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Electricity consumption forecasting in Italy using linear regression models

Vincenzo Bianco, Oronzio Manca*, Sergio Nardini

DIAM, Seconda Università degli Studi di Napoli, Via Roma 29, 81031 Aversa (CE), Italy

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ABSTRACT

The influence of economic and demographic variables on the annual electricity consumption in Italy has been investigated with the intention to develop a long-term consumption forecasting model.

The time period considered for the historical data is from 1970 to 2007. Different regression models were developed, using historical electricity consumption, gross domestic product (GDP), gross domestic product per capita (GDP per capita) and population.

A first part of the paper considers the estimation of GDP, price and GDP per capita elasticities of domestic and non-domestic electricity consumption. The domestic and non-domestic short run price elasticities are found to be both approximately equal to −0.06, while long run elasticities are equal to −0.24 and −0.09, respectively. On the contrary, the elasticities of GDP and GDP per capita present higher values.

In the second part of the paper, different regression models, based on co-integrated or stationary data, are presented. Different statistical tests are employed to check the validity of the proposed models.

A comparison with national forecasts, based on complex econometric models, such as Markal-Time, was performed, showing that the developed regressions are congruent with the official projections, with deviations of ±1% for the best case and ±11% for the worst. These deviations are to be considered acceptable in relation to the time span taken into account.

1. Introduction

Time series forecasting is a great challenge in many fields. In finance, one forecasts stock exchange courses or indices of stock markets, while data processing specialists forecast the flow of information on their networks.

Worldwide energy consumption is rising fast because of the increase in human population, continuous pressures for better living standards, emphasis on large-scale industrialization in developing countries and the need to sustain positive economic growth rates. Given this fact, a sound forecasting technique is essential for accurate investment planning of energy production/generation and distribution.

The common difficulty to the development of reliable forecasts is the determination of sufficient and necessary information for a good prediction. If the information level is insufficient, a forecasting will be poor; similarly, if information is useless or redundant, modelling will be difficult or even skewed.

It is common that complex models, even though they provide accurate predictions, are difficult to manage and often a less accurate model, but much simpler, is appreciated especially if the forecasting module is just a part of a more complex planning tool, as often is the case.

Some authors studied the electric consumption, in order to understand which are the demand drivers [1–3] and which are the fundamental pillars in building a forecasting model.

Jannuzzi and Shipper [1] analyzed the consumption of electrical energy for the residential sector in Brazil. They observed that the increase in electricity demand was faster than the income. Harris and Lon-Mu [2] studied the dynamic relationships between electricity consumption and several potentially relevant variables, such as weather, price, and consumer income. They used a 30 years data series from south east USA, finding a high seasonality of electricity demand. Ranjan and Jain [3] analyzed the consumption pattern of electrical energy in Delhi for the period 1984–1993 as a function of population and weather sensitive parameters. They developed multiple linear regression models of energy consumption for different seasons.

In the last 15 years, owing to the strong and constant increase in electricity consumption, which imposes an accurate planning in order to avoid electricity shortage and guarantee adequate infrastructures,

* Corresponding author: Tel.: +39 081 5010 217; fax: +39 081 5010 204.
E-mail address: oronzio.manca@unina2.it (O. Manca).

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many papers [4–11] focused on the forecasting of electricity demand using different techniques.

Abdel-Aal et al. [5] applied an AIM (abductory induction mechanism) model to the domestic consumption in the eastern province of Saudi Arabia in terms of key weather parameters, demographic and economic indicators. It is found that an AIM model which uses only the mean relative humidity and air temperature, gives an average forecasting error of about 5–6% over the year. Yan [4] also presented residential consumption models using climatic variables for Hong Kong.

Egelioglu et al. [6] investigated the influence of economic variables on the annual electricity consumption in Northern Cyprus and they found that a model using number of customers, number of tourists and electricity prices has a strong predictive ability.

Mohamed and Bodger [7] studied a model for electricity forecasting in New Zealand. The model is based on multiple linear regression analysis, taking into account economic and demographic variables. Saab et al. [8], instead, investigated different univariate modelling methodologies to forecast monthly electric energy consumption in Lebanon.

Recently Al-Ghandoor et al. [9] presented a model developed to forecast electricity consumption of the Jordanian industrial sector based on multivariate linear regression of time series in order to identify the main drivers behind electricity consumption.

Erdogdu [10] proposed a model based on ARIMA (autoregressive integrated moving average) providing an electricity demand estimation and forecast for Turkish electricity demand.

Very recently Amarawickrama and Hunt [11] presented a time series analysis of electricity demand in Sri Lanka. They studied how different time series estimation methods perform in terms of modelling past electricity demand, estimating the key income and price elasticities, and hence forecasting future electricity consumption.

As for the analysis of Italian electricity demand, only a paper by Gori and Takanen [12] is found in the literature. Their analysis is focused on energy consumption and the possible substitution among the different energy resources is investigated, including electricity. They use a modification of the econometric model EDM (Energy Demand Model) to forecast the national energy consumption.

The scope of the present paper is to investigate and forecast the long-term electricity consumption in Italy using different econometric models, based on cointegration and stationary time series.

According to the authors' best knowledge, this represents a first attempt to specifically study the Italian electricity consumption forecasting. In fact, the scientific literature facing Italian electricity consumption is extremely limited. The main studies and researches are provided by the firms involved in the electricity business or by the government, evidencing a lack of third party contributions, with the exception of [12] and of studies that include Italy in G7, OECD countries, etc. [13–15].

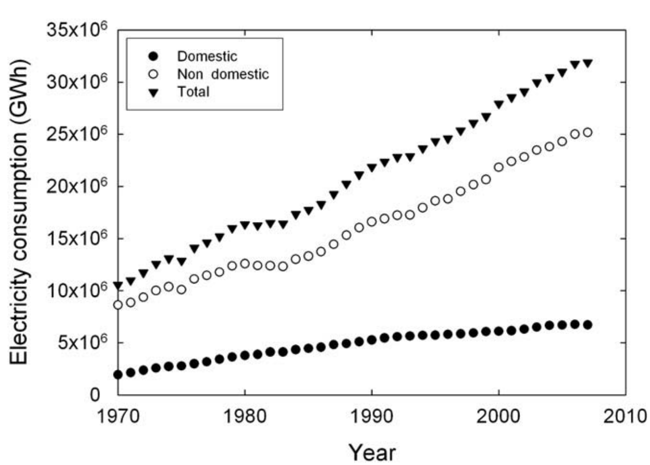

Fig. 1. Historical data for electricity consumption.

The first target of the present paper is the estimation of price and GDP consumption elasticities. The second target is to provide an accurate model for electricity consumption forecasting. Multiple linear regressions using GDP and population as selected variables to forecast electricity consumption in Italy up to 2030 are presented. Moreover a simplification is proposed considering regression models using the ratio between GDP and population (GDP per capita) as independent variable.

The model results are compared with the official Italian authority forecast [16] and with the forecast of a public/private research institution [17] active in the field of energy. It is shown that there is a good agreement among the different predictions.

2. Methods

2.1. Data sets

For the period 1970–2007, the annual values of electricity consumption categorized in terms of usage (domestic and non-domestic) were obtained by Terna reports [16]. Terna is a public–private company involved in the management of the high and medium voltage electricity distribution network and its data represent the official Italian statistics about electricity consumption.

The annual data for the population and GDP for the same period were taken by the ISTAT [18], the Italian statistic service office, while the source for electricity prices is EUROSTAT [19], which is the European statistic office.

The historical data of electricity consumption are reported in Fig. 1 and the independent variables (i.e. population, GDP, GDP per capita and price) are presented in Fig. 2.

It is possible to observe that the total consumption shows a substantial linear growth trend. In 1975, a marked decrease in the consumption was detected, probably due to the energy crisis of that period [16,17].

As for the non-domestic electricity consumption, a more irregular behaviour is detected, probably due to the different economic cycles and energy shocks [13,14]. In fact, if one compares the GDP, in Fig. 2(a), and non-domestic electricity consumption, in Fig. 1, a strong relation can be observed (i.e. for a decrease in GDP there is a corresponding decrease in non-domestic electricity consumption). As for the domestic consumption, in Fig. 1, it does not seem to be linked to the GDP, in Fig. 2(a), and up to 1981 it follows the population trend. After this period the population is nearly stable, but the domestic consumption grows (i.e. increase in the electricity intensity). Around 2002 consumption increased in a faster way and this can be explained in two ways: the growth is linked to the increase in population of the last years and the increase in electricity intensity, mainly due to summer air conditioning [17], which is diffusing among the domestic users.

The profile of population is reported in Fig. 2 (b) and it has a very interesting behaviour. In fact, population grows until 1980 and then remains almost stable until 2001 where it starts to increase again. This is mainly due to the strong decrease of the birth rate (i.e. the ratio between new births and resident population), which in 1965 was about 1.8%. In 2000 it dropped to 0.9% substantially equal to the death rate, causing stability of population [20]. From 2002, population started to grow again mainly because of the immigration, particularly from East Europe and North Africa [20].

The price data taken from [19] are available from 1985 till 2007 and they are divided into two categories: domestic and non-domestic, as reported in Fig. 2(d); the two price typologies refer to an average tariff for both kinds of users. They present an interesting profile, which has an oscillating nature, that should be linked to the oscillations in oil and

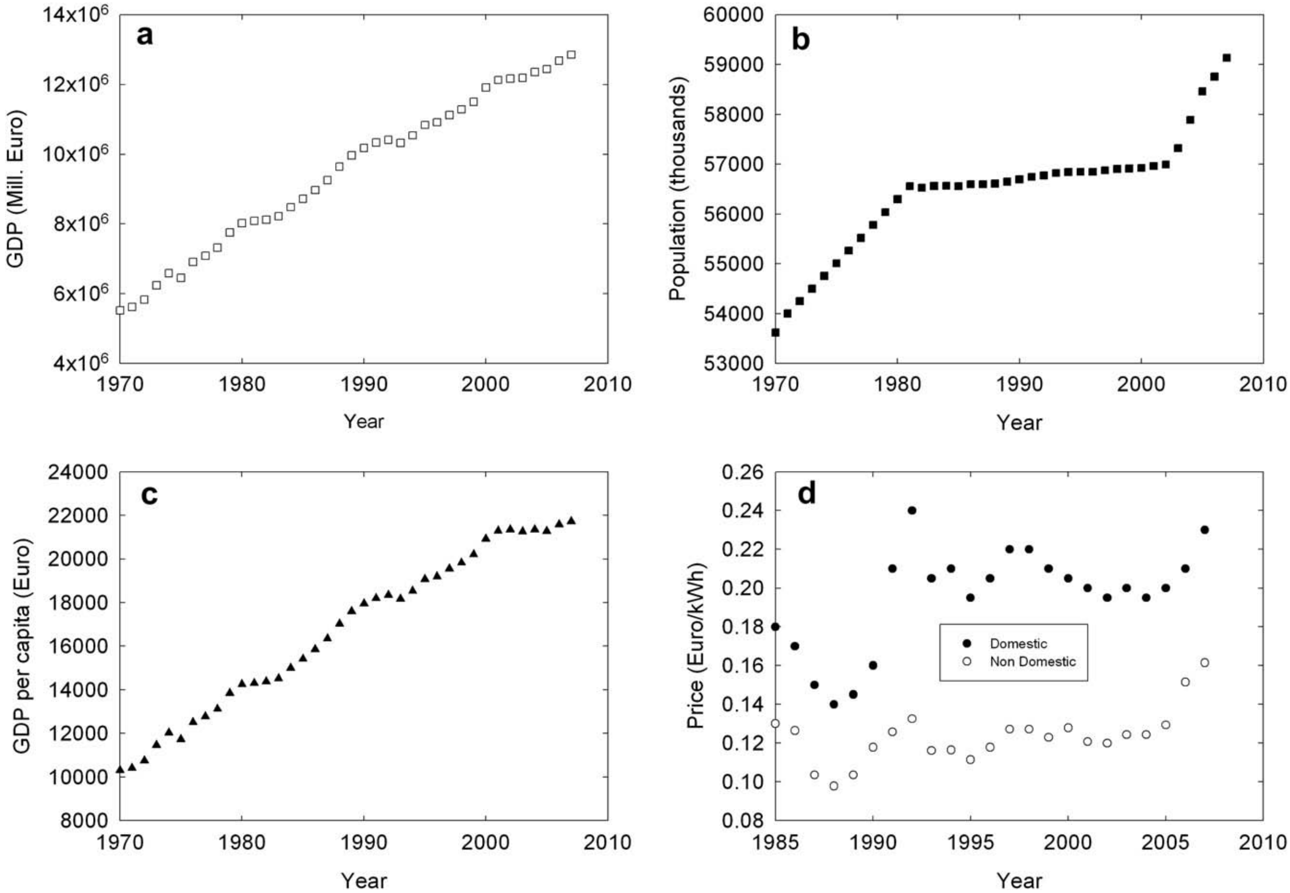

Fig. 2. Historical data for the explaining variables considered: (a) GDP, (b) population, (c) GDP per capita and (d) price.

gas prices, which represent the main primary energy sources used in Italy to generate electricity. For example there is an increase starting from 1990 with a peak around 1992–1993, which should reflect the effects of the First Gulf War or the marked growing trend observed from 2005 up to 2007 which reflects the record prices reached by oil and gas on the financial markets during that period.

2.2. Elasticities estimation

In this sub-section, two single equation consumption models, one for domestic and another for non-domestic consumption, are presented. They are expressed in linear logarithmic form linking the quantity of annual domestic electricity consumption to electricity price and GDP per capita in the first case, while in the second case the equation links annual non-domestic electricity consumption to GDP, electricity price and a time trend, which may be regarded as a proxy for technical progress [10].

The models take the form of a standard dynamic constant elasticity function of the consumption [10,13]:

Model 1

$$\log(Y_{\mathrm{dom},t}) = \alpha_0 + \alpha_1 \log(X_{3,t}) + \alpha_2 \log(\mathrm{PR}_t) + \alpha_3 \log(PR_{t-3}) + \alpha_4 \log(Y_{\mathrm{dom},t-3}) \qquad (1)$$

where $Y_{\mathrm{dom},t}$ is the domestic electricity consumption, $X_{3,t}$ is the GDP per capita, PR_t is the electricity price for domestic users, α_0, α_1, α_2, α_3, α_4 are the regression coefficients, and $t-i$ as subscript indicates the lag term (i.e. $t-1$ indicates lag 1)

Model 2

$$\log(Y_{\mathrm{ndom},t}) = \beta_0 + \beta_1 \log(X_{1,t}) + \beta_2 \log(\mathrm{PRND}_t) + \beta_3 \log(\mathrm{IND}_{t-3}) + \beta_4 \log(Y_{\mathrm{ndom},t-3}) \qquad (2)$$

where $Y_{\mathrm{ndom},t}$ is the non-domestic electricity consumption, $X_{1,t}$ is the GDP, PRND_t is the electricity price for non-domestic users, IND_t is a time trend, β_0, β_1, β_2, β_3, β_4 are the regression coefficients.

The coefficients α_1 and α_2 are very important, because they represent the short run income and price elasticities [10,13] of domestic consumption, whereas β_1 and β_2 represent the short run GDP and price elasticities of non-domestic consumption.

As for the expected signs in Eqs. (1) and (2), one expects that α_1 and β_1 are greater than zero, because higher real GDP and GDP per capita should result in greater economic activity and accelerate purchases of electrical goods and services. The coefficients of price are expected to be less than zero for usual economic reasons [21].

Long run elasticities are calculated by dividing short run elasticities by $(1-\alpha_4)$ and $(1-\beta_4)$ for Model 1 and Model 2, respectively, as indicated in [10,13]:

$$\mathrm{Ed}_1 = \alpha_1/(1-\alpha_4)$$

$$\mathrm{Ed}_2 = \alpha_2/(1-\alpha_4)$$

$$\mathrm{End}_1 = \beta_1/(1-\beta_4)$$

$$\mathrm{End}_2 = \beta_2/(1-\alpha_4)$$

where Ed_1 and Ed_2 are the long run income and domestic price elasticities, whereas End_1 and End_2 are the GDP and non-domestic price elasticities.

The results of these estimates for electricity consumption are reported in Table 1. The Breusch–Godfrey Serial Correlation LM test is applied to the two models, indicating the absence of serial correlation in the residuals. Moreover the Augmented Dickey–Fuller (ADF) test is used to test for the presence of unit roots and establish the order of integration of the variables (i.e. the natural logarithm of $Y_{dom,t}$, $Y_{ndom,t}$, $X_{3,t}$, $X_{1,t}$, PR_t and $PRND_t$) in the two models. On the basis of ADF statistics, reported in Table 2, the null hypothesis of a unit root cannot be rejected at 10% level of significance for the series PR_t. Stationarity is obtained running the ADF test on the first difference of the variables, indicating that the series PR_t is integrated of order 1, I(1), in nature. On the other hand, null hypothesis of unit root cannot be accepted for all the other series at 10% level of significance, showing that they are integrated of order 0, I(0), in nature.

2.3. Multiple regression models

To investigate the annual consumption of electricity up to 2030, a multiple regression model is used, considering the annual GDP and population time series, while price is not included because of its low estimated elasticity. A similar approach is also used in [10] in the case of Turkey.

The proposed model is represented by the following equations:

$$Y_{tot,t} = a + b_1X_{1,t} + b_2X_{2,t} + b_3X_{2,t-1} + b_4Y_{tot,t-1} + e \quad (3a)$$

$$Y_{dom,t} = a + b_1X_{1,t} + b_2X_{2,t} + b_3X_{2,t-3} + b_4X_{1,t-3} + b_5Y_{dom,t-1} + e \quad (3b)$$

$$Y_{ndom,t} = a + b_1X_{1,t} + b_2X_{2,t} + b_3X_{2,t-1} + b_4Y_{ndom,t-1} + e \quad (3c)$$

where $Y_{tot,t}$, $Y_{dom,t}$, $Y_{ndom,t}$ are total, domestic and non-domestic annual consumption in GWh, $X_{1,t}$ is the annual GDP in Euro million, $X_{2,t}$ is the annual population in thousands, a, b_1, b_2, b_3, b_4 and b_5 are the regression coefficients, and e is the error.

The independent variables, $X_{1,t}$ and $X_{2,t}$, are estimated and forecasted by a simple linear regression over the time t. They can therefore be represented by the following equations:

$$X_{1,t} = m_1 + k_1t \quad (4)$$

$$X_{2,t} = m_2 + k_2t \quad (5)$$

m_1, m_2, k_1, k_2 are the simple linear regression coefficients.

It is important to mention that for the year 1970 the corresponding time, t, is equal to 1970. Eqs. (4) and (5) are used to forecast GDP and population, in order to allow for electricity consumption forecast.

Another model is then proposed, which represents a simplification of the first one. The GDP per capita, ratio between GDP and population, is taken into account as explaining variable, therefore a simpler linear regression model is obtained, which results in the following equation:

$$Y_{tot,t} = a + b_1X_{3,t} + b_2Y_{tot,t-1} + e \quad (6a)$$

$$Y_{dom,t} = a + b_1X_{3,t} + b_2Y_{dom,t-1} + e \quad (6b)$$

$$Y_{ndom,t} = a + b_1X_{3,t} + b_2Y_{ndom,t-1} + e \quad (6c)$$

where Y_t is the annual electricity consumption in GWh, $X_{3,t}$ is the annual GDP per capita in Euro, c and b_3 are the regression coefficients, and e is the error.

The independent variable, $X_{3,t}$, is obtained by a simple linear regression over the time t, as previously done for $X_{1,t}$ and $X_{2,t}$, leading to the following equation:

$$X_{3,t} = m_3 + k_3t \quad (7)$$

m_3 and k_3 are the linear regression coefficients.

Table 3 shows the correlation matrix for all the variables considered in Eqs. (3a)–(3c) for the data ranging from 1970 to 2007. All the independent variables show a high degree of correlation versus the dependent variables, only the non-domestic and total consumption show a lower degree of correlation versus population. The correlation coefficient for GDP versus population (the two explaining variables) is 0.820 and the corresponding variance inflationary factor (VIF) is 5.56. In order to avoid multicollinearity, the VIF for some authors [22] should be less than 10 and for other authors [23, 24] should be less than 5; in the present case, because the VIF is considerably less than 10 and close to 5, it is reasonable to think that multicollinearity is not present.

The Breusch–Godfrey Serial Correlation LM test is applied to Eqs. (3a)–(3c) and (6a)–(6c), indicating the absence of serial correlation in the residuals.

To determine if the variables are stationary or not, the ADF test is performed on the variables (Y_t, $Y_{dom,t}$, $Y_{ndom,t}$, $X_{1,t}$, $X_{2,t}$, $X_{3,t}$) and a unit root problem was observed, meaning that they are non-stationary. In order to make them stationary, they were differentiated once and the ADF test was executed on the first difference variables, without detecting any unit root problem, as reported in Table 4. Therefore, it can be concluded that they are integrated of order 1, I(1).

Table 1
Summary of statistics, coefficients and estimation of price elasticities over the period 1985–2007, for Model 1 and Model 2 (the t statistics are reported in parenthesis).

Model 1		Model 2	
α_0	1.615 (1.56)	β_0	−11.770 (−11.17)
α_1	0.292 (2.00)	β_1	1.409 (13.22)
α_2	−0.060 (−1.70)	β_2	−0.0562 (−3.24)
α_3	−0.120 (6.059)	β_3	−0.0463 (−3.45)
α_4	0.751 (−4.16)	β_4	0.358 (5.92)
Ed_1	−0.241	End_1	−0.0875
Ed_2	1.172	End_2	2.195
R^2 adjusted	0.979	R^2 adjusted	0.998
F	228	F	2915

Table 2
Augmented Dickey–Fuller (ADF) unit root test on the logarithms of the considered variables. The confidence level, at which the hypothesis that the series contains a unit root can be rejected, is reported in parenthesis.

Variables	ADF test statistic	Test equation
$Y_{dom,t}$	−2.822 (92.8%)	Constant
$Y_{ndom,t}$	−3.760 (95.7%)	Constant + trend
$X_{1,t}$	−3.439 (92.7%)	Constant + trend
$X_{3,t}$	−3.384 (97.7%)	Constant
PR_t	−2.167 (77.7%)	Constant
$PRND_t$	−3.408 (92.1%)	Constant + trend
First difference		
PR_t	−3.071 (95.6%)	Constant

Table 3
Correlation matrix for variables considered in Eqs. (3a)–(3c).

	$Y_{dom,t}$	$Y_{ndom,t}$	$Y_{tot,t}$	$X_{1,t}$	$X_{2,t}$
$Y_{dom,t}$	1			0.989	0.989
$Y_{ndom,t}$		1		0.963	0.762
$Y_{tot,t}$			1	0.982	0.791
$X_{1,t}$				1	0.820
$X_{2,t}$					1

As given in [10,11,25,26], if all the variables are I(1), according to Engle and Granger [27], Eqs. (3)–(6) can be estimated by Ordinary Least Square (OLS) and if the resulting residuals are stationary, I(0), then the variables Y_t, $Y_{dom,t}$, $Y_{ndom,t}$, $X_{1,t}$, $X_{2,t}$, $X_{3,t}$ are said to co-integrate. Hence the estimated equations may be regarded as valid long run equilibrium relations. On the other hand, it is not possible to conduct conventional inference, such as t test; so the major disadvantage is the impossibility to confirm if the estimated coefficients are significantly different from zero or not [10,11].

The ADF test performed on the residuals, known as AEG (Augmented Engle–Granger) test [10], of Eqs. (3)–(6) confirmed that they are I(0). For all the equations, the hypothesis of unit root in the residuals can be rejected at high confidence level (more or close to 95%), as reported in Table 5. Therefore, it can be concluded that the variables are co-integrated and the estimated equations may be regarded as valid expressions to forecast electricity consumption. All the coefficients of the estimated equations are reported in Table 6.

As an example, the residuals of Eq. (3a) are reported in Fig. 3. More or less they all fit inside the range of ±4% and they do not seem to reveal a particular behaviour, confirming the absence of serial correlation.

2.4. Multiple regression models on year to year percentage difference data

To avoid the inconvenience linked to Engle and Granger about the impossibility to conduct conventional inference on the coefficients, an alternative method is developed in this sub-section.

The idea is to transform the data in order to make them stationary, thereby obtaining consistent forecasting equations. As seen in the previous sub-section, a way to operate is to differentiate the data to make them stationary. The resulting regression will therefore involve the first derivative of the variables. On the other hand, equations with derivatives are difficult to handle in simple ways.

The approach followed here is to consider the year to year percentage difference of the variables, such that the resulting equations are used to estimate the percentage increase or decrease with respect the previous year, allowing to perform the forecasting.

The proposed model assumes the following form:

$$\Delta Y_t = a + b_1 \Delta X_{1,t} + b_2 \Delta X_{2,t} + b_3 \Delta X_{2,t-2} + b_4 \Delta Y_{t-1} + e \quad (8a)$$

$$\Delta Y_{dom,t} = a + b_1 \Delta X_{1,t} + b_2 \Delta X_{2,t} + b_3 \Delta X_{2,t-1} + b_4 \Delta Y_{dom,t-1} + e \quad (8b)$$

$$\Delta Y_{ndom,t} = a + b_1 \Delta X_{1,t} + b_2 \Delta X_{2,t} + b_3 \Delta X_{1,t-1} + b_4 \Delta Y_{ndom,t-1} + e \quad (8c)$$

where Δ is the percentage difference operator (i.e. $\Delta Y_t = (Y_t - Y_{t-1})/Y_t$), while the variables are defined as in Eqs. (3) and (6). The same transformation is also considered when the electricity consumption is a function of GDP per capita, leading to:

$$\Delta Y_t = a + b_1 \Delta X_{3,t} + e \quad (9a)$$

$$\Delta Y_{dom,t} = a + b_1 \Delta X_{3,t} + b_2 \Delta Y_{dom,t-1} + e \quad (9b)$$

$$\Delta Y_{ndom,t} = a + b_1 \Delta X_{3,t} + e \quad (9c)$$

where $\Delta X_{1,t}$, $\Delta X_{2,t}$, $\Delta X_{3,t}$ are estimated from Eqs. (4), (5) and (7).

As shown in Table 7, it is possible to reject the null hypothesis that all the variables have a unit root at high confidence levels, greater than 99%, except for population which rejects the null hypothesis with a confidence level equal to 87.4%, considered acceptable. It can be therefore concluded that the data are stationary.

The Breusch–Godfrey Serial Correlation LM test is applied to Eqs. (8a)–(8c) and (9b), whereas for Eqs. (9a) and (9c) the Durbin Watson statistic is calculated. All the performed tests indicate the absence of serial correlation in the residuals. The coefficients of Eqs. (8) and (9) are reported in Table 8.

Table 4
Augmented Dickey–Fuller (ADF) unit root test on the first difference of the considered variables. The confidence level, at which the hypothesis that the series contain a unit root can be rejected, is reported in parenthesis.

Variables	ADF test statistic	Test equation
$Y_{tot,t}$	−4.852 (>99%)	Constant + trend
$Y_{dom,t}$	−5.792 (>99%)	Constant + trend
$Y_{ndom,t}$	−4.867 (>99%)	Constant + trend
$X_{1,t}$	−5.703 (>99%)	Constant + trend
$X_{2,t}$	−1.396 (85%)	Level
$X_{3,t}$	−5.484 (>99%)	Constant + trend

Table 5
Summary of Augmented Engle–Grenger (AEG) test.

Residuals	ADF test statistic	ADF 95% critical value
Eq. (3a)	−6.3210	−4.8137
Eq. (3b)	−5.2166	−5.2180
Eq. (3c)	−5.8231	−4.8137
Eq. (6a)	−5.8084	−4.0001
Eq. (6b)	−5.7080	−4.0001
Eq. (6c)	−5.7124	−4.0001

2.5. Error analysis and validation

An error analysis, based on the root mean square error, is provided, in order to estimate the model performances and their reliability. The standard error is calculated, according to the following:

$$S_{xy} = \sqrt{\frac{\sum_{i=1}^{N} (y - y_{est})^2}{N}} \quad (10)$$

where y is the true value and y_{est} is the estimation from the considered models.

The models represented by Eqs. (3a)–(3c) have an average standard error less than ±2.0% with respect to the average of true values (i.e. the historical data), while for Eqs. (6a)–(6c) the standard error ranges between ±2.0% and ±3.0%. A similar behaviour is also detected for Eqs. (8a)–(8c) and (9a)–(9c), with average standard error less than ±2.0%. Accordingly, the aforementioned regression models give similar results. To give complete indications regarding the validity of all the models proposed in this paper, total electricity consumption is calculated assuming that the present year is 2002, so that, as given in [10], 5 years observed data are used for validation. Moreover, in order to justify the modelling effort, the results are also compared with a naïve forecasting (i.e. simple regression over the time).

As can be seen in Table 9, all the estimated equations present deviations in a more than acceptable range. If compared with a naïve forecasting (i.e. straight line fit), their deviation is much smaller, even if the simple regression also has a good performance. Similar results are obtained also for domestic and non-domestic electricity consumptions, which are omitted for the sake of brevity.

Table 6
Regression coefficients for Eqs. (3a)–(3c) and (6a)–(6c).

	a	b_1	b_2	b_3	b_4	b_5	m	k
Eq. (3a)	145,200	10.413	0.107	−13.589	0.690			
Eq. (3b)	−23,528	−0.345	−0.0105	0.779	0.006	0.685		
Eq. (3c)	145,047	6.650	0.065	−9.670	0.789			
Eq. (4)							-3.89×10^7	2.00×10^4
Eq. (5)							-1.36×10^5	9.67×10^1
Eq. (6a)	−6700	2.156	0.884					
Eq. (6b)	114	0.482	0.852					
Eq. (6c)	−5062	1.319	0.920					
Eq. (7)							-6.36×10^5	3.28×10^2

Another validation test is performed estimating the forecasting equations on the data ranging from 1970 to 2002, such that the remaining 5 years are reserved for model evaluation on new data [28]. In this way, it is possible to assess equations validity on actual data. It should be noted that this training procedure gave slightly different coefficient values from those presented in Tables 6 and 8 as might be expected, since the 2003–2007 data are now excluded from the estimation.

As one can notice in Table 10, the equations seem to forecast the electricity consumption with a good accuracy and with acceptable deviation respect to the actual data. It is important to observe that for the years 2006 and 2007, the deviation is higher because the increase of electricity consumption in these two years was lower than the average increase rate. Accordingly, it is important to consider all the annual data available (i.e. 1970–2007) to develop the model, in order to include this information in the future projections. On the base of the performed validation test and error analysis, it is possible to say that the equations presented in this paper can be seen as valid models to estimate the Italian electricity consumption.

3. Results and discussion

3.1. Price and income elasticities

The estimated elasticities from Eqs. (1) and (2) showed that there is a low consumption elasticity to the price and high elasticity to the income. Expectedly, long run elasticities are greater than short run elasticities.

This result seems to be consistent with previous study. In fact, a short run price elasticity for domestic electricity consumption of −0.06 during the period 1985–1993 is reported in [13], practically the same calculated from Eq. (1). Instead in [15] the same elasticity is reported to be −0.096, using annual data ranging from 1978 to 2003. Also the short run income elasticity is in good agreement with [13], which reports a value of 0.28 very close to 0.29 obtained by Eq. (1); whereas [15] reports a value of 0.17.

The low price elasticity for domestic consumption implies that the level of electricity consumption cannot be regulated extensively through price policies.

An estimation of short and long run price and GDP elasticities for non-domestic consumption is given using Eq. (2). The price elasticity is quite low, −0.056 in the short run and −0.088 in the long run. On the contrary GDP elasticity is high, 1.41 in the short run and 2.20 in the long run. This shows that the Italian GDP is closely linked to the electricity consumption. For instance, if GDP doubles, the electricity consumption increases by 220%. In fact in the period 1985–2003, there was an increase in GDP of about 60%, while the corresponding increase in non-domestic electricity consumption was about 120%, provoking an increase similar to the estimated elasticity.

To the best of our knowledge, other estimations of Italian non-domestic consumption price and GDP elasticities are not available in literature, therefore a comparison is not possible. However, Narayan and Prasad [14] concluded that there is a positive causality between electricity consumption and GDP in Italy, which is consistent with the high GDP elasticity calculated for non-domestic consumption. As given in [14], recessions or any shocks that have negative impact on GDP will result in a negative impact on electricity consumption. Similarly economic growth will stimulate the electricity consumption.

The higher price elasticity presented by domestic users can be explained with their major flexibility in the use of electricity. When electricity bill increases, users can react saving energy. For example using the air conditioners for less time or turning off all the appliances rather than having them in stand-by. As pointed out in [12], other possibilities seem rather limited for Italian users, also in consideration of the fact that most of the heating systems and cooking facilities are fuelled with natural gas, gasoline or LPG (Liquid Petroleum Gas). A possible alternative is the diffusion of

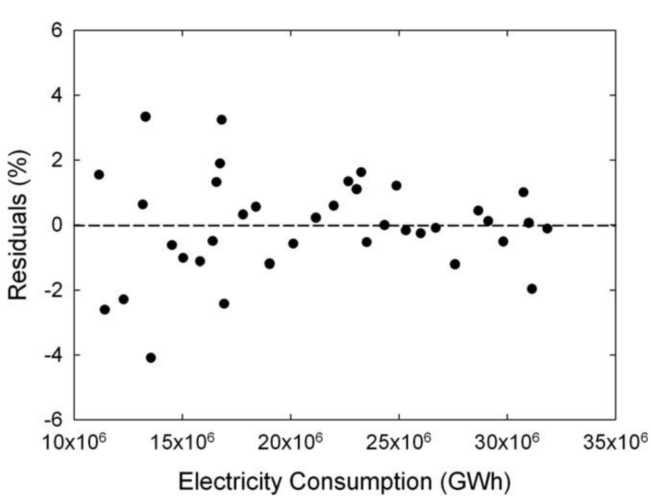

Fig. 3. Residual plots of Eq. (3a).

Table 7
Augmented Dickey–Fuller (ADF) unit root test on the variables considered in Eqs. (8a)–(8c) and (9a)–(9c). The confidence level, at which the hypothesis that the series contain a unit root can be rejected, is reported in parenthesis.

Variables	ADF test statistic	Test equation
$\Delta Y_{tot,t}$	−5.827 (>99%)	Constant + trend
$\Delta Y_{dom,t}$	−5.501 (>99%)	Constant + trend
$\Delta Y_{ndom,t}$	−5.026 (>99%)	Constant + trend
$\Delta X_{1,t}$	−5.230 (>99%)	Constant + trend
$\Delta X_{2,t}$	−1.488 (=87.4%)	Level
$\Delta X_{3,t}$	−5.233 (>99%)	Constant + trend

Table 8
Summary of coefficients for Eqs. 8(a)–(c) and 9(a)–(c) (the *t* statistics are reported in parenthesis).

	a	b_1	b_2	b_3	b_4
Eq. (8a)	0.0137 (4.328)	0.642 (0.938)	1.025 (12.272)	−1.923 (−2.821)	−0.176 (−2.342)
Eq. (8b)	0.0033 (0.593)	−2.097 (−1.140)	0.595 (3.397)	2.904 (1.595)	0.361 (2.737)
Eq. (8c)	0.0128 (3.448)	−0.923 (−1.445)	1.045 (10.77)	−0.640 (−3.704)	0.304 (2.118)
Eq. (9a)	0.0104 (3.887)	0.949 (9.611)			
Eq. (9b)	0.0053 (1.007)	0.581 (3.375)	0.415 (3.365)		
Eq. (9c)	0.0082 (2.710)	1.016 (9.136)			

photovoltaic plants for autonomous generation of electricity among domestic users, but the investment costs, including the government contribution, are still high.

As for the non-domestic users, the situation is more complex, because the possibility to save electricity is more limited and expensive. For example the replacement of relatively old electrical engines with new ones require a very high financial strength, which is justified only for energy intensive businesses.

Another common way proposed to increase price elasticity is the development of tariffs with different prices between day and night, or between working days and weekends [29]. These tariffs can be profitable for non-domestic costumers, if they are able to reschedule production plans and store some of the factor of productions, for example fresh food delivered during the week to be processed at the week end. Moreover the trade off between electricity savings and extra salary, due to evening or weekend working hours, must be carefully assessed.

Another idea could be to replace electricity with other forms of energy, for example natural gas which is evenly distributed in Italy, but also this way is difficult to follow [12]. In fact, as mentioned before, the substitution of electrical engines, with others alternatively fuelled, requires high investments and, moreover, natural gas is also subjected to price fluctuations.

A new perspective in the Italian electricity market is given by the market liberalization which started in 1999 and ended in 2007, because, as observed in [30], competition among generators should increase efficiency, by reducing costs and therefore price to final consumers. At the moment, the market is concentrated among few players and the competition is scarce.

3.2. Electricity consumption forecasting

The forecasts obtained on the basis of the regression models are compared with the results presented by Gori and Takanen [12] and two national forecasts published by Terna [16] and CESI [17].

The forecast provided by Terna represents the official statistic of the Italian Ministry of Productivities. Their forecasts are based on a macroeconomic model which takes into account historical consumption, GDP, value added per activity sector and the energy intensity of the different sectors. Terna furnishes the forecast up to 2017.

CESI is an important player in the energy sector in Italy and abroad. It was part of the national electricity company (ENEL), but with market liberalization it became an independent public/private company. They provided electricity consumption forecasts based on the MARKAL-TIMES model.

MARKAL is a linear-programming model of a generalised energy system. It is demand-driven for which feasible solutions are obtained only if all specified end-use demands for energy are satisfied for every time period. The objective is to determine the optimum activity levels of processes that satisfy the constraints at a minimum cost. Examples of constraints in the model include availability of primary energy resources, production/use balances, electricity/heat peaking, availability of certain technologies, and upper bounds on pollution emissions. CESI furnishes forecasts from 2010 to 2030.

Terna [16] and Gori and Takanen [12] data are available just for the total electricity consumption, while CESI [17] data are split for the different sectors (domestic and non-domestic), allowing for a more detailed comparison.

The total electricity consumption is reported in Fig. 4(a). All the four equations seem to be in agreement with the data given in [16,17] until about 2020; after Eqs. (8a) and (9a) tend to overestimate, by about 10%, the total electricity consumption with respect to the other forecasts.

As for the forecast proposed in [12], it leads to underestimated values and the deviation increases with time, with a maximum deviation of 15% in 2020.

Eqs. (3a) and (6a) seem to furnish the same forecast, in very good accord with [16,17] and also the results given by Eqs. (8a) and (9a) are very similar.

Fig. 4(b) shows the domestic electricity consumption, evidencing that Eq. (8b) fits almost perfectly the data given in [17]. Eq. (3b) leads to an estimation very close to [17], while Eqs. (6b) and (9b) give underestimated values, of 10% and 17% in 2030, respectively. It is important to remark that the explaining variables in Eqs. (3b) and (8b) are GDP and population, whereas in Eqs. (6b) and (9b) the GDP per capita is considered as the only explaining variable.

Finally, the non-domestic electricity consumption is presented in Fig. 4(c). In this case, a situation similar to that of Fig. 4(a) is detected, where Eqs. (8c) and (9c) give overestimated values of about 17% and 10% in 2030, respectively, while Eqs. (3c) and (6c) lead to nearly the same result, which almost perfectly fits the data given in [17].

The most outstanding outcome from the comparisons is that there is a substantial agreement between the available national

Table 9
Validation of the presented forecasting equations on total electricity consumption (the deviation with respect to the historical data is reported in parenthesis) and comparison with a naïve forecasting (i.e. simple linear regression over time of total electricity consumpation). The values reported in the table are in TWh.

Year	Eq. (3a)	Eq. (6a)	Eq. (8a)	Eq. (9a)	Naïve For.
2002	291.28 (0.11%)	291.71 (0.26%)	289.24 (−0.60%)	289.23 (−0.60%)	287.00 (−2.4%)
2003	298.24 (−0.52%)	296.36 (−1.16%)	295.18 (−1.56%)	292.90 (−2.35%)	292.81 (−2.4%)
2004	307.56 (1.00%)	304.34 (−0.05%)	307.97 (1.13%)	303.97 (−0.17%)	298.61 (−2.0%)
2005	309.98 (0.05%)	308.35 (−0.47%)	308.50 (−0.43%)	306.78 (−0.99%)	304.42 (−1.8%)
2006	311.40 (−1.97%)	313.71 (−1.22%)	314.16 (−1.07%)	317.10 (−0.14%)	310.23 (−2.4%)
2007	318.56 (−0.12%)	320.86 (0.59%)	320.16 (0.38%)	322.97 (1.24%)	316.04 (−0.9%)

Table 10
Validation of the forecasting equation estimated with data ranging from 1970 up to 2002 (the deviation with respect to the historical data is reported in parenthesis) and comparison with a naïve forecasting (i.e. simple linear regression over time of total electricity consumpation). The values reported in the table are in TWh.

Year	Eq. (3a)	Eq. (6a)	Eq. (8a)	Eq. (9a)	Naïve For.
2002	289.44 (−0.52%)	289.16 (−0.62%)	289.18 (−0.61%)	294.22 (1.11%)	283.28 (−2.71%)
2003	292.93 (−2.34%)	292.84 (−2.37%)	295.97 (−1.29%)	301.09 (0.43%)	288.91 (−3.77%)
2004	298.54 (−1.99%)	299.71 (−1.59%)	309.79 (1.71%)	308.17 (1.19%)	294.54 (−3.38%)
2005	298.77 (−3.70%)	302.91 (−2.28%)	308.63 (−0.38%)	311.44 (0.52%)	300.17 (−3.22%)
2006	301.22 (−5.42%)	308.14 (−3.05%)	312.14 (−1.73%)	324.61 (2.18%)	305.79 (−3.84%)
2007	306.32 (−4.13%)	314.51 (−1.41%)	318.38 (−0.18%)	323.89 (1.52%)	316.04 (−2.42%)

forecasts and the equations proposed in this paper. In fact, the differences among the various models present an acceptable degree of uncertainties, also in consideration of the forecasting time horizon of about 20 years. Another important feature of the proposed equations is that they are based on simple models, which require only fundamental data as input, allowing to cut the cost linked to data mining, which is one of the fundamental requirements for an econometric model [24].

Moreover, it is our opinion, that a better forecasting of the explaining variables would increase the accuracy of the proposed models. For example, more accurate data on the population projections are available from [18], while more accurate forecasting of GDP could be available from the Italian National Bank or purchasable from business intelligence companies or merchant banks.

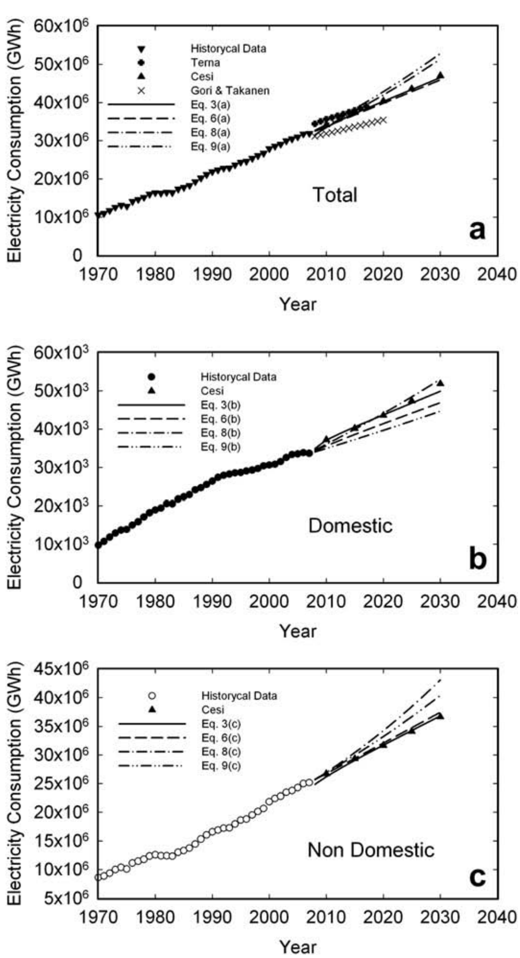

Fig. 4. Forecast of the electricity consumption: (a) total electricity consumption, (b) domestic electricity consumption, and (c) non-domestic electricity consumption.

4. Conclusion

The main objective of this paper were as follows.

(1) To estimate GDP, price and GDP per capita elasticities of domestic and non-domestic electricity consumption in Italy.
(2) To forecast the future growth of these consumptions using different regression models and compare our results with other available projections.

The elasticity analysis showed that the price elasticity of domestic and non-domestic consumption is quite limited, confirming some results presented in previous studies [13,15]. This finding leads to two main conclusions.

(1) There is no need to consider electricity price as explaining variable in forecasting models for Italian electricity consumption;
(2) Pricing policies cannot be used to promote the efficient use of electricity in Italy.

The estimation of GDP and GDP per capita elasticities showed higher values with respect to price elasticities, demonstrating that the consumption response to GDP and GDP per capita changes is relevant. Therefore, there is the need to assure an appropriate level of electricity supply to sustain the economic growth in Italy.

According to the second target of the paper, different long-term forecasting models were developed and they substantially lead to similar results. Therefore, in the next years, an increase in the total electricity consumption, driven by both domestic and non-domestic consumptions, should be expected in Italy with an average rate equal to about 2% per year.

If we assume that the data reported in [16,17] represent the reference benchmark, it can be concluded that Eqs. (3a), (8b) and (6c) guarantee the most accurate projections for total, domestic and non-domestic electricity consumptions respectively, because they fit the data given in [16,17] very well.

It is believed that the elasticities, forecasts and comments presented in this paper would be helpful to energy planners and policy makers to build future scenarios about the Italian electricity consumption.

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References

[1] Jannuzzi G, Schipper L. The structure of electricity demand in the Brazilian household sector. Energy Pol 1991;19(9):879–91.
[2] Harris JL, Lon-Mu L. Dynamic structural analysis and forecasting of residential electricity consumption. Int J Forecast 1993;9:437–55.
[3] Ranjan M, Jain VK. Modelling of electrical energy consumption in Delhi. Energy 1999;24(4):351–61.

[4] Yan YY. Climate and residential electricity consumption in Hong Kong. Energy 1998;23(1):17–20.
[5] Abdel-Aal RE, Al-Garni AZ, Al-Nassar YN. Modelling and forecasting monthly electric energy consumption in eastern Saudi Arabia using abductive networks. Energy 1997;22(9):911–21.
[6] Egelioglu F, Mohamad AA, Guven B. Economic variables and electricity consumption in Northern Cyprus. Energy 2001;26(4):355–62.
[7] Mohamed Z, Bodger P. Forecasting electricity consumption in New Zealand using economic and demographic variables. Energy 2005;30(10):1833–43.
[8] Saab S, Badr E, Nasr G. Univariate modeling and forecasting of energy consumption: the case of electricity in Lebanon. Energy 2001;26(1):1–14.
[9] Al-Ghandoor A, Al-Hinti I, Jaber JO, Sawalha SA. Electricity consumption and associated GHG emissions of the Jordanian industrial sector: empirical analysis and future projection. Energy Pol 2008;36(1):258–67.
[10] Erdogdu E. Electricity demand analysis using cointegration and ARIMA modelling: a case study of Turkey. Energy Pol 2007;35(2):1129–46.
[11] Amarawickrama HA, Hunt LC. Electricity demand for Sri Lanka: a time series analysis. Energy 2008;33(5):724–39.
[12] Gori F, Takanen C. Forecast of energy consumption of industry and household and services in Italy. Heat Technol 2004;22(2):115–21.
[13] Haas R, Schipper L. Residential energy demand in OECD-countries and the role of irreversible efficiency improvements. Energy Econ 1998;20(4):421–42.
[14] Narayan PK, Prased A. Electricity consumption-real GDP casuality nexus: evidence from a bootstrapped causality test for 30 OECD countries. Energy Pol 2008;36(2):910–8.
[15] Narayan PK, Smyth R, Prased A. Electricity consumption in G7 countries: a panel cointegration analysis of residential demand elasticities. Energy Pol 2007;35(9):4485–94.
[16] Terna. Forecasting of electricity demand and power needs in Italy for the years 2007–2017. [Previsioni della domanda elettrica in Italia e del fabbisogno di potenza necessario. Anni 2007–2017]. Terna, http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/dati_statistici/tabid/418/Default.aspx; 2007 [in Italian].
[17] CESI. Forecasting of the electricity demand for the years 2010-2030 on regional basis and variability elements to build alternative scenarios. [Previsione tendenziale della domanda elettrica 2010 – 2030 su base regionale ed elementi di variabilità per la costruzione di scenari alternativi]. Report no. A5023397. CESI, http://www.ricercadisistema.it/Documenti/rapportip.aspx?idP = 115&idT = 1&idN = 1244; 2005 [in Italian].
[18] National Institute of Statistics. Statistics on Italian population. Rome: ISTAT. See also: http://www.istat.it/popolazione; 2008.
[19] Eurostat. Energy statistics prices for 1985–2007. Bruxelles: Eurostat. See also: http://ec.europa.eu/eurostat/; 2008.
[20] Institute of Population and Social Policy Researches. Report on demographic situation in Italy. [Rapporto sulla situazione demografica italiana]. Report no. 2001. IRPPS, http://www.irpps.cnr.it/ricdin/osservatorio.htm; 2001 [in Italian].
[21] Halicioglu F. Residential electricity demand dynamics in Turkey. Energy Econ 2007;29(2):199–210.
[22] O'Brien RM. A caution regarding rules of thumb for variance inflation factors. Qual Quant 2007;41(5):673–90.
[23] Snee RD. Some aspects of nonorthogonal data analysis, part I. Developing prediction equations. J Qual Technol 1973;5(1):67–79.
[24] Marquardt DW. You should standardize the predictor variables in your regression models. J Am Stat Assoc 1980;75(1):87–91.
[25] Gujarati DN. Basic econometrics. New York: The Mc Graw Hill Companies; 2004.
[26] Wooldridge JM. Introductory econometrics: a modern approach. New York: South Western, Division of Thomson Learning; 2005.
[27] Engle RF, Granger CWJ. Co-integration and error correction: representation, estimation and testing. Econometrica 1987;55(2):251–76.
[28] Mirasgedis S, Sarafidis Y, Georgopoulou E, Lalas DP, Moschovits M, Karagiannis F, et al. Models for mid-term electricity demand forecasting incorporating weather influences. Energy 2006;31(2):208–27.
[29] Bruno S, De Benedictis M, La Scala M, Wangesteen I. Demand elasticity increase for reducing social welfare losses due to transfer capacity restriction: a test case on Italian cross border imports. Electr Power Syst Res 2006;76(6–7):557–66.
[30] Ferrari A, Giulietti M. Competition in electricity markets: international experience and the case of Italy. Utilities Pol 2003;13(3):247–55.