Modelling the Load Curve of Aggregate Electricity Consumption Using Principal Components
Matteo Manera and Angelo Marzullo
NOTA DI LAVORO 95.2003

Matteo Manera, Department of Statistics, University of Milano-Bicocca
and Fondazione Eni Enrico Mattei, Milano, Italy
Angelo Marzullo, Enifin, Eni S.p.A., Milano, Italy

This paper can be downloaded without charge at:
The Fondazione Eni Enrico Mattei Note di Lavoro Series Index:
http://www.feem.it/web/activ/_wp.html
Social Science Research Network Electronic Paper Collection:
http://papers.ssrn.com/abstract_id=XXXXXX

The opinions expressed in this paper do not necessarily reflect the position of Fondazione Eni Enrico Mattei
Modelling the Load Curve of Aggregate Electricity Consumption Using Principal Components

Summary

Since oil is a non-renewable resource with a high environmental impact, and its most common use is to produce combustibles for electricity, reliable methods for modelling electricity consumption can contribute to a more rational employment of this hydrocarbon fuel. In this paper we apply the Principal Components (PC) method to modelling the load curves of Italy, France and Greece on hourly data of aggregate electricity consumption. The empirical results obtained with the PC approach are compared with those produced by the Fourier and constrained smoothing spline estimators. The PC method represents a much simpler and attractive alternative to modelling electricity consumption since it is extremely easy to compute, it significantly reduces the number of variables to be considered, and generally increases the accuracy of electricity consumption forecasts. As an additional advantage, the PC method is able to accommodate relevant exogenous variables such as daily temperature and environmental factors, and it is extremely versatile in computing out-of-sample forecasts.

Keywords: Electricity, Load curves, Principal components, Fourier estimator, Constrained smoothing estimator, Temperature, Non-renewable resources, Hydrocarbon fuels, Environment

JEL: C51, C53, Q30, Q40

The authors would like to thank Marzio Galeotti, Alessandro Lanza, Anil Markandya, Alessandro Mauro, Michael McAleer and two referees for their many insightful suggestions. This paper does not necessarily reflect the views of Enifin or Eni S.p.A.

Address for correspondence:

Matteo Manera
Department of Statistics
University of Milano-Bicocca
Via Bicocca degli Arcimboldi, 8
Building U7 20126
Milano
Italy
Phone: +39-02-64487319
Fax: +39-02-6473312
E-mail: Matteo.Manera@unimib.it
Modelling the Load Curve of Aggregate Electricity Consumption
Using Principal Components

1. Introduction

In a Europe characterized by strong incentives towards the liberalization of national electricity markets, researchers and market operators are increasingly interested in obtaining reliable estimates and forecasts of the short-run demand for electricity.

The energy sector, which is intimately related with the oil and gas industry, is also crucial for its environmental implications. According to the European Energy Agency (2002), about 90% of the greenhouse effect is directly or indirectly attributable to the use of hydrocarbon fossils and deforestation. The International Energy Agency (2000) defines an important energy indicator, the so-called “total primary energy supply” (TPES), that is the total amount of energy produced by all existing sources. In 2002 the world TPES was about 10,000 mega-tons oil equivalent (MTOE), which are equivalent to $1.2 \times 10^8$ giga-Watt per hour. It is important to notice that crude oil only represents 35% of the TPES, and that the sum of all fossil combustibles (i.e. oil, gas and coal) amounts to 76.2% of the TPES. Another crucial energy indicator is the “total final consumption” (TFC). Since no energy plant is 100% efficient, TFC is less than TPES, and has been estimated around 7,000 MTOE. Out of 7,000 MTOE, 75% is given by fossil combustibles, which is equivalent to $6 \times 10^4$ tera-Watt per hour.

Since oil is a non-renewable resource with a high environmental impact, academics, research institutions and public opinion are engaged in a fast-growing debate on how to reduce the dependence of national economic systems on oil. Besides the development of alternative and more
efficient ways to exploit renewable resources, the simplest method to control this type of
dependence is to reduce oil consumption. As the most common use of oil is to produce
combustibles for electricity and transportation, more reliable methods to model, estimate and
forecast electricity consumption can contribute to a more rational employment of this fundamental
hydrocarbon fuel.

Early studies on the analysis of the load curve (e.g. Cargill and Mayer, 1971) generally
concentrate only on the long-run features of electricity consumption. Alternative traditional
approaches which explicitly take into account the short-run movements in the load curve are spline
and Fourier models (see Hendricks et al., 1979; Mouchart and Roche, 1987), while a more recent
methodology which embeds both splines and Fourier is the constrained smoothing splines estimator
(see Rodriguez-Poo, 2000).

The Principal Components (PC) method, combined with traditional regression analysis, represents
a much simpler and attractive alternative to modelling and forecasting electricity consumption as it
is extremely easy to compute, significantly reduces the number of variables to be considered, and
generally contributes to more accurate electricity consumption forecasts.

In this paper we apply the PC method to model and forecast the load curves of three European
countries, namely Italy, France and Greece, using hourly aggregate electricity consumption data.
The empirical results obtained with the PC approach are compared with those produced by Fourier
and constrained smoothing spline estimators.

The paper is organized as follows. Section 2 provides a description of cubic splines, Fourier and
constrained smoothing estimators for modelling the loading curve. An illustration of the PC method
is given in Section 3. The data are presented in Section 4. In Section 5 the empirical results obtained
with the PC method are presented and compared with the Fourier and constrained smoothing
splines estimators. In Section 6 the PC method is used to obtain out-of-sample forecasts of
electricity consumption for the French market. Section 7 provides some concluding comments.
2. Classical models of the load curve

Early research on the daily load curve were generally based on a two-stage estimation approach (see, among others, Cargill and Mayer, 1971). In the first stage, a simple ARMA time series model is fitted to consumption data for each consumption unit (e.g. household, firm, or industrial plant). In the second stage, the estimated coefficients of each ARMA model are regressed on a set of residential, demographical and socio-economic variables. One limitation of this method is that it concentrates only on long-run features of the data, since the selected explanatory variables do not change within a single day. On the other hand, load curves, which are subject to physical as well as atmospherical conditions, are characterized by intra-day marked variations.

Alternative approaches which concentrate on short-run movements in the load curve are given by spline and Fourier models. In both cases, the general problem can be described as follows. Indicate with \( y_i, i=1,...,n \), the electricity consumption between time \( t_{i-1} \) and time \( t_i \) for a given sample of data. The index \( i=1,...,n \) denotes the data frequency. We are interested in the statistical model:

\[
(1) \quad y_i = m(t_i) + \epsilon_i,
\]

where \( \epsilon_i \) are independent and identically distributed error terms with zero mean and constant variance, \( t_i = i/n \) is a time index, \( n \) indicates the total number of observations, and the function \( m(t_i) \) is to be specified.
2.1. Cubic splines

A spline estimator to fit the hourly load curve has used by Hendricks et al. (1979), and by Mouchart and Roche (1987). The function \( m(t) \) is specified as a cubic spline, that is, a polynomial series with continuous first and second derivatives, and a step-wise third derivative. The polynomials are thus linked by a series of nodes which correspond to flex points. The number of flex points \( q \) determines estimation accuracy. If \( q=n \), a smoothing spline is obtained, while \( q<n \) gives a parametric spline.

Assuming \( q=n \), a cubic spline function can be interpreted as a non-parametric regression estimator which arises from the solution to the following problem:

\[
(2) \quad \min_{m \in W_2^{2}\left[0,1\right]} L_n(m),
\]

where

\[
(3) \quad L_n(m) = n^{-1} \sum_{i=1}^{n} w_i \left[ y_i - m(t_i) \right]^2 + \lambda \int_{0}^{1} \left[ \frac{d^2m(t)}{dt^2} \right]^2 dt.
\]

In this context, \( W_2^{2}\left[0,1\right] \) indicates the class of all twice periodic differentiable functions, whereas the loss function \( L_n(m) \) is formed by two terms, the first being a weighted measure of goodness of fit, and the second a penalty.\(^1\) The solution to problem (2)-(3) yields an estimated \( \hat{m}_k = \left[ \hat{m}_k(t_1), \ldots, \hat{m}_k(t_n) \right]' \) that, for given values of \( \lambda \), is the best compromise between smoothness

\(^1\) In our empirical application, we assume equal weights, i.e. \( w_i = 1 \) for all \( i=1,\ldots,n \).
and goodness of fit (Rodriguez-Poo, 2000, p. 233). A model of this type is more sensible to changes in data structure than a standard parametric model.

2.2. Fourier estimator

Another classical method to model and forecast electricity consumption is provided by the Fourier estimator. Assuming that electricity consumption follows a daily pattern characterized by pronounced periodicity, a reasonable method to model the function $m(.)$ is to use sine and cosine polynomials at different frequencies. The aim is to estimate the parameters of the following function:

$$m(t) = \beta_{0\lambda} + \sum_{j=1}^{\lambda} \left[ c_{\lambda,j} \cos\left(\frac{2\pi j t}{p}\right) + s_{\lambda,j} \sin\left(\frac{2\pi j t}{p}\right) \right], \tag{4}$$

where $p$ is the periodicity.

The parameters $\beta_{0\lambda}, c_{\lambda,j}, s_{\lambda,j}$ and $\lambda$ can be estimated by exploiting the properties of the discrete Fourier transform (DFT). It is well known that the DFT of a period signal $y_m$ of period $n$ is the periodic sequence $F$ of period $n$, defined as:

$$F(k) = \sum_{m=0}^{n-1} y_m e^{-\frac{2\pi i k m}{n}}, \tag{5}$$

for any $k=0,1,\ldots,n-1$. Each complex element of the transform can be seen as the linear combination of the original data and a coefficient composed by a real (Re) and an imaginary (Im) part. If the original series is real-valued, the following property of the DFT holds:
(6) \( F(k) = c(k) - is(k) \)

where

(7) \( c(k) = \text{Re } F(k) = \sum_{m=0}^{n-1} y_m \cos\left(\frac{2\pi k}{n} \cdot m\right), \quad k=0,\ldots,n/2, \)

and

(8) \( s(k) = \text{Im } F(k) = \sum_{m=1}^{n-1} y_m \sin\left(\frac{2\pi k}{n} \cdot m\right), \quad k=1,\ldots,(n/2)-1. \)

Moreover, the inverse transform yields:

(9) \( y_n = \frac{1}{n} \left\{ b(0) + 2 \sum_{k=1}^{n-1} \left[ c(k) \cos\left(\frac{2\pi k}{n} \cdot m\right) + s(k) \sin\left(\frac{2\pi k}{n} \cdot m\right) \right] + c(k/2) \cos(km) \right\}. \)

In order to estimate the parameters \( \beta_{0k}, c_{k}, s_{k}, \lambda \) from the coefficients \( b(0), c(k), s(k) \) and \( c(n/2) \), we use the fast Fourier transform (FFT) algorithm and proceed as follows. First, recalling that the absolute value of the complex number \( F(k), |F(k)| \), is the “intensity” of the signal, we apply FFT on the original series \( y_i, i=1,\ldots,n \), to obtain the sequence of complex numbers \( F(k), k=0,\ldots,n \). Second, given the symmetric behaviour of \( F(k) \) when \( k=1,\ldots,(n/2)-1 \) and \( k=(n/2)+1,\ldots,n \), we calculate the standard deviation \( \sigma_{|F(k)|} \) of the series \( F(k), k=1,\ldots,(n/2)-1 \). Third, we select those
values of $c(k)$ and $s(k)$ which correspond to a significantly large signal intensity, according to the criterion $|F(k)| > 3\sigma_{|F(k)|}$. The estimated value of $\lambda$ is given by the number of times the criterion above is satisfied, while the estimated constant $b(0)$ is, by definition, $\hat{b}(0) = F(0)$. Moreover, we set $\hat{c}(n/2) = F(n/2)$ to zero since, in most of the empirical applications, the estimated value of this parameter is negligible. Thus, the selected parameter values are $\hat{\lambda}$, $\hat{c}(j)$, $\hat{s}(j)$, and $\hat{b}(0)$, with $j = 1,...,\hat{\lambda}$. Finally, we calculate the “fitted” electricity consumption series as:

\[
\hat{m}(t) = \hat{b}(0) + \sum_{j=1}^{\hat{\lambda}} \left[ \hat{c}(j) \cos \left( \frac{2\pi j t}{n} \right) + \hat{s}(j) \sin \left( \frac{2\pi j t}{n} \right) \right].
\]

When the DFT is computed using the FFT algorithm on a given sample of observations, and the subset of estimated parameters is selected appropriately, the original series can be interpreted as a linear combination of sine and cosine functions whose parameters are the corresponding real and imaginary parts of the transformed series. It is also clear from equations (4) and (10) that Fourier polynomials are useful to model the behaviour of volumes in many energy markets as they are able to accommodate marked seasonalities in the data. Nevertheless, this technique does not allow an analysis of phenomena other than the daily load curve.

2.3. Constrained smoothing splines

Rodriguez-Poo (2000) proposes the Constrained Smoothing Spline Estimator (CSSE), which is given by the combination of the Fourier estimator and the standard smoothing spline. The CSSE is the solution to the following optimization problem:
(11) \[ \min_{m \in W_{2}^{2}[0,1]} L_{n}(m) \]

where:

\[ (12) \quad L_{n}(m) = n^{-1} \sum_{i=1}^{n} w_{i} \left[ y_{i} - m(t_{i}) \right]^{2} + \lambda_{1} \int_{0}^{1} \left( \frac{d^{2}m(t)}{dt^{2}} \right)^{2} dt + \]

\[ + n^{-1} \lambda_{2} \sum_{i=1}^{n} \left[ m(t_{i}) - g_{0}(t_{i}) \right]^{2}. \]

The resulting estimator takes into account goodness of fit (that is, the weighted residual sum of squares), smoothness (that is, the integral of the second derivative), and the distance of the function \( m(.) \) with respect to some periodic parametric function \( g_{0}(.) \).

The function \( g_{0}(.) \) in (12) is given by the Fourier function (4), while the function \( m(.) \) in (12) is the cubic spline which solves equations (2)-(3). Thus, the aim is to find estimates of \( \lambda_{1} \) and \( \lambda_{2} \) which minimize the distance between CSSE and \( g_{0}(.) \), since the underlying idea of CSSE is to maintain a structure which is similar to the Fourier. For this reason, the solution of equations (11)-(12) is between the standard smoothing operator (that is, \( \lambda_{2} = 0 \)) and the Fourier polynomial when \( \lambda_{1} = 0 \) and \( \lambda_{2} \to \infty \).

3. Modelling the load curve with Principal Components

The method of Principal Components (PC) transforms the \( p \) variables of interest \( y_{1}, y_{2}, \ldots, y_{p} \), into a linear combination of other \( k \) variables, \( z_{1}, z_{2}, \ldots, z_{k} \), the so-called principal components, with \( k \leq p \). Notice that the only interesting case is when \( k < p \), that is, when we are able to represent \( p \) variables using a smaller number of linear combinations and with no loss of relevant
information. It must be stressed that, in our empirical application, \( y_r \) and \( z_s, r=1,\ldots,p, s=1,\ldots,k \), are column vectors of dimension \( d \times 1 \) of observations on electricity consumption, with \( d \) indicating the number of days in a year.

The first principal component is the linear combination with the largest variance. Define

\[
(13) \quad z_1 = a_{11} y_1 + a_{21} y_2 + \ldots + a_{p1} y_p = Ya_1,
\]

where \( Y = (y_1, y_2, \ldots, y_p) \) is a \( d \times p \) matrix, and \( a_1' = (a_{11}, a_{21}, \ldots, a_{p1}) \) is a \( 1 \times p \) vector of coefficients. The variance of \( z_1 \) is given by

\[
(14) \quad \sigma^2_{z_1} = a_1'Sa_1,
\]

where \( S \) is the \( p \times p \) sample covariance matrix of \( y_1, y_2, \ldots, y_p \). It is well know that, in order for (13) to be the linear combination with the largest variance (14), \( a_1 \) should be the first eigenvector of the matrix \( S \), that is, the eigenvector which corresponds to the largest eigenvalue of \( S \), say \( v_1 = a_1'Sa_1/a_1'a_1 \). The exercise is repeated to construct the \( d \times p \) matrix of principal components

\[
Z = (z_1, z_2, \ldots, z_p), \quad k=p,
\]

where \( z_s = a_{s1} y_1 + a_{s2} y_2 + \ldots + a_{sp} y_p = Ya_s, \quad s=1,\ldots,k. \)

An important property of PC allows us to represent the variables simply as linear combinations of the components. Defining the \( p \times p \) matrix of eigenvectors of \( S \) as \( A = (a_1, a_2, \ldots, a_p) \), so that

\[
(15) \quad Z = AY.
\]

Since the eigenvectors are orthogonal to each other, \( A^{-1} = A' \), which implies that \( A'A = AA' = I_p \).

Hence, equation (15) can be represented as
(16) $Y = ZA^{-1} = ZA'$, 

that is, $Y$ is expressed in terms of linear combinations of the components. If $k < p$, it is possible to partition the matrices $A$ and $Z$ as $A = (A_k, A_{p-k})$ and $Z = (Z_k, Z_{p-k})$, respectively. The $d \times k$ submatrix $A_k (Z_k)$ contains the first $k$ largest eigenvectors (principal components), while the $d \times (p-k)$ submatrix $A_{p-k} (Z_{p-k})$ is formed from the last $p-k$ eigenvectors (principal components). Using these partitioned matrices, we can rewrite expression (16) as

(17) $Y = Z_k A_k' + Z_{p-k} A_{p-k}' = Z_k A_k' + E$,

where $E$ is the approximation error in representing the $p$ variables $Y$ using the first $k$ principal components $Z_k$ only. The term $Z_k A_k'$ is defined as the “fitted” load curve, $\hat{Y} = Z_k A_k'$. 

If we want to improve the in-sample fit of the load curve without increasing the number of components $k$, we can combine the PC method with standard regression analysis. Specifically, given a $d \times g$ matrix $X$ of exogenous variables (with, in general, $g > k$), such as deterministic daily effects, holidays, seasonal patterns and weather conditions, we estimate $k$ separate regressions by OLS, which can be written compactly as follows:

(19) $Z_k = X \Pi + H$,

where $\Pi$ is a $g \times k$ matrix of coefficients and $H$ a $d \times k$ matrix of error terms. Then, we can calculate the matrix of fitted values as
where \( \hat{\Pi} \) is the matrix of OLS estimated coefficients \( \Pi \). Finally, we reconstruct the estimated load curve as

\[
\hat{Y} = \hat{Z}_t A_t'.
\]
curve is flatter than the other two, since the MW difference between a peak and a trough is less pronounced.

5. Estimation results

5.1. The PC method

We have applied the PC approach described in Section 3 to daily observations on electricity consumption of Italy, France and Greece. In the empirical application, we use \( p=24 \) (the number of hours in a day), and \( d=365 \), the number of days in a year.

In Figure 2 we report, for each country, the percentages of total variation in electricity consumption explained by the PC method. The first component explains for all countries the largest part of the total variation (91\%, on average), and represents the electricity consumption pattern within the typical week. The second and third components capture some specific aspects of electricity consumption, basically daily effects and environmental factors.

Concentrate on Italy, the mean aggregate load curve presented on Figure 3a exhibits a significant difference in consumption between night and day. On Figure 3b we show the eigenvectors associated with the first three components, \( a_s, s=1,...,k=3 \).

The 24 coefficients associated with the first component, \( a_1 \), mimic very closely the behaviour of the average load curve. This evidence confirms the explanatory power of this component. The daily curve, which is more “active” during working days and “less” active on week-ends and holidays, gives the general shape of the aggregate load curve. The contribution of the first component is to increase the imbalance effect in working days and, on the contrary, to flatten the load curve during week-ends. This last aspect can be visualized by graphing the values of the first component, \( z_1 \),

\[ \text{In the graphs the first three components are indicated with Pc1, Pc2 and Pc3, respectively.} \]
which are positive and almost constant during the first part of the week, while negative during the week-end (see Figure 5).

The coefficients of the second component, $a_2$, characterize more accurately the discrepancies between working days and week-ends within each week. For Italy, the second component captures the asymmetries in the load curve between morning and night hours. For France and Greece, this component helps define the shape of the load curve during working days (see Figures 4a-4d).

Although the third component explains, on average across countries, only a small part of the variability in electricity consumption, its interpretation is extremely interesting since it accounts for the effects of weather conditions and environmental factors. During winter, the days are shorter and the electricity consumption for heating and lighting is very high in late afternoon. On the contrary, in summer late afternoon consumption is lower, since daylight is intense and the average temperature is not as high as in the inside of the day to justify a massive use of air conditioning. This phenomenon is evident in all countries, although with different magnitudes (Figure 4).

We now calculate the “fitted” load curves, according to the procedure illustrated in Section 3. For each country, the matrix $X$ of exogenous regressors in equation (19) is formed by seven dummy variables indicating the seven days of the week (MON, TUE, WED, THU, FRI, SAT, SUN), two deterministic sine (SIN1, SIN2) and two cosine (COS1, COS2) variables with periods 1 and 2, respectively, in order to capture long-run seasonality effects, a dummy variable for national holidays (HOL), two variables measuring average temperature\(^3\) (TEMP) and its square (TEMP2), which capture the non-linearities in the relationship between electricity consumption and temperature.\(^4\)

The presence of non-linearities in the relationship between electricity consumption and temperature is well documented in the literature. For instance, Engle et al. (1986) provide empirical evidence in favour of a V-shaped relation between consumption and temperature, with a minimum

---

\(^3\) Average temperature is defined, for each country, as the arithmetic mean of daily temperatures recorded in three representative cities located in the North, Center and South.

\(^4\) The estimation results of equation (19) are reported, for each country, in Appendix 1.
around 18° C, for the US electricity market. This relation can be rationalized by noticing that temperature reductions increase electricity consumption through a more intense use of heating equipment, whereas a rise in temperature increases electricity consumption because of massive air conditioning.

The major drawback of this type of analysis is that it does not take into explicit consideration the shape of the load curve. Not only does temperature affect accumulated daily consumption (i.e. the area below the load curve), but also the shape of the consumption curve. Unfortunately, it is not easy to study the time series relationship between consumption and temperature, since the former is typically observed on an hourly base, whereas the latter is generally available with daily frequency. Using the PC method, we can overcome this problem by summarizing the shape of the load curve as the product between the hourly coefficients and the level of the corresponding principal component. Then we can model the relations between the components and a set of relevant exogenous variables, and analyze the changes in the daily accumulated electricity consumption, as well as the modifications of the shape of the load curve. If the daily temperature is included among the exogenous variables, it is also possible to concentrate attention on the impact of weather conditions on the shape of the load curve.

5.2. FFT, CSSE, and a comparison with the PC method

We have implemented the FFT estimator following the procedure described by equations (4)-(10) in Section 2.2. In the empirical application, the total number of observations is \( n = 8760 \) (i.e. 24 hours time 365 days), while the estimated values for the parameter \( \lambda \) in the Fourier model are 72 for Italy, 127 for France, and 115 for Greece. The estimated FFT consumption series has been constructed using expression (10).
The CSSE has been calculated along the lines illustrated in equations (11)-(12) of Section 2.3.\textsuperscript{5} The estimated CSSE consumption series has been calculated as the solution to the problems given in equations (2)-(3) and (11)-(12).

The results for Italy are reported in Figure 6, where the FFT and CSSE estimators (FFTIT and CSEIT, respectively) are compared with two versions of the PC method, namely with and without including the temperature variable as an exogenous variable in equation (19) (COMPTEMPIT and COMPIT, respectively). The scatter plot of the calculated (or “fitted”) values against actual consumption shows that the performance of each of the three methods is satisfactory, as all the data points for each of the four estimated models are very close to the 45° line. The squared correlation coefficients between the actual and fitted values indicate that the PC method which includes the temperature variable has the best fit ($R^2=0.96$), followed by the PC model without the temperature variable ($R^2=0.93$), while FFT and CSSE are very close (with $R^2$ values of 0.892 and 0.894, respectively). The estimated principal components seem to be more adaptable to the data, since they allow for long-run seasonality, daily and holiday effects. When the temperature variable is included, the principal components also capture modifications in the shape of the load curve.

Figure 7 reports the comparison between the PC method (without the temperature variable), FFT and CSSE for Greece and France. The motivation of this example is to emphasise the importance of the temperature variable in the PC approach. For both countries, the consumption series fitted by the PC method without the temperature variable has the lowest $R^2$. In particular, for Greece, the best performing $R^2$, which is associated with the FFT estimator, has an higher $R^2$ value by 0.15.

6. Forecasting the load curve with the PC method

Besides computational simplicity and the capability of accommodating relevant exogenous variables, such as daily temperature, one of the major advantages of the PC method is that it is

\textsuperscript{5} The Matlab routine written to solve the problem given in (11)-(12) is reported in Appendix 2.
versatile when out-of-sample forecasts are required. For instance, if $h$ additional out-of-sample observations on the exogenous variables are available, it is possible to define a matrix, $\hat{X}$, of dimension $h \times g$. Thus, given the matrix of estimated coefficients, $\hat{\Pi}$, obtained from equation (19), we can calculate the $k$ “out-of-sample” principal components as

\begin{equation}
\hat{Z}_k = \hat{X}\hat{\Pi}.
\end{equation}

Finally, the out-of-sample predicted values of the load curve can be obtained as:

\begin{equation}
\hat{Y} = \hat{Z}_k A_k^\prime.
\end{equation}

where $A_k$ is the matrix of coefficients associated with the $k$ “in-sample” principal components.

Given the availability of daily electricity consumption and temperature observations over the first three months of the year 2002 (i.e. $g=90$), we have applied the approach described by equations (19), (22) and (23) to France.

The results in terms of forecasted consumption are encouraging, with a mean absolute error of 0.055 on an hourly base. In Figure 8, a scatter plot of the forecasted hourly consumption against actual consumption is reported. The forecasting performance of the PC method is satisfactory, since the dispersion around the 45° line is limited, with an informative $R^2$ value of 0.81. Figure 9 presents the graphical behaviour of the hourly load curve and the corresponding hourly observed consumption on a subperiod of the forecasting horizon, namely from 28 January 2002 to 19 February 2002. Again, the goodness of fit of the PC method is evident.
7. Conclusion

In this paper we have applied the Principal Components (PC) method to model the load curves of Italy, France and Greece on hourly data for aggregate electricity consumption. The empirical results obtained with the PC approach have been compared with those produced by the Fourier and constrained smoothing spline estimators.

The PC method represents a simple alternative to modelling electricity consumption since it is easy to compute, significantly reduces the number of variables to be considered, and generally contributes to greater accuracy of electricity consumption forecasts. As an additional advantage, the PC method is able to accommodate relevant exogenous variables such as daily temperature, and is versatile when true out-of-sample forecasts are required.

The squared correlation coefficients between actual and in-sample fitted values indicate that the PC method with the temperature variable has the best fit, followed by the PC model without the temperature variable, the Fourier model and the constrained smoothing spline estimator. Thus, the estimated principal components seem to be more adaptable to data since they allow for long-run seasonality, daily and holiday effects and, when the temperature variable is included, also capture modifications in the shape of the load curve. The out-of-sample forecasting performance of the PC method is also encouraging.
References


Figure 1. Load curves for Italy (IT), France (FR) and Greece (GR) measured in Mega-Watt (MW) (aggregate data, January 2001).
Figure 2. Percentage of total variation of electricity consumption explained by the principal components (PC1 = first principal component, PC2 = second principal component, PC3 = third principal component and OTHER = remaining 24-3=21 components).
Figure 3. Mean hourly consumption calculated as the sample mean of 365 daily observations (3a), and coefficients of the first three principal components PC1, PC2, and PC3 for Italy (3b).
Figure 4. Mean hourly consumption calculated as the sample mean of 365 daily observations (4a), and coefficients of the first three principal components PC1, PC2, and PC3 for France (4b).
Figure 4. Mean hourly consumption calculated as the sample mean of 365 daily observations (4c), and coefficients of the first three principal components PC1, PC2, and PC3 for Greece (4d).
Figure 5. First and second components (PC1 and PC2) for Italy, France and Greece.
\[ R^2 = 0.9288 \text{ (COMPTEMPIT)} \]
\[ R^2 = 0.8918 \text{ (COMPIT)} \]
\[ R^2 = 0.9579 \text{ (CSEIT)} \]
\[ R^2 = 0.8943 \text{ (FFTIT)} \]
Figure 7. Fitted (=forecasted) versus actual (=real) values for 4 competing models applied to Greece (GR) and France (FR). COMPW = PC model with no temperature, FFTW = Fourier model, CSEW = Constrained Smoothing Spline model; W=GR, FR. $R^2$ = squared correlation coefficients between fitted and actual values for each model.
Figure 8. Out-of-sample forecasted and actual (=real) values for the PC model applied to France (FR). COMPFR = PC model with temperature, $R^2$ = squared correlation coefficients between forecasted and actual values.
Figure 9. Out-of-sample fitted and actual load curves for France.
### Appendix 1. OLS estimation of equation (19)

#### Coefficients

<table>
<thead>
<tr>
<th>Variable</th>
<th>PC1IT</th>
<th>PC2IT</th>
<th>PC3IT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MON</td>
<td>23025.76 **</td>
<td>7695.01 **</td>
<td>-2309.79 **</td>
</tr>
<tr>
<td>TUE</td>
<td>29348.17 **</td>
<td>721.14 **</td>
<td>-</td>
</tr>
<tr>
<td>WEN</td>
<td>29759.89 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>THU</td>
<td>30570.82 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FRI</td>
<td>29461.41 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SAT</td>
<td>-4469.11 **</td>
<td>2852.19 **</td>
<td>-</td>
</tr>
<tr>
<td>SUN</td>
<td>-22276.37 **</td>
<td>1168.59 **</td>
<td>-</td>
</tr>
<tr>
<td>HOL</td>
<td>-37288.89 **</td>
<td>4776.01 **</td>
<td>-642.84 **</td>
</tr>
<tr>
<td>TEMP</td>
<td>-2391.00 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TEMP2</td>
<td>91.31 **</td>
<td>-5.27 **</td>
<td>-</td>
</tr>
<tr>
<td>COS1</td>
<td>6445.04 **</td>
<td>1741.97 **</td>
<td>3933.41 **</td>
</tr>
<tr>
<td>COS2</td>
<td>4211.22 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SIN1</td>
<td>-2076.76 **</td>
<td>-</td>
<td>-715.07 **</td>
</tr>
<tr>
<td>SIN2</td>
<td>-</td>
<td>-506.45 **</td>
<td>-</td>
</tr>
</tbody>
</table>

R-squared 0.88 0.81 0.90

#### Coefficients

<table>
<thead>
<tr>
<th>Variable</th>
<th>PC1FR</th>
<th>PC2FR</th>
<th>PC3FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>MON</td>
<td>77051.51 **</td>
<td>-4360.39 **</td>
<td>-4268.02 **</td>
</tr>
<tr>
<td>TUE</td>
<td>84176.24 **</td>
<td>-8501.95 **</td>
<td>-7566.90 **</td>
</tr>
<tr>
<td>WEN</td>
<td>85031.96 **</td>
<td>-7700.80 **</td>
<td>-7422.43 **</td>
</tr>
<tr>
<td>THU</td>
<td>84077.38 **</td>
<td>-9073.16 **</td>
<td>-7898.34 **</td>
</tr>
<tr>
<td>FRI</td>
<td>84197.29 **</td>
<td>-8854.28 **</td>
<td>-10001.39 **</td>
</tr>
<tr>
<td>SAT</td>
<td>56965.18 **</td>
<td>-19164.56 **</td>
<td>-8293.43 **</td>
</tr>
<tr>
<td>SUN</td>
<td>41070.50 **</td>
<td>-23428.76 **</td>
<td>-4087.19 **</td>
</tr>
<tr>
<td>TEMP</td>
<td>-8060.17 **</td>
<td>1188.60 **</td>
<td>758.35 **</td>
</tr>
<tr>
<td>TEMP2</td>
<td>180.49 **</td>
<td>-19.38 **</td>
<td>-15.97 **</td>
</tr>
<tr>
<td>HOLFR</td>
<td>-13848.21 **</td>
<td>-4425.44 **</td>
<td>844.73 **</td>
</tr>
<tr>
<td>COS1</td>
<td>15546.42 **</td>
<td>-</td>
<td>4065.53 **</td>
</tr>
<tr>
<td>COS2</td>
<td>3625.07 **</td>
<td>-</td>
<td>1585.42 **</td>
</tr>
<tr>
<td>SIN1</td>
<td>-5259.42 **</td>
<td>-799.20 **</td>
<td>-1280.60 **</td>
</tr>
<tr>
<td>SIN2</td>
<td>-5649.34 **</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

R-squared 0.89 0.82 0.66

#### Coefficients

<table>
<thead>
<tr>
<th>Variable</th>
<th>PC1GR</th>
<th>PC2 GR</th>
<th>PC3GR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUN</td>
<td>-3072.98 **</td>
<td>-1049.60 **</td>
<td>387.67 **</td>
</tr>
<tr>
<td>HOLGR</td>
<td>-1143.74 **</td>
<td>-375.98 **</td>
<td>-</td>
</tr>
<tr>
<td>MON</td>
<td>504.19 **</td>
<td>-260.99 **</td>
<td>-</td>
</tr>
<tr>
<td>TUE</td>
<td>908.65 **</td>
<td>348.21 **</td>
<td>**</td>
</tr>
<tr>
<td>WEN</td>
<td>1048.54 **</td>
<td>299.27 **</td>
<td>-181.24 **</td>
</tr>
<tr>
<td>THU</td>
<td>1179.36 **</td>
<td>344.31 **</td>
<td>-</td>
</tr>
<tr>
<td>FRI</td>
<td>1041.92 **</td>
<td>307.94 **</td>
<td>-</td>
</tr>
<tr>
<td>SAT</td>
<td>-731.29 **</td>
<td>-547.10 **</td>
<td>178.03 **</td>
</tr>
<tr>
<td>COS2</td>
<td>2736.25 **</td>
<td>-368.70 **</td>
<td>301.23 **</td>
</tr>
<tr>
<td>SIN1</td>
<td>-488.95 **</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SIN2</td>
<td>580.57 **</td>
<td>-221.95 **</td>
<td>68.01 **</td>
</tr>
<tr>
<td>COS1</td>
<td>-475.61 **</td>
<td>545.20 **</td>
<td>833.21 **</td>
</tr>
</tbody>
</table>

R-squared 0.64 0.78 0.84

Notes: * significant at 5%; ** significant at 1%;

R$^2$ = squared correlation coefficient between actual and fitted;  
P$C_k$= k-th principal component, k=1,2,3;  
IT = Italy; FR = France; GR = Greece.
Appendix 2. Matlab program for the CSSE algorithm

function GCV=GCV(L);

global GG VETGRTNG STIMFFTG % Define the global variables in the Workspace

Y=VETGRTNG; % Y is the vector of historical hourly consumption
G0=STIMFFTG; % G0 is the previous estimates obtained using the FFT estimator
L1=L(1); % L1 indicates lambda1
L2=L(2); % L2 indicates lambda2

if L2==0 % Define the constraints on the parameters L1 and L2
  Lam=L1;
else
  Lam=(L2/(L1+L2)); % Define the smoothing values of the CSSE function
  % of L1 and L2
end

if Lam>1
  Lam=1
end

YS=csaps(GG,(Y+L2*G0)./(1+L2),Lam,GG); % Cubic smoothing spline
% function in Matlab, GG indicates days
GCV=((1/8760)*sum((Y-YS).^2))/(1-Lam)+((1/8760)*sum((YS-G0).^2))/(1-Lam));
% This is the revisited function of General Cross Validation to be
% minimized

assignin('base','YSA',YS); %The function returns to the Workspace
%the estimates
assignin('base','Lam',Lam); %and the solutions for lambda1 and lambda2
assignin('base','L1',L1);
assignin('base','L2',L2);
function end

After saving this function we set the follows instructions into the workspace:

fmins('GCV',[0.5 0.5],1)

Note: for each feasible solution, this process takes 1 min on a Celeron 400 Mhrz processor.
NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI
Fondazione Eni Enrico Mattei Working Paper Series
Our working papers are available on the Internet at the following addresses:
http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://papers.ssrn.com

SUST 1.2002 K. TANO, M.D. FAMINOW, M. KAMUANGA and B. SWALLOW: Using Conjoint Analysis to Estimate Farmers’ Preferences for Cattle Traits in West Africa
ETA 2.2002 Efrem CASTELNUOVO and Paolo SURICO: What Does Monetary Policy Reveal about Central Bank’s Preferences?
CLIM 4.2002 Andreas LöSCHEL: Technological Change in Economic Models of Environmental Policy: A Survey
VOL 5.2002 Carlo CARRARO and Carmen MARCHIORI: Stable Coalitions
KNOW 8.2002 Alain DESDOIGTS: Neoclassical Convergence Versus Technological Catch-up: A Contribution for Reaching a Consensus
NRM 9.2002 Giuseppe DI VITA: Renewable Resources and Waste Recycling
KNOW 10.2002 Giorgio BRUNELLO: Is Training More Frequent when Wage Compression is Higher? Evidence from 11 European Countries
ETA 11.2002 Mordecai KURZ, Hehui JIN and Maurizio MOTOLESE: Endogenous Fluctuations and the Role of Monetary Policy
KNOW 12.2002 Reyer GERLAGH and Marjan W. HOFKES: Escaping Lock-in: The Scope for a Transition towards Sustainable Growth?
NRM 13.2002 Michele MORETTO and Paolo ROSATO: The Use of Common Property Resources: A Dynamic Model
CLIM 14.2002 Philippe QUIRION: Macroeconomic Effects of an Energy Saving Policy in the Public Sector
CLIM 16.2002 Francesco RICCI (l): Environmental Policy Growth when Inputs are Differentiated in Pollution Intensity
ETA 17.2002 Alberto PETRUCCI (liv): Devaluation (Levels versus Rates) and Balance of Payments in a Cash-in-Advance Economy
Coalition Theory Network 18.2002 László Á. KÓCZY (liv): The Core in the Presence of Externalities
NRM 21.2002 Fausto CAVALLARO and Luigi CIRAOLO: Economic and Environmental Sustainability: A Dynamic Approach in Insular Systems
CLIM 22.2002 Barbara BUCHNER, Carlo CARRARO, Igor CERSOSIMO and Carmen MARCHIORI: Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation
CLIM 23.2002 Andreas LöSCHEL and ZhongXIANG ZHANG: The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech
ETA 24.2002 Marzio GALEOTTI, Louis J. MACCINI and Fabio SCHIANTARELLI: Inventories, Employment and Hours
ETA 26.2002 Adam B. JAFFE, Richard G. NEWELL and Robert N. STAVINS: Environmental Policy and Technological Change
SUST 27.2002 Joseph C. COOPER and Giovanni SIGNORELLO: Farmer Premiums for the Voluntary Adoption of Conservation Plans
SUST 28.2002 The ANSEA Network: Towards An Analytical Strategic Environmental Assessment
KNOW 29.2002 Paolo SURICO: Geographic Concentration and Increasing Returns: a Survey of Evidence
ETA 30.2002 Robert N. STAVINS: Lessons from the American Experiment with Market-Based Environmental Policies
31.2002 Carlo GIUPPONI and Paolo ROSATO: Multi-Criteria Analysis and Decision-Support for Water Management at the Catchment Scale: An Application to Diffuse Pollution Control in the Venice Lagoon

32.2002 Robert N. STAVINS: National Environmental Policy During the Clinton Years

33.2002 A. SOUBEYRAN and H. STAHN: Do Investments in Specialized Knowledge Lead to Composite Good Industries?

34.2002 G. BRUNELLO, M.L. PARISI and Daniela SONEDDA: Labor Taxes, Wage Setting and the Relative Wage Effect


36.2002 T.TIETENBERG (iv): The Tradable Permits Approach to Protecting the Commons: What Have We Learned?


40.2002 S.M. CAVANAGH, W.M. HANEMANN and R.N. STAVINS: Muddled Price Signals: Household Water Demand under Increasing-Block Prices


42.2002 C. OHL (ivi): Inducing Environmental Co-operation by the Design of Emission Permits

43.2002 J. EYCKMANS, D. VAN REGEEMORTER and V. VAN STEENBERGH (ivi): Is Kyoto Fatally Flawed? An Analysis with MacGEM

44.2002 S. ANTOCI and S. BORGHESE (ivi): Working Too Much in a Polluted World: A North-South Evolutionary Model

45.2002 P. G. FREDRIKSSON, Johan A. LIST and Daniel MILLIMET (ivi): Chasing the Smokestack: Strategic Policymaking with Multiple Instruments

46.2002 Z. YU (ivi): A Theory of Strategic Vertical DFI and the Missing Pollution-Haven Effect

47.2002 Y. H. FARZIN: Can an Exhaustible Resource Economy Be Sustainable?

48.2002 Y. H. FARZIN: Sustainability and Hamiltonian Value

49.2002 C. PIGA and M. VIVARELLI: Cooperation in R&D and Sample Selection

50.2002 M. SERTEL and A. SLINKO (iv): Ranking Committees, Words or Multisets

51.2002 Sergio CURRARINI (ivi): Stable Organizations with Externalities

52.2002 Paolo ROSATO and Edi DEFRANCESCO: Individual Travel Cost Method and Flow Fixed Costs

53.2002 Vladimir KOTOV and Elena NIKITINA (ivii): Reorganisation of Environmental Policy in Russia: The Decade of Success and Failures in Implementation of Perspective Quests


56.2002 Giovanni DI BARTOLOMEO, Jacob ENGWERDA, Joseph PLASMANS and Bas VAN AARLE: Staying Together or Breaking Apart: Policy-Makers’ Endogenous Coalitions Formation in the European Economic and Monetary Union


58.2002 Carlo CAPUCANO: Demand Growth, Entry and Collusion Sustainability

59.2002 Federico MUNARI and Raffaele ORIANI: Privatization and R&D Performance: An Empirical Analysis Based on Tobin’s Q

60.2002 Federico MUNARI and Maurizio SOBRERO: The Effects of Privatization on R&D Investments and Patent Productivity


62.2002 Carlo CAPUCANO: Demand Growth, Entry and Collusion Sustainability

63.2002 Federico MUNARI and Raffaele ORIANI: Privatization and R&D Performance: An Empirical Analysis Based on Tobin’s Q

64.2002 Federico MUNARI and Maurizio SOBRERO: The Effects of Privatization on R&D Investments and Patent Productivity

65.2002 Orley ASHENFELTER and Michael GREENSTONE: Using Mandated Speed Limits to Measure the Value of a Statistical Life


68.2002 Barbara K. BUCHNER and Roberto ROSON: Conflicting Perspectives in Trade and Environmental Negotiations

69.2002 Philippe QUIRION: Complying with the Kyoto Protocol under Uncertainty: Taxes or Tradable Permits?

70.2002 Anna ALBERINI, Patrizia RIGANTI and Alberto LONGO: Can People Value the Aesthetic and Use Services of Urban Sites? Evidence from a Survey of Belfast Residents

71.2002 Marco PERCOCO: Discounting Environmental Effects in Project Appraisal
Move to Markets? An Empirical Analysis of

Sudeshna GHOSH BANERJEE and Michael C. MUNGER

Andreas LANGE

Jens HORBACH

Alberto CHONG and Florencio LÓPEZ-DE-SILANES

Privatization and Labor Force Restructuring Around the

Haruo IMAI and Mayumi HORIE

Anna BOTTASSO and Alessandro SEMBENELLI

Does Ownership Affect Firms’ Efficiency? Panel Data

Vito FRAGNELLI and Maria Erminia MARINA

Massimo FLORIO and Katiuscia MANZONI

The Abnormal Returns of UK Privatisations: From Underpricing

Evidence from the Fixed-Line Telecommunications Sector in Developing Economies

Mohammed OMRAN:

Laurent FRANCKX

Alberto R. PETRUCCI

Government Debt, Agent Heterogeneity and Wealth Displacement in a Small Open

François DEGEORGE, Dirk JENTER, Alberto MOEL and Peter TUFANO

Nandini GUPTA

Selling Company Shares to

Privatization and Investment: Crowding-Out Effect vs Financial

Kate BISHOP, Igor FILATOTCHEV and Tomasz MICKIEWICZ: Endogenous Ownership Structure: Factors

Affecting the Post-Privatization Equity in Largest Hungarian Firms

Theodora WELCH and Rick MOLZ: How Does Trade Sale Privatization Work?

Evidence from the Fixed-Line Telecommunications Sector in Developing Economies

Alberto P. PETRUCCI: Government Debt, Agent Heterogeneity and Wealth Displacement in a Small Open Economy

Timothy SWANSON and Robin MASON (lvi): The Impact of International Environmental Agreements: The Case of the Montreal Protocol


Massimo FLORIO and Katiuscia MANZONI: The Abnormal Returns of UK Privatisations: From Underpricing to Outperformance

Nelson LOURENÇO, Carlos RUSSO MACHADO, Maria do ROSÁRIO JORGE and Luis RODRIGUES: An Integrated Approach to Understand Territory Dynamics, The Coastal Alentejo (Portugal)

Peter ZAPFEL and Matti VAINIO (lv): Pathways to European Greenhouse Gas Emissions Trading History and Misconceptions

Pierre COURTOIS: Influence Processes in Climate Change Negotiations: Modelling the Rounds

Vito FRAGNELLI and Maria Erminia MARINA (lvi): Environmental Pollution Risk and Insurance

Laurent FRANCKX (lvi): Environmental Enforcement with Endogenous Ambient Monitoring

Tino GOESCHL and Timothy M. SWANSON (lvi): Lost Horizons. The noncooperative management of an evolutionary biological system.

Hans KEIDING (lvi): Environmental Effects of Consumption: An Approach Using DEA and Cost Sharing

Wietze LISE (lvi): A Game Model of People’s Participation in Forest Management in Northern India

Jens HORBACH: Structural Change and Environmental Kuznets Curves

Martin P. GROSSKOPF: Towards a More Appropriate Method for Determining the Optimal Scale of Production Units

Scott BARRETT and Robert STAVINS: Increasing Participation and Compliance in International Climate Change Agreements

Batu BATRAMOGLU LISE and Wietze LISE: Climate Change, Environmental NGOs and Public Awareness in the Netherlands: Perceptions and Reality

Matthieu GLCHANT: The Political Economy of Emission Tax Design in Environmental Policy

Kenn ARIGA and Giorgio BRUNELLO: Are the More Educated Receiving More Training? Evidence from Thailand

Gianfranco FORTE and Matteo MANERA: Forecasting Volatility in European Stock Markets with Non-linear GARCH Models

Geoffrey HEAL: Bundling Biodiversity

Geoffrey HEAL, Brian WALKER, Simon LEVIN, Kenneth ARROW, Partha DASGUPTA, Gretchen DAILY, Paul EHRlich, Karl-Goran MALER, Nils KAUTSKY, Jane LUBCHENCO, Steve SCHNEIDER and David STARRETT: Genetic Diversity and Interdependent Crop Choices in Agriculture

Geoffrey HEAL: Biodiversity and Globalization

Andreas LANGE: Heterogeneous International Agreements – If per capita emission levels matter

Pierre-André JOUVET and Walid OUESLATI: Tax Reform and Public Spending Trade-offs in an Endogenous Growth Model with Environmental Externalities

Anna BOTTASSO and Alessandro SEMBENELLI: Does Ownership Affect Firms’ Efficiency? Panel Data Evidence on Italy

Bernardo BORTOLOTTI and Alessandro SEMBENELLI: Does Ownership Affect Firms’ Efficiency? Panel Data Evidence on Italy

Haruo IMAI and Mayumi HORIE (lvi): Pre-Negotiation for an International Emission Reduction Game

Sudeshna GHOSH BANERJEE, Frank DE JONG, Giovanna NICODANO and Ibolya SCHINDELE: Privatization and Stock Market Liquidity

Anna BOTTASSO and Alessandro SEMBENELLI: Does Ownership Affect Firms’ Efficiency? Panel Data Evidence on Italy

Guillaume GIRMENS and Michel GUILLARD: Privatization and Investment: Crowding-Out Effect vs Financial Diversification

Alberto CHONG and Florencio LÓPEZ-DE-SILANES: Privatization and Labor Force Restructuring Around the World

Nandini GUPTA: Partial Privatization and Firm Performance

François DÉGEORGE, Dirk JENTER, Alberto MOEL and Peter TUFANO: Selling Company Shares to Reluctant Employees: France Telecom’s Experience
PRIV 112.2002 Isaac OTCHERE: Intra-Industry Effects of Privatization Announcements: Evidence from Developed and Developing Countries

PRIV 113.2002 Yannis KATSOLAKOS and Elissavet LIKOYANNI: Fiscal and Other Macroeconomic Effects of Privatization


PRIV 115.2002 D. Teja FLOTTO: A Note on Consumption Correlations and European Financial Integration


PRIV 2.2003 Ilona SCHINDELE: Theory of Privatization in Eastern Europe: Literature Review

PRIV 3.2003 Witze LISE, Claudia KEMPERT and Richard S.J. TOL: Strategic Action in the Liberalised German Electricity Market


KNOW 5.2003 Reyer GERLAGH: Induced Technological Change under Technological Competition

ETA 6.2003 Efrem CASTELNUOVO: Squeezing the Interest Rate Smoothing Weight with a Hybrid Expectations Model

SIEV 7.2003 Anna ALBERINI, Alberto LONGO, Stefania TONIN, Francesco TROMBETTA and Margherita TURVANI: The Role of Liability, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers

NRM 8.2003 Elisias PAPYRakis and Reyer GERLAGH: Natural Resources: A Blessing or a Curse?

CLIM 9.2003 A. CAPARROS, J.-C. PEREAU and T. TAIZDAIFT: North-South Climate Change Negotiations: a Sequential Game with Asymmetric Information

KNOW 10.2003 Giorgio BRUNEELLO and Daniele CHECCHI: School Quality and Family Background in Italy

CLIM 11.2003 Efrem CASTELNUOVO and Marzio GALEOTTI: Learning By Doing vs Learning By Researching in a Model of Climate Change Policy Analysis

KNOW 12.2003 Carole MAIGNAN, Gianmarco OTTAVIANO and Dino PINELLI (eds.): Economic Growth, Innovation, Cultural Diversity: What are we all talking about? A critical survey of the state-of-the-art


KNOW 14.2003 Maddy JANSENS and Chris STEYERT (lix): Theories of Diversity within Organisation Studies: Debates and Future Trajectories

KNOW 15.2003 Tuzin BAYCAN LEVENT, Enno MASUREL and Peter NIJKAMP (lix): Diversity in Entrepreneurship: Ethnic and Female Roles in Urban Economic Life

KNOW 16.2003 Alexandra BITUSIKOVA (lx): Post-Communist City on its Way from Grey to Colourful: The Case Study from Slovakia

KNOW 17.2003 Billy E. VAUGHN and Katarina MLEKOV (lx): A Stage Model of Developing an Inclusive Community


Network Theory

PRIV 20.2003 Giacomo CALZOLARI and Alessandro PAVAN (lx): Monopoly with Resale


PRIV 22.2003 Marco Liccalzi and Alessandro PAVAN (lx): Tilting the Supply Schedule to Enhance Competition in Uniform-Price Auctions

PRIV 23.2003 David ETTINGER (lx): Bidding among Friends and Enemies

PRIV 24.2003 Hannu VARTIAINEN (lx): Auction Design without Commitment


PRIV 26.2003 Christine A. PARLOUR and Uday RAIKAN (lx): Rationing in IPOs

PRIV 27.2003 Kjell G. NYBORG and Ilya A. STREBULAEV (lx): Multiple Unit Auctions and Short Squeezes

PRIV 28.2003 Anders LUNANDER and Jan-Eric NILSSON (lx): Taking the Lab to the Field: Experimental Tests of Alternative Mechanisms to Proceed Multiple Contracts


ETA 31.2003 Michael FINUS and Bianca RUNDHAGEN: A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games

KNOW 32.2003 Michele MORETTO: Competition and Irreversible Investments under Uncertainty

PRIV 33.2003 Philippe QUIRION: Relative Quotas: Correct Answer to Uncertainty or Case of Regulatory Capture?

KNOW 34.2003 Giuseppe MEDA, Claudio PIGA and Donald SIEGEL: On the Relationship between R&D and Productivity: A Treatment Effect Analysis

ETA 35.2003 Alessandra DEL BOCA, Marzio GALEOTTI and Paola ROTA: Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation
GG 36.2003 Matthieu GLACHANT: Voluntary Agreements under Endogenous Legislative Threats
PRIV 37.2003 Narjess BOUBAKRI, Jean-Claude COSSET and Omrane GUEDHAMI: Postprivatization Corporate Governance: the role of Ownership Structure and Investor Protection
CLIM 38.2003 Rolf GOLOMBEK and Michael HOEL: Climate Policy under Technology Spillovers
KNOW 39.2003 Slim BEN YOUSSEF: Transboundary Pollution, R&D Spillovers and International Trade
CTN 40.2003 Carlo CARRARO and Carmen MARCHIORI:
KNOW 42.2003 Timo GOESCHL and Timothy SWANSON: On Biology and Technology: The Economics of Managing Biotechnologies
CLIM 44.2003 Katrin MILLOCK and Céline NAUGES: The French Tax on Air Pollution: Some Preliminary Results on its Effectiveness
PRIV 45.2003 Bernardo BORTOLOTTI and Paolo PINOTTI: The Political Economy of Privatization
SIEV 46.2003 Elbert DJUKGRAAF and Herman R.J. VOLLEBERGH: Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods
ETA 47.2003 Jens HORBACH: Employment and Innovations in the Environmental Sector: Determinants and Econometrical Results for Germany
CLIM 48.2003 Lori SNYDER, Nolan MILLER and Robert STAVINS: The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing
CTN 50.2003 László A. KOCZY and Luc LAUWERS (lxii): The Minimal Dominant Set is a Non-Empty Core-Extension
CTN 51.2003 Matthew O. JACKSON (lxii): Allocation Rules for Network Games
CTN 52.2003 Ana MAULEON and Vincent VANNETELBOSCH (lxii): Farsightedness and Cautiousness in Coalition Formation
CTN 54.2003 Matthew HAAG and Roger LAGUNOFF (lxii): On the Size and Structure of Group Cooperation
CTN 55.2003 Taiji FURUSAWA and Hideo KONISHI (lxii): Free Trade Networks
CTN 56.2003 Halis Murat YILDIZ (lxii): National Versus International Mergers and Trade Liberalization
CTN 57.2003 Santiago RUBIO and Alistair ULPH (lxii): An Infinite-Horizon Model of Dynamic Membership of International Environmental Agreements
KNOW 58.2003 Carole MAIGNAN, Dino PINELLI and Gianmarco I.P. OTTAVIANO: ICT, Clusters and Regional Cohesion: A Summary of Theoretical and Empirical Research
KNOW 59.2003 Giorgio BELLETTINI and Gianmarco I.P. OTTAVIANO: Special Interests and Technological Change
ETA 60.2003 Ronnie SCHÖB: The Double Dividend Hypothesis of Environmental Taxes: A Survey
CLIM 61.2003 Michael FINUS, Ekko van IERLAND and Robert DELLINK: Stability of Climate Coalitions in a Cartel Formation Game
SIEV 63.2003 Alberto PETRUCCI: Taxing Land Rent in an Open Economy
CLIM 64.2003 Joseph E. ALDY, Scott BARRETT and Robert N. STAVINS: Thirteen Plus One: A Comparison of Global Climate Policy Architectures
SIEV 65.2003 Edi DEFRANCESCO: The Beginning of Organic Fish Farming in Italy
SIEV 66.2003 Klaus CONRAD: Price Competition and Product Differentiation when Consumers Care for the Environment
CLIM 68.2003 ZhongXiang ZHANG: Open Trade with the U.S. Without Compromising Canada’s Ability to Comply with its Kyoto Target
KNOW 69.2003 David FRANTZ (lxii): Lorenzo Market between Diversity and Mutation
KNOW 70.2003 Ercole SORI (lxii): Mapping Diversity in Social History
KNOW 71.2003 Ljiljana DERU SIMIC (lxii): What is Specific about Art/Cultural Projects?
KNOW 72.2003 Natalya V. TARANOVA (lxii): The Role of the City in Fostering Intergroup Communication in a Multicultural Environment: Saint-Petersburg’s Case
KNOW 73.2003 Kristine CRANE (lxii): The City as an Arena for the Expression of Multiple Identities in the Age of Globalisation and Migration
KNOW 74.2003 Kazuma MATOBA (lxii): Glocal Dialogue- Transformation through Transcultural Communication
KNOW 75.2003 Catarina REIS OLIVEIRA (lxii): Immigrants’ Entrepreneurial Opportunities: The Case of the Chinese in Portugal
KNOW 76.2003 Sandra WALLMAN (lxii): The Diversity of Diversity - towards a typology of urban systems
<table>
<thead>
<tr>
<th>Journal</th>
<th>Volume</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOW</td>
<td>77.2003</td>
<td>Richard PEARCE (lxii): A Biologist’s View of Individual Cultural Identity for the Study of Cities</td>
</tr>
<tr>
<td>KNOW</td>
<td>78.2003</td>
<td>Vincent MERK (lxii): Communication Across Cultures: from Cultural Awareness to Reconciliation of the Dilemmas</td>
</tr>
<tr>
<td>KNOW</td>
<td>79.2003</td>
<td>Giorgio BELLETTINI, Carlotta BERTI CERONI and Gianmarco I.P. OTTAVIANO: Child Labor and Resistance to Change</td>
</tr>
<tr>
<td>ETA</td>
<td>80.2003</td>
<td>Michele MORETTO, Paolo M. PANTEGHINI and Carlo SCARPA: Investment Size and Firm’s Value under Profit Sharing Regulation</td>
</tr>
<tr>
<td>IEM</td>
<td>81.2003</td>
<td>Alessandro LANZA, Matteo MANERA and Massimo GIOVANNINI: Oil and Product Dynamics in International Petroleum Markets</td>
</tr>
<tr>
<td>CLIM</td>
<td>82.2003</td>
<td>Y. Hossein FARZIN and Jinhua ZHAO: Pollution Abatement Investment When Firms Lobby Against Environmental Regulation</td>
</tr>
<tr>
<td>CLIM</td>
<td>83.2003</td>
<td>Giuseppe DI VITA: Is the Discount Rate Relevant in Explaining the Environmental Kuznets Curve?</td>
</tr>
<tr>
<td>CLIM</td>
<td>84.2003</td>
<td>Reyer GERLAGH and Wietse LISE: Induced Technological Change Under Carbon Taxes</td>
</tr>
<tr>
<td>NRM</td>
<td>85.2003</td>
<td>Rinaldo BRAU, Alessandro LANZA and Francesco PIGLIARU: How Fast are the Tourism Countries Growing? The cross-country evidence</td>
</tr>
<tr>
<td>KNOW</td>
<td>86.2003</td>
<td>Elena BELLINI, Gianmarco I.P. OTTAVIANO and Dino PINELLI: The ICT Revolution: opportunities and risks for the Mezzogiorno</td>
</tr>
<tr>
<td>SIEV</td>
<td>87.2003</td>
<td>Lucas BRETSCGHER and Sjak SMULDERS: Sustainability and Substitution of Exhaustible Natural Resources. How resource prices affect long-term R&amp;D investments</td>
</tr>
<tr>
<td>CLIM</td>
<td>89.2003</td>
<td>Marzio GALEOTTI: Economic Development and Environmental Protection</td>
</tr>
<tr>
<td>CLIM</td>
<td>90.2003</td>
<td>Marzio GALEOTTI: Environment and Economic Growth: Is Technical Change the Key to Decoupling?</td>
</tr>
<tr>
<td>CLIM</td>
<td>91.2003</td>
<td>Marzio GALEOTTI and Barbara BUCHNER: Climate Policy and Economic Growth in Developing Countries</td>
</tr>
<tr>
<td>ETA</td>
<td>93.2003</td>
<td>Andrea BELTRATTI: Socially Responsible Investment in General Equilibrium</td>
</tr>
<tr>
<td>CTN</td>
<td>94.2003</td>
<td>Parkash CHANDER: The γ-Core and Coalition Formation</td>
</tr>
<tr>
<td>IEM</td>
<td>95.2003</td>
<td>Matteo MANERA and Angelo MARZULLO: Modelling the Load Curve of Aggregate Electricity Consumption Using Principal Components</td>
</tr>
</tbody>
</table>
### 2002 SERIES

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Title</th>
<th>Editor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIM</td>
<td>Climate Change Modelling and Policy</td>
<td>Marzio Galeotti</td>
</tr>
<tr>
<td>VOL</td>
<td>Voluntary and International Agreements</td>
<td>Carlo Carraro</td>
</tr>
<tr>
<td>SUST</td>
<td>Sustainability Indicators and Environmental Valuation</td>
<td>Carlo Carraro</td>
</tr>
<tr>
<td>NRM</td>
<td>Natural Resources Management</td>
<td>Carlo Giupponi</td>
</tr>
<tr>
<td>KNOW</td>
<td>Knowledge, Technology, Human Capital</td>
<td>Dino Pinelli</td>
</tr>
<tr>
<td>MGMT</td>
<td>Corporate Sustainable Management</td>
<td>Andrea Marsanich</td>
</tr>
<tr>
<td>PRIV</td>
<td>Privatisation, Regulation, Antitrust</td>
<td>Bernardo Bortolotti</td>
</tr>
<tr>
<td>ETA</td>
<td>Economic Theory and Applications</td>
<td>Carlo Carraro</td>
</tr>
</tbody>
</table>

### 2003 SERIES

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Title</th>
<th>Editor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIM</td>
<td>Climate Change Modelling and Policy</td>
<td>Marzio Galeotti</td>
</tr>
<tr>
<td>GG</td>
<td>Global Governance</td>
<td>Carlo Carraro</td>
</tr>
<tr>
<td>SIEV</td>
<td>Sustainability Indicators and Environmental Valuation</td>
<td>Anna Alberini</td>
</tr>
<tr>
<td>NRM</td>
<td>Natural Resources Management</td>
<td>Carlo Giupponi</td>
</tr>
<tr>
<td>KNOW</td>
<td>Knowledge, Technology, Human Capital</td>
<td>Gianmarco Ottaviano</td>
</tr>
<tr>
<td>IEM</td>
<td>International Energy Markets</td>
<td>Anil Markandya</td>
</tr>
<tr>
<td>CSRM</td>
<td>Corporate Social Responsibility and Management</td>
<td>Sabina Ratti</td>
</tr>
<tr>
<td>PRIV</td>
<td>Privatisation, Regulation, Antitrust</td>
<td>Bernardo Bortolotti</td>
</tr>
<tr>
<td>ETA</td>
<td>Economic Theory and Applications</td>
<td>Carlo Carraro</td>
</tr>
<tr>
<td>CTN</td>
<td>Coalition Theory Network</td>
<td></td>
</tr>
</tbody>
</table>