# APPENDIX A: Demand Methodology

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Data used for input to determine demand in NARG are derived from published statistics at the Energy Information Administration (EIA), the National Oceanic and Atmospheric Administration (NOAA), the US Bureau of Economic Analysis (BEA), the US Census Bureau, and offices internal to the California Energy Commission. Demand is forecast regionally for five end-use sectors (residential, commercial, non-chemical industrial, chemical industrial, and power generation). In all sectors except power generation, estimates of the elasticity of demand with respect to weather, gas price, oil price, income, industrial production, and population are obtained through econometric analysis of historical data spanning the time period 1986-2000. The estimates were obtained from the Modeling Subgroup of the National Petroleum Council's recently published study "Balancing Natural Gas Policy" (2003). For the power generation sector, a demand forecast in Western States for use in the NARG model was generated by successive iteration with the power model used by the Electricity Analysis Office of the California Energy Commission. EIA projections from the *Annual Energy Outlook 2005* where used in the remaining states.

### *A Note on Elasticity*

With regard to the estimation of the elasticity of demand for natural gas, simultaneous estimation (the method used herein) enables a distinction between, say, income and price effects. This is important because, for example, any demand projection that is not sensitive to price will overstate the effect of income growth.

Consider the income elasticity of natural gas demand. The income elasticity is defined as the percentage change in energy demand given a one percent change in income holding all else constant, or

$$\varepsilon_Y = \frac{\%\Delta NG}{\%\Delta Y} = \frac{dNG}{dY} \cdot \frac{Y}{NG}$$

where $Y$ denotes the income and $E$ denotes energy. One must use caution, however, when applying this definition of elasticity. It is not sufficient to simply divide the percentage change in natural gas demand by the percentage change in income for a given time period. This approach ignores the affect that other variables may have on demand and leads to erroneous, statistically biased results. To illustrate, recall that the income elasticity of natural gas demand is the percentage change in natural gas demand given a one percent change in income, *holding all else*

*constant*. Allowing natural gas demand to be a function of income, price, and possibly some other set of variables, $NG = f(Y, P, ...)$, then, in general, the total derivative of natural gas demand is given as $dNG = \frac{\partial NG}{\partial Y} dY + \frac{\partial NG}{\partial Y} dY + ...$. If we hold all factors but income constant, this equation reduces to $dNG = \frac{\partial NG}{\partial Y} dY$. We can then multiply both sides by $\frac{1}{dY} \cdot \frac{Y}{NG}$ to yield

$$\frac{dNG}{dY} \cdot \frac{Y}{NG} = \frac{\partial NG}{\partial Y} \cdot \frac{Y}{NG}.$$

The left-hand side of this equation is by definition the income elasticity of energy demand, but we only arrive at this result *when all variables except income are held constant*. It is a simple matter to show that if all other variables are not held constant then there will be a remainder term on the right-hand side of the above equation (i.e.- the term in brackets below)

$$\frac{dNG}{dY} \cdot \frac{Y}{NG} = \frac{\partial NG}{\partial Y} \cdot \frac{Y}{NG} + \left\{ \frac{\partial NG}{\partial P} \cdot dP \cdot \frac{1}{dY} \frac{Y}{NG} + ... \right\}.$$

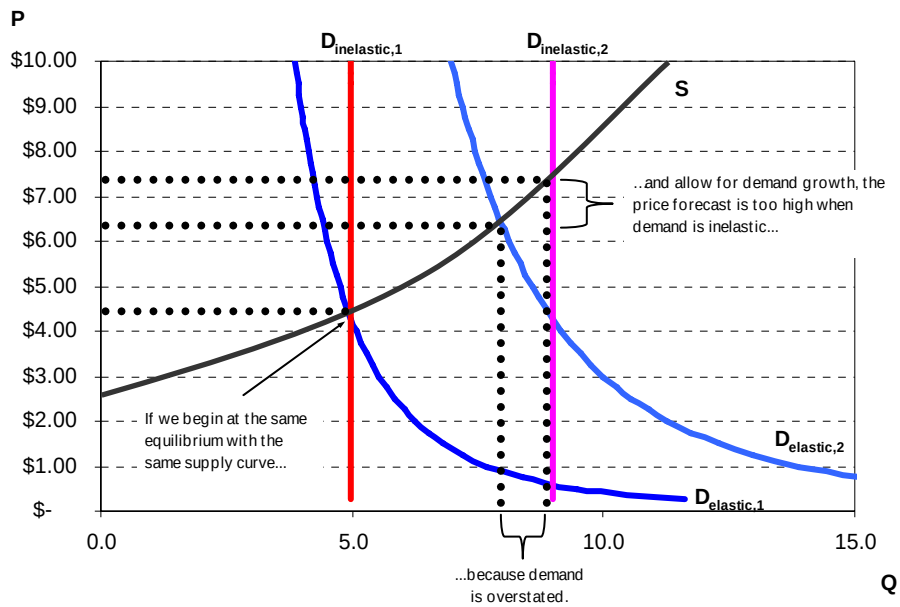
If, therefore, we seek an estimate of income elasticity, we cannot ignore the other relevant variables as it introduces a bias similar to the term in brackets.

For a numerical example, consider the following. If natural gas consumption has been increasing at 2% per year for 10 years, and income has been increasing at 3% per year for the same time period, a naïve approximation of income elasticity would be 0.67 $(= 2\%/3\%)$. However, if we consider that price may have been changing during the last 10 years, then our naïve estimate is biased. Specifically, if price had been falling, then, given a downward sloping demand curve, an income elasticity of 0.67 is an overestimate, and can lead to serious problems when forecasting future demand. *Therefore, when modeling energy demand it is important to recognize that many variables simultaneously influence energy use.*

For a graphical example of this concept, consider Figure 1. As indicated, income growth will tend to shift the demand curve horizontally to the right. If demand is not sensitive to price it is referred to as “price-inelastic” and is represented as a vertical line. If demand is sensitive to price, it is referred to as “price-elastic” and is represented as a downward sloping line. We see in Figure 1 that the income effect, while similar in the cases of both elastic and inelastic demand, results in a lower price when we have price-elastic demand compared to price-inelastic demand. This “price-effect” also works to increase demand when a new source of supply, such as liquefied natural gas (LNG) or Alaskan natural gas delivered via pipeline, is introduced. For example, if LNG can be provided to a market area at a price below that which has been realized historically, we would graphically represent this as an

outward shift of the supply curve. The price suppressing effect of LNG, however, will be muted somewhat by the increase in demand that is realized by lower prices.

**Figure 1 – Elastic vs. Inelastic Demand**



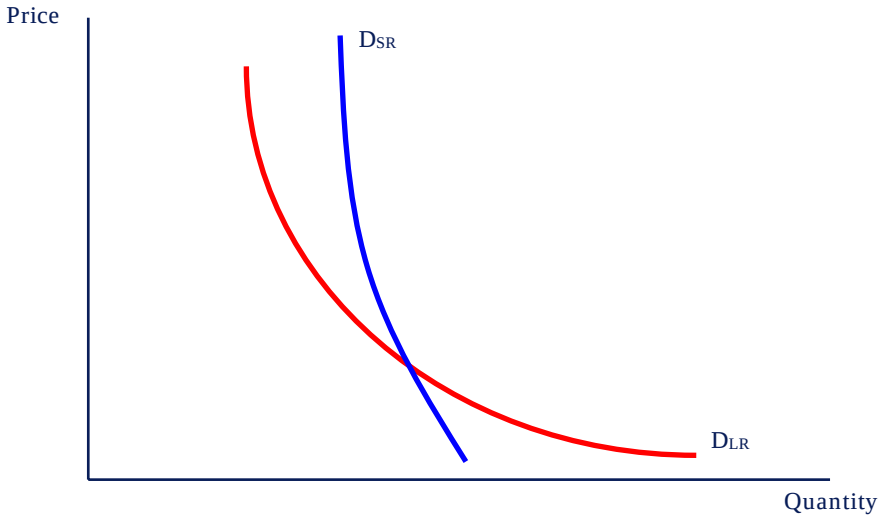

The price elasticity of energy demand is defined as the percentage change in energy demand given a one percent change in price holding all else constant, or

$$\varepsilon_P = \frac{\%\Delta NG}{\%\Delta P} = \frac{dNG}{dP} \cdot \frac{P}{NG}$$

where $P$ denotes the price of natural gas. This measures the influence of natural gas price on energy demand, and bears mention here because the long and short run effects of changes in natural gas prices can be difficult to disentangle. In general, energy demand is predicated on ownership of an energy-using capital good, the owner's decision as to the energy efficiency of the capital good, which is made when the capital is purchased, and utilization of the capital good. Once an energy-using capital good has been purchased, the capital utilization decision will dictate the responsiveness of energy demand to price in the short run, assuming the short run implies that capital and technology are fixed so that the consumer cannot 'trade-up' to higher energy efficiency. In the long run, however, the consumer is free to turn over capital equipment in favor of higher energy efficiency. Thus, the long run response to price involves a decision on both capital utilization rates and energy efficiency. The resulting effect on demand responsiveness to price can be illustrated as in Figure 2. In general, we see that the long run responsiveness in demand to higher prices is greater than in the short run, as consumers can adjust capital stocks accordingly. *The estimation methodology applied herein utilizes a Koyck lag*

*specification in order to differentiate between the short and long run elasticity with respect to all relevant variables.*

**Figure 2 – Long run versus short run demand elasticity**




In estimating demand by end-use sector, we must obtain suitable data and choose the appropriate econometric specification. In each end-use sector, various specifications of demand were tested, and variables with no statistical explanatory power were sequentially dropped from the analysis until a suitable functional form was obtained. Accordingly, residential and commercial sector demand is taken to be a function of income, population, weather, and the price of natural gas. Industrial demand, in both the chemical and non-chemical sectors, is taken to be a function of industrial production, the price of natural gas, and the price of crude oil. Population data is obtained from the U.S. Census Bureau, natural gas demand data, natural gas price and oil price data are all obtained from the U.S. EIA. Income and industrial production data are obtained from the U.S. Bureau of Economic Analysis and the Federal Reserve Bank, and heating degree day data are obtained from NOAA.

The parameters for each of the demand functions (see below) are estimated using a dynamic panel specification. Standard estimation procedures (such as ordinary least squares) applied to a model using dynamic panel data may be inconsistent due to correlation between the lagged endogenous variable and the error term.[1] Therefore, a suitable alternative must be chosen. We apply two-stage least squares

[1] For background in the estimation of dynamic panel data models see, among others, Matyas and Sevestre (*The Econometrics of Panel Data: Handbook of Theory and Applications*, Kluwer Academic Publishers, 1992), Balestra and Nerlove ("Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas," *Econometrica* 34, 1966), and Hsaio (*Analysis of Panel Data*, Cambridge University Press, 1986). One applied study of considerable interest is that of Baltagi and Griffin ("Pooled estimators vs. their heterogeneous counterparts in the context of dynamic demand for gasoline," *Journal of Econometrics* 77, 1997). They evaluate the out-of-sample forecast performance of a number of estimators that have been proposed for a dynamic panel data model applied to a very well researched field, gasoline demand.

(2SLS) regression to estimate the parameters in the demand equations, using as instruments for the lagged endogenous variable present and lagged values of the regressors.

In forecasting demand, the model equates demand and supply in each period by adjusting price. Thus, price is endogenous, but all other variables in the demand functions are taken to be exogenous. As a result, forecasts of those variables are required prior to each model run. It should be noted that variations in the assumed forecasts for the exogenous variables are an important component of scenario analysis.

### *Residential Demand*

Residential demand for natural gas, $q^*_{res,i,t}$, is assumed to be a function of population, $pop_{i,t}$, natural gas price, $p_{i,t}$, GDP, $y_t$, and weather, $hdd_{i,t}$. More specifically, we assume residential demand can be given as

$$q^*_{res,i,t} = A_{res,i}\, pop_{i,t}^{\alpha_1}\, p_{i,t}^{\alpha_2}\, y_t^{\alpha_3}\, hdd_t^{\alpha_4}$$

where *i* denotes the region and *t* denotes the time period, and the term $A_{res,i}$ is a region-specific constant term. Residential demand within a region is thus assumed to be a function of population, price and weather within that region, as well as national income. We can take the natural logarithm of both sides of the above equation and assume a Koyck lag adjustment mechanism of the form

$$\left(\ln q_{res,i,t} - \ln q_{res,i,t-1}\right) = \gamma\left(\ln q^*_{res,i,t} - \ln q_{res,i,t-1}\right) \text{ where } \gamma = (0,1]$$

to yield

$$\ln q_{res,i,t} = b_{res,i} + \beta_1 \ln pop_{i,t} + \beta_2 \ln p_{i,t} + \beta_3 \ln y_t + \beta_4 \ln hdd_{i,t} + (1-\gamma)\ln q_{res,i,t-1}$$

where the term $b_{res,i}$ is a region-specific intercept. We assume a lag adjustment mechanism in order to differentiate between the long and short run impacts of changes in demand induced by changes in the independent variables. Such lags may be generated by capital stock turnover, habit-persistence, etc. The mechanism allows that adjustment to the long run be instantaneous if the parameter $\gamma$, which is referred to as the speed-of-adjustment coefficient, is equal to 1. The parameters $\beta_i$ are estimated directly and are the short run elasticities of demand with respect to

population, price, income and weather, respectively. The long run elasticities, $\alpha_i$, can be recovered by dividing $\beta_i$ by $\gamma$.

The estimated coefficients, or elasticities, have the appropriate sign ($\beta_1, \beta_3, \beta_4 > 0$ and $\beta_2 < 0$). This tells us that an increase in population, a decrease in the price of natural gas, an increase in income, or an increase in heating degree days will have a positive influence on the quantity of gas demanded in the residential sector. (See Table 1 for a summary of the parameter estimates.)

### *Commercial Demand*

Commercial demand for natural gas, $q^*_{com,i,t}$, is also assumed to be a function of population, $pop_{i,t}$, natural gas price, $p_{i,t}$, income, $y_t$, and weather, $hdd_{i,t}$. Thus, commercial demand is assumed to be determined by the same factors as residential demand. Allowing for a Koyck adjustment mechanism to distinguish between long and short run effects results in the following equation describing commercial demand

$$\ln q_{com,i,t} = b_{com,i} + \beta_1 \ln pop_{i,t} + \beta_2 \ln p_{i,t} + \beta_3 \ln y_t + \beta_4 \ln hdd_{i,t} + (1-\gamma)\ln q_{com,i,t-1}$$

where the term $b_{com,i}$ is a region-specific intercept. As before, the parameters $\beta_i$ are estimated directly and are the short run elasticities of demand with respect to population, price, income and weather, respectively. The long run elasticities, $\alpha_i$, can be recovered by dividing $\beta_i$ by $\gamma$. Note, however, that despite the similarities in functional form, the estimated elasticities in the commercial sector need not be the same as those in the residential sector (and indeed they are not).

The estimated coefficients, or elasticities, have the appropriate sign ($\beta_1, \beta_3, \beta_4 > 0$ and $\beta_2 < 0$). This tells us that an increase in population, a decrease in the price of natural gas, an increase in income, or an increase in heating degree days will have a positive influence on the quantity of gas demanded in the commercial sector. (See Table 1 for a summary of the parameter estimates.)

### *Industrial (Chemical/Non-Chemical) Demand*

The National Petroleum Council Demand Sub-group went to extensive effort to model industrial demand by component. Specifically, demand was separated into Industry Group, End-use, and Region. (The reader is referred to “Balancing Natural Gas Policy” (2003) for more detail on the methodology used by the NPC.) In effort to honor the detailed analysis done by the Demand Sub-group, the Modeling Sub-group used a collection of outputs from the Industrial Demand Sub-module to

estimate elasticity. The data were aggregated into two broadly defined industrial sectors – Chemical and Non-chemical. Then, model generated forecasts of price and demand along with the associated oil price and industrial production forecasts were used to estimate the elasticity of demand in each sector with respect to each of the variables.

Industrial demand (both chemical and non-chemical) for natural gas, $q^*_{ind,i,t}$, is assumed to be a function of industrial production, $ip_t$, natural gas price, $p_{i,t}$, and oil price, $poil_{i,t}$. (It should be noted here that although the functional forms are the same, the parameter estimates are distinctly different across each sector.) More specifically, we assume industrial demand can be given as

$$q^*_{ind,i,t} = A_{ind,i}\, ip_t^{\alpha_1}\, p_{i,t}^{\alpha_2}\, poil_{i,t}^{\alpha_3} .$$

Again, we can take the natural logarithm of both sides of the above equation and assume a Koyck lag adjustment mechanism to yield

$$\ln q_{ind,i,t} = b_{ind,i} + \beta_1 \ln ip_t + \beta_2 \ln p_{i,t} + \beta_3 \ln poil_{i,t} + (1-\gamma)\ln q_{ind,i,t-1}$$

where the term $b_{ind,i}$ is a region-specific intercept. As before, the parameters $\beta_i$ are estimated directly and are the short run elasticities of demand with respect to industrial production, natural gas price and oil price, respectively. The long run elasticities, $\alpha_i$, can be recovered by dividing $\beta_i$ by $\gamma$.

The estimated coefficients, or elasticities, have the appropriate sign ($\beta_1, \beta_3 > 0$ and $\beta_2 < 0$). This tells us that an increase in industrial production, a decrease in the price of natural gas, or an increase in the price of oil will have a positive influence on the quantity of gas demanded in the industrial sector. (See Table 1 for a summary of the parameter estimates.)

### *Parameter estimates and NARG model execution of the demand methodology*

The parameter estimates along with standard errors and a goodness-of-fit measure are summarized in Table 1. Note that the parameter estimates are interpreted as elasticities since the data where transformed into natural logarithms prior to estimation.

**Table 1 – Parameter estimates and standard errors**

| | SECTOR | | | |
|---|---|---|---|---|
| | **Residential** | **Commercial** | **Industrial** | **Chemicals** |
| ***Own Price(t,i)*** | **-0.2270** | **-0.2104** | **-0.0919** | **-0.2903** |
| *standard error* | *0.0234* | *0.0284* | *0.0242* | *0.0681* |
| ***Cross Price(t,i)*** | | | **0.0251** | **0.0734** |
| *standard error* | | | *0.0227* | *0.0227* |
| ***GDP(t)*** | **0.1559** | **0.4000** | | |
| *standard error* | *0.0330* | *0.0645* | | |
| ***Industrial Production(t)*** | | | **0.0368** | **0.2522** |
| *standard error* | | | *0.0171* | *0.0967* |
| ***Heating Degree Days(t,i)*** | **0.5175** | **0.2913** | | |
| *standard error* | *0.0314* | *0.0391* | | |
| ***Population(t,i)*** | **0.7807** | **0.1776** | | |
| *standard error* | *0.0623* | *0.0667* | | |
| ***Q(t-1,i)*** | **0.2398** | **0.4658** | **0.4467** | **0.6836** |
| *standard error* | *0.0426* | *0.0731* | *0.0077* | *0.0107* |
| $R^2$ | **0.9327** | **0.9568** | **0.9958** | **0.9937** |

In order to use the estimated elasticities from the NPC version of NARG, it was first necessary to recalibrate the region-specific constant term to match the regional aggregation present in the CEC version of NARG. For each sector and region, this is done by setting the constant term so that the resulting demand estimate matches the historical value of demand for that sector and region. This is done for several years of data, and an average is taken for forecasting purposes. To reiterate, the calibration chooses the constant term so that, given the parameter estimates in Table 1, predicted demand equals actual demand. Or, for example, in the residential sector in region *i*, we have for 1997 the following calibrated constant term $b_{res,i}$,

$$b_{res,i} = \ln q_{res,i,1997} - \left(\beta_1 \ln pop_{i,1997} + \beta_2 \ln p_{i,1997} + \beta_3 \ln y_{1997} + \beta_4 \ln hdd_{i,1997} + (1-\gamma)\ln q_{res,i,1996}\right)$$

where such a calculation would be made for all years for which there is historical data available (1998-2004). Then, the average calibrated constant term is used to forecast 2005 and all subsequent years. (Note that there is little variation in the calibrated constants from year to year, and all are reasonably close to the values estimated by the NPC.) Similar calculations are also made for the commercial and industrial sectors.

Demand forecasts in each sector are then generated for a “reference” set of prices. The resulting “reference demand” forecasts are loaded into the NARG model along with the reference prices, the price elasticity and the parameter describing the impact of lagged demand. NARG then forecasts demand based on the internally-solved price, which is based on market balance. Therefore, the demand forecast generated by the model will differ from the reference forecast to the extent that the model-solved price differs from the reference price.