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AN EXPERIMENTAL ANALYSIS OF PRICE FORMATION ON THE POLISH POWER EXCHANGE

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Abstract

The Polish energy market gained its competitive character in late 1990s. At that time in majority of European countries a new law was enacted (in Poland – in 1987), which enabled the creation of internal energy markets. The Polish Power Exchange has been functioning since the end of 1999. However, from the very onset it has constituted a vital component of under grounding liberalization of electricity market. Since it was created the Polish Power Exchange has served as a market mechanism for setting objective energy market price. Support and control of the Polish Financial Supervision Authority guarantee the security of concluded transactions. The spot energy market was created as the first one and has functioned according to the rule of the double auction. The model of Sadrieh will be used for the description of the auction rules applied to the spot energy trade on the Polish Power Exchange. Furthermore, an algorithm on the basis of which it is possible to forecast transaction prices is presented. The effectiveness of this algorithm will be compared with other traditional methods of forecasting transaction prices.

Keywords: double auction, to forecast transaction price, energy market, stochastic algorithm

JEL classification: D44, C87

Introduction

The Polish energy market gained its competitive character in late 1990s. At that time in majority of European countries a new law was enacted (in Poland – in 1987), which enabled the creation of internal energy markets. The Polish Power Exchange has been functioning since the end of 1999. However, from the very onset it has constituted a vital component of under grounding liberalization of electricity market. Since it was created the Polish Power Exchange has served as a market mechanism for setting objective energy market price. Support and control of the Polish Financial Supervision Authority guarantee the security of concluded transactions.

Auctions play a pivotal role in the theory of exchange. In many markets, auctions are used to conduct a huge volume of economic transactions. Rule of auctions are applied to the sale of treasury bills, foreign exchange, mineral rights, and other assets such as firms to be privatized. Houses, used cars, agricultural products such as livestock, arts and antiques are commonly sold by auctions.

The energy market was created as the first one and has functioned according to the rule of the double auction and sometimes of share auction. Double auction are a form of money and goods exchange, during which the bids are made by purchases as well as by sellers. Besides the price, each bid discloses the amount of ware which is to be purchased by contracting parties. The rules of the double auctions, as well as of other auction types, are comparable to the rules of a game. The double auction is one of the most common exchange institution, used extensively in stock markets, commodity markets an in markets for financial instruments, including options and futures.

Searches and simulation experiments pertaining to the functioning of the double auctions have been conducted on a wide scale. They were initiated in 60s in twenties centuries by the Vernon L. Smith. Many authors such as: Wilson (1987), Friedman (1991), Gode and Sunder (1993), Gjerstad and Dickhaut (1998), Sadrieh (1998) attempted to construe models of behavior of double auction participants. Although these models have furthered understanding of the interaction of individual behavior and institution in the double auction. The model of Sadrieh will be used for description of the auction rules applied to the spot energy trade on the Polish Power Exchange. Furthermore, an algorithm on the basis of which it is possible to forecast transaction prices is presented. The effectiveness of this algorithm will be compared with other traditional methods of forecasting transaction prices.

Double auction markets are very important institution. They establish a single set of rules that organize the interaction of large number of individual traders. In spite of the diversity of choice and the complexity of interaction, the markets bring an efficient allocation.

In a static double auction, both the sellers and the buyers supply and demand schedules. A price is then selected that equates supply and demand at the price. If the pricing is nondiscriminating, then all traders are consummated at the selected clearing price. This procedure is sometimes called a demand- submission game. Often static double auctions relying on sealed bids and offers, are employed frequently in security markets. They are used to determine the opening price in stock exchanges and market for precious metals. Static double auctions are also used for trading on the major exchanges for financial instruments focused on using period (e.g. hourly) double auction to accomplish market clearing.

Dynamic double auction, in which buyers and sellers have repeated opportunities to submit or accept bids and offers, are commonly used in commodity market and some financial markets. In most organized exchanges, markets for storable commodities, industrial metals are applied the rule of dynamic versions of double auctions. Labor market involves interesting various of double auctions to match workers with positions in firms, students with opening at schools, etc. This version differs in that each buyer and seller offers an item with unique quality attributes by each partly on the other side of market (Sadrieh, 1998).

In a share auction there is an object of which shares are to be sold to several of the bidders. Each bidder submits a sealed tender specifying a schedule of price bid for varying fractional shares of the object. He also receives the number of shares he request at the price and for these he pays the sale per share. In other words, if supply offered by seller is divisible then the rules of auction allow that each bidder submits schedule indicating the quantity demanded at each price.

Our aim is to present a certain stochastic algorithm for forecasting price of transaction in double auction and to test it for the data from Polish Power Exchange. The paper is organized as follows: first – in chapter 1, we present the rules of trading energy and other derivatives on Polish Power Exchange. Our stochastic algorithm of calculation of theoretical price transaction for the double auctions is presented in chapter 2. In chapter 3 we tested it for the data from the Polish Power Exchange.

1. The rules of trading energy and other derivatives on Polish Power Exchange

1.1. Some information of the Polish Power Exchange (POLPX)

The POLPX commodity markets provide trading platform for major power industry players. The adventure of the electrical power sector with competition began at the end of nineties. Within six months from launch of the POLPX, the electrical power spot market was in place and running. Prices from this market became a benchmark for bilateral contacts. In 2003, as the first and so far only power exchange, POLPX has obtained a license from the Securities and Stock Exchange Commission for operation of a commodity market. In 2005 the exchange was appointed to establish and manage a register of certificates of origin for the electrical power generated for renewable sources. In 2008, POLPX has launched an Electrical Power Derivatives Market. In December 2012 POLPX has admitted forward contracts to trading on the Commodity Forward Instruments Market with physical delivery. POLPX is a continuously evolving power exchange. It offered the members of the exchange market a new brokerage application – CONOICO Trade, developed by NASDAQ OMX.

1.2. The some rule of trading on POLPX

The POLPX commodity markets provide a trading platform for major power industry players. The player can trade:

– electricity,
– liquid and gaseous fuels,
– production limits, specifically for electricity generation,
– emission allowances,
– property rights arising the certificates, financial instruments, energy efficiency certificates.

A trader can say that this is the place, where individuals and companies meet on a regular basis and on specific dates, to conclude "buy" or "sell transactions of a commodity, such for example electrical power. The key areas of POLPX operations are:

– Day Ahead Market (DAM),
– Intraday Market (IDM),
– Day Ahead Market gas (DAMg),
– Property Rights Market,
– CO_2 Emission Allowance Market (EAM).

A transaction represents a sales agreement entered into between exchange members. The exchange member shall be responsible for the accuracy if its orders. Each order shall specify in particular:

- designation of commodity being the object of the order,
- type of order (buy/sell),
- price limit for the commodity or instruction for excution of the order without price limit,
- number of trading units of commodity being the object of sell or buy,
- validity term,
- condition for the execution of the order,
- date and hour if order issuance.

Sell orders placed with a price limit below the price of the trading unit shall be executed in full, buy orders placed with the price limit above, the price shall be executed in full. Buy and sell orders placed with a place limit equal to the price of trading unit may be executed *n* part, in full or not executed at all. The transaction price shall be established on the basis of the ordered placed with most favorable buy and sell price limit that allows the transaction to be formed. The transactions shall be formed with the following principles. First, orders with the highest price limit in case of buy, and with the lowest price limit in case of sell shall be executed. Orders without a price limit shall be executed at the moment of the acceptance.

The traders can propose date of auction, type of auction, object and volume of auction. They must propose number of trading units of commodities, and offer price limit – the minimum price of case of sell or maximum price of a buy. Transactions shall be formed at the moment of matching a buy and a sell order in accordance with the principles set forth in these rules. If the price is lower, in case of sell, or higher, in case of a buy, the auction remains unresolved – no transactions. Immediately after the closing of the market session, the Exchange shall publish the results on the website.

2. The double auction as the market game

In a double auction, any seller may at any time, during a specified trading period, submit an offer that is then observed simultaneously by all buyers and sellers. Similarly, any buyer may submit at bid that is observed by the other buyers and by the sellers. Buyers may accept a seller's offer at any time. Each seller has costs and each buyers has valuations induced for the trading period. If a seller's ask is acceptable to a buyer, then a transaction is completed when the buyer takes (accepts) the seller's ask. Similarly, a buyer's bid may be accepted by a seller. Allocation of units is by mutual consent between any buyer and seller.

Buyer receive a surplus equal to the difference between their redemption value and the purchase price negotiated with a seller, and sellers receive a surplus equal to the difference between purchase price paid by the buyer and their unit cost.

2.1. Model of double auction

We assume that the market is the institution used for trading units of homogenous and indivisible good. It contains a set of players I with n members, divided distinctly into two subsets: buyers I_B with n_B members and sellers I_s with n_s members, so that $I = I_B \cup I_S$, $I_B \cap I_S = \varphi$ and $n = n_B + n_S$ .We assume that the number of players remains constant. Without loss of generality we will always assume that v is ordered from the highest to lowest redemption value. Each buyer $i \in I_B$ is assigned q redemption values v_{ik} $i = (1, ..., n_B; k = 1, ..., q)$. Each v_{ik} specifies the gross marginal value of the k-th purchase of a unit. Each seller $j \in I_S$ $j = (n_B + 1, ..., n)$ is assigned h unit costs e_{jh} $(h = 1, ..., q)$. Each e_{jh} specifies the marginal cost of the h-th sale of unit. We will use the generic term player valuation w for any redemption value v_{ik} or e_{jh}. All player valuations are assumed non-negative integers from given range $[\underline{p}, \overline{p}]$. This range is known to all players, but the players valuations are considered to be private information of the players. They know only distribution of the valuations.

Each buyer i can submit a bid b_{ik}^t for buying the k-th unit at time t. Each seller j can submit a non-negative integer ask a_{jh}^t for selling the h-th unit at time t. Assuming the buyer i and seller j have made a contract at trading price p the surplus of i from buying the k-th unit is

$$g_{ik} = \mathrm{v}_{ik} - p.$$

The surplus of the j from selling the h-th unit is

$$g_{jh} = p - e_{jh} .$$

2.2. Trading Periods and Intuition of the double auction

Each seller has costs induced for the trading period, and each buyer has valuation induced. A buyer's valuation for a unit remains in effect through the trading period or until the buyer transacts that unit. If a seller ask is acceptable to a buyer, then transaction is completed when the buyer accepts the seller's ask. Similarly, a buyer's bid may be accepted by a seller.

Traders can submit their offers at any given moment, in any given sequence. Well-defined sequence of actions is installed by dividing the market period into offer cycles. Each offer cycle consists of exactly one bidding round, in which the buyers are active, and one asking round, in which the sellers are active. A market period begins with a random, equal probabilities draw that determines which market side will be the opening market side. After market period termination a new market period with the same or different player valuation can begin. The market period ends when a given number $z \in N$ of offer cycles have passed without any new offers submitted. If $z = 1$, for example, the market period will end after the first cycle in which, neither the opening market side, nor the second moving market side submit new offers. For values of $z > 1$ the market period ends, after the first adjacent z cycles in which neither market side submits new offers. Valid offers are restricted by no-loss, the no-crossing, and ask-bid spread reduction rules. The period will also end when none of traders is able to submit any further valid offers. Thus, the double auction, when combined with the mentioned rules, represents a finite game. Each player, who had submitted an offer, is informed whether the offer was rejected or placed on the market, after the bidding or asking round. Valid offers must satisfy three conditions (Sadrieh, 1998).

No-loss. An offer is only valid, if it guarantees a non-negative payoff, in case it is accepted: a buyer's bid for purchasing the *k*-th unit must be smaller or equal to the buyer's *k*-th redemption value and a seller's ask for the sale of the *h*-th unit must be greater or equal to the seller's *h*-th unit cost. This condition is always binding.

1. No-crossing. An offer is only valid, if it guarantees a potential payoff greater or equal to the payoff that is achievable by accepting the other side's offer standing on the market: a buyer bid must be smaller or equal to the ask currently standing on the market and a seller's ask must be greater or equal to the bid currently standing on the market. This condition guarantees that the best bid is always smaller or equal to the best ask.
2. Ask-Bid-Spread –Reduction. An offer is only valid, if it reduces the ask-bid-spread on the market: a buyer's bid must be greater than the bid currently standing on the market and seller's ask must be smaller than the ask currently standing on the market.

These rules lead to the following conditions.

Let $\tilde{b}$ denote the bid and $\tilde{a}$ denote the ask currently standing on the market. The bid b_{ik} of the buyer *i* for *k*-th unit with the redemption value v_{ik} is valid under condition:

$$\text{If } \exists \ \tilde{a} \text{ and } \tilde{b} : \tilde{b} < b_{ik} \leq \min(\mathrm{v}_{ik}, \tilde{a}) \quad (i = 1, \ldots, n_B),$$

otherwise $\underline{p} - 1 < b_{ik} \leq \mathrm{v}_{ik}$.

The ask a_{jh} of the seller j for the h-th unit with the unit cost e_{jh} is valid under condition:

$$\text{If } \exists \ \tilde{a} \text{ and } \tilde{b}: \ \max(e_{jh}, \tilde{b}) \le a_{jh} < \tilde{a} \quad j = (n_B + 1, ..., n),$$

otherwise $e_{jh} \le a_{jh} < \overline{p} + 1$.

2.3. An algorithm of fixing the transaction price and empirical analysis

More formally, the time of trade is divided by the cycles. The time of one cycle is a random number. The traders submit their offers connected with an object l (l = 1, ..., q) during one market period. There is no loss of generality in assuming that q=1, for that reason we omit index l. The buyer i submits bid $b(c_i, p_i)$ and the seller j submits ask $a(c_j, p_j)$, where c_i, c_j are the quantities of commodity, p_i, p_j are prices offered by the buyer i and the seller j, respectively. We assume that the offers are valid so they satisfy the following conditions: no-loss, no-crossing and ask-bid-spread-reduction.

We shall make two standing assumptions under further consideration.

A1. The prices p_i and p_j satisfy the following condition

$$\forall i \in I_B \quad \forall j \in I_S \quad p_i, p_j \in \left[\underline{p}, \overline{p} \right] \tag{1}$$

where $\underline{p}$ is the minimum price for the bid or the offer, $\overline{p}$ is the maximum price for the bid or the offer.

A2. The following condition is satisfied

$$\sum_{i=1}^{n_B} b(c_i, p_i) 1_{\{p_i \in [\underline{p}, \overline{p}]\}} \le \sum_{j=n_B+1}^{n} a(c_j, p_j) 1_{\{p_j \in [\underline{p}, \overline{p}]\}} \tag{2}$$

where

p_i, p_j – prices offered by the buyer i and the seller j, respectively,

$\underline{p}$, $\overline{p}$ – the minimum and the maximum prices, which are accepted,

n – a number of players (buyers and sellers),

n_B – a number of buyers,

$1_{\{\}}$ – an indicator of event,

$b(c_i, \mathrm{p}_i)$ – a bid,

$a(c_i, \mathrm{p}_i)$ – an ask.

We are going to present an algorithm of fixing the transaction price p*.

The algorithm

We check whether the conditions (1) and (2) are satisfied. Otherwise the transaction does not come into effect.

We choose the minimal and the maximal quantity of commodities which players are going to sell or buy: $c_{\min} = \min_{i \in I} \{c_i\}$, $c_{\max} = \max_{i \in I} \{c_i\}$.

We fix a rectangle $D \subset \Re^2$, whose points are:

$$(c_{\min}, \underline{p}),\ (c_{\min}, \overline{p}),\ (c_{\max}, \underline{p}),\ (c_{\max}, \overline{p}),$$

where [$\underline{p}$, $\overline{p}$] is a range of prices in which all price offers are submitted.

By means of a number generator we fix not only the random amount of points $M_0 (M_0 \le 10000)$ but also the number of iterations k ($k \le 100$). All fixed points belonging to the rectangle D have following coordinates: $d_m(c_m, p_m) \in D$ (m = 1, ..., M_0).

Firstly we assume that n: = 1. We determine ”range of attraction” for all points d_m $(m = 1, ..., M_{n-1})$

$$U(d_m, \varepsilon_n) = \sqrt{(\overline{p} - \underline{p})^2 + (c_{\max} - c_{\min})^2} \times \left[\frac{5}{6} - \frac{1}{3} \sum_{i=1}^{n} \left(\frac{1}{i} \right)^{(1+\alpha)} \right] \tag{3}$$

where $\alpha \in [0,5; 1]$.

The point d_m will be taken into further consideration if there are some offers b_i and a_j in a ”range of attraction”, i.e.

$$\begin{aligned} &\exists_{i \in I_B} \quad b_i \in U(d_m, \varepsilon_n) \quad (i = 1, ..., n_B) \\ &\exists_{j \in I_S} \quad a_j \in U(d_m, \varepsilon_n) \quad (j = n_B + 1, ..., n) \end{aligned} \tag{4}$$

We calculate the number of points M_n satisfying the condition (3) and reject the remaining points.

Let us focus on the next iteration n: = n + 1. The points $d_m(c_m, p_m)$ (m = 1, ..., M_{n-1}) surround the set $U(d_m, \varepsilon_n)$ take a look at point 4a.

We repeat 4b until M_n = 0. If $0 < M_n < k$, we repeat it k times.

If M_n =1 ($n < k$) the wanted point is: $d_{M_n}(c_{M_n}, p_{M_n})$. In this situation the transaction price is $p^* = p_{M_n}$.

If $M_n > 1$ and we did the k iterations, we choose a point (from M_n remaining points), that had the largest number of offers (bids and asks) in the first ”range of attraction”.

The transaction price will be the second coordinate of the point $d_{m_0}(c_{m_0}, p_{m_0})$: $p^* = p_{m_0}$.

We are going to test the above algorithm for the data from the POLPX.

3. The experimental results

Let $\tilde{p} \in [p_{\min} - 0.5(p_{\max} - p_{\min}), p_{\max} + 0.5(p_{\max} - p_{\min})]$ be a theoretical price calculated by a random number generator and $\hat{p}$ be a theoretical price calculated by an algorithm. Let pairs of errors $(\hat{\varepsilon}_1, \tilde{\varepsilon}_1)$, $(\hat{\varepsilon}_2, \tilde{\varepsilon}_2)$, ..., $(\hat{\varepsilon}_t, \tilde{\varepsilon}_t)$ be i.i..d. pairs, such that

$$\hat{\varepsilon} = \frac{|\hat{p}_i - p_i|}{p_i}, \qquad \tilde{\varepsilon} = \frac{|\tilde{p}_i - p_i|}{p_i},$$

where:

$\hat{p}_i$ – the forecasting price,

$\tilde{p}_i$ – is the price which was generated by a random number generator,

p_i – the real price.

We must compare the forecasting procedure $\hat{p}$ (an algorithm) with $\tilde{p}$ (random number generator). For that, we formulate four hypotheses:

$H_0 : P(\hat{\varepsilon}_t > \tilde{\varepsilon}_t) = P(\hat{\varepsilon}_t < \tilde{\varepsilon}_t) = 0.5$, i.e. the average error for procedure $\hat{p}$ is identical with $\tilde{p}$.

$H_1 : P(\hat{\varepsilon}_t > \tilde{\varepsilon}_t) \neq P(\hat{\varepsilon}_t < \tilde{\varepsilon}_t)$, i.e. the average error differs in two procedures $\hat{p}$ and $\tilde{p}$.

$H_2 : P(\hat{\varepsilon}_t > \tilde{\varepsilon}_t) < 0.5$ – the procedure $\hat{p}$ is "better" than procedure $\tilde{p}$.

$H_3 : P(\hat{\varepsilon}_t > \tilde{\varepsilon}_t) > 0.5$ – the procedure $\tilde{p}$ $\hat{p}$ is "better" than procedure $\hat{p}$.

We use the Wicoxon rank sum test to verify the above hypotheses (Kohler, 1988).

The Wicoxon rank – sum test is a nonparametric test based on two independent simple random samples and is designed to determine whether two statistical populations are identical to or different from one another. The test uses a statistic symbolized *W*, that is derived by pooling the data contained in two independent samples (the size of which can be called n_1 and n_2), ranking the combined data from the smallest value to the largest, i.e.

W = rank sum of sample 1.

The null hypothesis of identical "populations" were not true, the value *W* would be very small or very large. The entire sampling distribution of W could be approximated by the normal curve: $N(\mu_W, \sigma_W) := N\left(\frac{1}{2}n_1 n_2, \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}\right)$. The normal deviate for Wilcoxon rank – sum test is

$$z_W = \frac{W - \mu_W}{\sigma_W},$$

if $n_1, n_2 \geq 10$.

Given a desired significance level of $\alpha = 0.05$. The critical normal deviate values is $\pm z_{\alpha/2} = \pm 1.96$. Thus, the decision rule must be either:

a) accept H_0 if $\mu_W - 1.96\sigma_W \le W \le \mu_W + 1.96\sigma_W$

or

b) accept H_0 if $-1.96 \le z_W \le 1.96$.

Table 1 shows the real and the forecasting price of transactions: p, $\tilde{p}$ $\hat{p}$. The table presents only certain (fulfilled) contacts in March 2015, i.e. Base_M, Base_Q, Peak_W, Peak_M. The remaining offers, i.e. for which the purchase price offered was significantly lowered than the sale price are ignored.

Table 1. The real and forecasting prices calculate by the algorithm and random number generator for the data (a chosen contracts) from POLPX – march 2015

Contact name	Settlement price PLN\ MWh P_i	Low price PLN\ MWh	High price PLN\ MWh	Theoretical price of transaction calculate by algorithm PLN\MWh $\hat{p}_i$	Theoretical price of transaction calculate by random number generator PLN\MWh $\tilde{p}_i$	$\hat{\varepsilon} = \frac{\lvert \hat{p}_i - p_i \rvert}{p_i}$ (%)	$\hat{\varepsilon} = \frac{\lvert \tilde{p}_i - p_i \rvert}{p_i}$ (%)
Base_M_04_15	159.05	158.00	160.00	159.00	158.25	0.03	0.63
Base_M_05_15	160.38	160.00	161.00	160.00	160.03	0.36	0.22
Base_M_6_15	164.00	164.00	164.00	164.00	164.00	0.00	0.00
Base_Q_3_15	172.23	172.00	172.51	172.30	172.53	0.57	0.18
Base_Q_4_15	171.65	171.50	171.85	171.67	171.83	0.01	0.11
Base_Q_5_15	165.13	164.75	165.50	165.20	165.60	0.04	0.25
Peak_5_W_14_15	171.97	171.00	172.90	171.80	170.10	0.1	1.10
Peak_5_W_16_15	202.00	201.00	203.00	201.70	203.40	0.15	0.70
Peak_5_M_4_15	200.41	199.20	201.00	200.90	199.00	0.25	0.06
Peak_5_Q_2_15	204.88	204.50	205.00	204.70	204.30	0.08	0.70
Peak_5_Q_4_15	221.95	221.75	222.00	221.90	222.10	0.02	0.07

Source: calculated by Author.

The statistic W is equal 34. We cannot accept H_0, because $z_{w_1} \notin [-1.96; 1.96]$. Average error for the algorithm is $\langle \hat{\varepsilon} \rangle = 0{,}15\%$, for the random method $\langle \tilde{\varepsilon} \rangle = 0.37\%$ where $\langle \cdot \rangle$ is symbol of average. In our case H_2 is true: $H_2 : P(\hat{\varepsilon}_t > \tilde{\varepsilon}_t) < 0.5$ – the procedure $\hat{p}$ is "better" than procedure $\tilde{p}$.

Conclusions

Auctions are an extremely old method of exchange, but the double auction is a rather new form of market. The double auction used in stock markets such as the New York Stock Exchange, commodity markets such as the Chicago Mercantile Exchange, and in markets for financial instruments, including options and futures (Dickhaut et al., 1998).

In this paper we have defined a selected stochastic algorithm on the basis of the double auction theory and we have tested it on the data of Polish Power Exchange, new market on the Polish Stock Exchange (GPW).

The algorithm introduced in the paper is based upon stochastic principles. Its irrefutable advantage resides in the fact the auction participants are not required to be acquainted with the bidding prices of a given good. The results presented in the works: (Drabik, 1999), (Drabik, 2010) as well as in this article confirm the applicability of the algorithm under study for the purposes of identifying a price of transaction.

In short, the algorithm may be constructed as a set of activities which subsequently lead to defining a “ range of attraction area” of a possibly smallest radius which includes the highest number of bids. The trade procedures of Polish Power Exchange are “similar” to the rules of a double auction (sometimes share auction), therefore the verification of an algorithm with the use of data from POLPX proved justifiable.

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