlier for a considerable time. The number of births remained high after the demographic transition, in combination with a very low rate of female participation in the labour force. In an already densely populated country such as Italy, the rate of population growth was lower than in the other three countries.

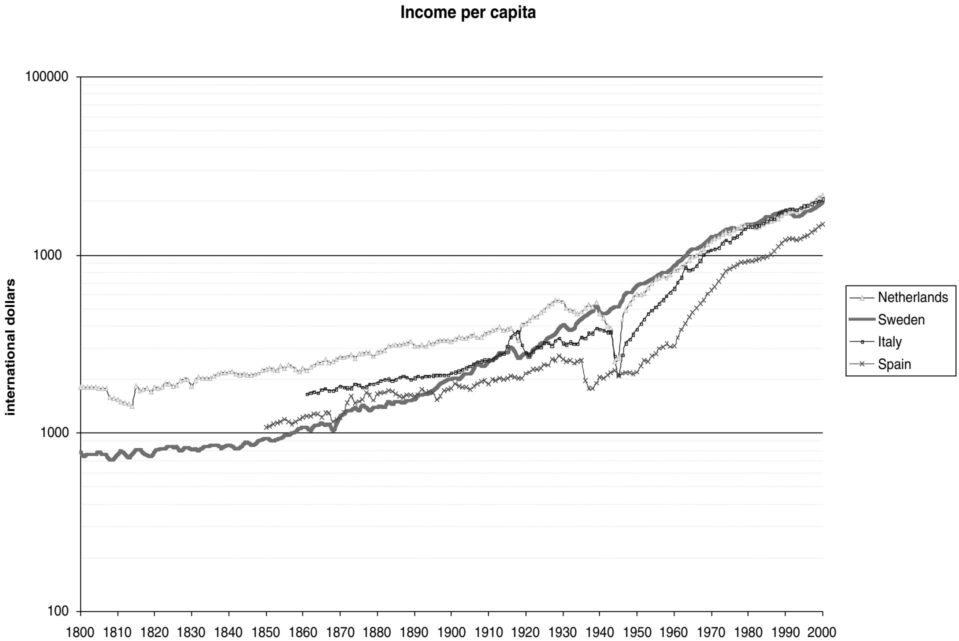

Figure 7. *Income per capita (constant international 1990 PPP dollars).*

On the whole, the P-factor shows small variations in growth rates over time (less than 1 per cent per year in 1950–2000),[23] and is thus incapable of explaining a factor that shows large fluctuations, such as energy. Globally, in our four countries, population grew 3.7 times, while energy consumption increased 30 times. We need then to look at the income *per capita* variable, the Y/P-factor.

4.2. The Y/P-factor

The Y/P-factor (in Equation 3) or the income *per capita* factor (Figure 7)[24] is a more volatile variable than the P-factor and as such is more able to 'explain' development of the E-factor over time. Energy consumption, however, is not merely a function of income, as the differences between countries show.

Naturally this is not the place to discuss the long-term economic development of these four countries, but the differences across them appear as much in levels as in trends. The start of 'modern growth' coincided in these four countries with the transition to the exploitation of modern energy

[23] With the exception of the Netherlands in 1950–73.

[24] Data on which Figure 7 is based are from: *Italy*: Malanima (2006); *Spain*: Prados de la Escosura (2003); *The Netherlands*: Smits *et al.* (2000); *Sweden*: Schön and Krantz (2007). Data in these series are expressed in 1990 international PPP dollars by means of Maddison (1995).

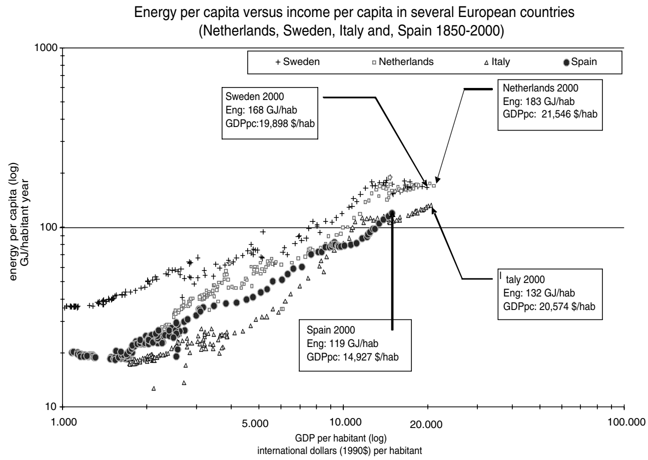

Figure 8. *Energy* per capita *versus income* per capita.

carriers and with the transition from an energy system based on vegetable carriers to a mineral one. For a long time the Netherlands enjoyed a leading position. When, after World War II, GDP growth accelerated, a trend toward convergence characterised the four economies. At the end of the century, the levels of *per capita* GDP are the same in Sweden, Holland and Italy, and Spain is rapidly converging.

The rise in *per capita* GDP was the strongest variable in determining an unprecedented growth in energy consumption (Figure 8), even though energy intensity decline contributed to neutralise partially this upward trend. In log figures a nearly linear relationship exists between GDP and energy consumption.

4.3. The E/Y-factor

E/Y (in Equation 3) is a factor, or a residual, that catches up everything that has not been taken in by the P-factor and Y/P-factor (Figure 9). Its growth corresponds to:

$$\frac{\left(\frac{\dot{E}}{Y}\right)}{\frac{E}{Y}} = \frac{\dot{E}}{E} - \left[\frac{\dot{P}}{P} + \frac{\left(\frac{\dot{Y}}{P}\right)}{\frac{Y}{P}}\right] \tag{5}$$

One main result is that Sweden is an outlier in its energy intensity. The long-term decline is impressive in this country. Some analogy exists with Italy, but in none of the other countries was it the same as in Sweden. A weak linear decline can be discerned for Spain, but the Netherlands show no time trend at all. The reason is that, as an early-comer, its energy system was already different and, in a sense, more modern than those of the three

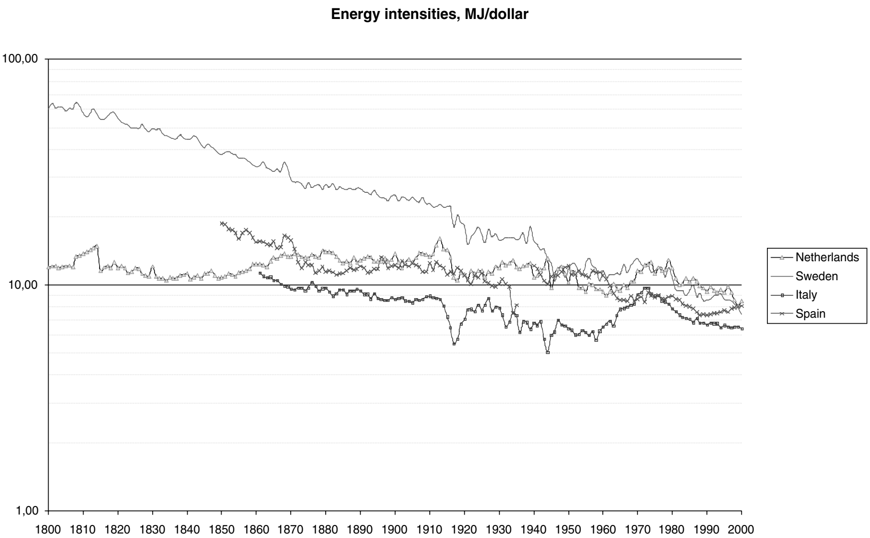

Figure 9. *Energy intensity (Mj/int. PPP 1990 $).*

late-comers. Still, with the exception of the Netherlands, the levels of energy intensity in the nineteenth century are higher than in the twentieth. Despite the wide increases in energy consumption over the last 100 years, production has slowly become cheaper in energy terms. Towards the end of the twentieth century, three out of the four countries (Sweden, Italy, Spain) have dropped to less than 10MJ/$, a level which is well below those of the previous 100 years. The search for more efficiency in the use of energy partially depended on the fast rise in prices. In the 1960s the price of oil on the international markets was less than 10 1999 dollars per barrel, while in 1974 it was four times higher and in 1979 more than seven times. While the low level of prices had resulted in increasing energy-intensity, from 1973 onwards the trend was declining under the pressure of rising fuel costs.[25]

Efficiency in energy consumption, that is the ratio of the output of useful energy to the total input, certainly improved during the transition. It was estimated that, while subsistence agriculture exploits energy with an efficiency of about 10 per cent, a more advanced agrarian economy (an economy, that is, based on food, fodder and plants as the main carriers) before industrialisation can even reach 25 per cent.[26] This is probably an overestimation. We know that the efficiency of a working animal hardly

[25] Data refer to the price per barrel of crude oil in 1999 dollars (source: British Petroleum). A closer examination of the relationships between energy intensity and prices would, however, require a reconstruction of energy price indices at the country level. It is not our purpose here.

[26] Cook (1976, p. 135). For a more in-depth discussion of this issue, see Malanima (1996, pp. 119 ff).

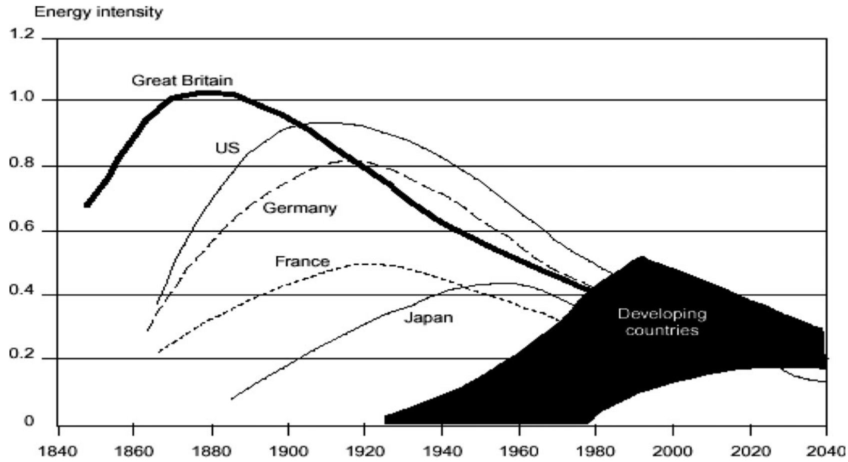

Figure 10. *Traditional portrait of the long-term evolution of energy intensities.*

Source: Adapted from Goldenberg and Reddy (1990).

reaches 10 per cent. Most fodder is used for the metabolism and does not produce mechanical energy. In the case of a human being, efficiency is higher: about 20 per cent. Traditional fireplaces and stoves usually had a very low efficiency, hardly reaching 20 per cent, and in most cases not even 10 per cent. A weighted average provides an estimate of overall efficiency at around 20 per cent and perhaps less. Today modern energy systems are credited with an efficiency of about 35 per cent.[27] In the end, the transition to the use of modern carriers and the exploitation of machines as converters resulted in higher efficiency. Biological, animal converters of traditional, vegetable sources are, on the whole, less efficient than the inanimate machines.

The transition from traditional energy carriers to modern ones therefore implied a decrease of energy intensity in any country. At the same time technological improvements in mechanical converters contributed in that the declining trend continued and even intensified.

How does our approach change the perception of the relationship between energy intensity and economic growth? The most widely accepted perspective on this relationship is probably the one by Goldenberg and Reddy (1990) (Figure 10). In their opinion, energy intensity will increase at low levels of income *per capita*, as countries industrialise, and then, after attaining

[27] The topic of efficiency in the exploitation of energy is discussed in depth by Cook (1976, pp. 133 ff). The efficiency of 35 per cent refers to modern, advanced energy systems on the whole; that is, to the ratio of the output of useful energy to the input. The efficiency of energy converters today runs from less than 5 per cent for the ordinary incandescent lamp to 99 per cent for large electric generators. On the efficiency of specific energy converters, see also Summers (1971).

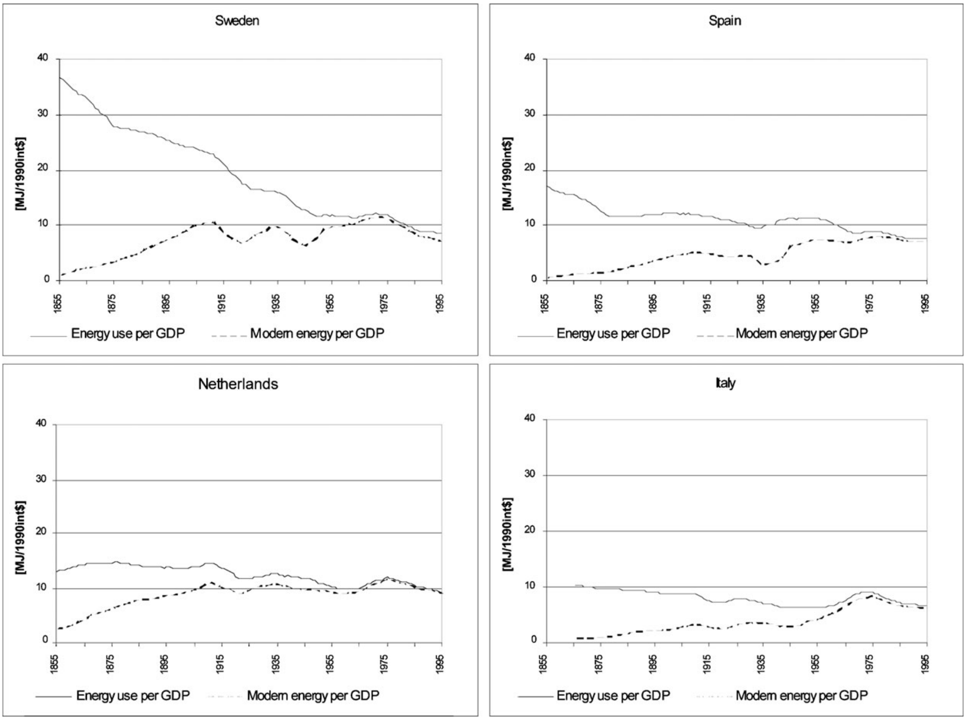

Figure 11. *Two views on energy intensities (11-year moving averages).*

a certain level of *per capita* income, energy intensity will start to decrease. A straight implication of this inverted U-curve is that developing nations could achieve comparable levels of economic growth with a lower ratio of consumed energy to GDP after a transition across a path of increasing energy intensity. A quadratic logarithmic model would represent the movement very well.[28]

The inclusion of traditional energy carriers changes the implied relation. The immediate consequence is to elevate the levels of energy consumption, and thus energy intensities, of the earlier periods.

In the case of Italy, the Netherlands, Spain and Sweden we find a straightforward difference between the traditional view of energy intensity and the one we elaborated. In the first case, the curve is rising until the recent decades, when the inverted U appears in the graph. According to our new series, energy intensity tends to decrease, except during the 1950s and 1960s: a period of fast economic growth and very low energy prices (Figure 11).[29]

[28] Such the one used by Galli (1998).

[29] In fact, this result was also found for the US (from 1800) and Japan (only from 1900), with the inclusion of bio-fuels (Grübler 2004). For Italy the traditional rising curve of energy intensity is presented by Clô (1994) and Toninelli (1999).

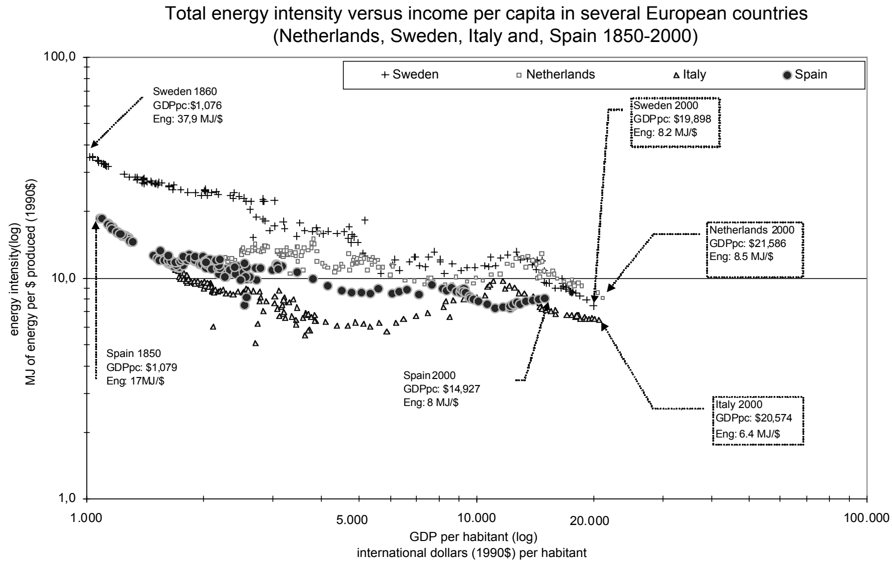

Figure 12. *Energy intensity* versus *income* per capita.

The standard presentation of the inverted U-curve normally has the levels of income *per capita*, rather than time, on the *x*-axis. In Figure 12 energy intensity includes all types of energies put into use by the economic system and it is represented in the *y*-axis. Income *per capita*, measured by the GDP per inhabitant of each of our four countries, is represented in the *x*-axis. The result does not have the expected inverted-U shape implied by past literature on the subject. For the most part, the figure looks more like a wave, moving towards higher levels of income with a long-term trend of lower levels of energy intensity. In fact, the only inverted-U shape that can be identified is the one peaking around the first oil crisis for three of the four countries (Spain being the exception). From the level of $ 8,000 *per capita* (around 1960 in Italy, Sweden and the Netherlands) the levels of energy intensity increased to the level of $ 13,000 *per capita* (which was achieved in 1973 by all three countries). From then on all three reached higher levels of income *per capita* with lower levels of energy intensity. The decline in energy intensity caused by the oil crisis is also observable in the case of Spain, but at a lower level of income per capita: $ 7,700.

Over a longer period, the trend exhibits a steady decline in energy intensity at higher levels of income per inhabitant. Therefore, what remains untouched of the original representation of the relationship between energy intensity and income *per capita* proposed by Goldenberg and Reddy, is the fact that late-comers may achieve comparable levels of economic output *per capita* with a lower ratio of consumed energy to GDP.[30]

[30] On the prospects of energy intensity in the near future, see Kaufmann (2004).

4.4. *Unpacking the E/Y-factor*

The E/Y-factor, or energy intensity, is a residual and may be perceived as technical change in a broad sense. This technical change can arise both from process innovations that increase efficiency within a specific kind of production, from the introduction of superior energy carriers, or from product innovations that give rise to new branches, thus stimulating structural change in the economy. Within an existing branch or sector, the innovations can be explicitly directed at energy savings (such as improving the thermal efficiency of a machine) or at innovations that save on the production factors that need energy to run (the total factor productivity). However, two things complicate the picture and make the gains in energy intensity less predictable:

1. Rebound or 'take-back' effects, which means that the consumption of energy services increases as they become relatively cheaper, which is the case when technical energy efficiency improves.[31] This stimulates structural change in a more energy-intensive direction;
2. Biases in technical change, which may lead to fewer gains in energy savings than in total factor productivity. A normal feature of the economic development is that capital per worker (K/L) increases. The capital ratio to GDP (the K/Y ratio) varies among countries. In cases where capital is not saved in relation to GDP it may be that energy is not saved either, although in general energy is saved in relation to capital.[32]

Thus energy intensity may not decrease at all, even though we have substantial efficiency improvements of various kinds in the economy.

A widely held belief is that energy intensity will increase during industrialisation and decline later, as soon as services grow in their share of product.[33] We think there is reason to be sceptical about the idea that the transition to the service economy will bring about any relative decline in energy intensity.[34] Because of its importance, we have, however, to devote attention to the topic. Our problem is to find a way of distinguishing the role of the structural change in the overall decline in energy intensity from that of the technical efficiency. The question is then: how much of the decline of energy intensity in these last decades can be explained by the increasing importance of services?

To answer the question, we will begin by decomposing energy intensity in:

$$\frac{E}{Y} = \frac{E_i + E_s}{Y} \tag{6}$$

[31] Howarth (1997).
[32] Kander and Schön (2007); Ayers and Warr (2003, 2005).
[33] Panayotou *et al.* (2000).
[34] Kander (2005).

where E_i and E_s are, respectively, energy consumption in industry and in services (transport included).[35]

Energy consumption in industry and services can be resolved in:

$$E_i = e_i \cdot i \cdot Y \tag{7}$$

and

$$E_s = e_s \cdot (1 - i)Y \tag{8}$$

where e_i and e_s are respectively energy intensity in industry and services (expressed in Mj per unit of constant money; here 1990 international PPP \$), i is the ratio of industrial production out of total product Y and $(1 - i)$ is the quote of the services (for example, 0.40, 0.50 in the 1970s).

The change in the energy intensity from the year o to the year n can be described by the following equation:

$$_{n}e_y - {}_{0}e_y = \Delta e_y = \frac{_{n}E_i + {}_{n}E_s}{_{n}Y} - \frac{_{0}E_i + {}_{0}E_s}{_{0}Y} \tag{9}$$

where the subscripts on the right refer to the sector of the economy and to the aggregate energy intensity (e_y) and those on the left to the year.

Substituting (7) and (8) into (9) and developing the equation our result is:

$$\Delta e_y = (e_i - e_s)({}_{n}i - {}_{0}i) \tag{10}$$

The change in the overall energy intensity depends on the difference between e_i and e_s and on the change in time of the relative weight of industry in the economy between o and n.[36]

We can now express both the differences in the energy intensity (until now in Mj per unit of money) between industry and services, and in the importance of the industry, in relative terms. The difference in total energy intensity (here referred to as Δ_e) explained by the structural change from industry to services is then:

$$\Delta_e = \frac{\dfrac{e_i - e_s}{e_i} \cdot \dfrac{_{n}i - {}_{0}i}{_{0}i}}{\dfrac{_{n}e_y - {}_{0}e_y}{_{0}e_y}} \tag{11}$$

Between 1970 and 2000 the service sector increased by 2 percentage units in Sweden, while transport grew by 4 percentage units (together their

[35] To simplify the following analysis, we neglect the primary sector. Its inclusion, however, would not change the results.

[36] Here and in the following examples, we assume that energy intensity is stable in time. We could, however, take this change into account without difficulty (using a mean value between the beginning and the end of our period both for industry and services).

increase was 6 percentage points).[37] In Spain the service sector actually declined by 1 percentage unit (transport included) and in Holland services grew by 5 percentage units, while transport grew by another 2 percentage units. Only Italy saw a relatively large increase in the service sector by 14 percentage units (transport included).

Since in Italy the decrease of industry in favour of services from 1973 to 2000 was stronger than in the other three countries, let's compute its importance on the aggregate decline in energy intensity, using the previous formula (11). The coefficient resulting from $(e_i - e_s)/e_i$ is 0.20 and represents the actual difference in energy intensity in the services (transports included). The weight of industry decreased from 0.50 of GDP to 0.36. In the same period the aggregate energy intensity dropped from 10 Mj per international 1990 PPP $ to 6 Mj. The decline was then 0.4. Substituting these values in (11), we find that the decline deriving from the change in GDP composition was –0.14, that is 14 per cent of the total change in energy intensity. The rest –86 per cent – is explained by the increase in technical efficiency.[38]

Italy is characterised by light industry and the industry–services' difference in intensity is relatively small. The same result for Italy could be reached with a different combination of our coefficients: taking, for instance, an energy-intensive industry and a smaller decline of industry in the structure of the economy. If we assume services with an energy intensity of 40 per cent that of industry (and then, a difference of 60 per cent between the energy intensities in industry and services) and a rise of 14 percentage points in the services, the result on the aggregate energy intensity would be 28 per cent. It seems that in any case the influence of a structural change on energy intensity, within plausible values both for the difference in energy intensity in industry-services and structural change, has been marginal in the recent three decades.

We have to notice, furthermore, that the passage to a service economy is largely an illusion in terms of real production, since it is generated by the fall in the price of manufacturing goods relative to services, which is in turn caused by more rapid productivity growth in manufacturing than in services.[39] Efficient production, which is still mainly of industrial goods, provides great scope for consumption in the service economy. It is of course true that parts of the service sector have high productivity and contain inputs from the industrial sector, such as computers, which complicates the picture.[40] Baumol's main argument is still relevant: that is, for activities where human time makes up part of the product (the services) it is not

[37] In the following we use sector shares in constant prices.

[38] Reliable data on sectoral energy intensity are available only for the last three decades in our four countries. However, for the Swedish case it has been possible to establish a few benchmarks, allowing us to prove that the structural effects from industrialisation were increasing energy intensity (Kander 2002; Kander and Lindmark 2004).

[39] Baumol (1967), Kander (2005).

[40] Baumol (1985).

possible to rationalise production by substituting machines for labour, and such labour-intensive activities make up a large share of the service sector.

Still, the more rapid decline in energy intensity after 1973 compared to earlier periods has partly to do with the increase in the relative price of energy which has stimulated energy savings, and partly to do with the changes within the industrial sector, with a relative growth of energy-light branches like information and communication technology and bio-technology, plus the indirect energy-saving effects of introducing ICT in many of these industrial branches.[41] The grand transformation of societies related to the micro-electronic revolution, sometimes referred to as the third industrial revolution, is thus partly responsible for the relative savings of energy.[42]

5. Concluding remarks

Our two aims in the present research have been:

1. Analysis of the process of the energy transition in four European countries, representative of the North and South;
2. Revision of the widely held opinion that energy intensity shows the pattern of an inverted U-curve.

We have investigated energy consumption in the long term in Sweden, Holland, Spain and Italy and the energy transition taking place in our four countries. The relative importance of the traditional energy carriers differed among the countries, with Sweden relying upon firewood, Spain and Italy upon fodder and food, and wind and peat being substantial in the Netherlands. The coal age was a twentieth-century phenomenon, but here too, its maximum share in energy consumption varied between 42 and 84 per cent.

In order to analyse energy consumption, we used a Commoner-Ehrlich type of decomposition of the aggregate into major components, population, income *per capita* and energy intensity as a proxy for technology. Our main result has been the reshaping of the trend of energy intensity on the basis of our new data on traditional energy carriers in a very long perspective. The dominating view of an inverted U movement in energy intensity is not confirmed by our research and depended on concentration, by most scholars, only upon 'modern' energy carriers. Our figures show, on the contrary, a long-term decline in energy intensity.

As to the causes of this declining trend, there is reason to be sceptical about the commonly held belief of a correlation between energy intensity decline and the rising importance of services in the economic structure. In each of our four countries this change did not account for more than 15 per cent of the total reduction of energy intensity. Our opinion is,

[41] Mårtensson (1995)

[42] Schön (1990), Kander (2005).

therefore, that technological changes accounted much more for this decline than the rise of services. In any case, looking at the movement of energy consumption and energy-GDP in a very long perspective, there are some grounds for being less pessimistic than the majority of observers. Technical advance has over the long run limited the rise in energy consumption and its importance has grown in the last few decades. So, a continuing decrease in energy intensity could realistically enable further economic growth.

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Appendix

The series of energy consumption exploited in the present article include both traditional and modern energy carriers. The traditional energy carriers are firewood, food for the population and fodder for draught animals, direct working water, wind and peat. The modern energy carriers are coal, oil, natural gas and electricity.

We go as far back in the different countries as the direct data allow. For Sweden and the Netherlands this means back to 1800, for Spain to 1850 and for Italy to 1861. The methods followed in the collection and elaboration of the basic data are fully explained by Kander (2002) and Malanima (2006). See also Rubio (2005).[43] Here we recall only some main features.

[43] Spanish firewood data were updated for this article with regard to the figures in Rubio (2005).

Firewood consumption is based on direct information in documents and coeval literature on the subject. Men's and working animals' energy is the food they consume. Both for water and wind, the best possibility for estimating energy is through power. In order to estimate energy consumption from power, we have to know for how long the engine – mill or ship – worked; which can be found in the coeval literature on the topic. Peat in the Netherlands is included among the traditional carriers.

Data on modern energy carriers are more easily available in production or import statistics and are less problematic.

The series are expressed in joules. GJ = 10^9 J, PJ = 10^{15}J. For people used to seeing energy expressed in calories or tons of oil-equivalents, the conversion factors are: 1 Toe = 10 Gcal = 42 GJ.

Table 1A. *Total energy consumption (PJ), consumption per capita (GJ) and percentage of traditional carriers in Sweden and the Netherlands 1800–2000.*

	Sweden			Netherlands		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1800	110.5	47.3	99.8	46.1	21.8	90.6
1801	110.8	47.3	99.7	46.4	21.9	90.3
1802	110.4	46.8	99.8	46.8	22.0	90.0
1803	111.3	46.8	99.7	45.8	21.5	92.5
1804	111.2	46.5	99.6	46.4	21.7	91.7
1805	111.7	46.3	99.7	46.6	21.7	91.6
1806	112.0	46.3	99.5	47.0	21.8	91.2
1807	111.2	45.8	99.4	46.3	21.4	92.9
1808	110.4	45.7	99.2	45.8	21.2	94.2
1809	106.7	44.6	99.3	45.8	21.3	94.3
1810	106.2	44.3	99.5	45.7	21.2	95.0
1811	106.5	44.2	99.6	45.8	21.2	95.2
1812	106.8	44.2	99.6	46.0	21.2	95.3
1813	106.6	44.0	99.7	46.3	21.3	94.8
1814	106.5	43.7	99.7	46.3	21.2	94.8
1815	107.5	43.6	99.5	46.6	21.1	94.5
1816	109.7	43.9	99.5	46.7	20.9	94.9
1817	110.1	43.7	99.5	48.0	21.3	92.9
1818	110.7	43.5	99.6	48.5	21.3	92.2
1819	111.3	43.4	99.6	49.6	21.5	92.2
1820	111.9	43.3	99.6	50.9	21.8	91.9
1821	111.7	42.8	99.6	51.4	21.7	91.7
1822	112.1	42.4	99.6	51.6	21.5	91.9
1823	113.6	42.2	99.6	52.2	21.5	91.8
1824	114.4	41.9	99.6	53.6	21.7	90.4
1825	115.2	41.6	99.6	55.1	21.9	88.9
1826	115.8	41.3	99.6	55.8	21.9	88.4
1827	115.5	40.8	99.5	56.4	22.0	88.0
1828	115.7	40.6	99.6	57.5	22.3	87.0
1829	114.5	40.0	99.6	57.8	22.1	87.6

Table 1A. *Continued.*

	Sweden			Netherlands		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1830	115.1	39.9	99.4	58.6	22.2	87.1
1831	114.9	39.6	99.6	57.2	21.6	89.7
1832	115.0	39.3	99.6	58.8	22.1	86.5
1833	115.4	39.0	99.6	58.5	21.8	87.8
1834	115.5	38.7	99.4	57.9	21.4	89.6
1835	117.0	38.7	99.3	60.1	22.0	88.4
1836	117.5	38.4	99.3	62.2	22.5	87.9
1837	117.4	38.2	99.4	64.6	23.1	86.8
1838	117.4	38.0	99.3	68.1	24.1	85.7
1839	117.8	37.9	99.2	68.9	24.1	86.5
1840	118.4	37.7	99.2	71.7	24.9	84.6
1841	118.8	37.4	99.2	69.1	23.7	85.4
1842	119.6	37.3	98.9	69.4	23.5	85.9
1843	119.5	36.9	99.1	70.1	23.5	84.9
1844	119.2	36.4	99.1	69.3	23.0	85.9
1845	119.6	36.1	98.8	73.1	24.0	80.8
1846	120.6	36.1	98.9	73.5	24.0	85.6
1847	120.7	35.9	99.0	75.8	24.7	82.1
1848	121.8	35.8	98.5	73.9	24.1	82.5
1849	121.8	35.4	98.3	74.1	24.1	82.5
1850	123.4	35.4	98.0	77.1	24.9	81.4
1851	124.8	35.5	97.9	79.4	25.4	83.0
1852	125.4	35.4	97.9	81.7	25.8	81.3
1853	125.5	35.2	98.0	79.5	24.9	81.4
1854	127.5	35.3	97.6	83.8	26.1	79.1
1855	129.5	35.6	97.5	84.7	26.2	77.0
1856	131.0	35.7	96.4	90.1	27.7	79.1
1857	132.6	35.9	95.5	89.6	27.4	79.2
1858	133.7	35.8	95.7	89.7	27.2	77.0
1859	137.3	36.2	94.5	90.5	27.4	76.0
1860	139.0	36.0	94.6	95.2	28.7	71.8
1861	142.2	36.3	93.3	93.8	28.1	74.8
1862	144.7	36.5	93.2	97.3	28.9	75.8
1863	145.5	36.2	93.3	98.4	29.0	76.3
1864	148.0	36.4	93.0	109.5	31.9	66.6
1865	149.2	36.3	92.8	114.6	33.1	63.5
1866	150.6	36.2	92.6	117.6	33.7	61.9
1867	150.5	35.9	93.1	118.3	33.7	61.9
1868	151.5	36.3	92.0	122.4	34.5	61.6
1869	150.5	36.2	92.9	124.0	34.7	61.0
1870	153.0	36.7	91.3	129.9	36.0	58.3
1871	153.9	36.6	90.8	132.6	36.5	57.3
1872	162.0	38.1	88.9	134.9	36.8	56.3
1873	162.6	37.8	89.0	135.3	36.6	58.0
1874	161.8	37.3	87.9	131.8	35.2	59.8
1875	168.7	38.5	86.0	139.0	36.7	56.6
1876	171.8	38.8	85.2	147.5	38.5	53.5

Table 1A. *Continued.*

	Sweden			Netherlands		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1877	173.0	38.6	84.5	148.3	38.2	53.2
1878	169.3	37.4	86.6	147.8	37.6	49.9
1879	170.5	37.2	86.5	153.5	38.5	48.0
1880	178.2	39.0	83.5	161.4	40.0	45.3
1881	176.9	38.7	83.9	164.3	40.3	44.3
1882	180.6	39.4	82.2	167.2	40.5	43.4
1883	183.3	39.8	81.4	172.7	41.3	39.9
1884	185.8	40.0	80.7	168.6	39.9	40.9
1885	189.3	40.4	79.6	168.8	39.5	40.8
1886	187.2	39.7	79.8	174.3	40.3	39.5
1887	187.4	39.6	79.4	174.9	40.0	39.4
1888	190.6	40.2	77.6	188.4	42.5	36.5
1889	197.8	41.4	74.7	186.1	41.5	37.0
1890	200.0	41.8	74.8	181.8	40.1	37.6
1891	202.5	42.2	73.6	185.0	40.3	36.9
1892	201.8	42.0	73.6	194.0	41.9	36.8
1893	202.0	41.9	73.3	191.8	40.9	35.0
1894	213.8	43.9	70.1	193.5	40.8	34.8
1895	215.2	43.7	69.9	194.9	40.6	34.1
1896	220.4	44.4	69.6	204.5	42.0	33.1
1897	230.2	46.0	67.5	215.5	43.7	32.0
1898	235.3	46.5	66.2	212.4	42.5	33.3
1899	254.1	49.9	60.7	218.1	43.0	33.9
1900	259.8	50.6	61.4	229.9	44.8	30.3
1901	250.0	48.3	62.5	222.4	42.8	29.2
1902	258.9	49.8	62.1	218.6	41.5	29.4
1903	266.6	51.1	59.5	230.2	43.1	28.1
1904	271.7	51.7	58.1	241.3	44.5	26.8
1905	279.9	52.9	59.9	246.4	44.8	26.6
1906	293.9	55.1	57.5	262.5	47.1	25.1
1907	309.6	57.6	54.3	270.3	47.8	24.5
1908	315.9	58.2	52.0	275.6	48.1	24.3
1909	299.7	54.7	53.2	287.4	49.4	23.4
1910	320.9	58.1	54.8	290.7	49.2	22.2
1911	316.7	56.9	54.6	309.1	51.6	22.3
1912	329.8	58.9	52.3	349.3	57.4	23.1
1913	362.8	64.3	51.1	390.4	63.1	16.1
1914	356.7	62.8	53.2	342.6	54.5	19.3
1915	363.9	63.7	52.9	350.8	54.9	19.0
1916	390.7	67.9	53.5	332.9	51.4	20.9
1917	304.3	52.5	73.5	255.9	38.9	30.2
1918	315.6	54.3	69.8	231.7	34.9	33.2
1919	304.9	52.1	70.1	309.5	46.1	24.6
1920	312.6	52.9	61.1	314.7	46.2	23.9
1921	243.5	40.9	70.3	319.0	46.1	19.9
1922	289.3	48.3	59.5	364.3	51.8	17.3
1923	313.5	52.2	54.9	364.5	51.1	17.2

Table 1A. *Continued.*

	Sweden			Netherlands		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1924	347.8	57.6	51.4	401.2	55.3	15.6
1925	327.6	54.1	53.4	418.7	56.9	15.0
1926	324.3	53.4	53.8	425.8	57.0	14.7
1927	379.8	62.4	45.4	468.2	61.8	13.3
1928	362.3	59.3	47.4	481.7	62.8	13.0
1929	401.8	65.6	43.7	522.6	67.2	11.9
1930	392.9	64.0	43.5	513.4	65.1	12.1
1931	387.9	62.9	42.5	510.4	63.8	12.2
1932	381.3	61.6	42.1	490.5	60.4	12.6
1933	393.8	63.4	41.4	498.0	60.5	12.4
1934	422.2	67.7	39.4	504.2	60.4	12.3
1935	435.6	69.7	38.0	490.1	58.1	12.8
1936	462.6	73.8	35.3	507.6	55.5	12.5
1937	505.7	80.5	32.0	553.9	60.3	11.5
1938	473.3	75.0	33.4	547.0	58.9	11.9
1939	599.5	94.5	40.9	592.5	63.4	11.2
1940	480.1	75.4	52.0	455.4	47.2	14.9
1941	460.0	71.8	58.2	435.7	48.6	15.2
1942	456.0	70.6	62.1	422.8	46.8	16.3
1943	485.9	74.5	57.3	422.0	46.4	15.9
1944	450.3	68.3	61.4	304.4	33.2	21.8
1945	450.2	67.5	80.0	236.4	25.5	27.9
1946	421.6	62.3	42.1	459.9	48.8	14.2
1947	497.5	72.7	31.6	558.0	57.9	11.9
1948	534.1	77.1	27.3	635.6	64.9	10.9
1949	491.7	70.4	28.6	641.6	64.5	10.4
1950	573.7	81.5	24.0	628.0	62.1	9.9
1951	633.2	89.2	20.7	713.2	35.2	14.5
1952	642.7	89.9	19.6	716.1	35.1	14.7
1953	608.8	84.6	19.8	671.1	64.0	9.2
1954	629.0	86.9	18.7	714.2	67.3	8.8
1955	720.0	98.8	15.8	738.6	68.7	8.3
1956	789.1	107.5	13.8	823.3	75.6	7.4
1957	767.0	103.8	13.7	841.8	76.3	7.2
1958	754.6	101.6	13.4	803.6	71.8	7.8
1959	696.9	93.4	13.7	844.6	74.4	7.5
1960	811.6	108.2	11.4	888.2	77.3	7.1
1961	805.7	106.8	11.1	861.9	74.1	7.3
1962	855.8	112.9	9.6	958.2	81.2	6.4
1963	906.9	118.9	8.6	1,074.0	89.8	5.7
1964	992.3	129.0	7.6	1,106.3	91.2	5.5
1965	1,020.9	131.3	6.9	1,139.9	92.7	5.3
1966	1,136.9	145.0	6.0	1,246.0	100.0	4.9
1967	1,093.0	138.5	6.0	1,271.2	100.9	4.7
1968	1,214.1	153.0	5.1	1,439.9	113.1	4.1
1969	1,319.6	164.9	4.6	1,537.8	119.4	3.8

Table 1A. *Continued.*

	Sweden			Netherlands		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1970	1,444.5	178.7	4.2	1,807.5	138.6	3.3
1971	1,386.0	170.8	4.1	1,862.6	141.2	3.2
1972	1,385.5	170.4	4.1	2,063.9	154.8	2.8
1973	1,445.1	177.4	3.9	2,186.0	162.7	2.7
1974	1,409.4	172.4	4.0	2,305.3	170.2	2.6
1975	1,455.2	177.3	3.6	2,051.4	150.1	2.9
1976	1,511.8	183.6	3.8	2,296.0	166.7	2.7
1977	1,462.4	176.9	4.2	2,269.8	163.8	2.8
1978	1,382.5	166.9	4.9	2,358.6	169.2	2.6
1979	1,572.0	189.3	4.6	2,664.1	189.8	2.3
1980	1,440.6	173.2	5.5	2,472.7	174.8	2.6
1981	1,292.0	155.2	6.9	2,216.3	155.6	2.9
1982	1,276.7	153.3	7.5	2,049.8	143.2	3.1
1983	1,323.8	158.9	8.0	2,113.4	147.1	3.0
1984	1,319.0	158.1	8.5	2,312.2	160.3	2.8
1985	1,442.7	172.6	7.9	2,300.0	158.7	2.8
1986	1,518.7	181.2	7.5	2,449.5	168.1	2.6
1987	1,417.7	168.5	7.7	2,400.7	163.7	2.9
1988	1,508.7	178.4	8.9	2,361.7	160.0	2.9
1989	1,424.3	167.0	9.1	2,402.1	161.8	2.5
1990	1,441.3	167.8	11.4	2,429.8	162.5	2.5
1991	1,428.3	165.2	13.0	2,600.1	172.5	2.4
1992	1,412.4	162.5	16.4	2,549.7	167.9	2.4
1993	1,427.8	163.3	14.0	2,514.9	164.5	2.5
1994	1,442.0	163.6	17.5	2,672.6	173.7	2.3
1995	1,477.2	167.2	15.1	2,654.0	171.7	2.4
1996	1,488.4	168.3	15.8	2,916.9	187.8	2.2
1997	1,495.9	169.1	16.0	2,857.3	183.0	2.2
1998	1,500.0	169.4	16.6	2,757.1	175.5	2.3
1999	1,492.7	168.5	16.7	2,695.5	170.5	2.4
2000	1,485.0	167.2	16.2	2,916.9	183.2	2.2

Table 2A. *Total energy consumption (PJ), consumption per capita (GJ) and percentage of traditional carriers in Italy and Spain 1850–2000.*

	Italy			Spain		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1850				300.5	20.2	98.4
1851				303.9	20.3	96.8
1852				302.4	20.1	96.8
1853				300.6	19.9	96.8
1854				298.7	19.6	96.7
1855				294.7	19.3	96.7
1856				304.8	19.8	94.6

Table 2A. *Continued.*

	Italy			Spain		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1857				305.4	19.8	94.6
1858				306.1	19.7	94.6
1859				303.0	19.4	94.6
1860				300.5	19.2	94.5
1861	485.3	18.8	92.8	305.4	19.5	92.7
1862	480.3	18.5	93.5	306.3	19.5	92.0
1863	484.5	18.6	93.5	307.0	19.5	91.2
1864	483.7	18.4	93.7	304.9	19.3	91.5
1865	490.2	18.5	93.6	305.9	19.3	91.7
1866	497.3	18.7	93.8	300.4	18.9	91.5
1867	467.5	17.4	93.1	302.9	19.0	90.9
1868	466.6	17.3	93.0	306.0	19.2	90.6
1869	476.3	17.5	93.2	308.2	19.2	90.6
1870	483.4	17.7	93.1	309.7	19.3	89.5
1871	478.5	17.3	94.1	306.9	19.1	89.1
1872	485.5	17.5	93.0	304.8	18.9	88.9
1873	486.8	17.5	93.4	311.6	19.3	88.4
1874	501.3	17.9	92.8	302.5	18.6	88.2
1875	510.9	18.1	92.8	303.1	18.6	87.2
1876	529.1	18.6	90.9	308.9	18.9	86.2
1877	515.9	18.0	91.4	314.6	19.2	86.2
1878	512.8	17.8	91.2	312.0	18.9	86.7
1879	530.1	18.3	90.1	306.6	18.5	85.2
1880	546.5	18.8	89.2	318.5	19.1	84.1
1881	539.3	18.4	87.3	328.9	19.5	80.6
1882	528.6	17.9	86.0	329.6	19.4	80.0
1883	551.8	18.6	85.6	327.8	19.2	80.5
1884	559.4	18.7	84.3	332.2	19.3	80.0
1885	578.0	19.2	82.8	326.0	18.8	79.3
1886	574.0	18.9	82.9	327.7	18.8	78.2
1887	602.8	19.7	80.2	332.1	18.9	77.7
1888	599.9	19.5	78.7	337.9	19.2	76.2
1889	597.6	19.3	77.9	340.8	19.2	74.7
1890	603.9	19.4	76.2	349.0	19.6	73.2
1891	596.0	19.0	78.2	351.6	19.7	72.2
1892	594.3	18.8	78.3	361.2	20.1	72.3
1893	578.4	18.2	78.4	350.5	19.4	71.4
1894	614.2	19.2	74.7	365.1	20.2	69.6
1895	594.3	18.4	76.0	361.4	19.9	69.3
1896	595.3	18.3	77.2	376.0	20.6	68.3
1897	593.3	18.1	76.2	375.3	20.4	66.0
1898	599.5	18.2	75.5	379.7	20.6	67.0
1899	625.7	18.9	74.2	394.1	21.3	63.3
1900	628.4	18.8	73.7	407.0	21.9	62.0
1901	646.1	19.3	75.0	423.0	22.6	62.6
1902	665.3	19.7	73.0	441.2	23.4	63.6

Table 2A. *Continued.*

	Italy			Spain		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1903	658.4	19.5	72.1	426.8	22.5	62.9
1904	674.9	19.8	71.1	417.4	21.8	59.1
1905	680.6	19.9	68.7	427.0	22.2	58.7
1906	729.7	21.2	65.1	438.7	22.6	58.0
1907	747.1	21.6	63.1	444.5	22.8	57.8
1908	769.5	22.0	63.2	442.1	22.5	56.6
1909	805.7	22.9	61.3	448.8	22.7	56.2
1910	819.4	23.0	61.7	473.1	23.7	57.3
1911	820.5	22.9	60.4	473.2	23.6	55.6
1912	844.9	23.4	59.7	503.9	24.9	55.0
1913	874.7	24.1	58.1	509.1	25.0	53.1
1914	846.3	22.7	60.9	488.9	23.9	57.0
1915	845.2	22.4	65.4	464.8	22.5	59.1
1916	842.4	22.3	65.1	503.7	24.3	56.2
1917	749.0	20.0	72.1	487.0	23.3	58.6
1918	795.7	21.6	69.3	510.6	24.3	57.4
1919	776.1	21.0	70.6	500.6	23.7	60.3
1920	744.0	20.0	69.9	509.0	23.9	64.7
1921	811.7	21.7	67.6	499.6	23.2	62.3
1922	855.0	22.6	64.5	500.0	23.0	62.0
1923	882.7	23.2	63.8	549.9	25.0	59.2
1924	956.2	24.9	58.4	559.2	25.2	57.4
1925	958.4	24.8	59.7	617.9	27.5	60.4
1926	1,024.1	26.2	56.4	568.2	25.1	57.8
1927	1,072.7	27.2	53.1	605.8	26.5	53.7
1928	1,017.4	25.6	54.2	588.5	25.5	53.0
1929	1,090.3	27.2	50.7	626.9	26.9	50.8
1930	1,032.5	25.5	51.4	623.0	26.4	51.4
1931	952.4	23.3	53.4	635.7	26.7	54.0
1932	875.4	21.3	57.3	617.1	25.7	55.1
1933	912.4	22.0	54.8	590.2	24.3	58.4
1934	1,003.6	24.0	48.3	467.9	19.1	46.2
1935	1,070.6	25.4	45.1	518.4	21.0	45.1
1936	901.1	21.2	52.2			
1937	1,077.9	25.2	45.8			
1938	1,073.3	24.9	47.1			
1939	1,077.8	24.7	46.8			
1940	1,152.6	26.2	45.3	655.4	25.3	51.2
1941	1,111.9	25.1	52.6	622.2	23.8	50.2
1942	1,137.1	25.5	55.2	619.3	23.5	49.5
1943	957.7	21.4	58.8	604.0	22.8	43.6
1944	614.6	13.7	71.5	611.0	22.9	43.2
1945	571.9	12.7	73.6	616.1	22.9	42.9
1946	776.3	17.1	58.8	651.9	24.0	41.7
1947	1,030.7	22.5	48.1	660.9	24.2	40.9
1948	1,040.4	22.5	50.4	687.3	24.9	40.1

Table 2A. *Continued.*

	Italy			Spain		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1949	1,100.8	23.7	47.4	714.6	25.7	38.5
1950	1,155.7	24.7	45.3	747.3	26.7	38.5
1951	1,225.8	26.0	37.2	754.7	26.7	38.7
1952	1,258.2	26.5	36.7	816.8	28.7	36.3
1953	1,351.1	28.4	34.6	846.6	29.5	34.9
1954	1,473.4	30.7	31.7	871.2	30.1	34.2
1955	1,534.4	31.8	30.2	899.4	30.8	33.6
1956	1,556.1	31.9	29.3	957.7	32.5	31.8
1957	1,709.3	35.2	26.8	1,052.2	35.4	30.1
1958	1,643.6	33.6	28.1	1,075.5	35.9	29.9
1959	1,890.8	38.9	24.6	1,057.6	35.0	30.7
1960	2,078.0	42.4	22.8	1,036.5	34.1	31.1
1961	2,314.0	47.1	20.5	1,126.9	36.6	30.0
1962	2,582.5	52.1	18.5	1,171.2	37.6	29.5
1963	2,823.8	56.5	17.0	1,205.1	38.3	27.8
1964	3,049.6	60.5	15.9	1,260.1	39.6	26.1
1965	3,324.2	65.4	13.7	1,316.9	41.0	24.7
1966	3,531.2	68.9	13.0	1,409.7	43.4	21.5
1967	3,854.4	74.6	12.1	1,491.7	45.5	20.9
1968	4,258.1	81.8	11.1	1,666.8	50.3	18.1
1969	4,556.0	87.0	10.4	1,723.7	51.4	15.9
1970	5,128.1	97.2	9.4	1,864.6	55.0	15.0
1971	5,309.0	99.9	9.1	2,015.3	58.7	13.1
1972	5,750.3	107.5	8.5	2,075.9	59.7	12.3
1973	6,109.2	113.4	8.1	2,479.7	70.5	9.7
1974	6,066.9	111.5	8.1	2,573.9	72.4	9.4
1975	5,792.9	105.8	8.5	2,613.1	72.7	9.1
1976	6,202.8	112.6	7.9	2,795.5	77.1	8.4
1977	6,049.6	109.5	8.1	2,806.4	76.8	8.2
1978	6,222.4	112.2	7.8	2,881.2	78.0	7.9
1979	6,421.7	115.5	7.5	3,002.8	80.7	7.7
1980	6,329.0	113.7	7.6	3,095.7	82.6	7.4
1981	6,206.7	111.3	7.7	3,016.8	79.3	7.4
1982	6,017.5	107.5	8.0	3,040.1	79.6	7.6
1983	5,981.5	106.4	8.0	2,993.4	77.9	7.6
1984	6,078.0	107.9	7.9	2,988.6	76.2	7.6
1985	6,173.1	109.3	7.6	3,008.2	76.0	7.6
1986	6,238.0	109.0	7.6	3,050.2	75.8	7.3
1987	6,515.4	113.6	7.3	3,113.4	76.8	7.2
1988	6,651.5	115.8	7.1	3,167.5	77.0	7.2
1989	6,869.7	119.4	6.9	3,375.3	81.5	6.3
1990	6,932.6	120.1	6.9	3,486.3	84.2	6.1
1991	7,005.6	123.4	6.7	3,623.8	87.2	6.2
1992	7,061.6	124.0	6.7	3,670.2	87.9	6.1
1993	6,978.2	122.1	6.8	3,619.8	86.2	6.1
1994	6,852.5	119.7	6.9	3,762.8	89.5	5.7

Table 2A. *Continued.*

	Italy			Spain		
	Total PJ	Per c. GJ	Trad. %	Total PJ	Per c. GJ	Trad. %
1995	7,200.5	125.7	6.6	3,938.5	93.5	5.7
1996	7,179.3	124.9	6.6	3,958.1	93.4	5.8
1997	7,284.8	126.6	6.5	4,249.3	100.3	5.2
1998	7,468.6	129.6	6.4	4,486.0	105.4	4.9
1999	7,579.1	131.4	6.3	4,716.9	110.6	4.8
2000	7,670.9	132.6	6.2	4,941.6	115.3	4.7