Food vs. Fuel? Impacts of the North Dakota oil boom on agricultural prices

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Abstract

Farmers and politicians in North Dakota and nearby states claim dramatic increases in shipments of crude oil by rail in 2013-14 caused service delays and higher costs. We investigate these claims accounting for other potential sources of rail congestion. We show that grain price spreads between the market hub and regional elevators expanded significantly when crude oil shipments increased. However, the incidence of those effects was borne mostly by buyers paying higher prices at the hub, rather than farmers receiving lower prices. The effects differ by the type of grain being transported. Wheat markets were affected much more than corn and soybeans, most likely because shipping delays were more costly for wheat than corn and soybeans. When rail capacity is scarce, railroads use railcar auctions to price discriminate over the time sensitivity of a shipment.

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1 Introduction

One consequence of the technological revolution in the extraction of fossil fuels has been a dramatic increase in transportation of crude oil by rail. Annual oil shipments from North Dakota increased from about 26,000 cars in 2010 to over 340,000 cars in 2014, which was 50% of all rail shipments from the state. This trend is largely due to hydraulic fracturing and the opening of new regions to large-scale oil and gas production. The oil boom, and its associated impacts on railroads may have caused substantial rail network congestion and declining service quality in 2013 and 2014. Reports at the time claimed farmers and grain shippers bore the brunt of this congestion with long shipping delays, increased storage costs and spoilage (Koba, 2014; Nixon, 2014). This suggests a fundamental trade-off of "food vs. fuel" in a traditionally agricultural state like North Dakota faced with the prospect of rapidly expanding energy development.

To study these claims, we exploit detailed data on grain prices for elevators in North Dakota, South Dakota, Minnesota and Montana, and information on shipments of oil by rail in North Dakota. Using a series of panel regressions, we first show increased oil shipments increased spreads between elevator prices for corn, soybeans and wheat and prices at major grain trading hubs. These effects are particularly large for hard red spring wheat from North Dakota and Minnesota. Then, using time series techniques, we analyze the incidence of the shock and show nearly all of the wheat spread increase comes from an increase in the wheat market hub price with only a small decrease in elevator prices paid to farmers. This contradicts accounts in the popular press of large price impacts of oil by rail shipments on farmers.

Under most framings of the food vs. fuel debate, land is the scarce resource over which producers compete. The main concern is understanding the consequences of devoting farmland to growing biofuel feedstocks instead of food crops. Recent work on biofuel policies and commodity prices studies the extent to which transportation energy policies can spill over to agricultural commodity markets (De Gorter and Just, 2010; McNew and Griffith, 2005; Roberts and Schlenker, 2013; Wright, 2014; Carter, Rausser, and Smith, 2017). A novel feature of North Dakota during this period is that the scarce resource over which producers compete is transportation capacity rather than land. This suggests a new channel through which energy policy can affect food markets. Our results indicate oil shipments did indeed impact grain markets, but the incidence of those effects was borne mostly by buyers such as food processing firms, rather than farmers. The fact that wheat markets were affected much more than corn and soybeans suggests shipping delays were more costly for wheat than corn and soybeans.[1]

There are fewer substitutes for North Dakota hard red spring wheat than for corn and soybeans.[2] Therefore, residual demand for North Dakota wheat production is less elastic than for these other crops. We argue our incidence results and the differential effects for wheat versus corn and soy spreads, come from railroads' use of railcar auctions to price discriminate when rail capacity is scarce leading to service delays.[3] We show that the prices paid in railcar auction markets increased dramatically in 2013-2014, are highly correlated with wheat spread changes, and rise to levels that can account for the entire increase in the wheat spread during the period. Moreover, we find only small increases in tariff rates paid for wheat shipments when oil shipments were high; these increases are substantially smaller than the increase in wheat spreads during the period. Thus, we conclude that the railways used railcar auctions to allocate scarce capacity to the customers with the highest willingness to pay, namely buyers of hard red spring wheat.

We explore several potential mechanisms and effects of increased oil by rail shipments and obtain results consistent with our two main findings. Using shipment level data from the Surface Transportation Board Confidential Waybill Sample, we show increased oil shipments decreased North Dakota corn and soybean shipments but not wheat shipments. When oil shipments increase, shippers in western North Dakota and Montana are more likely to ship

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[1] Pass through of cost shocks has been an area of general interest to economists. The interactions of cost shocks and product prices can be quite complex and are largely dependent upon characteristics of the demand function (Weyl and Fabinger (2013)). Empirically, measures of pass through have been used to diagnose market frictions (Goldberg and Hellerstein (2008)) and assess the incidence of energy taxes (Marion and Muehlegger (2011)) and subsidies (Knittel, Meiselman, and Stock (2017)).

[2] Minnesota and North Dakota produce about two-thirds of the hard red spring wheat produced annually in the United States, but less than 15% of the corn and soybeans.

[3] The term railcar auction is something of a misnomer since grain shipments made under the public tariffs use railroad owned cars and are priced accordingly. Instead, shippers in a railcar auction purchase a guarantee that an empty railcar will be delivered to its facility by a specified date, ensuring timely delivery of their grain.

wheat to West Coast destinations however, we find no evidence of a statistically significant decrease in eastbound shipments from North Dakota. This indicates that while some wheat was rerouted to avoid delays, the incidence of the wheat price shock fell on downstream firms and consumers (to the east), rather than North Dakota farmers or elevator operators. Finally, we investigate wheat storage costs, captured by "carry" calculated from the difference between forward and spot elevator prices.[4] Large increases in storage costs would contradict our finding that wheat shipments were not substantially delayed. While we do find that carry increases with oil shipments, the effect is an order of magnitude less than the spread increase, suggesting only a small increase in storage demand.

Our work builds on several descriptive studies of the effects of oil transportation by rail on grain markets in the Upper Great Plains in 2013-14. As in our study, Olson (2016) uses changes in the price difference between North Dakota and market hubs to argue that rail congestion affected North Dakota farmers. Assuming the incidence of price changes falls on farmers and local elevators, he estimates a loss of over $66 million to North Dakota farmers during the first four months of 2014. Villegas (2016) generates a similar estimate using the same incidence assumption and a two stage least squares estimation strategy. Unlike these studies, we make no incidence assumption *a priori*. Instead, we estimate incidence directly and find the costs of the transportation shock fell mainly on grain buyers rather than farmers and elevator operators.

Further, there is a large empirical literature investigating how the difference between local cash prices for agricultural commodities and prices at major exchanges or export terminals respond to changes in transportation costs.[5] Sorenson (1984) studies the effects of rail rates and deregulation on grain prices. Wilson and Dahl (2011) investigate the effects of shipping costs, including rail tariffs and car auction values on grain prices and Tilley and Campbell

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[4] The difference between commodity spot and forward prices at a given location is commonly termed the "carrying cost" or simply "carry." It is well known that carry provides information about the marginal cost of storage in addition to market expectations and risk premia. For instance, see Brennan (1958) and Working (1949). To the extent these other factors are orthogonal to changes in oil shipments conditional on our control variables, our analysis identifies the relationship between oil shipments and carrying costs.

[5] A related literature investigates how spatial and temporal price spreads interact with transportation and storage (e.g., Benirschka and Binkley (1995), Brennan, Williams, and Wright (1997), Coleman (2009), Frechette and Fackler (1999)).

(1988) highlight the role of exports in addition to other supply and demand factors on Gulf Coast grain prices. Here, we focus on a specific transportation costs shock due to energy development in the Upper Great Plains and the role of price discrimination on the incidence of the cost shock and overall price effects. More recent work by the U.S. Department of Agriculture (2015) argues that increased transportation costs due to rail congestion are a significant factor in explaining why local prices diverge from prices at export destinations or market hubs. However, the authors do not attempt to quantify the effects of oil-induced transportation disruptions on local prices for wheat, corn, and soybeans. Serfas, Gray, and Slade (2018) study how the U.S. and Canadian markets respond differently to rail congestion. They show that rail transportation costs in the Upper Great Plains increased in 2013-14 in response to congestion, whereas in Canada rail congestion rents tend to be captured by grain handling firms because grain freight rates are regulated tightly there. More generally, the trade literature has explored the role of improved transportation technology in market integration. Keller and Shiue (2008) find the development of railroads in 19th century Europe had a substantially larger effect on grain market integration than did customs liberalizations and currency agreements. Donaldson (2018) studies colonial India during the late 19th and early 20th centuries and finds an expanded railroad network decreased trade costs and increased trade and real (agricultural) income levels. Here, we document the regional agricultural market effects of transportation cost shock.

Our results have implications beyond this particular region and episode. While the North Dakota oil boom has subsided since 2013 and 2014, future oil booms in the region or elsewhere could lead to similar rail cost shocks and agricultural market effects. For instance, following several years of decline, oil by rail shipments from Petroleum Administration for Defense District (PADD) two, which includes North Dakota, began rising again in 2018 attaining half the 2013/2014 peak by early 2020. Further, while the effects we study here are due to a particular oil boom, similar impacts could arise from any number of transportation cost shocks. For example, severe winter weather during 2019 led to long service delays in the Upper Great Plains (Kennedy, 2019) and railcar auction prices rose to their highest levels since 2013/2014 (U.S. Department of Agriculture, 2020). Our results shed light on the downstream market impacts of these events.

2 Industry background

Technological advances in drilling technology have dramatically increased U.S. production from non-conventional (shale) oil resources in regions without sufficient oil pipeline infrastructure. As a result, producers have chosen to transport crude via rail tanker.[6] In 2013, approximately 60% of North Dakota crude production was moved by rail.[7] Figure 1 plots monthly oil carloads shipped from North Dakota rail terminals from 2012 through 2015. Shipments peak at approximately 25,000 cars per month, or about 500,000 barrels per day, during late 2013 and early 2014. Rail's share has since declined due to investments in pipeline and refining capacity, and lower oil production caused by the drop in oil prices.

North Dakota grain producers also rely on railroads to transport the majority of their crop to market.[8] In 2014, 90% of North Dakota wheat, 92% of soybeans and 78% of corn moved by rail according to a survey of elevator operators (Vachal and Benson, 2015). North Dakota is the largest producer of hard red spring wheat in the U.S., producing 250 to 300 million bushels per year, approximately half the nation's harvest. Hard red spring wheat is a high-quality wheat variety used to produce flour for breads and hard-baked goods; it makes up about a quarter of all wheat produced in the United States.[9] North Dakota also produces approximately 300 to 400 million bushels of corn and 150 to 200 million bushels of soybeans per year, approximately 2% to 4% and 4% to 5% of U.S. production, respectively (U.S. Department of Agriculture, 2017c).

Grain elevators are located mainly in the southeast corner of North Dakota, western Minnesota and northeastern South Dakota. There are a smaller number of elevators in

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[6] The choice of rail may be a durable one even in the long run. Covert and Kellogg (2017) hypothesize that the flexibility benefits of rail shipping can outweigh the cost advantages of pipelines.

[7] Authors' calculations based on 2013 North Dakota oil production data (North Dakota, 2013) and Genscape (Genscape, 2016) rail loading data.

[8] We use the term grain to include both coarse grains such as corn and wheat and oilseeds such as soybeans.

[9] A further 40% of United States wheat production is hard winter wheat, which is produced in central and southern great plains states such as Kansas. Most of the remaining production is soft winter wheat, which is used for cakes and cookies. Winter wheat is planted in the fall and lays dormant over the winter before sprouting in the spring and being harvested in the early summer. Spring wheat is planted in the spring and harvested in the late summer to early fall. Hard winter wheat is somewhat substitutable for hard spring wheat, although only to a limited extent because of its lower protein content. North Dakota also produces 40 to 60 million bushels of Durum wheat for pasta and a small quantity of hard winter wheat (U.S. Department of Agriculture, 2017c).

western North Dakota and the northeast corner of Montana. Oil terminals are concentrated in the northwest corner of North Dakota. Because transportation costs vary with distance, grain grown further west is more likely to be marketed to Pacific Coast export terminals and grain grown further east in more likely marketed to eastern destinations, including Midwestern processing plants and exporters in the Louisiana Gulf or the Great Lakes. In contrast, oil is shipped to the nations major refining centers in the Northeast, Gulf Coast and to a lesser extent the Pacific Northwest. Because oil moves on the same regional rail network as grain it can contribute to local congestion. More importantly, because rail is a network industry, congestion effects often occur in regional terminals (rail yards) where switching and interchanging occur and through which many shipments must pass. Industry reports during 2014 indicate major delays at terminals in Minnesota and Chicago.

Grain farmers in the Upper Great Plains sell their crop to local elevators, which then market grain to domestic producers or exporters. Elevators in this region are typically owned by farmers' cooperatives or small agribusiness firms. Major elevators offer a variety of forward contracts in addition to daily cash prices for spot deliveries. In addition, corn, soybean and wheat futures contracts are traded at several large commodity hubs. Because there are relatively few elevators in each state, local market power is a potential concern. For instance in North Dakota, our sample consists of approximately 60 elevators. Since truck transportation over long distances is relatively expensive, farmers may be reliant on local elevators to market their crop. However, the effect of local elevator market power is likely mitigated by the fact many elevators are cooperatively owned by the farmers themselves. If elevator operators do exercise market power in local grain purchasing, the response to a transportation supply shock could be larger or smaller than under perfect competition depending on the shape of farmers grain supply (Weyl and Fabinger, 2013).

The Upper Great Plains of the U.S. are served by two large "Class I" railroads, the Burlington Northern Santa Fe (BNSF) and the Canadian Pacific (CP), plus several smaller regional railroads. Railroads ship oil and grain either as part of large unit trains, generally 100 to 110 cars per shipment or as part of smaller multi-car shipments. Unit trains offer dedicated service between one origin and one destination but require facilities capable of loading or unloading 100 cars in several hours.[10] Combined, grains and crude oil represented over 89% of oil carloads originating in and around North Dakota during 2014.[11] Oil share grew from approximately 8% of shipments in 2010 to over 50% by 2014 while total shipments of grain (wheat, soybeans, corn and barley) remained relatively constant.

The pricing of railroad freight shipments has been partially deregulated since 1980. A system of public common carriage tariffs, subject to review by the Surface Transportation Board and loosely based upon cost-of-service principles, is still required of all major railroads.[12] The majority of grain shipments, which originate from a large number of small shippers following an intermittent schedule, fall under common carriage and pay rates based upon the railroads' public tariffs. In principle, the public tariff prices are intended to be "take it or leave it" rates available to any shipper. Further, shipments made under common carriage are generally made on a first-come first-served basis, with no specific guarantees or penalties relating to delivery time. In contrast, shippers in many industries reach private, bilateral arrangements with rail carriers with individually negotiated prices and performance conditions, including terms for timely delivery of empty cars and shipments. The vast majority of North Dakota oil moves under private contract. These distinctions can be important when system capacity becomes constrained.

Railroad congestion can occur when demand exceeds equipment, crew or track capacity constraints. Because rail is a network industry utilizing central terminals for routing and interchanging shipments, congestion can lead to yard delays and regional effects. Further, congestion can have direct spillovers to other railroads when interchange terminals become congested or can have indirect spillovers when shippers divert traffic to other firms. Industry metrics such as the number of cars on line, terminal dwell times, average train speeds, and more recently, prices for cars in primary and secondary railcar markets and the number of ordered cars past-due, can be used as proxies for system performance and congestion (Vachal

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[10] For instance, BNSF requires grain unit or "shuttle" trains be loaded within fifteen hours.

[11] Authors' calculations using the Surface Transportation Board Public Waybill Sample. Since the Public Waybill reports originations by BEA areas, we focus on shipments beginning in the Bismark, Fargo-Moorhead, Grand Fork and Minot areas. These areas include some shipments originating in Minnesota, Montana and South Dakota.

[12] For more details see Wilson and Wolak (2016).

and Bitzan, 2005).

Pricing via common carriage tariff is somewhat rigid and poorly suited to periods of congestion. The tariffs require a 20 day notification period before they can be increased and, because they are available to all shippers on a first come first served basis, are poorly suited to allocating resources to customers with varying delivery priorities. As a consequence, major railroads operate railcar auctions to mitigate congestion and to allocate scarce rail capacity under common carriage (Wilson and Dahl, 2005). The auctions provide supplies of empty railcars that, importantly, are offered with guaranteed delivery windows. For instance, in BNSF's Certificate of Transportation (COT) Program the railroad pays a penalty for car deliveries outside of the guaranteed delivery window. Under these programs, shippers pay a premium for *delivery priority*, in addition to the usual tariff. These mechanisms increase efficiency as shippers' with the highest valuations for timely service are given priority in allocating capacity. Further, auctions equate to rail price discrimination since shippers with higher valuations pay higher prices, *i.e.* the public tariff plus the car auction price (Wilson and Dahl, 2005).[13]

The period from 2013 through 2014 is well-known throughout the industry as a time of congestion and poor rail service quality in the Upper Great Plains. For instance, during the spring of 2014 BNSF had as many as 15,000 past due orders for grain cars (BNSF Railway Company, 2014). The average speed of BNSF grain trains declined from approximately 25 miles per hour during the first quarter of 2012 to approximately 20 miles per hour during the second half of 2014. Dwell times at BNSF's Chicago terminal increased from 29 hours to over 38 hours during the same period. As a result of these delays and shipper complaints, the Surface Transportation Board convened hearings in June of 2014 to investigate delays on the BNSF and CP lines. BNSF reported at the hearings that its agricultural product shipments were running 30 days late on average in June 2014.[14] In addition to increased demand for oil by rail, several factors may have contributed to congestion during this period including: increased freight demand following the Great Recession; severe cold temperatures

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[13] When information about shippers' valuations for service priority is asymmetric, auctions enable railroads to sort customers based on their (heterogenous) valuations for timely service.

[14] See the 6/4/14 report at https://www.stb.gov/stb/railserviceissues/rail_service_reports.html

during the 2013/2014 winter; and large grain harvests in 2013 and 2014.

3 Data

We combine detailed data on elevator-level grain prices with market-level data from central grain trading hubs. We obtained daily spot and forward prices for wheat, corn and soybeans for approximately 60 locations in North Dakota, South Dakota, Montana, Minnesota, Iowa and Nebraska from GeoGrain (2016). We use spot prices to calculate the spread between each elevator and the market hub.[15] We use the forward contract data to calculate carry at each elevator. For wheat, we focus on hard red spring wheat, which represents approximately 75% to 80% of North Dakota wheat production (U.S. Department of Agriculture, 2017c).

Market level prices for the major midwestern grain hubs are from the Agricultural Marketing Service of the U.S. Department of Agriculture (2017b). We use Minneapolis prices for spring wheat and Chicago prices for corn and soybeans. These two cities are par delivery points for the main spring wheat futures contract (MGEX) and the main corn and soybean futures contracts (CME). Therefore, MGEX and CME prices are viewed as nationally representative.

For wheat, we observe daily high and low bid prices by variety (protein content), transportation mode and delivery period. We average high and low bids to approximate average daily price and use only "cash" deliveries made by rail to Minneapolis. Our main results average over the traded wheat varieties.[16] For corn, we use Chicago prices for US #2 yellow. We use only 15-day delivery contracts for rail-truck modes delivered to mills and processors. As with wheat, average daily prices are estimated by averaging the high and low daily bids. Soybean prices are for US #1 deliveries by truck-rail to "Terminals-Mills-Processors-Exporters." As with corn we use prices for 15-day delivery.

We construct time series of locational price "spreads" by combining simultaneous prices

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[15] Our results below aggregate the daily price data to monthly averages. While elevators report prices in most months, there are a few missing elevator month observations in each year resulting in a slightly unbalanced panel.

[16] The varieties are defined by protein content, specifically, 12%, 13%, 14% and 15%.

at various origin and destination pairs. Figure 1 shows that spreads increased substantially as oil carloads peaked in 2014 and 2015. Interestingly, spreads remained relatively constant during the initial increase in oil carloads from 2012 through the spring and summer of 2013. This suggests either railroads had sufficient slack capacity to accommodate the increased oil traffic or grain market participates undertook temporary measures to alleviate the effects of congestion. Anecdotal evidence supports the former. In reports filed with the Surface Transportation Board during 2014, Canadian Pacific data (Canadian Pacific Railway, 2014) show grain car movements exceeded car orders during the late summer of 2013 but fell behind during the fall of 2013 as weekly car requests began to exceed fulfillment. This period coincides with the initial spread increase we see in Figure 1.

Figure 2 shows this effect spatially by plotting the mean spread between elevator and Minneapolis spring wheat spot prices for several months during 2013 and 2014. The colors correspond to the quintiles of spread, with reds indicating larger spreads.[17] Two features stand out. First, spreads tend to be higher in the interior of North and South Dakota. Spreads are on average lower in Minnesota, eastern North and South Dakota. This is consistent with larger transportation costs associated with moving this grain to Eastern markets or Minneapolis. Western elevators, in Montana and western North Dakota, also have lower spreads. Since these elevators tend to ship west to export terminals in the Pacific Northwest, we expect lower average spreads, due to lower transportation costs, for these locations. Second, looking at spreads across months we see average spreads are low, mainly in the first three quintiles, during the beginning of 2013. However, during the fall and winter of 2013 and 2014, spreads increase dramatically. By January of 2014, mean spreads at all elevators fall in the fifth quintile (black).

The timing of this spread shock coincides with the jump in North Dakota oil by rail shipments. Oil shipments increased dramatically from 2012 to 2016 and peak during late 2013 and early 2014. However, numerous other factors could be at play, including changes in demand for other goods shipped by rail, severe weather, seasonal patterns, or shocks to grain production. We attempt to isolate the effect of oil shipments in our empirical analysis

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[17] We calculate quintiles based on the entire sample from 2012 through 2015.

below.

For our measure of oil shipments we use daily car loading data from Genscape (2016). Genscape collects data on the number of cars shipped from twelve terminals in North Dakota. We sum daily shipments at the twelve terminals to monthly totals for the entire state. Because we observe the latitude and longitude of each grain elevator and oil loading terminal it is possible to locate each facility on a railroad network map and to infer the railroad serving each elevator. However, railroad specific measures of oil carloads provided little benefit over our base specification, likely due to the regional impact of congestion.

These data are summarized in Table 1, which shows mean wheat elevator prices, Minneapolis prices and spreads. In addition, we summarize oil carloads and control variables used in the baseline regressions. Several features are worth noting. Mean wheat prices fall from \$8.24 per bushel in 2012 to \$5.06 per bushel in 2015. Elevator prices fall faster than Minneapolis market prices over the period such that mean spreads increase from \$1.49 per bushel in 2012 to \$2.59 in 2014 before decreasing to \$1.95 in 2015. As with the statistics from the Public Waybill Data (Appendix Table 1), we see oil carloads increase dramatically from 8.8 thousand carloads per month in 2012 to 23.5 thousand carloads per month in 2014.

Our analysis below also exploits detailed shipment-level rail prices and quantities from the Surface Transportation Board Confidential Waybill Sample from 2010 through 2014. The data are a stratified sample, covering approximately 6% of shipments, for goods transported by rail in the US. We observe rail revenues and shipment characteristics such as good shipped, shipment size, distance, equipment type, car ownership, origin, destination, basic routing information, originating and terminating railroad. In specifications below that use rail revenue per bushel as the dependent variable, we divide rail revenue by the reported tons shipped and assume 33 bushels per ton to construct a measure of average price.

In addition to our analysis of grain price and quantity effects, we also use the waybill data to measure the total number of cars (excluding oil and grain) moved by both BNSF and CP (BNSF, CP and UP for corn and soy) across their entire networks in a given month. We use this measure in empirical specifications below to account for shifts in the total demand for rail freight that could affect the cost or supply of grain transportation. For instance, industry reports suggest freight traffic grew substantially during the period following the Great Recession.

Finally, to allow for the possibility severe weather may curtail rail traffic, we collect daily weather observations from the National Oceanic and Atmospheric Administration (2017). We use the weather station located at the airport of each state capital and average the daily minimum temperatures to create a monthly temperature measure.

4 Oil carloads and grain prices

Figures 1 and 2 indicate growing price spreads between grain elevators in the upper midwest and trading hubs. Our empirical approach attempts to isolate the effects of increased oil shipments on grain transportation costs from other factors contributing to rail congestion. In particular, increased demand for grain transportation, extremely cold temperatures and the post-recession economic recovery could have contributed to the decline in rail service quality from 2012 through 2014. We find strong evidence the increase in oil shipments increased wheat spreads throughout the Upper Great Plains.

4.1 Empirical approach

To identify the effect of oil shipments from North Dakota on grain prices in the Upper Great Plains we estimate models of the form:

$$P_t^{hub} - P_{it} = \beta Oil_t + \gamma Pdiesel_t \times miles_i + \sum_{m=1}^{12} [Prod_{sy} \times \delta_m] + \xi T_{st} + \zeta X_t + \delta_i + \varepsilon_{it} \quad (1)$$

where P_t^{hub} is the market hub spot price and P_{it} is the spot price at elevator i and month t. Oil_t is the *total* number of oil carloads originating in North Dakota during month t.[18] We assume monthly oil shipments respond to technological changes and oil market conditions and

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[18] We aggregate our data to the month level because grain shipment delays during the congested period averaged 30 days. Results using data aggregated to the week level are very similar to those presented below.

not current grain prices such that our estimates represent the causal effects of oil shipments on grain spreads.

We include the interaction between diesel prices and the distance between elevator i and the market hub, $Pdiesel_t \times miles_i$, to account for the potential impact of fuel prices on railroad costs.[19] Controlling for fuel costs also helps account for any change in trucking competitiveness from changes in price and the difference in fuel efficiency across truck and rail modes. We model time invariant spatial heterogeneity, such as differences in crop quality (*e.g.* protein content), with elevator fixed effects δ_i.

Price spreads typically vary depending on the amount of available inventory, which in turn varies annually based on the size of the harvest and seasonally between one harvest and the next. Harvest size effects may be especially important since the 2013-2014 wheat harvest was historically large. We control for these effects using month mean effects δ_m interacted with total production for each state in a given crop-year ($Prod_{sy}$). Another potential confounding factor relates to extreme weather. Anecdotally, cold winter temperatures due to the 2013-2014 Polar Vortex limited the effectiveness of trains' pneumatic brakes forcing railroads to cut train lengths. To account for the effect of temperature on rail capacity we control for average monthly low temperature (T_{st}) in state s and time t.[20] Finally, freight demand was increasing during the period. We control for changes in total rail freight demand X_t, that may affect rail service in the Upper Great Plains, using the sum of monthly carloads, excluding oil and grain, for BNSF and CP.

The main parameter of interest β measures the effect of monthly oil shipments from North Dakota on elevator-level spreads. We focus on total oil shipment from North Dakota rather than on rail line specific, or other fine geographic measures, because rail congestion typically occurs in regional rail yards due to the network nature of the industry, as dis-

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[19] Distance is calculated "as the crow flies." Specifications using shortest distance routings from GIS rail network data yield very similar results. However, because rail network data are incomplete, the shortest-distance measure increases the number of missing observations. Therefore, we use as the crow flies distance in our results below.

[20] We experimented with more flexible specifications for temperature controls including indicator variables for the deciles of minimum temperature. The estimated relationships between oil carloads and spreads are nearly identical to those presented below using a linear temperature control.

cussed previously.[21] Therefore, the parameter β is identified from time-series variation in monthly oil shipments conditional on the controls described above. Further, oil shipments are plausibly exogenous given that production during the oil boom was driven primarily by the development and deployment of new drilling technology.

4.2 Results

The top panel of Table 2 presents results from several specifications where the dependent variable is the difference between the Minneapolis wheat spot price and the elevator price measured in dollars per bushel. Standard errors clustered by elevator and month of sample (*i.e.* two-way) are shown in parentheses, and the sample period is 2012-2015. Model 1 is the most parsimonious specification with only fuel cost controls. The estimated coefficient on oil carloads shipped from North Dakota is 0.047; it is large, positive and statistically significant. It implies that an increase of 10,000 oil carloads per month is associated with an increase in spread of approximately $.47 per bushel. The estimated effect is substantial, given oil by rail shipments reached nearly 24,000 cars per month in 2014 and mean spreads grew by approximately $1 per bushel between 2012 and 2014.

Looking across the specifications, the estimated relationship between oil carloads and spreads does not vary substantially when additional controls for elevator effects, seasonal effects, harvest size or minimum temperature are added. When total rail traffic is included as a control, model 6, the estimated relationship between oil carloads and spread decreases somewhat to 0.039 but remains statistically significant.[22]

The other parameter estimates support interpreting the spread as a measure of transportation costs. The estimated impact of other rail traffic, measured in thousand carloads per month, is positive and small, though not statistically significant. The estimated tem-

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[21] In earlier versions of the paper we experimented with railline specific measures of oil shipments and found no benefit over the aggregate measure.

[22] Note that the sample size drops from 4442 observations in models 1-5 to 3292 observations in model 6. This is because total rail traffic excluding oil and rail is constructed using the STB waybill sample, which is only currently available through 2013. Estimating model 5 excluding the last year of data yields an oil carload coefficient of 0.044, suggesting about half the difference between model 5 and model 6 is due to the restricted sample.

perature coefficient suggests a decrease in average daily minimum temperature of 10 degrees (Fahrenheit) increases mean spread between \$.05 and \$.08 per bushel. Surprisingly the fuel price-distance interaction effect, in model 1, suggests spread decreases for elevators further from Minneapolis. To the extent spread captures transportation cost, we would expect spreads to be larger for more distant elevators. This result could be due to fact the most distant elevators, in Montana and western North Dakota, typically ship wheat west to export terminals in the Pacific Northwest instead of east to Minneapolis.

For the other major grains produced in the region, corn and soybeans, we find much smaller effects. The middle and bottom panels of Table 2 presents spread models similar to those shown above for wheat. Although the estimated coefficients on oil carloads are positive and in general statistically significant, the point estimates are an order of magnitude smaller than for wheat. An increase of 10,000 oil carloads per month is associated with spread increases of \$0.01 to \$0.06 per bushel for corn and \$0.02 to \$0.08 per bushel for soybeans.

These results may at first seem surprising because wheat, corn and soybeans travel on the same rail network, utilize the same equipment, and often originate from the same elevators. However, the markets for the three crops are quite different. In particular, our sample region includes the majority of hard red spring wheat production. In contrast, corn and soybean production for the Upper Great Plains elevators in our sample represent a modest share of total national corn and soybean production. Thus, residual demand for Upper Great Plains wheat is likely less elastic than for corn and soybeans because there are many more substitute suppliers for the latter crops. If railroads are able to price discriminate, for instance using railcar auctions, we anticipate a given transportation cost shock will increase wheat spreads more than corn or soy spreads, all else equal. Similarly, we expect relatively small quantity effects and that consumers rather than producers would bear the burden of a cost shock. Conversely, while relatively elastic residual demand for corn and soybeans implies producers bear the burden of a cost shock, it also mitigates the magnitude of the spread increase. We discuss these hypotheses further below.

We use Minneapolis spreads in our main regressions since it is the site of price discovery for hard read spring wheat. However, elevators located further west from Minneapolis may ship to the Pacific Northwest (Portland) instead of Minneapolis. If the two spreads diverge, the Portland spread may be more relevant for this subset of elevators. As a check on our main results, we split our elevators into two groups based on their location from Portland and Minneapolis. We assume elevators located closer to Portland than to Minneapolis ship west and replace the Minneapolis spread with the equivalent Portland spread.[23] Table 3 presents the alternate specifications for wheat spreads. We see increased oil shipments have a similar effect on spreads, now either the Portland or Minneapolis spread, as in our main results. A increase of 10,000 oil carloads per month is associated with an increase in spread of approximately $.50 per bushel. The Minneapolis and Portland spreads are highly correlated during this period, suggesting congestion had a similar effect at both locations, consistent with the results in Table 3. Therefore, since the overall result is essentially the same, we use Minneapolis spreads for the remainder of the paper.

5 Incidence

The previous section presents evidence that the wheat price spread between elevators and the market hub increased as oil transportation by rail increased. These results imply the price of transporting these grains increased. Reports during this period claimed farmers and grain shippers bore the brunt of this congestion with long shipping delays, increased storage costs and spoilage (Koba, 2014; Nixon, 2014). If this is true, then we expect the increase in transportation costs to cause a drop in elevator prices. On the other hand, if the incidence falls downstream, we expect to see a relative increase in the market hub prices. In this section, we estimate how much of the incidence fell on elevators and how much fell on the hub. For each grain, we use the average over all elevators in North Dakota as the elevator price.[24] As above, we use the Minneapolis hub price.

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[23] According to this classification, elevators that ship west are all located in Montana. For these westward shipping elevators we replace the Minneapolis spread with the Portland spread. We do not observe Portland spot prices directly, but we do observe the Portland wheat basis (U.S. Department of Agriculture, 2018), which is the spread between the Portland spot price and the Minneapolis futures price. The Portland spread is then equal to the Portland basis plus the Minneapolis futures price minus the spot price at each elevator.

[24] We also conducted our analysis separately for each elevator in North Dakota. The results were similar on average, and we did not observe statistically significant heterogeneity, so we do not report those results

5.1 Empirical approach

Our objective is to decompose the wheat spread effects presented in Table 2 into effects on each of the two prices. We use a cointegrated error correction model over the same 2012-2015 sample period as in the previous section. For parsimony, we include in the model only the two prices and the oil carloads variables. Table 2 shows that the relationship between the spread and oil carloads is robust to including additional controls. For identification, we assume that grain prices do not affect oil carloads within the same week. With this assumption, the impulse response function from the error correction model (which is a restricted vector autoregression) produces dynamic causal effects (Ghanem and Smith, 2019). In essence, we are running regressions of each price on past values of railcars and both prices.[25]

The model is

$$
\begin{aligned}
\Delta P_{hub,t} &= \alpha_{hub}\left(P_{hub,t-1} - P_{ND,t-1} - \beta oil_{t-1} - \delta\right) \\
&\qquad + \gamma_{11}\Delta P_{hub,t-1} + \gamma_{12}\Delta P_{ND,t-1} + \gamma_{13}\Delta oil_{t-1} + \varepsilon_{hub,t} \qquad (2) \\
\Delta P_{ND,t} &= \alpha_{ND}\left(P_{hub,t-1} - P_{ND,t-1} - \beta oil_{t-1} - \delta\right) \\
&\qquad + \gamma_{21}\Delta P_{hub,t-1} + \gamma_{22}\Delta P_{ND,t-1} + \gamma_{23}\Delta oil_{t-1} + \varepsilon_{ND,t} \qquad (3) \\
\Delta oil_{t} &= \alpha_{oil}\left(P_{hub,t-1} - P_{ND,t-1} - \beta oil_{t-1} - \delta\right) \\
&\quad \gamma_{31}\Delta P_{hub,t-1} + \gamma_{32}\Delta P_{ND,t-1} + \gamma_{33}\Delta oil_{t-1} + \varepsilon_{oil,t} \qquad (4)
\end{aligned}
$$

We interpret the correlation between $\varepsilon_{oil,t}$ and the errors in the two price equations as representing causation from oil cars to prices. This interpretation follows from our identification assumption that grain prices do not affect oil carloads within the same week. The α coefficients capture the responses of each price to deviations from the equilibrium price spread. These coefficients play an important role in determining the long-run incidence. We expect $\alpha_{hub} < 0$ and $\alpha_{ND} > 0$. If α_{hub} is larger in absolute value than α_{ND}, then it indicates that, when the spread is above its equilibrium value, equilibrium is restored more by hub prices

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here.

[25] In this approach, a common demand or technology shock that affects the hub and elevator prices equally would not affect the spread and would therefore not be part of the identification in this analysis.

decreasing than by elevator prices increasing.

The β coefficient captures the long-run effect of oil carloads on the spread and we expect it to be similar to the oil carload coefficient reported in Table 2. The γ coefficients capture short-run adjustments. We include a single lag of the first differences because this minimizes the Akaike Information Criterion (AIC). To measure higher frequency price responses, we use weekly data, with prices measured at the end of the week and cumulative oil cars during the week. We used monthly data in Table 2.

As discussed in Section 2, North Dakota is a small producer of corn and soybeans. This means North Dakota producers face an elastic residual demand curve. Its prices move in step with hub prices, and shocks have little effect on spreads, as we show in Table 2. Moreover, the high correlation between elevator and hub price changes makes it difficult to identify separate responses of the two prices to shocks, so the model in (2)-(4) does not work well for these commodities. In the 2012-2015 sample period, the correlations between elevator and hub weekly price changes were 0.95 for corn and 0.92 for soybeans, compared to 0.59 for wheat.[26] Thus, because there is a negligible spread effect for corn and soybeans and because it is difficult to credibly identify separate responses of the two prices, we focus our incidence analysis on wheat.

5.2 Results

Table 4 reports maximum likelihood estimates of the parameters. We apply the Dickey-Fuller GLS test to each series and cannot reject the null hypothesis of a unit root, which validates cointegration analysis. The Johansen trace test rejects the null hypothesis of no cointegration but does not reject the null of a single cointegration relationship. This validates the cointegration specification in (2)-(4), which contains a single cointegration relationship. We use a likelihood ratio statistic to test the null hypothesis that the coefficient on $P_{ND,t-1}$ in (2)-(4) equals one. We cannot reject this null hypothesis with a p-value of 0.40. The AIC is minimized for the model with one lagged change.

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[26] In the pre-oil-by-rail period of 2002-2011, the correlations were even higher at 0.96 for corn and 0.98 for soybeans compared to 0.83 for wheat.

Estimates of the cointegrating vector are somewhat larger than those in Table 2 in the previous section. The coefficient on oil carloads is 0.31, which translates to an effect of $0.31/(52/12) = 0.072$ at the monthly frequency. We obtained 0.035–0.048 in Table 2 depending on the specification. The error correction terms show that, when the spread is one unit above its equilibrium, the hub price responds the next week by decreasing by 0.13 units and the North Dakota price increases by 0.03 units depending on the specification. These estimates reveal robust evidence that hub wheat prices respond much more to shocks than do North Dakota prices.

To quantify the effect of an oil car shock on the two wheat prices, we compute the impulse response function of prices to a shock to oil carloads. Impulse responses quantify the dynamic causal effect of a shock to one variable on the variables in the model (Ghanem and Smith, 2019). The long-run impulse response corresponds to a long-run causal effect. Table 4 shows that a 1000 railcar per week increase in oil carloads predicts a $0.31 increase in Minnesota wheat prices and a negligible decrease in North Dakota prices. These estimates imply that the incidence of the oil-by-rail boom fell entirely on buyers of wheat. This is consistent with the conclusion that flour millers in Minneapolis were prepared to pay a premium to avoid supply disruptions.

The supplementary appendix shows the results if we treat the oil-by-rail boom as a discrete event and apply the Relative Price of a Substitute method as in Carter and Smith (2007). The results also imply that the incidence falls mostly on buyers. As shown in Appendix Figure 1, Minneapolis prices increased beginning in early October 2013, whereas North Dakota prices decreased in this period. The spring wheat harvest occurs in September and October and spot prices usually decrease around this time as the market absorbs an influx of new product. The estimates clearly show the incidence of the transportation cost shock falling mostly on Minneapolis buyers.

Overall, these results suggest the residual demand in Minneapolis for North Dakota wheat is relatively less elastic than corn or soybeans. Because North Dakota produces half of the spring wheat grown in the US, buyers have fewer options than for other grains. Therefore, Minneapolis purchasers need to offer a higher price to attract wheat from North Dakota when transportation costs increase. In contrast, North Dakota produces between 2% and 5% of US corn and soybeans, so it is not able to materially affect prices in Chicago, which is the site of global price discovery through the CME futures markets.

6 Why was wheat more affected than corn or soybeans?

The wheat spread results presented in Table 2 show that large shocks to grain transportation costs occurred concurrently with the increase in shipments of oil by rail in North Dakota. Table 4 shows that the incidence of these effects fell mainly on wheat consumers as opposed to farmers. Further, the effects of rail congestion on corn and soybean spreads were substantially smaller compared to wheat. This latter finding presents a puzzle because all three grains are shipped along the same routes using similar equipment, and so one would expect them to be affected similarly. The wheat spread increases during the oil boom could be the result of several different factors including rail price increases, congestion-related shipping delays or increased grain storage costs. In this section we investigate each of these possibilities. The specific mechanisms and any differential effects for wheat versus corn and soybeans help explain this puzzle.

We first investigate the response of rail rates to oil shipments. Congestion due to oil shipments may appear as higher tariff rates for grain shipments. Larger increases for wheat compared with corn or soy shipments and would explain the differences in spreads we observe. Our approach follows Equation (1), except with average rail *revenue per bushel* as the dependent variable in place of spread.[27]

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[27] The STB Waybill data used here necessitate several minor changes to Equation (1). In the Waybill Sample we observe shipment origination by county, not elevator. Therefore, we use county fixed-effects instead of elevator effects. We also replace the fuel price-distance interaction with fuel prices (un-interacted), and rely on county fixed-effects to capture differences in shipment distance. To maintain consistency between our dependent and independent variables, we construct the oil carloads variable using the Surface Transportation Board Confidential Waybill sample instead of the Genscape data noted above. We model harvest shocks and seasonality using crop-year production and month-effects using the approach discussed previously. Unobserved heterogeneity across counties originating shipments is captured with mean effects.

Table 5 presents results from several specifications. We focus on wheat shipments from Minnesota, Montana, North Dakota and South Dakota. Across all models, our estimates imply a modest positive relationship between oil carloads and rail rates. An increase of 10,000 oil carloads per month is associated with an increase in rail rates of approximately $0.06 per bushel. Looking at heterogeneity across states, model 5 implies the effect for shipments originating in Minnesota is approximately twice as large as for other states, approximately $.11. However, even this effect is substantially smaller than the large spread increases, $.35 to $.49 per bushel, for the same increase in oil shipments.[28]

The relatively small magnitude of these coefficients may be due in part to railroads' reluctance or inability to adjust tariff prices to market conditions in the short run. For instance, federal law requires railroads give shippers twenty days notice prior to any rate increase.[29] Sticky prices may also reflect menu costs or the desire to avoid regulatory scrutiny stemming from firms charging substantially different prices for similarly costly shipments. However as discussed above, railroads have established railcar markets to allocate capacity in times of high demand or congestion.[30] Because cars purchased on these auctions have guaranteed delivery windows, prices capture shippers' willingness to pay to avoid congestion-related delays. Figure 4 plots rail car auction prices for the BNSF railroad. Prices shown are from the secondary market where third parties buy and sell car contracts previously purchased from BNSF's car market.[31] We divide car prices by 3,500, the approximate capacity in bushels of a covered hopper car, to obtain a measure comparable to our grain price spreads. Prices for shuttle and non-shuttle shipments are plotted separately alongside the mean spread, calculated at the week level, across all wheat elevators in our sample.

Looking at BNSF auctions, we see car prices begin to increase during the middle of 2013.

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[28] In unreported results we conduct a similar analysis of rail tariffs for corn and soy bean shipments. For both grains, we estimate a small positive relationship between rail rates and oil shipments for originations in North Dakota. These estimates are comparable to the spread increases we estimate for North Dakota corn and soybean shipments in Appendix Table 2. The estimated relationships are smaller, and sometimes negative, for originations in other states. Interestingly, for shipments beginning in North Dakota, the estimated effects for wheat, corn and soybeans are of similar magnitudes.

[29] The twenty day notification period is specified as part of rules governing common carriers, U.S. Code, Title 49, Chapter 111, Subchapter I.

[30] The number of cars offered at auction in a given month is small relative to total car demand, on the order of a few percent, nevertheless, auction prices reflect the value of delivery priority for marginal shipments.

[31] Data from BNSF's primary auctions show similar patterns.

Shuttle prices reach a peak of approximately \$1.68 per bushel (\$5,875 per car) in early 2014, fall over the summer and reach a second peak of approximately \$1.67 per bushel during the fall of 2014. Mean spreads are positively correlated with car prices over the period from 2013 through 2014. Moreover, a simple regression of wheat spread on shuttle prices yields a coefficient of 0.98. The striking similarity of the time series suggest BNSF's car auction markets are an important mechanism of grain shippers' response to increased oil traffic (congestion, or market conditions) during this time period.

High car auction prices suggest some shippers are willing to pay a premium for delivery priority. However, because all three grains in the Upper Great Plains are covered by the same market, we are unable to determine which shippers are purchasing cars at auction. Therefore, we investigate changes in grain shipment quantities using the STB Waybill sample. Decreases in grain carloads shipped suggest some grain is put into storage, potentially for sale and transport at a later date. If instead, grain quantities do not respond to congestion from oil shipments, this may reflect shippers' use of car auctions to avoid shipping delays.

To estimate quantity effects we again follow the empirical approach used for spreads and tariff rates above but instead use total rail *carloads* shipped by county and month as the dependent variable.[32] Table 6 presents results from our analysis of county-level wheat shipments. The estimated coefficients on oil carloads are negative and are statistically significant in specifications that control for total rail traffic. On average, a 10 percent increase in oil carloads is associated with a 0.45 percent decrease in monthly wheat carloads shipped by rail. Model 5 suggests an effect about twice as large for counties in Minnesota and South Dakota, but little to no effect in Montana and North Dakota.[33] The lack of a substantial

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[32] The nature of grain shipments requires several small changes to Equation (1) Because the timing of the harvest varies from year to year due to weather and other factors, demand for grain transportation depends on timing relative to harvest and not the calendar year. To account for these shifting patterns, we use crop progress reports to identify the week in which the percent of wheat acres harvested first exceeds 90 percent. Crop progress reports were obtained from the U.S. Department of Agriculture (2017a). We use average values across the major states producing each grain as determined by USDA. Harvest dates based on this definition range from early September to early December depending on crop and year. We then define a series of 4-week intervals relative to this date for each crop year. We model annual patterns in grain transportation demand as a series of mean effects using indicator variables for each of these 4-week blocks. To account for differences in scale across counties, the dependent variable is the natural logarithm of the total number of wheat carloads shipped from each county in a given month.

[33] The relatively larger effects in Minnesota and South Dakota could be the result of substitution to trucks, which is a more viable option for elevators closer to Minneapolis.

quantity effect for wheat shipments from North Dakota is consistent with the railcar auction mechanism.

Next, we conduct a similar exercise looking at corn and soybean shipments. Table 7 shows evidence of quantity reductions in corn and soybean shipments. Increased oil shipments reduce corn shipments everywhere except South Dakota. For soybeans, shipments decrease in Iowa and North Dakota but increase in South Dakota. Note that while we find no relationship between oil shipments and wheat quantities in North Dakota. We do find modest negative effects for corn and soybean shipments. These results highlight the possibility of intertemporal substitution of wheat for corn or soybean shipments. In other words, one potential response to rail congestion is to store corn and soybeans in order to continue shipping wheat.

Figure 3 shows North Dakota corn and soybean shipments deviate from their historical patterns during the congested period while wheat shipments are relatively unaffected. We plot total (cumulative) carloads of wheat, corn and soy shipped from North Dakota by crop-year month as a percentage of the total quantities of those grains transported during the year. During the 2013 crop year, North Dakota wheat shipments closely follow the 2010-2012 average, suggested limited shipping disruptions. However, shipments of both corn and soybeans fall below historical levels early in the crop year before catching up later in the year. This pattern is consistent with intertemporal substitution whereby corn and soy shipments are delayed in favor of shipping wheat.

We look to grain storage markets for evidence that would contradict our wheat shipment quantity results. Anecdotes from 2013 and 2014 suggest elevator operators increased grain storage because they were unable to ship out grain on congested railroads. If an increase in demand for storage coming from delayed shipments increases the price of grain storage, this effect should be captured by "carry" metrics, *i.e* the difference between spot and forward month prices, during this period. Intuitively, carry captures the storage premium associated with delivery at a future date relative to today. If the marginal cost of storage is non-zero, carry will be positive. The relationship between carry and oil shipments will be positive if storage costs are increasing in quantity and more oil shipments lead to more storage.

We construct several measures of "carry" that compare spot prices with prices for future deliveries. Using these carry measures as our dependent variables we again estimate models of the form of Equation (1).

Table 8 presents results using 1-month, 3-month and 6-month horizons. We divide the calculated carry by the horizon to obtain a estimate comparable across models. Further, we estimate models that allow for heterogeneity across states. There is some evidence of a positive relationship between oil shipments and carry. For 6-month carry, a increase of 10,000 oil carloads per month is associated with an increase in carry of approximately $0.02 per bushel per month for Minnesota elevators. This is consistent with the results presented in Table 6 where Minnesota counties experienced the largest reductions in wheat shipments during the oil boom. The estimated relationship is about half as large in North and South Dakota. To put these numbers in perspective, MGEX and CME cap storage costs on grain delivered on futures contracts at $0.05 to $0.07 per bushel per month. In light of these reference points, our estimates are nontrivial, but they are small relative to our estimated increase in wheat price spreads.[34] These small effects are consistent with small changes in North Dakota wheat shipments documented above. If wheat shipments were being delayed, then we would expect to have seen a substantial increase in the price of storage.

Overall, the all of the effects in also consistent with the incidence results presented in Section 5. If the incidence had fallen on North Dakota elevators and farmers, we would have expected substantial reductions in quantities shipped and increases in storage costs. Instead, we find only small effects on wheat quantities limited intertemporal substitution as compared to corn and soybean shipments originating in North Dakota, and small increases in storage costs. The large spread differences can be explained by the auction mechanism railroads used to allocate scarce rail capacity. In these auctions, shippers pay a premium for access to a railcar during a specified time window, thereby enabling them to avoid shipping delays. The greater diversity of corn and soybean supply meant that purchasers of these grains had the ability to substitute over space and time for North Dakota sources of these crops. Conversely, the concentration of hard red spring wheat production in the Upper Great Plains

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[34] Analogous results for corn and soybeans, available upon request, suggest a small negative relationship between increased oil car shipments and carry.

left consumers of this grain with few substitutes, implying a less elastic residual demand for North Dakota wheat than for North Dakota soy or corn. As a result, higher auction prices drove up the price of wheat at the Minneapolis market hub.

7 Conclusions

The shale revolution has generated tremendous changes in not just the amount, but also the geography of oil production. The rapid increase of gas and oil production in locations such as North Dakota has outpaced the expansion of traditional pipeline infrastructure and led to a much greater reliance on rail transportation than in regions with an older and established oil industry. While the reliance on railroads to transport shale oil may have been borne of necessity, it could very well be a lasting relationship. The flexibility of rail infrastructure presents significant advantages relative to pipelines in the face of uncertainty in both production and prices. Going forward, periodic or even chronic rail transportation capacity constraints could be the norm in shale heavy regions.

We show that the massive increase in oil shipments out of the upper great plains created congestion in rail networks, which in turn impacted the spatial relationship of commodity prices, particularly for wheat. We find that the price spreads between wheat production centers and commercial hubs grew substantially during this period, and that oil shipments had a significant impact on regional prices. These findings are consistent with news coverage that highlighted the plight of farmers facing difficulties shipping their output to market.

Our results highlight several more subtle aspects of the relationship between grain prices and transportation costs. First, price impacts were substantially larger for wheat compared to corn or soybeans, grains that are shipped along the same routes using similar equipment. Second, the incidence of this shock to transportation costs was borne largely by buyers of wheat rather than by farmers. Both of these findings are consistent with railroad price discrimination and the observation that residual demand for North Dakota wheat was considerably less elastic than that for corn or soybeans, for which many alternative regional sources were available. Moreover, although we study rail congestion induced by oil production, we expect that other shocks to rail capacity in the region would have similar effects.

Last, our paper shows the important role of railcar auctions as a mechanism for rationing scarce rail capacity. We find that, while rail tariffs for grain transportation are significantly impacted by oil shipments, the magnitude of these effects are nowhere near as large as the resulting increase in grain price spreads. These tariffs played a decreasing role in shipping costs as oil traffic reached its peak. Because they are available to all shippers and may reflect regulatory constraints on the timing of price adjustments, these tariffs may be ineffective in separating high priority grains and consumers from lower priority ones. Railcar auctions on the other hand, create a mechanism for price discrimination by allowing shippers with higher valuations for timely shipping to pay a premium for priority service.

Grain shipments were increasingly influenced by auction prices. When these auction rates are combined with the traditional open-access tariff rates, they explain almost all of the observed differences in wheat locational commodity prices. Further, we find increases in oil shipments led to decreases in shipments of corn and soy, but not decrease in wheat shipments. These results are consistent with an interpretation that the railcar auctions were used as a mechanism to allocate scarce capacity to the customers with the highest willingness to pay, namely buyers of wheat in Minneapolis.

Because the shale oil phenomenon is still relatively new, our sample is necessarily limited to five years or less. While this is sufficient to capture substantial variation in the utilization of northern rail networks as oil prices rose and then fell, it is insufficient to empirically estimate long-run effects. In particular there are not enough growing seasons captured in our sample to test whether planting patterns would have changed had oil prices remained at 2012-14 levels for a substantially longer period.

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Figures

Figure 1: North Dakota oil carloads, wheat prices and wheat price spread.

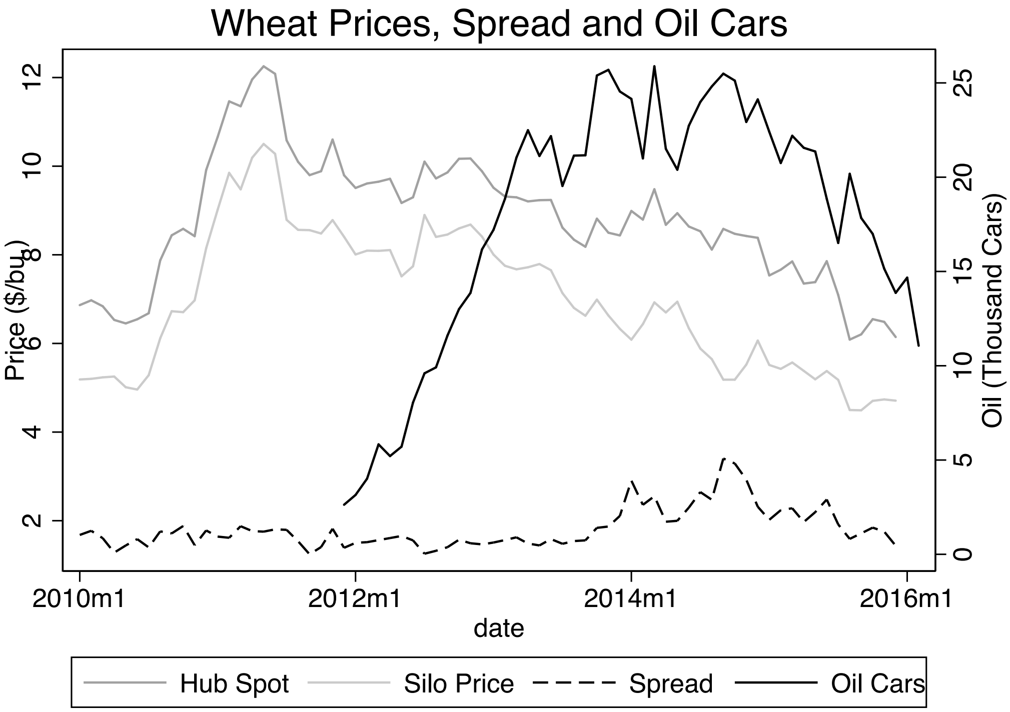
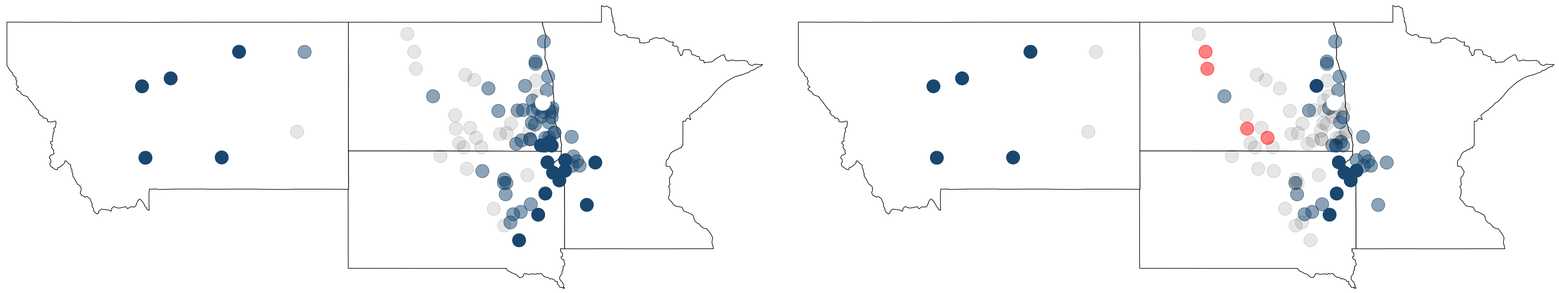
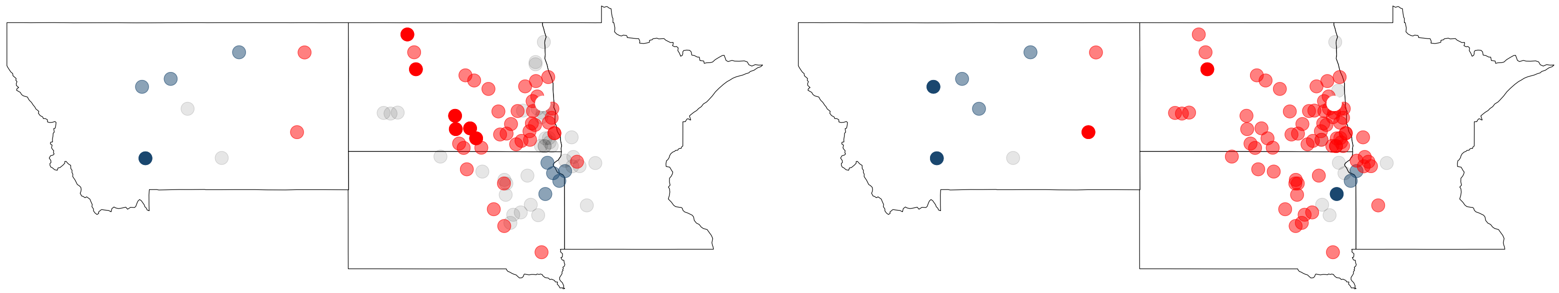


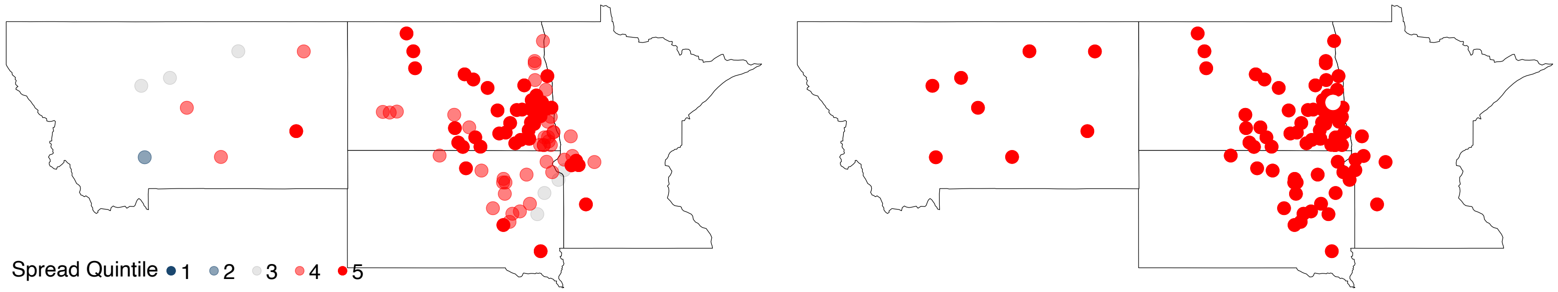
Figure 2: The progression of elevator-level wheat spreads before and during the period of rail congestion.


(a) Jan. 2013

(b) June 2013


(c) Oct. 2013

(d) Nov. 2013


(e) Dec. 2013

(f) Jan. 2014

Figure 3: Time shifting in the transportation of North Dakota grain.

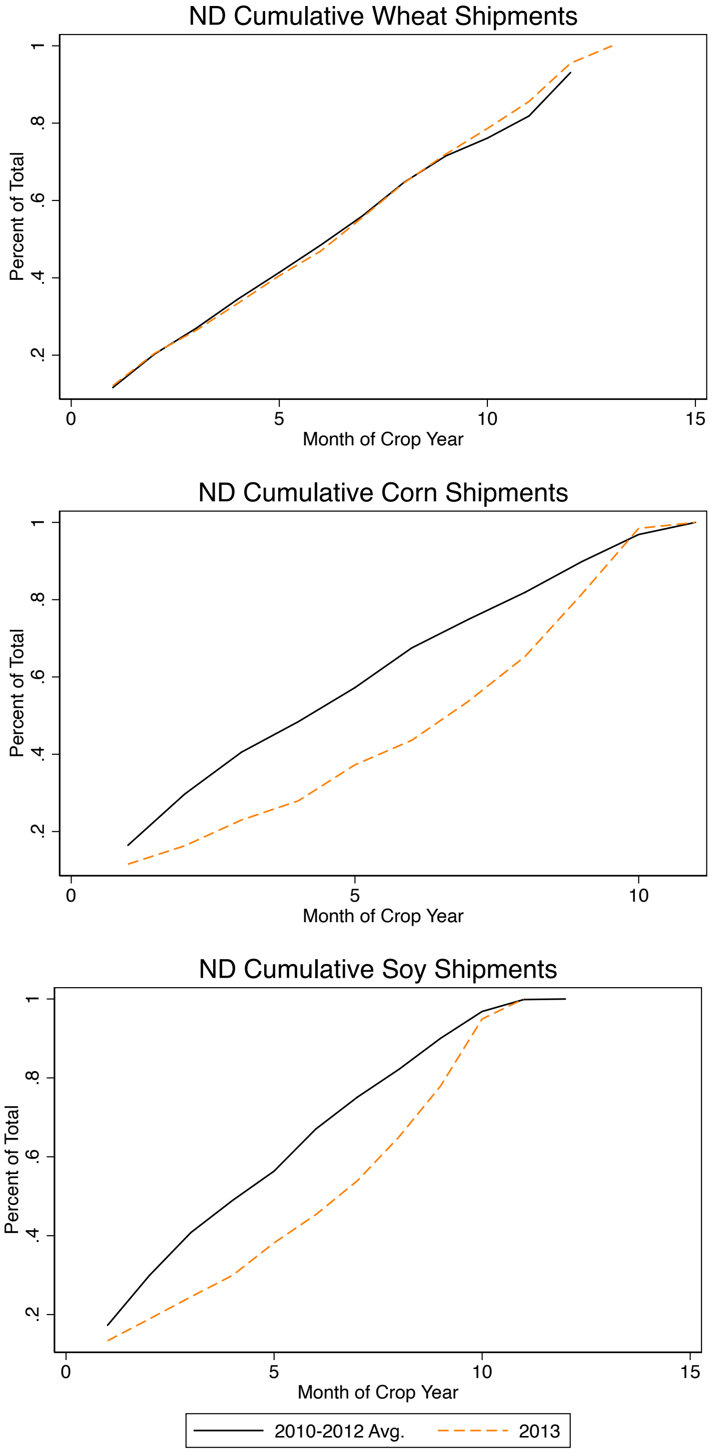
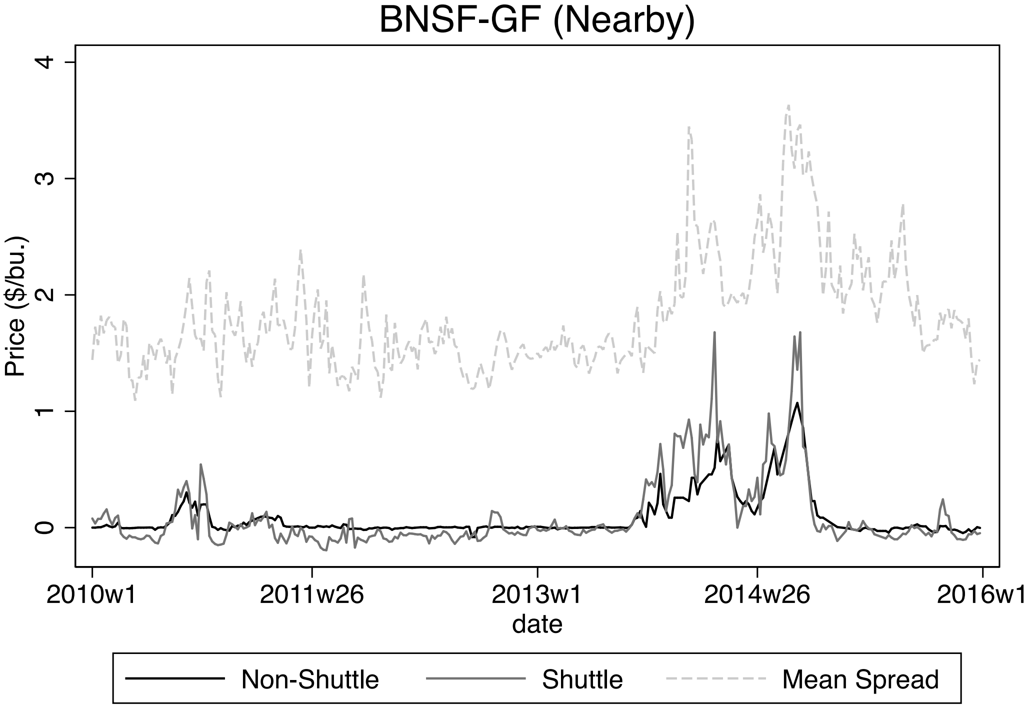


Figure 4: Secondary grain car market prices and spreads. Car prices converted to dollars per bushel assuming 3,500 bushels per car.



Tables

Table 1: Wheat elevator cash prices, Minneapolis (MGEX) hub price, spreads, oil carloads and control variables.

	Mean	Std. Dev.	Min.	Max.
Wheat Spread Regressions				
Cash Price ($/bu.)	$ 6.66	$ 1.32	$ 4.08	$ 9.26
Minneapolis Spot - Cash Price ($/bu.)	$ 1.91	$ 0.55	$ 0.59	$ 3.87
Total Oil Cars (1000/month)	18.11	6.40	3.15	25.88
Diesel Price ($/gal.)	$ 3.55	$ 0.56	$ 2.26	$ 4.08
Dist. to Minneapolis (100 mi.)	3.03	1.65	1.10	8.77
Avg. Min. Temperature (degrees)	33.04	19.09	-3.65	67.81
Total Rail Traffic (1000/month)	754.10	42.77	670.87	838.63
Wheat Harvest (Million bu.)	231.84	107.36	66.47	370.02
Wheat Price and Quantity Regressions				
1-Month Carry ($/bu.)	-$0.007	$0.058	-$0.620	$0.300
3-Month Carry ($/bu.)	-$0.006	$0.060	-$0.236	$0.145
6-Month Carry ($/bu.)	-$0.009	$0.055	-$0.172	$0.103
Wheat Price and Quantity Regressions				
Wheat Carload (Cars/month)	236	189	36	1,542
Rail Price ($/bu.)	$ 1.31	$ 0.45	$ 0.04	$ 7.07
Oil Carloads	12.65	10.66	0.08	32.46
Diesel Price ($/gal.)	$ 3.65	$ 0.41	$ 2.77	$ 4.10
Avg. Min. Temperature (degrees)	33.26	19.33	-3.89	72.50
Total Rail Traffic (1000/month)	666.11	90.11	47.27	757.37
County Wheat Harvest (Million bu.)	5.95	5.40	0.00	24.09

Table 2: Wheat, corn and soybean price spreads and oil carloads.

Grain Price Spreads and Railroad Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
			Wheat			
Oil Carloads (thousands)	0.047***	0.047***	0.048***	0.048***	0.047***	0.039***
	(0.0090)	(0.0090)	(0.0080)	(0.0090)	(0.0090)	(0.0100)
Diesel Price X Miles	-0.011***	0.000	-0.003	-0.005	-0.007	-0.376***
	(0.0040)	(0.0190)	(0.0170)	(0.0180)	(0.0180)	(0.1340)
Average Daily Low Temp.					-0.005	-0.008
					(0.0040)	(0.0050)
Rail Traffic Excl. Oil and Grain						0.002
						(0.0030)
Observations	4442	4442	4442	4442	4442	3292
Adj. R-sq.	0.32	0.37	0.41	0.41	0.42	0.48
			Corn			
Oil Carloads (thousands)	0.006**	0.005*	0.005**	0.003	0.005**	0.001
	(0.0030)	(0.0030)	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Diesel Price X Miles	0.028***	0.003	0.003	0.004	0.006	0.008
	(0.0030)	(0.0050)	(0.0050)	(0.0040)	(0.0050)	(0.0240)
Average Daily Low Temp.					0.004***	0.001
					(0.0010)	(0.0010)
Rail Traffic Excl. Oil and Grain						0.001***
						0.0000
Observations	5413	5413	5413	5413	5413	4090
Adj. R-sq.	0.37	0.65	0.74	0.71	0.75	0.78
			Soybeans			
Oil Carloads (thousands)	0.008**	0.006*	0.006*	0.004	0.007**	0.002
	(0.0040)	(0.0030)	(0.0030)	(0.0030)	(0.0030)	(0.0030)
Diesel Price X Miles	0.040***	-0.001	-0.001	0.006	0.009*	0.043
	(0.0050)	(0.0060)	(0.0050)	(0.0060)	(0.0050)	(0.0360)
Average Daily Low Temp.					0.008***	0.005*
					(0.0020)	(0.0030)
Rail Traffic Excl. Oil and Grain						0.002***
						(0.0010)
Observations	5202	5201	5201	5201	5201	3910
Adj. R-sq.	0.32	0.58	0.61	0.60	0.63	0.63
Market (Silo) Effects	No	Yes	Yes	Yes	Yes	Yes
Month Effects	No	No	Yes	Yes	Yes	Yes
Harvest X Month Effects	No	No	No	Yes	Yes	Yes

Notes: Dependent variable is the difference between silo cash price and market hub spot price in dollars per bushell. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. Standard errors clustered by silo and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 3: Wheat spreads and oil carloads for Pacific Northwest and Minneapolis destinations.

Wheat Price Spreads (Portland or Minneapolis) and Railroad Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Oil Carloads (thousands)	0.047***	0.047***	0.048***	0.049***	0.048***	0.038***
	(0.0090)	(0.0090)	(0.0080)	(0.0090)	(0.0090)	(0.0100)
Diesel Price X Miles	-0.009*	-0.010	-0.014	-0.017	-0.021	-0.509***
	(0.0050)	(0.0210)	(0.0180)	(0.0200)	(0.0200)	(0.1350)
Average Daily Low Temp.					-0.005	-0.009*
					(0.0040)	(0.0050)
Rail Traffic Excl. Oil and Grain						0.002
						(0.0030)
Market (Silo) Effects	No	Yes	Yes	Yes	Yes	Yes
Month Effects	No	No	Yes	Yes	Yes	Yes
Harvest X Month Effects	No	No	No	Yes	Yes	Yes
Observations	4442	4442	4442	4442	4442	3292
Adj. R-sq.	0.32	0.37	0.42	0.41	0.42	0.51

Notes: Dependent variable is the difference between silo cash price and either Portland or Minneapolis spot price in dollars per bushell. Average low temperature is the average of recorded daily low temperatures in each state capital each week. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. Standard errors clustered by silo and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 4: Cointegrated Error Correction Model for Weekly Wheat Price Changes

Cointegrated Error Correction Model for Weekly Wheat Price Change

	Hub Price	ND Price	Oil Cars
Cointegrating Vector			
Oil Carloads (β)		0.31***	
		(0.073)	
Constant (δ)		0.71**	
		(0.32)	
Error Correction Equations			
Error Correction Term (α)	-0.13**	0.03	0.06
	(0.05)	(0.03)	(0.08)
Lagged Change in Hub Price (γ_1)	-0.13	-0.04	0.21
	(0.09)	(0.05)	(0.13)
Lagged Change in ND Price (γ_2)	0.06	0.08	-0.23
	(0.14)	(0.09)	(0.22)
Lagged Change in Oil Carloads (γ_3)	0.03	0.06**	-0.34***
	(0.05)	(0.03)	(0.07)
Long-Run Impulse Response to Oil Carloads	0.31	0.00	1000
(LR shock size: 1000 cars/wk)			
Unit Root and Cointrgration Tests			
DFGLS Unit Root test (5% cv = -2.93	-2.84	-2.58	-1.34
Trace test for no cointegration (5% cv = 34.91)		29.36**	
Trace test for one cointegrating vector (5% cv = 19.96)		10.18	
Diagnostics			
Sample Size		206	
LR test of identifying restrictions (p-val)		0.40	
corr($\varepsilon_{hub,t}$, $\varepsilon_{ND,t}$)		0.62	
LLF		-3478.40	
AIC (0 lagged changes)		33.986	
AIC (1 lagged change)		33.907	
AIC (2 lagged changes)		33.948	

Notes: Estimation using maximum likelihood (vec command in Stata). Each week's ND price is the average daily price across all elevators reporting prices in that week in $/bu. Hub prices are Minneapolis. Oil carloads in thousands. DFGLS test implemented using dfgls command in Stata and with lag length chosen by SIC. Sample period: 1/01/2012-12/31/2015. Frequency: weekly. Standard errors in parentheses. Impulse responses identification assumption: grain prices do not affect oil carloads within that same week. Impulse responses scaled to show price response in $/bu to a long-run 1000 car/week increase in oil carloads. *** **

Table 5: Rail prices for wheat shipments, in revenue per bushel, and oil carloads.

Wheat Revenue Per Bushel and Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5
Oil Carloads (thousands)	0.006***	0.006***	0.006***	0.006***	0.011***
	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0020)
Diesel Prices	0.124***	-0.017	-0.019	-0.019	-0.017
	(0.0260)	(0.0470)	(0.0500)	(0.0500)	(0.0510)
Average Daily Low Temp.			0.0000	0.0000	0.0000
			(0.0010)	(0.0010)	(0.0010)
Rail Traffic Excl. Oil and Grain				0.0000	0.0000
				0.0000	0.0000
Montana X Oil Carloads					-0.004*
					(0.0020)
North Dakota X Oil Carloads					-0.006**
					(0.0020)
South Dakota X Oil Carloads					-0.006**
					(0.0020)
County Effects	Yes	Yes	Yes	Yes	Yes
Harvest X Month Effects	No	Yes	Yes	Yes	Yes
Observations	3103	2501	2501	2501	2501
Adj. R-sq.	0.27	0.24	0.24	0.24	0.24

Notes: Dependent variable is the price of rail transportation in dollars per bushel. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. In model 5, Minnesota is the omitted state category. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 6: Harvest-month adjusted rail wheat quantities and oil carloads.

	Wheat and Oil Shipments				
	Model 1	Model 2	Model 3	Model 4	Model 5
ln(Oil Carloads)	-0.027	-0.034	-0.030	-0.045**	-0.107***
	(0.0200)	(0.0210)	(0.0210)	(0.0200)	(0.0260)
ln(Diesel Prices)	0.043	-0.07	-0.158	-0.229	-0.257
	(0.1880)	(0.3640)	(0.3680)	(0.3700)	(0.3690)
Average Daily Low Temp.			0.0000	0.0000	0.0000
			(0.0010)	(0.0010)	(0.0010)
ln(Rail Traffic Excl. Oil and Grain)				0.352***	0.345***
				(0.0660)	(0.0650)
Montana X ln(Oil Carloads)					0.071**
					(0.0310)
North Dakota X ln(Oil Carloads)					0.107***
					(0.0310)
South Dakota X ln(Oil Carloads)					0.004
					(0.0440)
County Effects	Yes	Yes	Yes	Yes	Yes
Harvest X Month Effects	No	Yes	Yes	Yes	Yes
Observations	3103	2501	2501	2501	2501
Adj. R-sq.	0.34	0.33	0.33	0.33	0.33

Notes: Dependent variable is logged county monthly grain shipments. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. In model 5, Minnesota is the omitted state category. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 7: Oil carloads, rail prices and harvest-month adjusted quantities for corn and soybeans.

Corn, Soy and Oil Shipments

	Corn	Soy
ln(Oil Carloads)	-0.089***	-0.055*
	(0.0240)	(0.0300)
ln(Diesel Prices)	0.645**	0.630***
	(0.2520)	(0.2290)
Average Daily Low Temp.	0.0040	0.005*
	(0.0020)	(0.0030)
ln(Rail Traffic Excl. Oil and Grain)	0.331***	0.300***
	(0.0550)	(0.0740)
Minnesota X ln(Oil Carloads)	0.064	0.063
	(0.0480)	(0.0490)
Nebraska X ln(Oil Carloads)	0.03	0.057
	(0.0570)	(0.0620)
North Dakota X ln(Oil Carloads)	0.014	0.0000
	(0.0360)	(0.0390)
South Dakota X ln(Oil Carloads)	0.08	0.094*
	(0.0500)	(0.0500)
	Yes	Yes
	Yes	Yes
	3155	3271
	0.41	0.40

Notes: Dependent variable is logged county monthly grain shipments. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. Iowa is the omitted state category. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 8: Wheat carry and oil carloads.

Wheat Carry, Oil Shipments and Production

	1-Month	3-Month	6-Month
Oil Carloads (thousands)	0.000	0.000	0.002**
	(0.0010)	(0.0010)	(0.0010)
Montana X Oil Carloads	-0.001	-0.002***	-0.002***
	(0.0010)	(0.0010)	(0.0000)
North Dakota X Oil Carloads	-0.002*	-0.001	-0.001
	(0.0010)	(0.0010)	(0.0010)
South Dakota X Oil Carloads	-0.002**	-0.001*	-0.001***
	(0.0010)	(0.0000)	(0.0000)
Market (Silo) Effects	Yes	Yes	Yes
Harvest X Month Effects	Yes	Yes	Yes
Min Daily Temperature	Yes	Yes	Yes
Rail Traffic	Yes	Yes	Yes
Observations	2747	2208	1335
Adj. R-sq.	0.35	0.53	0.69

Notes: Dependent variable is the difference between silo spot price and forward price at the horrizon indicated. Standard errors clustered by silo and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Supplementary appendix

Spatial variation of impacts

One perhaps counter-intuitive aspect of our base analysis was the non-uniform relationship between price spreads and distance from major trading hubs. For example, in our basic model 1, wheat spreads decreased with distance from the primary trading hub in Minneapolis.

Price effects

To investigate this issue further, Table 2 explores heterogeneity in wheat spreads by distance and state. Model 1 uses the full set of controls but allows for a quadratic relationship between elevator distance and spread. We leave out silo mean effects to avoid collinearity with the distance controls. The estimated effects suggest mean spread increases with distance from Minneapolis for approximately 400 miles, roughly the diagonal distance across North Dakota, and then decreases with distance. This is consistent with Figure 2 that suggests elevators in western North Dakota and Montana may be less closely tied to the Minneapolis exchange than the rest of the sample.

To explore whether wheat spreads behave differently in different locations in response to increasing oil car shipments, we interact the number of oil cars shipped with dummy variables for each state. The omitted state is Minnesota. We take this approach rather than interacting our distance measures with carloads to preserve power.[35] The estimated relationship for elevators in Minnesota is consistent with our earlier estimates. An increase of 10,000 oil carloads per month is associated with an increase in mean spread of approximately \$0.43 per bushel. The estimate for North Dakota is not significantly different. However, the estimated relationships for Montana and South Dakota are smaller than Minnesota.[36] This

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[35] If instead we use a quadratic distance relationship and oil carload interactions, the point estimates imply increasing oil carloads increases spread more with distance until about 400 miles from Minneapolis. However, the estimates are not statistically significant.

[36] *I.e.* 0.043 minus 0.019 or 0.024 for Montana.

again suggests elevators in these states may be affected differently by the increase in oil carloads.

Table 3 explores heterogeneity in the effects on corn and soybean spreads, as well as wheat, across states. Overall, spread increases for corn and soybeans are substantially smaller than for wheat. Column 1 reproduces the wheat results from Table 2 for comparison. For both corn and soybeans the omitted state category is Iowa, where we see small negative relationships between carloads and spreads for corn and soybeans.[37] Elevators in Nebraska are similar to those in Iowa and there is essentially no effect for elevators in Minnesota and South Dakota. Estimates for North Dakota are positive and statistically significant for both corn and soy. An increase of 10,000 oil carloads per month is associated with a \$.04 and \$.09 per bushel increases in corn and soybean spreads, respectively.[38] These effects are an order of magnitude smaller than our estimates for wheat spreads.

Quantity effects

In section 5, we present evidence that congestion of railroads was a significant driver of price-spreads during our sample period. We also present evidence that average shipment quantities declined with the increase in congestion and rail-car prices. We now further explore the spatial heterogeneity of the impacts on shipping quantities.

As discussed previously, elevators in Montana typically ship wheat west to Pacific export terminals. Elevators in Minnesota and eastern parts of the sample are more likely to ship to eastern destinations. We refine the analysis on shipment quantities, presented in Table 6, by estimating separate effects for eastbound and westbound shipments. We create an indicator variable equal to one if the waybill lists California, Oregon or Washington as the shipment destination. We then aggregate all the cars from a given county in each month by either West Coast or Eastern destinations and use these totals as the dependent variable in our regression analysis. The results are presented in Table 4. For Minnesota, a ten percent

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[37] The negative effect on spreads could be evidence of increase demand for grain from locations further from North Dakota and therefore less affected by rail congestion.

[38] (*i.e.* $10 \times (-0.007 + 0.011)$ and $10 \times (-0.010 + 0.019)$))

increase in oil carloads is associated with a 0.76 percent decrease in oil carloads headed to Eastern destinations. For Montana, a 10 percent increase in oil carloads is associated with a 2.1 percent decrease in shipments headed east but a 0.44 percent increase in shipments to the West Coast. For shipments from North Dakota, there is essentially no effect for eastbound shipments (-0.076 + 0.072 = -0.003), consistent with our assumption that Eastern demand for North Dakota wheat is inelastic. However, an increase in oil shipments is associated with a fairly large increase in shipments from North Dakota to the West coast (-0.076 + 0.072 + 0.070=0.066).

Table 5 investigates whether the destinations for wheat shipments change when oil traffic increases. Using the STB waybill shipment level data, we estimate linear probability and probit models where the dependent variable is an indicator equal to one if a shipment's final destination is in California, Oregon or Washington and zero otherwise. Models 1 though 4 are linear probability models estimated with OLS and model 5 assumes a Probit model. In each case we control for harvest effects, minimum temperature, other rail traffic and mean effects for originating county.

Model 1 assumes the relationship between oil carloads and the probability of shipping to the west coast varies linearly with an elevator's distance from Minneapolis. Model 2 assumes a quadratic relationship. In both cases, increasing oil shipments decreases the likelihood an elevator ships to the West Coast. Model 3 presents results from a less restrictive specification where we estimate the mean effects across states. Here, a 10 percent increase in oil shipments is associated with a 0.33 percentage point increase in the likelihood an elevator in Montana ships to the West Coast and a 0.22 percentage point decrease in the probability and elevator in South Dakota ships to the West Coast. However, this model still masks potentially interesting heterogeneity in the locations of elevators and where they tend to ship wheat.

Our preferred models take the form of model 4 and model 5 where we create 200 mile wide distance bins, again relative to Minneapolis, interacted with logged oil car shipments. In model 4, an increase in oil car shipments is associated with a decrease in the likelihood an elevator ships to the West coast for locations up to 400 miles from Minneapolis, though our point estimates are quite noisey. For elevators further west, increasing oil traffic is associated with an increase in the likelihood an elevator ships west. For instance, at 400 to 600 miles, a 10 percent increase in oil car shipments is associated with a 0.33 percentage point increase in the probability a shipment goes west. This effect decrease somewhat for elevators located further west, perhaps due to the fact the majority of these shipments already go to West Coast destinations. Model 5 shows similar results, though the point estimates suggest somewhat larger effects. Elevators less than 200 miles from Minneapolis are less likely to ship west when oil traffic increases and elevators further west are more likely to ship to the West Coast. The estimate for 400 to 600 miles, 0.789, equates to an average marginal effect of 0.174. In other words, a 10 percent increase in oil shipments is associated with a 1.74 percentage point increase in the probability of shipping west. Overall, these effects suggests some redirection of shipments associated with increase oil traffic.

Incidence

Here, we use an approach similar to the Relative Price of a Substitute (RPS) method of Carter and Smith (2007). We fit a cointegrated error correction model to the elevator and hub price time series. The model is

$$\begin{aligned} \Delta P_{it} &= \beta_i \left(P_{hub,t-1} - P_{i,t-1} - \mu \right) + \varepsilon_{it} && (5) \\ \Delta P_{hub,t} &= \beta_{hub} \left(P_{hub,t-1} - P_{i,t-1} - \mu \right) + \varepsilon_{hub,t} && (6) \end{aligned}$$

We fit this model to weekly data from October 2009 through September 2013, which is the period immediately before oil-by-rail affected grain prices. We use the estimated parameters to project into the oil-by-rail period. For each grain, we use as the elevator price the simple average over all elevators in North Dakota.[39] The results we report here are robust to using a longer estimation sample (2002-2013) and to including lagged price changes to soak up any residual autocorrelation. We estimate the parameters using OLS regressions of the two price changes on the lagged spread $(P_{hub,t-1} - P_{i,t-1})$ and a constant.

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[39] We also fit the model separately to each elevator in North Dakota. The results were similar on average, and we did not observe statistically significant heterogeneity, so we do not report those results here.

The two prices in (5) and (6) are cointegrated if $\beta_{hub} - \beta_i < 0$, which implies that the spread reverts to μ in the long run. For example, if the spread exceeds μ, then arbitrageurs will seek to buy grain at the elevator and ship it to the hub. This action will cause the elevator price to increase ($\beta_i \geq 0$) and/or the hub price to decrease ($\beta_{hub} \leq 0$), thereby pushing the prices back together. Thus, the relative magnitudes of β_i and β_{hub} reveal how prices in the two markets adjust to shocks that disrupt the spatial equilibrium.

Table 6 reports the coefficient estimates for each of the three grains. For wheat, a $1 increase in the spread one week portends a 15.9c decrease in the Minneapolis price and a 5.7c increase in the North Dakota price the following week. Thus, Minneapolis prices respond about 3 times as much to spread shocks as do North Dakota prices. North Dakota produces half of the spring wheat grown in the US and Minneapolis has a large flour milling industry. This result suggests that the residual demand in Minneapolis for North Dakota wheat is quite inelastic. In response to high transportation costs, Minneapolis purchasers need to offer a higher price to attract wheat from North Dakota.

In contrast, the response parameters for corn and soybeans are imprecisely estimated and not statistically significant. North Dakota produces between 2% and 5% of US corn and soybeans, so it is not able to materially affect prices in Chicago, which is the site of global price discovery through the CME futures markets. For both commodities, the correlation between the residuals of the two equations exceeds 0.96. This means that weekly prices in the two locations move almost entirely in lock step, so there is not enough variation in weekly spreads to identify differential responses the following week. We find the same result if we estimate the models using daily data. These findings suggest that North Dakota elevators typically set corn and soybean prices as the Chicago price minus a transportation cost that changes little.

A change in transportation costs entails a change in μ, which changes current and future prices through the lag structure in the model. It can be shown that the long-run effect of a change in μ is[40]

$$\frac{\partial P_{it}}{\partial \mu} = \frac{\beta_i}{\beta_i - \beta_{hub}} \tag{7}$$

$$\frac{\partial P_{hub,t}}{\partial \mu} = \frac{\beta_{hub}}{\beta_i - \beta_{hub}} \tag{8}$$

The results in the previous section imply that oil transportation by rail increased grain price spreads beginning with the harvest in October 2013 and persisted for two years. Using (7) and (8), we estimate the effects on the two prices as

$$\Delta P_i = \frac{\beta_i}{\beta_i - \beta_{hub}} * \Delta\mu \qquad \texttt{and} \qquad \Delta P_{hub} = \frac{\beta_{hub}}{\beta_i - \beta_{hub}} * \Delta\mu \tag{9}$$

For the change in the spread ($\Delta\mu$), we use the difference between the mean spread in the period Oct 2013 - Sep 2015 and the mean in the period Oct 2009 - Sep 2013. We obtain 84.45c for wheat, 15.65c for corn, and 27.07c for soybeans.

Figure 1 shows estimated counterfactual prices in the absence of the oil-by-rail transportation shock as dotted lines. We estimate counterfactual prices by subtracting the estimated changes in (9) from the observed prices. Thus, we are using estimates of the price dynamics in 2009-2013 to predict the responses to a post-sample transportation cost shock. The shaded regions denote 95% confidence intervals estimated by applying the delta method to (9).

For wheat, we see that actual Minneapolis prices increased beginning in early October 2013, whereas North Dakota prices decreased in this period. The spring wheat harvest occurs in September and October and spot prices usually decrease around this time as the market absorbs an influx of new product. The estimates clearly show the incidence of the transportation cost shock falling mostly on Minneapolis buyers. This is consistent with the conclusion that flour millers in Minneapolis were prepared to pay a premium to avoid supply disruptions.

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[40] To derive these expressions, write the model in vector autoregression form as $P_t = -\beta\mu + AP_{t-1} + \varepsilon_t$, where $\beta = [\beta_i, \beta_{hub}]'$. Then, invert to obtain the moving average representation: $P_t = -(I + A + A^2 + \ldots)\beta\mu + \varepsilon_t + A\varepsilon_{t-1} + A^2\varepsilon_{t-1} + \ldots$. It turns out that $-(I + A + A^2 + \ldots)\beta = \beta/(\beta_i - \beta_{hub})$.

Consistent with the estimated coefficients in Table 6, we cannot parse the corn and soybean price responses. The expansion in spreads was relatively small for these commodities, and the 95% confidence bands include both extremes, i.e., the possibility that the incidence fell fully on farmers/elevators and the possibility that it fell fully on processors/consumers.

Appendix figures and tables

Figure 1

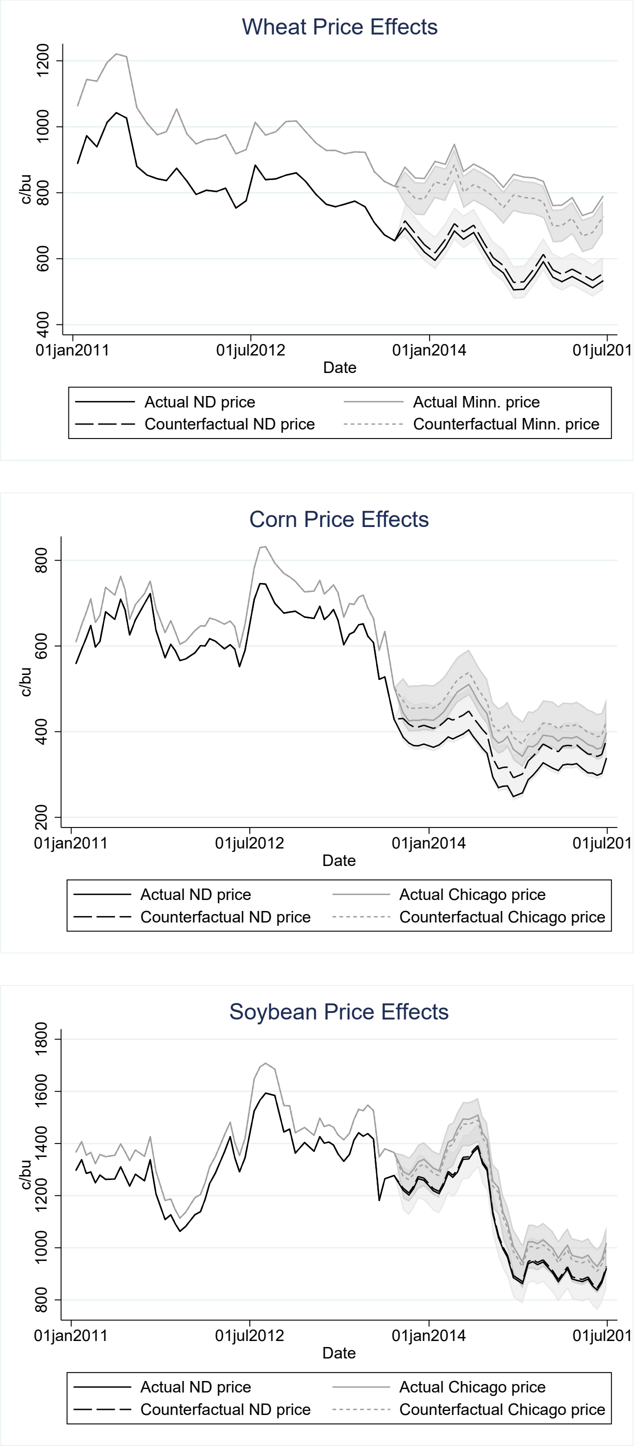

Table 1: Major goods shipped by rail originating in North Dakota.

	2010	
	Cars (1000s)	Share (%)
Wheat	120.4	38%
Soybeans	58.5	18%
Corn	37.8	12%
Oil	25.6	8%
Barley	13.2	4%
Total	255.5	81%
	2012	
	Cars (1000s)	Share (%)
Oil	171.2	39%
Wheat	80.0	18%
Soybeans	62.1	14%
Corn	53.4	12%
Alcohols	10.6	2%
	377.2	87%
	2014	
	Cars (1000s)	Share (%)
Oil	343.2	50%
Wheat	94.8	14%
Soybeans	65.3	10%
Corn	63.2	9%
Coal	39.6	6%
	606.1	89%

Notes: Compiled from STB Public Waybill Sample for shipments beginning in the Bismark, Fargo-Moorhead, Grand Forks and Minot BEA areas.

Table 2: Wheat price spreads and oil carloads by elevator distance and state.

Wheat Price Spreads, Oil Shipments and Distance

	Model 1	Model 2
Oil Carloads (thousands)	0.034***	0.043***
	(0.0090)	(0.0090)
Minneapolis Distance (100 miles)	0.243***	
	(0.0340)	
MN Dist. Squared	-0.029***	
	(0.0030)	
Diesel Prices	-1.941***	
	(0.4700)	
Diesel Price X Miles		-0.377***
		(0.1380)
Montana X Oil Carloads		-0.019
		(0.0140)
North Dakota X Oil Carloads		0.003
		(0.0100)
South Dakota X Oil Carloads		-0.013***
		(0.0020)
Average Daily Low Temp.	-0.011**	-0.0080
	(0.0050)	(0.0050)
Rail Traffic Excl. Oil and Grain	0.0030	0.0020
	(0.0030)	(0.0030)
Market (Silo) Effects	No	Yes
Harvest X Month Effects	Yes	Yes
Observations	3292	3292
Adj. R-sq.	0.53	0.49

Notes: Dependent variable is the difference between silo cash price and Minneapolis spot price in dollars per bushell. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. Standard errors clustered by silo and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 3: Wheat, corn and soybean price spreads and oil carloads by elevator state.

Grain Price Spreads, Oil Shipments by Elevator State

	Wheat	Corn	Soy
Oil Carloads (thousands)	0.043***	-0.007**	-0.010*
	(0.0090)	(0.0030)	(0.0060)
Diesel Price X Miles	-0.377***	0.011	0.042
	(0.1380)	(0.0230)	(0.0360)
Minnesota X Oil Carloads		0.006*	0.008*
		(0.0030)	(0.0050)
Montana X Oil Carloads	-0.019	0.017**	
	(0.0140)	(0.0080)	
North Dakota X Oil Carloads	0.003	0.011***	0.019**
	(0.0100)	(0.0040)	(0.0080)
Nebraska X Oil Carloads		0.001	0.000
		(0.0020)	(0.0040)
South Dakota X Oil Carloads	-0.013***	0.006**	0.009
	(0.0020)	(0.0030)	(0.0050)
Average Daily Low Temp.	-0.0080	0.0010	0.005*
	(0.0050)	(0.0010)	(0.0030)
Rail Traffic Excl. Oil and Grain	0.0020	0.001***	0.002***
	(0.0030)	0.0000	(0.0010)
Market (Silo) Effects	Yes	Yes	Yes
Harvest X Month Effects	Yes	Yes	Yes
Observations	3292	4090	3910
Adj. R-sq.	0.49	0.79	0.64

Notes: Dependent variable is the difference between silo cash price and Minneapolis or Chicago spot price in dollars per bushell. Average low temperature is the average of recorded daily low temperatures in each state capital each month. Rail traffic exlcuding oil and grain is the total number of carloads, measured in thousands, for BNSF and CP not including oil and grain each month. Standard errors clustered by silo and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels. For wheat, Minnesota is the omitted state. For corn and soybeans Iowa is the omitted state.

Table 4: Number of carloads shipped to the West Coast and oil carloads.

Quantities Shipped East and West

	Wheat
ln(Oil Carloads)	-0.076**
	(0.0370)
MN X West X ln(Oil Carloads)	-0.075
	(0.0700)
MT X ln(Oil Carloads)	-0.135***
	(0.0500)
MT X West X ln(Oil Carloads)	0.255***
	(0.0280)
ND X ln(Oil Carloads)	0.072*
	(0.0410)
ND X West X ln(Oil Carloads)	0.070***
	(0.0160)
SD X ln(Oil Carloads)	0.0000
	(0.0470)
SD X West X ln(Oil Carloads)	0.0350
	(0.0430)
County Effects	Yes
Diesel, Temperature and Traffic Control	Yes
Harvest X Month Effects	Yes
Observations	2812
Adj. R-sq.	0.29

Notes: Dependent variable is logged county monthly grain shipments. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 5: Wheat shipments to the West Coast and oil carloads.

Wheat Shipments to the West Coast and Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5
	OLS	OLS	OLS	OLS	Probit
ln(Oil Carloads)	-0.035**	-0.048**	-0.006	-0.016	-0.673***
	(0.0150)	(0.0210)	(0.0060)	(0.0110)	(0.2490)
Distance X ln(Oil Carloads)	0.001**	0.001			
	(0.0000)	(0.0010)			
Distance Squarred X ln(Oil Carloads)		0.000			
		(0.0000)			
Montana X ln(Oil Carloads)			0.039***		
			(0.0140)		
North Dakota X ln(Oil Carloads)			-0.001		
			(0.0170)		
South Dakota X ln(Oil Carloads)			-0.028*		
			(0.0140)		
Dist. 200 to 400 mi. X ln(Oil Carloads)				-0.019	0.461*
				(0.0170)	(0.2680)
Dist. 400 to 600 mi. X ln(Oil Carloads)				0.049***	0.789***
				(0.0160)	(0.2220)
Dist. 600 to 800 mi. X ln(Oil Carloads)				0.026	0.852**
				(0.0220)	(0.3740)
Dist. 800 to 1000 mi. X ln(Oil Carloads)				0.040*	0.889***
				(0.0240)	(0.3100)
ln(Diesel Prices)	0.1840	0.1940	0.1610	0.1350	0.4490
	(0.1250)	(0.1210)	(0.1310)	(0.1280)	(0.6920)
Average Daily Low Temp.	0.000	0.001	0.000	0.000	0.002
	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0040)
ln(Rail Traffic Excl. Oil and Grain)	-0.060***	-0.067**	-0.048**	-0.049**	-0.234**
	(0.0210)	(0.0270)	(0.0200)	(0.0200)	(0.1040)
County Effects	Yes	Yes	Yes	Yes	Yes
Harvest X Month Effects	Yes	Yes	Yes	Yes	Yes
Observations	4711	4711	4711	4711	3966
Adj. R-sq. (Pseudo R-sq.)	0.50	0.50	0.50	0.51	0.40

Notes: Dependent variable is one if shipment terminates in CA, OR or WA and zero otherwise. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 6: Error correction models for weekly price changes

Error Correction Model for Weekly Price Changes

	Wheat		**Corn**		**Soybeans**	
	ND Price	Minneapolis Price	ND Price	Chicago Price	ND Price	Chicago Price
Lag Spread	0.057	-0.159**	0.120	0.077	0.035	-0.081
	(0.054)	(0.072)	(0.102)	(0.105)	(0.129)	(0.124)
Constant	-8.0	26.177**	-5.9	-3.1	-1.0	8.1
	(8.65)	(11.52)	(6.37)	(6.53)	(10.15)	(9.74)
Observations	208	208	208	208	208	208
Adj. R-sq.	0.00	0.02	0.00	0.00	0.00	0.00
Residual Correlation	0.82		0.96		0.97	
Change in Spread	84.42		15.65		27.07	

Notes: Dependent variables are the weekly change in price at the specified location. Each week's ND price is the average daily price across all elevators reporting prices in that week. The spread is the hub price (Minneapolis or Chicago) minus the North Dakota price. Sample period: 10/01/2009-09/30/2013. Standard errors clustered by silo and date in parentheses. ***, ** and * denote statistical significance at the 1 percent, 5 percent, and 10 percent levels.