Optimal Design for Hourly Electricity Price in the Italian Market. Preliminary results.

BY SIMONA BIGERNA AND CARLO ANDREA BOLLINO*

MAY 2014, PRELIMINARY NOT TO BE QUOTED

In this paper we derive optimal prices in the Italian day ahead electricity market using estimation of a complete system of hourly demand in 2010-2011. We use ex ante individual bids expressed by heterogeneous consumers, which are distinguished by geographical zone. This is a new result in the literature, as previous studies have used ex post market data. Using empirical estimation of heterogeneous consumer behavior we compute optimal prices according to different weighting schemes of a social welfare function: Ramsey, equivalence scales, expenditure marginal utility. Results show that optimal pricing can improve welfare with respect to both the existing uniform price scheme and the proposed zonal price scheme.

*Department of Economics, University of Perugia, 06123 Perugia, Italy (e-mail: carloandrea.bollino@unipg.it). Acknowledgments. We would like to thank Giovanni Battista Aruta of GME for helpful suggestions to access market data. We also thank Maria Chiara D’Errico for her valuable research assistance for data computation. All errors are ours.

JEL Category Selection: D11 D12 C10 H21 Q41

1. Introduction

Our research bridges the ongoing literature of theoretical and empirical analysis of deregulated electricity markets and the optimal price design regulatory literature.

The Italian 2004 deregulation of the electricity sector stated that market prices had to be determined in an auction market, named day-ahead market, by the equilibrium point given by the merit order of the supply generators bids and of the demand traders and industries bids. Zonal differences arise due to network congestion which determines differences in zonal prices. The specific feature of the Italian market is that the legislator has established in the day-ahead market a Unique System Marginal Price (USMP) on the demand side, computed by averaging zonal supply prices. Thus, the actual regulation assumes that consumers are sheltered completely from local congestion issues. This decision was based on the fact that at the beginning of the deregulation, the localization of generation plants had been decided by the former national monopolist according to its own objective function. Thus, because Northern regions were abundant of low cost hydro while Southern regions were abundant of high cost thermal plants, it would have been fair to charge different prices to consumers who had no responsibility in generation localization.

Recently, there has been a debate to introduce zonal prices on the demand side, too. Contrary to the existing regulation, advocates of zonal pricing think that consumers should fully bear congestion costs, so that they have an incentive to support new network development. They also think that this will discourage opportunistic opposition to new plants and transmission lines, i.e discourage NIMBY-type (not-in-my-back-yard) opposition to new developments. In reality, given the shape of the country (long and narrow from North to South) the Italian electric network has some structural peculiarities. The network is not heavily meshed. Imports from neighboring northern countries (France, Swizerland, Austria, Slovenia) are structurally around 15% of total Italian consumption. There are structural bottlenecks across the Appennine Mountains, which are difficult to overcome. In addition, in the two main Islands – Sicily and Sardinia – electricity often flows in the export direction, as ruled by the System Operator for security reasons, in order to maintain adequate spinning reserve within each Island. So zonal prices in the Islands, as well as in other zones, may be higher for reasons of security and not necessarily because residents express a NIMBY-type opposition to new infrastructural developments. While the debate in Italy is abundant on these issues, there is lack of analysis of zonal differences in the demand structure. It should be rather obvious that differences in demand behavior across zones should be the basis to allocate system externality costs, such as congestion costs. We attempt to fill this gap and we study zonal demand structure in Italy assuming a theoretical model of hourly electricity consumption.

The main aim of our research is to assess the welfare implications of USMP and of zonal prices in the electricity market. In order to perform such evaluation we perform a calculation of optimal prices according to optimal pricing theory with the objective to maximize social welfare. Then we compare actual prices and zonal prices to optimal prices, in order to assess whether adoption of zonal prices goes in the direction of optimality.

To our knowledge, this is the first attempt in the literature to analyze optimal prices in the day-ahead electricity market and so we attempt to bridge the literature of theoretical and empirical analysis of deregulated electricity markets and the literature on optimal price design.

Specifically, we use IPEX data published by the Italian Market Operator ("Gestore mercato elettrico", GME) considering individual bids in order to construct demand schedules in the period 2010-2011.

This paper is organized as follows. Section 2 presents the theoretical framework of optimal taxation and the empirical methodology to estimate consumer behavior and describes the data set used. Section 3 presents the results. Section 4 discusses the empirical results. Section 5 presents policy implications and concludes the paper.

2. Optimal taxation and consumer behavior

We estimate demand elasticity, developing the model in Bigerna and Bollino (2014). We postulate that consumer behavior can be described with a two-stage cost function, for each consumer j, which consumes electricity in each hour h. In the first stage consumer chooses to allocate his budget between consumption during the day and during the night. This yields demand for two aggregate goods defined as "group demand": daily and nightly electricity demand. In the second stage consumer chooses within each group to consume hourly electricity during the day (hours 10:00 to 21:00) for many different economic usages and during the night (hours 22:00 to 9:00) for less differentiated needs. This yields demand for 24 elementary goods, defined as "elementary demand" for electricity (12 hourly demand function within each group).

The implicit cost functions for each consumer j (belonging to zone j) at each stage are of the form:

$$c_j = c_j (p, u_j) \tag{1}$$

In the first stage $p=(p_{ed}, p_{en})$ can be interpreted as the vector of aggregate daily and nightly prices and u_j as a measure of the utility derived by consumer j from total energy consumption. In the second stage, during the day $p=(p_{10},\ldots,p_{21})$ and $u_j=u_{jd}$ is the utility of daily consumption; during the night $p=(p_{22},\ldots,p_9)$ and $u_j= u_{jn}$ is the utility of nightly consumption.

We can invert the cost function (1) into indirect utility function:

$$V_j=V_j (p,E_j) \tag{2}$$

where p is price vector and E_j is total expenditure of consumer j. From indirect utility function, using Roy's Identity, we obtain Marshallian demand functions for each consumer j and each hour h:

$$e_{jh} =e_{jh}(p,E_j) \tag{3}$$

Notice that in eq. (2)-(3) it is understood that in the first stage suffix h denotes daily and nightly consumption and E_j denotes total expenditure; in the second stage suffix h denotes hourly consumption and E_j denotes total expenditure on aggregate daily and nightly consumption.

We assume that the policy maker has knowledge of individual demand functions and is willing to charge to consumers (or groups of consumers) optimal prices taking into account efficiency and equity objectives. We consider two main objectives for the policy maker.

As a starting point, the first objective is to maximize only hourly efficiency, so that the policy maker considers each hour independently and takes into account only differences in zonal elasticities. This entails to compute for each hour h optimal prices for all zones j according to the classic Ramsey (1927) formula:

$p^*_{ih}/p^*_{jh}= (1\text{-}1/|\varepsilon_{jh}|)/\ (1\text{-}1/|\varepsilon_{ih}|)$ subject to the constraint: $\sum p_{jh}e_{jh} = \sum p_{jh}{*}je_{jh}$ (4)

where $p^*_{ih,}$ p^*_{jh} are optimal prices, p_{jh} are historical prices e_{jh} are quantities, ε_{jh} are estimated own price elasticities[1] for each hour h and zones i and j.

The second objective is to consider explicitly consumer welfare, so that the policy maker considers explicitly the problem of aggregating individual behaviors of J individuals in a social welfare function:

$W = W\ (V_1,\ V_{2,}\ldots,V_J)$ (5)

where $\partial W/\partial Vj>0$. The policy maker constraint is to obtain the same amount of revenue G from market equilibrium outcome, adopting an optimal charging rule t_h (this is the optimal charge to be added the uniform price USMP which can be positive or negative, given the constraint G) in each hour such that:

$G= \Sigma_h\ t_h\ \Sigma_j\ e_{jh}(p,E_j)$ (6)

Notice the crucial feature that revenue G is derived charging t_h to each consumer j according to his/her consumption behavior. In this case we can interpret price in each hour as the USMP plus the optimal charge t_h:

$p_h=p_{usmph} + t_h$ (7)

so that standard maximization problem yields a Lagrange function:

[1] Given the two stage structure of the demand system, we need to use unconditional elasticities for each hour in eq. (4), which depend on both aggregate and hourly behavior. Detailed description of the relation between conditional and unconditional elasticities under weak separability in two stage demand systems can be found in Bigerna and Bollino (2014) and Edgerton (1997).

$$L = W(V_1, V_{2,\ldots,}V_J) + \lambda\, [\, G - \Sigma_h\, t_h\, \Sigma_j\, e_{jh}(p,E_j)\,] \qquad (8)$$

where the first order conditions are:

$$\Sigma_j\, \partial W/\partial Vj \quad \partial Vj/\partial t_h = \lambda\, [\Sigma_j\, e_{jh\, +}\, \Sigma_h\, t_h\, \Sigma_j\, \partial e_{jh}/\partial t_h] \qquad (9a)$$

$$G= \Sigma_h\, t_h\, \Sigma_j\, e_{jh}(p,E_j) \qquad (9b)$$

The first order conditions (9a)-(9b) can be solved to derive the optimal structure of charges t_h. Notice that using the representative consumer hypothesis is equivalent to the standard Ramsey (1927) rule. i.e. charges are inversely proportional to demand elasticity. In this case there is not consideration for distributive equity, but only for efficiency, so that charges are higher for inelastic goods with respect to more elastic goods. Alternatively, we can consider an optimal structure of welfare distribution, by considering consumers relative conditions. These latter can be evaluated in terms of true cost of living, using equivalence scales (Muellbauer, 1974) or in terms of expenditure marginal utility (Diamond, 1975); in this case, a charge structure has to take into consideration expenditure marginal utility, so that charges will be lower for those goods consumed proportionately more by consumers who exhibit lower expenditure marginal utility.

We avoid the philosophical question of impossibility of interpersonal comparability and of measurement of individual preferences. We define an additive social welfare function, following the classic literature on money metric utility function (Muellbauer 1974) using parametric functions for measuring, via duality, the true cost of living (Jorgenson and Slesnick 1984). Specifically, we assume a parametric social welfare function using (2) and (3):

$$W = \Sigma_j \;\; w_j(p,a_j)V_j(p,E_j) \qquad (10)$$

where we specify three alternative structures of weights w_j:

$$w_j = 1 / J \qquad (11a)$$

$$w_j = [E_j(p,a_j) / E_j^*] \;\; / \Sigma_j \;\; [E_j(p,a_j) / E_j^*] \qquad (11b)$$

$$w_j = \partial V_j/\partial E_j \;\; / \Sigma_j\, \partial V_j/\partial E_j \qquad (11c)$$

The structure of weights (11a) assumes that consumers have equal importance for the social welfare. Weights (11b) use equivalence scales, where the term $E_j(p,a_j)/E_j^*$ defines the necessary expenditure for consumer j to achieve the same welfare level of reference consumer. Weights (11c) take into account the expenditure marginal utility, considering more heavily those consumers who exhibit higher evaluation of expenditure increase.

To empirically estimate the demand system we use individual bid data published by Italian Market operator (GME) from January 2010 to September 2011 (about 1 million records per month). Some aggregate statistic are reported in Table 1. We construct aggregate demand quantity and price for 6 geographical zones. There are three domestic areas and three border countries: North, Center-South, Islands, France, Switzerland, Greece. We have considered the neighboring foreign countries because Italy imports about 14% of total electricity consumption.

We obtain about 537 thousand observations per year, which are used to estimate demand systems for hourly electricity. We assume that consumer behavior is differentiated by zone, so that we have six heterogeneous aggregations of consumer behavior. We use as parametric function the Generalized Almost Ideal demand system (Bollino, Economics Letters, 1987), which satisfies consumer theory restrictions, i.e., adding up, symmetry, homogeneity and heterogeneous consumer exact aggregation constraints. The typical functional form at both stages for demand functions is:

$$e_{jh}= \gamma_{jh} + c^*/p_{eh} \left[\alpha_{jh} + \sum\alpha_{jhk} \ln(p_{ek}) + \beta_{jh} \ln(E^*/p^*)\right]; \quad E^* = E-(\sum\gamma_{jh}\, p_{eh}); \quad p^* = \sum w_h \ln(p_{eh}) \qquad (12)$$

In eq. (12) suffix j denotes zone; suffix h denotes hourly demand (group demand at the first stage and elementary demand at the second stage); γ_{jh} are committed quantity parameters, α_{jh}, α_{jhk}, β_{jh} are structural coefficients, w_h are average budget shares, E^* is supernumerary expenditure and p^* is price aggregator (Stone index).

3. Results

We estimate demand functions given in eq. (12) at both stages with seemingly unrelated regression (SUR) method using TSP program and we derive unconditional elasticities for each quarter and each zone in the period 2010-2011. Observations used for estimation are in 2010: 4292 in Q1, 4000 in Q2, 3500 in Q3 4000 in Q4; in 2011: 4000 in Q1, 5000 in Q2 4000 in Q3. For each quarter, we estimate in each equation of the SUR system 316 coefficients to be estimated at the first stage and 316 coefficients at the second stage, for a total of 3792 estimated parameters[2].

Empirical estimations are plausible and quite accurate, with R squared in the .986 - .999 range for all equations and very high proportion of coefficient significance. Specifically, at 1% confidence level about 99% of estimated coefficients are significant; most of the remaining non significant coefficients are intercept terms $\gamma_{jh.}$ Thus, we obtain quite high precision estimation of price response parameters, which we use to estimate demand elasticities.

Estimation shows that price elasticities are significantly different across zones and time of the year (elasticity range - .05 – -.14).

In addition, nightly hours appear to be necessity goods (elasticity range .5 – .8) and daily hours luxury goods (elasticity range 1.1 – 1.3) and daily hours are substitutes for nightly hours and some afternoon hours while they appear to be complements for morning daily hours.

Finally, zone estimation shows that price elasticities are relative higher for zones x x x (elasticity range -.05 – -.08) and lower for other zones (elasticity range -.03 – -.04). Expenditure elasticities confirm that electricity is a necessity goods during the night and luxury good during the day. These characteristics are more pronounced for zones x x x (elasticity range 1.4 – 1.9).

These results are important because the differences in estimated elasticities by zones and hours motivate our analysis of optimal prices taking into account distributive equity assumptions about the weights of the social welfare function. We compute optimal prices with two methods.

The first method considers each hour independently and takes into account only differences in zonal elasticities as in eq (4). The second method considers the whole demand system estimations simultaneously for all 24 hours, assuming the existence of six heterogeneous consumer groups

[2] In order to use a parsimonious specification, in empirical estimation we impose $\alpha_{jhk} = \alpha_{hk}$ for $h \neq k$.

(differentiated by zone). In this case, we consider different social welfare assumptions in order to find the structure of optimal charges given in eqs. (9a)-(9b).

We use the above results to maximize a social welfare function subject to the constraint that charge revenue in every day leaves unaltered the aggregate market equilibrium outcome. We postulate that policy-maker wants to optimally allocate congestion costs on hourly prices using the three assumptions embodied in eqs. (11a)-(11c): (i) Ramsey pricing without equity considerations across zones; (ii) welfare weights equal for each zone; (iii) welfare weights proportional to estimated expenditure marginal utility in each zone. This involves the solution of a systems of 25 equations for the 25 unknowns (t_h, λ).

4. Discussion

We report the results of the maximization of the social welfare function subject to the constraint that charge revenue in every day is given by market equilibrium outcome in table 1.

We consider the two stages and we report results for the first stage, i.e. aggregate consumption in the upper part of the table. We report results for the second stage, i.e. 24 hours, in the lower part.

In column 1 we report the historical average zonal prices, while in columns 2-4 we report the optimal prices (inclusive of the optimal charges) for the three alternative weights structure.

Notice, when weights are uniform that prices for those hours which are more elastic become lower than zonal prices. These reductions are compensated by price increase in the order o f 10% and more in peak hours.

The optimal price range changes with uniform weights is not higher than 20% with respect to zonal prices.

Using equivalence scale weights, the changes are bigger in magnitudes both upward and downward, with respect to zonal prices.

Using expenditure marginal utility weights, we obtain a pronounced changes in hourly prices.

In general, our preliminary results show that under (i) optimal prices should be higher than USMP (by approximately 3 - 8%) when price elasticities are lower, namely in peak hours and Winter. Taking into account welfare effects, under (ii) and (iii), optimal prices should be lower than USMP (by approximately 2%) in nightly hours (necessity goods), but higher (by approximately 5%) for northern foreign demand (France and Switzerland).

5. Conclusion and Policy Implications

In conclusion our results show that than zonal prices are not optimal and that there are better solutions, suggesting to adopt appropriate price regulation to increase consumer welfare.

The relevant policy implication is that reforming pricing in the electricity market by charging zonal prices to consumers is not optimal in the sense of welfare maximization.

This is so because line congestion causes price differentials, which are not necessarily induced by consumer behavior. In this sense, we think that line congestion has to be considered as a public good which generates exeternalities to the whole electric system.

Thus, the optimal solution is not zonal pricing. This latter scheme would be akin to the idea of letting consumers living in the plains to have access to low cost wheat produced in the more fertile fields and forcing consumers living in the hillside to consume high cost wheat produced in the high cost fields. Centralized dairy produce markets show the way.

In conclusion, we advocate a market reform with demand prices, which are differentiated according to the demand elasticity structure.

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TABLE 1 — MARKET PRICES, QUANTITIES AND ZONAL AVERAGE PRICES* - YEARS 2010-2011 EURO/MWH AND MWH

Years	2010				2011			
	Equilibrium Market price and quantity							
	PRICE			QUANTITY	PRICE			QUANTITY
	MIN	AVERAGE	MAX		MIN	AVERAGE	MAX	
ALL HOURS	10.0	66.5	174.6	26438	10.0	71.1	164.8	25958
PEAK HOURS	71.5	84.2	174.6	41104	75.9	86.5	142.9	40263

Zonal average prices

ZONES	2010	2011
Northern Italy	61.95	70.15
Central-Northern Italy	62.43	71.13
Central-Southern Italy	62.56	70.82
Southern Italy	58.97	68.99
Sicilia	89.77	93.01
Sardegna	73.51	79.86
Annual Average Price	68.19	75.66

* Upper part of the table – Equilibrium market prices minimum, average and maximum values and equilibrium market quantity in the year. All hours refers to all 24 hours of the day; peak hours refers to 11:00-15:00 business days hours only. Lower part of the table – Zonal average electricity equilibrium prices – euro/MWh

TABLE 2 – OPTIMAL AND ACTUAL HOURLY PRICES BY ZONE – RAMSEY SCHEME* - YEAR 2010

ZONES	*1*	*2*	*3*	*4*	*5*	*6*	*1*	*2*	*3*	*4*	*5*	*6*
	AGGREGATE GROUP OPTIMAL ZONAL PRICES						AGGREGATE GROUP ACTUAL ZONAL PRICES					
DAILY	66	75	71	90	85	76	65	70	75	95	78	75
NIGHTLY	53	53	43	49	48	44	56	66	45	47	47	48
	HOURLY ELEMENTARY OPTIMAL ZONAL PRICES						HOURLY ELEMENTARY ACTUAL ZONAL PRICES					
1	45	45	45	55	55	56	44	44	44	44	44	45
2												
3												
4												
5												
6												
7												
8												
9												
10												
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16												
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18												
19												
20												
21												
22												
23												
24	47	66	66	66	45	45	55	55	55	55	55	55

* Optimal prices computed according to eq. (11). Zones are: 1=North; 2= Center and South; 3= Islands; 4= France; 5= Switzerland ecc; 6=Greece. Upper part of the table: average annual prices in the first stage- daily: 10:00-21:00; nightly :22:00-9:00. Lower part of the table: average annual values for hourly prices in the second stage.

TABLE 3 – OPTIMAL AND ACTUAL HOURLY PRICES BY ZONE – RAMSEY SCHEME* - YEAR 2011

ZONES	*1*	*2*	*3*	*4*	*5*	*6*	*1*	*2*	*3*	*4*	*5*	*6*
	AGGREGATE GROUP OPTIMAL ZONAL PRICES						AGGREGATE GROUP ACTUAL ZONAL PRICES					
DAILY	72	89	81	96	90	72	75	80	85	99	86	79
NIGHTLY	56	56	45	47	47	48	56	66	45	47	47	48
	HOURLY ELEMENTARY OPTIMAL ZONAL PRICES						HOURLY ELEMENTARY ACTUAL ZONAL PRICES					
1	45	45	45	55	55	56	44	44	44	44	44	45
2												
3												
4												
5												
6												
7												
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21												
22												
23												
24	47	66	66	66	45	45	55	55	55	55	55	55

* Optimal prices computed according to eq. (11). Zones are: 1=North; 2= Center and South; 3= Islands; 4= France; 5= Switzerland ecc; 6=Greece. Upper part of the table: average annual prices in the first stage- daily: 10:00-21:00; nightly :22:00-9:00. Lower part of the table: average annual values for hourly prices in the second stage.

TABLE 4 – OPTIMAL HOURLY PRICES – SOCIAL WELFARE FUNCTION* - YEAR 2010

SCHEME	*ACT*	*A*	*B*	*C*	*ACT*	*A*	*B*	*C*
	YEAR 2010				YEAR 2011			
	AGGREGATE GROUP DEMAND PRICES							
DAILY	84	88	90	86	87	90	95	88
NIGHTLY	52	48	45	47	49	43	45	47
	HOURLY ELEMENTARY DEMAND PRICES							
1	45	45	45	55	44	44	44	44
2								
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24	47	66	66	66	55	55	55	55

*ACT= actual prices. Optimal prices computed according to weights defined in eqs. (9a)-(9c). A=Ramsey weights; B=Equivalence scales weights; C=expenditure marginal utility weights. Upper part of the table: average annual values for prices in the first stage- daily: 10:00-21:00; nightly :22:00-9:00. Lower part of the table: average annual values for hourly prices in the second stage.