Technology Adoption and Agricultural Trade Reform: Farm-Level Evidence from the Canadian Prairies [1]

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Abstract

We estimate the heterogeneous impact of the removal of a railway transportation subsidy on technical change using detailed census data covering over 30000 farms in Alberta, Saskatchewan and Manitoba, Canada. The removal of the subsidy for wheat and other grains in 1995 led to a large decrease in farm-gate prices, and regional variation in the subsidy allows us to infer causal effects of lower grain prices on technology adoption and land use. In the decomposition analysis we find that the aggregate technology adoption and land use changes between 1991 and 2001 were driven mainly by the with-farm effect. In contrast, exiting farms played a very small role in explaining overall technology adoption patterns. In the regression analysis we find that the within-farm effect of the reform on technology adoption varied along the farm size dimension, with larger farms tending to adopt the more advanced zero-tillage technology in response to the reform. Small- and medium-sized farms responded to the reform by adopting the more affordable minimum-tillage technology. The results suggest that farm size is an important factor in determining the impact of subsidy reform on technical change.

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Understanding the link between trade reform and technical progress has been a central question in economic research. In the context of agriculture, many countries continue to subsidize agriculture heavily today in the name of preserving small farms, and these agricultural subsidies are a major roadblock in trade agreement negotiations. It is thus crucial to understand how the removal of government support affects farm size and aggregate productivity.

In this paper, we exploit the removal of a railway transportation subsidy on the Canadian Prairies in 1995 to study the causal impacts of the reform loss on cropping patterns and adoption of new farming methods. This CAD700 million per year subsidy (Klein et al 1994) applied to exports of grains and oilseeds, and the impact of the reform was location-dependent, with locations farthest from the nearest seaport experiencing the greatest increase in transportation costs upon the subsidy removal. The export-dependent nature of grain production on the prairies combined with the institutional features of the grain marketing and transportation system imply that the increase in freight rates translated directly into a decrease in the price of grains at the farm gate.[i] We exploit this large regional variation in this historic reform across locations that otherwise are very similar in terms of pre-treatment characteristics in order to identify the causal effects of the subsidy loss on the adoption of new labour- and fuel-saving technologies for sowing grain crops, fertilizer usage and the prevalence of summerfallow and various crops.

This setting is well-suited to studying the impact of increased competitive pressure on technology adoption in the form of new "zero tillage" and "minimum tillage" seeding technologies in the 1990's, that became widely adopted in the grain-growing regions of Alberta, Saskatchewan and Manitoba. We will also measure the effects on fertilizer use and several other aspects of land use that may have been affected by the reform either directly, or indirectly via the adoption of the new seeding technologies.

Using highly detailed census data on over 30000 farms covering over 70 million acres of farmland we find several new results. In the decomposition analysis we find that the aggregate technology adoption and land use changes between 1991 and 2001 were driven mainly by the with-farm effect. In contrast, exiting farms played a very small role in explaining overall technology adoption patterns. In the regression analysis we find that the within-farm effect of the reform on technology adoption varied across farms, with larger farms tending to adopt the more advanced zero-tillage technology in response to the reform. Small- and medium-sized farms tended to adopt the more affordable minimum-tillage technology. Since the zero-tillage involved

a larger up-front equipment cost compared to minimum-tillage technology, the sorting of farms into zero- versus minimum-tillage technologies may be driven by the size of the fixed cost of adoption, where larger farms could afford larger fixed costs associated with the zero-tillage technology.

This study builds on Ferguson and Olfert (2016), who also study the impact of the same transportation subsidy reform in Western Canada using data aggregated at the Census Consolidated Subdivision (CCS) level. They show that higher freights rates – and hence lower farm gate prices – resulted in the adoption of newer, more efficient production technologies within these geographic areas. They also find that those CCSs where farmers experienced the greatest transportation cost increases also saw increased fertilizer usage and significant land use changes. The limitations of the aggregate data mean that they could not explore the heterogeneity in technology adoption among farmers within the same geographic location (CCS), as the results reflect only inferred behaviour of a 'representative' farmer in the CCS. This means that they do not estimate the underlying farm-level characteristics that drive the decision to adopt new technologies, nor can they investigate the complementarities with farm size and the role of reallocation in land from low-tech to high-tech farmers.

This study contributes to a growing literature on how firms upgrade their technology when trade liberalizes. Bustos (2012), Lileeva and Trefler (2012) and Baldwin and Gu (2004) show that trade liberalization reveals a complementarity between exporting and technology upgrading. Our study is also related to literature that evaluates the impact of import competition on technology adoption. Pavcnik (2002) provides evidence that firms in import-competing sectors in Chile raised their productivity when exposed to competition from abroad during the late 1970s and early 1980s. Galdon-Sanchez and Schmitz (2002) and 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.

There is a dearth of studies on the effect of agricultural trade liberalization on farm-level outcomes, 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. Using a sample of 32 farms, they find that farms with low debt/equity ratios were better able to adjust to the New Zealand reforms.

Our results will test the importance of competitive pressure as a determinant of technology adoption in agriculture, building on earlier contributions that emphasize the importance of human capital (Rahm and Huffman 1984), and uncertainty (Chavas and Holt 1996).

Relatively few papers have studied the impact of farm-level attributes on technology adoption, and none have investigated the heterogeneous impact of agricultural trade liberalization. Davey and Furtan (2008) find that farm size, proximity to a research station, soil type, and weather conditions are important in adopting minimum tillage practices. Liu (2012) finds that Chinese farmers that are more risk averse or more loss averse adopt Bt-cotton earlier.

Background

We begin with a brief overview of the grain transportation subsidy and its reform, as well as a description of the grain market in Western Canada.

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).[5] 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.[6] 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.[7] These increased transportation costs translated into lower grain prices at the farm-gate.

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

[5] The announcement came in February of 1995 to be effective August 1995 (Doan, Paddock and Dyer 2003). This was the culmination of decades of threats to repeal the subsidy, all of which may have led to expectations of its removal. However, since it was under discussion for so long, it would have been hard to anticipate the actual timing of the repeal, which had as much to do with federal government deficits as with the grain industry. Further, though there were reforms in the 1983 Western Grain Transportation Act, this Act institutionalized the payment of a 'Crow Benefit' to the railways, keeping farm rates low (Klein et al. 1994), thus giving farmers confidence that farm-level transportation cost increases may be avoided.

[6] See Vercammen (1996a) for a detailed overview of reforms to the Western Canadian grain transportation system.

[7] This assumes an average grain price of $200/tonne.

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).

While the repeal of the WGTA affected farmers in all locations across the prairies, there was substantial spatial heterogeneity in the size of this impact. Prior to the reform, rail transportation rates for wheat from the prairies to seaport (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 largest increase in freight rates being in locations that were farthest from the seaports. It is this spatial heterogeneity that allows us to identify the impact of the WGTA repeal, even in the midst of a range of other changes in the agriculture and labor markets. For example, world grain prices varied greatly during this time, which impacted farm revenues and asset values, but the effect of world prices were generally the same for all farmers, not differentiated by distance to seaport. [8] Similarly, the Canadian economy grew and contracted several times during the period 1981-2006, but macroeconomic conditions arguably affected all rural regions in a similar way.

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 that 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 the subsidy.[9]

Farmers were partially compensated for the increase in freight rates (and the expected drop in land values that would result from the repeal of the WGTA) with a one-time payment of $1.6 billion, and an additional $300 million to assist producers that were most severely affected. Also, there were payments to municipalities to invest in rural roads. Land that had been used for the

[8] Ross (2006) indicates that major changes in elevator design began as early as the late 1970's when increased capacity handling facilities began to appear, but in the 1990s most grain companies constructed high capacity, high throughput terminals with 50,000 tonnes storage, allowing for an entire train of 53 cars to be loaded in a single day.

[9] 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).

subsidy-eligible crop in 1994 or was summerfallow was eligible. Payments were based on acreage of eligible land, a productivity factor, a distance factor and a provincial allocation factor. 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, Highmoor and Schmitz 2002). Resistance to the inadequate compensation was likely muted because the subsidy repeal had long been anticipated and because grain prices were relatively high in 1995, supporting considerable optimism about the grain-based economy.

Two other reforms occurred concurrently with the elimination of the WGTA. First, the federal government and railways 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.[10]

Overall, the WGTA rates subsidized exports of grain to non-U.S. locations and thus the repeal of the WGTA increased the cost to ship to a seaport but did not increase the cost to ship to the U.S. In the case of grains exported by the CWB (wheat and barley for human consumption), the CWB's catchment area for exports to the U.S. was located in southern Manitoba. The WGTA repeal would have increased the U.S. catchment area, resulting in more wheat exports to the U.S. via Manitoba.[11]

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[10] The re-location of the eastern export basis point discouraged the export of wheat and barley to ports in eastern Canada. However, west coast capacity constraints led to an additional measure, the freight rate adjustment factor (FAF), which had the effect of re-establishing freight rates consistent with a Thunder Bay export basis point, for eastward movement of wheat and barley. Financed by all producers across the prairies, the FAF largely averted the additional impact of moving the eastern basis point to the St. Lawrence (Fulton et al. 1998). Freight rates for wheat, adjusted for west coast capacity constraints, can thus be interpreted as an "export basis."

[11] An additional and important part of the context was the grain transportation deregulation and innovations that had been underway in the U.S. Midwest for at least two decades prior to WGTA repeal in Canada. Major efficiency gains had been won through the adoption of covered hopper cars, multi-car shipments, shuttle cars, forward shipping instruments and short line rail lines (Wilson 2000, 2011). These ongoing changes both underlined potential efficiency improvements in grain handling and transportation for Canada, and the potential for increased grain flows through and to U.S. destinations from prairie origins, in the absence of the WGTA and CWB in Canada (Wilson 1995).

Following the repeal of the WGTA a range of possible adaptations by farmers to the lower prices for export grains have been described (see Doan, Paddock and Dyer 2003, 2006). It was expected that some farmers would adapt to the new environment by shifting to high-value export crops, feed grain production or by pursuing economies of size in grain production. In a highly competitive market with small margins, farmers facing suddenly lower net product prices were confronted with the options of switching to higher valued crops, adopting new technologies that would reduce per unit costs or exiting the industry.

Most analysts hypothesised, at the time, that areas with a larger increase in freight rates (i.e. a larger decline in grain prices) would experience larger increases in livestock production which would dampen the impact of the reform on aggregate gross farm revenue.[12]

Following the repeal of the WGTA a range of possible adaptations by farmers to the lower prices for export grains have been described (see Doan, Paddock and Dyer 2003, 2006). It was 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 was hastened where freight rate increases led to some farmers no longer being competitive, thus exiting the industry, allowing farm size expansion by others. In a highly competitive market with small margins, farmers facing suddenly lower net product prices were confronted with the options of switching to higher valued crops, adopting new technologies that would reduce per unit costs or exiting the industry. The choice of adjustment strategy would depend on individual circumstances.

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'

[12] In retrospect, the access to efficient slaughter plants became a more important factor after 2006 (Bell 2006) and this constrained the growth of hog production in CCSs with a larger increase in freight rates because these CCSs were also more distant from the efficient hog slaughtering facilities.

production and technology adoption decisions. While Ferguson and Olfert (2016) are able to tease out the causal effects of the reform from all other factors, the aggregated nature of their data does not allow them to investigate the farm-level characteristics that drive the aggregate results.

Existing *ex-post* studies of the impacts of the removal of the WGTA do not directly exploit the spatial variation in the reform impacts, 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, Paddock and Dyer 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. The dramatic increase in Canola production over this period followed from the introduction of genetically modified, herbicide resistant (HR) canola in 1995, resulting in an increase of canola acreage from 8% in 1990 to 20% in 2000 (Doan, Paddock and Dyer 2003; Gusta et al. 2011). Reports of this rapid adoption attribute it primarily to easier and improved weed control and higher net returns, though HR canola also facilitated the adoption of conservation tillage (Beckie, Harker and Légère 2011). These prairie-wide patterns will be purged by our difference in differences estimation procedure, allowing us to identify the effects (production choices and conservation tillage) attributable only to the spatially differentiated freight rate increases. Comparing before and after acreages can lead to erroneously attributing observed changes, due to concurrent events, to the increase in freight rates. 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.[13]

[13] Prior to 1995, opponents of the WGTA had long contended that if it were eliminated, local processing would increase and the livestock industry would expand due to lower feed grain prices. *Ex post* studies largely failed to isolate WGTA-specific impacts though Doan, Paddock and Dyer (2003) find that production shifted to specialty crops and livestock, and that food processing increased 'modestly.' Another endogenous response might have been improvements in local road transportation to offset higher rail freight costs. Agriculture and Agrifood Canada

The advent of zero tillage and minimum tillage on the Canadian Prairies

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 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.

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. Minimum tillage also saved labour and fuel

(AAFC) (2006) report that rail and truck traffic in Western Canada under went dramatic restructuring following repeal of the Crow due to branch line closures and a consolidation of grain elevators; between 1995 and 2005, 80% of the grain shifted from 645 delivery points to 178. As a result distances over which farmers hauled grain and the size of trucks increased dramatically, leading to an overall deterioration of surface and safety of municipal and provincial roads, affecting quality of life of residents (AAFC 2006). As a result the federal government Prairie Grain Roads Program (PGRP) was launched ($169 million), for road reconstruction and improvement.

costs compared to conventional methods and was considered an intermediate step between the tillage-intensive conventional methods and zero-tillage. The fixed equipment cost to adopt zero-tillage was typically higher compared to minimum tillage, since zero-tillage seeding technology was newer compared to the minimum-tillage alternative. In some cases farmers could retrofit their conventional tillage equipment in order to convert it to a minimum tillage system, while zero tillage required an entirely new tillage implement.

Conceptual Framework

Economic theory predicts that competitive pressure leads to a reallocation of production from small and less productive firms to larger and more productive firms and also by providing incentives to make investments or exert effort. Bustos (2011) suggests that larger and more productive firms may be able to best take advantage of a tougher competitive environment because they can afford to upgrade their technology, while Melitz (2003) predicts that smaller and less productive firm may be forced to shut down. Previous empirical work (Paul et al. 2000) suggests that farms with a low debt/equity ratio are best able to adapt to product market reforms. Our goal is to test these models' predictions using data on farms size and liquidity from the Census of Agriculture data.

While the studies mentioned above suggest that larger firms with more resources will respond more favourably to competitive pressure, there are theories of "induced innovation" with contrasting predictions. Chen (2012) suggests that managers may work harder to raise productivity and save the firm when pushed to the edge of bankruptcy by tougher competition. The role of induced effort may thus lead small farms to respond strongly and adapt to the tougher environment by adopting technology or producing higher-value, management-intensive output. Bloom et al.'s (2012) "trapped factor" model suggests that firms choose to innovate in the face of competitive pressure because factors such as human capital have far less value outside of the firm, which reduced the shadow cost of innovating. This theory suggests that farmers with lower outside options may be more willing to adopt new technologies or learn to grow new, higher-value crops instead of exiting.

We posit that the lower net (of transport costs) farm gate prices for grains and oilseeds led to hastened technology adoption via two main forces. First, the harsher economic conditions may have induced a reallocation of production from smaller and less modern farms to towards larger

and more modern farms. Second, family farmers may have had strong incentives to modernize their operation in order to cope with higher relative opportunity costs of labour or as a risky attempt to regain profitability in the face of lower grain prices. We now discuss these two mechanisms in greater detail.

The reallocation mechanism follows the work by Melitz (2003) and Foster, Haltiwanger and Krizan (2001), where changes in aggregate productivity are caused by more productive firms taking larger market shares and smaller firms shutting down or shrinking in size. Larger farms tend to be more productive in the United States (Sumner 2014), which is arguably comparable to the Canadian case. Empirical studies using Canadian farm data suggest that larger farms are more likely to adopt conservation tillage (Davey and Furtan 2008) and, in particular, zero tillage (Awada 2012). Large farms are more likely to have the size economies required to justify the fixed cost to purchase zero tillage seeding equipment.

An alternative mechanism not relying on reallocation is provided by Kislev and Peterson (1982). In their model, an increase in income potential from off-farm work increases the opportunity cost of farm labour, which encourages farmers to invest in labour-saving machinery. Their model would be one plausible explanation for the faster adoption of zero tillage in areas where grain prices decreased the most due to the policy reform (and hence relative opportunity costs of off-farm work increased). The moisture-savings provided by zero tillage then allowed for a reduction in summerfallow acreage and a corresponding increase in the area fertilized. Their model is well-suited to the Canadian Prairies since grain production is dominated by family farms where family members supply the bulk of labour.

Prospect theory may also explain why farmers made efforts to modernize their farms in response to the harsher economic conditions (Kahneman and Tversky 1979, 1984). In the context of the WGTA reform, the removal of the subsidy led to many farms being unprofitable (in the absence of adjustments), and would then imply that these farmers were prepared to take risks to invest in new methods to regain profitability and avoid bankruptcy and exit from the industry.

It is worthwhile to note that the standard neoclassical model would predict that lower net output prices should result in less intensive use of inputs in production. The alternative theories that we suggest provide a more nuanced implication for input use. On the one hand, investments in new tillage technology may imply higher capital intensity. Similarly, a reduction in

summerfallow implies more intensive land use and greater fertilizer use in production. On the other hand, however, the new tillage technology would lead to reduced use of fuel and labour.

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 regression using a first-differenced specification for explaining the impact of freight costs on farm outcomes:

(1)

$$\Delta Y_{i,2001-1991} = \alpha + \sum_{r=1}^{4} \beta_r \left(\Delta freight_{i,2001-1991} \times Q_r\right) + \sum_{r=2}^{4} \beta_r Q_r + \gamma\left(\Delta localdist_{i,2001-1991}\right) + \delta_1 controls_i + \varepsilon_i,$$

where $\Delta Y_{i,2001-1991}$ is the change in the outcome variable of interest for Census Consolidated Subdivision (CCS) location *i* between the pre-reform year 1991 and the post-reform year 2001. $\Delta freight_{i,2001-1991}$ is the change in freight costs per tonne of grain shipped from CCS location *i* to port between 1991 and 2001. We interact $\Delta freight_{i,2001-1991}$ with indicator variables that take a value of 1 if a farm belongs to the *r*th quartile of the farm size distribution, and takes a value of 0 otherwise. We use 1991 gross farm revenue as our proxy for farm size, which we

argue is a geography-neutral way to measure farm size[14]. Farms are divided into quartiles using the 25th, 50th and 75th percentiles of the farm size distribution in the entire sample. Following the methodology of Bustos (2012), we include the uninteracted quartile indicator variables as a control in equation (1), which controls for any quartile-specific trends in technology adoption or land use that affected all locations identically. For example, it may be the case that the largest farms adopted new technology at a faster rate than small farms regardless of the location of the farm, and this phenomenon would be caught by the uninteracted farm size quartile indicators. $\Delta localdist_{i,2001-1991}$ is the change in average distance from each CCS to its nearest delivery point, and is a proxy for local trucking distance. Local trucking distance also increased in most locations during the period from 1991 to 2001 and varied spatially, making it an important control variable. $controls_i$ includes time-constant controls such as long-term average weather, which varies across CCS locations.

It is important to emphasize that the first-differencing process subsumes the CCS fixed effects, which capture all time-constant factors that may influence the outcome variables. Adding long-run weather controls after the first-differencing process controls for the possibility that underlying climatic conditions affect adoption rates or changes in production patterns. Long-run weather is likely to affect the return to technology adoption or production changes and thus affect the rate at which new technologies are adopted.[15] We include July average temperatures and annual precipitation as controls because they reflect the availability of moisture, which can affect adoption of new tillage technologies and the use of summerfallow and fertilizer. Moisture availability and growing season temperatures also affect the types of crops that can be grown in a CCS. We also include average January temperature because it may affect the economics of cattle production, since cattle require more feed in cold temperatures. Moreover, January temperatures are inherently related to distance from the west coast, which is correlated with our freight rate measure.

[14] Farm size in acres is an alternative proxy to measure farm size, but this measure may cause bias since farms tend to be larger in hotter and drier parts of the prairies, and the propensity to adopt new technologies may also vary with climatic conditions.

[15] Davey and Furtan (2008) find that soil zone and growing season weather averages explained regional differences in conservation tillage adoption levels in using a pooled sample of farm-level data for 1991, 1996 and 2001.

The constant term α in this first-differenced specification picks up the change in the dependent variable that is due to factors that affect all farms identically. This includes the effect of world prices, the advent of new technologies such as herbicide-tolerant canola or any technological innovation that became available to all locations at the same time.

We estimate Eq. (1) using several different dependent variables that capture various aspects of adaptation and technology adoption. The main coefficients of interest are the β_r's, with the null hypothesis that $\beta_r = 0$. A statistically significant point estimate for β_r would indicate that the increase in railway freight rates led to a change in the outcome variable for the group of farms in the *r*th quartile of the farm size distribution. The expected sign of the β_r's will depend on the outcome variable we are using in a particular regression.

The size of the coefficient β_r can be interpreted is a measure of inter-regional differences in the impact of the reform for a particular farm size quartile. In other words, the coefficient β_r indicates how a $1/tonne rise in freight rates between 1991 and 2001 impacts within-farm technology adoption or production changes. For example, consider two locations on the Prairies where freight rates rise between 1991 and 2001 by $15/tonne and $25/tonne respectively. Given that the increase in freight rates for these two locations differed by $10/tonne, the coefficient β_r allows us to predict that a $10\times\beta_r$ difference in the dependent variable between these two locations can be attributed to the reform for farms in size quartile *r*.

It is important to emphasize that our identification strategy is able to tease out the marginal impacts of the policy change across regions but does NOT capture the total impact of the policy. 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.

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.

Census of Agriculture data

The primary data is taken from the Canadian Longitudinal Census of Agriculture dataset, which links the census-farm records from the Censuses of Agriculture from 1986 to 2011. The census data also indicates the location of each farm at 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 1991 and 2001 census years in the baseline estimations. The data includes a rich set of information such as gross farm revenues, interest expenses, the number of acres devoted to different crops and land uses. We also use census data on the use of different tillage technologies and fertilizer use. Each census farm can report up to three operators and we include the age of the primary farm operator in the analysis, as well as whether the operator uses a personal computer. Constant 2011 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.

Freight rate data

We combine data on farm outcomes from the Census of Agriculture with railway freight rate data supplied by *Freight Rate Manager*, a service provided by a consortium of government, academic and farmer organizations.[16] The freight rate data encompass the freight rate for wheat from at most 992 delivery locations spread across Alberta, Saskatchewan and Manitoba.[17] Since we do not know where each farm in the census delivers its grain, we measure average railway freight rates for each CCS in the data. We measure freight rates from several grid points within each CCS, using a 0.1 degree grid of the earth's surface, then take the average freight rate for all grid points within a given CCS as our measure of each CCS's freight rate.[18]

We measure average local trucking costs from the farm to the delivery location using the average distance measure from each grid point to the nearest delivery location. The change in distances over time reflects the effect of the branch line abandonment or other rail transport consolidation that may have happened even in the absence of the subsidy repeal. Controlling for

[16] 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.

[17] Using shipment volume data from the Canadian Grain Commission (2014) for each station, we exclude stations that report total train deliveries per year of 1000mt or less.

[18] We restrict the grid points to only those where crops are actually grown, using satellite data from Ramankutty et al. (2008). Grid points are excluded if less than 10% of the surrounding land is devoted to crops or pasture. The average number of grid points in a CCS is 17, and the median number of grid points in a CCS is 12. See figure A1 in the Appendix for an example of how grid points are matched to delivery locations.

the change in distance allows us to isolate the other effects of the change in freight rates. Figure A1 in the Appendix illustrates how local trucking distance increased between 1991 and 2001 for one particular CCS (South Qu'Appelle No. 157).

The pattern of freight rate changes between 1991 and 2001 by CCS is illustrated in figure 1. Note that while freight rates increased for all locations between 1991 and 2001, there was large variation in the size of this increase, even within individual provinces. 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.

Figure 2 illustrates the abrupt increase in freight rates in the 1995-1996 crop year, using data for Saskatoon, Saskatchewan, a location in the middle of the Canadian prairies. The figure also illustrates that primary elevator tariffs for wheat, which is the fee charged by grain companies to store and load grain onto railway cars, were generally constant over the 1986-2006 period.[19] Figure 2 also illustrates that wheat prices fluctuated greatly during this period.

Soil and weather data

The weather data include 20-year average precipitation 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 represent the weather data available from the nearest weather station with at least 20 years of data.

As a robustness check we also include soil zone data as an additional CCS-level control. 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 moister 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 Appendix figure A2.

Facts on farm size

It is important to note that the definition of agricultural operation used by the Census of Agriculture includes many operations where farming is not the main occupation of the operator

[19] Handling charges and freight rates for canola and other grains evolved similarly to those for wheat, (SAFRR 2003, Tables 2-43 and 2-44).

and gross farm revenues are very small. Small acreages, for example, are included in the definition of a "census farm". Figure X shows the distribution of farm sizes in the Census of Agriculture combining data for Alberta, Saskatchewan and Manitoba. Farm size is very heterogeneous measured both in acres and in gross farm revenue. Since we are interested in the behavior of grain farms of sufficient size to avoid including hobby or lifestyle farms, figure X includes only agricultural operations that define themselves as "grain and oilseed" farms.

In table X we show that land productivity in 1991 (defined as gross farm revenues per acre) is negatively correlated with farm size in terms of acres, but positively correlated with farm size in terms of gross farm revenues. Adamopoulos and Restuccia's (2014) also find a negative correlation between land productivity and farm acreage using the entire sample farms from the 2007 U.S. Census of Agriculture. In contrast, using gross farm revenues as the proxy for farm size suggests that larger farms have a higher land productivity. These results are likely driven by the fact that farms tend to be larger (in term of acreage) in regions where land productivity is lower due to soil quality or climatic constraints. Land productivity in the wheat belt of North America, for example, is lower than in the Central Valley of California, and farms tend to be larger in the Wheat Belt in term of acreage, but not necessarily larger in terms of total gross revenues. The fact that gross farm revenues is arguably a more geography-neutral proxy for farm size than acreage leads us to use gross farm revenues as our proxy for farm size throughout the rest of the analysis.

Table X also shows that the value of machinery per acre in 1991 decreases with farm size, using either acreage or gross farm revenue as a proxy for farm size. Even though larger farms use more machinery, the fact that the value of machinery per acre decreases with farm size suggest that there are economies of size in machinery, so larger farms spread their machinery costs over more acres (or revenues).

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… 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 X 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 tillage, it was practiced by very few farmers in Western Canada in 1986, so the trends were arguably parallel prior to 1991.

Decomposing the Sources of Aggregate Changes in Technology Adoption

We begin the analysis by decomposing aggregate changes in technology adoption and land use patterns into the contribution by exiting farms, entrants and continuing farms between 1991 and 2001. We follow Foster et al (2008). Overall, we find that the within-farm effect is the largest contributor to aggregate changes in technology and land use. Since the within-farm effect is strongest we explore this mechanism more in-depth in the regression analysis.

Within-Farm Regression 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 technology adoption and production outcomes, including only continuing farms that were present in the census both 1991 and 2001. All specifications control for local trucking distances. 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 in outcomes over the period from 1991 to 2001. We cluster all regressions at the Census Division level, which are larger geographical units composed of several CCS's. This provides us with 54 clusters, depending on the specification.

Technology adoption

The effect of increased freight rates on technology adoption is shown in table 3.

Short- vs. long-run effects

The results for the freight coefficient using 5-, 10-, 15 and 20-year differences are presented in columns (1), (2) and (3) respectively of table 5.

Conclusion

The sudden and spatially differentiated increases 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.

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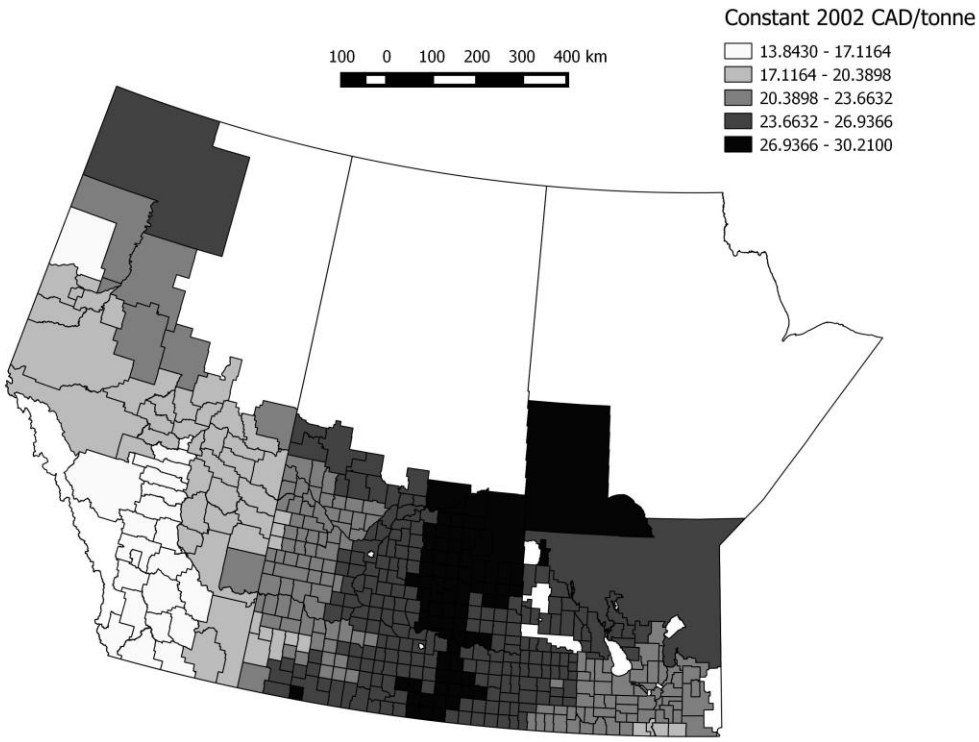


Figure 1. Freight rate changes between 1991 and 2001 and 1996 Census Consolidated Subdivision boundaries for the prairie provinces

Note: Areas with no fill indicate CCS's without Census data or CCS's where data was amalgamated with neighboring CCS's for confidentiality reasons.

Source: Statistics Canada and *Freight Rate Manager*.

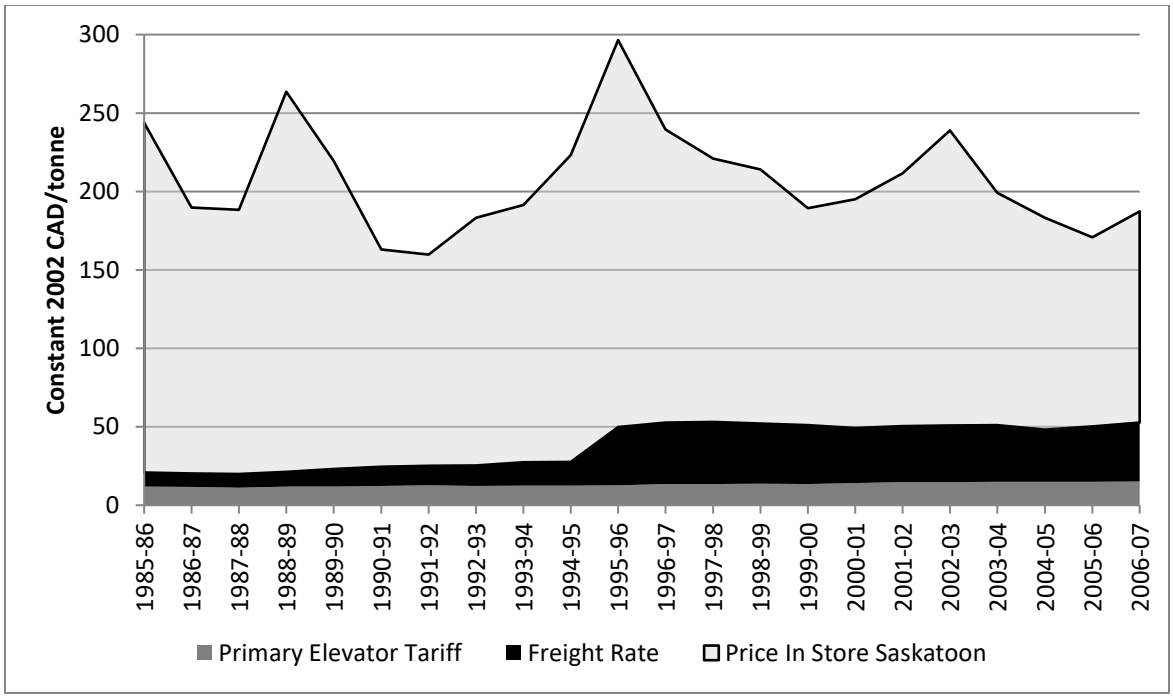


Figure 2. Primary elevator tariff, freight rate and price in store, Saskatoon SK, #1 Canada Western Red Spring Wheat, 12.5% protein

Source: Saskatchewan Agriculture and Food.

[i] Two main institutional features allow us to infer farm-gate prices directly from the freight rate data. First, the Canadian Wheat Board (CWB) marketed wheat and barley on behalf of prairie farmers and pooled prices for a given quality of grain delivered during each "crop year" (August 1st – July 31st). Price pooling meant that the price at the farm gate equalled the pooled price minus the cost of railway transportation to seaport. Pooling prices regardless of whether wheat was exported to the east or west also meant that any divergences in world wheat prices between east and west coast seaports did not affect the spatial variation in prices across the prairies. Second, freight rates were regulated, publicly available and constant during each crop year, which meant that freight rate changes translated directly into changes in the price of wheat at the farm-gate. The combination of CWB price pooling and a time-constant export basis each crop year implies that all farmers delivering their grain at a given location received the same price net of railway freight costs regardless of which day during the crop year they delivered.