Storage Under Backwardation: A Direct Test of the Wright-Williams Conjecture

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Abstract

Commodities are often stored when the spot price exceeds the future price in a central market. Wright and Williams conjectured that inventories are held in locations far from the central market on these occasions. In these locations the spot price is lower than the price for forward delivery because transport costs are temporarily high. This hypothesis has not been directly tested, because prices for forward delivery are not normally available at non-central locations. This paper uses an example where these prices exist to test the hypothesis. The evidence, from the late nineteenth century corn markets in Chicago and New York, strongly supports the conjecture.

JEL classification
L92, N71, Q13

Keywords
Inventories, commodity prices, transport costs.

Contents

1 Introduction

In almost all commodity markets, inventories are sometimes held when the future price is lower than the spot price — that is, when prices are in backwardation. This behaviour is so widespread that "supply of storage" graphs showing the spot-future price spread as a function of the quantity of storage are routinely drawn. These curves have a characteristic form: when storage volumes are low, the future price is typically lower than the spot price, but when storage quantities are high, the future price exceeds the spot price. The standard explanation for this curve, dating back to Kaldor (1939), Working (1949), and Brennan (1958), is that some agents hold inventories when the future price is lower than the spot price because they gain a "convenience yield" from their stocks.

In the last two decades, several authors have questioned the necessity of the "convenience yield" explanation for a supply of storage curve. Wright and Williams (1989) argued that the supply of storage curve might be an artifact of an inappropriate method of aggregating inventory levels. They suggested an aggregate supply of storage curve could be drawn even if there were no convenience yield if the spot-future price-spread in one location were compared to the sum of inventories held at a wide range of locations. In particular, they argued that inventories could be profitably held at locations far from a central market where prices were in backwardation if transport costs varied through time, because intertemporal transport price variation makes it possible for spot-future price spreads to vary over space.

A simple two-centre example makes their argument clear. Suppose there is a central market C with a spot price S_t^C and a future price $F_t^{C,1}$ that imports from a distant market D. If it costs K_t^T to ship goods immediately, and K_{t+1}^T to ship them at *t+1,* the spot and future prices in the distant market will be $S_t^D = S_t^C - K_t^T$ and $F_t^{D,1} = F_t^{C,1} - K_{t+1}^T$. The spot-future price spreads in the central and distant markets will be $S_t^C - F_t^{C,1}$ and $S_t^C - F_t^{C,1} + (K_{t+1}^T - K_t^T)$ respectively. Consequently, if transport costs are temporarily high, spot prices can be lower than future prices in the distant centre (or lower than the expected future spot price, if a futures market does not exist) even if the reverse is true in the central market.

Brennan, Williams and Wright (1997) examined the rail transportation and storage networks used to transport wheat to the Australian port of Freemantle to provide empirical support for this argument. They demonstrated that wheat was stored alongside railroads far from the port even when port prices were in backwardation because it was more profitable to store the grain and wait for off-peak transportation than it was to ship it in the peak transport season. Yet they were unable to show that the future price was higher than the spot price in the areas where inventories were held, because future prices did not exist in these locations.

So far it has proved difficult to test this aspect of the Wright-Williams conjecture, because futures markets for a commodity seldom exist near each other. In general, the non-central locations where inventories are mainly held do not have futures markets, so spot-future price spreads cannot be calculated in these locations. This paper circumvents this difficulty by using an historic example where two futures markets existed in close proximity. The example is the New York and Chicago corn markets in the late nineteenth century - markets that were a part of the huge trans-Atlantic grain trade. The data are ideally suited to test their hypothesis because transport costs varied seasonally and both cities had active futures markets with spot-future price spreads that were often different.

The data support their hypothesis. Each year, transport costs from Chicago to New York were high during the winter because the lowest cost transportation method — by ship to Buffalo and then by canal to New York — was unavailable. During this season shipping agents stored large amounts of grain in Chicago, choosing to store grain and wait for the opening of the lakes in May rather than to ship by rail immediately. The May future price exceeded the spot price during this time by an amount similar to the cost of carrying inventories. In contrast, the May future price in New York was lower than the spot price in several of the years examined, normally when New York inventories were low, although not literally zero. On these occasions, a comparison of the New York spot-future price spread against total (New York plus Chicago) inventories would falsely suggest that large quantities of inventories were held when the spot price exceeded the future price, for most of these inventories were held in Chicago where future prices exceeded spot prices.

If transport prices are variable, the Wright-Williams model has a further implication: inventories can be profitably stored in a centre where local prices are in backwardation if prices are expected to increase before decreasing. For example, corn could have been stored in New York in January even though the January spot price exceeded the May future price if the price for delivery in February was higher than the January price. This possibility was tested to see if it explains why inventories were held in New York when the spot price exceeded the May future price. It does not. Even though May transport costs were lower than winter transport costs, there were almost no examples when the spot price in winter was lower than the price for delivery one month later.

The focus of the paper is deliberately limited: it simply tests the Wright-Williams conjecture using data from a particular historic episode. Nonetheless, the paper includes a theoretical section deriving the arbitrage relationships that should link spot-future price spreads to transport costs, trade patterns and inventories because this test has not been directly applied before. These results are derived in section 2. The operation of the late nineteenth New York and Chicago corn markets is described in section 3, while the test of the Wright-Williams conjecture is presented in section 4. Lastly, conclusions are offered in section 5.

2 Arbitrage Price Relations

Consider a model of trade and storage in a central market C and a "distant" market D that regularly exports to C. In each location *i* there is a spot price P_t^i for immediate delivery and a future price $F_t^{i,n}$ for delivery in n periods. It is assumed that trade from D to C can take place instantaneously. Let T_t^D be the shipments from D to C, and K_t^T the cost of shipping goods at time t. Let S_t^C and S_t^D be the quantities stored in each centre at time t. There are two storage costs: a storage fee of K^S per period, and an interest rate opportunity cost r. For ease of exposition, in the following derivation it is assumed the storage costs are the same in each centre and invariant through time.

Following Samuelson (1952) and Williams and Wright (1991), the conditions for profitable trade from D to C at time *t* and *t+n* are:

$$P_t^C \leq P_t^D + K_t^T; \qquad \left[P_t^C - (P_t^D + K_t^T)\right].T_t^D = 0 \tag{1}$$

$$F_t^{C,n} \leq F_t^{D,n} + K_{t+n}^T; \qquad \left[F_t^{C,n} - (F_t^{D,n} + K_{t+n}^T)\right].E[T_{t+n}^D] = 0 \tag{2}$$

where $E[T_{t+n}^D]$ is the expected trade at time *t+n*.

These equations state that the price in centre C will equal the price in centre D plus shipping costs when C imports from D; otherwise, the price in centre C will be less than the price in centre D plus shipping costs.

The conditions for profitable storage at time t when there is no convenience yield are :

$$\tfrac{1}{1+r} F_t^{i,1} \leq P_t^i + K^S \qquad \left[\tfrac{1}{1+r} F_t^{i,1} - \left(P_t^i + K^S\right)\right].S_t^i \quad = 0 \tag{3}$$

This pair of equations states that the future price in a centre will equal the spot price plus the costs of storage if inventories are positive; if inventories are zero, the future price will be less than the spot price adjusted for storage costs. Equation 3 has the implication that storage will be zero whenever spot prices are greater than the future price.

These equations can be used to analyse two different relationships between inventories and price spreads. The conditions when the central market has no inventories and when prices are in backwardation even though there are inventories in the distant market can be derived by analysing arbitrage relationships over two periods. The conditions when the central market has inventories even though the spot price is greater than a future price can be derived by analysing arbitrage relationships over three periods. These derivations are presented below.

2.1 Two period arbitrage relationships.

In this section, price relationships in the two centres are calculated under the assumptions:

A1: Inventories are held in centre D at time t; and

A2: D is expected to export to C at time t+1.

From equation 2 and equation 3 applied to D, $F_t^{C,1} = F_t^{D,1} + K_{t+1}^T$ and $\frac{1}{1+r} F_t^{D,1} = P_t^D + K^S$.

Let P^{*S} be the centre C price at time t at which it is just profitable for inventories to be held, and let P^{*M} be the centre C price at time t at which it is just profitable to import. At P^{*S}, equation 3 applied to C holds with equality and implies

$$P^{*S} = P_t^D + \tfrac{1}{1+r} K_{t+1}^T \tag{4}$$

At P^{*M}, equation 1 holds with equality and implies

$$P^{*M} = P_t^D + K_t^T \tag{5}$$

There are two different cases. Suppose transport prices in period t are low compared to prices in period t+1, that is $K_t^T \le \frac{1}{1+r} K_{t+1}^T$. Then $P^{*M} \le P^{*S}$ and

a. if $P_t^C > P^{*S}$ $\quad S_t^C = 0; T_t^D > 0$;

b. if $P^{*M} \le P_t^C \le P^{*S}$ $S_t^C > 0; T_t^D > 0$;

c. if $P_t^C < P^{*M}$ $S_t^C > 0; T_t^D = 0$.

Alternately, suppose transport prices in period t are high compared to prices in period t+1, that is $K_t^T > \frac{1}{1+r} K_{t+1}^T$. Then $P^{*S} \le P^{*M}$ and

d. if $P_t^C > P^{*M}$ $S_t^C = 0; T_t^D > 0$;

e. if $P^{*S} \le P_t^C \le P^{*M}$ $S_t^C = 0; T_t^D = 0$;

f. if $P_t^C < P^{*S}$ $S_t^C > 0; T_t^D = 0$.

Case (e) is of particular interest. It says that when transport costs are sufficiently high in period *t* compared to *t+1,* it is possible for centre C to neither import nor have inventories even though centre D has positive inventories. This, of course, is the argument made by Wright and Williams. In these circumstances, the following price relationships apply

1. $P_t^C > \frac{1}{1+r} F_t^{C,1} - K^S$ and $S_t^C = 0$

2. $P_t^D = \frac{1}{1+r} F_t^{D,1} - K^S$ and $S_t^D > 0$

3. $P_t^C < P_t^D + K_t^T$ and $T_t^D = 0$

4. $K_t^T > \frac{1}{1+r} K_{t+1}^T$

Note that the first of these conditions is less stringent than the requirement that prices in centre D be in backwardation.

2.2 Three period arbitrage relationships.

If the above model is extended to three periods, a further implication of the Wright-Williams conjecture can be derived. In particular, inventories may be profitably held in the central market when prices in that market are in "long-term" backwardation if prices in the central market are expected to first rise and then fall. This can occur if transport prices are expected to be temporarily high for some of the time between the present and the time that they are required for future delivery. To show this, the initial assumptions are modified:

A3: Inventories are held in centre D at times t and t+1; and

A4: D is expected to export to C at time t+2.

These assumptions imply the following price relationships:

$F_t^{C,2} = F_t^{D,2} + K_{t+2}^T$,

$\frac{1}{1+r} F_t^{D,1} = P_t^D + K^S$, and

$\frac{1}{1+r} F_t^{D,2} = F_t^{D,1} + K^S = (1+r)P_t^D + (2+r)K^S$.

Let P_1^{*S} be the centre C price at time *t+1* at which it is just profitable for inventories to be held, and let P_1^{*M} be the centre C price at time *t+1* at which it is just profitable to import. At P_1^{*S} , equation 3 applied to C holds with equality and implies

$$P_1^{*S} = F_t^{D,1} + \frac{1}{1+r} K_{t+2}^T \quad (6)$$

At P_1^{*M} , equation 2 holds with equality and implies

$$P_1^{*M} = F_t^{D,1} + K_{t+1}^T \quad (7)$$

Assume that transport prices are higher in period 1 than period 2, $K_{t+1}^T \geq \frac{1}{1+r} K_{t+2}^T$, so that $P_1^{*S} \leq P_1^{*M}$. It is then possible to calculate centre C prices in period *t* as a function of centre C future prices at *t+1*. Let the price for future delivery in C at period *t+1* be

$$F_t^{C,1} = P_1^{*M} + \varepsilon(1+r) = F_t^{D,1} + K_{t+1}^T + \varepsilon(1+r) \quad (8)$$

If $\varepsilon \geq 0$, $S_{t+1}^C = 0$ and $T_{t+1}^D \geq 0$; if $\left(\frac{1}{1+r} K_{t+2}^T - K_{t+1}^T\right) < \varepsilon < 0$, $S_{t+1}^C = 0$ and $T_{t+1}^D = 0$; and if $\varepsilon \leq \left(\frac{1}{1+r} K_{t+2}^T - K_{t+1}^T\right)$, $S_{t+1}^C \geq 0$ and $T_{t+1}^D = 0$. There are two critical thresholds for prices at time t : the price P_0^{*S} at which storage occurs at t; and the price P_0^{*M} at which C imports. The equation for equation for P_0^{*S} is

$$P_0^{*S} = \frac{1}{1+r} F_t^{C,1} - K^S$$

$$= P_t^D + \frac{1}{1+r} K_{t+1}^T + \varepsilon \quad (9)$$

and the equation for P_0^{*M} is

$$P_0^{*M} = P_t^D + K_t^T \ . \quad (10)$$

Suppose centre C prices are in "long-term" backwardation, that is $P_t^C > F_t^{C,2}$. This implies

$$\begin{aligned} P_t^C &> F_t^{D,2} + K_{t+2}^T \\ &\equiv (1+r)^2 P_t^D + (1+r)(2+r)K^S + K_{t+2}^T \\ &\equiv P_t^D + (2+r)(rP_t^D + (1+r)K^S) + K_{t+2}^T \end{aligned} \quad (11)$$

If at the same time $P_t^C < P_0^{*S}$ and $\left(\frac{1}{1+r}K_{t+2}^T - K_{t+1}^T\right) < \varepsilon < 0$, there will be storage in centre C at time *t* even though prices are in long-term backwardation, and there will be no storage or imports at C at *t+1*. For this to occur,

$$P_t^C < P_t^D + \tfrac{1}{1+r}K_{t+1}^T + \varepsilon; \qquad \left(\tfrac{1}{1+r}K_{t+2}^T - K_{t+1}^T\right) < \varepsilon < 0 \quad (12)$$

Equations 11 and 12 can be satisfied simultaneously if

$$(2+r)(rP_t^D + (1+r)K^S) + K_{t+2}^T < \tfrac{1}{1+r}K_{t+1}^T + \varepsilon \quad (13)$$

which will be true if transport costs in period *t+1* are sufficiently high compared to transport costs in period *t+2* and ε is sufficiently close to zero. In these conditions it is possible for storage to take place in C at time *t* even though prices are in long term backwardation.

3 The New York and Chicago nineteenth century corn markets

This paper uses data from the New York and Chicago corn markets in the late nineteenth century to test the Wright-Williams conjecture. The period has been chosen because both cities had active futures markets in the same grade of corn and thus spot-future price spreads can be calculated at the two locations. The relatively close proximity of these two futures markets is unusual, but provides an ideal setting to examine the hypothesis.[1] The markets co-existed because seasonal transport fluctuations meant that a contract promising delivery in Chicago was not always a good substitute for a contract promising delivery in New York. In this section the major features of these markets including trade-flows, transport costs and storage patterns are described.

[1] Carlton (1984) and Williams (1986) discuss why it is unusual to find futures markets for the same commodity in close proximity. The basic argument is that futures markets have high fixed costs so if the futures contracts are close substitutes for each other one market usually dominates.

3.1 Basic production and shipping patterns

In the late nineteenth century, the Great Plains region west of Chicago was the main corn producing area in North America. Nebraska, Iowa, and Illinois typically produced a third of the U.S. crop, which amounted to 2000 million bushels in 1891; in contrast, New York, New Jersey, and Pennsylvania only produced 75 million bushels per year[2]. Chicago was the preeminent midwestern transportation centre as a result of its inward and outward transport networks. It shipped an average of 62 million bushels per year during the period 1875 – 1889, primarily to New York, Boston, Baltimore, and Philadelphia. Most of this corn was exported to Europe. New York was the most important of these ports and frequently accounted for more than half of East Coast corn exports. Both Chicago and New York developed elaborate infrastructure to handle large volumes of corn and other grains.

The transport links between Chicago and New York were central to the operation of this market. There were three ways that corn could be shipped from Chicago to New York:

1. by ship over the Great Lakes to Buffalo, and thence by canal boat to New York;
2. by ship over the Great Lakes to Buffalo, and thence by rail to New York; or
3. by rail to New York, using various lines.

While the Great Lakes shipping route was the primary means of transporting corn from Chicago, it was not available between December and April as the harbours and canals froze. In contrast, the rail route operated all year round. However, since rail freight rates were significantly more expensive than lake and canal freight rates, most grain sold in Chicago and shipped to New York was shipped via the lakes and canals during the open water season[3]. From 1881 - 1891, when transport prices were relatively stable, the average cost of shipping a bushel of corn from Chicago to New York was 7.7 cents by Lake and canal, 10.3 cents by lake and rail, and 14.6 cents by rail (Chicago Board of Trade, 1892, p. 122).

Freight prices from Chicago to New York had a marked seasonal pattern. In part this reflects the unavailability of the lake-canal route during the winter months, and in part reflects seasonal fluctuation in lake-canal and rail freight prices. Figure 1 shows weekly

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[2] A bushel of corn weighed 56 pounds.

[3] See Coleman (forthcoming) for a detailed analysis of the Chicago-New York freight patterns. The analysis is complicated because the Chicago freight statistics include shipments of grain that were sold in Chicago and shipped east and grain that passed through Chicago but which was never unloaded in the city. He uses regression analysis to demonstrate that the vast majority of grain that was sold in Chicago and shipped to New York was shipped via the Great Lakes during the open water season. Throughout the year, however, there were large through shipments by rail that started in the Great Plains region and passed through Chicago. Thus, even though a casual inspection of the data suggests that Chicago frequently shipped grain by rail to New York, this was not the case.

transport costs by lake and canal, and by rail from 1879 - 1891.[4] Figure 2 shows the mean transport price by week calculated for each week in each of the years 1881 - 1891 for the lake and canal and all-rail transport modes. On average, lake and canal rates fell from the beginning of the season in May until July before increasing by 0.2 cents per week until the end of the shipping season. There is a similar, but much less marked pattern in the lake and rail rates, while the rail rates essential comprise high (winter) and low seasons.

Figure 2 also shows the average difference between the New York and Chicago spot prices. The average spot price difference was higher during the winter than the open water season. Note, however, that while the average spot price difference exceeded the lake-canal freight rate during the open water season, it was less than the average cost of rail transport during the winter. During the winter it was ordinarily not profitable to buy grain in Chicago and send it to New York by rail, and the rail shipments from Chicago to New York during these months were almost all through-shipments originating to the west of Chicago[5].

The seasonal pattern in freight prices is the reason why this dataset can be used to test the Wright-Williams conjecture. Transport prices from Chicago to New York were high between December and April because low cost lake and canal transport was unavailable. The alternative transport technology, rail, was considerably more expensive than lake and canal shipping and in practice was little used in winter. Rather, shipping agents in Chicago stored grain, waiting for the opening of the open-water season some time in April or May.

3.2 Basic storage patterns

Chicago inventories were largely determined by shipping patterns. Inventories increased steadily over the winter as corn was brought to Chicago from the surrounding hinterland and stored until the opening of the Great Lakes shipping season. They declined after the shipping season opened in May, and reached a seasonal low at the end of the open water season in November. New York inventories followed a different seasonal pattern.

[4] Initially there was marked seasonality in both rail and lake and canal prices, as railroads competed aggressively with each other for the grain business in the summer season. This price competition is understated in the official price data, as much of the business was transacted at lower, unrecorded prices (See the discussion by Nimmo in his reports on the internal commerce of the United States: United States Bureau of Statistics, 1879, 1881, 1884.) The competition was sufficiently fierce to divert substantial quantities of the grain trade from the water route to rail (Tunell, 1897.) The seasonal pattern in rail prices persisted until the mid 1880s, but declined after the passing of the Interstate Commerce Act 1887, which regulated rail transport and substantially reduced price competition between the lines.

[5] I have been unable to assemble a consistent series on freight charges for these through shipments. It appears, however, that they were not noticeably higher in winter than during the open water season. Much larger volumes were shipped during winter than the open water season, however, presumably because grain prices were relatively high in New York in winter as cheap supplies from Chicago were unobtainable.

Receipts were highest from May through July, corresponding to the opening of the Great Lakes shipping route, and again in September and October, corresponding to the first of the new crop. For this reason, inventories reached a peak late in the year, and then declined through winter. Even at peak times, New York had surplus storage capacity, and it was extremely rare for more than 70 percent of the total capacity to be utilised[6].

Storage charges were subject to regulation. In Chicago maximum storage charges for public warehouses were proscribed by a series of legislative acts and constitutional articles passed by the Illinois State Government, in part because the industry was heavily concentrated[7]. In 1888, it cost ⅝ of a cent per bushel to deposit grain in an elevator, including the cost of 10 days storage; thereafter, storage costs (excluding the interest opportunity cost, and other costs such as insurance) were ¼ of a cent per bushel per ten days with a maximum of 4 cents for storage between December and May. Storage charges in New York were similar. Insurance and interest costs were approximately 1.4 cents a bushel per month in 1913.

It is important to note that in both cities the grain elevators served two purposes. First, the elevators could be used to store grain for long periods. Secondly, they were used to transfer grain from inward bound shipping to outward-bound shipping. When grain arrived in New York, either by rail or by canal boat, it was transferred to an elevator or a lighter and then either stored or shipped. [8] The transfer charge included allowance for a few days storage while the grain was in transit. Since corn was always arriving in New York, the grain held in transit meant that recorded storage quantities were never literally zero even when no grain was held for long term storage[9].

4 Storage under Price Backwardation in Chicago and New York

The simultaneous existence of two future markets relatively close to each other means that it is straightforward to directly test the Wright-Williams conjecture. The future-spot spread in New York is calculated at various dates. At each date that prices are in

[6] In 1890 there were 21 million bushels storage capacity in New York and Brooklyn, and a further 6 million in New Jersey. The elevators were mainly used for storing wheat, not corn. In 1887, for example, inventory levels in New York and Brooklyn peaked at 16 million bushels, of which 11 million bushels were wheat and 4 million bushels were corn.

[7] In 1870, ninety percent of capacity was owned by five concerns, a pattern that continued for the whole period.

[8] Grain from canal boats could be unloaded to an elevator or be sold "afloat", whereupon it could be transferred directly to a ship using a lighter.

[9] Corn receipts exceeded 200 000 bushels per week on 90 percent of the weeks in the period. Median receipts were approximately 600 000 bushels per week.

backwardation, the future-spot spread in Chicago is calculated. The Wright-Williams conjecture implies (i) that the future price in Chicago will be greater than the spot price if Chicago has positive inventories and (ii) the transport cost on that date will be higher than the transport price in the future. Both propositions can be simply tested by calculating the average premiums and testing whether they are significantly greater than zero.

The test is applied to data from the period 1878 – 1891 described in Coleman (forthcoming). The data comprise weekly spot and forward prices from Chicago and New York, weekly storage quantities in both cities, and weekly transport costs. The test is applied to price data from the second week of December, January, February, March, and April and in each case the forward-spot premium is calculated with respect to the May future. The mean future-spot premium in Chicago is calculated on the dates that the future-spot premium in New York is negative.

4.1 Chicago and New York inventory and price patterns

Tables 1 – 5 present the data for the five months, while table 6 and 7 present the summary statistics for the dates on which prices in New York were in backwardation. Consider the data for February, in table 3 and also displayed in figure 3. On seven of the thirteen years, the New York May future price was lower than the spot price, by an average of 2.1 cents. On these occasions, Chicago inventories averaged 2.65 million bushels (table 7) and the Chicago May future price was higher than the spot price by 3.7 cents. A test of the hypothesis that the difference between the Chicago May future price and the spot price was equal to zero has a t-statistic of 5.78 and can be rejected at the 1 percent significant level. In addition, on these seven occasions, the February transport cost exceeded May transport cost by an average of 7.7 cents, an amount that is statistically different from zero, with a t-statistic of 8.82.

Table 6 shows the results for January and March were similar to those in February. When prices were in backwardation in each of these months, future prices exceeded spot prices in Chicago by an average of approximately 3 cents. In each case, this amount is statistically significant at the one percent significance level. During these months, transport prices exceeded May transport prices by an average of 6 – 8 cents, and these differences were also statistically significant at the 1 percent level. This is clear evidence that inventories were held in Chicago when the future price exceeded the spot price and when transport prices were temporarily high.

The results for April are similar, but the average difference between the May future and spot prices was not different from zero at a statistically significant level. In

Chicago the May future prices exceeded the spot prices on 6 out of 7 occasions that New York prices were in backwardation, but the average excess was only 1.4 cents. Presumably the future-spot spread was so small in part because the inventory only needed to be held for a month so only a small carrying charge was warranted.

The results for December are most perplexing. In the second week of December, Chicago prices were in backwardation in three of the seven years that New York prices were in backwardation, that is in 1882, 1884, and 1885. On average, the May future price exceeded the spot price by 1.3 cents, but the hypothesis they were equal cannot be rejected at the 5 percent level. Inventories on the three occasions that Chicago prices were in backwardation were below average, but in each case amounted to more than 600,000 bushels. It is not clear why inventories were held on these occasions, although on all of the occasions the spot price had declined substantially in the previous four weeks and the markets appeared to be unusually unsettled. In two of these years, the spot price had fallen sufficiently by the end of December that the future price exceeded the spot price by a considerable margin; indeed, price patterns in the fourth week of December were very similar to those in January, February, and March.[10]. Nonetheless, it would appear that just at the end of the open water transport season the Chicago markets were sufficiently unsettled that norm price relationships did not always hold.

Despite the December patterns, the evidence presented is strongly supportive of the Wright-Williams conjecture. For most of the winter season, when transport prices were temporarily high, inventories were held in Chicago at a positive spread even when prices were in backwardation in New York. They were not shipped to New York because the premium that could be earned for immediate delivery was insufficient to pay the additional transport costs; it was more profitable to keep the grain in Chicago and wait for a cheaper shipping time.

4.2 New York price patterns

A second test is used to examine the reason why inventories were held in New York while prices were in backwardation. In section 2 it was shown that it would be profitable to hold inventories in a month like January even if the spot price exceeded the May future price if prices were expected to increase before subsequently falling. This hypothesis has superficial plausibility, for large volumes of corn were shipped to New York at the end of the open water season in anticipation of the high transport costs over the winter. As such, it is quite possible that price for delivery in one month exceeded the price for spot delivery for much of the winter, as inventories were run down, even though the spot price exceeded the price for May delivery. At least one piece of data is consistent with this story: on average, inventories declined in New York each month between January and April.

The hypothesis can be tested by examining the spread between the one-month future price and the spot price on the occasions that spot prices exceeded the May future price in New York, and testing to see whether the average spreads were positive. There is no support for the hypothesis. On six out of seven occasions that prices were in "long-term" backwardation in December, February, and March, and seven out of eight cases in January, the one-month future price was also below the spot price. It follows that in each month the mean price spread was negative, not positive as hypothesised; in three out of the four months one can reject the hypothesis that the one month future price was equal to the spot price at the five percent significance level, in each case because the future price was less than the spot price.

The explanation for why New York had positive inventories while the spot price exceeded both the one month future and the May future must lie elsewhere. As suggested in section 3, it may be because the elevators were dual purpose and the grain in the elevators was being held in transit rather than held for long term storage.

5 Conclusion

This paper adds to the literature including Benirschka and Binkley (1995), Brennan, Williams, and Wright (1998), and Frechette and Fackler (1999) that has examined the hypothesis that a supply of storage curve may be an artifact of an inappropriate method of aggregating inventory levels. Unlike the other literature, this paper has directly tested whether inventories held in a distant location are held at positive carrying charges when prices in a central market are in backwardation. In the historic episode considered, the answer is an over-whelming "yes": most of the time when corn prices in New York were in backwardation, inventories in Chicago were positive and future prices in Chicago exceeded spot prices. Moreover, the reason why corn was not shipped to New York to take advantage of the temporarily high spot prices is also clear. In accordance with the Wright-Williams conjecture, transport prices were temporarily high in Chicago and it was not worth paying a very high transport price to immediately ship corn to New York to take advantage of the high spot prices in that city.

[10] In the fourth week of December, Chicago future prices exceeding spot prices in six out of the seven years The exception was 1882, a year of considerable irregularity in the Chicago and New York corn

The paper has been able to conduct a very simple test of the Wright-Williams conjecture because futures markets existed in Chicago and New York. It is unusual to find futures markets for the identical commodity in the same proximity for, as Williams (1986) pointed out, if the prices are highly correlated the market with the highest transactions costs will usually shut down. The fact that these two markets existed so close to each other is not a coincidence, however. The seasonality in the transport costs caused by the closure of the Great Lakes shipping lanes every winter meant that the spot-future price spreads in each city were not highly correlated with each other, so the New York futures markets could not be used as a substitute for the Chicago markets. In some sense, therefore, it would be surprising if it had not been found that Chicago prices were in contango while those in New York were in backwardation. The circumstances that meant the test could be carried out are the circumstances where one would expect the conjecture to be true.

The second result of the paper was less obvious. An implication of the Wright-Williams conjecture is that if transport costs are variable, inventories can be profitably held in a centre even if the price for forward delivery is below the spot price if prices are expected to increase before declining. In these circumstances inventories are expected to fall to zero sometime before the future contract expires, but they are not run down immediately as speculators realise it will be unusually expensive to import goods in the mean time. Since New York usually started the winter period with large inventories and ran them down over the winter, it is plausible that this theory could have explained why inventories were held in New York over the winter even though the spot price exceeded the price for May delivery. The theory does not explain the data, however. Quite simply, almost all the time that spot prices exceeded May prices in New York, spot prices also exceeded the price for delivery in one month's time. An alternative explanation for why inventories were held in New York despite prices being in backwardation is needed.

In this historic episode, transport prices varied because of seasonal weather related factors. As Stopford (1988) and Fackler and Goodwin (2001) make clear, however, transport prices vary for a variety of reasons. They could vary because of the price of fuel; they could vary because of capacity constraints in the shipping industry (Brennan, Williams and Wright 1998; Coleman 2008); or they could vary because the transport industry has a steeply rising short run marginal cost curve. A steep upwardly sloping supply curve is common because low cost transport systems (such as rail networks) are capital intensive, and operators minimise costs by limiting capacity but operating it throughout the year. If there is an increase in demand, less capital intensive transport systems (such as trucks) can be used to

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markets.

supplement the capacity; but these systems have higher costs, and so transport costs must rise to justify their employment. For this reason, a short term increase in demand in an importing centre can lead to a steep increase in the price of transport for immediate delivery without affecting the price of transport for future delivery. Even if the variation is not sufficiently regular to justify the existence of a separate futures market, it is plausible that transport cost variation makes it profitable to hold inventories in distant locations while prices in the central market are in backwardation, as in this case. If so, it is quite possible that supply of storage curves for many commodities reflect transport price variability rather than convenience yield.

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Appendix A: Data Sources

Corn Prices.

Prices were collected for Number 2 Yellow corn in Chicago and New York. Spot prices for both cities were collected in the Thursday edition of the New York Times, 1878- 1892. The prices were for the preceding Wednesday, or Tuesday if the Wednesday were a public holiday. If the markets were closed on both Wednesday and Tuesday, the data was skipped for that week. New York futures prices were also collected from the Thursday edition of the New York Times. The Chicago future prices were collected from the Annual Report of the Chicago Board of Trade. In each case, the quotes are for seller delivery: the seller could choose any day to deliver within the said month. Wednesday quotes were collected.

Storage Data.

Storage data for Chicago was sourced from the Chicago Board of Trade Annual Reports. The New York data came from a variety of sources. Where possible, it came from the New York Produce Exchange Annual Reports, but data from 1882 and 1887 came from the weekly newspaper, the Commercial and Financial Chronicle. Information on the cost of storage come from the Chicago Board of Trade and New York Produce Exchange Annual Reports, and from Goldstein (1928).

Transport Data.

The transport cost data were published by the Chicago Board of Trade and New York Produce Exchange Annual Reports. They are similar not identical to the data published in the Aldrich Report, (United States 52nd Congress 2nd Session (1893) *Senate Report 1394: Wholesale Prices, Wages, and Transportation. Report by Mr Aldrich from the Committee on Finance March 3 1893 Part 1*. (Washington: Government Printing Office).

Table 1: April data, 1879-1991

	New York				Chicago				Transport	
	Spot	Stores	F^1-S	F^M-S	Spot	Stores	F^1-S	F^M-S	Spot	May
1879	45.2	0.8	0.3	0.3	34.0	2.9	1.75	1.75	11.20	6.75
1880	54.1	0.7	-6.1	-6.1	35.1	4.3	1.00	1.00	19.60	10.5
1881	58.0	0.3	-3.3	-3.3	41.1	4.0	1.75	1.75	14.00	12
1882	82.9	0.7	-1.6	-1.6	70.9	3.5	3.13	3.13	14.00	7.375
1883	63.9	1.2	0.1	0.1	49.0	7.7	3.69	3.69	16.80	9.25
1884	55.4	1.1	1.5	1.5	48.5	6.8	1.31	1.31	8.40	5.875
1885	54.5	2.1	0.4	0.4	46.5	2.4	1.13	1.13	11.20	8.15
1886	46.0	3.4	0.3	0.3	34.0	3.9	3.75	3.75	14.00	9.26
1887	49.1	1.8	0.1	0.1	34.5	9.4	5.00	5.00	14.00	8.625
1888	65.0	0.1	-3.8	-3.8	48.3	2.7	4.13	4.13	14.00	6.375
1889	43.1	1.0	-0.4	-0.4	34.6	4.2	0.56	0.56	14.00	6.5
1890	38.4	1.3	-0.3	-0.3	30.0	8.7	1.00	1.00	11.20	6
1891	80.5	0.4	-3.9	-3.9	71.4	0.3	-2.00	-2.00	11.20	4
Mean	56.6	1.1	-1.3	-1.3	44.5	4.7	2.01	2.01	13.4	7.7

Spot: spot price in New York or Chicago
Stores: inventories in millions of bushels
F^1-S: one month future price minus the spot price
F^M-S: May future price minus the spot price
Spot transport prices for the second week of April (all rail) and the lake and canal price in the first week of May.

Table 2: March data, 1879-1891

	New York				Chicago				Transport	
	Spot	Stores	F^1-S	F^M-S	Spot	Stores	F^1-S	F^M-S	Spot	May
1879	45.8	1.4	1.0	1.5	33.8	3.2	-1.00	3.13	20	6.75
1880	60.8	0.2	-6.8	-8.0	36.5	5.3	0.13	3.94	20	10.5
1881	57.8	0.6	-1.1	-3.0	37.8	4.5	0.44	4.38	20	12
1882	72.0	2.5	0.6	1.8	62.0	5.3	-1.25	3.69	14	7.375
1883	71.3	0.9	0.4	0.5	57.9	4.9	0.06	3.88	17	9.25
1884	61.6	1.5	0.3	1.1	53.5	6.3	-1.63	2.88	17	5.875
1885	51.5	0.6	-0.5	-1.0	39.3	1.8	-0.69	2.94	11	8.15
1886	49.9	4.4	-0.9	-1.5	37.3	3.3	0.31	3.13	14	9.26
1887	49.5	1.8	0.4	0.4	34.9	6.0	0.31	5.44	17	8.625
1888	60.0	0.7	0.0	-0.3	47.4	2.6		4.38	14	6.375
1889	43.9	1.6	0.1	-0.3	34.4	3.6		1.19	14	6.5
1890	36.2	3.6	0.6	0.9	28.0	3.9		1.69	11	6
1891	69.6	0.4	-1.1	-3.1	60.1	0.3		0.88	11	4
Mean	56.1	1.5	-0.5	-0.8	43.3	3.9	-0.37	3.19	15.3	7.7

Spot: spot price in New York or Chicago
Stores: inventories in millions of bushels
F^1-S: one month future price minus the spot price
F^M-S: May future price minus the spot price
Spot transport prices for the second week of March (all rail) and the lake and canal price in the first week of May.

Table 3: February data, 1879-1891

	New York				Chicago				Transport	
	Spot	Stores	F^1-S	F^M-S	Spot	stores	F^1-S	F^M-S	Spot	May
1879	45.8	1.5	0.3	1.8	31.6	2.9	0.38	4.56	20	6.75
1880	58.5	0.6	-2.8	-5.1	35.0	4.9	0.69	4.75	22	10.5
1881	54.9	1.4	-0.9	-0.6	36.4	4.9	0.25	5.88	20	12
1882	66.6	3.8	1.0	3.6	56.4	5.9	0.38	5.81	9	7.375
1883	72.3	1.0	0.8	0.3	55.3	4.9	0.31	3.38	17	9.25
1884	62.5	1.8	0.6	4.0	53.9	6.3	-0.31	5.00	17	5.875
1885	50.0	0.7	-0.8	-0.9	36.9	1.8	0.25	3.69	14	8.15
1886	51.3	0.8	-1.5	-2.4	36.3	3.3	0.13	3.88	14	9.26
1887	48.1	2.5	0.9	1.6	35.4	6.0	0.31	5.38	17	8.625
1888	59.8	1.5	-0.4	-0.5	46.9	2.6	0.00	4.44	15	6.375
1889	43.8	2.7	0.5	-0.6	34.3	3.6	-0.06	0.88	14	6.5
1890	36.2	3.5	0.6	0.9	28.0	3.9		1.69	11	6
1891	64.1	0.3	-2.0	-4.8	50.6	0.2		2.13	11	4
Mean	54.9	1.7	-0.3	-0.2	41.3	3.9	0.21	3.96	15.5	7.7

Spot: spot price in New York or Chicago
Stores: inventories in millions of bushels
F^1-S: one month future price minus the spot price
F^M-S: May future price minus the spot price
Spot transport prices for the second week of February (all rail) and the lake and canal price in the first week of May.

Table 4: January data, 1879-1891

	New York				Chicago				Transport	
	Spot	Stores	F^1-S	F^M-S	Spot	Stores	F^1-S	F^M-S	Spot	May
1879	47.7	2.7	-1.8	-1.8	29.9	2.4	0.31	4.63	20	6.75
1880	59.4	1.4	-0.2	-1.4	39.8	4.4	0.38	5.06	22	10.5
1881	57.5	2.0	0.3	-2.6	37.5	4.7	0.31	5.13	20	12
1882	70.3	4.9	1.0	3.4	62.3	5.3	0.19	5.38	9	7.375
1883	69.1	1.2	-2.6	-4.6	56.9	2.8	-3.50	-1.88	17	9.25
1884	67.8	2.1	-1.6	-0.9	56.8	3.7	0.00	3.25	11	5.875
1885	54.0	0.3	-4.6	-4.6	37.3	1.6	-0.19	3.56	14	8.15
1886	50.8	1.1	-1.6	-2.6	36.4	2.6	0.13	3.44	14	9.26
1887	47.8	4.0	1.0	3.3	36.1	5.3	0.19	5.75	17	8.625
1888	60.9	1.7	0.1	1.6	48.6	1.4	0.25	5.38	15	6.375
1889	44.5	3.6	0.8	0.9	33.3	2.0	0.88	3.56	14	6.5
1890	41.1	1.6	-2.6	-1.5	29.0	2.2	0.44	2.88	11	6
1891	59.4	0.6	0.4	0.0	49.0	0.2	0.50	3.38	11	4
Mean	56.2	2.1	-0.9	-0.8	42.5	3.0	-0.01	3.81	15.0	7.7

Spot: spot price in New York or Chicago
Stores: inventories in millions of bushels
F^1-S: one month future price minus the spot price
F^M-S: May future price minus the spot price
Spot transport prices for the second week of January (all rail) and the lake and canal price in the first week of May.

Table 5: December, 1878-1890

	New York				Chicago				Transport	
	Spot	Stores	F^1-S	F^M-S	Spot	Stores	F^1-S	F^M-S	Spot	May
1878	47.0	3.4	0.9		30.9	1.7			20	6.75
1879	64.0	1.6	-0.3		41.3	2.5			22	10.5
1880	58.8	2.6	0.5	-1.6	39.9	4.2	0.25	4.94	20	12
1881	70.6	4.9	0.4	3.8	60.6	5.5	0.44	5.50	9	7.375
1882	75.2	1.3	-7.2	-11.8	55.1	1.7	-1.94	-0.38	17	9.25
1883	66.8	3.0	2.1	2.3	59.8	1.5	0.56	3.00	17	5.875
1884	56.3	0.3	-9.0	-9.9	37.1	1.1	-2.50	-0.13	14	8.15
1885	53.6	0.6	-3.5	-4.9	41.2	0.7	-2.63	-1.00	14	9.26
1886	47.8	4.4	0.6	4.0	36.5	3.7	0.31	6.25	14	8.625
1887	61.9	1.7	-0.4	0.8	48.6	1.1	0.13	5.31	14	6.375
1888	47.1	1.4	-0.4	-1.3	34.6	1.7	0.25	3.06	11	6.5
1889	43.0	0.8	-1.0	-1.5	32.0	0.7	-0.75	1.31	11	6
1890	62.9	0.2	-1.0	-1.9	51.4	0.2	-0.25	2.63	11	4
Mean	58.1	2.0	-1.4	-2.0	43.8	2.0	-0.56	2.77	14.9	7.7

Spot: spot price in New York or Chicago
Stores: inventories in millions of bushels
F^1-S: one month future price minus the spot price
F^M-S: May future price minus the spot price
Spot transport prices for the second week of December (all rail) and the lake and canal price in the first week of May.

Table 6: Test of mean spreads when New York May future-spot spread is negative

	New York May-Spot spread mean	variance	t-test	Chicago May-Spot spread mean	variance	t-test	Transport price May-Spot spread mean	variance	t-test
April 7 obs	-2.75	4.46	3.44*	1.37	3.85	1.84	6.46	5.24	7.47**
March 7 obs	-2.46	7.33	2.40	2.97	2.08	5.45**	6.69	4.25	8.59**
February 7 obs	-2.10	4.19	2.72*	3.66	2.81	5.78**	7.69	5.31	8.82**
January 8 obs	-2.50	2.00	5.01**	3.26	5.03	4.10**	7.63	9.75	6.91**
December 7 obs	-5.16	21.54	3.14*	1.30	5.29	1.60	5.94	1.78	12.61**

t-test is a test of the hypothesis that the mean of the difference between the price for delivery in May and the spot price is zero.
* implies the test can be rejected at the 5% significance level.
** implies the test can be rejected at the 1% significance level.

Table 7: One month future-spot premium when New York May future-spot spread is negative

	New York inventories mean	var	F1 –Spot spread mean	var	t-test	Chicago inventories mean	var	F1 –Spot spread mean	var	t-test
March 7 obs	1.21	2.16	-1.47	5.65	-1.64	2.99	3.10	0.05	0.26	0.25
February 7 obs	1.14	0.66	-1.11	1.16	-2.72*	2.65	3.18	0.21	0.07	0.10
January 8 obs	1.55	0.54	-1.84	2.32	-3.42*	3.04	1.25	1.55	0.54	5.95**
December 7 obs	1.19	0.65	-3.43	15.17	-2.49*	1.7	1.73	-1.22	1.73	2.62*

t-test is a test of the hypothesis that the mean of the difference between the price for delivery inone month and the spot price is zero.
* implies the test can be rejected at the 5% significance level.
** implies the test can be rejected at the 1% significance level.

Figure 1: Chicago – New York transport prices, 1879-1891

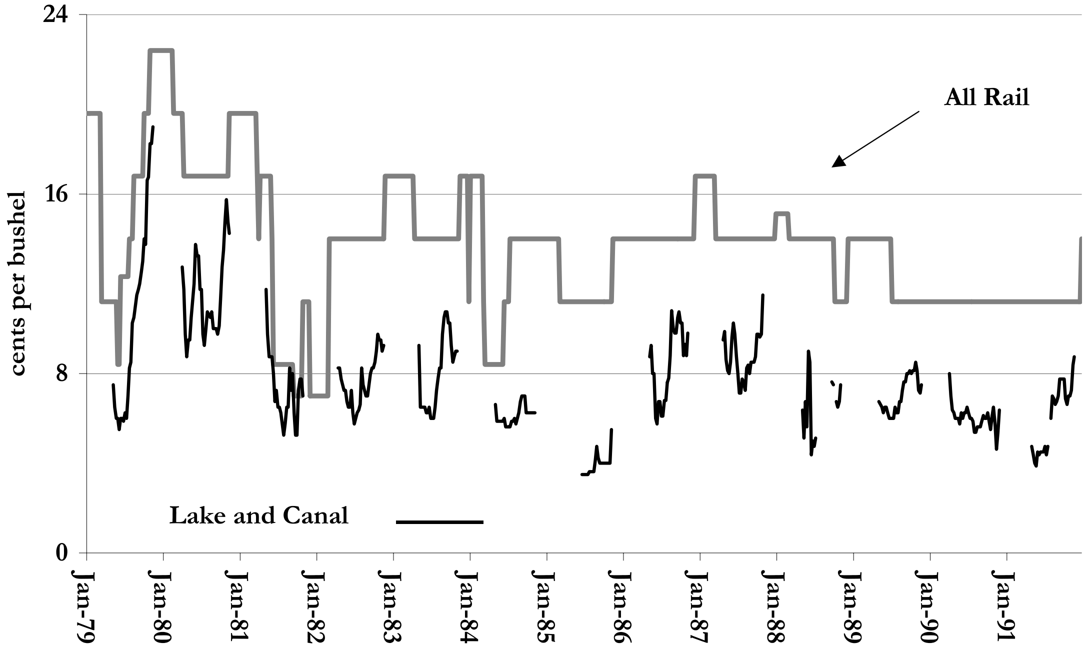


Figure 2: Average transport costs and NY-Chicago spot price difference, 1881-1891

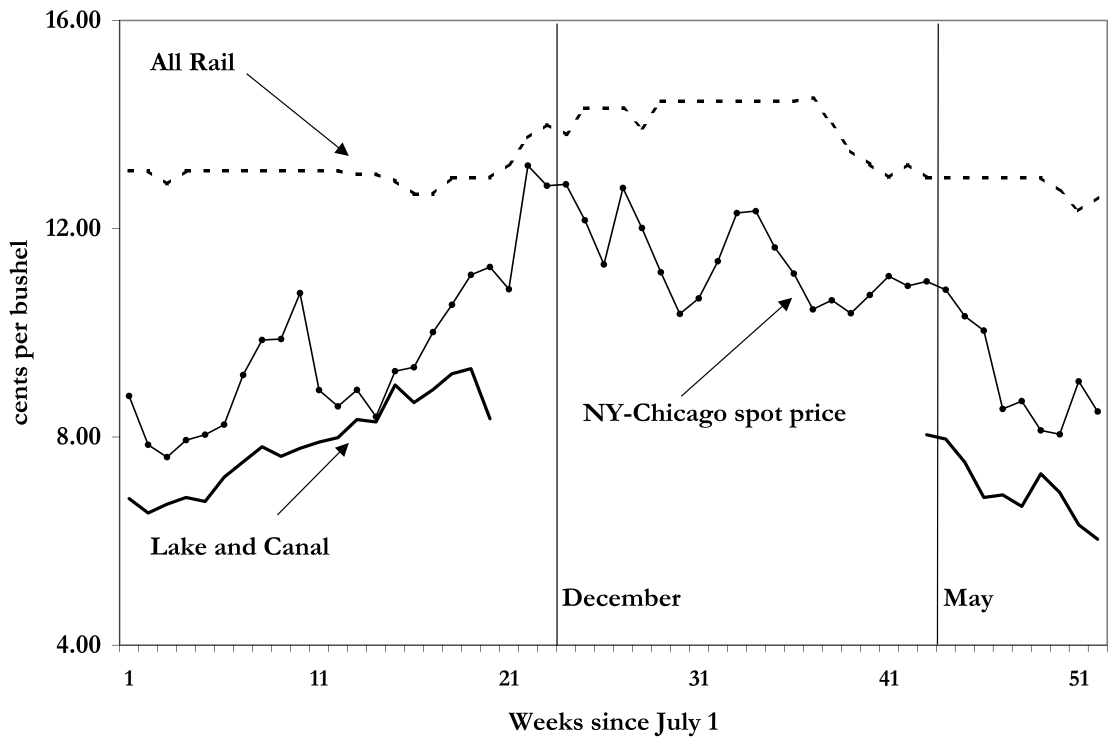
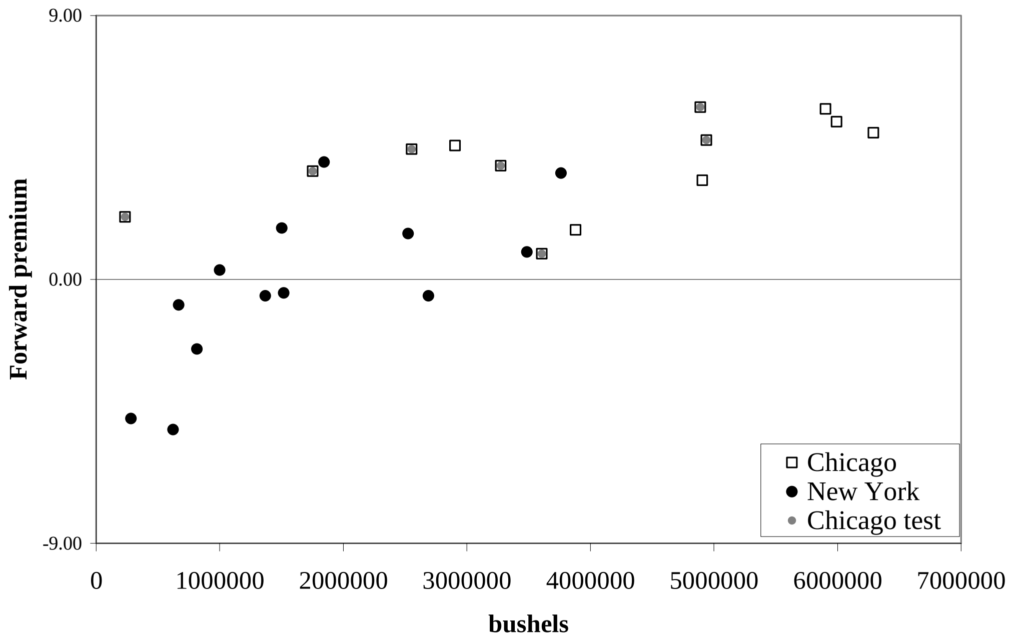


Figure 3: Storage and May future premium, Chicago and New York, February 1879-1891



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