IFN Working Paper No. 966, 2013

Competitive Pressure and Technology Adoption: Evidence from a Policy Reform in Western Canada

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Evidence from a Policy Reform in Western Canada[*]

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Abstract

We measure the impact of the removal of a railway transportation subsidy on the adoption of technology for Western Canadian farms, using a unique combination of Census and freight rate data. We exploit the large regional variation in these one-time freight rate increases in order to identify causal effects of increased competitive pressure. Using a difference-in-differences methodology we find that higher freights rates – and hence lower farm gate prices – induced farmers to adopt new, more efficient production technology. We also find that farmers experiencing the greatest transportation cost increases also increased fertilizer usage and made significant land use changes.

JEL Classification Codes: F14, O13, Q16, Q17, Q18

Keywords: Agricultural Trade Liberalization, Export Subsidy, Technical Change

[*] We thank Julian Alston, Richard Gray, Ken Rosassen and the seminar participants at the University of Saskatchewan and the 2013 CAIRN workshop for comments and suggestions. We also thank Mony Louk and Whitney Mosley for their assistance with the data. A special thanks to Jason Skotheim for assistance with the freight rate data. Financial assistance from CAIRN and the Jan Wallander and Tom Hedelius Foundation is gratefully acknowledged.
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1. Introduction

Identifying the effect of competitive pressure on technology adoption has been a central question in economic research. However, there are two main empirical obstacles to correctly identifying the effect of trade liberalization and/or import competition on the adoption of new technologies. First, it is difficult to find an appropriate comparison group in order to identify the effects. Even if there is substantial variation in exposure to a reform across firms or industries, such sources of variation are susceptible to problems of selection and endogeneity. Second, it can be difficult to observe technology adoption and the extent to which a particular technology is adopted within a firm.

In this paper, we are able to overcome the identification problem by exploiting the removal of a railway transportation subsidy in Western Canada in 1995. This subsidy applied to exports of several agricultural commodities, and was deemed an export subsidy under the General Agreement on Tariffs and Trade (GATT). Crucially, the impact of the reform was location-dependent, with locations farthest from port experiencing the greatest increase in transportation costs upon the subsidy removal. We take advantage of this large regional variation across locations that otherwise are very similar in terms of climate, topography and pre-treatment characteristics in order to identify the causal effects of the subsidy loss on technology adoption and land use.

We examine one particular industry, the agriculture sector, for which we have detailed information on the use of various technologies from Census data. This setting is well-suited to studying the impact of competitive pressure on technology adoption in the form of a new seeding technology – "zero tillage" – in the 1990's, a technology that subsequently became widely adopted in the grain-growing regions of Western Canada[1]. We also measure the effects on fertilizer use and several other aspects of land use which were affected by the reform either directly or indirectly via the adoption of the new seeding technology.

Evaluating the impact of transportation costs in this setting is ideal for several reasons. The cost per tonne to ship grain from various inland locations in Western Canada to port position are transparent and publically available, providing us with a directly observable measure of transportation costs, which directly affect farm gate prices. Given the export-dependent nature of agricultural production in this region, prices for most agricultural commodities at inland locations are also highly transparent and driven primarily by the world price less the cost of

[1]Zero tillage, also referred to as "no-till," has been adopted rapidly in several countries, with equipment often tailored to local conditions and crops. Worldwide acreage in no-till increased from 111 to 274 million acres between 1999 and 2009, and predominates in the United States, Brazil, Argentina, Canada and Australia (Derpsch et al. 2010).

railway transport. Crucial to this argument, the share of production transported by rail has remained large and consistent over time. An average of 28.4 million tonnes of agricultural commodities are shipped by rail each year in Western Canada, constituting 59% of total production during the period 2001-2011, (Canadian Transportation Agency 2012a).

While this study contributes to a growing literature evaluating the impact of competitive pressure on technology adoption[2], evaluating the impact of this reform on the agricultural sector in Western Canada is worthwhile in its own right. Agriculture continues to be a large component of the economy in the region we study, with gross farm receipts totalling CAD 26.4 billion and total exports of CAD 11.8 billion in 2011, about 5% of regional exports.

This study also contributes to a literature on the effect of reduced market price support, which has fallen drastically in many OECD countries, decreasing on average from 32.1 percent of production value in 1986 to 8.8 percent in 2011 (OECD 2012). Rigorous evaluations of the impact of reduced market price support on farm-level outcomes are sorely lacking in the literature, with the notable exception of Paul et al. (2000), who evaluate the impact of dramatic regulatory reforms in New Zealand on farm productivity and production. Our paper, in contrast, focuses on technology adoption impacts and exploits geographic variation in the policy change within a difference-in-differences empirical framework as the basis of identification. Our results highlight the importance of competitive pressure as an important determinant of technology adoption in agriculture, building on earlier contributions that emphasized the importance of human capital (Rahm and Huffman 1984), risk aversion (Liu 2012) and uncertainty (Chavas and Holt 1996)[3].

Utilizing extensive Census and independent freight rate data for approximately 400 finely detailed spatial units across the Canadian provinces of Alberta, Saskatchewan and Manitoba, we present a range of new results. First, we find that higher freight rates led farmers to adopt new seeding technology, increase fertilizer use, and to reduce the share of land left idle each year (a practice commonly referred to as "summerfallowing"). We also find that farmers in areas with the greatest freight rate increases adapted by devoting a smaller share of their farm to growing wheat, the crop most clearly affected by the reform. Local feed grain prices were historically artificially high due to the export subsidy, leaving the livestock industry at a disadvantage. We find no evidence, however, that livestock production increased where grain

[2] Schmitz (2005) shows that imports of low-cost Brazilian iron ore to North America in the 1970's led to a doubling of labour productivity in U.S.-Canada Iron Ore sector. Bloom et al. (2012) show that import competition induces manufacturing firms to invest more in information technology. Similarly, Bustos (2012) and Lileeva and Trefler (2012) show both theoretically and empirically that trade liberalization induces manufacturing firms to simultaneously expand into export markets upgrade their production technology.

[3] See Sunding and Zilberman (2001) for a comprehensive literature review of the determinants of technology adoption in agriculture.

transportation costs increased the most (and local feed grain prices potentially decreased the most). The results for wheat acreage are in line with expectations and confirm the economic significance of the reform. The lack of positive effects on livestock production runs counter to conventional wisdom, but may be explained by the presence of agglomeration economies in large-scale livestock production that override considerations of locating close to low-cost feed supplies.

The paper proceeds as follows. Some essential background information on the transportation subsidy and its subsequent removal, the grain market and concurrent agricultural innovations is provided in Section 2. Our unique data combining freight rates with the census of agriculture is described in Section 3. The difference-in-differences empirical methodology is laid out in Section 4. The main results of the regression analysis are presented in Section 5, with robustness checks following in Section 6. Conclusions and suggestions for future research are discussed in Section 7.

2. Background

a. History of the Western Grain Transportation Act

In 1995 the Canadian Government abolished an export subsidy on railway shipments of grain from the Canadian Prairies known as the Western Grain Transportation Act (WGTA). This decision marked the end of one of the longest-running agricultural subsidies in the world, first known as the Crow's Nest Pass Agreement of 1897[4]. These subsidized freight rates were commonly referred to as the “Crow Rate.” The removal of this transportation subsidy increased the cost of exporting grain from the prairie region of Canada by $17-$34/tonne, equivalent to 8%-17% of its value[5]. These increased transportation costs translated into lower grain prices at the farm-gate.

Subsidization of transportation rates to move western Canadian grains to export position was an important part of the national policy to bring immigrants to the Prairie provinces and develop the so-called “wheat economy”. Under the Dominion Lands Act of 1872 Canada offered settlers in Western Canada free land and incentives to expand initial holdings. While the subsidized grain exporters benefitted from the subsidy, livestock producers and processors were disadvantaged by the resulting higher local prices of grains and the Crow Rate was seen as contributing to dependence on a very narrow range of crops, namely those whose export was subsidized (Klein and Kerr 1996). Removal of the transportation subsidy was expected to have significant impacts on the grains and livestock industries of the prairie region (Kulthreshra and Devine 1978).

[4]See Vercammen (1996) for a detailed overview of reforms to the Western Canadian grain transportation system.
[5] This assumes an average grain price of $200/tonne.

While the loss of the Crow Rate affected farmers in all locations across the prairies, some regions were affected more than others. Prior to the reform, rail transportation rates for wheat from the prairies to export position (Vancouver, BC or Thunder Bay, ON) ranged from $8 to $14/tonne, depending on location. After the reform, the rates were $25-46/tonne, with the highest freight rates in locations that were farthest from the ports.

The timing of the WGTA removal is attributable to two main reasons. First, a recession in the early 1990's forced the Canadian federal government to implement fiscal austerity measures which initially reduced the subsidy in the 1993-94 and 1994-95 crop years. The pressure to balance the budget is seen as the major contributing factor to the complete removal of the subsidy in 1995. Second, the GATT deemed the WGTA to be a trade-distorting export subsidy and the Canadian government was under international pressure to reduce it. The Uruguay Round's Agriculture Agreement stipulated that export subsidies were to be reduced by 36 percent of what was spent in 1991-92 by the year 2000. Moreover, this reduction was to apply to at least 21 percent of the volume shipped in 1991-92 (Kraft and Doiron 2000).

Farmers were compensated for the higher freight rates resulting from the repeal of the WGTA and the subsequent drop in land values with a one-time payment of $1.6 billion, and an additional $300 million to assist producers that were most severely affected and to invest in rural roads. This compensation was equivalent to approximately two years of the annual subsidy amount and was thus not large enough to fully compensate farmers for the loss of the subsidy (Schmitz et al. 2002).

Two other reforms occurred concurrently with the elimination of the WGTA. First, the federal government began to speed up the process of abandoning prairie branch rail lines that were too inefficient to maintain. Second the federal government also amended the Canada Wheat Board (CWB) Act in order to change the point of price equivalence to St. Lawrence/Vancouver, rather than Thunder Bay/Vancouver. The new pricing regime accounted for the cost to ship grain on lake freighters from Thunder Bay to the mouth of the St. Lawrence Seaway. This change resulted in lower grain prices in eastern Saskatchewan and Manitoba relative to Alberta for grain sold through the CWB (Schmitz et al. 2002).

The repeal of the WGTA has been associated with a range of adaptations by farmers to the lower prices for export grains (see Doan et al. 2003, 2006). It is expected that some farmers adapted to the new environment by shifting to high-value export crops, feed grain production and animal production or by pursuing economies of size in grain production. Many also suspected that the long-term trend of farm consolidation may have been hastened if freight rate increases led to some farmers no longer being competitive, thus exiting the industry, allowing farm size expansion by others.

It is important to note, however, that the 1990's were a dynamic time for prairie agriculture for several reasons, not just because of the repeal of the WGTA. Improvements in farm equipment led to larger and more efficient farms, and breeding techniques for high-value crops led to their increasing popularity. Many farmers were approaching retirement age and often sold or rented their land to other farmers who were seeking size economies. World prices for agricultural commodities also varied widely from 1995 onward, which surely affected farmers' production and technology adoption decisions. It is thus a challenging empirical question whether the observed post-1995 prairie agriculture structural changes were attributable to the end of the WGTA or if farmers would have adopted new technologies, adapted their production, or been weeded out by increasing competition even without the repeal of the WGTA. To the best of our knowledge such an empirical investigation has not been undertaken to date.

Existing *ex-post* studies of the impacts of the removal of the WGTA do not directly exploit the spatial variation in the reform, but instead compare before vs. after the reform and compare outcomes across the three Prairie provinces. Looking at the prairies as a whole, the pattern of crop diversification post-1995 agrees with the predicted outcome, with wheat's share of total crop area decreasing from 47% in 1990 to 32% in 2000 (Doan et al. 2003). Friesen (2002) finds that crop diversification increased most in Saskatchewan between 1990 and 2000, catching up to the relatively higher crop diversification in Alberta and Manitoba. While Friesen (2002) finds that cattle production increased in Alberta and hog production increased in Manitoba over the time period 1990-2000, he finds little evidence that farmers diversified their farms by converting from producing crops only to producing a mix of crops and livestock. Casual inspection of Friesen's results suggests that the positive trend in cattle inventories in Alberta pre-dated the transportation subsidy removal in 1995.

b. The grain market

While the economies of the Prairie provinces (Alberta, Saskatchewan, Manitoba) have diversified away from agriculture since the early 1900's, grain and livestock production remain a large component of the economy. Wheat has historically been the largest crop, but farmers also grow a variety of cereal crops (oats, barley, rye), oilseeds (canola, flax) and legumes (peas, lentils). Livestock production is also common on the prairies, and many farms produce both crops and livestock. Most crop and cattle producers are small-scale "family farms" with no external employees. In contrast, economies of scale have allowed for hog production and cattle feeding (feedlots) to become dominated by larger companies instead of family farms.

The marketing channel that farmers use depends on the type of grain and its quality. In the case of grains that are suitable for human consumption, it is most common for farmers to sell to a grain company, which acts as a middleman between the farmer and the downstream buyers in Canada or abroad[6]. Most grain companies have a large network of delivery locations across the prairies, usually beside a railway line. Farmers deliver their grain to the grain companies' "elevator", a short-term storage facility usually located along a rail line. The grain is then loaded onto rail cars for transport to ports in on Canada's west coast (Vancouver or Prince Rupert), the Lakehead (Thunder Bay) or Hudson's Bay (Churchill), then loaded on boats for export.

Farmers can also sell their grains to end-users locally or within the prairie region, where transportation by truck is most common. It is common for farmers to sell their grains directly to canola crushers, food processors, feed-lots, hog producers and other livestock producers. Grain companies can also act as a middleman for sales to large local customers.

c. The advent of zero tillage in Western Canada

The 1990's marked the beginning of large-scale adoption of a new seeding technology called zero tillage in Western Canada. The innovation was a seeding method that could prepare the seedbed and deposit the seed all in one operation while disturbing the soil as little as possible. The conventional seeding method was to first cultivate the soil, then seed, which disturbed the soil and led to erosion problems under windy conditions. The benefits of zero tillage were to reduce fuel use, conserve soil moisture, decrease soil erosion and reduce labor requirements.

The moisture conservation benefits of zero tillage allowed many farms to sow a crop every year in their fields instead of leaving them to lie idle every 2nd or 3rd year, a practice commonly referred to as "summerfallowing". The latter practice allowed for moisture to accumulate for the next year and eased the control of weeds using tillage. A reduction in summerfallow also meant that more fertilizer needed to be applied since leaving the soil idle increased plant-available nitrogen levels via the natural soil process of mineralization. Moreover, zero tillage required the use of herbicides to control weeds.

Awada (2012) posits that four economic factors hastened the adoption of zero tillage in Western Canada during the 1990's. First, the zero tillage seeding equipment improved substantially during this time. Second, the price of "Roundup" herbicide decreased to a point

[6] Until August 2012, wheat and barley for human consumption could only be sold to the Canadian Wheat Board (CWB). In this case, grain companies accepted delivery, stored and handled the wheat and barley as agents of the CWB using the same elevator facilities as for other "non-board" grains.

where it became economical to use it as a primary weed control method. Third, interest rates decreased, making it easier for farmers to finance the cost of the new technology. Finally, the price of fuel increased during this time. The combination of these four factors made zero tillage a viable option for prairie grain farmers.

Zero tillage has become the dominant seeding technology on the prairies, increasing from 8% to 49% of cultivated acres between 1991 and 2006. At the same time, the use of "minimum tillage" technology was relatively stable between 1991 and 2006 at 25% of cultivated acres. Minimum tillage technology involved less tillage than conventional methods (often seeding in one operation) but more than zero tillage technology.

3. Data and Descriptive Statistics

One of the unique features of our data is that it combines freight rate data with data from the Census of Agriculture. This section explains the data sources and how they were combined.

a. Census of Agriculture data

The primary data consists of the Census of Agriculture, aggregated to the Census Consolidated Subdivision (CCS) level. A CCS is equivalent to a Rural Municipality in the case of Saskatchewan and Manitoba and a County in the case of Alberta. The Census of Agriculture is undertaken every five years. We require data for several years before and after the 1995 reform in order to identify the effect of the WGTA repeal on farm outcomes. We therefore use data from the 1986, 1991, 1996, 2001 and 2006 census years in our analysis. We use data on the number of farms, land use and livestock production. We also use census data on the use of minimum-tillage technology, fertilizer and pesticide use. Constant 1996 CCS boundaries were used to control for changes in boundaries between years and amalgamations of CCS's over time. The CCS boundaries are illustrated in figure 1.

b. Freight rate data

We combine data on farm outcomes from the Census of Agriculture with freight rate data supplied by *Freight Rate Manager*, a service provided by a consortium of government, academic and farmer organizations.[7] The freight rate data encompass the freight rate for wheat from at most 1300 delivery locations spread across Alberta, Saskatchewan and Manitoba. We use GIS techniques to build a concordance whereby each CCS from the Census is matched with its closest delivery location, with the distance calculated from the each CCS's centroid. We then match our freight rate data to our Census of Agriculture data for each census year using this CCS-delivery location concordance. We capture local transportation costs from the farm to the delivery location using the distance measure from each CCS centroid.

[7] This service provides farmers with information on the cost of shipping various crops by rail, depending on their location. See http://freightratemanager.usask.ca/index.html for more details on the source of the freight rate data.

The pattern of freight rates over time in four different locations is illustrated in figure 2. Note that while freight rates increased for all locations between 1991 and 1996, there was large variation in the size of this increase. In general the freight rates increase was less pronounced in Alberta and became more pronounced as one moved eastward towards Saskatchewan and Manitoba. The largest freight increases were in Northeastern Saskatchewan, which is the most remote location in terms of distance to both the west coast and the Great Lakes. Note in figure 2 that freight rates decreased slightly in 2001 after rising sharply in 1996, especially in Manitoba. This was caused mainly by a change in grain transportation policy starting in 2001 that led to small freight rates adjustments.

c. Soil and weather data

We include controls for soil zone and weather in all specifications. The soil data describes the percentage of each CCS that is brown, dark brown, black dark gray or gray soil. The color of the soil is determined by the level of organic matter it contains, which is itself related to the vegetation and hence by long-run weather. Brown soil is found most arid parts of the prairies were previously a grassland ecosystem. Black soil is found in more moist areas of the prairies were previously covered by long grass and deciduous trees. Gray soil is found in areas with coniferous forest. The soil data originates from the Soil Science GIS Lab at the University of Saskatchewan. A map of the soil zones is provided in figure 1.

The weather data include 20-year average precipitation, humidity and temperature in each CCS. Environment Canada weather data for every weather station across the prairies was matched to our CCS-level data using GIS. The weather data for a specific CCS represents the weather data available from the nearest weather station with at least 20 years of data.

d. A first glance at the data

As a first pass at the data we compare several characteristics in 1991 for regions that subsequently experienced relatively large and small freight rate increases. We divide CCS's into two groups: CCS's where the change in the freight rate between 1991 and 2001 is above the median, and CCS's where the change in the freight rate is below the median.

Table 1 illustrates that regions experiencing a relatively large increase in freight rates also exhibited a larger dependence on wheat in 1991, had more summerfallow acres and had less livestock. As already noted, the 'high' and 'low' freight-rate-increase CCSs are also unevenly distributed over provinces, and across soil zones. For example, twice as many CCSs in the brown soil zone fell into the 'low' freight rate increase category. These *ex ante* characteristics must, of course, be controlled for when evaluating the impact of the reform.

We illustrate the changes in our outcome variables over time using a graphical approach. Figure 3 shows how the technology adoption outcome variables changed over time in regions that experienced relatively large or small freight rate increases. Trends in zero tillage and minimum till adoption (Panels A and B respectively) can only be observed from 1991 since the Census of Agriculture did not collect data on tillage practices until that year. In the case of zero till, it was practiced by very few farmers in Western Canada in 1986, so the trends were arguably parallel prior to 1991. It is more difficult to argue that minimum tillage adoption was trending parallel in both groups prior to 1991 since the adoption levels were already quite high for both groups in 1991. Panel C shows that the share of acres in summerfallow was trending parallel in both groups, but fell much faster for the area that experienced a relatively larger freight rate increase after the reform. Panel D illustrates that fertilizer usage was more variable from year to year, and that there was already some divergence between the groups prior to the reform.

Figure 4 shows how land use and production patterns changed over time in areas that experienced relatively large vs. relatively small freight rate increases. The percent of farm area devoted to wheat (Panel A) trended in parallel prior to the reform but then decreased more rapidly in the areas where freight rates increased the most. Trends in canola acreage (Panel B) diverged after 1996, which is also the same time when new genetically modified canola varieties were introduced on the market. The trends in pasture and cattle production (Panels C and D respectively) were roughly parallel throughout the entire time period. Hog production (Panel E) was roughly parallel prior to the reform but then decreased in the areas that experienced the largest freight rate increases.

One may expect that some of the changes in technology adoption and land use after the reform may be correlated with each other. The matrix of correlation coefficients of our nine dependent variables is reported in Table 2. It turns out changes in zero tillage adoption is negatively correlated with summerfallow use and positively correlated with fertilizer use. This suggests that adoption of zero tillage is associated with more continuous cropping and increased fertilizer use, which is in line with expectations.

Trends in farm size, defined as the number of acres in crops or summerfallow, are illustrated in figure 5. The average number of acres devoted to crops or summerfallow across all farms in the census is illustrated in Panel A; the share of farms with crops and fallow greater than 1600 acres in Panel B. Figure 5 highlights that farm size increased over time for all locations, but the share of large farms was already diverging between the two groups prior to the policy reform.

4. Empirical Methodology

As mentioned earlier, the main methodological challenge is to separate the impact of the policy reform from all of the other sources of change during the same time period. We are able to overcome this problem in the case of the WGTA reform since the effect of the freight rate increase in 1995 on a particular farm depended on its location. The effect of removing the transportation subsidy should be greater in geographic areas farther from port that experienced a larger freight rate increase in 1995 when the WGTA was repealed. We can exploit this spatial variation in the reform consequences in order to untangle the causal effect of the removal of the transportation subsidy from that of other exogenous factors that changed over time (such as world prices and the availability of new technologies) independently of the policy reform. In this sense, the removal of the WGTA serves as a valuable "natural experiment" of the effect of increased transportation costs on the agriculture sector.

The analysis will take the form of an OLS panel regression using a generalized difference-in-differences methodology. We propose the following linear model for explaining the impact of freight costs on farm outcomes:

$$Y_{it} = \alpha_i + \alpha_t + \beta\, freight_{it} + \gamma X_{it} + \varepsilon_{it} \tag{1}$$

where Y_{it} is the outcome variable of interest for CCS region *i* in year *t*, for a panel of 461 CCSs with observations in each of our 5 Census years. $freight_{it}$ is the transportation cost to ship grain from CCS region *i* to port. The repeal of the WGTA will cause $freight_{it}$ to increase disproportionately across CCS regions after 1995. X_{it} is a vector of controls that vary across CCS regions and years. α_i is a set of CCS region fixed effects, which captures all time-constant factors that may influence the outcome variables, such as soil and climate normals. α_t is a set of census year fixed effects, which capture any explanatory variables that vary over time but not across regions, such as world prices. ε_{it} is the error term.

Differencing Eq. (1) across periods yields our baseline first-differenced specification:

$$Y_{i1} - Y_{i0} = \alpha + \beta(freight_{i1} - freight_{i0}) + \gamma(X_{i1} - X_{i0}) + \upsilon_r \tag{2}$$

Where $\alpha \equiv \alpha_1 - \alpha_0$, $\upsilon_i \equiv \Delta\varepsilon_i$ and the CCS fixed effect α_i is differenced out. The constant in this first-differenced regression picks up the change in Y_{it} that is due to factors that affect all locations identically. This includes the effect of world prices, technology developments and other phenomena that affect all farms. In all regressions we will add a vector of time-constant controls, X_i, which includes long-term weather averages. These control for the possibility that outcome variables change over time due to underlying geographical trends.

We estimate Eq. (2) using several different dependent variables that capture various aspects of adaptation and technology adoption. The main coefficient of interest is β, with the null hypothesis that $\beta = 0$. The expected sign of β will depend on the outcome variable we are using in a particular regression.

It is important to emphasize that our identification strategy is able to tease out the differential impacts of the policy change across regions but does not capture the total impact of the policy. The size of the coefficient β can thus be interpreted is a measure of inter-regional differences in the impact of the reform. All locations experienced higher freight rates as a result of the WGTA repeal, and the measurement of the total impact is confounded by other time varying factors during the same time period.

5. Main Results

The main results are summarized in Tables 3 and 4, where we report the impacts of the increase in freight rates between 1991 and 2001 on several outcome variables. All specifications control for local trucking distances, as well as long-term weather conditions, including average temperatures in January and July, average precipitation and average precipitation squared. We also report the mean of each dependent variable between 1991 and 2001 at the top of each column. This allows us to compare the size of the coefficients to the average change over time.

a. Technology adoption

The effect of increased freight rates on technology adoption is shown in Table 3. We find that higher freight rates led to increased adoption of zero tillage technology, reduced prevalence of summerfallow and increased adoption of fertilizer. These results are shown in columns (1), (3) and (4) of Table 3. The interpretation of the coefficients is that a one dollar per tonne increase in the freight rate in a CCS led to an increase in zero tillage adoption by 0.97 percentage points, an increase in fertilizer adoption by 1.29 percentage points and a reduction in summerfallow by 0.96 percentage points. The results are consistent with the common pattern that zero tillage is associated with a reduction in summerfallow and an increase in fertilizer usage.

The effects of higher freight rates on zero tillage adoption are large. For example, comparing two locations that experienced a \$20/tonne vs. \$30/tonne freight rate increase, our results indicate that zero tillage adoption will be \$10/tonne*0.97=9.7 percentage points higher in the more severely affected location. Compared with the average increase in zero tillage adoption of 23 percent between 1991 and 2001, the impact of transportation costs is economically significant.

We do not find significant results for minimum tillage adoption, as shown in column (2) of Table 3. The lack of results for minimum tillage adoption is consistent with the graphical interpretation in figure 3, where the minimum tillage adoption first increased, then decreased.

The results for the distance and weather control variables are mixed. The signs for the coefficients are not always significant, Tables 3 and 4, but the results generally agree with our *ex ante* expectations in most cases. For example, zero tillage adoption is higher in locations with less precipitation and colder winter temperatures. This result agrees with the expectation that zero tillage is not practical in locations where moisture is excessive, or where the growing season is long and the main crops are not compatible with zero tillage technology.

b. Production of crops and livestock

The effect of increased freight rates on crop and livestock production is presented in Table 4. We find strong evidence that the increase in freight rates led to a statistically significant decrease in wheat acreage (column 1). This result agrees with the conventional wisdom regarding the effect of the reform. The coefficients indicate that wheat acreage decreased by 0.75 percentage points for every one dollar increase in freight rates.

We find a weak positive effect of higher freight rates on the share of acres in canola in column (2) of Table 4. We do not find any effect on the share of acres in pasture or the number of cattle produced in columns (3) and (4). The lack of a strong impact on canola acreage may stem from the fact that there was only a 2.5 percentage point average increase in canola acreage over the 1991-2001 period across all CCS's. The non-significance result for cattle production is likely due to the fact that cattle production has been concentrated in Alberta, where freight rates did not increase as much as in Saskatchewan or Manitoba. Moreover, the graph in figure 4 shows cattle production increasing before the removal of the freight rate subsidy in 1995. Given the lack of an effect on cattle production, it is intuitive that the share of acres devoted to pasture did not increase either. We find a negative and significant effect of freight rates on hog production in column (5) of Table 4. It is important to note though that the results here measure the differential impact of higher freight rates in different locations, not the average change before vs. after the reform. The number of cattle and hogs increased in all locations on average after 1991, and some of this may be attributable to the policy reform. Moreover, the offsetting subsidies for animal feed may have encouraged livestock production prior to the WGTA repeal.

6. Robustness

We check whether our results are robust to changing the time horizon of the first-difference regressions and by performing the analysis separately by soil zone. We also discuss issues of identification and check whether our results are robust to controlling for the effect of farm size on technology adoption.

a. Short- vs. long-run effects

The results for the freight coefficient using 5-, 10- and 15-year differences are presented in columns (1), (2) and (3) respectively of Table 5. While the 5-year difference does not allow for much time for the reform to impact technology adoption and land use, it us useful to check whether the partial reductions in the subsidy in the 1993-94 and 1994-95 crop years or any anticipation of the subsidy removal had any effect on the outcome variables.

We find that the effect of higher freight rates on fertilizer use and summerfallow has the same signs across all three time periods. In column (1) minimum tillage adoption is positive and significant while zero tillage adoption is not significant. This is likely due to the fact that adoption of minimum tillage technology was increasing in the early 1990's before being eclipsed by zero tillage technology in later years. Higher freight rates led to higher adoption of zero tillage even in the 15-year difference specification.

The coefficient for the percentage of acres in wheat is negative across all columns of Table 5, increasing in size and significance over time. This result suggests that it took many years for farmers to adjust their land use after the subsidy removal. We find no effects on canola acreage and cattle production in the 5- and 15-year time horizons. The results for pasture are inconsistent over the different time periods, with pasture initially decreasing in the CCS's most affected by the subsidy removal but without any long run impact.[8]

b. Results by soil zone

We perform the analysis by soil zone in Table 6 for all dependent variables. Weather conditions and hence agronomic practices are highly similar within each soil zone and thus provide a more credible comparison between locations that vary in their exposure to the reform. In the zero till, fertilizer and canola regressions we find positive effects of higher freight rates for CCS's with at least 50% black soil. The negative coefficients for summerfallow and hog production appear to be driven by changes in the gray, dark gray and black soil zones. The lack of robust results for minimum tillage, pasture and cattle seem to hold regardless of soil zone.

It is important to note that the pattern of significance in Table 6 may be an artefact of the shape of the soil zones and the relative number of observations within each soil zone. As figure 1 illustrates, the black soil zone is geographically large and spread out over a wide area.

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[8] As an additional check we perform a panel regression with CCS fixed effects and world grain price and exchange rate controls. We find that hog production is sensitive to exchange rates, but our result for freight rate continues to be negative and significant. These results are available upon request.

Observations from the black zone thus contain the most variation in the freight variable compared to other soil zones.

c. Identification and farm size

While reverse causality is unlikely to be a problem in the analysis, a potential concern is that a correlation between freight rate increases and our outcome variables may be driven by other factors, such as geography. The difference-in-difference approach controls for all time-invariant differences across Census units, which arguably controls for much of the underlying geographical factors.

The interaction between farm size and technology adoption is another potential concern. Awada (2012) finds that larger farms are more likely to adopt zero till. It may thus be the case that farm size patterns drive adoption of zero till. While farm size was likely affected by the reform, we include a farm size farm size control variable as a robustness check. The results, presented in Table 7, suggest that changes in zero tillage adoption were not correlated with changes in the percent of large farms in a CCS. Farm size is, however, correlated with the incidence of summerfallow and fertilizer use. Nonetheless, we maintain significant results on the effect of higher freight rates with coefficients that are largely unchanged. This robustness check suggests that underlying changes in farm size are not driving our main results.

7. Conclusion

The sudden increase in freight rates experienced in Western Canada after 1995 serves as a useful natural experiment that allows us to evaluate the impact of increased competitive pressure on technology adoption. Overall, we find large and statistically significant effects of the policy reform on the adoption of zero-till seeding technology, fertilizer use and summerfallow. We find that the reform encouraged a reduction in wheat acreage, but negligible effects on livestock production. While the results on wheat production are not surprising, the lack of verifiable effects on cattle production goes against the conventional wisdom among policymakers and academics. The impact of higher freight rates on technology adoption is a new result in the context of agriculture, but is in line with the results of recent studies in other sectors.

This study is strictly an empirical evaluation, leaving questions regarding the underlying mechanisms for future research. A theory explaining why increased competitive pressure induced farmers to adopt technologies does not exist to the best of our knowledge, but is an obvious direction for further research. We hope that the empirical results of this analysis will stimulate more work in understanding the effects of agricultural trade liberalization and other reforms on the agricultural sector.

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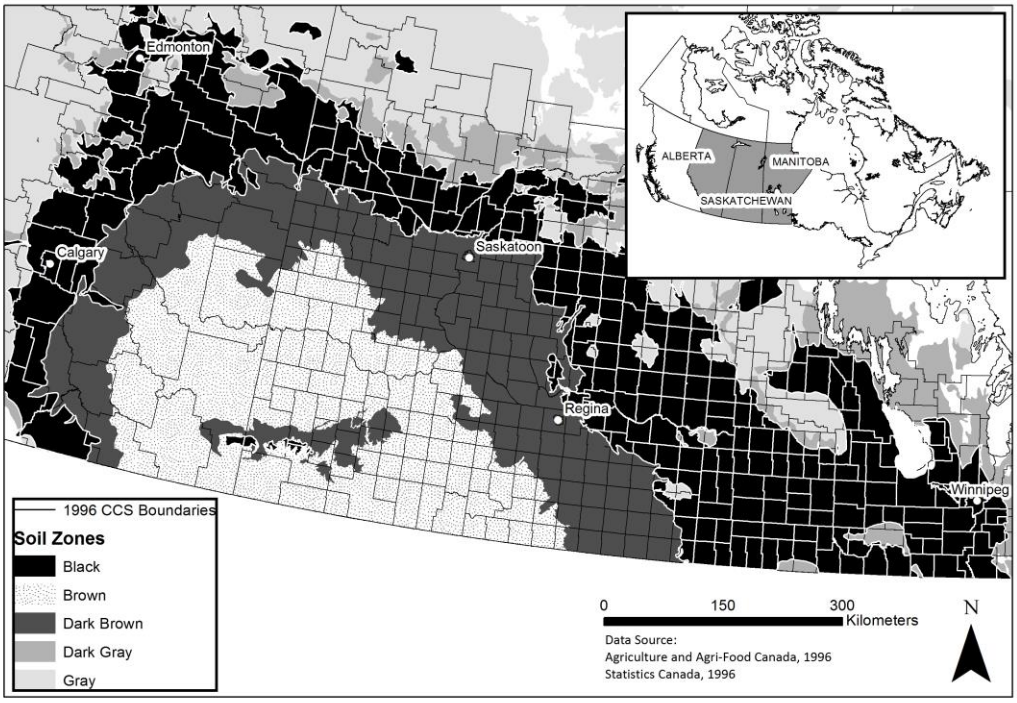

Figure 1: Soil Zones and 1996 Census Consolidated Subdivision Boundaries for the Prairie Provinces

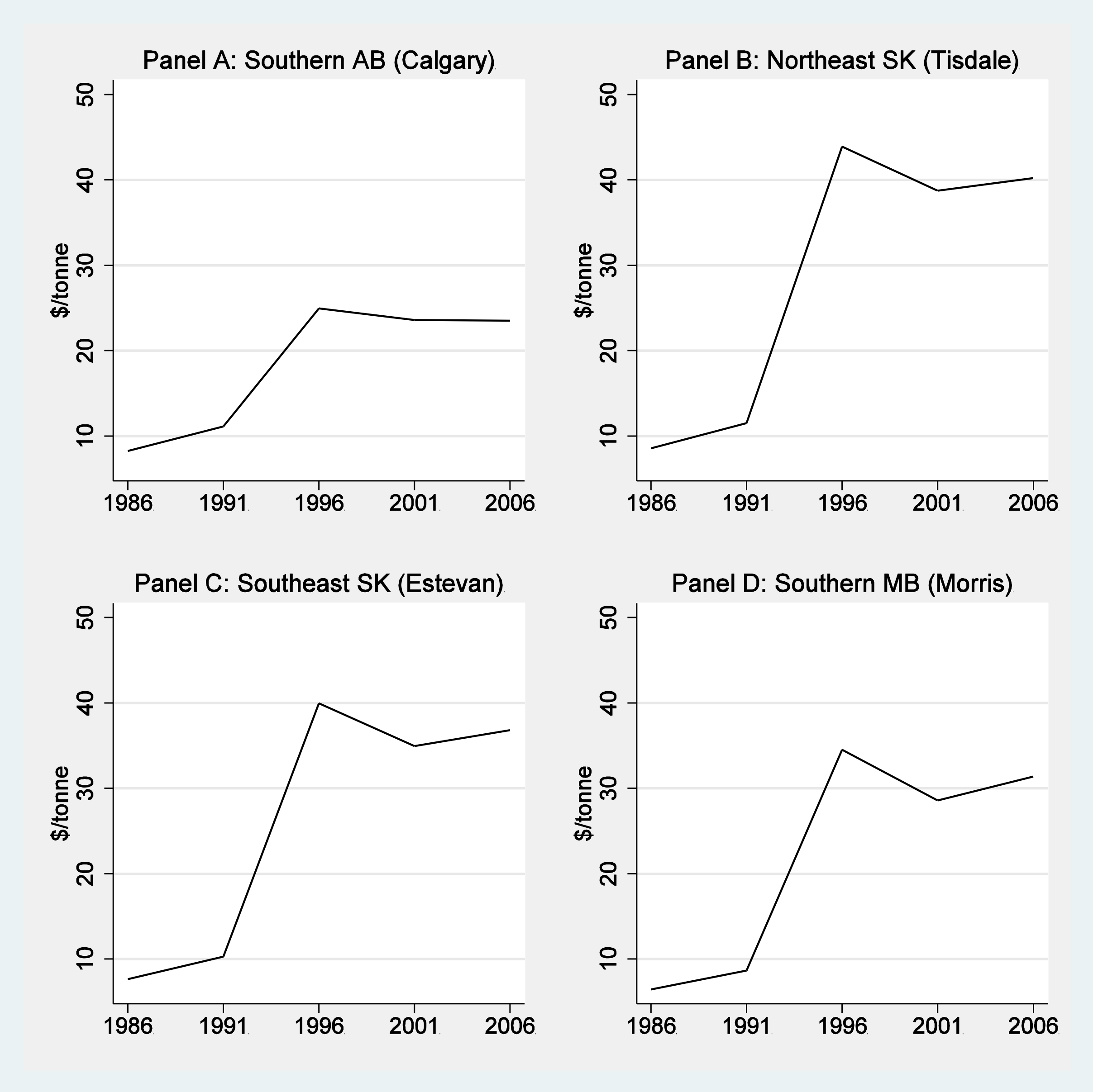

Figure 2: Freight rate changes in various locations, adjusted for inflation, constant 2002 dollars.

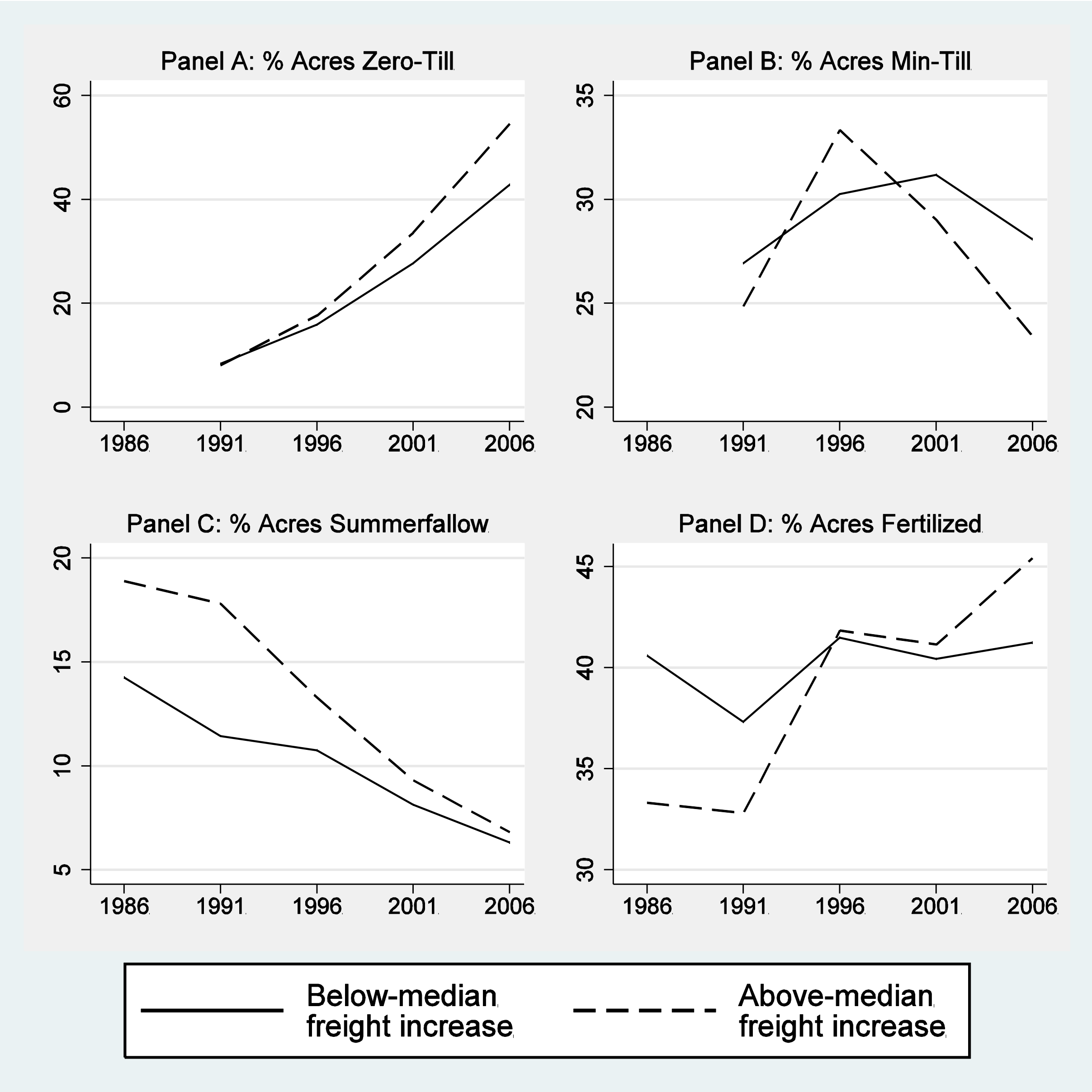

Figure 3: Trends in technology adoption for CCS's with freight rate changes above vs. below the median

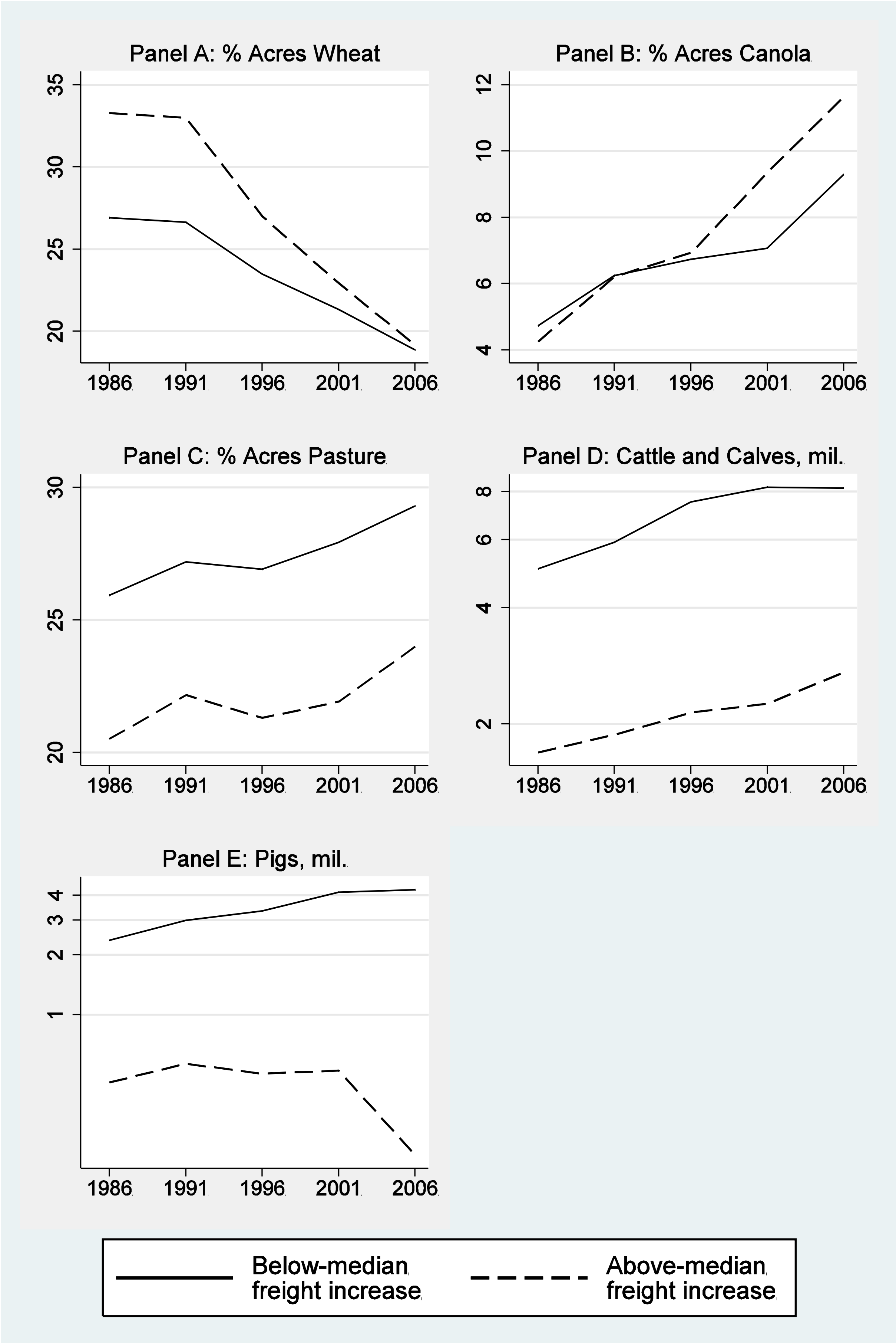

Figure 4: Trends in production for CCS's with freight rate changes above vs. below the median

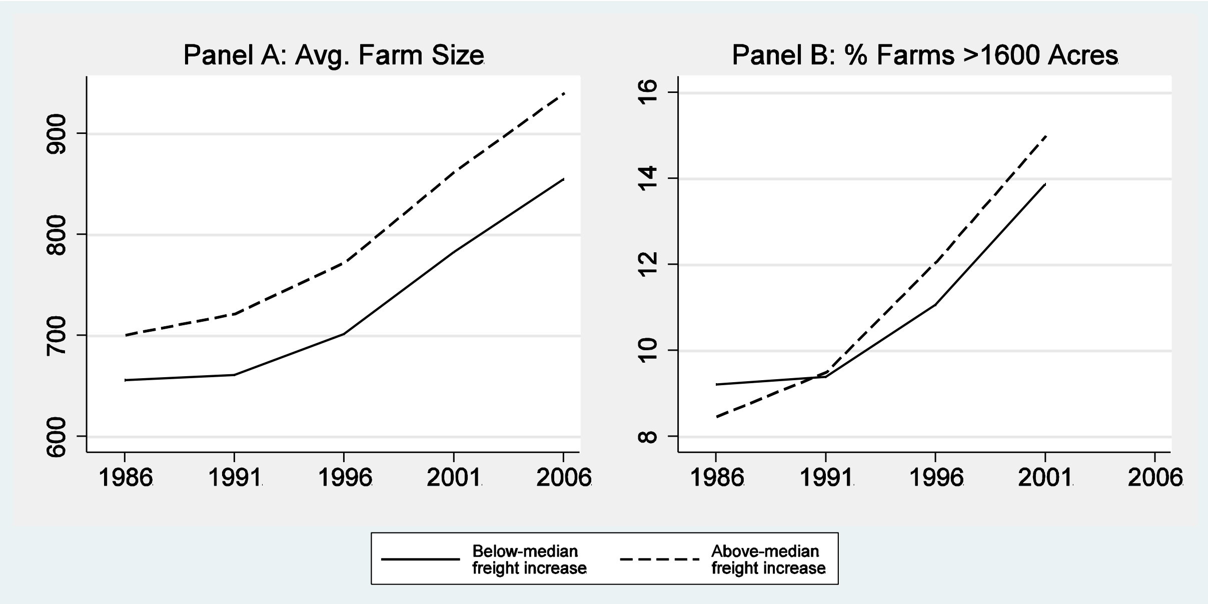

Figure 5: Trends in farm size for CCS's with freight rate changes above vs. below the median

Note: Farm size is defined as the number of acres in crops or summerfallow.

Table 1: Descriptive Statistics

Freight rate increase, relative to median, 2001-1991:	year=1991 Above median	Below median	All CCS's
Dependent Variables:			
Percent of acres:			
using zero-tillage ($zerotill_{it}$)	8.1	8.3	8.2
using minimum-tillage ($mintill_{it}$)	24.9	26.9	25.9
in summerfallow ($fallow_{it}$)	17.9	11.5	14.8
applied with fertilizer ($fertilizer_{it}$)	32.8	37.3	35.1
planted to wheat ($wheat_{it}$)	33.0	26.6	29.8
planted to canola ($canola_{it}$)	6.3	8.2	7.3
in pasture ($pasture_{it}$)	22.2	27.2	24.7
Number of cattle and calves ($cattle_{it}$)	8149.8	25582.2	16884.9
Number of hogs ($hogs_{it}$)	2864.9	14579.1	8838.6
Independent Variables:			
Freight rate increase, 2001-1991, wheat, $/tonne ($\Delta freight_{it}$)	25.28	19.82	22.55
Distance from CCS centroid to delivery point ($distance_{it}$)	10.8	11.8	11.3
Average January temperature (jan_temp_i)	-16.5	-15.0	-15.7
Average July temperature ($july\_temp_i$)	18.2	17.9	18.0
Average annual precipitation ($precip_i$)	437.1	440.9	439.0
Percent of farms larger than 1600 acres ($largefarm_{it}$)	9.5	9.4	9.4
Number of CCS's by category:			
Alberta	58	1	59
Saskatchewan	100	193	293
Manitoba	73	36	109
Brown Soil Zone	33	65	98
Dark Brown Soil Zone	86	66	152
Black Soil Zone	141	137	278
Dark Gray Soil Zone	55	84	139
Gray Soil Zone	75	53	128

Notes: A CCS is considered belonging to a particular soil zone if that soil type covers at least 50% of its area.

Table 2: Correlation coefficients, change in dependent variables between 1991 and 2001

	$\Delta zerotill_{it}$	$\Delta mintill_{it}$	$\Delta fallow_{it}$	$\Delta fertilizer_{it}$	$\Delta wheat_{it}$	$\Delta canola_{it}$	$\Delta pasture_{it}$	$\Delta log(cattle_{it})$
$\Delta mintill_{it}$	-0.37*							
$\Delta fallow_{it}$	-0.52*	0.27*						
$\Delta fertilizer_{it}$	0.35*	-0.25*	-0.71*					
$\Delta wheat_{it}$	-0.09	0.23*	0.33*	-0.07				
$\Delta canola_{it}$	0.08	-0.14*	-0.09	0.02	-0.07			
$\Delta pasture_{it}$	0.12*	-0.02	-0.14*	0.10*	-0.01	-0.04		
$\Delta log(cattle_{it})$	0.01	-0.13*	0.11*	-0.13*	0.05	0.14*	0.12*	
$\Delta log(hogs_{it})$	-0.22*	0.00	0.33*	-0.17*	0.04	0.11	-0.04	0.06

Notes: * indicates pairwise correlation coefficients significant at the 5% level or better.

Table 3: The effect of higher freight rates on technology adoption

Dependent Var:	10 year difference-in-differences (2001-1991)			
	$\Delta zerotill_{it}$	$\Delta mintill_{it}$	$\Delta fallow_{it}$	$\Delta fertilizer_{it}$
	(1)	(2)	(3)	(4)
Mean Dep. Var:	22.88	4.24	-6.37	5.82
$\Delta freight_{it}$	0.966**	-0.201	-0.959***	1.288***
	(0.411)	(0.255)	(0.175)	(0.288)
$\Delta distance_{it}$	0.000920	-0.0440	0.00181	0.0819*
	(0.0753)	(0.0735)	(0.0206)	(0.0453)
jan_temp_i	1.806***	-1.221***	-0.908***	1.924***
	(0.540)	(0.342)	(0.200)	(0.358)
$july\_temp_i$	-1.357	-3.590***	-0.106	1.666**
	(0.989)	(0.623)	(0.343)	(0.712)
$precip_i$	-0.0547***	0.0205**	0.0418***	-0.0508***
	(0.0163)	(0.00991)	(0.00509)	(0.00844)
$(precip_i)^2$	-0.000807***	-0.000118	6.87e-06	1.23e-05
	(0.000178)	(0.000104)	(5.51e-05)	(0.000104)
Observations	441	443	418	461
R-squared	0.282	0.234	0.491	0.369

Notes: The dependent variables are given at the top of each column. Census Consolidated Subdivision-level data used in all specifications. Clustered at Census Division Level in all specifications. A constant term is included in all specifictions. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: The effect of higher freight rates on production of crops and livestock

Dependent Var:	10 year difference-in-differences (2001-1991)				
	$\Delta wheat_{it}$	$\Delta canola_{it}$	$\Delta pasture_{it}$	$\Delta log(cattle_{it})$	$\Delta log(hogs_{it})$
	(1)	(2)	(3)	(4)	(5)
Mean Dep. Var:	-7.69	2.47	0.20	0.27	0.55
$\Delta freight_{it}$	-0.754***	0.272*	-0.0655	-0.0150	-0.139***
	(0.203)	(0.141)	(0.0928)	(0.0153)	(0.0290)
$\Delta distance_{it}$	0.0857***	-0.0698***	-0.0132	0.00299	-0.00606
	(0.0311)	(0.0128)	(0.0463)	(0.00424)	(0.00924)
jan_temp_i	-0.495**	0.166	0.218*	0.00257	-0.0639
	(0.213)	(0.188)	(0.118)	(0.0174)	(0.0464)
$july\_temp_i$	-1.513***	0.999***	-0.481*	0.0205	0.254***
	(0.470)	(0.260)	(0.255)	(0.0405)	(0.0624)
$precip_i$	-0.0130*	0.00917	-0.00736***	-0.000643	0.00359*
	(0.00730)	(0.00602)	(0.00256)	(0.000581)	(0.00192)
$(precip_i)^2$	7.03e-05	-2.64e-05	-4.15e-05	3.32e-06	1.03e-05
	(6.71e-05)	(3.81e-05)	(4.89e-05)	(9.15e-06)	(1.63e-05)
Observations	461	426	459	458	241
R-squared	0.247	0.220	0.070	0.008	0.198

Notes: The dependent variables are given at the top of each column. Census Consolidated Subdivision-level data used in all specifications. Clustered at Census Division Level in all specifications. A constant term is included in all specifictions. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Short- and long-run effects of higher freight rates

	($\Delta freight_{it}$) coefficients and standard errors		
	5 years (1996-1991)	10 years (2001-1991)	15 years (2006-1991)
	(1)	(2)	(3)
Technology adoption:			
$\Delta zerotill_{it}$	0.237	0.966**	1.886***
	(0.237)	(0.411)	(0.517)
$\Delta mintill_{it}$	0.477**	-0.201	-0.496
	(0.202)	(0.255)	(0.302)
$\Delta fallow_{it}$	-0.398***	-0.959***	-0.881***
	(0.110)	(0.175)	(0.213)
$\Delta fertilizer_{it}$	0.731***	1.288***	1.876***
	(0.213)	(0.288)	(0.310)
Production:			
$\Delta wheat_{it}$	-0.312*	-0.754***	-0.993***
	(0.186)	(0.203)	(0.226)
$\Delta canola_{it}$	-0.0664	0.272*	0.215
	(0.100)	(0.141)	(0.148)
$\Delta pasture_{it}$	-0.196***	-0.0655	-0.0134
	(0.0667)	(0.0928)	(0.128)
$\Delta \log(cattle_{it})$	-0.00719	-0.0150	0.0142
	(0.0155)	(0.0153)	(0.0171)
$\Delta \log(hogs_{it})$	-0.0876**	0.187***	-0.258***
	(0.0390)	(0.0580)	(0.0635)

Notes: The independent variables in columns (1), (2) and (3) are the change in freight rates at each Census Consolidated Subdivision over 5, 10 and 15 years respectively. All regressions include same control variables as Table 2. Clustered at Census Division Level in all specifications. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Effect of freight rates by soil zone

	($\Delta freight_{it}$) coefficients and standard errors by soil zone				
	Gray	Dark Gray	Black	Dark Brown	Brown
	(1)	(2)	(3)	(4)	(5)
Technology adoption:					
$\Delta zerotill_{it}$	0.371	1.146*	1.226**	-0.0595	0.336
	-0.545	-0.589	(0.484)	(0.348)	(0.655)
$\Delta mintill_{it}$	-0.336	0.287	-0.232	-0.526	-0.593
	-0.516	-0.572	(0.319)	(0.310)	(0.401)
$\Delta fallow_{it}$	-0.514***	-0.456***	-1.046***	-0.199	-0.271
	-0.138	-0.0943	(0.216)	(0.280)	(0.377)
$\Delta fertilizer_{it}$	0.194	0.442	1.580***	0.648**	-0.0131
	-0.324	-0.571	(0.372)	(0.293)	(0.230)
Production:					
$\Delta wheat_{it}$	-0.817**	0.207	-1.112***	-0.945***	-0.396**
	-0.374	-0.362	(0.239)	(0.152)	(0.154)
$\Delta canola_{it}$	0.184	0.0125	0.605***	0.207	-0.0896*
	(0.199)	(0.164)	(0.114)	(0.144)	(0.0462)
$\Delta pasture_{it}$	-0.232	-0.117	-0.123	0.00906	0.216
	-0.295	-0.252	(0.119)	(0.118)	(0.122)
$\Delta log(cattle_{it})$	0.0208	-0.0186	-0.0101	-0.0175	-0.00593
	-0.0289	-0.0329	(0.0228)	(0.0377)	(0.0327)
$\Delta log(hogs_{it})$	-0.112***	-0.123***	-0.126***	-0.121	-0.0514
	-0.0374	-0.0374	(0.0322)	(0.0878)	(0.122)

Notes: The independent variable are the change in freight rates at each Census Consolidated Subdivision between 1991 and 2001. All regressions include same control variables as Table 2. Clustered at Census Division Level in all specifications. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Farm size and technology adoption

Dependent Var:	10 year difference-in-differences (2001-1991)			
	$\Delta zerotill_{it}$	$\Delta mintill_{it}$	$\Delta fallow_{it}$	$\Delta fertilizer_{it}$
	(1)	(2)	(3)	(4)
$\Delta largefarm_{it}$	0.0520	0.259**	-0.420***	0.707***
	(0.171)	(0.0984)	(0.0914)	(0.123)
$\Delta freight_{it}$	0.957**	-0.249	-0.831***	1.135***
	(0.414)	(0.259)	(0.168)	(0.260)
$\Delta distance_{it}$	0.00211	-0.0380	-0.0110	0.104**
	(0.0756)	(0.0728)	(0.0196)	(0.0450)
jan_temp_i	1.810***	-1.202***	-0.859***	1.959***
	(0.539)	(0.351)	(0.173)	(0.305)
$july\_temp_i$	-1.389	-3.748***	0.165	1.292*
	(0.997)	(0.638)	(0.291)	(0.672)
$precip_i$	-0.0539***	0.0245**	0.0372***	-0.0392***
	(0.0168)	(0.0102)	(0.00453)	(0.00801)
$(precip_i)^2$	-0.000809***	-0.000125	5.53e-06	-1.67e-05
	(0.000178)	(0.000104)	(4.89e-05)	(8.87e-05)
Observations	441	443	419	461
R-squared	0.282	0.241	0.553	0.417

Notes: The dependent variables are given at the top of each column. Census Consolidated Subdivision-level data used in all specifications. Clustered at Census Division Level in all specifications. A constant term is included in all specifictions. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1