Food vs. Fuel? Impacts of petroleum shipments on agricultural prices.

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Abstract

Grain shippers and political figures in North Dakota and nearby states have voiced concern that the dramatic increases in shipments of crude oil by rail have caused service delays and higher costs. We investigate the potential impact of crude shipments on grain markets accounting for harvest effects and other potential sources of rail congestion. Increased crude oil shipments are associated with substantially larger spreads between wheat prices at regional elevators and in Minneapolis, the market hub. The effect on corn and soybean spreads are an order of magnitude smaller. Increased oil traffic is associated with small increases in rail rates but large increases in rail car auction prices. We document increases in wheat carry (storage) costs and decreases in shipment quantities. Surprisingly, little of the spread increase is due to lower prices paid to farmers, suggesting consumers rather than producers paid the cost of increased rail congestion.

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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 traditionally agricultural state like North Dakota faced with the prospect of rapidly expanding energy development.

However, as with other aspects of the food vs fuel debate, assigning winners and losers is complex. The spillover effects of increased demand for rail access likely increased the costs of shipping other commodities from the Upper Great Plains. However, the incidence of any cost shock depends upon the market conditions and elasticities of the affected products. In this paper, for example, we present evidence that oil shipments did indeed impact markets for some grains, but counter to the narrative at the time, the incidence of those impacts was borne mostly by consumers and food processing firms, rather than farmers.

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.[1] We show increased oil shipments are associated with increases in 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. The estimated relationship between wheat spreads and oil shipments remains strong when we account for other factors that contributed to rail congestion during this period, including

[1] 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 (Sorenson, 1984; Wilson and Dahl, 2011) and other supply and demand factors (Tilley and Campbell, 1988).

severe cold temperatures, large harvests and increased demand for rail transportation.

Next, we investigate the incidence of the congestion shock on farmers/elevator operators and grain consumers. 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)).

We use time series techniques to forecast counterfactual elevator and market hub grain prices from 2013 through 2015. We 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 impacts of oil by rail shipments on farmers, and it suggests that the residual demand for North Dakota wheat is much less elastic than the residual demand for corn or soybeans from that state. Further, this result echoes the literature on biofuel policies and commodity prices that studies the extent to which transportation energy policies can spill over to food markets (De Gorter and Just, 2010; Roberts and Schlenker, 2013; Wright, 2014; Carter, Rausser, and Smith, 2017). Our results suggest policies related to new oil and natural gas production may have implications for food prices.

We explore several potential mechanisms and effects of increase oil by rail shipments on grain transportation markets. Using shipment level data from the Surface Transportation Board Confidential Waybill Sample, we show that increased oil shipments are associated with significant decreases in corn and soybean shipments from North Dakota and nearby states. However, there is no significant decrease in North Dakota wheat shipments associated with increased oil traffic, which is also consistent with residual wheat demand being much less elastic than residual corn or soybean demand.

Most grain shipments are made using rail cars owned by the railroad at prices published in tariffs. Under rules of common carriage, any shipper meeting the criteria established by the tariff may ship at the posted price. Shippers submit requests for service, including timelines for delivery of empty rail cars. Railroads typically fulfill these requests on a first-come first-served basis. We find that increased oil shipments are associated with small increases in rates paid for grain shipments, though these increases are substantially smaller than the increase in wheat spreads during the period. This could be the result of statutes requiring railroads give shippers twenty days notice prior to any rate increase. 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.[2]

During times of high demand or railroad congestion, some railroads allocate scarce capacity using railcar auctions.[3] A successful bid in a railcar auction guarantees that a rail car will be delivered for loading during a specified time window. We find that the prices paid in rail car markets increased dramatically in 2013-2014, are highly correlated with wheat spread changes, and rise to levels that could account for the entire increase in spread during the period.

We also show wheat storage costs, captured by "carry" calculated from the difference between forward and spot elevator prices, increase with increasing oil shipments, although by an order of magnitude less than the spread increase.[4] This finding suggests that there was enough storage capacity on farms and at elevators to accommodate the rail service delays without much cost. This result is consistent with the incidence of the wheat price shock falling on downstream firms and consumers, rather than farmers or elevator operators.

Finally, shippers in western North Dakota and Montana are more likely to ship wheat to West Coast destinations when oil shipments increase.[5] The increase in westward shipments

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

[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. The auction is for a specified and guaranteed car delivery date and not a fee for the car itself. Auction winners must still pay the tariff price in addition to the railcar auction price.

[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]Anecdotally, service disruptions during this period seemed to be particularly severe in the Minneapolis and Chicago rail terminals.

suggests some wheat was rerouted to reduce delays. However, we find no evidence of a statistically significant decrease in eastbound shipments of North Dakota wheat associated with increased oil shipments.

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) used 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 fell 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) generated a similar estimate using the same incidence assumption and a two stage least squares estimation strategy. U.S. Department of Agriculture (2015) argued that increased transportation costs due to rail congestion are a significant factor in explaining why local prices may diverge from prices at export destinations or market hubs. However, they did not attempt to quantify the effects of oil-induced transportation disruptions on local prices for wheat, corn, and soybeans.

Overall, the larger wheat spread and market hub price increases, smaller elevator price and quantity decreases, suggest mills and other consumers are more reliant on wheat from the Upper Great Plains than corn or soybeans from the region. This conclusion is supported by the geography of grain production in the United States. 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. Therefore, the effects we document are likely the result of a transportation cost shock in the Upper Great Plains and the lack of substitute wheat production outside the region.

2 Industry background

This research investigates the interaction of three overlapping industries: rail freight, oil production, and cash-crop agriculture. Each industry has developed somewhat distinctive commercial arrangements and data reporting conventions. In this section we briefly describe these conventions in order to provide context for the empirical analysis that follows.

2.1 Railroad service, pricing and congestion

The rail transportation industry in North America is dominated by seven large "Class I" railroads, which account for 94% of revenue (Association of American Railroads, 2017). The market is geographically segmented with Burlington Northern Santa Fe (BNSF) and Union Pacific operating in the western United States and Norfolk Southern and CSX Transportation operating in the east. Two Canadian firms, Canadian Pacific (CP) and the Canadian National Railway operate primarily in the northern United States. Kansas City Southern serves mainly the south central U.S. and Mexico.

The Upper Great Plains of the U.S. are served by BNSF and CP, plus several smaller regional railroads. Railroads ship grain either as part of large shuttle trains, generally 100 to 110 cars per shipment or as part of smaller multi-car shipments. Shuttle trains offer dedicated service between one origin and one destination but require large elevators capable of loading 100 cars in several hours.[6] Oil shipments also move in large hundred car unit trains or smaller single or multicar shipments.

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.[7] However in many industries, shippers 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.

In contrast, the majority of grain shipments, which originate from a large number of smaller 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 many cases, these distinctions are inconsequential, but

[6]For instance, BNSF requires shuttle trains be loaded within fifteen hours.

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

they 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 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 also operate railcar auctions to mitigate congestion and to allocate scarce rail capacity under common carriage. 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 for a *delivery priority*, in addition to the usual tariff. Below, we explore the effects of rail congestion on both grain railcar auction prices and tariffs.

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.[8] Several factors are thought to have contributed to congestion during this period including: increased freight demand following the Great Recession; severe cold temperatures during the 2013/2014 winter; large grain harvests in 2013 and 2014; and increased demand for oil by rail.

2.2 Oil and grain production and transportation from the Upper Great Plains

Technological advances in drilling technology, namely horizontal drilling and hydraulic fracturing, have dramatically increased U.S. production from non-conventional (shale) oil resources. Further, the shale oil boom has increased oil production in regions without sufficient oil pipeline infrastructure. As a result, producers have chosen to transport crude via truck and rail tanker.[9] The share of crude deliveries by truck is small owing to the relatively higher cost of moving large shipments over long distances. Further, lack of sufficient refining capacity means states like North Dakota have shipped a large share of crude production out of state. For instance in 2013, approximately 60% of North Dakota crude production was moved by rail.[10] 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.[11] 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

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

[9] 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.

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

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

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.[12] 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).

Combined, grains and crude oil represented over 89% of oil carloads originating in and around North Dakota during 2014.[13] The overall trends in rail shares are shown in Table 1. The oil share grew from approximately 8% of shipments in 2010 to over 50% by 2014. Total shipments of grain (wheat, soybeans, corn and barley) remain relatively constant over the period, increasingly slightly in 2014. The remaining carloads represent a diverse set of other agricultural goods and manufactured items.

Both the oil and grain industries in North Dakota are geographically isolated from major downstream markets. With grains, farmers typically sell their crop to local elevators, which market grain to domestic producers or exporters. Major elevators typically 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. Historically, the Minneapolis Grain Exchange (MGEX) has been the main U.S. market hub for hard red spring wheat futures. The Chicago Mercantile Exchange (CME) is the main hub for corn and soybean futures contracts. Because transportation costs vary with distance, grain grown further west is more likely to be marketed to Pacific Coast export terminals and grain grown

[12]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).

[13]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.

further east in more likely marketed to eastern destinations, including Midwestern processing plants and exporters in the Lousiana Gulf or the Great Lakes. For instance, from 2006-2010 over 83% of Montana wheat shipments went to West Coast destinations while more than 71% of Minnesota wheat shipments went to eastern destinations (Prater and Sparger, 2014a,b).

3 Data

We combine detailed data on elevator-level grain prices with market-level data from central grain trading hubs. We obtained spot and forward prices for wheat, corn and soybean for approximately 60 locations in North Dakota, South Dakota, Minnesota Iowa and Nebraska from GeoGrain (2016). The data consist of daily observations of spot price at each elevator as well as prices for any forward contracts offered on a given date. 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). 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.[14]

For corn, we use the Chicago prices for US yellow #2. 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.

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

We construct time series of locational price "spreads" by combining simultaneous prices at various origin and destination pairs. Figure 2 plots the mean spread between local and Minneapolis spring wheat spot prices for several months during 2013 and 2014. The shading corresponds to the quintiles of spread, with darker colors indicating larger spreads.[15] 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. 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 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 2, which shows mean elevator prices, spreads and oil carloads shipped by year. 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

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

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 (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 construct monthly total carloads shipped by BNSF and CP (excluding oil and grain) to use as controls in the specifications described below.

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 indicates 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 estimate:

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

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.

We include diesel prices $Pdiesel_t$ to account for the potential impact of fuel prices on railroad costs. Controlling for diesel prices 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. We control for this factor using month mean effects δ_m interacted with total production for each state in a given crop-year ($Prod_{sy}$). 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.[16] We also control for changes in total rail freight demand X_t using the sum of monthly carloads, excluding oil and grain, for BNSF and CP.

Table 3 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. Model 1 is the most parsimonious specification with controls for diesel prices and distance, as the crow flies, between each elevator and Minneapolis. The estimated relationship between oil carloads shipped from North Dakota is large, 0.047, positive and statistically significant. Specifically, 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

[16] 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.

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 0.035 but remains statistically significant.[17]

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 temperature coefficient suggests a decrease in average daily minimum temperature of 10 degrees (Fahrenheit) increases mean spread between $.05 and $.11 per bushel. Surprisingly the distance 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. Tables 4 and 5 present spread models similar to those shown above for wheat. Interestingly, while the estimated relationships between oil carloads and spreads 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 $0.05 per bushel for corn and $0.02 to $0.07 per bushel for soybeans.

These results may at first seem surprising since wheat, corn and soybeans travel on the same rail network and utilize the same equipment. In many cases, shipments of these crops also originate from the same elevators. However, the markets for the three crops are quite different. In particular, our sample includes the majority of hard red spring wheat

[17]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 0.041, suggesting about half the difference between model 5 and model 6 is due to the restricted sample.

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. Therefore, we anticipate larger overall price changes for wheat in response to a given transportation cost shock, all else equal. Similarly, we expect relatively small quantity effects and that consumers rather than producers would bear the burden of a cost shock. We discuss these hypotheses further below.

5 Incidence

The previous section presents evidence the spread between elevator and market hub grain prices increased as oil transportation by rail increased, especially for wheat. 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 the elevator prices. On the other hand, if the incidence falls downstream, we expect to see a relative increase in the market hub prices.

To assign the incidence, we use the approach in Carter and Smith (2007). We fit a cointegrated error correction model to the elevator and hub price time series. The model is

$$\Delta P_{it} = \beta_i \left(P_{hub,t-1} - P_{i,t-1} - \mu\right) + \varepsilon_{it} \tag{2}$$

$$\Delta P_{hub,t} = \beta_{hub} \left(P_{hub,t-1} - P_{i,t-1} - \mu\right) + \varepsilon_{hub,t} \tag{3}$$

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.[18] The results we report here are robust to using

[18] We also fit the model separately to each elevator in North Dakota. The results were similar on average,

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.

The two prices in (2) and (3) 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

and we did not observe statistically significant heterogeneity, so we do not report those results here.

prices through the lag structure in the model. It can be shown that the long-run effect of a change in μ is[19]

$$\frac{\partial P_{it}}{\partial \mu} = \frac{\beta_i}{\beta_i - \beta_{hub}} \tag{4}$$
$$\frac{\partial P_{hub,t}}{\partial \mu} = \frac{\beta_{hub}}{\beta_i - \beta_{hub}} \tag{5}$$

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 (4) and (5), we estimate the effects on the two prices as

$$\Delta P_i = \frac{\beta_i}{\beta_i - \beta_{hub}} * \Delta\mu \qquad \texttt{and} \qquad \Delta P_{hub} = \frac{\beta_{hub}}{\beta_i - \beta_{hub}} * \Delta\mu \tag{6}$$

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 3 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 (6) 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 (6).

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.

[19] 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: $P_t = -(I + A + A^2 + ...)\beta\mu + \varepsilon_t + A\varepsilon_{t-1} + A^2\varepsilon_{t-1} + ...$ It turns out that $-(I + A + A^2 + ...)\beta = \beta/(\beta_i - \beta_{hub})$.

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.

6 Mechanisms and effects

The wheat spread results presented in Table 3 show that large shocks to grain transportation costs occurred concurrently with the increase in shipments of oil by rail in North Dakota. We now turn our attention to potential mechanisms and effects of the observed spread increases by investigating the relationships between the number of oil carloads transported and rail prices and quantities. As before we account for potential confounding factors related to freight demand and temperature.

We estimate models of the form:

$$Y_{ct} = \beta Oil_t + \gamma Pdiesel_t + \sum_{m=1}^{12} [Prod_{sy} \times \delta_m] + \xi T_{st} + \zeta X_t + \delta_c + \varepsilon_{ct} \tag{7}$$

where Y_{ct} is average rail *revenue per bushel* or total *carloads* shipped from county c in month t. As before Oil_t, is the total number oil cars shipped, $Pdiesel_t$ are diesel prices, T_{st} is monthly low temperature and X_t is other rail freight.[20] Similarly, we model harvest shocks and seasonality using crop-year production and month-effects using the approach discussed above. Unobserved heterogeneity across counties originating shipments is captured with mean effects δ_c.

Table 7 presents results from several variations of Equation (7). We focus on wheat shipments from Minnesota, Montana, North Dakota and South Dakota. We use revenue per bushel as the dependent variable to facilitate comparison with our spread results. Model 1 is the most parsimonious specification with diesel prices and mean effects for the county in

[20] 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.

which each wheat shipment originates. Model 2 adds harvest size by month interactions. Model 3 adds minimum temperature controls, model 4 accounts for other rail traffic and model 5 explores heterogeneity by originating state.

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. This may be due in part to railroads' reluctance or inability to adjust tariff prices to market conditions in the short run. For instance, the federally mandated twenty day notification period for rate increases, menu costs or pressure due to regulatory oversight. If tariffs are sticky in the short-run this would not necessarily prevent price responses to market shocks lasting months or years. However, it could lead to the creation of other mechanisms for responding to short-run changes in market conditions, for instance railcar auction programs discussed previously. We explore the potential role of rail car auctions below.

Next, we explore whether there is a relationship between oil and grain shipment quantities. Table 8 presents results from an analysis of county-level wheat shipments in the STB waybill data. 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.[21] When 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. Otherwise, models 1 through 5 are analogous to those used in the rail rate regressions. To account for differences in scale across counties, the dependent variable is the natural logarithm of the total number of wheat

[21] While 90 percent is an arbitrary baseline, we require some benchmark for consistent comparisons across crop years. 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.

carloads shipped from each county in a given month.

The estimated coefficients on oil carloads are negative and are statistically significant in specifications that control for total rail traffic in each month. 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.[22]

We conduct a similar exercise looking at rail rates and quantities for corn and soybean shipments. These results are summarized in Table 9. For both corn and soybeans, we estimate a small positive relationship between rail rates and oil shipments for originations in North Dakota. An increase of 10,000 carloads per month is associated with an increase in rates of approximately $0.04 per bushel.[23] 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.

Table 9 also shows evidence of quantity reductions in corn and soybean shipments. Increased oil shipments are associated with fewer corn shipments everywhere except South Dakota. For soybeans, elevators in Iowa and North Dakota have fewer shipments when oil traffic increases, while our estimates suggest shipments may increase in South Dakota. Note that while we find no relationship between oil shipments and wheat quantities in North Dakota. However, we do find modest negative effects for corn and soybean shipments. This result is again consistent with less elastic residual demand for North Dakota wheat as compared to corn and soybeans.

Given the relatively small change in rail rates but relatively large increase in wheat spreads, an important mechanism may be rail car auctions. As discussed above, railroads have established markets to allocate capacity in times of high demand or congestion. 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

[22] 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.

[23] Interestingly, these estimates are comparable to the spread increases we estimate for North Dakota corn and soybean shipments in Appendix Table 11

for the BNSF and Union Pacific (UP) railroads. Prices shown are from the secondary market where third parties buy and sell car contracts previously purchased from either BNSF's or UP's car market.[24] 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 first at BNSF auctions, we see car prices begin to increase during the middle of 2013. 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 spread on shuttle prices yields a coefficient of 0.98. The striking similarity of the time series suggest BNSF's car auction markets could be an important mechanism of grain shippers' response to increased oil traffic (congestion, or market conditions) during this time period.

Interestingly, we see similar behavior in the UP car market. Both markets are national because cars bought at auction can be used to originate grain across each railroad's network. We note UP does not serve origins or destinations in North Dakota, or for that matter most of the Upper Great Plains. Therefore, grain shippers on UP's network are not *directly* affected by any increase in North Dakota oil shipments. However, because grain cars are substitutable across grains and many shippers outside the region have access to both the BNSF and UP networks, shocks to BNSF's network may spillover to the UP network. Spillovers may also occur at major interchange terminals such as Chicago during this time period. The UP car price data seem consistent with these types of spillovers.

Anecdotes from 2013 and 2014 suggest elevator operators increased grain storage because they were unable to ship out grain on congested railroads. We investigate changes in storage costs by studying carry, *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

[24] Data from BNSF and UP primary auctions show similar patterns.

relationship between carry and oil shipments will be positive if storage costs are increasing in quantity and more oil shipments lead to more storage. Carry may also capture factors such as risk premia, which we assume are orthogonal to oil shipments, conditional on our controls. We construct several measures of "carry" that compare spot prices with prices for future deliveries. Specifically, we estimate models of the form:

$$P_{it+h} - P_{it} = \beta Oil_t + \gamma Pdiesel_t + \sum_{m=1}^{12} [Prod_{sy} \times \delta_m] + \xi T_{st} + \zeta X_t + \delta_i + \varepsilon_{it} \quad (8)$$

where P_{it+h} is the forward price at elevator i with horizon h and P_{it} is the cash price at elevator i and time t.

Table 10 presents estimates of Equation (8) 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. 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.[25] These small effects are also consistent with the incidence results presented in Section 5. If the incidence had fallen on North Dakota elevators and farmers, then we would expect to have seen a substantial increase in the price of storage. Our results suggest that there were no meaningful storage capacity constraints during this period.

Finally, another possibility is that some elevators shipped grain to alternate destinations in response to oil related rail congestion. We explore the spatial variation in shipping quantities in more detail in the Appendix. The analysis indicates heterogeneity in impacts by shipping location. In particular, elevators closer to the West-Coast, particularly those

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

in Montana, substantially increased their west-bound shipments during our sample period. By contrast, east-bound shipments from sources further east, displayed very little change. These heterogenous effects support both the notion that railroad congestion was present and yet the residual demand for east-bound shipping from major source locations was inelastic relative to both other sources of wheat and to the demand for shipping corn or soybeans.

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 the Dakotas 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 have examined one of the most notable episodes of the shale transportation phenomenon, the boom in oil-by-rail shipments out of the upper great plains since 2010. The massive increase in oil shipments appears to have created at least periodic congestion in rail networks, which has 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 have 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.

However, our results also highlight several more subtle aspects of the relationship between grain and oil prices. 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 purchasers of wheat at the Minneapolis commercial hub, rather than by farmers. Both of these findings are consistent with 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.

Last, our paper demonstrates the deployment of an interesting mechanism for the rationing of potentially scarce rail freight 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 spreads in grain prices. 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. Grain shipments were instead increasingly influenced by auctions for railcars that combined delivery performance guarantees with the physical transportation infrastructure. When these auction rates are combined with the traditional open-access tariff rates, they explain almost all of the observed differences in locational commodity prices. 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.

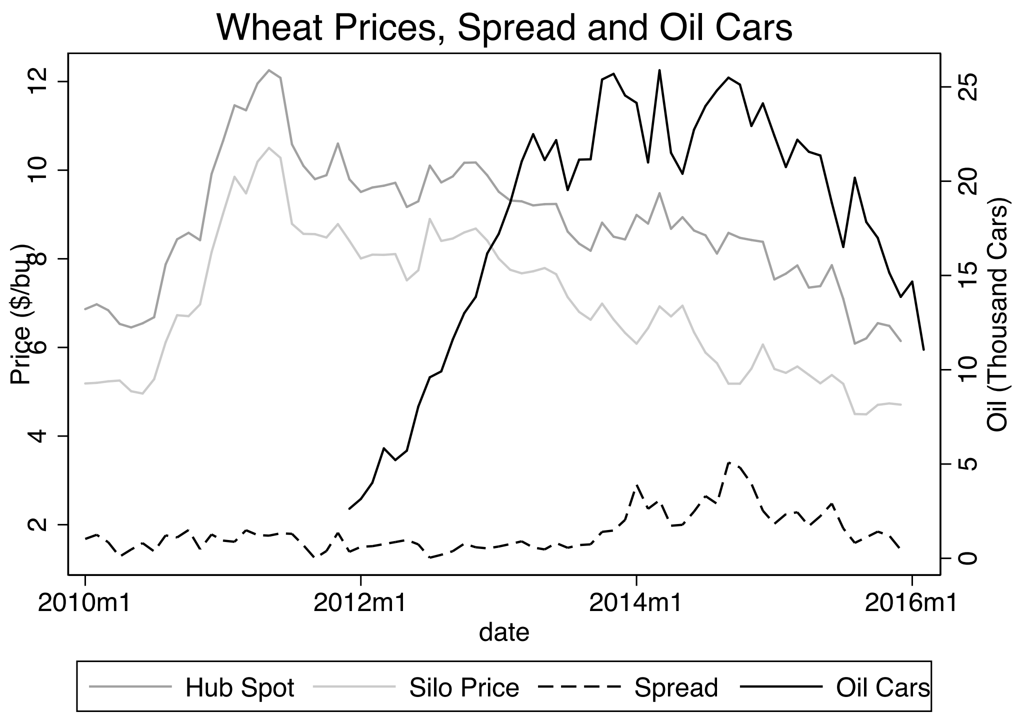


Figure 2: Wheat spread quintiles

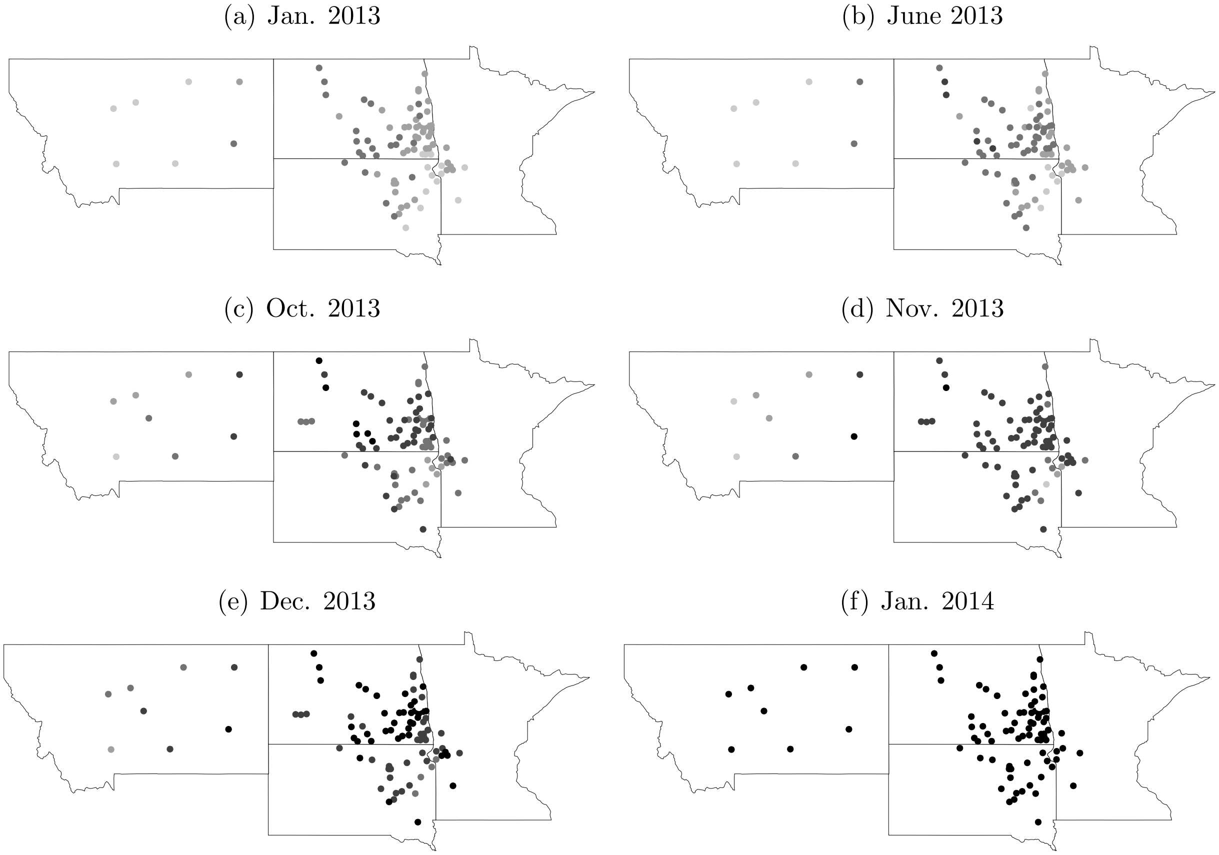


Figure 3

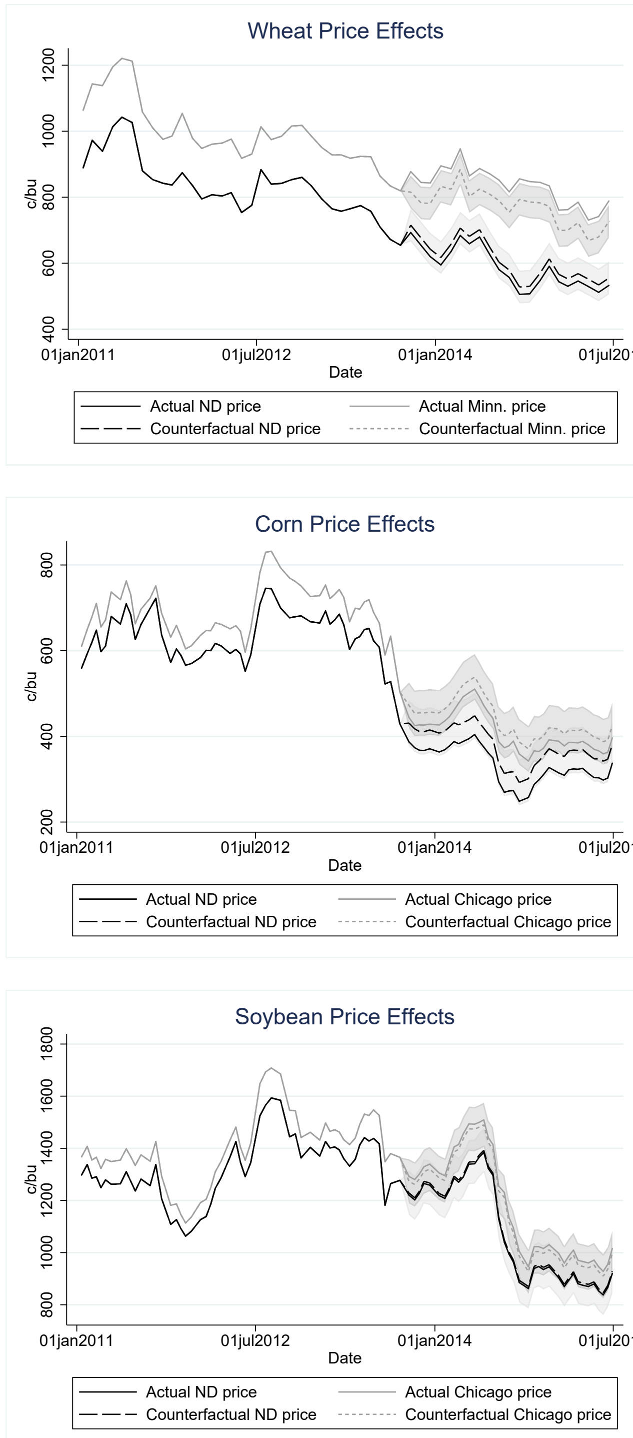
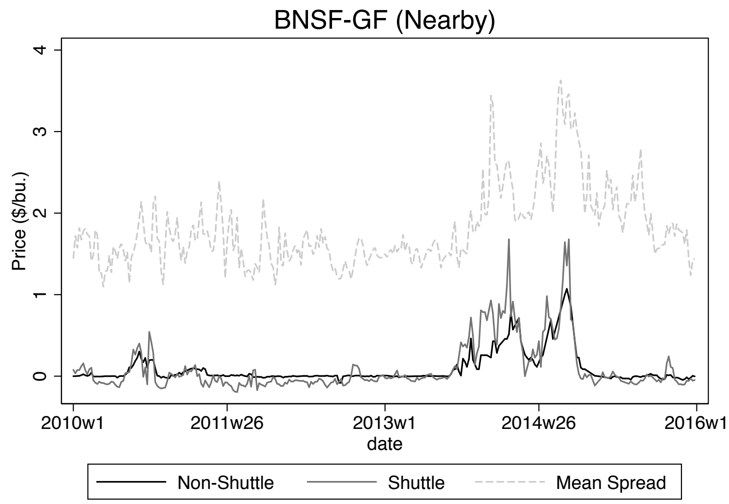
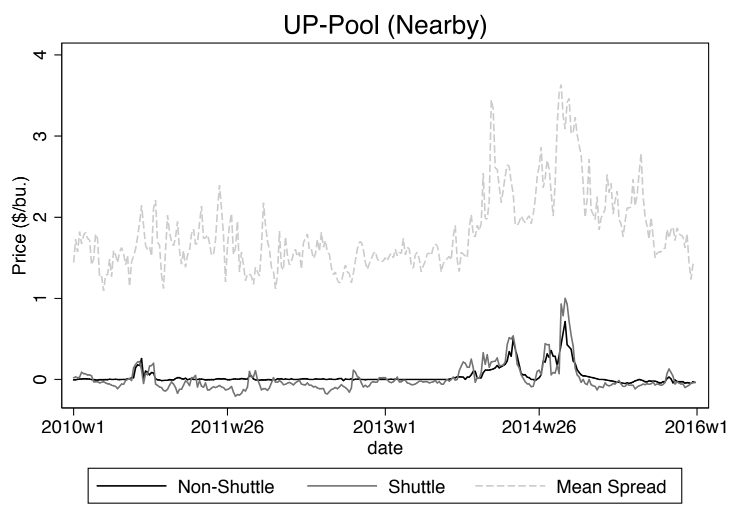

Wheat Price Effects
1200
1000
800
600
400
c/bu
01jan2011
01jul2012
01jan2014
01jul201
Date
Actual ND price
Counterfactual ND price
Actual Minn. price
Counterfactual Minn. price
Corn Price Effects
800
600
400
200
c/bu
01jan2011
01jul2012
01jan2014
01jul201
Date
Actual ND price
Counterfactual ND price
Actual Chicago price
Counterfactual Chicago price
Soybean Price Effects
1800
1600
1400
1200
1000
800
c/bu
01jan2011
01jul2012
01jan2014
01jul201
Date
Actual ND price
Counterfactual ND price
Actual Chicago price
Counterfactual Chicago price

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

(a) BNSF



(b) UP



Tables

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 elevator cash prices, Minneapolis (MGEX) hub price and oil carloads.

	2012	2013	2014	2015
Cash Price ($/bu.)				
Mean	$ 8.24	$ 7.26	$ 6.08	$ 5.06
Min.	$ 6.84	$ 5.81	$ 4.64	$ 4.08
25th percentile	$ 7.97	$ 6.74	$ 5.59	$ 4.67
Median	$ 8.27	$ 7.42	$ 6.08	$ 5.14
75th percentile	$ 8.54	$ 7.74	$ 6.62	$ 5.35
Max.	$ 9.26	$ 8.41	$ 7.81	$ 6.96
Minneapolis Spot - Cash Price ($/bu.)				
Mean	$ 1.49	$ 1.63	$ 2.59	$ 1.95
Min.	$ 0.89	$ 1.03	$ 0.59	$ 0.66
25th percentile	$ 1.36	$ 1.48	$ 2.24	$ 1.69
Median	$ 1.50	$ 1.60	$ 2.51	$ 1.95
75th percentile	$ 1.62	$ 1.76	$ 2.95	$ 2.26
Max.	$ 2.33	$ 2.62	$ 3.87	$ 2.84
Total Oil Cars (1000/month)				
Mean	8.8	21.7	23.5	19.0
Min.	3.1	17.2	20.4	13.9
25th percentile	5.2	21.0	21.5	17.0
Median	8.0	21.2	24.1	18.9
75th percentile	11.6	24.5	25.1	21.4
Max.	16.2	25.7	25.9	22.4
Obs.	1136	1113	1044	1150

Table 3: Wheat price spreads and oil carloads.

Wheat Price Spreads 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***	0.035***
	(0.0090)	(0.0090)	(0.0080)	(0.0090)	(0.0090)	(0.0100)
Diesel Prices	-0.044	-0.039	-0.052	-0.072	-0.086	-1.910***
	(0.0800)	(0.0800)	(0.0700)	(0.0810)	(0.0820)	(0.4890)
Minneapolis Distance (100 miles)	-0.042***					
	(0.0150)					
Average Daily Low Temp.					-0.005	-0.011**
					(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	0.96	0.96	0.96

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 4: Corn price spreads and oil carloads.

Corn Price Spreads and Railroad Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Oil Carloads (thousands)	0.005*	0.005*	0.004**	0.003	0.005**	0.001
	(0.0030)	(0.0030)	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Diesel Prices	0.007	0.008	0.01	0.025	0.036	0.048
	(0.0260)	(0.0260)	(0.0250)	(0.0220)	(0.0250)	(0.1380)
Chicago Distance (100 miles)	0.134***					
	(0.0110)					
Average Daily Low Temp.					0.004***	0.001
					(0.0010)	(0.0010)
Rail Traffic Excl. Oil and Grain						0.001***
						0.0000
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	5413	5413	5413	5413	5413	4090
Adj. R-sq.	0.47	0.65	0.74	0.94	0.95	0.95

Notes: Dependent variable is the difference between silo cash price and 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.

Table 5: Soybean price spreads and oil carloads.

Soy Price Spreads and Railroad Oil Shipments

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Oil Carloads (thousands)	0.006*	0.006*	0.006*	0.004	0.007**	0.002
	(0.0030)	(0.0030)	(0.0030)	(0.0030)	(0.0030)	(0.0030)
Diesel Prices	-0.013	-0.011	-0.011	0.036	0.053*	0.281
	(0.0310)	(0.0310)	(0.0250)	(0.0320)	(0.0290)	(0.2120)
Chicago Distance (100 miles)	0.203***					
	(0.0170)					
Average Daily Low Temp.					0.008***	0.005*
					(0.0020)	(0.0030)
Rail Traffic Excl. Oil and Grain						0.002***
						(0.0010)
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	5202	5201	5201	5201	5201	3910
Adj. R-sq.	0.46	0.58	0.61	0.91	0.91	0.90

Notes: Dependent variable is the difference between silo cash price and 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.

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.

Table 7: 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. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 8: 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. Standard errors clustered by county and date in parentheses. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Table 9: Oil carloads, rail prices and harvest-month adjusted quantities for corn and soybeans.

Corn, Soy and Oil Shipments

	Corn		Soy	
	$/bu.	Cars	$/bu.	Cars
ln(Oil Carloads)	-0.005**	-0.089***	-0.007**	-0.055*
	(0.0020)	(0.0240)	(0.0030)	(0.0300)
ln(Diesel Prices)	0.079	0.645**	0.09	0.630***
	(0.0820)	(0.2520)	(0.0710)	(0.2290)
Average Daily Low Temp.	0.003***	0.0040	0.0010	0.005*
	(0.0010)	(0.0020)	(0.0010)	(0.0030)
ln(Rail Traffic Excl. Oil and Grain)	0.0000	0.331***	0.0000	0.300***
	0.0000	(0.0550)	0.0000	(0.0740)
Minnesota X Oil Carloads	0.006	0.064	0.006	0.063
	(0.0040)	(0.0480)	(0.0040)	(0.0490)
Nebraska X Oil Carloads	-0.002	0.03	0.002	0.057
	(0.0040)	(0.0570)	(0.0040)	(0.0620)
North Dakota X Oil Carloads	0.009***	0.014	0.011***	0.0000
	(0.0030)	(0.0360)	(0.0030)	(0.0390)
South Dakota X Oil Carloads	0.007*	0.08	0.007*	0.094*
	(0.0040)	(0.0500)	(0.0040)	(0.0500)
County Effects	Yes	Yes	Yes	Yes
Harvest X Month Effects	Yes	Yes	Yes	Yes
Observations	3155	3155	3271	3271
Adj. R-sq.	0.36	0.41	0.37	0.40

Notes: Dependent variable is either the price of rail transportation in dollars per bushel or 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 10: 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.

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 11 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.[26] 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 $0.37 per bushel. The estimate for North Dakota is not significantly different. However, the estimated relationships for Montana and South Dakota are about a third smaller than Minnesota.[27] This again suggests elevators in these states may be affected differently by the increase in oil carloads.

Table 12 explores heterogeneity in the effects on corn and soybean spreads, as well as

[26] 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.

[27] *I.e.* 0.037 minus 0.011 or 0.26 for Montana.

wheat, across states. Overall, spread increases for corn and soybeans are substantially smaller than for wheat. Column 1 reproduces the wheat results from Table 11 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.[28] 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.[29] 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 8, 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 13. For Minnesota, a ten percent 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

[28] 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.

[29] (*i.e.* $10 \times (-0.007 + 0.011)$ and $10 \times (-0.009 + 0.018)$))

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 14 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.

Table 11: 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***	0.037***
	(0.0090)	(0.0090)
Minneapolis Distance (100 miles)	0.243***	
	(0.0340)	
MN Dist. Squared	-0.029***	
	(0.0030)	
Diesel Prices	-1.941***	-1.892***
	(0.4700)	(0.4980)
Montana X Oil Carloads		-0.011
		(0.0070)
North Dakota X Oil Carloads		0.005
		(0.0090)
South Dakota X Oil Carloads		-0.010***
		(0.0020)
Average Daily Low Temp.	-0.011**	-0.010*
	(0.0050)	(0.0060)
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	0.526	0.546
Adj. R-sq.	0.53	0.55

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 grair 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 12: 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)	0.037***	-0.007*	-0.009
	(0.0090)	(0.0030)	(0.0060)
Diesel Prices	-1.892***	0.055	0.253
	(0.4980)	(0.1310)	(0.2070)
Minnesota X Oil Carloads		0.006*	0.007
		(0.0030)	(0.0050)
Montana X Oil Carloads	-0.011	0.016***	
	(0.0070)	(0.0050)	
North Dakota X Oil Carloads	0.005	0.011***	0.018**
	(0.0090)	(0.0040)	(0.0080)
Nebraska X Oil Carloads		0.000	0.000
		(0.0020)	(0.0040)
South Dakota X Oil Carloads	-0.010***	0.006*	0.008
	(0.0020)	(0.0030)	(0.0050)
Average Daily Low Temp.	-0.010*	0.0010	0.0050
	(0.0060)	(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.	0.55	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 13: 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 Controls	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 14: Wheat shipments to the West Coast and oil carloads.

Wheat Shipments to the West Coast and Oil Shipments

	Model 1 OLS	Model 2 OLS	Model 3 OLS	Model 4 OLS	Model 5 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.