The Supply of Storage in Energy Futures Markets

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INTRODUCTION

The theory of storage, which postulates that the supply of storage is positively related to time basis, has enjoyed considerable success in explaining price spreads for storable commodities (see Working (1948), Brennan (1958), and Telser (1958)). Though not formally tested for energy futures contracts (i.e., crude oil, gasoline, and heating oil contracts), the theory of storage is widely accepted by participants of energy futures markets. Market participants, for example, interpret a large negative time basis (i.e., the futures price is significantly lower than the spot price) as a signal to draw energy products out of storage and a small negative basis or positive basis as a signal to store commodities.[1] Refiners frequently rely on basis in timing their crude oil purchases and in scheduling production and delivery of refined products. Any market signals contained in time basis are also relevant to the activities of hedgers and speculators. The success of energy futures markets, especially after the introduction of crude oil futures contracts in 1983, adds a significance to the study of basis in energy futures markets.

An examination of the theory is warranted for energy futures contracts because of the unique characteristics of energy products and energy futures markets. Energy futures markets trade contracts on both the primary input (crude oil) and outputs of a production process. In addition, refiners have some control over the allocation of output among gasoline, heating oil, and chemical stocks. This means the time basis in one energy futures contract may be affected by the inventory levels of other energy products.

Both sweet and sour grade crude oil are important to total energy supply, but only sweet West Texas Intermediate is traded in a futures market. The availability of sour crude when there is a shortage of sweet crude may affect the pricing relationship between futures and spot prices predicted by the theory of storage.

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[1]For a discussion of industry practices, see Keith Schap (1989).

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The theory of storage was advanced mainly for commodities subject to seasonal variations in supply (e.g., harvest). While demand for gasoline and heating oil are subject to seasonal fluctuations, the supply of crude oil and other refined products is not inherently seasonal. The absence of seasonal supply shifts may weaken the incentive to store commodities, even in the presence of high futures prices and low spot prices.[2]

Empirical validation of the theory of storage is also important in modeling the behavior of futures prices. The theory suggests that futures prices are largely determined by the conditions in spot markets; that is, futures markets are backward looking. Whether futures markets are backward or forward looking is a point of continuing debate.[3]

THE THEORY OF STORAGE AND TESTS PROPOSED

The traditional explanation for the supply curve of storage makes use of the concept of convenience yield (Telser (1958), Working (1948, 1949)). Commodities are stored even at inverse carrying charges, i.e., negative basis, because current stock provides nonmonetary benefits to the holder. For example, inventory allows a firm to avoid potential work stoppages and loss of sales and enhances a firm's ability to change production schedules without incurring extraordinary marginal or adjustment costs.

It is hypothesized that convenience yield is inversely related to the total stock available. That is, the marginal net benefits of inventory decline with increased stocks. One source for this decline is the increased cost of storage as storage space declines. Facing rising storage costs, users of a commodity have increased preferences for commodities available in the future relative to having the commodity available now. Increases in total stock (current supply) also tend to lower spot prices more than futures prices because the demand elasticity is lower in the spot market than in the futures market. Furthermore, it is assumed that the rate of decline in convenience yield diminishes with stock. That is,

$$\mathrm{CY} = f(\mathrm{TS}), \qquad f' < 0, \qquad f'' > 0 \tag{1}$$

where CY denotes convenience yield and TS total stock, and f' and f'' are first and second derivatives, respectively.

Wright and Williams (1989) present an analytical model showing that inverse carrying charges can arise if reported inventory figures are calculated by aggregating similar products and the marginal transformation costs between these products are time-varying. They argue that convenience yield disappears with sufficient disaggregation and cite studies by Gary and Peck (1981) and Thompson (1986) as providing evidence consistent with this hypothesis.[4]

The existence of the supply of storage curve in energy futures markets is investigated here in light of these two alternative hypotheses about the source of inverse carrying charges, using direct and indirect tests of the theory of storage. The direct

[2]Recent tests by Fama and French (1988) on industrial commodities, which are not subject to seasonal variations, support the supply of storage hypothesis.

[3]See Kolb (1988, pp. 63–64) for a summary of studies addressing this question.

[4]Keynes (1930) and Hicks (1939) attribute a negative basis to the premium hedgers pay to speculators for shifting price risk. Thus, there are three possible sources for a negative price spread: (i) convenience yield; (ii) risk premium; and (iii) aggregation. No one explanation necessarily negates the others.

test relates convenience yield to domestic inventory levels utilizing a simple statistical model: for example; Telser (1958) and Brennan (1958).

Because of the difficulty in defining and measuring the relevant inventory, Fama and French (1988) utilized indirect tests based on the relative variation observed in spot and futures prices. In applying their tests, they argue that the Samuelson hypothesis, which states that futures prices are less variable than spot prices, holds when inventory is low (Samuelson (1965)).[5]

Price elasticities of supply and demand are smaller in the short run than in the long run. Thus, supply or demand shocks generate relatively greater variability in spot prices compared with futures prices. Any differences in variability should be especially evident when inventories are low and, therefore, unable to accommodate shifts in supply and demand. When inventories are high, however, the variability in spot and futures prices tend to be nearly equal since existing inventories can be used to absorb supply and demand shocks.

If spot prices are observed to fluctuate more than futures prices when basis is negative, it can be concluded that the negative carry is associated with relatively low inventory levels. Alternatively, if the variation in spot and futures prices is nearly equal when basis is positive, it can be concluded that the positive carry is associated with relatively high inventory levels. Thus, by comparing the relative variation of spot and futures prices when the basis is positive and negative, it is possible to reject or confirm the positive relationship between carrying costs and inventory level.

Because the Fama and French tests do not make use of measured stocks, they are especially useful in examining the supply of storage curves in energy markets. As a practical matter, it is difficult to define and measure relevant inventory levels for energy products. For example, storage of crude oil and its by-products takes place in tankers and pipelines, and can affect domestic inventories in a short period of time. While stocks are stored throughout the nation, crude oil futures contracts call for delivery at Cushing, Oklahoma and gasoline and heating oil futures contracts call for delivery at New York harbor. This raises a question as to the relevance of stocks held at locations distant from the delivery points in explaining basis of energy futures contracts. The Fama and French tests are also attractive because they avoid the aggregation phenomenon introduced by Wright and Williams.

DATA AND INTEREST ADJUSTED BASIS

Basis is measured by the difference in prices between a futures contract deliverable in a nearby month and one deliverable in the next nearby month. In the case of crude oil futures, the price of the first nearby futures price is very close to, and frequently identical to, the spot price of West Texas Intermediate crude in Cushing, Oklahoma. In fact, the spot price and the first nearby futures price are so close that the first nearby month contract is referred to as the "spot contract." Thus, the difference between two nearby futures prices, rather than the difference between the spot and the first nearby futures prices, is an appropriate measure of time basis.

Crude oil contracts are usually available for each month extending 18 months into the future and gasoline and heating oil contracts are usually available for each month extending 12 months into the future. The average time difference between

[5]See Anderson (1985) for a discussion of the mathematical assumptions underlying the Samuelson hypothesis.

two contracts expiring in consecutive months is approximately 30 days.[6] Because of the similarity in the time interval between the nearest contract and next nearest contract, it is reasonable to assume that the behavior of time basis reflects factors other than the length of the time interval and to pool basis over time in conducting an empirical study.

Weekly estimates on domestic stocks of crude oil and petroleum products are prepared by the American Petroleum Institute (API) and are used here for direct tests of the theory of storage. To take advantage of the weekly inventory data, daily closing prices for crude oil, gasoline and heating oil are converted to weekly average price series.[7] Time basis is calculated using these weekly averages. The sample period extends from the first week in January, 1985 to the second week in May, 1989.

There are a couple of anomalies affecting the calculated basis. With sudden, fast moves, the change in daily price (usually, a decline) occasionally hits the daily price limit established for contracts deliverable in the months following the nearest contract month. Since there is no price limit for the nearest futures contract, the observed basis is constrained when trading of the second nearby month contract is suspended. Weeks in which one or more days hit the price limit are deleted from the sample to avoid the bias from such constrained values.[8]

Also, abrupt movements in the price of the nearest futures contract are common on its last trading day as traders adjust themselves out of positions. Because of this technical trading adjustment, the time basis observed on contract expiration dates are frequently significantly different from the basis one or two days before and/or after the last trading day. The data are not adjusted for this, however, as weekly averages tend to smooth these erratic changes.

Because marginal storage costs are difficult to estimate, only interest costs are included in the adjustment for carrying cost. Though marginal storage costs are negligible much of the time because of the availability of unutilized storage capacity, the omission of storage costs can result in a positive measured adjusted basis when total stocks are large.[9]

Basis is divided by the price of the nearby contract month to yield "interest adjusted basis."

$$\mathrm{IAB} = [\mathrm{F}_2 - \mathrm{F}_1(1 + i)]/\mathrm{F}_1 \tag{2}$$

where IAB stands for interest adjusted basis, F_2 and F_1 denote the prices of second

[6]The last trading day for crude oil futures is the third working day preceding the 25th day of the month prior to delivery, i.e., between the 20th and 23rd day of the month. Thus, the number of days between two nearby futures contracts can vary between 25 and 33 days. The last trading days for gasoline and heating oil futures fall on the last trading day of the month prior to delivery. Thus, the number of days between two nearby futures contracts for these products varies between 28 to 31 days.

[7]The weekly inventory figures measure stocks on Friday. Friday prices are not matched with these inventory figures, however, because the trading volume on Friday is usually low, and this may introduce a systematic bias. Instead, weekly average prices are used because it is assumed that they are the next best source of relevant price information. Also, averaging (average prices) smoothes for erratic price movements associated with technical adjustments by traders.

[8]The daily price limit is $1.00 per barrel for crude oil futures and those for gasoline and heating oil futures are 2 cent per gallon. Larger price changes are allowed on subsequent trading days if price limits are reached. Weeks that have limit price moves are not included because such price changes are assumed to be an indication of volatile expectations. Excluding these weeks is an attempt to remove the effect of volatile expectations in the study of storage curves.

[9]The positive value may be interpreted as marginal storage cost.

nearest and nearest (spot) month contracts, respectively, and i is the weekly average annual yield on 90 day commercial papers divided by 12. Interest adjusted basis is in percentage terms and thus provides a convenient unitless measure of backwardation or contango among several commodities.[10]

The mean and standard deviation of the IAB's are, respectively, −0.0186 and 0.0181 for crude oil; −0.021 and 0.03 for gasoline; and −0.019 and 0.0308 for heating oil. As noted above, the analysis excludes weeks in which daily price limits are observed. With this exclusion, valid sample sizes are 209 for crude oil, 204 for gasoline, and 203 for heating oil. For the reduced sample, the mean of crude oil IAB's is −0.019 or −1.9% of the nearby futures (or spot) price and the standard deviation is 0.017 or 1.7%. For gasoline, the mean and standard deviation are −0.021 and 0.03; and for heating oil, the mean and standard deviation are −0.016 and 0.026. The average of the basis is smaller for heating oil compared to those of crude oil and gasoline for the weeks observed; the volatility, measured by the standard deviation, is greater in refined product markets than in the crude oil market.

TEST RESULTS

Direct Tests Using Domestic Stocks

A direct test of the theory of storage is obtained by regressing IAB's on the logarithm of the level of total stock:

$$\mathrm{IAB} = a + b\mathrm{LN(TS)} + e \tag{3}$$

where LN(TS) is the logarithm of total stock (TS) and e is the error term, assumed to be distributed approximately normal with mean 0 and constant variance. The intercept term, a, is expected to be negative and the slope term, b, is expected to be positive. A semi-logarithmic specification is used to account for the nonlinearity in convenience yield relation, i.e., the second derivative of the yield with respect to inventory level is positive.

Figures 1–3 show the IAB's for crude oil, gasoline, and heating oil futures contracts against the relevant stock over the reduced sample periods. The scatter diagrams appear to support the semilog specification.

Regression results are reported in Table I.[11] The R-squared values are relatively high, ranging from 0.64 in the crude oil model to 0.84 in the gasoline model. The slope term for the IAB in the gasoline futures model is statistically significant at the 1% level, supporting the presence of the supply of storage curve in this oil products market. There also is statistical support for the presence of the supply curve of storage in heating oil and crude oil markets, but the evidence is not as strong. The slope term for the IAB in heating oil is statistically significant at the 5% level and that for crude oil IAB is significant at the 10% level.

The value of the slope term measures the likely change in IAB for a small percentage change in the level of stock. Evaluated at the sample mean value of 333 million barrels of crude oil, the coefficient in the crude oil equation suggests that a

[10]Fama and French (1988) and Thompson (1986) make use of interest adjusted relative basis because both interest rates and prices have fluctuated widely in recent years. See Gary and Peck (1981, p. 100) for further explanations.

[11]The results are adjusted for autocorrelation in residuals. Without adjustment the sampling errors of the estimated coefficients are understated, which overstates the statistical significance of the coefficients.

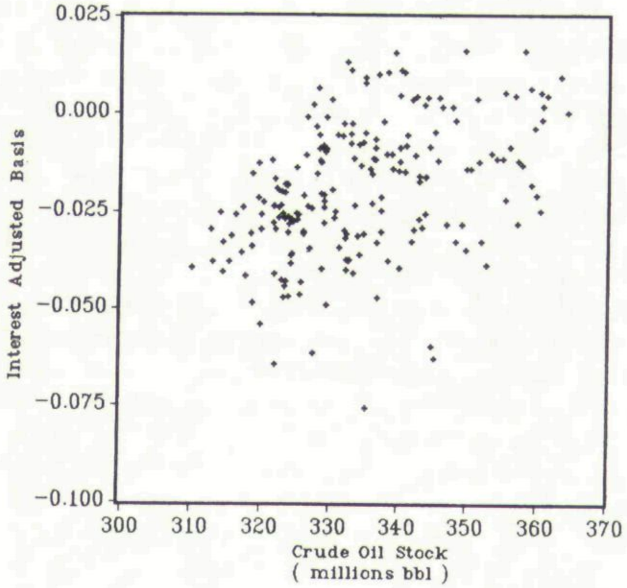

Figure 1
Interest adjusted basis (IAB) for crude oil futures contracts against crude oil stock over the reduced sample period.

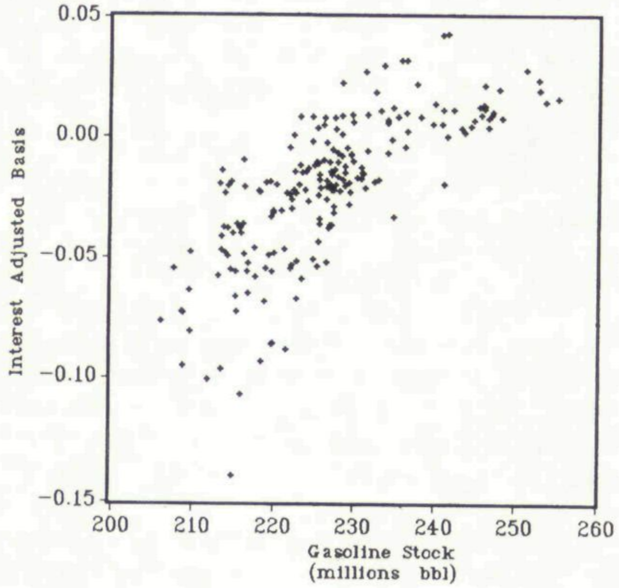

Figure 2
Interest adjusted basis (IAB) for gasoline futures contracts against gasoline stock over the reduced sample period.

[12]Note that $d(\text{IAB})/d(\text{TS}) = b/\text{TS}$.

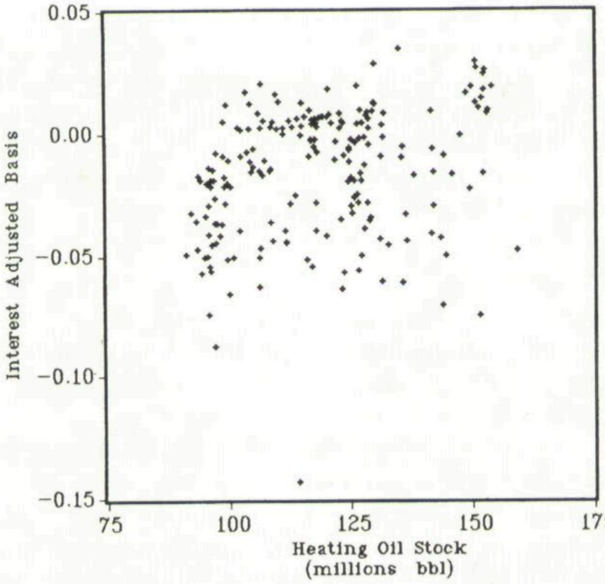

Figure 3
Interest adjusted basis (IAB) for heating oil futures contracts against heating oil stock over the reduced sample period.

one million barrel increase in crude oil stock increases crude oil IAB by 2.5 basis points.[12] Since the average value of IAB is about 200 (negative) basis points, such a change in the level of stock provides a negligible impact on the IAB of crude oil. At the average heating oil stock of 154 million barrels, the coefficient estimate of 0.073 implies a relatively a minor impact of a 4.7 basis point change in the heating oil IAB for a one million barrel change in stock.

Compared to the above results, the impact of a change in gasoline inventory levels on gasoline IAB is much more consequential. At a mean stock of 223 million barrels, the estimated coefficient of 0.369 implies a 16.5 basis point change in the

Table I
REGRESSION RESULTS FOR INTEREST ADJUSTED BASIS (IAB)
IAB = *a* + *b* LN(TS)

	Crude Oil	Gasoline	Heating Oil
a	−1.067	−4.57	−.87
	(−1.79)*	(−6.93)***	(−2.60)***
b	.082	.369	.073
	(1.76)*	(6.89)***	(2.56)**
N	209	204	203
R^2	.64	.84	.77
Durbin-Watson	2.28	1.92	2.04
Mean (IAB)	−.019	−.021	−.016

All regressions are adjusted for autocorrelation in residuals.
The figures in parentheses are *t* values with * indicating statistical significance at the 10% level, ** statistical significance at the 5% level, and *** statistical significance at the 1% level.

gasoline IAB for a one million gallon change in gasoline stocks. Recognizing the risk of extrapolation, an increase of 5 to 6 million barrels in the stock of gasoline could increase this gasoline IAB by approximately 100 basis points, which corresponds to a 50% increase in IAB, over the average IAB of 2 percentage points.

It appears that IAB in the gasoline futures market is highly sensitive to changes in gasoline inventories, but that IAB's in crude oil and heating oil futures markets are not so sensitive to changes in their inventory levels.

Fama and French Test

Because of the uncertainty about the appropriate measure of stock and the differences in the precision of coefficient estimates across the crude oil and products markets, it is appropriate to conduct the alternative tests suggested by Fama and French to detect the presence of a convenience yield.

To implement the Fama and French tests of the theory of storage, IAB's are first grouped according to algebraic sign (negatives and positives). Two alternative propositions are tested. First, it is posited that if the supply of storage curve exists, spot (or nearby futures) prices will fluctuate more than futures prices when IAB's are negative. As noted earlier, the underlying reasoning behind this proposition is that supply and demand elasticities are lower in the short run, implying spot or nearest delivery futures price adjustments occur in a wider range compared with distant futures price adjustment. In the more distant future, quantity adjustments absorb more of the shock from changes in supply or demand. Therefore, greater variability of the spot over the futures price when IAB's are negative (or when convenience yield is large) implies low inventories; which indirectly confirms the existence of an inverse relationship between the level of stock and the level of convenience yield noted in Eq. (1).

Over the time series tested for crude oil, 178 weeks have a negative IAB. For gasoline and heating oil markets, the number of weeks with a negative IAB is, respectively, 147 and 133 weeks. For each commodity, standard deviations of changes in spot and futures prices are calculated for negative and positive IAB groups. F tests for equal variance are conducted and F values are reported in Table II. In the gasoline and heating oil markets, the null hypothesis of equal variances is rejected when IAB's are negative but it is not rejected when IAB's are positive. These markets pass the Fama-French indirect test. In neither situation is the null hypothesis of equal variances rejected in the crude oil futures market. Thus, the crude oil market fails this Fama-French indirect test.

Second, it is posited that IAB's fluctuate more when they are negative than when they are positive, which really is an extension of the first test. That is, if the spot price fluctuates more than the futures price when IAB's are negative, then IAB's fluctuate more when they are negative than when they are positive. The energy markets easily passed this test, as evidenced by the calculated F values reported in Table III. All values are relatively large and significant at any reasonable level of significance. These tests confirm that these energy markets exhibit characteristics consistent with the theory of storage.

It should be noted, however, that tests involving IAB's are likely easier to pass than tests involving individual prices because movements in IAB's reflect the variability in both spot and futures prices. That is, IAB's may display a greater variability when they are negative because spot prices fluctuate more for given futures prices, and at the same time, futures prices fluctuate more for given spot prices.

Table II
COMPARISONS OF VARIATION OF PRICES

	Crude Oil		Gasoline		Heating Oil	
Basis	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.
N	178	31	147	57	133	70
St Dev of Changes in Prices						
1st Month	.71	.65	2.79	4.11	2.15	1.86
2nd Month	.67	.66	2.32	3.92	1.80	1.86
F ratio	1.12	.97	1.45**	1.10	1.43**	1.00

Table F Values:

$F_{.10}(120, 120) = 1.26$
$F_{.05}(120, 120) = 1.35$
$F_{.01}(120, 120) = 1.53$

**Significant at the 5% level.

SUMMARY AND CONCLUSIONS

The theory of storage is tested for crude oil, heating oil, and gasoline futures markets using the time basis of two nearby futures prices. Traditional, direct tests and Fama-French indirect tests are conducted. No single test is perfect for evaluating the applicability of the theory of storage in energy futures markets. The traditional test suffers from difficulties in identifying and measuring relevant stock or inventories. While the weekly API inventory figures are widely followed in the markets, it is arguable whether domestic inventory levels are appropriate stock measures for examining the supply of storage relationships in energy futures markets. The appearance of convenience yield may result from aggregation in reporting inventory levels as pointed out by Wright and Williams. Fama-French indirect tests, while avoiding the aggregation problems discussed by Wright and Williams, are not valid if the underlying assumptions about short run and long run supply and demand

Table III
COMPARISONS OF VARIATION OF IAB'S

	Crude Oil		Gasoline		Heating Oil	
Basis	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.
N	178	31	147	57	133	70
St Dev of Changes in Basis	.011	.007	.013	.009	.013	.008
F value	2.47***		2.07***		2.64***	

Table F values:

$F_{.01}(120,30) = 1.86$

***Significant at the 1% level.

elasticities do not hold. With these concerns in mind, it is prudent to evaluate the theory of storage using both direct and indirect tests.

The results confirm the existence of the supply of storage curve in both gasoline and heating oil markets. In addition, the gasoline time basis is highly sensitive to changes in inventory level. A one million barrel increase in gasoline stock increases the interest adjusted time basis 16.5 basis points. The evidence of the supply of storage curve in the crude oil market is weaker, whether derived from direct tests or indirect tests. The crude oil market passes the traditional test at a lower level of confidence. The crude oil market fails to pass the more stringent Fama and French test.

A more pronounced supply curve of storage in product markets may be attributed to seasonal factors in the demand for gasoline and heating oil. With strong seasonal demands for these products, market participants may pay closer attention to inventory conditions. Peculiarities of the crude oil market may explain weaker support for the theory of storage in the crude oil futures contracts. For example, (i) sweet crude traded in futures markets constitutes only a part of total crude supply; (ii) world production capacity and OPEC production quotas are more important in the crude oil market; and (iii) futures prices often reflect the degree of congestion in pipelines near the delivery point, Cushing, Oklahoma. These characteristics parallel conditions underlying the Wright and Williams thesis that convenience yield is a result of aggregation.

Despite a relative weakness in the crude oil market, the evidence for the theory of storage is robust for energy markets taken as a whole. This implies that time basis provides price signals which are useful to energy suppliers and users in making intertemporal allocation of production and distribution. Nonetheless, the results of this study should not be interpreted as support for trading strategies based on time basis models incorporating inventory figures. Though a more systematic relationship exists between time basis and inventory level in gasoline and heating oil markets, caution still should be exercised in predicting actual time basis. For example, this analysis excludes weeks in which daily price limits are reached. Volatile daily price changes may be indicative of shifting market expectations. By omitting these observations, the analysis ignores the possible role of expectations in determining time basis.

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