Impulse Response Function Analysis of Shandong Residential Electricity Demand Based on the VAR Model

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Abstract. This work is attempting to analyse the responses of Shandong residential electricity demand by the impulses from GDP and other important factors with a VAR model approach. We use IRF analysis method to do the research. From the research, we can say that the impulses of Shandong GDP will cause a temporary big upward and later downward impact to the residential electricity demand. The impulses of GDP per capita will lead to increased residential electricity demand and the impulses from number of household will lead to smooth development of residential electricity demand and the impulses from population will lead to lower level of electricity in the short periods but an increased trend in the long periods. The significance of our study is that we can provide some indication for policy making that investment measures have to be adopted to ensure the steady growth of the GDP and GDP per capita so as to keep a steady demand in residential electricity demand.

1. Introduction
Shandong, a province with a population nearly reaching 100 million, is one of the most important provinces in China. The residential demand for electricity is increasing annually with the growing population and the development of the economy in Shandong. With the spread of Covid-19 during the first half of 2020, people have to stay at home and the residential electricity demand will also change accordingly. The purpose of this paper is to study on the responses of the residential electricity demand by the impulses coming from the gross domestic product (GDP) and/or other factors with the help of the method of impulse response function analysis. This paper is written in five parts: part two is literature review, part three is about the econometric model and data, the fourth part is about test results and discussion. Fifth part, we draw on some conclusions.

2. Literature Review
Electricity demand, especially residential demand is influenced by socioeconomic development and the overall quantity of people [1]. Many researchers suggest that appropriate pricing of electricity, especially real time pricing would have pushed the electricity demand higher [2]. Electricity demand and GDP development have reasonable causal relations so that policies concerning the future electricity construction are often under studies [3]. Studies on consumer’s behavior suggest that consumers of electricity could do their best to increase the efficiency of energy consumption [4]. And by estimating the electricity demand elasticity, some researchers try to determine the price sensitivity variation and form of relations [5]. Since electricity
demand is difficult to forecast, many researches attempt to focus their attention on the factors and drivers including climate change to separate the variations from the study and try to get a new smooth research method to continue the study [6-7].

Investigations have been done upon the relation of GDP by sector and consumption of energy by type in emerging states. Coingration relationship is found between the two variables [8]. Some studies investigate the causal relations of consumption of energy, urbanization and development of economy by adopting panel data analysing method [9-12].

Literature review shows that there are few studies on the impulse response on the residential electricity demand. This paper will take Shandong as the sample to study the impacts to the residential electricity demand due to the changes in GDP, GDP per capital and population etc.

3. Model Analysis

Vector auto-regression (VAR) model is a research method to test the dynamic influences of some disturbance especially random ones in a research system. The expression of a VAR model with $X_t$, a k-dimensional vector in general is like this:

$$X_t = \alpha + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \cdots + \beta_p X_{t-p} + \mu_t$$  \hspace{1cm} (1)

Generally the research and test could be estimated directly if the unit root doesn't exist in the variables. But usually it is not the case. So the difference of the variables is necessary to be adopted in order to get the research done as in equation (2):

$$\Delta X_t = \beta_1 \Delta X_{t-1} + \beta_2 \Delta X_{t-2} + \cdots + \beta_p \Delta X_{t-p} + \Delta \mu_t$$  \hspace{1cm} (2)

We know that a shock to one variable can influence this variable itself, and most importantly, this shock can spread its influences to all the other variables especially endogenous ones by lag number or structures. We use an impulse response function (IRF) method to study the influences by a standard shock to some innovations $e_t$ on the values of endogenous variables in this paper. In theory, if the innovations are all unrelated, the results of the test of impulse response are direct and clear. However, since the innovations are usually linked with each other, somewhat having a common factors together, we have to use a transformation $p$ to get them unlinked so as to further the study.

$$v_t = p e_t \sim (0 \ D)$$  \hspace{1cm} (3)

In the equation (3), D is a diagonal covariance matrix.

We get the data from the Statistical Yearbook of Shandong and Energy Statistical Yearbook of China. Because of data shortage, study period is chosen from year of 1995 to 2018. We use the following variables to do the study including residential electricity consumption (REC), GDP, GDP per capita (GDPPC), number of household (NOH) and population (POP). Variables are used in the form of the natural logarithm, that is, LNREC, LNGDP, LNGDPPC, LNNOH and LNPOP.

4. Tests & Discussion

4.1. Unit Root Test

Group unit root method is used test the variables’ stationarity. Table 1 is the result of the stationarity test of LNREC, LNGDP, LNGDPPC, LNNOH, LNPOP in level. The null 1 hypothesis is to take the assumption that common unit root exist and the Levin test tells us that the probability is 0.1100 which is much higher than the 0.01 significance as required. So we know that a common unit root do exist and variables are not stationary. The null 2 hypothesis is to take the assumption that individual unit root exist and Im etc. method, ADF method, etc. are used to test the variables. The results show the same conclusion as in the group.
Table 1. Level Common and individual Unit Root Results

| Method                               | Statistic | Prob.** |
|--------------------------------------|-----------|---------|
| Levin, Lin & Chu t*                  | -1.22626  | 0.1100  |
| Im, Pesaran and Shin W-stat          | 0.82764   | 0.7961  |
| ADF - Fisher Chi-square              | 4.69617   | 0.9105  |
| PP - Fisher Chi-square               | 8.27822   | 0.6017  |

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

We have to test the 1st degree difference of the variables' stationarity. Table 2 gives results of tests following the same methods as in level. The results are showing that the variables in 1st difference do not have unit root and they are stationary.

Table 2. 1st Difference Common and individual Unit Root Results

| Method                               | Statistic | Prob.** |
|--------------------------------------|-----------|---------|
| Levin, Lin & Chu t*                  | -8.25150  | 0.0000  |
| Im, Pesaran and Shin W-stat          | -10.0159  | 0.0000  |
| ADF - Fisher Chi-square              | 90.4102   | 0.0000  |
| PP - Fisher Chi-square               | 311.916   | 0.0000  |

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

4.2. Lag Determination

In order to do the cointegration test, we have to determine the lag number first. In this part, we choose criteria such as Lagrange(LR), Final prediction error (FPE), etc. to find the appropriate number of the lag. Table 3 indicates that 2 is the lag number determined by five criteria.

Table 3. Lag number

| Lag | LogL       | LR         | FPE           | AIC            | SC             | HQ              |
|-----|------------|------------|---------------|----------------|----------------|-----------------|
| 0   | 113.4162   | NA         | 3.61e-11      | -9.856023      | -9.608058      | -9.797610       |
| 1   | 234.6878   | 176.3950   | 6.12e-15      | -18.60798      | -17.12020      | -18.25750       |
| 2   | 292.7873   | 58.09952*  | 4.61e-16*     | -21.61703*     | -18.88942*     | -20.97449*      |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion
4.3. Cointegration Equation
In VAR model, stationarity test show that each variable of LNREC LNGDP LNGDPPC LNNOH LNPOP is I(1) first-order stationary. In this paper, we employ the cointegration method to test stable relations of above variable exist or not in the long run. Maximum eigenvalue statistics test result indicates there is 1 cointegration equation exiting at the 5% level as in Table 4.

Table 4. Number of equations

| Hypothesized No. of CE(s) | Max-Eigen Value | Statistic | Critical Value | Prob.** |
|---------------------------|-----------------|-----------|----------------|---------|
| None *                    | 0.970796        | 77.73616  | 33.87687       | 0.0000  |
| At most 1                 | 0.682896        | 25.26757  | 27.58434       | 0.0962  |
| At most 2                 | 0.561643        | 18.14387  | 21.13162       | 0.1246  |
| At most 3                 | 0.366947        | 10.05842  | 14.26460       | 0.2081  |
| At most 4                 | 0.024550        | 0.546830  | 3.841466       | 0.4596  |

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Equation (4) is the estimated VAR coefficients with a lag number 2. From this equation we know that variables under study have a stable relation under the study period.

\[
\text{LNREC} = 0.77*\text{LNREC}(-1) - 0.023*\text{LNREC}(-2) + 0.076*\text{LNGDP}(-1) - 0.11*\text{LNGDP}(-2) + 0.36*\text{LNGDPPC}(-1) - 0.25*\text{LNGDPPC}(-2) + 0.41*\text{LNNOH}(-1) + 0.047*\text{LNNOH}(-2) - 0.811*\text{LNPOP}(-1) + 2.29*\text{LNPOP}(-2) - 16.48
\]

4.4. Impulse Response Function Analysis Based on VAR Model
The overall effect on VAR model estimation is good, and degree of approximation of the equation is between 77%-96%. AIC and SC values are -21.67 and -18.88, which are relatively small. Based on cointegration analysis, we will use IRF analysis to measure the influences on the values of variables by the innovation originated from the shock in the system as shown in Figure 1.

Figure 1. IRF analysis results
Variable IRF analysis shows that the impulse of Cholesky S.D.Innovations of LNGDP will lead to increased LNREC in the first and two periods, but soon to decreased LNREC in the third period, however the LNREC will increase and become smooth in the long run. The impulses of LNGDPPC will lead to increased LNREC and will reach highest level in the coming 4th period. The impulses from LNNOH will lead to smooth development of LNREC and the impulses from LNPOP will lead to lower level of LNREC but an increased trend in the later period.
5. Conclusion
This work is attempting to analyse the responses of Shandong residential electricity demand by the impulses from GDP and other important factors with a VAR model approach. We use IRF analysis method to do the research. From the research, we can say that the impulses of Shandong GDP will cause a temporary big upward and later downward impact to the residential electricity demand. The impulses of GDP per capita will lead to increased residential electricity demand and the impulses from number of household will lead to smooth development of residential electricity demand and the impulses from population will lead to lower level of electricity in the short periods but an increased trend in the long periods.

The significance of our study is that we can provide some indication for policy making that investment measures have to be adopted to ensure the steady growth of the GDP and GDP per capita so as to keep a steady demand in residential electricity demand. Emergency plans should also be prepared to prevent the possible harm to the power plant planning and production due to upward and downward impacts of the residential electricity demand. Further studies could be focused on the real-time impacts of the policies issued by Shandong in the sample period.

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