The Demand for Electricity Intensity

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ABSTRACT

A demand curve for electricity intensity and one for electricity inefficiency[1] are estimated using IEA/OECD 1997 panel data. Intensity and inefficiency as demanded "goods" reflect end-user preferences for a plethora of electric services and for a quiet life.
It has been observed that electricity intensities vary significantly between otherwise similar countries. Limiting our panel to the wealthiest OECD nations[2] makes the cross section quite homogeneous and excludes income and access to technology as explanatory factors. We estimate the long-run price elasticity of electricity intensity at -1.04. The electricity bill of the countries in the panel clusters around 3.4% of their GDP.
Electricity intensity is the product of structure, modal choice and technical efficiency. By normalising the panel data for structure and for modal choice, the residual variance in the data is due to differences in technical efficiency in using electricity. The long-run price elasticity of the demand for electricity inefficiency is estimated at -0.86.
The results confirm that "prices do matter" most, also in the market of the dispersed, diffuse and hidden use of electricity. We conclude that energy efficiency policies without deliberate energy tax strategy fall short in overall effectiveness.

INTRODUCTION

The study of energy systems and of energy intensity/ efficiency are subject of a vast and long-standing literature, briefly overviewed here to frame our approach.
Top-down or *behavior-oriented* energy system models use an economic approach to characterize the consumption choices of consumers and the technical relationships between the 'factors of production'(capital, labour, materials and energy) of firms. Utility and profit maximizing behavioural relationships are endogenized as much as possible, based on observed aggregated market data. The models assume market-clearing in a partial or full equilibrium approach. Input-output tables are used to capture intersectoral transactions. Early studies for industrialised countries [e.g. Bohi, 1981; Kouris, 1983; Bohi and Zimmerman, 1984] are based on time series data, including time series pooled for various countries/regions. The reliability of these early price and income elasticity estimates is questioned mainly because they assume stationarity for most economic variables. Engsted and Bentzen (1997) provide a survey of recent literature on non-stationary time-series in an energy economic context. Starting from production theory, the key factors that could reduce or strengthen the linkage between energy use and economic activity over time are substitution between energy and other inputs within an existing technology, technological change, shifts in the composition of energy inputs, and shifts in the composition of economic outputs. The long run capital (K) for energy (E) substitution or cross-price elasticity was intensely debated in the 1970/80's Some found a complementary relationship [e.g. Berndt and Wood, 1975], others one of substitutability [e.g. Halvorsen and Ford, 1979]. Recent research leads Stern (2004) to conclude that '… capital and energy are at best weak substitutes and possibly are complements. The degree of complementarity likely varies across industries and the level of aggregation considered.' Alongside the elasticity of substitution one uses the 'autonomous energy efficiency index' (AEEI) to characterize technological change. The AEEI specifies that the required amount of energy for producing a given level of output declines over time as a result of technological change, independent of energy prices. Most economic models aggregate several energy flows by adding up their thermal equivalents, ignoring their

[1] Intensity is the amount of kWh per $GDP. (In)efficiency is measured by the amount of kWh per physical activity, and not directly observable in the aggregate of plants, sectors or economies. In this article inefficiency and efficiency will be used interchangeably.
[2] The data sources used are documented in the Appendix.

qualitative differences (energy quality refers to the relative economic usefulness per heat equivalent unit of different fuels and electricity). A number of authors [e.g. Cleveland *et al.*, 2000] note the key role played by a shift towards higher quality energy input vectors in explaining the decline in US energy intensity over time. Reductions in energy intensity are also (partially) explained by changes in the output mix [e.g. Bernstein *et al.*, 2003].

Bottom-up or *engineering-approach* models use databases recording various technologies to meet the many energy service demands in the economy. Data about energy end-uses and technological options are highly disaggregated. The choice of technologies by households and firms is assumed to depend on 'life cycle cost minimization'. The technology with the lowest discounted total costs in present value terms is chosen, given an exogenously derived demand for energy services and a set of (factor) prices. Bottom-up models rely on normative theory rather than observed market behavior. Whether the gap between revealed and market discount rates is due to market failures subject to government intervention or to real economic costs in the operation of the energy efficiency market, is still debated [Bataille and Nyboer, 2001]

Over the past twenty years several attempts have been made to reconcile the strengths of top-down (behavioural realism and incorporation of macro-economic feedbacks) and bottom-up (technological explicitness) energy models into a *hybrid* form of energy model. A review of some efforts at hybrid modelling is given by Rivers *et al* (2003). From a completely different angle Botterud (2001) sees the use of *system dynamics* (a tool for developing general mathematical simulation models for different kinds of processes) as an alternative to top-down or bottom-up approaches.

In contrast to engineering optimization models, energy accounting or end-use models do not guarantee least-cost technological options but can represent cost-minimizing behaviour based on the judgement of the analyst. Energy accounting models track the energy for satisfying a specific energy service through identities as E=AI, where E indicates energy, A activity, and I intensity. The analyst may estimate energy savings and associated costs using energy intensities of current and of more energy-efficient technologies [Sathaye and Meyers, 1995].

The collection of information on very detailed energy end-uses to analyze changes in energy efficiency can be prohibitively expensive, which is why many analysts try to extract information about energy efficiency from relatively accessible macro and sector data. One method is the decomposition of the energy/GDP ratio or energy intensity. The total change in energy intensity is the combined effect of a *structural* effect, an *energy substitution* effect and a *technical* effect. The structural effect measures the change in energy intensity due to relative growth of energy intensive sectors. The energy substitution effect measures the change in energy intensity due to the change in the relative proportion of high-quality energy inputs used. The technical effect measures the change in energy intensity due to technical change. The technical effect, however, combines the effects of energy-capital / labour substitution and energy efficiency improvements. Early index decomposition techniques sometimes left a (large) residual, arising from the fact that the analyst can only observe data at discrete rather than continous intervals. Ang *et al.* (2003) give an overview of *perfect* decomposition techniques (without residual), which have become available after 1997. The decomposition method is used for both cross-country analysis [e.g. Phylipsen *et al.*, 1998; Mulder and de Groot, 2003] and intertemporal analysis [e.g. Ang and Choi, 1997; Ang and Zhang, 2000]. Ang (2004) provides an overview of the application and methodology development of index decomposition analysis.

This article focuses on electricity intensity/inefficiency and on the role of electricity prices in explaining most of the significant variances in observed intensities. Our focus on electricity is because of data quality considerations, but is acceptable given electricity is the most expansive energy end-use, attracting large investment and energy resources while the popular belief is widespread that its growth cannot be controlled and that prices have little impact on it. Our analysis is based on observations about the wealthiest nations of the globe. Again this restriction does not erode the significance of the results because the status of wealthiest nation is targeted by the other nations, and understanding why intensities differ in this panel is instructive for designing the global electricity future.

Section 1 introduces the discussion on electricity (and energy) intensity, referring to an IEA graph supporting the expansive investment forecasts in the power sector. A brief overview of recent articles in the field shows that the question why intensities vary so much between otherwise similar countries remains unanswered but merits academic and policy attention.
Section 2 analyses electricity intensity as the product of three factors: structure, modal choice (between electricity and non-electric energy) and technical inefficiency. We study intensity and inefficiency as separate economic goods, demanded by consumers and producers. The treatment of electricity intensity as a common economic good confirms the findings that the demand for electricity by consumers and by producers is a derived demand. The demand for inefficiency follows from the preference of people for a quiet life above awareness. While intensity is statistically observed, (in)efficiency in the aggregate is not directly measurable.
A demand *curve* for electricity intensity is estimated, because neither income nor access to technology are explanatory variables when the panel is limited to the wealthiest OECD member states.
For testing our hypothesis that variance in technical efficiency is a major factor in the observed spread in intensity, we estimate the demand curve for electricity inefficiency in Section 3. Normalisation of the intensity data for structure and for modal choice is necessary to identify technical (in)efficiency.
In the conclusions (section 4) we focus on the policy relevance of the approach and of the empirical results.

1. ECONOMIC GROWTH AND ELECTRICITY CONSUMPTION

We first show under 1.1 the importance of electricity intensity as a policy variable. Under 1.2 we review some recent empirical studies about energy and electricity intensities. IEA-OECD statistics in 1.3 reveal significant divergence in electricity intensities of the wealthy nations, with the question unanswered what causes the variance.

1.1 The IEA model of Economic Growth and Electricity Consumption

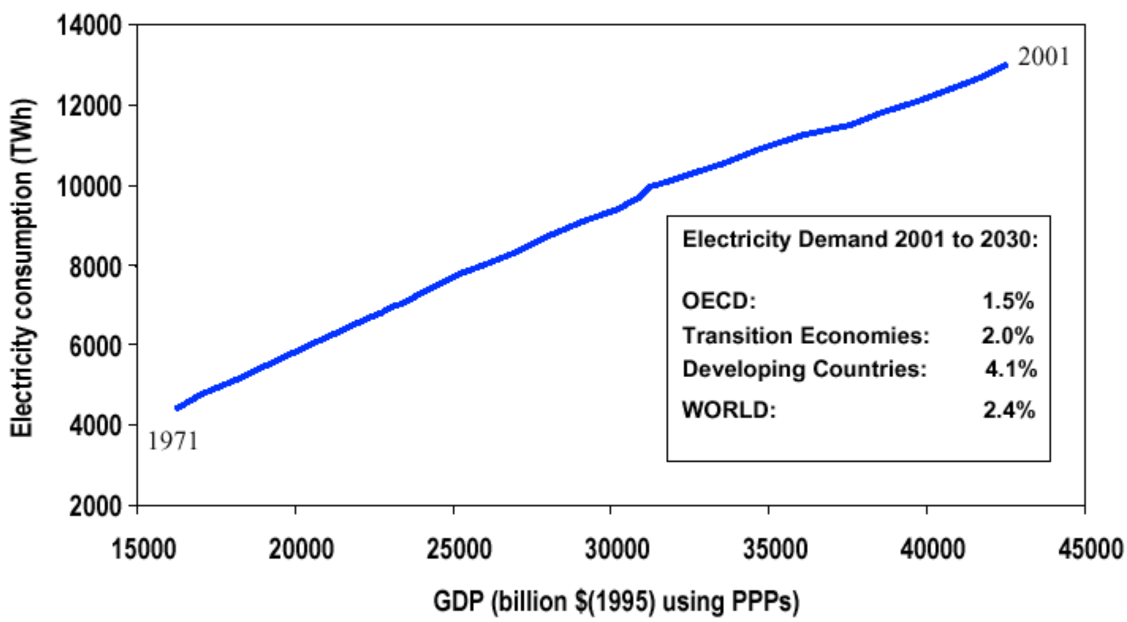
The IEA's World Energy Investment Outlook [IEA, 2003] brings the discussion about economic growth and energy/electricity use to the forefront again. In 2003 also major power black-outs in North America and Western Europe have raised the interest in electricity supply and investment issues. Most essential in finding out how much electricity is to be supplied in the future, is the (future) relationship between wealth creation and electricity use, i.e. electricity intensity.

The market share of electricity is growing, mainly because of its merits as a dense energy carrier for versatile end-uses, meeting the full scope of capacity needs from a few Watt to the hundreds MegaWatt without major splitting or aggregation losses. This growth is unhampered by its drawbacks of being non storable, of requiring wires and transformers for its transport and of being relatively more expensive than fossil fuels. “At the world level, the share of electricity in final consumption has increased from 12.5% in 1980 to 18% at present” [WEC, 2001, p.15]. “In the course of the present century [the 20th], electricity has become the preferred and dominant form of energy over an expanding portion of economic life in industrial economies. The dynamics of ongoing technological change offer no compelling reasons for expecting this trend to end” [Rosenberg, 1998, p.22]. On this point, Fri [2003, p.53] quotes Schurr et all: “Why has the electricity share [of total energy consumption] risen so dramatically throughout this century despite electricity’s relative price disadvantage? How has this rise been related to productivity increases? And how can it be consistent with steady improvements of energy use? … The answer to all three questions lies in technological progress strongly dependent on the use of electricity”.

On the role of energy and electricity in productivity growth Jorgenson found “support for the hypothesis that electrification and productivity growth are interrelated”, but continuing: “Somewhat surprisingly, we discovered that the use of non-electrical energy and productivity growth are even more strongly interrelated” [1984, p.24]. This latter finding, combined with the observed trend of decoupling energy use from economic development, weakens the argument that electricity use cannot be decoupled from economic growth because of its high productivity.

But the tight relationship between electricity use and economic growth remains the dominant view, also because at the macro level statistical evidence of electricity decoupling is difficult to provide [3]. This gives ground to widely accepted statements such that economic growth of a nation *depends on* a higher consumption of electricity, that efficient fuel use and decrease in fuel intensity *requires* the paired consumption of more electricity by substitution of power for fuel use or by the necessity of accompanying power consuming technology, that electricity is generally used efficiently in industrial economies, and that savings are either not feasible or very costly.

Figure 1: World Electricity Consumption vs. GDP 1971-2001



[3] E.g. Rosenberg [1998, p.11] notes that “in the aggregate, the US economy since the 1920s has become, simultaneously, less energy-intensive and more electricity intensive”.

Source: Birol [2003]

IEA official Birol [2003] presents the almost linear correlation between world electricity consumption and world GDP (figure 1). This graph is sufficient proof for the business community, for policy makers and for a vast majority of the constituency that the world needs more electricity in order not to block economic growth. The IEA [2003] prediction of world electricity demand 2001 to 2030 with a growth rate of 2.4% per annum is based on the hypothesis of a constant intensity (at about 320 kWh/1000 US$-1995PPP GDP, as figure 1 shows). Although its evidence is very convincing, figure 1 is not sufficient as a scientific proof that the future of the next 30 years will be perfectly similar as the past 30 years. More study on the electricity intensity of economies and on policies to bring average intensity down is recommended.

1.2 The energy/electricity intensity question

Some recent publications are reviewed. Medlock & Soligo [2001] address the evolution of energy intensities with the state of development of economies. Schipper *et al.* [2001] criticise the macro aggregation and adopt an intermediate approach that however does not solve the major issues of aggregation and interpretation.

Intensity at the aggregate level

In a longitudinal analysis of end-use *energy* demand Medlock and Soligo [2001] investigate the impact of development (expressed as increasing GDP/capita) on energy intensity (Energy/GDP). Next to income (GDP/capita) they include price as explanatory variable, mainly to avoid specification errors and to obtain unbiased income elasticity's. Due to the goal of their research and the constraints accepted their "panel data consists of 28 countries from all levels of development" in order to "construct a 'map' of energy use by sector during the course of economic development" [Medlock and Soligo, 2001, p.77-78].
They show that the shifting structure of economies from agricultural over industrial to tertiary activities along growth in GDP/capita is paired by nonlinear shifts in energy use/capita in the main sectors (Industrial and Other, Residential and Commercial, Transportation). Structure is shown to be very important in explaining shifting energy intensities over time.
Medlock and Soligo use their econometric model results to construct energy intensity curves as a function of real GDP per capita for a hypothetical *average* country. By intention they waive the differences in energy intensity that exist between nations of equal income.
Their article is convincing in showing decreasing average energy intensity with higher average income of countries. At the highest income levels the decline is flattening out. The authors provide no separate information on electricity intensity, where the decrease may be less prominent (or even absent?) because of the growing market share of electricity in more wealthy economies.

Intensity at the sector level

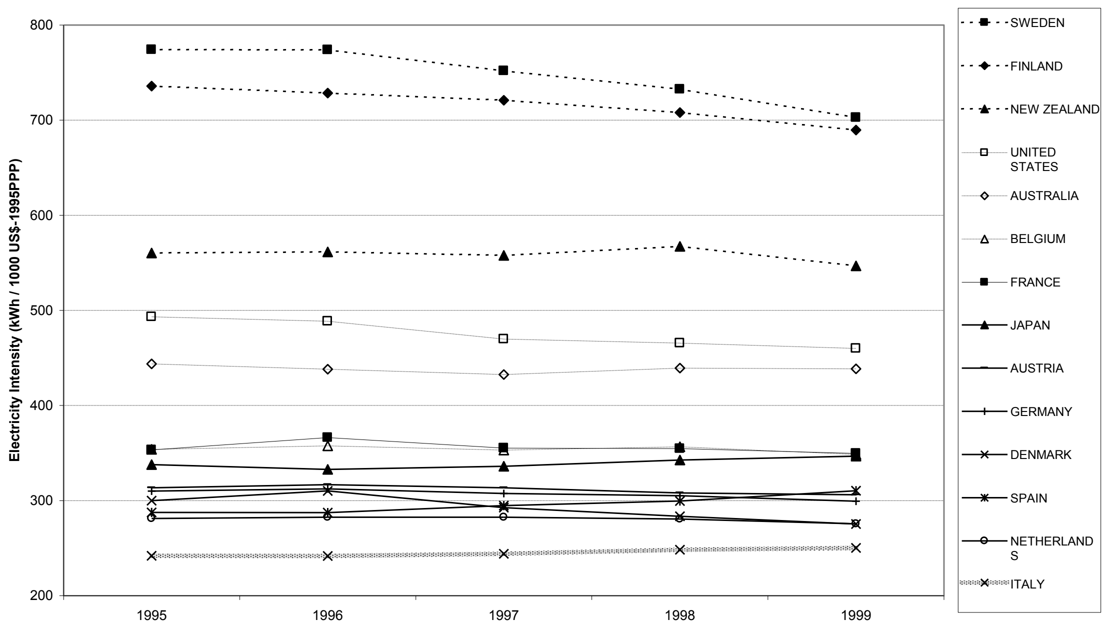
Variances in energy and electricity intensities at the sector level have been investigated and documented extensively by Schipper and his many co-authors [Schipper & Meyers, 1992; Schipper *et al*., 2001]. In the 2001-article they argue intensity is a too broad variable: "One of the most widespread indicators – the ratio of energy use to GDP – does not measure much. Little can be said, on the basis of that ratio, about why energy use for any sector has reached a

certain level, how efficient that use is, or why use varies so much between otherwise similar countries" [p.50]. The authors' finding that an aggregate indicator does not reveal changes in its components, is trivially true, but the essential question is at the end of the quote: *why energy use varies so much between otherwise similar countries?*
For Schipper *et al*, "measuring the impact of 'structural' changes is crucial to understanding how the ratio of energy use to GDP changes over time" [2001, p.54]. They therefore step down from the aggregate level and define energy intensity at the sector or activity level, adding that "intensities reflect behaviour, choice, capacity or system utilisation, and other factors besides just process efficiencies" [p.55]. They however face a lot of data problems to assess the more detailed models, e.g. "observations of actual end uses are difficult to develop, but surveys can be combined with regression techniques to estimate the relative importance of each end use …" [p.60]. After applying adjustments to make the intensities comparable among a small (due to data shortcomings) sample of developed OECD nations, they conclude that "there are still wide variations across countries. These variations indicate that the levels of sub-sector intensities differ from country to country." [p.65]. Although there is notice that "prices play a strong role" [p.76], they conclude that the (detailed) "indicators approach offers the only way to explain large differences in aggregate energy use, energy to GDP ratios, or sectoral shares (…)" [p.76]. Our analysis contests this conclusion, and shows that intensity can be studied in a more comprehensive way with the explicit inclusion of prices as explanatory variables of the differences.

1.3 Significant Variance in Electricity Intensities

While figure 1 shows a quasi constant world average electricity intensity, figure 2 shows the evolution over 1995-1999 of quite different electricity intensities (kWh end-use per 1000 US$-1995PPP GDP) of 14 wealthy OECD countries. Sweden and Finland at ~700 kWh, New Zealand at ~550 kWh and USA and Australia mark above the others, whose intensities range between 250~350 kWh.

Figure 2: Yearly electricity use intensities over the period 1995-2000 in 14 OECD countries



The electricity intensity by country shifts only slowly over time. On the one hand this is an expected pattern because the technological stock that uses electricity has an average lifetime of several years. On the other hand the stability can result from a rather stable evolution of the main determinants that influence intensity. The significant variance in electricity intensities in otherwise similar countries rises the question what could explain the differences.

2. EXPLAINING THE VARIANCE IN ELECTRICITY INTENSITY

In 2.1 we discuss the composition of electricity intensity and the variables that drive its evolution. The main determinants incomes and prices are further presented in respectively 2.2 and 2.3. Finally in 2.4, a demand curve for electricity intensity is estimated.

2.1 Components of Electricity Intensity

Energy intensity is decomposed in structure and in technical (in)efficiency by the identity

$$\frac{\text{Joules}}{\text{\$ GDP}} = \frac{\text{Activities}}{\text{\$ GDP}} \times \frac{\text{Joules}}{\text{Activity}}$$

Structure represents the spreading of activities over sectors (agriculture, industry, and transport, commercial, domestic), etc., but also is affected by culture, geography, climate, policies, etc. [Bernstein *et al.*, 2003]. Technical (in)efficiency reflects the type of infrastructures, apparatus and systems, and how they are used.

When addressing electricity intensity a component is added to reflect the modal choice in favour of electricity compared to other energy modes. So electricity intensity equals structure, times modal choice times technical (in)efficiency in electricity use.
Structure and technical (in)efficiency can be decomposed further in an unlimited number of specific activities and technologies. This giant challenge is taken up in the previously mentioned 'bottom-up' studies revealing an astonishing diversity and pointing to many opportunities for saving energy.

In economic theory electricity demand and its evolution are explained by height of and growth in incomes, by levels of and changes in prices of electricity and of other production factors, and by technological progress. Obviously the same variables have an impact on electricity intensity and on its components.

Technology permeates all composing factors. But because the analysis is based on a cross section of data of highly developed OECD countries in a particular year, technology can be considered as given. Medlock and Soligo [2001, p.85] state "that technology is a function of energy prices and common across countries for a given level of economic development"[4]. There is little argument against the common *availability* of electricity end-use technology in the wealthiest OECD nations, but we investigate the main causes of the different levels of efficient electric technology *adoption and implementation*, reflected in different electricity intensities and efficiencies among countries of similar economic affluence. In our cross section study therefore the state of technology is constant and cannot be an explanatory variable.
Incomes are decisive for explaining the kind and amount of activities people and societies undertake. They consequently affect the structure of economies also with modal choice more in favour of electricity. Our panel data show little correlation between incomes and intensities (see §2.2).

[4] Bernstein and al [2003, p.15] argue similarly for technological change in the states of the USA over the period 1977-1999.

The price of electricity has some impact on the structure of economies, e.g. some electric intensive sectors will ‘vote with their feet’ for low-priced electricity states. The price plays a more decisive role in modal choice although the physical extent of natural gas supply in a country is a crucial factor in modal choice. Our proposition is that the price of electricity is very influential on the (in)efficiency of its end-use.

2.2 Incomes

For the panel of OECD Member States to own similar incomes we impose the constraint that GDP must exceed 15,000 US$-1995PPP per capita for all years of the period considered. This reduces the data set from 30 to 21 countries, excluding the East European countries Slovak Republic, Czech Republic, Poland, Hungary, but also Turkey, Greece and Portugal, Mexico and Korea Figure 3 shows the scatter between electricity intensity and GDP per capita in 1997 of the 30 OECD countries, and visualizes the truncation of the data set.
Due to missing data on prices and on sector structure variables we must also omit Canada, Iceland, Ireland, Luxembourg (an outlier in figure 3), Norway, Switzerland and the United Kingdom. Because after 1997 data on electricity prices are also lacking for Australia and Sweden, 1997 is retained as the most recent year with sufficient panel data (14, marked with triangles in figure 3).

Figure 3: Scatter of Electricity Intensity versus GDP per capita (1997)

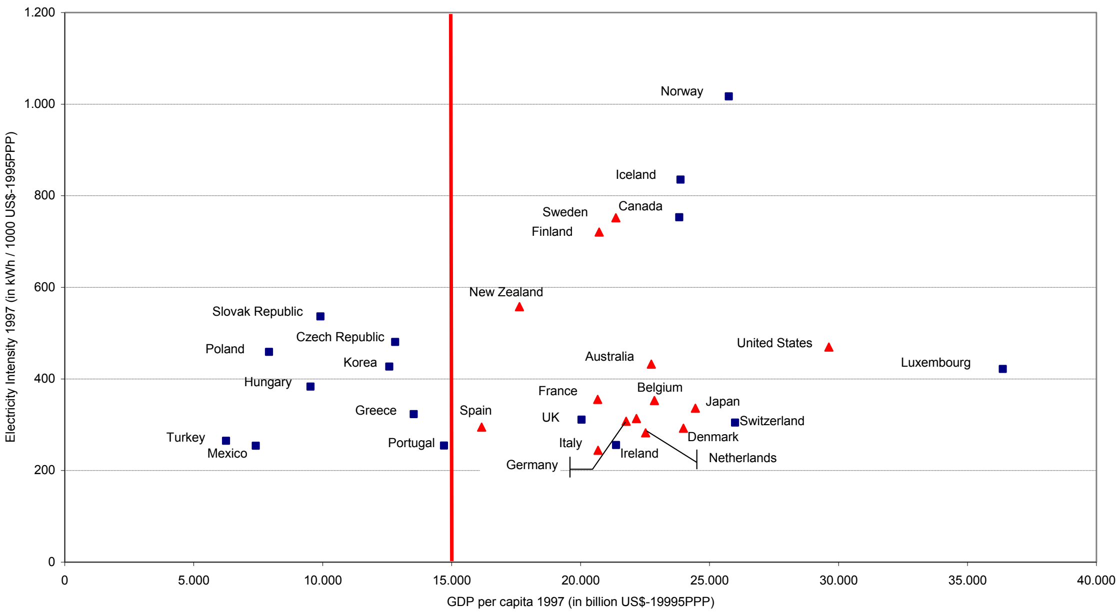


Table 1: Descriptive Statistics of GDP per capita (1997)

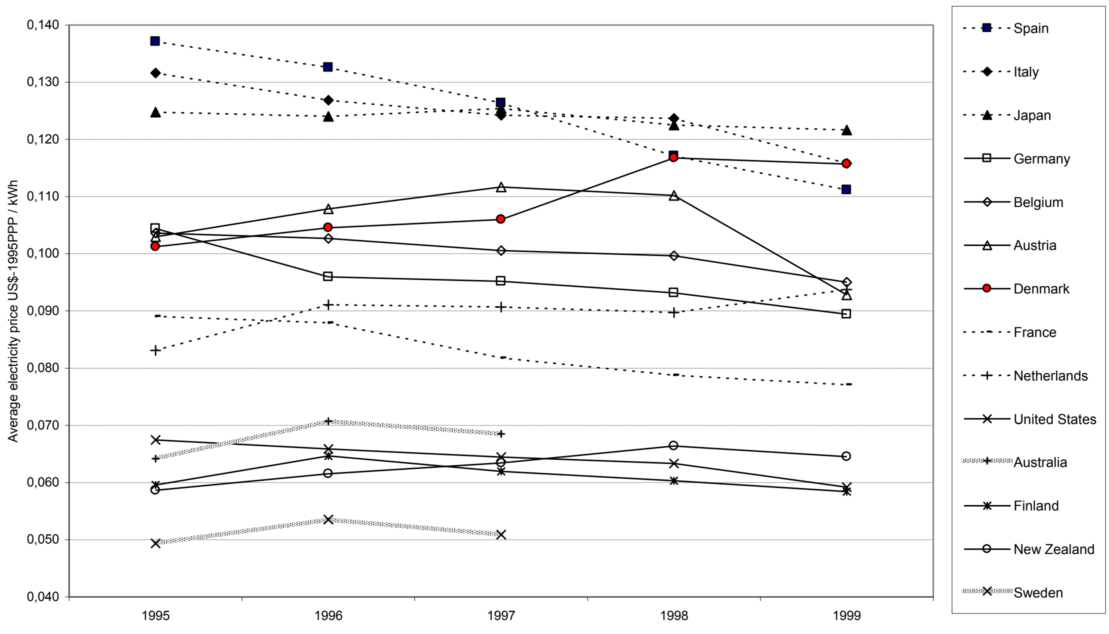
GDP per capita (US$-1995PPP)	*30 OECD countries*	*21 OECD countries*	*14 OECD countries*
Mean	19,317	23,080	21,951
Standard Error	1,275	916	840
Median	21,042	22,521	21,962
Standard Deviation	6,987	4,198	3,144
Range	30,116	20,230	13,469
Minimum	6,273	16,159	16,159
Maximum	36,390	36,390	29,628
Confidence Level(95,0%)	2,609	1,911	1,815

By truncating the data set, income no longer is an explanatory variable of observed differences in intensities. Table 1 shows that the final 14 country set is symmetric in income per capita (mean and median about equal), and that the standard deviation is limited although the range at 13,469 $/capita (Spain-USA) remains significant.

2.3 Electricity Prices

Figure 4 shows the average prices of electricity over the years 1995-1999 for the subset of 14 countries. The average price is the weighing of the domestic and industrial electricity end-use prices with the respective shares in end use consumption. Some countries show a *slightly* decreasing trend over the 1995-1999 period (Japan, United States, Finland) and some a *more pronounced* decreasing trend (Spain and Italy in particular, but also France, Belgium and Germany). Others have seen an increase in their average electricity price, most notably Denmark, but also the Netherlands and to a lesser extent New Zealand. Price information for Australia and Sweden (the latter has the lowest average electricity price) is only available for the 1995-1997 period, during which time the prices seemed relatively stable.

Figure 4: Yearly average electricity prices (US$-1995PPP) over the period 1995-1999 for fourteen OECD countries



2.4 Regression of Electricity Intensity on Electricity Price.

By analysing electricity intensity as a normal economic good, we accept two propositions: (1) people want to maximize number and quality of 'activities' they get from the \$GDP, and (2) people prefer a quiet life above awareness about efficiency. The first proposition is in line with arguments that people are interested in goods and services, not in invisible, untouchable and dangerous kilowatt-hours, whose demand therefore is fully derived. The second proposition is not generally accepted, and marks the gap between the observed behavioural approach and the normative behavioural approach regarding the implementation of efficiency measures. In this section the demand for intensity is estimated. In the following section we separate the demand for inefficiency.
The variance in observed electricity intensities among countries (figure 1) is explained by the variance in observed electricity prices (figure 4). Statistical estimates are reported for the year 1997 only. Observations over 1995-1999 reveal high stability in the data, assuring that the results based on a single year are representative.

The electricity intensities of the 14 OECD countries are regressed on the average end-use prices of the same year 1997[5]. A hyperbolic function $EI = \alpha.P^{\beta}$ [EI = Electricity Intensity; P = Price] has been estimated, leaving 12 degrees of freedom. This specification $EI = \alpha.P^{\beta}$ means that β equals the price elasticity of electricity intensity and that the %-share of the GDP that is spent on the electricity bill is given by $\alpha.P^{\beta+1}$. In particular, when $\beta \sim -1$ this 'budget share' is independent of the height of the price and given by the α parameter.

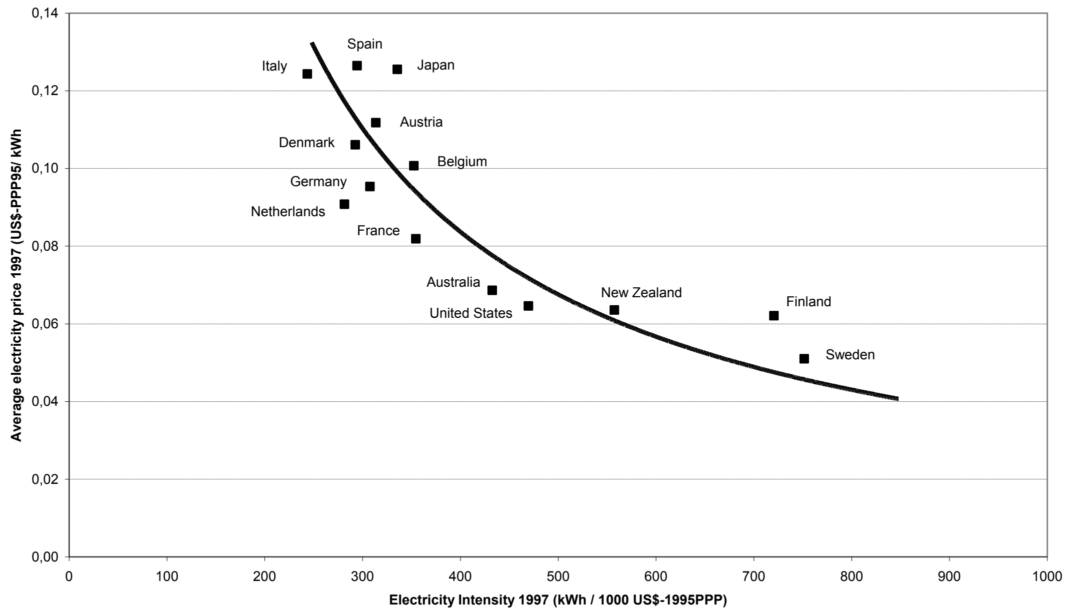
Results of the regression are:

Price elasticity β		Constant α		R^2	Sum Squares of regression
estimate	standard error	estimate	standard error		
-1.04	0.15	3.41	0.37	80	1.28

Figure 5 shows the 1997 observed market equilibriums (squares) in the 14 countries and the fitted curve (solid black line).
The statistical results indicate that the assumed hyperbolic relationship between average electricity prices and electricity intensity of an economy is most likely true, and that it even approaches the form of an orthogonal hyperbole given that the elasticity is near to -1.

Figure 5: The 1997 demand curve for electricity intensity (wealthy OECD countries)

[5] The electricity intensity attained in a given year is embodied in technologies and practices that have been growing over years and cannot be explained simply by the actual price noted in the year of the cross-sectional analysis. Therefore we tested the impact of composed prices $P = \Sigma \lambda j \ Pj$ with j referring to preceding years. The statistical results did not improve. This is due to the electricity end-use price stability over time. Countries are clearly locked in a given (low or high) end-use price (including tax) corridor and it is not evident how to change altitude on this flight (except that declining seems easier than mounting). This observed price stability emptied the statistical significance of the tested weighed price constructs.



3. THE DEMAND FOR ELECTRICITY INEFFICIENCY

As discussed above, electricity intensity is composed of three factors: structure, modal choice and technical inefficiency. One may argue that the significant price elasticity shown in section 2 is due to shifting structures within wealthy economies or is due to a massive substitution for or by electricity because of high or low electricity prices. In order to assess the impact of price on technical inefficiency, we normalise the data for differences in structure of the economies (3.1), and additionally for modal choice between electricity and other energy use (3.2). The demand curve estimated in 3.3 is the one for electricity inefficiency.

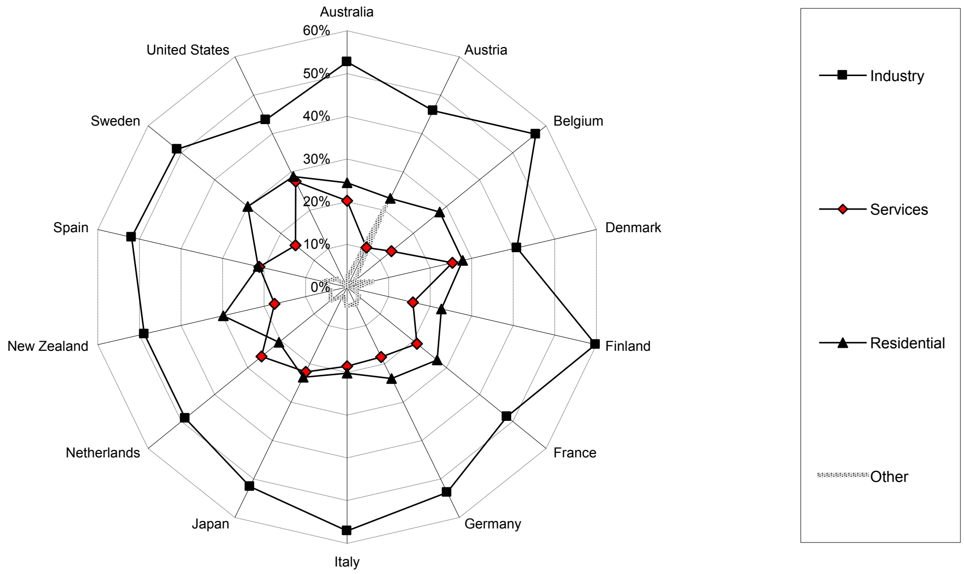
3.1 Normalising for Varying Structure of the Economies

The same quantity wealth as GDP/capita may cover quite different economic structures with diverging energy demanding activities. Divergent economic structures are assessed as main factor of divergent energy intensity scores of countries at an uneven state of development [Medlock and Soligo, 2001].

Figure 6 shows the 1997 shares in electricity consumption of industry, services, households and other. Total electricity consumption of the industry sector includes total electricity consumption of the energy sector, including the electricity transmission and distribution losses. The ‘Other’ category encompasses agriculture, the transport sector and non-specified electricity consumption, accounting for less than 10 % of total electricity consumption (the outlying position of Austria is due to a statistical problem).

In all countries the industry sector with around 50% covers the largest share in total electricity consumption. Some notable exceptions are Belgium, Italy and Finland (higher than average), and the Unites States and Denmark (lower than average). The shares of households and services show a more varied pattern.

Figure 6: The Shares of 4 Sectors in Electricity Consumption in 14 OECD countries (1997)



To estimate the electricity intensity with constant structure, following equation [Bosseboeuf *et al.*, 2003] is applied with as reference the average of the 14 retained OECD economies:

$$EI_i^{cs} = \frac{EC_{industry,i}}{VA_{industry,i}} \frac{VA_{industry}^{reference}}{GDP^{reference}} + \frac{EC_{services,i}}{VA_{services,i}} \frac{VA_{services}^{reference}}{GDP^{reference}} + \frac{ECi}{HFCE_i} \frac{HFCE^{reference}}{GDP^{reference}} + \frac{EC_{other,i}}{GDP_i}$$

Where (monetary values in billions US$-1995PPP):

EI_i^{cs} = Electricity Intensity of a country i with constant structure (kWh/$)

$EC_{industry,i}$ = Electricity Consumption of industry in country i (kWh)

$VA_{industry,i}$ = Value Added of industry in country i ($)

$VA_{industry}^{reference}$ = Value Added of industry of the *reference* ($)

GDP_i = Gross Domestic Product of country i ($)

$GDP^{reference}$ = Gross Domestic Product of the *reference* ($)

$HFCE_i$ = Household Final Consumption Expenditures of country i ($)

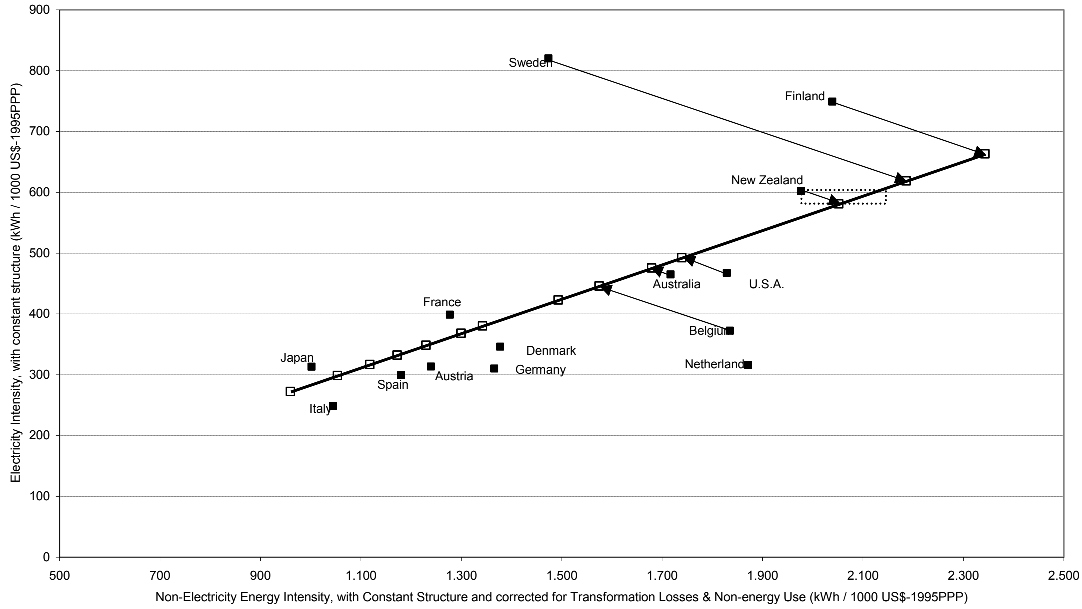
$HFCE^{reference}$ = Household Final Consumption Expenditures of the *reference* ($)

In this normalisation process all variables in this list interact, and the final outcomes may contradict prior expectations about higher or lower values for particular countries.

3.2 Normalising for Modal Choice

Modal choice is between either electricity or non-electric energy use. The latter is defined as total primary energy supply (TPES) minus total electricity consumption, and minus energy transformation losses of (both public and on site) electricity plants and co-generation plants, and minus fuel use for non-energy purposes. A priori one could expect that nations parsimonious in electricity consumption show higher non-electric energy intensities (and vice versa), but this expectation is not confirmed by the data, on the contrary: figure 7 shows a positive correlation between both intensities. The slope of the ray shown is assessed at 0.27 (standard error 0.02 with 13 degrees of freedom; $R^2 = 32$). The lower R^2 is due to some clear outliers mainly because of the (non-)availability of natural gas distribution in these countries. The farthest outlier Sweden owns no gas distribution but expanded its power system significantly after the 1970's oil crisis.

Figure 7: Correlation between electricity intensity and non-electric energy intensity in 14 OECD countries (1997)



The normalisation for modal choice is based on the assumption that everywhere 0.27 electric kWh substitute for 1 kWh non-electric energy, and vice versa. Graphically the normalisation brings every country on the regressed ray with slope 0.27 by following a diagonal with slope -0.27 through the data point (see the dashed arrows in figure7).
The 'overshooting' in this normalisation follows from the heterogeneity of reasons why modal choices differ (availability of natural gas being an important factor but not the only one).

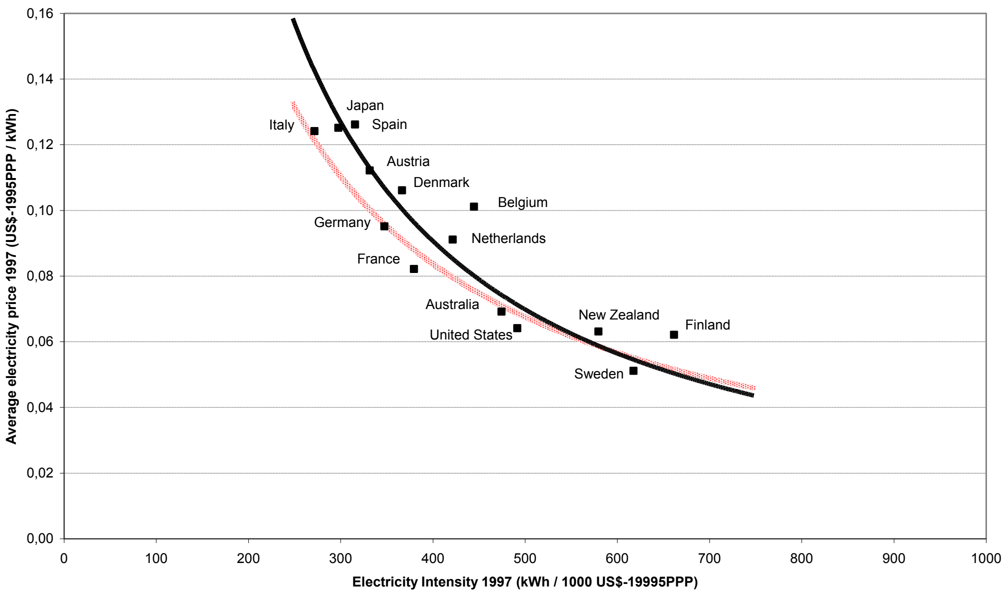
3.3 The Demand Curve for Electricity Inefficiency

After the two step normalisation, the remaining variance in the panel data reflects the differences in technical efficiency in using electricity by the wealthy OECD nations. Testing the hyperbolic demand curve $EE = \alpha.P^{\beta}$ [EE = Electric Inefficiency; P = Price] provides as results of the regression (12 degrees of freedom):

Price elasticity β		Constant α		R^2	Sum Squares of regression
estimate	standard error	estimate	standard error		
-0.86	0.11	3.94	0.25	86	0.87

The estimated demand for inefficiency curve is shown in figure 8, with in the background the demand for intensity curve (see figure 5). The former has a steeper slope than the latter, but the dominant role of the electricity price in inciting end-users to efficiency is obvious.

Figure 8: The 1997 demand curve for electricity inefficiency (wealthy OECD countries)



4. CONCLUSION

Electricity intensity stays very central in the planning of power capacity expansion. The IEA investment outlook is based on the invariability up to 2030 of the world average electricity intensity of about 320 kWh per 1000 US$-1995PPP GDP observed over the last three decades of the 20th century (see figure 1). Many academic and policy papers address the evolution of energy and electricity intensities over time in a variety of countries and states [Ang, 1997; Medlock&Soligo, 2001; Schipper et al, 2001; Bernstein et al, 2003]. The question why intensities vary so much between otherwise similar countries got no satisfactory answer. For contributing to this answer this article draws on the basic economic theory pointing to price, income, preference and technology as main determinants of consumer and producer behaviour. By selectivity in our IEA/OECD 1997 panel data we exclude income and technology as explanatory variables: only wealthy OECD nations with full access to electricity technology are considered.

We model intensity and inefficiency as demanded "goods" to reflect end-user preferences for a plethora of electric services and for a quiet life. Intensity is the product of structure (activities per $GDP) times modal choice (electricity versus non-electric energy use) times technical inefficiency (kWh used per activity). A demand curve for *electricity intensity* is estimated revealing a statistically significant long-run price elasticity of -1.04. Because one cannot observe *electricity inefficiency* in the aggregate, we normalise the observed intensities for structure and for modal choice. Testing a hyperbolic demand curve on the normalised panel data shows a long-run price elasticity of the demand for inefficiency of -0.86.

The results confirm that "prices do matter" most, also in the market of the dispersed, diffuse and hidden use of electricity. With the elasticity around one, the share of GDP spent on electricity is not higher for a high-price than for a low-price country. It follows that overall and lasting improvement in technical efficiency must be supported by a deliberate pricing (tax) policy and cannot be left to efficiency campaigns with soft instruments.

Also such strategic tax policy (implemented wisely over a planned period of time) will not harm the economies but make them more efficient. When the wealthiest nations raise their electricity efficiency to the best practices of fellow countries (that may further improve in performance), and when the rest of the world follows this example the investment needs in power supply can be curbed significantly. This will help a lot in mitigating climate change. The demand curves we estimated should also be considered in international negotiations when assigning emission quota to various countries. One can argue that the quota should be less stringent for countries that already attained a high efficiency level due to tax policies in the past.

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Appendix: Data sources

Variable	Source: CD-ROM	Source: Data series	Original Unit
Total Primary Energy Supply (TPES)	IEA Electricity information 2002	Energy consumption, GDP, population and TPES by source	Mtoe
Electricity Prices for Households	IEA Electricity information 2002	Electricity Prices for Households in US dollars / kWh converted with PPP and PPP in national currency / US dollars	US dollars / kWh converted with PPP
Electricity Prices for Industry	IEA Electricity information 2002	Electricity Prices for Industry and Households in US dollars / kWh and in US dollars / toe	US dollars / kWh
Electricity consumption (EC)	IEA Energy Statistics of OECD countries (2001 edition)	Basic Energy Statistics	GWh
Electricity Transformation Losses	IEA Energy Balances of OECD countries (2001 edition)	Extended Balances – Total (Electricity Plants & Combined Heat and Power Plants)	Ktoe
Gross Domestic Product (GDP)	OECD Economics	Annual National Accounts – comparative tables based on exchange rates and PPPs	US dollars at the price levels and PPPs of 1995
Value Added (VA)	OECD Economics	National Accounts of OECD countries – Detailed Tables, Volume II, 1970-2001 (2002 prov) – Aggregates in millions of national currency	National currency at constant 1995 prices
Household Final Consumption Expenditures (HFCE)	OECD Economics	National Accounts of OECD countries – Detailed Tables, Volume II, 1970-2001 (2002 prov) – Aggregates in millions of national currency	National currency at constant 1995 prices