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authoritative analysis

Electricity vs. total energy demand

Analysis of the changing composition of demand

Report to the Electricity Commission

June 2005

Preface

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NZIER was established in 1958.

Authorship

This report has been prepared at NZIER by Simon Hope and John Stephenson.

8 Halswell St, Thorndon

P O Box 3479, Wellington

Tel: +64 4 472 1880

Fax: +64 4 472 1211

econ@nzier.org.nz

www.nzier.org.nz

Executive Summary

The Electricity Commission has undertaken some initial investigation into the relationship between total energy consumption (demand) and electricity demand for the commercial and industrial sectors in New Zealand. This investigation has shown a significant shift in the proportion of total energy demand made up by demand for electricity in the commercial and industrial sectors. Since 1975 electricity consumption has moved from around 36% of total energy demand to around 66% in recent years.

These apparent changes in the underlying composition of total energy demand have the potential to impact on the way the Commission produces its forecasts of electricity demand.

Given these observations, this report set out to answer a number of key questions:

- What can we conclude about the changing composition of energy demand, and the remaining potential impact for growth in the share of electricity demand?
- What does this mean for the Electricity Commission's forecasting methodology?
- What do we recommend the Electricity Commission do? (re: methodology)

The approach adopted was to undertake an initial high level analysis of the available data, followed by an analysis to assess whether there were any structural breaks within the series. This was complemented with a more formal analysis of a series of possible demand functions for electricity, in order to assess what we could surmise about the demand for electricity and its share of total electricity demand.

The analysis produced a number of key conclusions:

- The raw data indicate that in certain sectors some substitution between fuels has occurred – sectors such as food processing and building and construction for example where oil demand was replaced by demand for electricity from the early 1990's.
- For commercial gas and coal demand, and industrial coal demand there appears to be some evidence of structural breaks in demand. These tended to be in the mid to late 1980's/early 1990's. This does not however allow us to decompose why the breaks may have occurred in terms of the changes that occurred in the key drivers of demand. We cannot say whether such a change may have been driven by a substitution effect between fuels, changing technology or possibly a change in the relative price of the fuels for example.

- Substitutability between fuels is not likely to be captured by response to the price of other fuels alone as modelled. Rather, the decision to switch would depend on the overall economics of using one particular fuel in producing a product, as opposed using an alternative. Looking at the fuel alone does not capture the interaction between the price of fuel, the capital which uses the fuel, and the total cost of producing the product, and whether it is rational economically.
- A number of factors could potentially drive changes in shares, substitution being just one. The importance of knowing the magnitude (and drivers) of each level of demand cannot be underestimated.
- If the focus is on the shares, rather than the levels (i.e. a top down approach) a major risk is assuming that total energy demand is a system 'in-and-of itself'. What this means is that we cannot assume that an increase in a particular share will necessarily be directly responsible for an equal and opposite reduction in share of another fuel (or fuels). It may be the case if the substitution is direct i.e. one fuel for another, but there are so many other factors outside of perfect substitution that to assume so would be assuming away a number of key factors which could affect the level of demand, and thus the shares. Given that it is generally accepted that there is some long-run relationship between demand for output and for fuel demand, working from a total energy basis may miss out on the characteristics of demand for each fuel, by industries which vary considerably in their reasons for using fuel, and the processes in which they use (and are able to substitute between) fuels.
- Our ability to assess the remaining potential for the share of electricity demand to continue to increase is limited. At a high level, the limited data on sectoral industrial use by fuel does suggest some substitution has occurred, with oil demand in some sectors being replaced with electricity demand. This, in conjunction with expectations of an easing in growth for a number of sectors, indicates that the potential for electricity demand to continue to increase its share of total energy demand may be limited. This is based on consideration of a number of selected industries where some data is available, and is considered in isolation of a number of factors (relating to drivers of the level of demand) which we feel should be granted more attended than the share necessarily.
- Our estimates of a demand system for electricity were not very successful. The econometric results achieved were generally inconsistent with economic theory and achieving econometric significance would have required abandoning economic intuition. However, we found that these problems are likely to have arisen due mainly to changes in equilibrium relationships in energy demand over time. The analysis tended to indicate little response in electricity demand to price. In terms of response to the price of other fuels, we would expect that as the relative price of electricity to other fuels increases, that demand for electricity would decline. These relationships were not able to be formally identified.

- Our econometric (state space modelled) estimates of equilibria in energy demand suggest that electricity demand is becoming increasing de-linked from demand for other types of energy/fuels. In addition, our estimates suggest that electricity demand in both commercial and industrial sectors are converging towards a (more) stable equilibrium state relative to production/GDP.
- Overall, while there are widely accepted limitations to producing demand estimates for individual fuels and aggregating them, the approach seems likely to incorporate more of the overall long run relationships between drivers of fuel demand, than could be gained from using a top down approach. The top down approach assumes an interpretation of total demand that may introduce more complications than it adds. Models of individual fuel demands using key drivers may only be able to explain a share of the change in fuel demand using major macro variable such as output or capital stock, but they are likely to capture important long run equilibrium relationships which give good indication of magnitude and direction to levels of demand (and which there is some evidence that they may have converged towards a more stable equilibrium as noted above).
- In terms of recommendations for the Electricity Commission, we suggest continued use of the existing general modelling approach, with a focus on continued development over time. Particular emphasis should be placed on seeking to understand demand by industry for particular fuels, rather than for fuels by industry. This could be done through consideration of the relative energy intensities of different sectors.

Contents

Figures

Tables

1. Introduction

1.1 Background

The Electricity Commission (the Commission) has undertaken an initial investigation into the relationship between total energy consumption (demand) and electricity demand for the commercial and industrial sectors in New Zealand.

This investigation has shown a significant shift in the proportion of total energy demand made up by demand for electricity in the commercial and industrial sectors. Since 1975 electricity consumption has moved from around 36% of total energy demand to around 66% in recent years.

These apparent changes in the underlying composition of total energy demand have the potential to impact on the way the Commission produces its forecasts of electricity demand. At present, the Commission (and a number of other parties) forecast electricity demand using a 'bottom up' approach, estimating electricity demand from the aggregation of three sub-components of demand – residential, light industrial and commercial, and heavy industry demand. While this is a widely used methodology which allows for the inclusion of component specific drivers of demand, there is some risk that this does not take full account of the changing proportion of total energy demand that electricity demand forms. The Ministry of Economic Development adopts a more 'top down' approach, whereby they forecast total energy demand, and individual fuel demands subsequently.

The scope for a continuation of this changing composition could effectively act as a constraint on the Commissions' aggregated growth forecast. The impact of users switching between fuel types and changes in the industry make-up of those users could also determine just how much scope there is for electricity demand to continue to increase as a proportion of total energy demand. For example, could it be the case that rapid growth in the relatively electricity intensive commercial sector has helped change the composition of demand, or that changes in the product mix of some major fuel users has contributed to this effect?

1.2 Scope of analysis

This report presents the findings of analysis of the changing composition of total energy demand, in particular focussing on the clarifying the changing contribution of electricity demand, possible reasons for the changes, and identifying the scope for a continuation of the change.

The analysis is approached in three different ways, with the major objective of the combined analysis being a recommendation to the Commission as to the extent of this issue as a problem for their current forecasting methodology, and a subsequent recommendation as to a way forward.

The three strands of analysis covered in this report are:

1. An initial high level compositional analysis, with some testing for structural breaks in the demand series'

2. An analysis of a demand function for electricity

3. A look at what we might expect in the years ahead, given the first two steps

2. The changing composition of demand

2.1 High level compositional analysis

Data from the Ministry of Economic Developments' Energy Data Files provide a useful starting point for looking into the demand for various (energy) fuels by sub-groups of the industrial and commercial sectors where possible.

While consistent sub-group data is only available for the industrial sector, it still provides a useful initial examination of the changing demands over time.

In general, there is a lack of consistent long-term information on the demand for different energy types. This is likely to be, in part, due to the small number of businesses within some sectors, and thus the potential for identification of commercially confidential information.

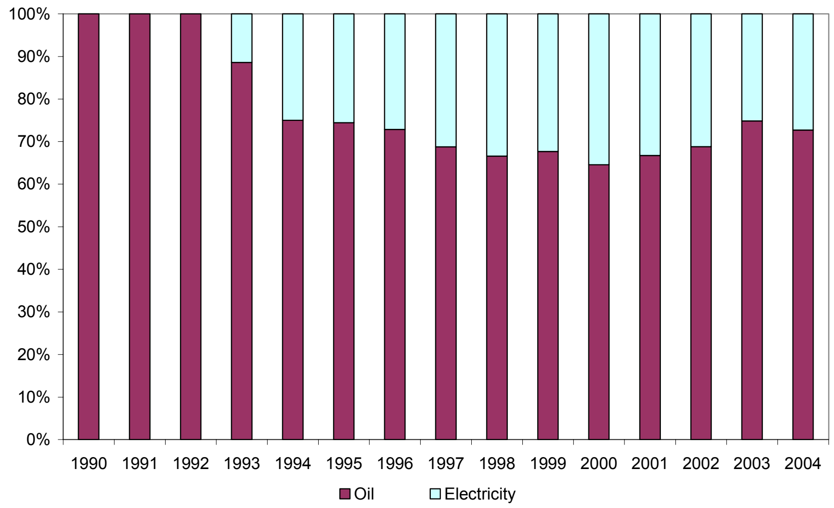
Figure 1 through Figure 4 below show the composition of energy demand (coal, gas, oil and electricity) for four sub-groups of the industrial demand category who use more than one major fuel type – other primary industries (those other than agriculture, hunting and fishing, such as forestry), food processing, basic metals, and building and construction.

For the other primary industries, food processing and building and construction sectors, there is a marked increase in the use of electricity over the period shown balanced by a reduction in the use of oil. For the other primary industries and building and construction sectors, the substitution from oil to electricity is particularly evident in the mid 1990's.

For the basic metals sector, the use of oil (though relatively minor) was phased out early in the 1990's, being substituted for increased use of electricity and coal.

Figure 1 Energy demand composition for the industrial sector – other primary industries*

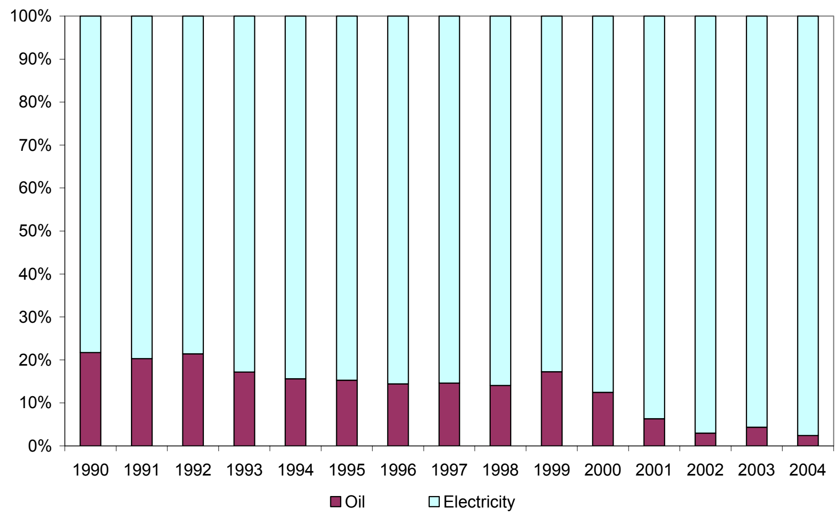
* Other than agriculture, hunting & fishing
Gross demand, PJ – March years



Source: Ministry of Economic Development

Figure 2 Energy demand composition for the industrial sector – food processing

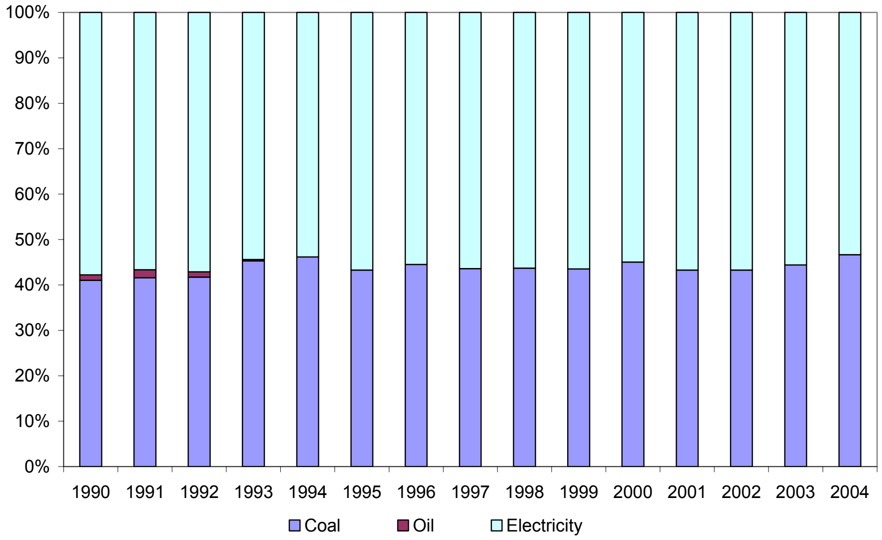
Gross demand, PJ – March years



Source: Ministry of Economic Development

Figure 3 Energy demand composition for the industrial sector – basic metals

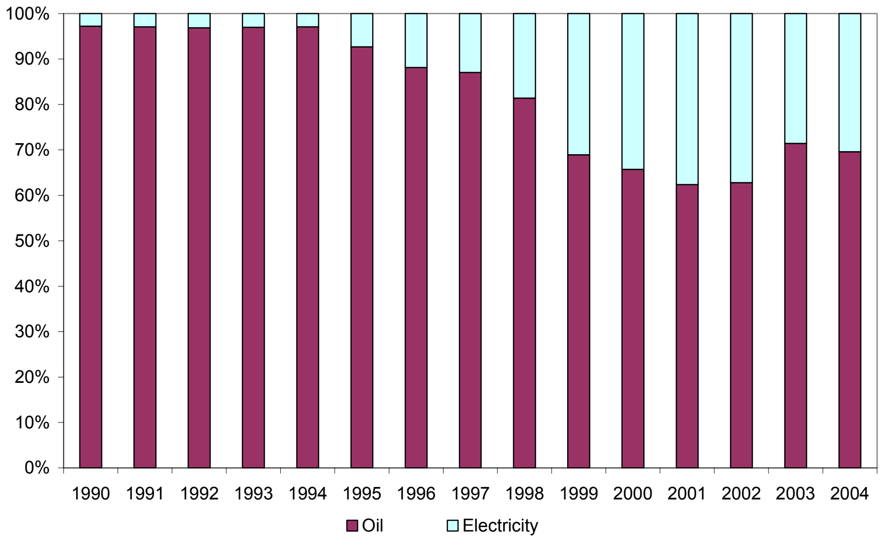
Gross demand, PJ – March years



Source: Ministry of Economic Development

Figure 4 Energy demand composition for the industrial sector – building and construction

Gross demand, PJ – March years

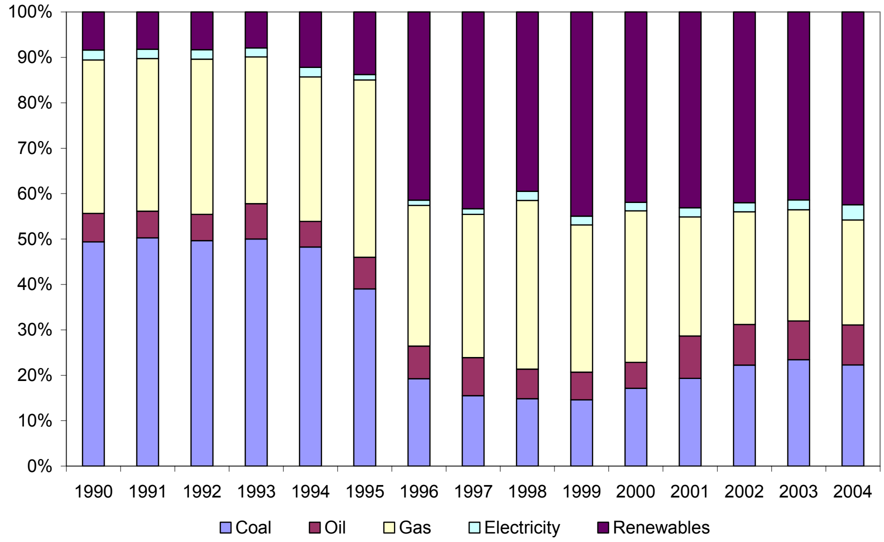


Source: Ministry of Economic Development

Figure 5 below indicates the compositional demand for energy the 'Unallocated' sectors of the industrial aggregate grouping. For these sectors, the use of oil and electricity has stayed relatively constant over the 1990 – 2004 period, however the proportion of demand made up by renewable fuels increased significantly from the mid 1990's. This came at the expense of demand for gas, but more prominently for coal, which fell from nearly 50% of demand in 1990 to less than 20% a decade later.

Figure 5 Energy demand composition for the industrial sector – unallocated sectors

Gross demand, PJ – March years

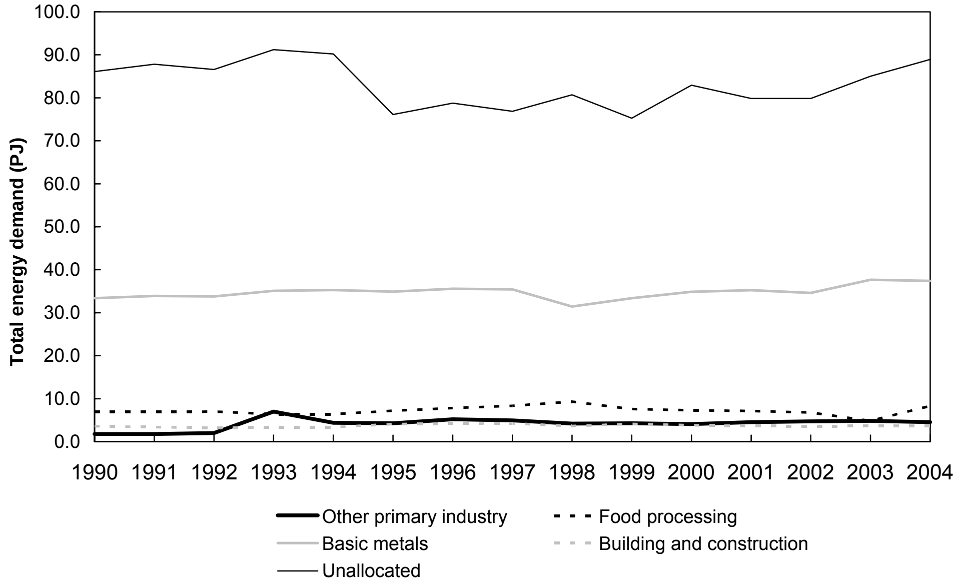


Source: Ministry of Economic Development

The figures above give a useful indication as to the compositional shares of demand for various fuel types, but do not indicate the relative levels of demand by the various sectors who use multiple fuel types.

Figure 6 below does this by presenting the total energy demand in PJ for users of more than one major fuel type. The combined Unallocated groups are a significant source of total energy demand which has been growing in level since the late 1990's. The basic metals sector is also a significant source of energy demand – the biggest of any individual sector shown at around 35 PJ per annum.

Figure 6 Total energy demand – for users of multiple fuel types
Gross demand, PJ – March years

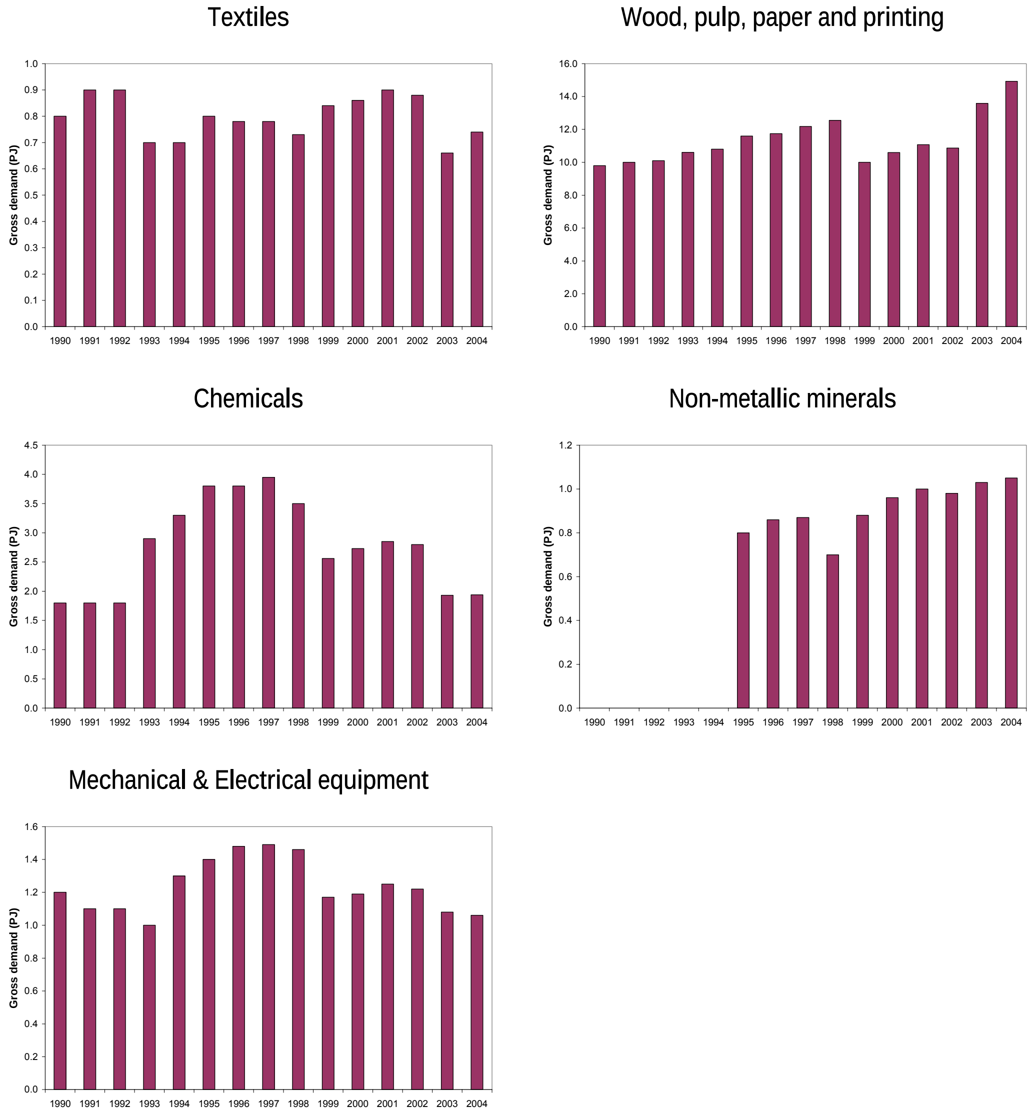


Source: Ministry of Economic Development

Within the aggregate industrial grouping there are a number of sectors who demand only electricity. These include the textiles, wood, pulp, paper and printing, chemicals, non-metallic minerals and mechanical & electrical equipment sectors. Their changing patterns of demand for electricity (in PJ to be comparable) are shown below in Figure 7.

Clearly, the wood, pulp, paper and printing sector is a fairly significant final user of electricity. The demand for the other sectors shown has been somewhat changeable, although there appears to have been strong demand for electricity by some of the sectors through the middle of the 1990's.

__Figure 7 Electricity demand by industrial sub-group__
Sub-groups of the industrial category. Gross demand PJ – March years.



Source: Ministry of Economic Development

Although sectoral breakdowns of demand for energy by fuel type are available for the industry aggregate from 1990, only a commercial aggregate level figure is available in a consistent series.

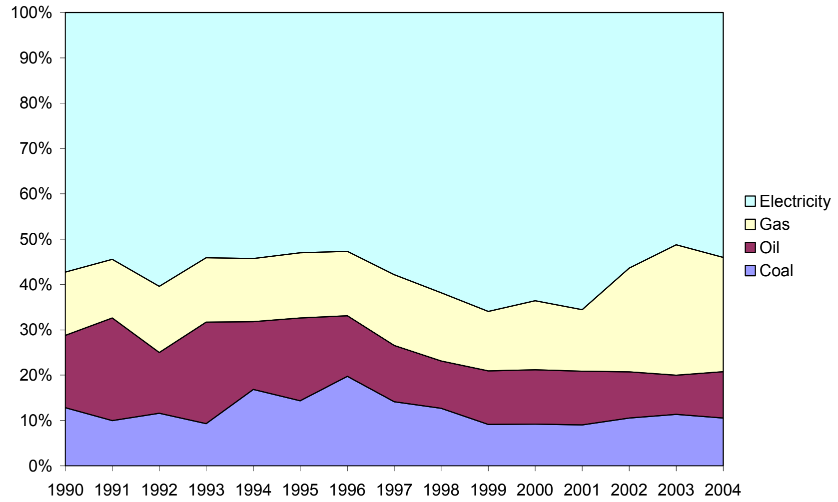
Figure 8 below shows the shares of total energy demand for the commercial sector in aggregate. The combined shares for electricity and gas have grown to nearly 80% of total energy demand in 2004, from around 70% in 1990. This has come at the expense of demand for coal and oil, in a similar fashion to the industrial sectors. Gas demand has increased its share noticeably for the commercial aggregate sectors since 2002.

Total demand for energy by the commercial sector in aggregate grew from around 35 PJ per annum in the early 1990's to over 50 PJ per annum in

2004. While demand was fairly steady over the early 1990's it has grown significantly since 1999, at an average annual rate of around 6%.

Figure 8 Compositional energy demand by the Commercial sector in aggregate

Gross demand, PJ – March years



Source: Ministry of Economic Development

Note: Excludes renewable energy demand (0.17 PJ in 2004)

2.2 Testing for structural breaks

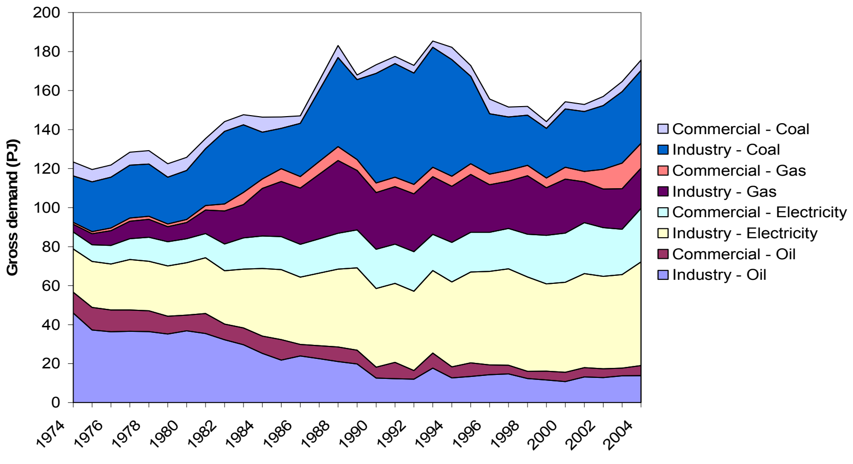
The previous section gave us a preliminary view of the changing levels and shares of demand for various major fuel types in the aggregated commercial sector, and for some industrial sub-sectors. In this section we take this idea further by looking at the possibility of identifying periods when structural breaks occurred within the demand series'.

As we noted earlier, the sub-sectoral breakdowns by fuel type within the industrial sector are only available from 1990, so for this analysis we are limited to using an aggregated industrial sector, and aggregated commercial sector demand by fuel type to gain a longer time series. Given this longer time series (from 1974) we gain valuable information as to longer term trends, along with the useful industrial/commercial trends in demand.

We begin by looking at the longer time-series information for the various fuel types for the aggregated industrial and commercial sectors.

Figure 9 shows a demand 'stack' for energy, with Figure 10 showing the same information in terms of a compositional chart (shares of a total). Oil demand by industry and commercial users has declined in both level and share terms since the early 1970's, displaced by growing shares in the other fuel types. Industrial use of gas, and electricity demand by both commercial and industrial users has been quite strong in its growth in level and share terms over the period shown. Industrial use of coal increased quite sharply at the very end of the 1980's for a 3 – 5 year period, partially displacing use of a number of the other fuel types.

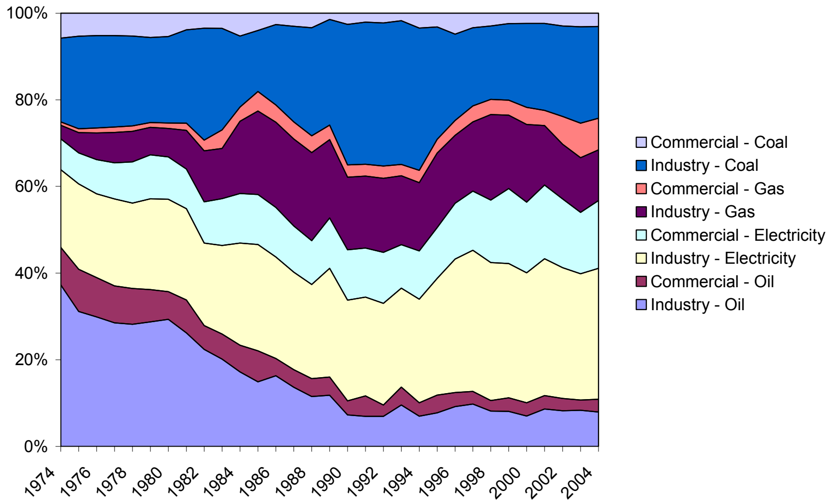
Figure 9 A demand 'stack' for energy
Gross demand (PJ)



Source: Ministry of Economic Development

Figure 10 Composition of demand

Gross demand (PJ)



Source: Ministry of Economic Development

While the relatively sharp rise in industrial coal demand during the short period identified gives us a preliminary indication that there may be a point where a break may have occurred, in general there don't appear to be any other significant shifts in composition during the period. Both in terms of the levels of demand, and the shares, the patterns of demand appear fairly steady.

The ability to identify significant shifts however, is somewhat clouded using the data as it stands, given that there is a lot of noise surrounding the raw data series. Before being able to make inferences about any apparent shifts in demand, it is necessary to isolate the trends in the demand series'.

2.2.1 Hodrick-Prescott filter

In order to try and gain a better perspective on the trends underlying the individual commercial and industrial fuel demands (by fuel type – gas, oil, coal and electricity) we employed a method called a Hodrick-Prescott Filter. This widely used tool allows us to obtain a smooth estimate of the long-term trend component of a series, which should assist us in attempting to identify any structural breaks that occur in the individual demand series.

The trend is isolated via a two-sided linear filter which computes the smoothed series s of y by minimising the variance of y around s, subject to a penalty that constrains the second difference of s i.e. it chooses s to minimise:

$$\sum_{t=1}^{T}(y_t - s_t)^2 + \lambda \sum_{t=2}^{T-1}((s_{t+1} - s_t) - (s_t - s_{t-1}))^2$$

The parameter λ is the penalty/smoothing parameter and controls the smoothness of the series, and as λ approaches ∞, s approaches a linear trend.[1]

Figure 11 below shows the Hodrick Prescott trend component for the levels of demand (as opposed to the shares) for industrial and commercial users by gas, oil, electricity and coal fuel types.

For oil use, the clear trend for both commercial and industrial users is that of decline, with industrial oil use seemingly having reached a plateau of around 13 PJ per annum since about 1995.

The rise in coal demand in the late 1980's/early 1990's earlier identified is more defined in the filtered trend series, interrupting an upward trend in demand. Commercial use of coal trended downward till the early 1990's where, like industrial oil use it seems to have reached a plateau, of around 5 PJ.

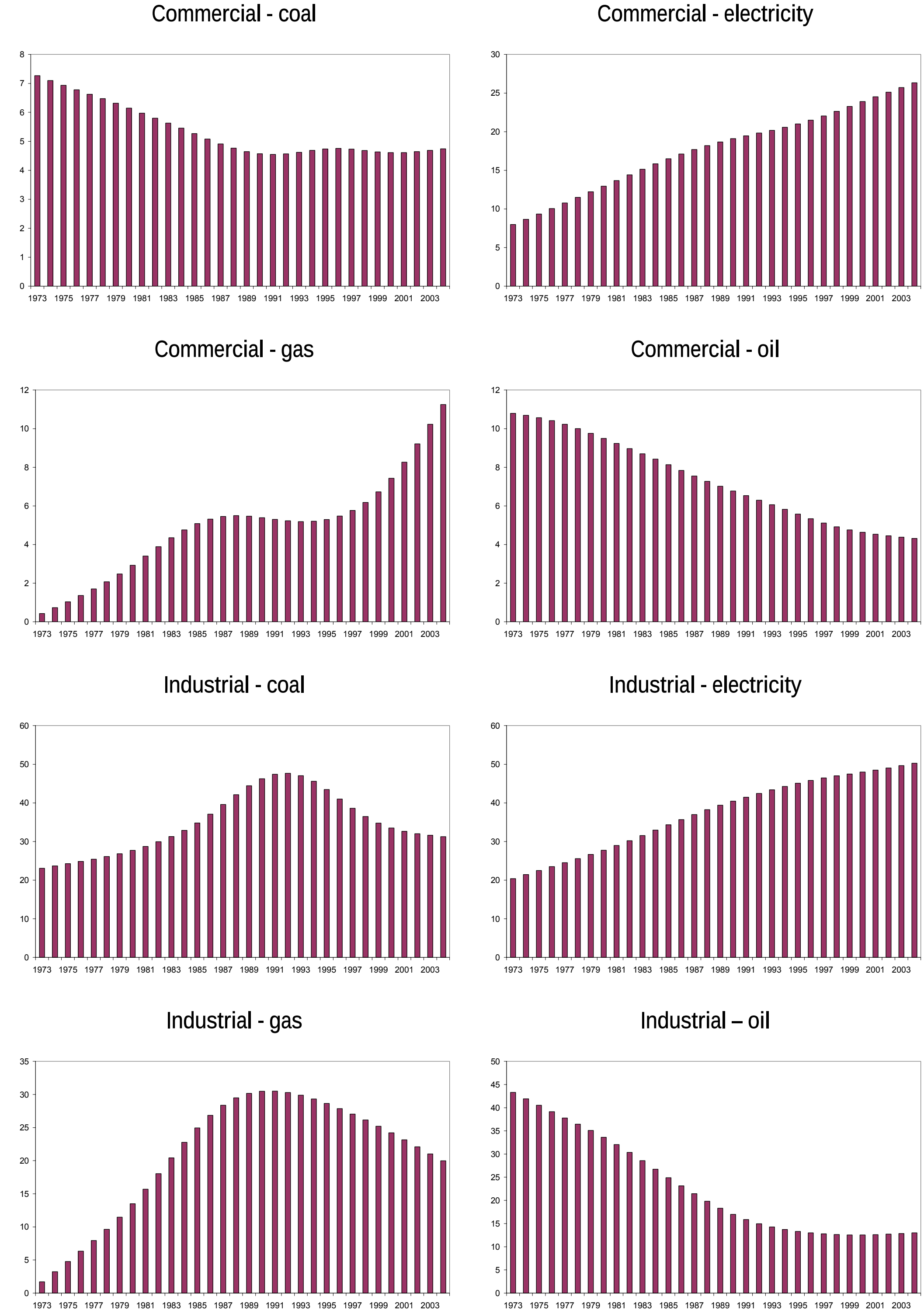
The difference in trend between gas use in the industrial and commercial sectors is particularly interesting. For commercial use, an easing upward trend in the early to mid-1990's has been superseded by a strong increasing upward trend. The trend in industrial use peaked in around 1991 after growing strongly, but has now declined in a fairly steady manner.

The trends in electricity use by commercial and industrial users are fairly similar, both have relatively steady upward trends over time. In the last 20 years, the trend in commercial electricity use has grown over 60%, with the equivalent figure for industrial use growing by nearly 50%.

[1] www.eviews.com

Figure 11 Hodrick-Prescott trends

Gross demand (PJ) – Commercial and industrial by fuel



Source: Ministry of Economic Development, NZIER

From these trends, we can visually identify where there may be potential points of interest – points where structural breaks may occur, which could represent a number of underlying factors.

On this basis, the coal demand series (both for commercial and industrial use) and gas demand (again, both commercial and industrial) series seem to indicate some alterations in trends which warrant further investigation. The trend changes tend to have occurred near the late 1980's or early 1990's for all groups.

We look to investigate these changes in trend by testing the stability of a time coefficient in a regression equation, with the filtered Hodrick-Prescott series[2] as the dependent variable. Rather than being a highly quantitative measure of a break, this method is a more descriptive way of identifying where some instability in a time coefficient occurs which may help indicate a structural break.

Simply, we specified a linear regression equation: $\log Y = \alpha + \beta T$ for each fuel demand series of interest i.e. Y = commercial coal demand, commercial gas demand, industrial coal demand, industrial gas demand, with T being a simple time variable.

We tested the stability of the coefficient of the time variable β by running a number of linear OLS regressions using 15 subsequent years of data, each time shifting the 15 year block one year to test the coefficient over separate sub-samples i.e. in the first regression we use 15 years worth of data from the starting date of the series, for the second regression we use 15 years of data beginning with the second year etc. This is relatively similar to a common Chow test.

The value of the time coefficient, and its significance are shown below in Table 1. The coefficients are also presented in Figure 12, along with the changes in the coefficients.

[2] The log of the filtered series' was used to account for the apparent non-linear nature of the dependent variable.

Table 1 Time coefficient output

OLS linear regression – log dependent variable vs. time. 15 year period, moving in one year increments

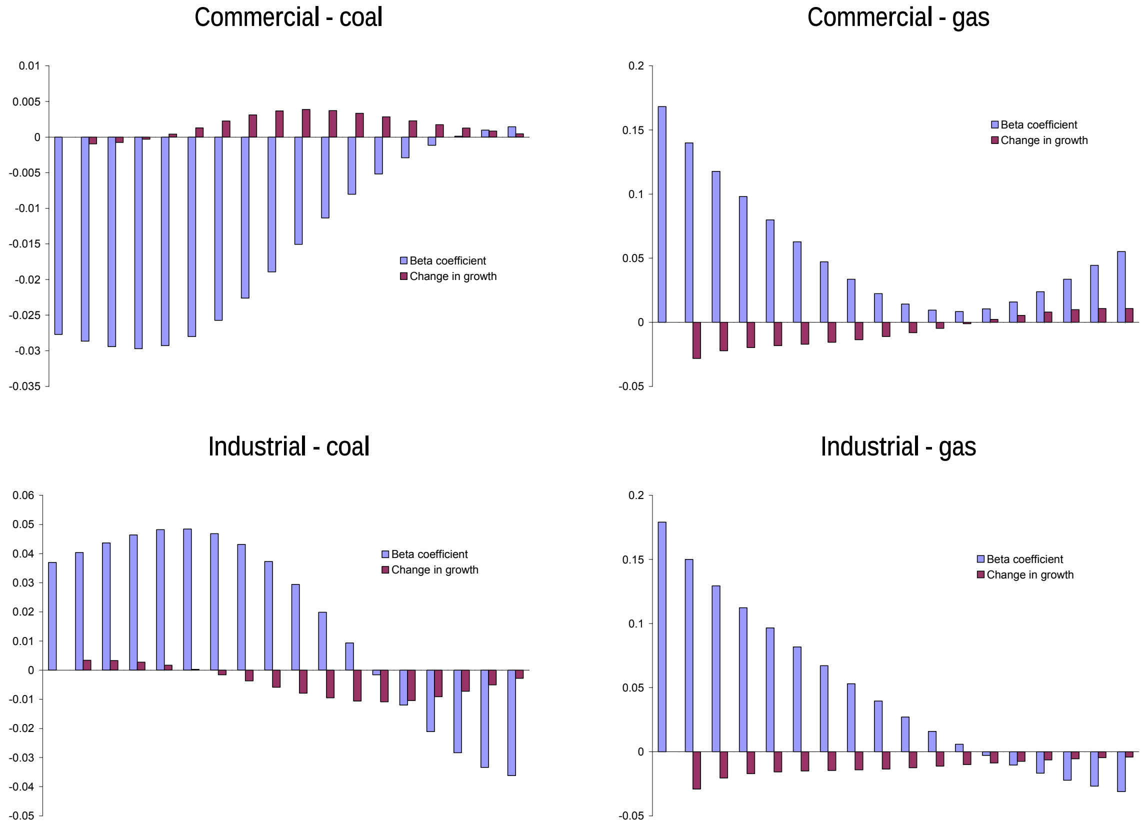
	Commercial coal		Commercial gas		Industrial coal		Industrial gas	
Start year	Significance	Time coeff.	Significance	Time coeff.	Significance	Time coeff.	Significance	Time coeff.
1973	0.000	-0.028	0.000	0.168	0.000	0.037	0.000	0.179
1974	0.000	-0.029	0.000	0.140	0.000	0.040	0.000	0.150
1975	0.000	-0.029	0.000	0.118	0.000	0.044	0.000	0.129
1976	0.000	-0.030	0.000	0.098	0.000	0.046	0.000	0.112
1977	0.000	-0.029	0.000	0.080	0.000	0.048	0.000	0.097
1978	0.000	-0.028	0.000	0.063	0.000	0.048	0.000	0.082
1979	0.000	-0.026	0.000	0.047	0.000	0.047	0.000	0.067
1980	0.000	-0.023	0.001	0.034	0.000	0.043	0.000	0.053
1981	0.000	-0.019	0.003	0.022	0.000	0.037	0.000	0.040
1982	0.000	-0.015	0.008	0.014	0.000	0.029	0.001	0.027
1983	0.001	-0.011	0.011	0.010	0.009	0.020	0.017	0.016
1984	0.007	-0.008	0.010	0.008	0.205	0.009	0.262	0.006
1985	0.028	-0.005	0.010	0.011	0.827	-0.002	0.505	-0.003
1986	0.101	-0.003	0.005	0.016	0.089	-0.012	0.011	-0.010
1987	0.364	-0.001	0.001	0.024	0.002	-0.021	0.000	-0.017
1988	0.896	0.000	0.000	0.034	0.000	-0.028	0.000	-0.022
1989	0.248	0.001	0.000	0.044	0.000	-0.033	0.000	-0.027
1990	0.101	0.001	0.000	0.055	0.000	-0.036	0.000	-0.031

Notes: The start year indicates the first year of the 15 years considered for the regression i.e. the statistics for start year 1990 use the time period for the regression of 1990 – 2004 (inclusive)

Source: NZIER, Ministry of Economic Development

Figure 12 Regression output – coefficient stability over time

β coefficient – from time variable, and change in coefficient



Source: Ministry of Economic Development, NZIER

For the analysis of the commercial coal series, the coefficient was primarily negative, increasingly so for the first few regressions. It then became less and less negative until turning positive in the last three regressions. The change in the coefficient highlights this by showing how the growth rate changes over time (i.e. initially increasingly negative growth, followed by growth which became less negative over time). The changing coefficient reflects the trend in the demand series, and highlights the potential breakpoint in the late 1980's (i.e. as less and less of the steep downward trend is included in the time series, and more of the change in trend is included). As the regressions move toward this point, the level of significance of the coefficient declines to where it is not significantly different from zero.

The commercial gas series analysis also highlights a potential break, with the coefficient showing relatively consistent declining positive growth until the mid 1980's, upon when a sharp change occurred in the time trend coefficient, and the rate of change over time (the change in the coefficient). From then on, the trend was toward positive growth, increasing at an increasing rate.

The industrial coal series is one where we previously identified a possible structural break, with a relatively sharp shift in trend, again in the late 1980's/early 1990's. The trend coefficient calculated is increasingly positive for the first five or so regressions, reflecting the increasing positive trend in demand. It does become not significantly different from zero though once the period covered by the regressions excludes the initial increasingly positive growth. This tends to reinforce the possibility of some kind of break or structural change near the mid to late 1980's and possibly early 1990's.

Although industrial gas demand was increasing till around 1990, the coefficients shown in Figure 12 reflect a fairly consistent declining rate of growth – becoming less positive over time to the point where demand actually declines over time. The difference in the coefficients accentuates this consistency of declining growth, with consistent negative values. This seems to point to a lack of any significant structural breaks in this series.

2.2.2 Summary on potential structural breaks

So for three demand series; commercial coal, commercial gas and industrial coal, there are some indications to suggest potential structural breaks. These tended to be in the mid to late 1980's/early 1990's. Although this is valuable information in terms of highlighting the potential presence of some structural change in demand, this analysis does not allow us to decompose the changes in demand via its key drivers. Despite indications that a change in demand may be present, we cannot say whether such a change may have been driven by a substitution effect between fuels, changing technology or possibly a change in the relative price of the fuels for example.

With the goals of this report being to investigate the changing role of electricity demand, and the potential for its share of total energy to continue to grow, we need to be able to take the information about potential structural breaks identified above a step further, and to try and incorporate them as one of a number of key drivers of demand for electricity. For example, the possibility of a structural break in the demand for coal (commercial or industrial) or gas may reflect substitution toward a different fuel, possibly electricity. Other key drivers also need to be considered.

For example, while there may be no apparent structural breaks in the demand series for oil, the demand for oil has reduced significantly over time. We noted earlier that a number of industrial energy users have increased their use of electricity at the expense of demand for oil. Other factors such as the relative price of fuels, factors affecting technology and the composition of the economy (in terms of the relative shares of industrial and commercial users) could potentially drive the demand for electricity and should be considered.

3. Analysis of a possible demand function

This section looks to formalise the key drivers of electricity demand into a possible demand function, with changes in the demand for electricity (or its share of total energy demand) being affected by a number of key drivers or explanatory variables.

3.1 Analysis of electricity demand and key drivers

Our first approach was to estimate separate demand functions for industrial and commercial electricity demand based on theoretical demand drivers:

$$E_D = f(GDP, K, P_E, F_D, G_D, C_D)$$

Where E_D = Electricity demand by commercial/industrial users as a share of total energy demand

GDP = Output of the commercial/industrial sector

K = Capital stock of the commercial/industrial sector

P_E = relative price of electricity to energy/ fuel alternatives

F_D = Fuel oil demand by commercial/industrial users

G_D = Gas demand by commercial/industrial users

G_D = Coal (and other solid fuel) demand by commercial/industrial users.

We assume producers respond to the need for energy in their production functions (capital intensity proxied by growth in a sector's capital stock), demand for their production (GDP), and the relative price of energy alternatives. We then split energy demands between fuel/energy types and specify electricity demand as the dependent variable.

By modelling electricity demand in this manner we are assuming that electricity demand is a part of a larger market for energy demand, within which fuel or energy alternatives are readily substitutable over the long run.

In practice, time series data on GDP by sector was too short and so we had to drop GDP from our initial model specification. This was not considered problematic because the capital stock data holds a lot of the same information as GDP.

Using our model we can test for equilibrium demand relationships between fuel types and other demand drivers. We can then test whether there have been periods of substantial deviation from equilibrium (i.e. structural breaks).

To test for the presence of equilibrium relationships we turn to the workhorse of contemporary time series analysis; the theory of cointegration. This theory suggests that when a set of related economic variables behaves in an unstable manner over time there may exist a linear combination of these variables which behaves in a stable manner over time because it reflects an economic equilibrium.

The first step in the analysis is to determine whether or not the variables we are using individually follow similar unstable (“non-stationary”) processes. In econometric terms this means testing whether the variables follow non-stationary processes of the same order. If they do, then we can proceed to see if they have an equilibrium relationship (i.e. if they are cointegrated).

We found that all variables of interest followed similar unstable processes except commercial oil consumption. Consequently we included all variables except commercial oil consumption in our analysis of the equilibrium in our electricity demand system.

When we tested for cointegration, we found weak evidence of an equilibrium relationship between our variables in both our industrial demand and commercial demand models. However, when we proceed to estimate this relationship we found that we could not disprove the hypothesis that some of the variables were unrelated to electricity demand (coefficients in the cointegrating vector could not be shown to be all non-zero). This was true for both commercial demand and industrial demand for electricity. This leads us to conclude that our demand system was mis-specified or the equilibrium has been unstable over time.

Table 2 Estimated cointegrating vectors for electricity demand

Based on vector error correction model estimation

	Industrial demand		Commercial demand	
	Coefficient	Std error	Coefficient	Std error
Electricity demand	1	--	1	--
Coal demand	2.9543	0.10852	0.1402	0.02157
Gas demand	0.6637	0.07097	-0.1493	0.01114
Oil demand	1.7248	0.17979	--	--
Relative price of electricity	-1.2237	0.05524	0.0777	0.03122
Capital stock	-0.35912	0.33194	-0.9053	0.02844

Source: NZIER

Results from our estimates of cointegrating vectors from a vector error correction model are shown in Table 2. This was the best performing model we employed – in terms of delivering the greatest number of statistically non-zero coefficients. However, the model estimates suggest the coefficient on commercial capital stock is not significantly different from zero and that the coefficient on relative price of energy, in the case of commercial energy demand has the wrong sign for our demand system to have appropriate (theoretically consistent) economic interpretations.

We tested several model specifications, including classical linear regression models with various lags on our explanatory variables (and leads as used in dynamic OLS specifications) and systems of equations through the technique of seemingly unrelated regressions (SUR) estimation, to see if our results were sensitive to equation/model specification. We found that in some cases coefficients were positive, but the varying results we achieved has lead us to the conclusion that there is no stable equilibrium relationship in our demand systems.

One result which is worth noting and which is likely to be familiar to electricity forecasters, is that price had virtually no explanatory power in our models and in many cases it had the wrong sign (i.e. suggesting that an increase in price results in more consumption).

The results of our demand analyses were not surprising given our initial exploratory analysis of energy demand over time, which suggested that demand for energy has experienced some structural change over time. Because our demand system has not conformed to our expectations, we sought to find other methods of testing for changes in equilibrium relationships over time.

To test for structural changes in relationships over time we return to our approach of testing cointegrating relationships between variables, this time specified with the additional possibility that the cointegrating vectors are changing over time. We do this by specifying an equilibrium relationship, testing for evidence of cointegration and then testing for time varying cointegrating vectors using a state space modelling technique which allows for stochastic regressors as in Haldane and Hall (1991).

Conscious that our earlier regression estimates may have been confounded by over-specified models (i.e. a lot of highly related information with a small sample) we decided to look at simple relationships between sets of two variables. The first relationship we investigated was the extent to which electricity demand is related to demand for other fuel types and whether this has this changed over time. The second was the extent to which electricity demand is related to output and whether this has changed over time.

We tested for evidence of cointegration (equilibrium relationships) between commercial electricity demand and commercial demand for other types of fuels/energy and also between industrial electricity demand and industrial demand for other types of energy/fuels. We did this using Johansen's cointegration test (as in Johansen (1991)). We found no evidence that cointegrating relationships exist.

However, given our standard cointegration techniques are estimated across an entire sample, this lack of relationship may in fact reflect a changing equilibrium through time. To test this we specified a simple time-varying cointegrating relationship and estimated the relationship using a state space model (a Kalman filter time varying parameter model). A generic representation of the model is:

$$(1) \quad y = \alpha + \beta X_t + \varepsilon_t$$
$$(2) \quad \beta_t = \beta_{t-1} + \sigma_t$$

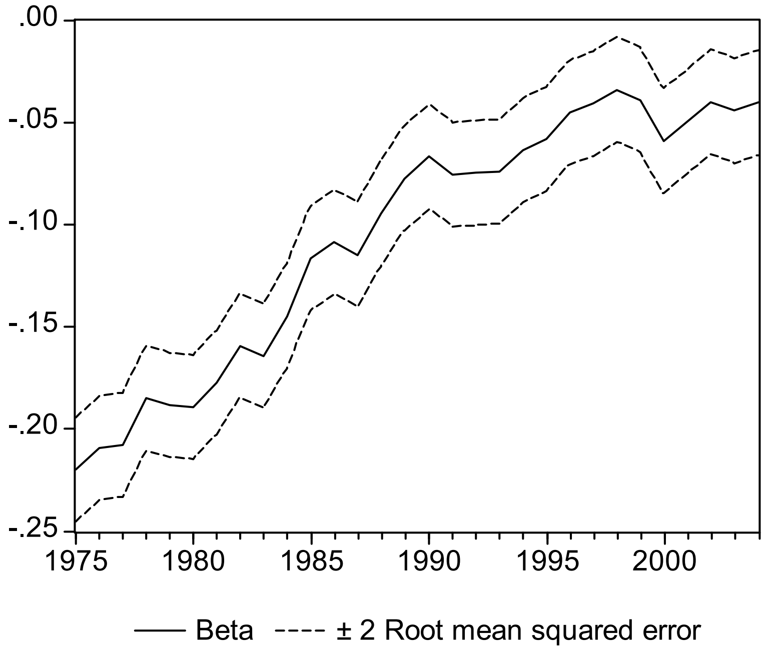
Where we allow the coefficient β to vary according to a random process known as a random walk.

When estimating our state space model our interest is in whether the relationship it describes is stable over time and if it is not, what the variation is, over time, of the parameter β.

When we modelled commercial electricity demand as a function of other energy demand and industrial electricity demand as a function of other demand, the predicted series' did not exhibit any major breaks or other interesting features. However, when we reviewed the paths of the stochastic parameters over time we found signs of highly unstable relationships and evidence that historical equilibrium relationships were breaking down over time.

Figure 13 describes the path of β in our model of commercial electricity demand as a function of commercial demand for other types of energy. This suggests that the relationship between commercial electricity demand and demand for other energy has broken down over time and is approaching zero. This suggests that these demands do not (at least currently) have an equilibrium or long run relationship.

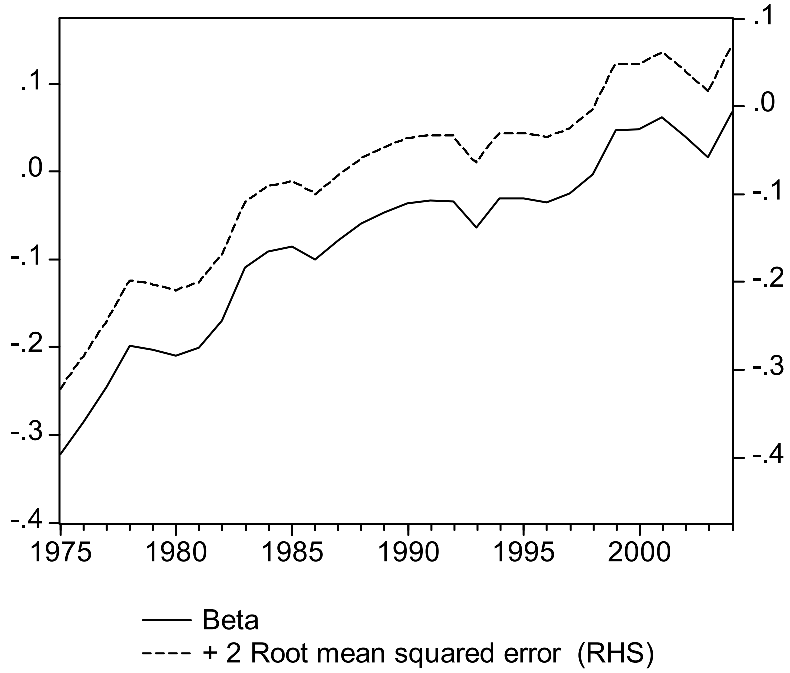
Figure 13 Time varying coefficient on other commercial energy demand



Source: NZIER

Figure 14 describes the path of β in our model of industrial electricity demand as a function of industrial demand for other types of energy. This also suggests that the relationship between industrial electricity demand and demand for other energy has broken down over time and is approaching zero.

Figure 14 Time varying coefficient on other industrial energy demand



Source: NZIER

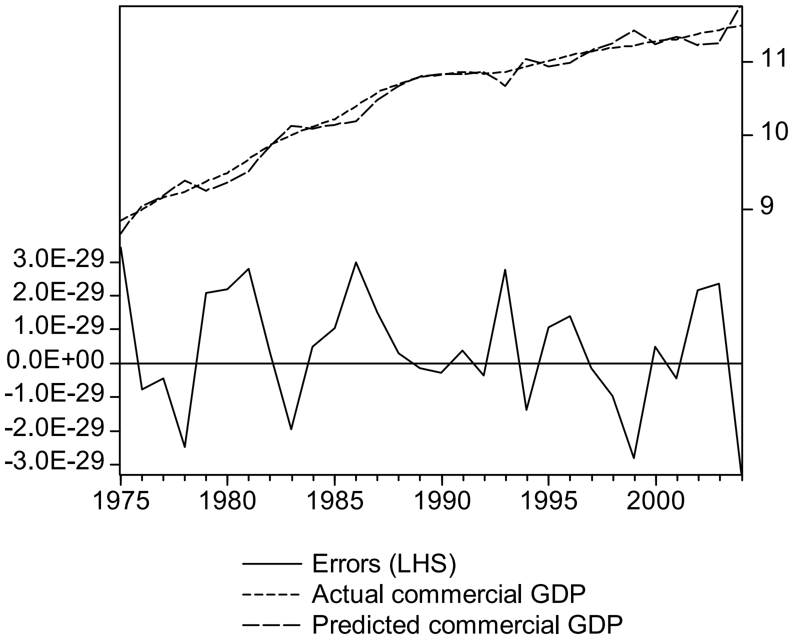
To estimate the second set of relationships, electricity demand relative to output, we used NZIER estimates of GDP by sector based on current figures and estimates from Philpott (1994). Using estimates is not (theoretically) a major problem in terms of robustness of our estimation procedure because GDP enters our equations on the left hand side. In practice it may reduce the explanatory power of our model.

In our second set of estimates electricity demand is the explanatory variable which we model with a time varying parameter on sector GDP.

Figure 15 shows the predictive power of the relationship between commercial output and commercial electricity demand according to our state space model. This shows a remarkably good fit with no major breaks, although the models explanatory power appears to break down a little towards the end of our sample.

Figure 15 State space predicted commercial GDP

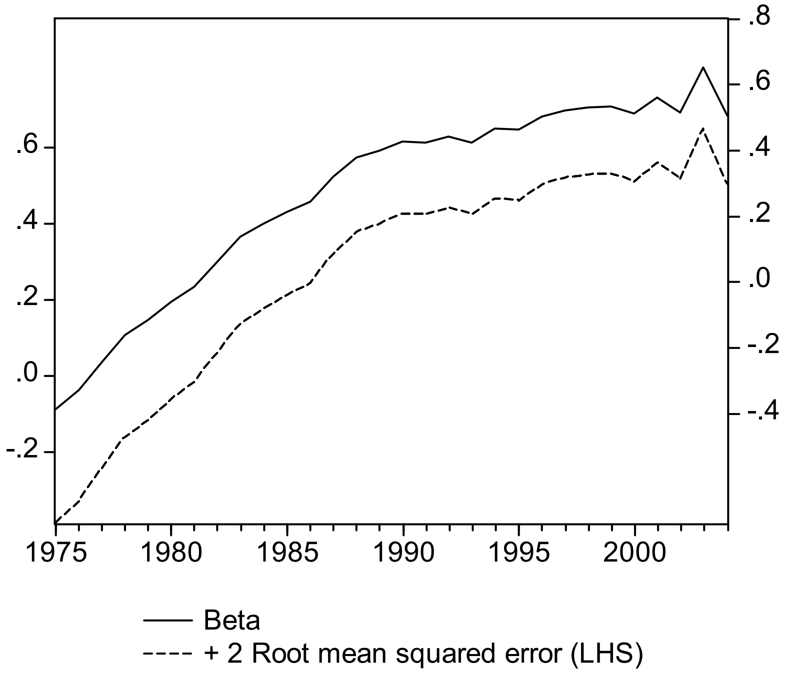
GDP is logs



Source: NZIER

Figure 16 describes the path of β in our model of commercial GDP as a function of commercial demand for electricity. This suggests an unstable equilibrium relationship, but one that is tending towards the positive and appears to be plateauing.

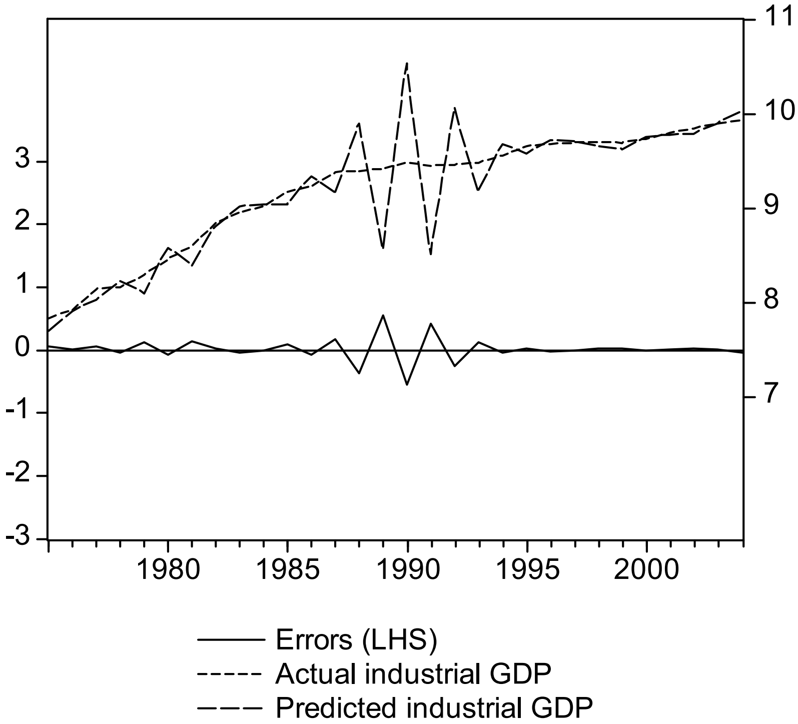
Figure 16 Time varying coefficient on commercial electricity demand



Source: NZIER

Figure 17 shows the predictive power of the relationship between industrial output and industrial electricity demand according to our state space model. This shows a major break in the relationship beginning in the late 1980s and ending towards the middle of the 1990s.

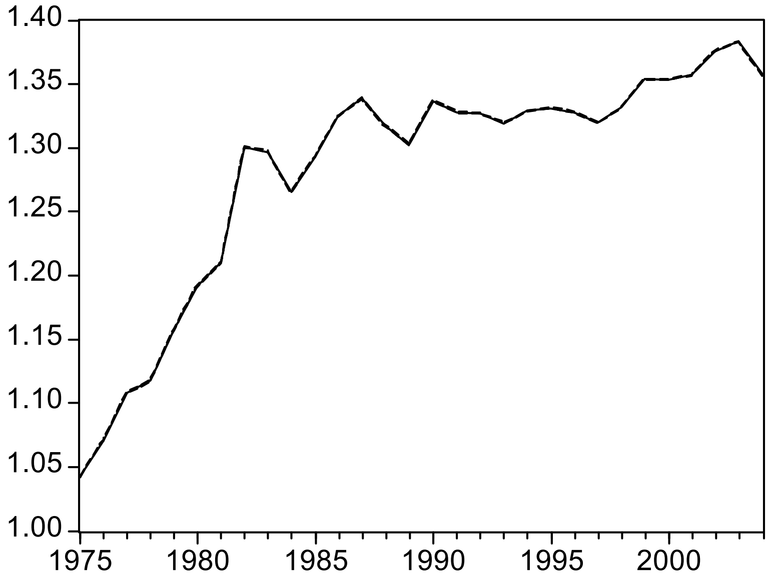
Figure 17 State space predicted industrial GDP
GDP is logs



Source: NZIER

Figure 18 describes the path of β in our model of industrial GDP as a function of industrial demand for electricity. Like the model for commercial electricity and GDP, this suggests an unstable equilibrium relationship, but one that appears to be plateauing. This would suggest that historical rates of growth in electricity demand will diminish (i.e. will not continue to increase necessarily as much as in the past).

Figure 18 Time varying coefficient on industrial electricity demand



Source: NZIER

4. Looking ahead, and key conclusions

4.1 Using the past to look ahead

This report set out to answer a number of key questions:

- What can we conclude about the changing composition of energy demand, and the remaining potential impact for growth in the share of electricity demand?
- What does this mean for the Electricity Commission's forecasting methodology?
- What do we recommend the Electricity Commission do? (re: methodology)

By definition, for the **share** of electricity demand (out of total energy demand) to continue to increase, the shares of demand for other fuels must decline – the shares of total demand will always sum to 100%. For this to occur, either (or both) of two things must happen to the demand (levels, and hence shares) for fuels other than electricity:

1. They decline in isolation, independent of other fuels e.g. demand for the products using the energy declines, the user shuts down production; or

2. The increase in share by electricity demand comes at the direct expense of another fuel e.g. a user switches from using coal to using electricity i.e. substitution through some change to the production function.

We identified in section 2.1 some case where it appeared that substitution had occurred. In general, industrial use of oil has declined fairly steadily since the 1970's, and for some sectors (such as the building and construction sector) this has meant an opposing increase in demand for electricity, for example. We also identified in section 2.2 points where there was potential evidence of a structural break of some description – typically near the late 1980's or very early 1990's. However, some significant problems arise in taking this information, and that identified in the demand analysis in section 3, and using the two paths for the electricity demand share above to help answer our key questions:

- For option 1 (i.e. where the demand for fuels other than electricity declines in isolation to the extent that their share declines) a lack of suitably lengthy time series data on output or employment by industry type does not permit us to make suitable inferences about how we might expect demand to grow given changes to growth for various sectors in the wider economy. This meant we were also unable to account for any structural changes (e.g. from industrial to commercial).

The sectoral information within the wider industry grouping is also only available in a short time series (1990) meaning its value is limited. We can make some lose inferences given our expectations about sectoral growth and the potential for various fuel growth, but these are not derived formally, and should be interpreted with caution.

Table 3 below presents this information for selected industrial sectors who use more than one fuel. A number of industrial sectors such as textiles and chemicals demand only electricity. Looking at their expected growth with tell us nothing about relative shares of fuel use we might expect in the future.

Table 3 Inferences on industrial fuel use

Real GDP: average annual percent change, March year

Sector[1]	Historical energy use	Real GDP 1999-2004[2]	Real GDP 2004-2009 (forecast)	Real GDP 2009-2014 (projected)	Possible implication
Other primary industries	Increased use of electricity at the expense of oil since early 1990's. Still largely dominated by oil.	4.8	3.7	3.2	Lower expected growth in oil intensive user.
Food processing	Oil use historically around 20%, nearly completely displaced by electricity.	3.1	2.1	1.6	Weaker growth predicted for electricity intensive producers.
Basic metals	Steady shares of coal and electricity, small oil share phased out.	6.0	2.5	2.2	Relatively large easing in growth from high level for users of near equal shares of coal and electricity
Building and construction	Increased use of electricity at the expense of oil, particularly since mid 1990's.	6.4	0.2	0.9	Relatively large easing in growth for oil intensive producer

Notes: These inferences do not include any reference to impacts of the effects of prices (either own or alternatives)

1 - The sector descriptions are those from the Energy Data File

2 – The GDP figure used are proxies for the Energy Data File sector descriptions. They do not exactly match. The growth figure used for the Other primary industries sector is that predicted for the Forestry and logging sector. The growth figure used for the food processing sector, is that predicted for the food, beverage and tobacco manufacturing sector. The growth figure used for the building and construction sector is that predicted for the construction industry.

Source: NZIER estimates – *June 2005 Quarterly Predictions*, Ministry of Economic Development

As we noted earlier, even though this gives us some lose inferences about possible changes in demand for various fuels, it still fails to provide us with enough information to confidently predict changes in shares. Again, we do not know enough about the demand for each of the fuels to be able to comment firmly about changes to shares of total energy demand.

This means that our ability to speculate on the extent to which the share of electricity demand will continue to increase is extremely limited. The charts shown in section 2.1 do indicate that while electricity demand for some industrial sectors has displaced oil use in particular, that rate of displacement has levelled out in most cases (i.e. possibly the majority of the substitution that is likely to occur has already occurred) or that the displacement of oil is nearly complete. The analysis of demand equations also shows that the significance of electricity demand in terms of output for that sector (industrial or commercial) seems to be reaching a plateau, after some form of structural break.

- For option 2 (i.e. increased electricity demand share comes at the direct expense of shares for other fuels via substitution) we identified in the analysis of the demand functions (section 3), the problems associated with trying to identify substitution formally via responses to changes in price for alternative fuels and/or the levels of demand for other fuels. A firms choice to substitute between fuels will not come only from factors associated with the fuel (typically its price, or availability).

  For example, an industrial user of coal uses the coal in association with capital to produce a particular product. Should the price of the coal change significantly, the decision to switch from coal to another fuel will depend on the effect of this on the total cost (which will include the cost of the capital equipment as well as the fuel) and whether this is sustainable. The user would only switch if the total cost (covering capital + fuel etc.[3]) for the alternative is a more economic choice rather than the existing capital, fuel (etc) cost mix. This cost function/production function would be valuable, but extremely difficult to obtain. Firms are unlikely to be willing to part with this information. Hence, we are unlikely to be able to properly identify actual substitution between fuels. Considering reactions to price alone for example, does not necessarily indicate substitution will occur, or has occurred.

4.2 Conclusions

The observations above should not be viewed entirely as negative, in terms of our ability to say anything about the mix of fuel demands expected in the future.

Rather, a number of conclusions can be drawn from the analysis and information presented in this report:

- The raw data indicate that in certain sectors some substitution between fuels has occurred – sectors such as food processing and building and construction for example.
- For commercial gas and coal demand, and industrial coal demand there appear to be some evidence of structural breaks. These tended to be in the mid to late 1980's/early 1990's. However, from this we cannot decompose why the breaks may have occurred in terms of the changes that occurred in the key drivers of demand. We cannot say whether such a change may have been driven by a substitution effect between fuels,

[3] Clearly a number of other factors would form the overall decision around switch-ability e.g. the effect of changing the capital/fuel mix on the rest of production, overall cost structure, the ability to pass on increased costs etc. The point is that price alone (and demand responses) are not sufficient to identify substitution.

changing technology or possibly a change in the relative price of the fuels for example.

- Our estimates of a demand system for electricity were not very successful. The econometric results achieved were generally inconsistent with economic theory and achieving econometric significance would have required abandoning economic intuition. However, we found that these problems are likely to have arisen due mainly to changes in equilibrium relationships in energy demand over time. The equations tended to indicate little response in electricity demand to price. While we might theoretically expect an inverse relationship between demand and price, this did not come through in the regression analysis. In terms of response to the price of other fuels, we would expect that as the relative price of electricity to other fuels increases, that demand for electricity would decline. These relationships were not able to be formally identified.
- Our econometric (state space modelled) estimates of equilibria in energy demand suggest that electricity demand is becoming increasing de-linked from demand for other types of energy/fuels. In addition, our estimates suggest that electricity demand in both commercial and industrial sectors are converging towards a (more) stable equilibrium state relative to production/GDP.
- The issue of substitutability is not simply a price related phenomenon. The regressions indicated a lack of demand response to changes in the price of other fuels, whether they were aggregated into an 'other price' form, or by individual fuel. No intuitive significant relationship could be identified. What this does highlight however, is the inability to capture the entire decision around the ability to switch between fuels and the effect on demand. For example, firms demand fuel on the basis that it is used in conjunction with capital to produce a particular product. The costs of producing the product are therefore related to not only the fuel price, but other costs involved in producing the product (labour, capital costs etc). Theoretically, the producer uses this fuel because it makes overall economic sense. Again, we might reasonably suppose that the firm will only switch to an alternative fuel if the **overall** cost of doing so makes rational sense i.e. whether the capital/labour costs change with the fuel or not, does the overall cost of producing the same product with the new fuel make economic sense? Because of this, we would expect that a change in the price of fuel is one factor in a total investment decision about the cost of production, rather than being the sole driver.
- A number of factors could potentially drive changes in shares, substitution being just one. The importance of knowing the magnitude (and drivers) of each level of demand cannot be underestimated.
- Our ability to assess the remaining potential for the share of electricity demand to continue to increase is thus limited, and we suggest that we do not have the formal relationships available to be able to form a robust conclusion on this. The other issues noted above, including the ability to define substitution, also mean that the focus may need to be more on the

individual levels, rather than the share of a total given uncertainties around the ability to predict a share in isolation.

At a high level, the limited data on sectoral industrial use by fuel interpreted in section 2.1 does suggest some substitution has occurred, with oil demand in some sectors being replaced with electricity demand. For the other primary industry sector and the building and construction sector the displacement seems to be stable i.e. the shares have not changed significantly in recent years. For the food processing sector, the share of oil demand is nearly negligible. Shares between coal and electricity for the basic metals sector do not appear to be shifting in any trending manner. This, in conjunction with expectations of an easing in growth for a number of sectors, indicates that the potential for electricity demand to continue to increase its share of total energy demand may be limited. This is not to say that its share will diminish, rather that its ability to grow further may be limited. Again, this is based on consideration of a number of selected industries where some data is available, and is considered in isolation of a number of factors which we feel should be granted more attended than the share necessarily.

The demand equation analysis also provided some information to suggest that the significance of electricity demand (in both commercial and industrial sectors) is converging towards a (more) stable equilibrium state relative to production/GDP.

4.3 Effect on modelling methodology

As well as providing information on the growth potential of electricity demand in terms of total demand and of analysis of the key drivers, the conclusions highlight the important differences between modelling levels of fuel demand independently and then aggregating them (a bottom up approach), versus a top down approach of allocating total fuel demand.

If forecasting using a bottom up approach, there are risks in terms of being able to identify the drivers of demand for each fuel – is it price, demand for the output, technology that is driving demand? We know from the Commission's previous work, and that undertaken here that relationships between price and demand are difficult to formalise. We have determined that identifying substitution between fuels is far from being a trivial exercise, and that existing data prevent us from doing this. There are relationships with more macro variables like capital stock and output. What is important about this method though, even if we only have one or two major macro explanatory variables, is that we gain an insight into realistic future levels of demand – the magnitude of the levels (even in the face of potential variability of inputs) being the important point. What would improve this method would be additional information about how firms use fuels in relation to demand for their outputs.

If the focus is on the shares, rather than the levels (i.e. a top down approach) we still need to know about what's happening to the other shares, to work out whether the share of interest is likely to change. How would a top down approach deal with (and explain) changes in demand by users who only demand a single fuel for example? Also, in doing so we cannot assume that total energy demand is a system 'in-and-of itself'. This is probably the major risk to this approach. What this means is that we cannot assume that an increase in a particular share will necessarily be directly responsible for an equal and opposite reduction in share of another fuel (or fuels). It may be the case if the substitution is a direct substitute[4] i.e. one fuel for another, but there are so many other factors outside of perfect substitution that to assume so would be assuming away a number of key factors which could affect the level of demand, and thus the shares. Given that it is generally accepted that there is some long-run relationship between demand for output and for fuel demand, working from a total energy basis may miss out on the characteristics of demand for each fuel, by industries which vary considerably in their reasons for using fuel, and the processes in which they use (and are able to substitute between) fuels.

4.4 Recommendation to the Commission

Overall, while there are widely accepted limitations to producing demand estimates for individual fuels and aggregating them, the approach seems likely to incorporate more of the overall long run relationships between drivers of fuel demand, than could be gained from using a top down approach. The top down approach assumes an interpretation of total demand that may introduce more complications than it adds. Models of individual fuels demands using key drivers may only be able to explain a share of the change in fuel demand using major macro variable such as output or capital stock, but it is likely to capture important long run equilibrium relationships which give good indication of magnitude and direction to levels of demand.

In terms of recommendations for the Electricity Commission, we suggest continued use of the existing general modelling approach, with a focus on continued development over time. The information of sub-sectoral demands for fuels by industry is likely to prove of value once a longer-run consistent series is available for example. Another approach that may warrant investigation is forecasting demand by industry (smaller aggregations than industrial and commercial) in terms of some relationship with output, such as energy intensity in different industries. While this would necessitate assumptions about how such as how this intensity might change over time, forecasting demand for industrial output may introduce less risk than forecasting by fuel type i.e. forecast industry demand by fuel, rather than fuel type by industry.

[4] Although it is unlikely to be equal in magnitude, given the different energy contents of different fuels.

5. References

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