Chapter 4

Estimation of Energy Demand Formulas

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Chapter 4

Estimation of Energy Demand Formulas

Minh Bao Nguyen

Energy is an important commodity for achieving economic development. As economic activities increase, the demand for energy increases. In addition, changes in energy prices make a direct influence on energy consumption and economic growth. Rising energy prices bring an incentive to use energy sources more efficiently and conservatively, resulting in lower energy consumption. On the other hand, the increase of energy prices leads to inflation through the increase of the cost of other goods and then the gross domestic product (GDP) will decrease. Therefore, there is a direct link between energy consumption and socioeconomic variables such as energy price and economic output (or GDP). Logically, an increase in GDP leads to an increase in energy consumption, but on the contrary, an increase in energy prices results in lower energy consumption.

This chapter focuses on the estimation of energy demand formulas based on historical data on energy consumption, socioeconomic data, and activity indicators for forecasting the future energy demand of the Lao People's Democratic Republic (Lao PDR) until 2040.

4.1 Methodology

The demand function was estimated using the econometric approach which is a top-down approach linking the macroeconomic model and energy model.

In the econometric approach, energy demand is modelled as a function of macroeconomic activities such as income (or GDP), relative prices amongst sources of energy, and energy consumption at previous period.

$$E = f(Y, Pe/CPI) \text{ or } E = f(Y, Pe/CPI, E\text{-}1)$$

Where:

E: Energy demand

Y: Income (or GDP)

Pe: Energy price

CPI: Consumer price index

Pe/CPI: Relative energy price over CPI

E-1: Energy consumption at previous period

The relationships amongst the above variables are derived by regression analysis software, a computer programme for carrying out econometric analysis, estimating and testing equations, data processing, file management, graphic display, estimation, hypothesis testing, and forecasting under univariate and multivariate model specifications.

The future energy demand for various energy sources will be forecast by using the estimated formulas mentioned above with the assumed future values of the macroeconomic, energy price, and other activity indicators. However, not all energy consumption of the sectors could be estimated as a demand formula due to the limitation of the data.

To estimate the energy demand formulas for the economic activities in different sectors such as the industry, transport, commercial, and residential sectors, we disaggregate energy consumption by each sector into type of energy such as gas, petroleum products, electricity, and coal consumption and then test the regression results for their relationship with GDP, energy prices, and other related indicators.

Historical energy demand data were taken from the national energy data compiled by the Economic Research Institute for ASEAN and East Asia and the Lao PDR Ministry of Energy and Mines. The economic indicators used in energy modelling such as gross domestic product (GDP) and manufacturing GDP, value-added (MFGGDP) were taken from the World Bank's *World Development Indicators*. Other socioeconomic data such as number of households and electricity prices were obtained from national sources.

In cases where regression analysis is not applicable due to insufficient data or failure to derive a statistically effective equation, other exogenous approaches such as growth as GDP or the share of percentage approach were used.

4.2 Estimation of Energy Demand Formulas

Industry sector

The total energy consumption in the industry sector is not broken down into subsectors. On the basis of fuel type, the total energy consumption each year since 2000 to 2015 is the sum of the different types of fuel, consisting of coal (anthracite and lignite coal), petroleum products (diesel and fuel oil), other (fuelwood and other biomass, etc.), and electricity.

Based on the available data, the estimation of demand formulas has been done for the total energy consumption in the industry sector and by type of fuel if applicable.

1) Total energy demand in industry sector

The total energy demand in the industry sector (INTT) was estimated by using the independent variables such as the real price of crude oil (RPOIL), manufacturing GDP (MFFGDP), and energy consumption of the previous year. A dummy variable was included for the year 2013 to get a sound equation.

The result of the estimated demand equation is:

$$INTT=-93.1478*CONS - 0.0092903*RPOIL + 0.7749E\text{-}4*MMFGGDP + 0.15530*INTT(-1) + 119.2306*DUM13$$

More detail on the result of the regression analysis is shown in Table A4.1 and Figure A4.1 (see Annex).

2) Fuel oil demand in industry sector

Fuel oil demand in the industry sector (INFO) was estimated using RPOIL, GDP (shown as MGDP) and energy consumption of the previous year as the independent variables. The regression test was also done with INGDP, but the use of GDP is better than INGDP. A dummy variable was also included for the year 2011.

The result of the estimated demand equation is as follows:

$$INFO = 0.85902*CONS - 0.1207E\text{-}3*RPOIL + 0.5747E\text{-}7*MGDP + 0.38105*INFO(-1) + 1.8212*DUM11$$

More detail on the result of the regression analysis is shown in Table A4.2 and Figure A4.2 (see Annex).

3) Lignite coal demand in industry sector

Lignite coal demand in the industry sector (INLG) was estimated using the independent variables including GDP (shown as MGDP) and energy consumption of the previous year. RPOIL is not applicable, because lignite coal is local coal and the demand for using lignite coal is not affected by RPOIL. The regression test was done with INGDP, but the use of GDP is also better than INGDP. A dummy variable was included for 2013 to get a sound equation. The result of the estimated demand equation is as follows:

$$INLG = -76.4174*CONS + 0.1335E\text{-}5*MGDP + 0.94608*INLG(-1) + 110.2891*DUM13$$

Basically, the estimation of the lignite coal demand formula using the above variables is a sound one. However, when this formula was linked with the energy model for energy projection, lignite coal demand was increasing at an annual growth rate of 13.7% in the period 2015–2040, which is higher than the annual growth rate GDP (6.2%) by about 2.2 times. This is irrational and in this case we assume that INLG will increase as GDP but higher with elasticity of 1.1. The formula should be as follows:

$$INLG = GrowthAs(Key\backslash MGDP, 1.1)$$

4) Electricity demand in industry sector

Electricity demand in the industry sector (INEL) was estimated using the real price of electricity (RPELC), GDP (shown as MGDP), and energy consumption of the previous year as the independent variables. However, the result showed that the sign of coefficient of RPELC is positive. This is irrational because, electricity demand will increase when the price

increases. We have changed this formula in type of log form with a dummy variable used for 2006 and get the result as follows:

$$LINEL = -8.4861*CONS - 0.013641*LRPELC + 0.52512*LMGDP + 0.79083*LINEL(-1) + 0.66174*DUM06$$

The result on electricity projection also is irrational because the result was too high due to a data problem; therefore, we used only INGDP (shown as MINGDP) as the main variable for electricity demand as follows:

$$INEL= GrowthAs(Key\backslash MINGDP,1.35)$$

5) Other fuels

- **Biomass demand in industry sector**

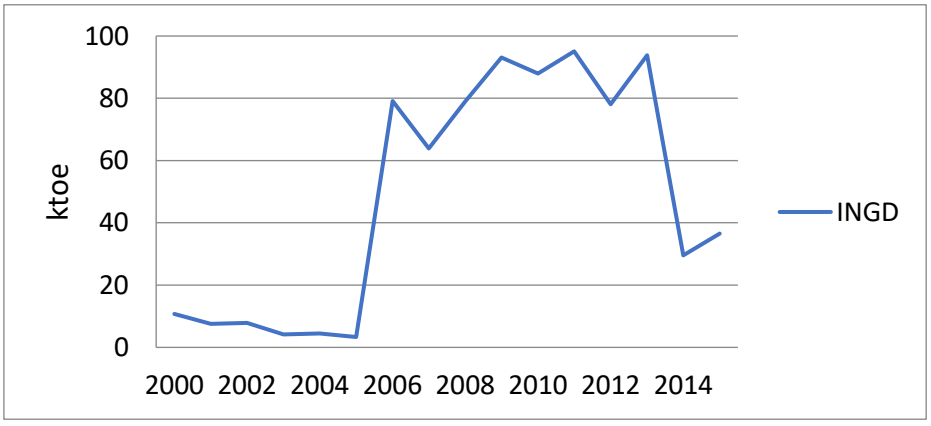
  Biomass demand in the industry sector (INBS) is not affected by RPOIL and is not fit for regression analysis because of a data problem. Based on the historical data trend and use INGDP used as main variable, the biomass demand could be estimated as follows:

$$INBS=GrowthAs(Key\backslash MINGDP,0.5)$$

- **Diesel oil demand in industry sector**

  In the case of diesel oil demand in the industry sector (INGD), the data for 2000–2015 showed irregularities (Figure 4.1), so that the formula for diesel oil could not be estimated.

Figure 4.1 Diesel Oil Consumption in Industry Sector, 2000–2015



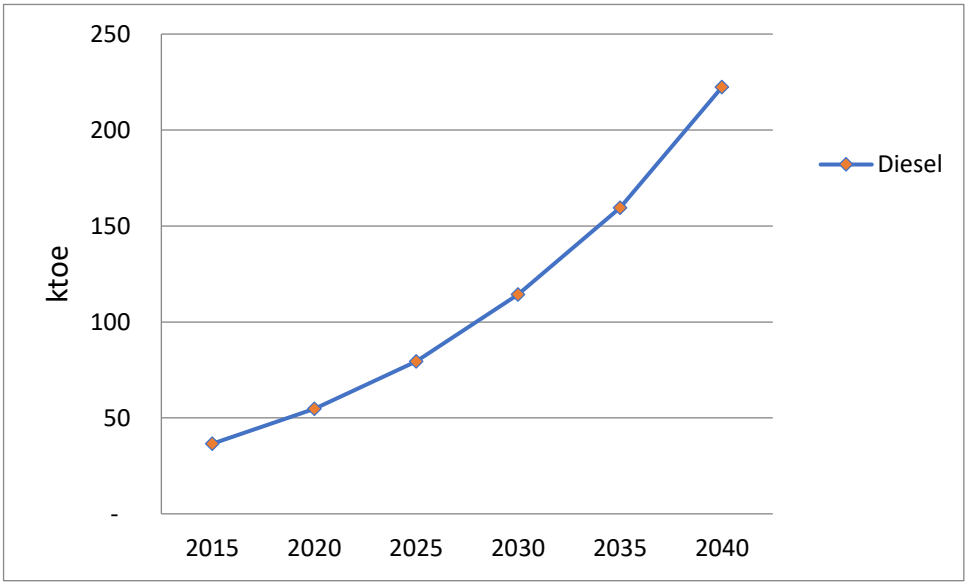
ktoe = thousand tons of oil equivalent, INGD = diesel oil consumption in the industry sector.
Source: Author's analysis.

We assumed that GDP is the only main driver for diesel oil demand as follows:

$$INGD = GrowthAs(Key \backslash MGDP, 1.2)$$

Figure 4.2 below shows the diesel oil demand in the industry sector from 2015 to 2040.

Figure 4.2 Diesel Oil Demand in Industry Sector, 2015–2040



ktoe= thousand tons of oil equivalent.
Source: Author's analysis.

- **Anthracite coal demand in industry sector**

  Anthracite coal demand in the industry sector (INAN) is equal to total energy demand minus the remaining fuels in the industry sector as formula below:

$$INAN=INTT–INFO–INLG–INEL–INBS–INGD$$

Transport sector

The total energy demand of the transport sector is broken-down by subsectors, including air and road transport. There are no data for rail transport and for transport on inland waterways.

The majority of the fuels consumed by the transport sector are petroleum products including motor gasoline, gas/diesel oil, lubricants (or non-energy petroleum products), and jet fuel.

Motor gasoline, gas/diesel oil, and lubricants are used by the road subsector, while jet fuel is used for aviation transport.

1) Road transport

Fuels used in road transport consist of gasoline, diesel oil, and lubricants. We have used the regression analysis to test for each fuel in road transport; however, due to the limitation of statistical data, the regression analysis results were not better than the other method of the share of percentage approach. Therefore, the share of percentage approach was used to estimate the fuel demand formulas in road transport.

a) Total energy demand for road transport

Because of the limitation of data to estimate the demand formula for each of the petroleum products, the function is only estimated for total energy demand in road transport (RDTTT), and then each fuel demand formula will be estimated based on the share of each fuel in the total energy demand.

RDTTT was estimated as a function of GDP, RPOIL, and the previous year consumption. The demand equation for RDTTTis as follows:

$$RDTTT = 37.9381*CONS + 0.7211E\text{-}5*MGDP - 0.011166*RPOIL + 0.14203*RDTTT(-1)$$

The result of the regression analysis is shown in Table A4.3 and Figure A4.3 (see Annex).

b) Fuel types used in road transport

Based on the statistical data, we can estimate the share of each fuel type in the total fuels used in road transport. Assuming that the share of each fuel type is still maintained in the coming years, we can estimate the fuel demand in road transport as follows:

$$RDGD = DSRDSH(-1)*RDTTT$$

$$RDMG=GSRDSH(-1)* RDTTT$$

$$NEPP = LBRDSH(-1)* RDTTT$$

Where:

RDGD = Diesel demand in the road transport

DSRDSH= Diesel share of road transport

RDMG = Gasoline demand in the road transport

GSRDSH= Gasoline share of road transport

NEPP = Non-energy petroleum products

LBRDSH= Lubricant share of road transport

2) Aviation transport

Aviation transport includes international and domestic aviation. The total energy demand for aviation transport (AVTT) was estimated using the GDP and energy consumption of the previous year, because it was impossible to use RPOIL. However, the result of the energy demand projection for aviation transport is irrational with an annual average growth rate of 1.1% in the period 2015–2040 (very low compared to the GDP growth rate of 6.2%). In this case, the exogenous approach was used, with the formula estimated as follows:

$$AVTT = GrowthAs(Key\backslash MGDP, 0.5)$$

Because the data on domestic aviation transport are almost unchanged during the period of 2000–2015, the jet fuel demand for domestic aviation transport (TSJF) was estimated based on the relationship with international aviation. The estimated result of demand formula for TSJF is:

$$TSJF = - 0.063395*CONS + 0.076231*AVTT$$

The result of the regression analysis is shown in Table A4.4 and Figure A4.4 (see Annex).

Residential sector

Energy used in the residential sector consists of electricity, liquefied petroleum gas (LPG), and other fuel (biomass). Because of data problems, biomass is not fit for regression analysis, thus biomass is estimated based on the total energy consumption in the residential sector minus the other remaining fuels.

1) Total energy demand in residential sector

The total energy demand in the residential sector (RETT) was estimated using the residential real price of electricity (RERPELC), population (POP), and the energy consumption of the previous year as the independent variables. A dummy variable was included for the years 2006 and 2008. The result of the estimated demand equation is as follows:

$$RETT= 101.3128*CONS -9.8821*RERPELC + 0.2835E-4*POP + 0.81543*RETT(-1) + 70.1772*DUM0608$$

The result of the regression analysis is shown in Table A4.5 and Figure A4.5 (see Annex).

2) Electricity demand in residential sector

Electricity demand in the residential sector (REEL) was estimated using the independent variables including the residential real price of electricity (RERPELC), GDP per capita (GDPC), and electricity consumption of the previous year. The result of the estimated demand equation is as follows:

$$REEL = -18.3522*CONS – 1.6288*RERPELC + 5.6521*GDPC + 0.62271*REEL(-1)$$

The result of the regression analysis is shown in Table A4.6 and Figure A4.6 (see Annex).

3) LPG demand in residential sector

LPG consumption per capita in the residential sector (LRELPP) was estimated using Log Form with the independent variables including RPOIL, GDPC, and a dummy variable used for the year 2002.

The result of the estimated demand equation is as follows:

$$LRELPP = -15.8834*CONS - 0.17513*LRPOIL + 0.74058*LGDPC + 0.065054*DUM02$$

Thus, LPG demand in the residential sector will be:

$$RELP = (Exp(LRELPP)) * POP.$$

However, the result of the calculation in the energy model showed that the LPG demand by 2040 is low, with an annual average growth rate of 5% in the period 2015–2040, which is lower than the growth rate of the GDP in the same period.

Urban population (or the urbanisation rate) and income are two main drivers impacting LPG demand. Normally, when the urbanisation rate and income increase, the LPG demand will increase accordingly (with a higher growth rate at the initial period of using LPG compared to the next periods).

Therefore, another exogenous approach is applied with summing that LPG demand will increase with an annual average growth rate higher than GDP around 1.2 times.

As with the above analysis, LPG demand formula is estimated as follows:

$$RELP= GrowthAs(Key\backslash MGDP, 1.2)$$

4) Biomass demand in residential sector

Biomass demand (or other fuels) in the residential sector (REOTH) could be estimated as follows:

$$REOT= RETT-REEL-RELP$$

Commercial sector

Energy used in the commercial sector consists of electricity, LPG, and other fuels (biomass). Similar to the residential sector, biomass is also equal to the total energy consumption in the commercial sector minus the other remaining fuels.

1) Total energy demand in commercial sector

The total energy demand in the commercial sector (CSTT) was estimated using the independent variables consisting of the commercial real price of electricity (CSRPELC), commercial GDP (MCSGDP), and energy consumption of the previous year. The years for estimation started from 2005 to 2015 to get a better equation. A dummy variable was included for the years 2009 and 2014. The result of the estimated demand equation is as follows:

$$CSTT = 336.5932*CONS - 12.7326*CSRPELC + 0.9150E\text{-}6*MCSGDP + 0.28293*CSTT(-1) + 19.4497*DUM09 - 19.9742*DUM14$$

The result of the regression analysis is shown in Table A4.7 and Figure A4.7 (See Annex).

2) Electricity demand in commercial sector

Electricity demand in the commercial sector (CSEL) was estimated using the independent variables such as the commercial real price of electricity (CSRPELC) and commercial GDP (MCSGDP). The years for estimation also started from 2005 to 2015 to get a better equation. A dummy variable was used for the years 2012 and 2014. The result of the estimated demand equation is as follows:

$$CSEL = 104.8994*CONS - 8.2225*CSRPELC + 0.1266E\text{-}5*MCSGDP + 15.6876*DUM12 - 14.7276*DUM14$$

The result of the regression analysis is shown in Table A4.8 and Figure A4.8 (See Annex).

3) LPG demand in commercial sector

LPG demand in the commercial sector (CSLP) was estimated using RPOIL, MCSGDP, and energy consumption of the previous year. A dummy variable was also included for the years 2006 and 2011. The result of the estimated demand equation is as follows:

$$CSLP = 0.0035573*CONS - 0.8711E\text{-}5*RPOIL + 0.9167E\text{-}8*MCSGDP + 0.91328*CSLP(-1) + 0.12769*DUM06 + 0.27396*DUM11$$

The result of the regression analysis is shown in Table A4.9 and Figure A4.9 (See Annex).

4) Biomass demand in commercial sector

Similar to the residential sector, biomass demand (or other fuels) in the commercial sector (REOTH) could be estimated as follows:

$$CSOT = CSTT - CSEL - CSLP$$

Other key variables

Aside from the main variables such as GDP, RPOIL, etc. other related key variables worked as the main drivers for energy demand projection are very important, including GDP deflator, sectoral GDP, and price of electricity. However, these future variables are still lacking due to the limitation of data. Thus, in this study, these functions are also estimated based on the relationships amongst other related available variables by regression analysis.

1) GDP deflator

The crude oil price is clearly tied to economic activity and inflation. In the case of the crude oil price increasing, the consumer price index (CPI) also increases. Therefore, GDP deflator (PGDP) was estimated as a function of the price of crude oil (POILJ) and PGDP of the previous year as follows:

$$PGDP = 3.9492*CONS + 0.063211*POILJ + 0.95527*PGDP(-1)$$

The result of the regression analysis is shown in Table A4.10 and Figure A4.10 (see Annex).

2) Industrial GDP

Industrial GDP (MINGDP) is the main component and contribution to GDP growth. Thus, MINGDP was estimated as a function of GDP and MINGDP of the previous year with the equation as follows:

$$MINGDP = -4101490*CONS + 0.19218*MGDP + 0.59237*MINGDP(-1)$$

The result of the regression analysis is shown in Table A4.11 and Figure A4.11 (see Annex).

3) Manufacturing GDP

Manufacturing GDP (MMFGGDP) was also estimated as a function of GDP (MGDP) and MMFGGDP of the previous year. The estimated equation is shown as follows:

$$MMFGGDP = 148716.0*CONS + 0.012981*MGDP + 0.89060*MMFGGDP(-1)$$

The result of the regression analysis is shown in Table A4.12 and Figure A4.12 (see Annex).

4) Commercial GDP

Similar to MINGDP, commercial GDP (MCSGDP) was estimated as a function of GDP and MCSGDP of the previous year. The estimated equation is as follows:

$$MCSGDP = -235667.1*CONS + 0.15436*MGDP + 0.68017*MCSGDP(-1)$$

The result of the regression analysis is shown in Table A4.13 and Figure A4.13 (see Annex).

5) Industrial price of electricity

Similar to the oil price, the electricity price is strongly relative to economic activities. The electricity price is affected by general inflation such as PGDP and CPI. Therefore, the industrial price of electricity (PELC) was estimated as a function of PGDP and PELC of the previous year. A dummy variable was also included for the years 2007 and 2011. The equation is estimated as follows:

$$PELC = 161.9270*CONS + 0.55127*PGDP + 0.69916*PELC(-1) - 48.7882*DUM0711$$

The result of the regression analysis is shown in Table A4.14 and Figure A4.14 (see Annex).

6) Residential price of electricity

Similarly, the residential price of electricity (REPELC) was also estimated as a function of PGDP and REPELC of the previous year. The equation is estimated as follows:

$$\text{REPELC} = 17.4258*\text{CONS} + 2.6132*\text{PGDP} + 0.53734*\text{REPELC}(-1)$$

The result of the regression analysis is shown in Table A4.15 and Figure A4.15 (see Annex).

7) Commercial price of electricity

The commercial price of electricity (CSPELC) was also estimated as a function of PGDP. Dummy variables were also included for the years of 2002, 2006, 2007, and 2009. The equation is estimated as follows:

$$CSPELC = 75.5422*CONS + 8.5988*PGDP + 251.3462*DUM0206 + 126.7228*DUM0709$$

The result of the regression analysis is shown in Table A4.16 and Figure A4.16 (see Annex).

Annex

Results of Microfit Regression Analysis

1. Industry Sector

- **Total energy demand**

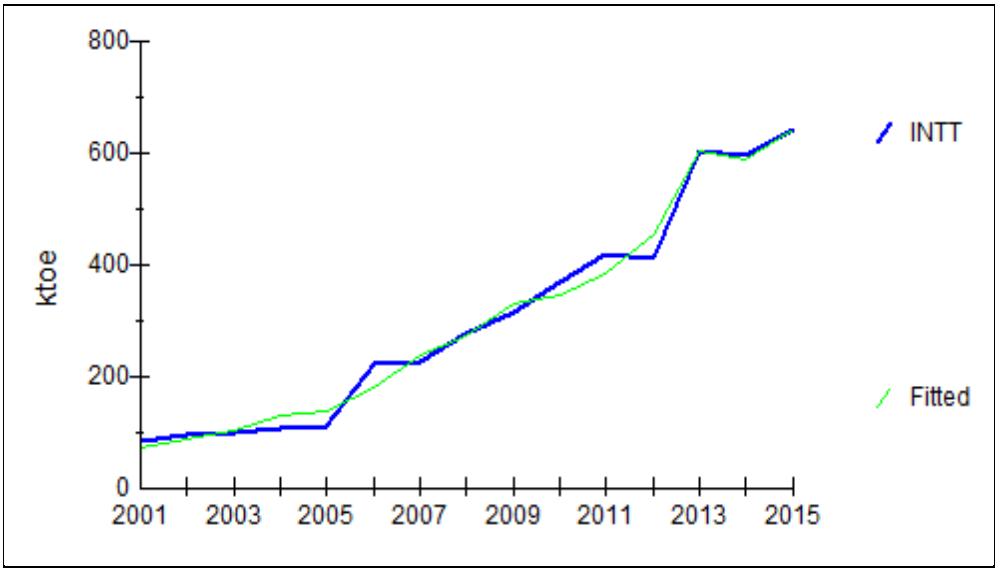
$$INTT=-93.1478*CONS - 0.0092903*RPOIL + 0.7749E-4*MMFGGDP + 0.15530*INTT(-1) + 119.2306*DUM13$$

Table A4.1 Ordinary Least Squares Estimation for INTT

```
********************************************************************************
 Dependent variable is INTT
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     -93.1478           42.5758           -2.1878[.054]
 RPOIL                   -.0092903          .0053491           -1.7368[.113]
 MMFGGDP                  .7749E-4          .2472E-4            3.1348[.011]
 INTT(-1)                   .15530            .27457             .56562[.584]
 DUM13                    119.2306           31.7539            3.7548[.004]
********************************************************************************
 R-Squared                    .98695   R-Bar-Squared                   .98173
 S.E. of Regression         26.5668   F-stat.    F(  4,  10)  189.0852[.000]
 Mean of Dependent Variable 304.5698  S.D. of Dependent Variable    196.5561
 Residual Sum of Squares     7058.0   Equation Log-likelihood       -67.4380
 Akaike Info. Criterion     -72.4380  Schwarz Bayesian Criterion    -74.2082
 DW-statistic                 2.5609  Durbin's h-statistic            *NONE*
********************************************************************************
```

INTT = total energy demand in the industry sector, CONS = constant, RPOIL = real price of crude oil, MMFGGDP = manufacturing GDP, INTT(-1) = total energy demand in the industry sector of the previous year, DUM13 = dummy variable at the year of 2013.
Source: Microfit analysis result.

Figure A4.1 Plot of Actual and Fitted Values for INTT



INTT =total energy demand in the industry sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

- **Fuel oil demand**

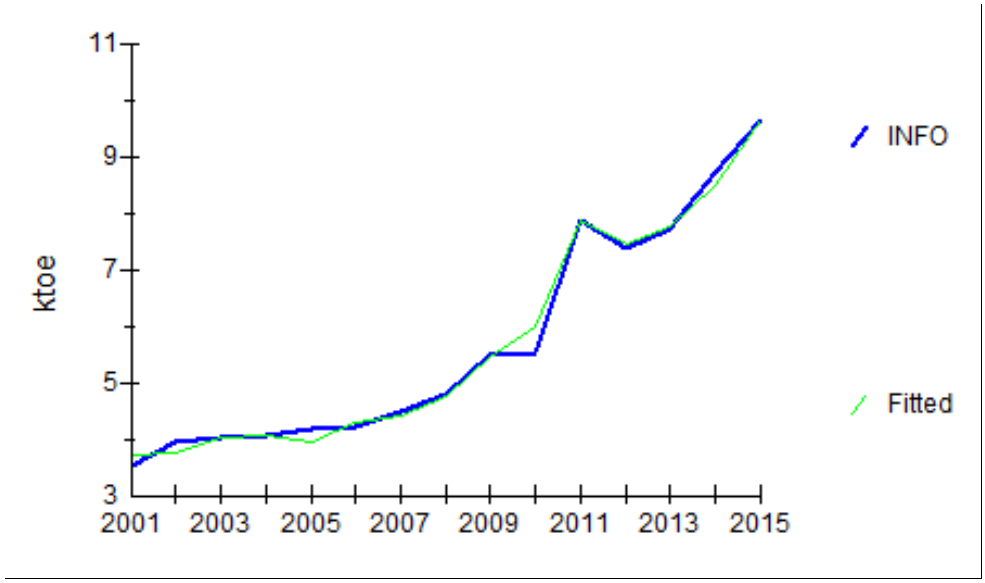
$$INFO = 0.85902*CONS - 0.1207E\text{-}3*RPOIL + 0.5747E\text{-}7*MGDP + 0.38105*INFO(-1) + 1.8212*DUM11$$

Table A4.2 Ordinary Least Squares Estimation for INFO

```
********************************************************************************
 Dependent variable is INFO
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor             Coefficient       Standard Error         T-Ratio[Prob]
 CONS                      .85902            .31371             2.7382[.021]
 RPOIL                   -.1207E-3          .2964E-4            -4.0741[.002]
 MGDP                     .5747E-7          .1125E-7             5.1070[.000]
 INFO(-1)                  .38105            .13480             2.8268[.018]
 DUM11                     1.8212            .24101             7.5568[.000]
********************************************************************************
 R-Squared                      .99275   R-Bar-Squared                   .98985
 S.E. of Regression             .20240   F-stat.    F(  4,  10)  342.2573[.000]
 Mean of Dependent Variable    5.7097   S.D. of Dependent Variable     2.0087
 Residual Sum of Squares        .40964   Equation Log-likelihood        5.7198
 Akaike Info. Criterion         .71982   Schwarz Bayesian Criterion    -1.0503
 DW-statistic                  2.2568   Durbin's h-statistic     -.58314[.560]
********************************************************************************
```

INFO = fuel oil demand in the industry sector, CONS = constant, RPOIL = real price of crude oil, MGDP = gross domestic product, INFO(-1) = fuel oil demand in the industry sector of the previous year, DUM11= dummy variable for the year of 2011.
Source: Microfit analysis result.

Figure A4.2 Plot of Actual and Fitted Values for INFO



INFO = fuel oil demand in the industry sector, ktoe = thousand tons of oil equivalent.
Source: Microfit analysis result.

2. Transport Sector

- **Total energy demand in road transport**

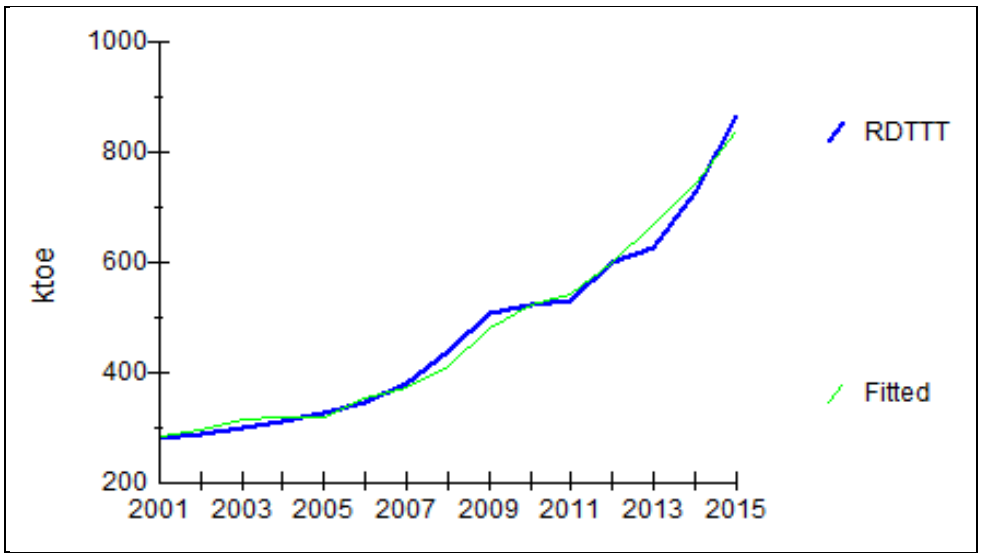
$$RDTTT = 37.9381*CONS + 0.7211E\text{-}5*MGDP - 0.011166*RPOIL + 0.14203*RDTTT(-1)$$

Table A4.3 Ordinary Least Squares Estimation for RDTTT

```
********************************************************************************
 Dependent variable is RDTTT
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor             Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     37.9381            30.8044             1.2316[.244]
 MGDP                    .7211E-5           .2452E-5             2.9405[.013]
 RPOIL                   -.011166           .0032606            -3.4245[.006]
 RDTTT(-1)                .14203             .35211              .40338[.694]
********************************************************************************
 R-Squared                    .98892   R-Bar-Squared                   .98590
 S.E. of Regression         21.0531   F-stat.    F(  3,  11)  327.2701[.000]
 Mean of Dependent Variable 470.0620  S.D. of Dependent Variable    177.2902
 Residual Sum of Squares     4875.6   Equation Log-likelihood       -64.6636
 Akaike Info. Criterion     -68.6636  Schwarz Bayesian Criterion    -70.0797
 DW-statistic                1.3290   Durbin's h-statistic            *NONE*
********************************************************************************
```

RDTT = total energy demand in road transport, CONS = constant, MGDP = gross domestic product, RPOIL = real price of crude oil, RDTT(-1) = total energy demand in road transport in the previous year.
Source: Microfit analysis result.

Figure A4.3 Plot of Actual and Fitted Values for RDTTT



ktoe = thousand tons of oil equivalent, RDTT = total energy demand in road transport.
Source: Microfit analysis result.

- **Jet fuel demand for domestic aviation transport**

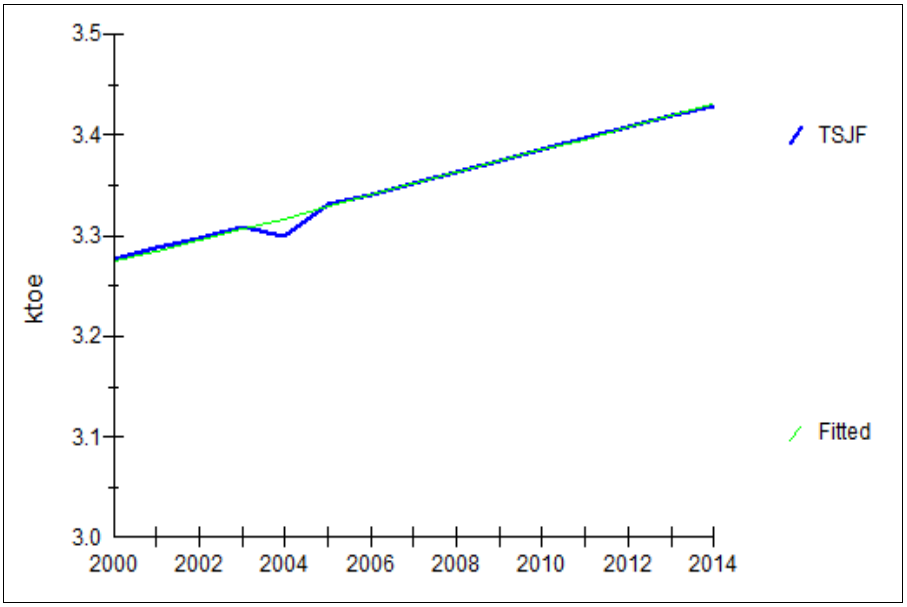
$$TSJF = - 0.063395*CONS + 0.076231*AVTT$$

Table A4.4 Ordinary Least Squares Estimation forTSJF

```
**************************************************************************
 Dependent variable is TSJF
 15 observations used for estimation from 2000 to 2014
**************************************************************************
 Regressor             Coefficient       Standard Error         T-Ratio[Prob]
 CONS                    -.063395            .087224           -.72681[.480]
 AVTT                     .076231           .0019470           39.1521[.000]
**************************************************************************
 R-Squared                    .99159   R-Bar-Squared                  .99094
 S.E. of Regression         .0047659   F-stat.    F(  1,  13)    1532.9[.000]
 Mean of Dependent Variable   3.3513   S.D. of Dependent Variable     .050081
 Residual Sum of Squares    .2953E-3   Equation Log-likelihood        59.9831
 Akaike Info. Criterion       57.9831  Schwarz Bayesian Criterion     57.2750
 DW-statistic                 2.2219
**************************************************************************
```

TSJF = domestic aviation transport, CONS = constant, AVTT=total energy demand for aviation transport.
Source: Microfit analysis result.

Figure A4.4 Plot of Actual and Fitted Values for TSJF



ktoe = thousand tons of oil equivalent, TSJF=domestic aviation transport.
Source: Microfit analysis result.

3. Residential Sector

- **Total energy demand**

$$RETT= 101.3128*CONS -9.8821*RERPELC + 0.2835E-4*POP + 0.81543*RETT(-1) + 70.1772*DUM0608$$

Table A4.5 Ordinary Least Squares Estimation for RETT

```
********************************************************************************
 Dependent variable is RETT
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor             Coefficient       Standard Error         T-Ratio[Prob]
 CONS                    101.3128           106.3270             .95284[.363]
 RERPELC                  -9.8821            11.7774            -.83907[.421]
 POP                     .2835E-4           .3140E-4             .90299[.388]
 RETT(-1)                 .81543             .11105             7.3430[.000]
 DUM0608                  70.1772            15.6485             4.4846[.001]
********************************************************************************
 R-Squared                    .96642   R-Bar-Squared                    .95299
 S.E. of Regression         23.4325   F-stat.    F(  4,  10)    71.9510[.000]
 Mean of Dependent Variable  1170.4   S.D. of Dependent Variable    108.0736
 Residual Sum of Squares     5490.8   Equation Log-likelihood       -65.5549
 Akaike Info. Criterion     -70.5549   Schwarz Bayesian Criterion    -72.3251
 DW-statistic                1.9281   Durbin's h-statistic      .15419[.877]

********************************************************************************
```

RETT = total energy demand in the residential sector, CONS = constant, RERPELC = the residential real price of electricity, POP = population, RETT(-1) = total energy demand in the residential sector in the previous year, DUM0608= dummy variable for the years of 2006–2008.
Source: Microfit analysis result.

Figure A4.5 Plot of Actual and Fitted Values for RETT

ktoe = thousand tons of oil equivalent, RETT = total energy demand in the residential sector.
Source: Microfit analysis result.

- **Electricity demand**

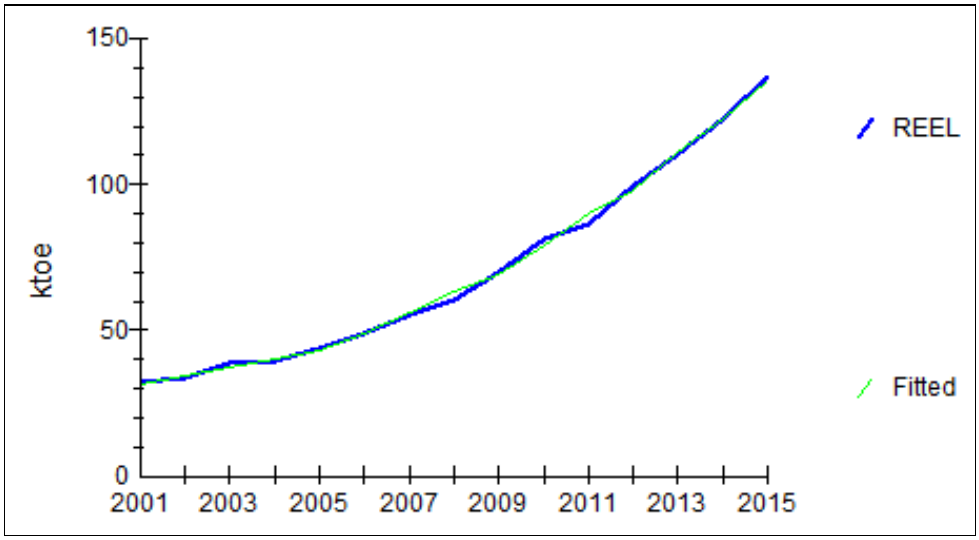
$$REEL = -18.3522*CONS - 1.6288*RERPELC + 5.6521*GDPC + 0.62271*REEL(-1)$$

Table A4.6 Ordinary Least Squares Estimation for REEL

```
********************************************************************************
 Dependent variable is REEL
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     -18.3522            9.2434            -1.9854[.073]
 RERPELC                   -1.6288            1.0132            -1.6076[.136]
 GDPC                       5.6521            2.2208             2.5451[.027]
 REEL(-1)                   .62271            .19808             3.1437[.009]
********************************************************************************
 R-Squared                    .99732   R-Bar-Squared                  .99659
 S.E. of Regression          1.9884    F-stat.    F(  3,  11)     1363.5[.000]
 Mean of Dependent Variable 70.6347   S.D. of Dependent Variable     34.0341
 Residual Sum of Squares    43.4919   Equation Log-likelihood       -29.2680
 Akaike Info. Criterion    -33.2680   Schwarz Bayesian Criterion    -34.6841
 DW-statistic                2.8493   Durbin's h-statistic      -2.5640[.010]
********************************************************************************
```

REEL = electricity demand in the residential sector, CONS = constant, RERPELC = the residential real price of electricity, GDPC = GDP per capita, REEL (-1) = electricity demand in the residential sector in the previous year.
Source: Microfit analysis result.

Figure A4.6 Plot of Actual and Fitted Values for REEL



ktoe = thousand tons of oil equivalent, REEL = electricity demand in the residential sector.
Source: Microfit analysis result.

4. Commercial Sector

- **Total energy demand**

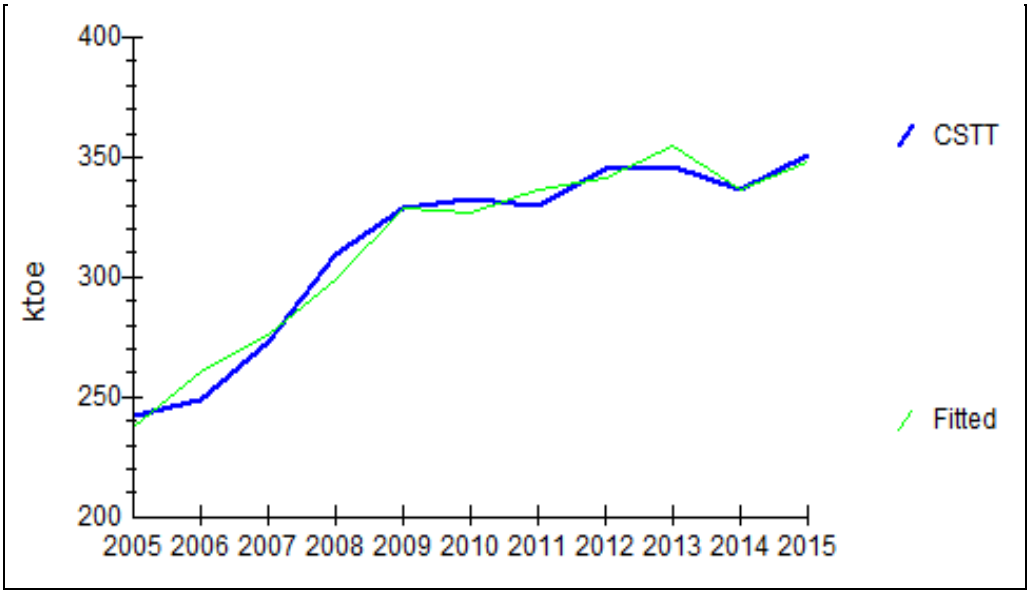
$$CSTT = 336.5932*CONS - 12.7326*CSRPELC + 0.9150E\text{-}6*MCSGDP + 0.28293*CSTT(-1) + 19.4497*DUM09 - 19.9742*DUM14$$

Table A4.7 Ordinary Least Squares Estimation for CSTT

```
********************************************************************************
 Dependent variable is CSTT
 11 observations used for estimation from 2005 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     336.5932          120.8273             2.7857[.039]
 CSRPELC                  -12.7326            5.3545            -2.3779[.063]
 MCSGDP                   .9150E-6          .9425E-6             .97091[.376]
 CSTT(-1)                   .28293            .24849             1.1386[.306]
 DUM09                     19.4497           10.8702             1.7893[.134]
 DUM14                    -19.9742           10.7942            -1.8505[.123]
********************************************************************************
 R-Squared                      .97296   R-Bar-Squared                   .94591
 S.E. of Regression            9.2407   F-stat.    F(  5,   5)   35.9787[.001]
 Mean of Dependent Variable  313.1328   S.D. of Dependent Variable     39.7342
 Residual Sum of Squares     426.9513   Equation Log-likelihood       -35.7316
 Akaike Info. Criterion      -41.7316   Schwarz Bayesian Criterion    -42.9253
 DW-statistic                  2.5790   Durbin's h-statistic     -1.6953[.090]
********************************************************************************
```

CSTT = total energy demand in the commercial sector, CONS = constant, CSRPELC = the commercial real price of electricity, MCSGDP = commercial GDP, CSTT(-1) = total energy demand in the commercial sector in the previous year, DUM09 = dummy variable at the year of 2009, DUM14 = dummy variable for the year of 2014.
Source: Microfit analysis result.

Figure A4.7 Plot of Actual and Fitted Values for CSTT



CSTT = total energy demand in the commercial sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

- **Electricity demand**

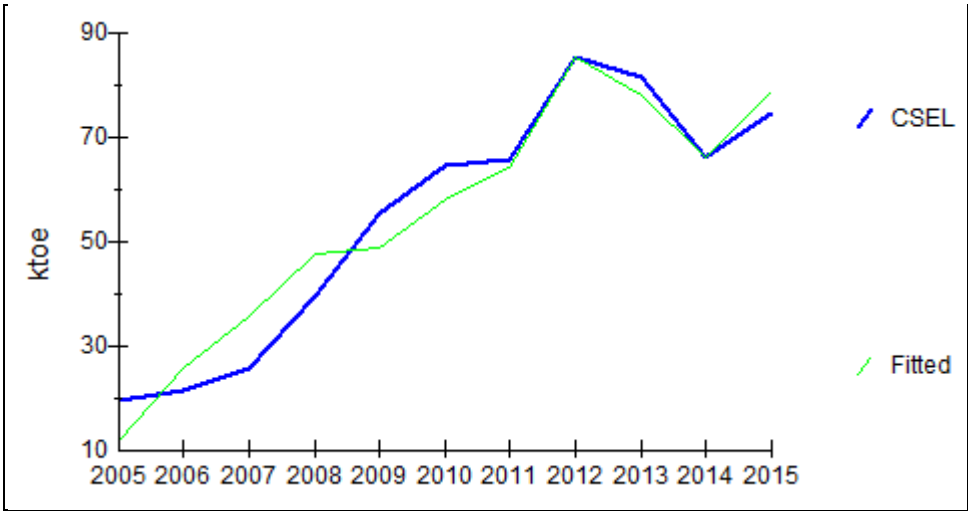
$$CSEL = 104.8994*CONS - 8.2225*CSRPELC + 0.1266E\text{-}5*MCSGDP + 15.6876*DUM12 - 14.7276*DUM14$$

Table A4.8 Ordinary Least Squares Estimation for CSEL

```
********************************************************************************
 Dependent variable is CSEL
 11 observations used for estimation from 2005 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     104.8994            47.5697             2.2052[.070]
 CSRPELC                   -8.2225             2.7448            -2.9957[.024]
 MCSGDP                   .1266E-5           .6865E-6             1.8443[.115]
 DUM12                     15.6876             8.6229             1.8193[.119]
 DUM14                    -14.7276             9.1915            -1.6023[.160]
********************************************************************************
 R-Squared                    .93743   R-Bar-Squared                    .89571
 S.E. of Regression          7.7740   F-stat.    F(  4,   6)   22.4720[.001]
 Mean of Dependent Variable  54.5322  S.D. of Dependent Variable     24.0728
 Residual Sum of Squares    362.6109  Equation Log-likelihood       -34.8332
 Akaike Info. Criterion     -39.8332  Schwarz Bayesian Criterion    -40.8280
 DW-statistic                 1.3019
********************************************************************************
```

CSEL = electricity demand in the commercial sector, CONS=constant ,CSRPELC = the commercial real price of electricity, MCSGDP = commercial GDP, DUM12 = dummy variable at the year of 2012, DUM14 = dummy variable at the year of 2014.
Source: Microfit analysis result.

Figure A4.8 Plot of Actual and Fitted Values for CSEL



CSEL = electricity demand in the commercial sector, ktoe= thousand tons of oil equivalent.

Source: Microfit analysis result.

- **LPG demand**

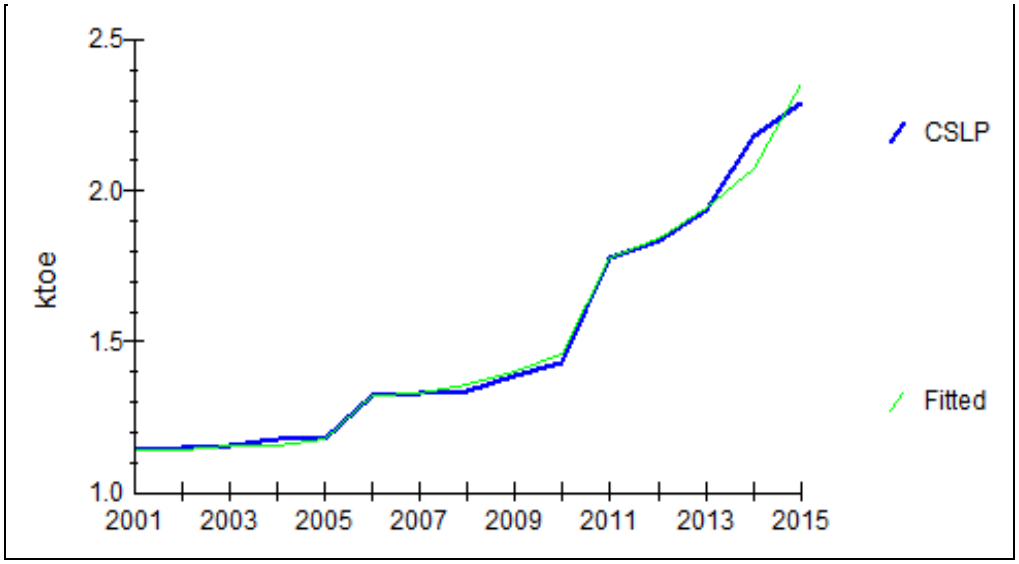
$$CSLP = 0.0035573*CONS - 0.8711E\text{-}5*RPOIL + 0.9167E\text{-}8*MCSGDP + 0.91328*CSLP(-1) + 0.12769*DUM06 + 0.27396*DUM11$$

Table A4.9 Ordinary Least Squares Estimation for CSLP

```
********************************************************************************
 Dependent variable is CSLP
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     .0035573            .14778            .024071[.981]
 RPOIL                   -.8711E-5           .8196E-5           -1.0629[.316]
 MCSGDP                   .9167E-8           .7317E-8            1.2528[.242]
 CSLP(-1)                  .91328             .19316            4.7281[.001]
 DUM06                     .12769             .050137           2.5469[.031]
 DUM11                     .27396             .055377           4.9471[.001]
********************************************************************************
 R-Squared                    .99125   R-Bar-Squared                   .98639
 S.E. of Regression          .045644   F-stat.    F(  5,   9)  203.9077[.000]
 Mean of Dependent Variable   1.5094   S.D. of Dependent Variable      .39123
 Residual Sum of Squares     .018751   Equation Log-likelihood        28.8503
 Akaike Info. Criterion      22.8503   Schwarz Bayesian Criterion     20.7261
 DW-statistic                 2.5403   Durbin's h-statistic     -1.5768[.115]
********************************************************************************
```

CSLP = LPG demand in the commercial sector, CONS = constant, RPOIL = real price of crude oil, MCSGDP = commercial GDP, CSLP(-1) = LPG demand in the commercial sector in the previous year, DUM06= dummy variable for the year of 2006, DUM11= dummy variable for the year of 2011.
Source: Microfit analysis result.

Figure A4.9 Plot of Actual and Fitted Values for CSLP



CSLP = LPG demand in the commercial sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

5. Other Key Variables

- **GDP deflator**

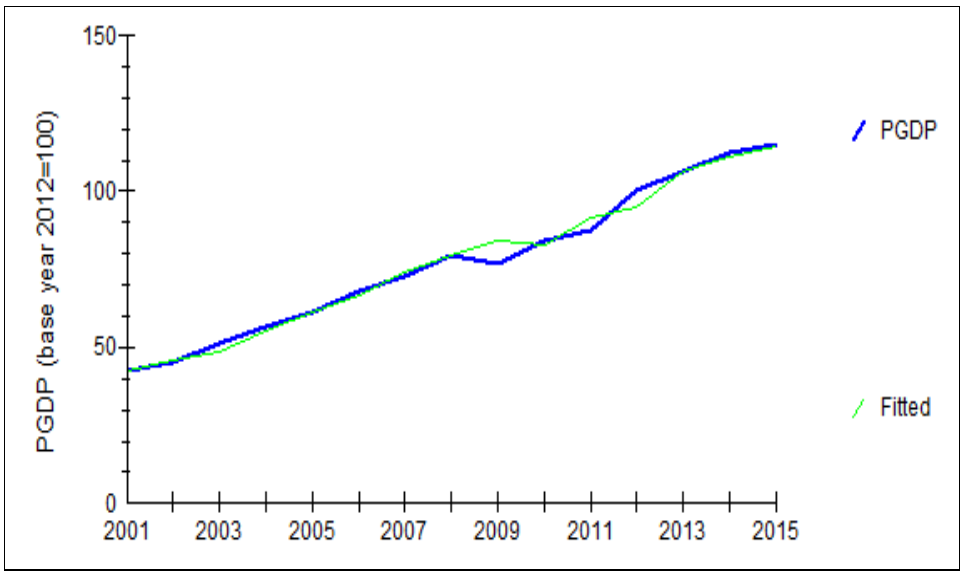
$$PGDP = 3.9492*CONS + 0.063211*POILJ + 0.95527*PGDP(-1)$$

Table A4.10 Ordinary Least Squares Estimation for PGDP

```
********************************************************************************
 Dependent variable is PGDP
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                       3.9492            2.5441             1.5523[.147]
 POILJ                     .063211           .034247             1.8457[.090]
 PGDP(-1)                   .95527           .046218            20.6685[.000]
********************************************************************************
 R-Squared                    .98703   R-Bar-Squared                   .98487
 S.E. of Regression          2.9372   F-stat.    F(  2,  12)  456.5266[.000]
 Mean of Dependent Variable  77.2977   S.D. of Dependent Variable     23.8758
 Residual Sum of Squares    103.5285   Equation Log-likelihood       -35.7726
 Akaike Info. Criterion     -38.7726   Schwarz Bayesian Criterion    -39.8346
 DW-statistic                 2.5993   Durbin's h-statistic     -1.1796[.238]
********************************************************************************
```

PGDP = GDP deflator, CONS = constant, POILJ = the price of crude oil, PGDP(-1) = GDP deflator in the previous year.
Source: Microfit analysis result.

Figure A4.10 Plot of Actual and Fitted Values for PGDP



PGDP = GDP deflator.
Source: Microfit analysis result.

- **Industrial GDP**

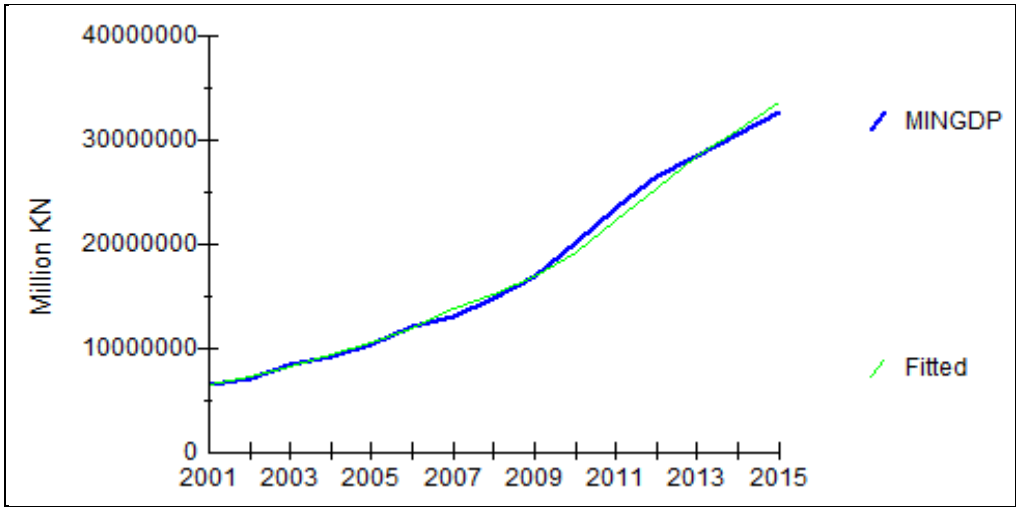
$$MINGDP = -4101490*CONS + 0.19218*MGDP + 0.59237*MINGDP(-1)$$

Table A4.11 Ordinary Least Squares Estimation for INGDP

```
********************************************************************************
 Dependent variable is MINGDP
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     -4101490            2290085           -1.7910[.099]
 MGDP                       .19218            .091138            2.1086[.057]
 MINGDP(-1)                 .59237             .22843            2.5932[.024]
********************************************************************************
 R-Squared                    .99555   R-Bar-Squared                    .99481
 S.E. of Regression         648481.8   F-stat.    F(  2,  12)    1343.7[.000]
 Mean of Dependent Variable 1.73E+07   S.D. of Dependent Variable     9004807
 Residual Sum of Squares    5.05E+12   Equation Log-likelihood      -220.3463
 Akaike Info. Criterion     -223.3463  Schwarz Bayesian Criterion   -224.4084
 DW-statistic                 .88296   Durbin's h-statistic      4.6403[.000]
********************************************************************************
```

INGDP = Industrial GDP, CONS = constant, MINGDP(-1) = industrial GDP in the previous year.
Source: Microfit analysis result.

Figure A4.11 Plot of Actual and Fitted Values for INGDP



KN = Lao kip, INGDP = Industrial GDP.
Source: Microfit analysis result.

- **Manufacturing GDP**

$$MMFGGDP = 148716.0*CONS + 0.012981*MGDP + 0.89060*MMFGGDP(-1)$$

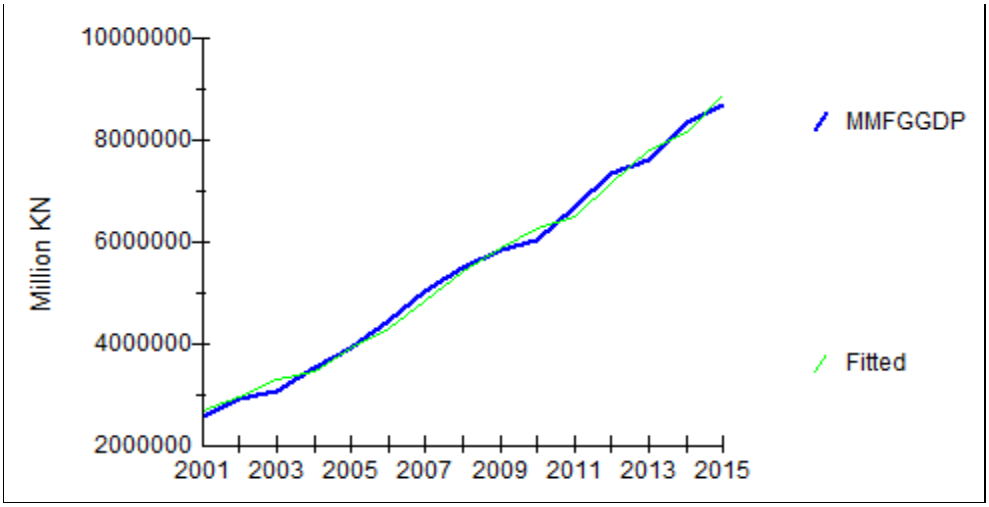
Table A4.12 Ordinary Least Squares Estimation for MFGGDP

```
********************************************************************************
 Dependent variable is MMFGGDP
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     148716.0           230113.8             .64627[.530]
 MGDP                      .012981            .019290             .67294[.514]
 MMFGGDP(-1)               .89060             .20832             4.2753[.001]
********************************************************************************
 R-Squared                    .99352   R-Bar-Squared                    .99244
 S.E. of Regression        174642.7    F-stat.    F(  2,  12)  919.6464[.000]
 Mean of Dependent Variable  5433333   S.D. of Dependent Variable     2008278
 Residual Sum of Squares    3.66E+11   Equation Log-likelihood      -200.6680
 Akaike Info. Criterion    -203.6680   Schwarz Bayesian Criterion   -204.7300
 DW-statistic                 2.2636   Durbin's h-statistic     -.86410[.388]

********************************************************************************
```

MMFGGDP = manufacturing GDP, CONS = constant, MGDP = gross domestic product, MMFGGDP(-1) = manufacturing GDP in the previous year.
Source: Microfit analysis result.

Figure A4.12 Plot of Actual and Fitted Values for MFGGDP



KN = Lao kip, MMFGGDP = manufacturing GDP.
Source: Microfit analysis result

- **Commercial GDP**

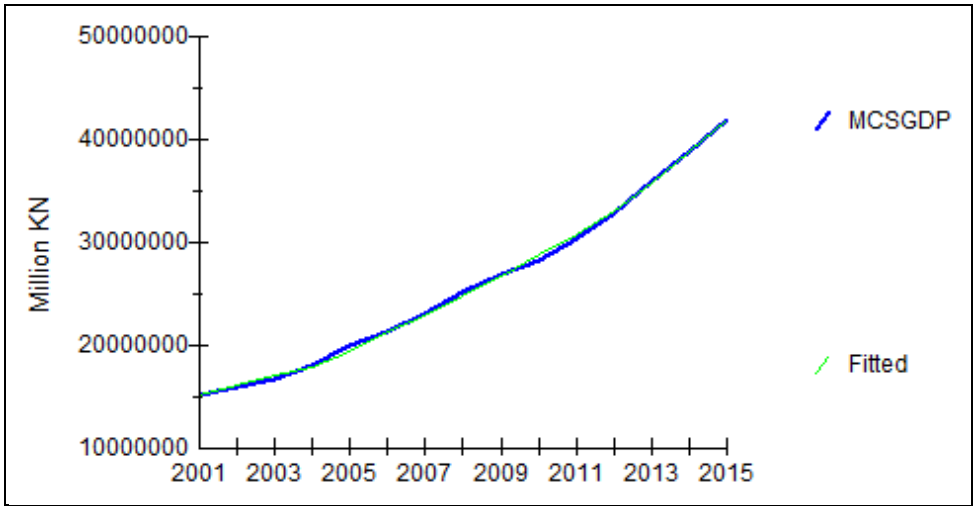
$$MCSGDP = -235667.1*CONS + 0.15436*MGDP + 0.68017*MCSGDP(-1)$$

Table A4.13 Ordinary Least Squares Estimation forCSGDP

```
********************************************************************************
 Dependent variable is MCSGDP
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                    -235667.1          288128.8            -.81792[.429]
 MGDP                      .15436            .092351             1.6714[.120]
 MCSGDP(-1)                .68017             .24692             2.7546[.017]
********************************************************************************
 R-Squared                    .99884   R-Bar-Squared                   .99864
 S.E. of Regression        316236.6    F-stat.    F(  2,  12)    5149.2[.000]
 Mean of Dependent Variable 2.60E+07   S.D. of Dependent Variable     8581930
 Residual Sum of Squares    1.20E+12   Equation Log-likelihood      -209.5742
 Akaike Info. Criterion    -212.5742   Schwarz Bayesian Criterion   -213.6363
 DW-statistic                 1.4154   Durbin's h-statistic      3.8732[.000]
********************************************************************************
```

MCSGDP = commercial GDP, CONS = constant, MGDP = gross domestic product, MCSGDP(-1) = commercial GDP in the previous year.
Source: Microfit analysis result.

Figure A4.13 Plot of Actual and Fitted Values for CSGDP



KN = Lao kip, MCSGDP = commercial GDP.
Source: Microfit analysis result.

- **Industrial price of electricity**

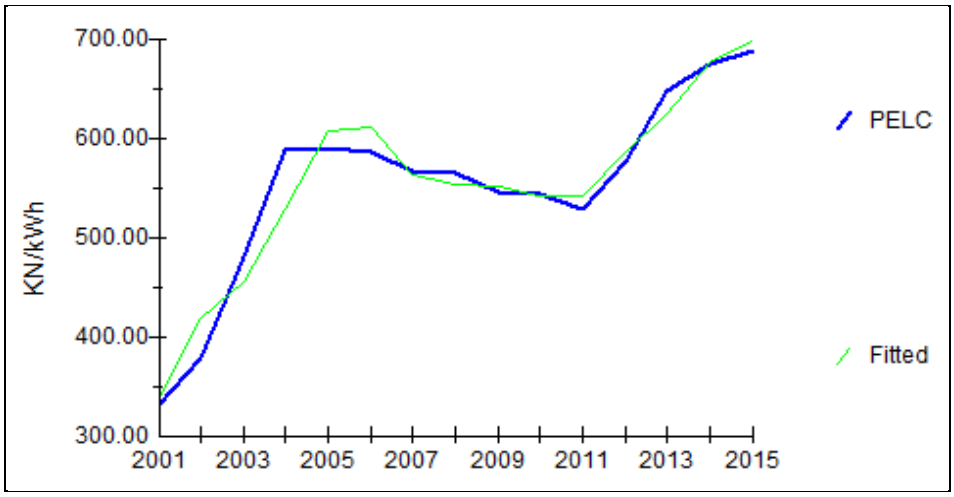
$$PELC = 161.9270*CONS + 0.55127*PGDP + 0.69916*PELC(-1) - 48.7882*DUM0711$$

Table A4.14: Ordinary Least Squares Estimation forPELC

```
********************************************************************************
 Dependent variable is PELC
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     161.9270            31.1829             5.1928[.000]
 PGDP                       .55127             .48157             1.1447[.277]
 PELC(-1)                   .69916            .096019             7.2815[.000]
 DUM0711                  -48.7882            15.2450            -3.2003[.008]
********************************************************************************
 R-Squared                    .94045   R-Bar-Squared                    .92421
 S.E. of Regression         26.6848   F-stat.    F(  3,  11)    57.9034[.000]
 Mean of Dependent Variable 553.0340  S.D. of Dependent Variable     96.9273
 Residual Sum of Squares     7832.9   Equation Log-likelihood       -68.2194
 Akaike Info. Criterion     -72.2194  Schwarz Bayesian Criterion    -73.6355
 DW-statistic                 2.0270  Durbin's h-statistic    -.056408[.955]
********************************************************************************
```

PELC = industrial price of electricity, CONS = constant, PELC(-1) = industrial price of electricity in the previous year, DUM0711 = dummy variable at the years of 2007–2011.
Source: Microfit analysis result.

Figure A4.14 Plot of Actual and Fitted Values for PELC



KN = Lao kip; kWh = kilowatt-hour, PELC = industrial price of electricity.
Source: Microfit analysis result.

- **Residential price of electricity**

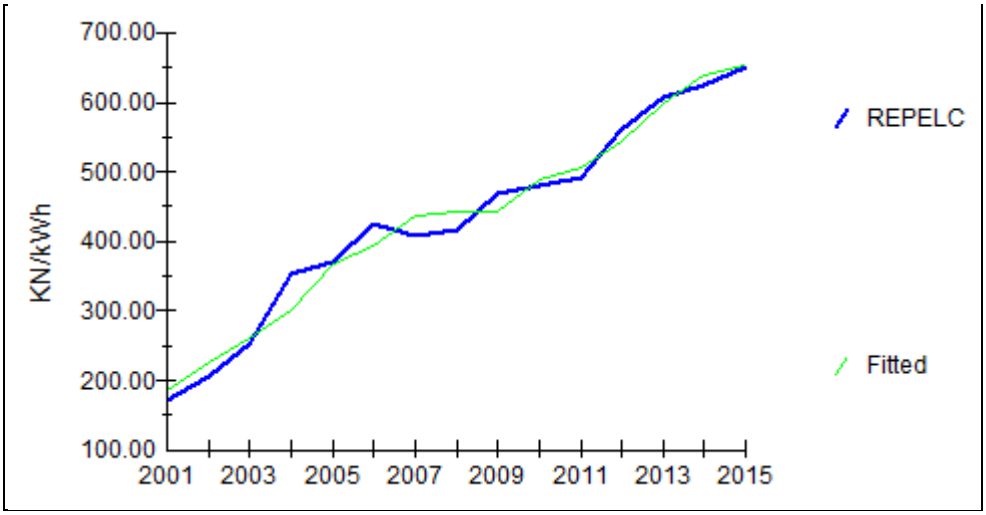
$$REPELC = 17.4258*CONS + 2.6132*PGDP + 0.53734*REPELC(-1)$$

Table A4.15 Ordinary Least Squares Estimation for REPELC

```
********************************************************************************
 Dependent variable is REPELC
 15 observations used for estimation from 2001 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     17.4258            29.3288             .59415[.563]
 PGDP                      2.6132             1.2494             2.0916[.058]
 REPELC(-1)                .53734             .19136             2.8080[.016]
********************************************************************************
 R-Squared                    .97429   R-Bar-Squared                    .97001
 S.E. of Regression         25.4770   F-stat.    F(  2,  12)  227.4023[.000]
 Mean of Dependent Variable 432.3640  S.D. of Dependent Variable    147.1135
 Residual Sum of Squares     7789.0   Equation Log-likelihood       -68.1772
 Akaike Info. Criterion     -71.1772  Schwarz Bayesian Criterion    -72.2392
 DW-statistic                 2.1426  Durbin's h-statistic     -.41138[.681]
********************************************************************************
```

REPELC = residential price of electricity, CONS = constant, PGDP = GDP deflator, REPELC(-1)= residential price of electricity in the previous year.
Source: Microfit analysis result.

Figure A4.15 Plot of Actual and Fitted Values for REPELC



kWh = kilowatt-hour, KN = Lao kip, REPELC = residential price of electricity.
Source: Microfit analysis result.

- **Commercial price of electricity**

$$CSPELC = 75.5422*CONS + 8.5988*PGDP + 251.3462*DUM0206 + 126.7228*DUM0709$$

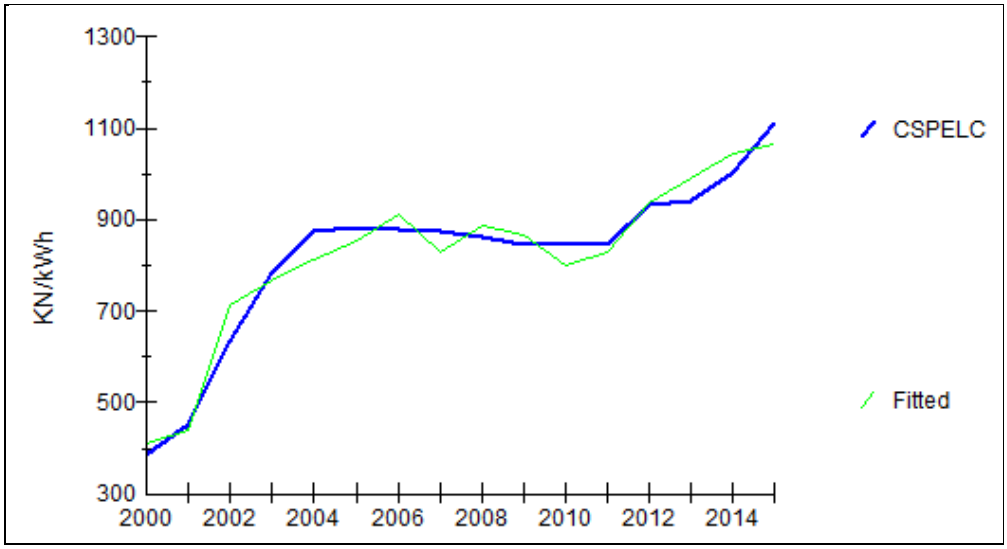
Table A4.16 Ordinary Least Squares Estimation for CSPELC

```
********************************************************************************
 Dependent variable is CSPELC
 16 observations used for estimation from 2000 to 2015
********************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     75.5422            50.3153             1.5014[.159]
 PGDP                      8.5988             .55517            15.4886[.000]
 DUM0206                 251.3462            30.6202             8.2085[.000]
 DUM0709                 126.7228            31.1180             4.0723[.002]
********************************************************************************
 R-Squared                    .95286   R-Bar-Squared                    .94107
 S.E. of Regression         45.3103   F-stat.    F(  3,  12)   80.8451[.000]
 Mean of Dependent Variable 821.8325  S.D. of Dependent Variable    186.6487
 Residual Sum of Squares    24636.2   Equation Log-likelihood       -81.4181
 Akaike Info. Criterion     -85.4181  Schwarz Bayesian Criterion    -86.9633
 DW-statistic                 2.1057

********************************************************************************
```

CSPELC = commercial price of electricity, CONS = constant, PGDP = GDP deflator, DUM0206 = dummy variable for the years of 2002–2006, DUM0709 = dummy variable for the years of 2007–2009.
Source: Microfit analysis result.

Figure A4.16 Plot of Actual and Fitted Values for CSPELC



CSPELC = commercial price of electricity, kWh = kilowatt-hour, KN = Lao kip.
Source: Microfit analysis result.