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Farm Size, Technology Adoption and Agricultural Trade Reform: Evidence from Canada

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Abstract

Using detailed census data covering over 30,000 farms in Alberta, Saskatchewan and Manitoba, Canada, we document the vast and increasing farm size heterogeneity, and analyse the role of farm size in adapting to the removal of an export subsidy in 1995. Consistent with the Alchian-Allen hypothesis, the increase in per-unit trade costs due to the reform was associated with farms of all sizes shifting their production of crops from low value wheat to higher value canola. We find that switching to new labour-saving tillage technologies and away from summerfallow in response to the large negative shock to grain prices caused by the reform varied across the farm size distribution. We develop a theory of heterogenous farms and technology adoption that can explain our findings.

Keywords: *Agricultural trade liberalization*; *export subsidy*; *farm size*; *firm heterogeneity*; *technical change*.

JEL classifications: *F14, O13, Q16, Q17, Q18*.

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1. Introduction

Understanding the link between trade reform and technical progress at the micro level is an important economic question. In agriculture, many countries continue to pursue policies that may have a differential effect on small and large producers, policies that often are a major point of discussion in trade agreement negotiations. It is thus important to understand how small versus large farms respond to the removal of government support.

In this paper we establish several new stylised facts on farm size heterogeneity and the farm-level response to the 1995 removal of a railway transportation subsidy in Western Canada. Our analysis employs highly detailed census data on over 30,000 farms covering over 70 million acres of farmland across Alberta, Saskatchewan and Manitoba. We document the vast size heterogeneity across farms during the period we study, with a farm size distribution that has become more skewed towards large farms over time. Farm size has been shown to be an important factor in explaining productivity in developed countries such as the United States (Sumner, 2014). Adamopoulos and Restuccia (2014) find that differences in farm size across countries can explain a great deal of the cross-country differences in agricultural productivity.[2]

The repeal of the Western Grain Transportation Act effectively removed a CAD700 million per year export subsidy (Klein *et al*., 1994) that applied to the major crops. The subsidy varied spatially such that farms located further from seaports received a greater subsidy per tonne of grain shipped. The subsequent increase in railway freight rates due to the reform translated directly into a decrease in the price of grains at the farm gate. Using detailed data on the export basis at over 1,000 delivery locations across the prairies, we study how farms adapted to this transportation cost shock by changing their land use and tillage practices.

In the conceptual framework we discuss several possible mechanisms that can explain farms' crop choice and technology adoption decisions. Incorporating these stylized facts on farm size, we develop a simple theory of technology choice with heterogeneous farms in order to guide our empirical analysis. The framework predicts that only farms of a sufficient size will adopt new tillage technologies that entail a larger fixed cost but a smaller variable labour cost of production. The presence of fixed capital costs to adopt new tillage technologies implies that smaller farms cannot afford the investment. In contrast, shifting from wheat to canola production entails no fixed cost and thus all farms can make this adaptation, regardless of size.

In the empirical analysis we find that the within-farm effect of the reform on wheat versus canola production did not vary across the farm size dimension, which is reasonable given that this adaption entailed no fixed cost. In contrast, we find evidence suggesting that technology adoption varied along the size dimension, with larger farms more likely to shift away from conventional tillage and, by implication, away from summerfallow.

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[2]Empirical studies using Canadian farm data suggest that larger farms are more likely to adopt conservation (or what is also termed minimum) tillage (Davey and Furtan, 2008) and zero tillage (Awada, 2012). A positive relationship between farm size and technology adoption has also been found in the context of pest control (Sharma *et al.,* 2011).

This study contributes to a growing literature on how firms adapt their technology when trade liberalises, which has focused mainly on non-farm enterprises. Our empirical results are similar to findings of heterogeneous technology adoption by Baldwin and Gu (2006), Lileeva and Trefler (2010) and Bustos (2011), where only larger or more productive firms upgraded technology in response to trade liberalisation. In these studies, technology upgrading was complementary to exporting, exporting was encouraged by a reduction in trade costs, and only larger or more productive firms had the capacity to pay the fixed costs to export and upgrade. In contrast, the agricultural trade liberalisation event that we study led to higher trade costs for farmers, yet we also find a positive impact on technology upgrading. Our finding that competitive pressure encourages farmers to adopt new technologies thus relates to empirical studies in non-farm contexts by Pavcnik (2002), Galdon-Sanchez and Schmitz (2002), Schmitz (2005) and Bloom *et al.* (2016), who show that import competition compels firms to improve productivity.

Our work is complementary to existing farm-level studies on the effect of subsidies on efficiency by Morrison Paul *et al.* (2000), Rizov *et al.* (2013) and Zhu and Lansink (2010). Morrison Paul *et al.* (2000) evaluate the impact of dramatic regulatory reforms in New Zealand on farm productivity and production using a sample of 32 farms and find that farms with low debt/equity ratios were better able to adjust to the New Zealand reforms. Zhu and Lansink (2010) and Rizov *et al.* (2013) find that Common Agricultural Policy (CAP) subsidies have a negative impact on farms' technical efficiency. Our results will test the importance of competitive pressure as a determinant of technology adoption in agriculture, building on earlier contributions that emphasise the importance of human capital (Rahm and Huffman, 1984), uncertainty (Chavas and Holt, 1996) and risk aversion (Liu 2013).

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 and that those CCSs where farmers experienced the greatest transportation cost increases also saw 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, such as farm size. This study also builds on Brown *et al.* (2019), who decompose the impact of the trade reform on technology adoption and land use to study how aggregate changes were driven by reallocation versus within-farm adaptation. Using the same detailed census data, they find that the reform-induced shift from producing low-value to high-value crops for export, the adoption of new seeding technologies and reduction in summerfallow observed at the aggregate level between 1991 and 2001 were driven mainly by the within-farm effect. Furthermore, they find that farm exit had a very small effect on aggregate technology adoption, but reallocation of land from small farms to large farms could explain some of the aggregate technology adoption observed over the longer 1991–2011 period. Their finding of a dominant within-farm effect motivates our focus on continuing farms.

2. Background

2.1. The Western Grain Transportation Act

The subsidisation of railway freight for grain grown on the Canadian Prairies began with the Crow's Nest Pass Agreement of 1897. The subsidised freight rates stipulated by the agreement were commonly referred to as the 'Crow Rate'. The federal statute defining the subsidy after 1983 was formally known as the Western Grain Transportation Act (WGTA), and its repeal in 1995 ended one of the longest-running agricultural subsidies in the world.[3]

The price of grain destined for export from the prairies was determined by the price at the nearest seaport (Vancouver, British Columbia or Thunder Bay, Ontario), minus the cost of railway transportation and minus handling fees at the country elevator.[4] The transportation subsidy thus led to higher grain prices in the prairie region compared to a scenario without government support. Railway freight rates per tonne were strictly regulated before and after the end of the WGTA and were set according to a publicly available schedule of freight rates. Railway freight rates were location- and crop-specific and were highly correlated with the distance travelled by rail to the nearest seaport. The railways were regulated by a revenue cap from 2000 onwards, but the railway companies were still obliged to report the shipping charges per tonne at each delivery location.[5]

Grain farmers benefitted from the export subsidy, while 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 subsidised crops (Klein and Kerr, 1996). The removal of the subsidy was expected to have a major impact on the agricultural sector in the prairie region (Kulthreshra and Devine, 1978). In particular, it was expected that grain farmers would adapt to the lower prices for export grains by shifting to high-value export crops or by pursuing economies of size in grain production (Doan *et al.*, 2003, 2006).

While the repeal of the WGTA reduced the farm gate price of grain across the entire region, there was substantial spatial heterogeneity in the magnitude of the price shock. Prior to the reform, railway transportation deductions for wheat shipped from the prairies to seaport ranged from $8 to $14/tonne. After the reform, the rates were $25–46/tonne, with the largest increase in railway freight rates occurring in locations that were farthest from the seaports.

The removal of the WGTA was precipitated by two main factors that were beyond the control of grain farmers in the region. First, a recession in the early 1990s forced

[3]The announcement came in February of 1995 to be effective August 1995 (Doan *et al.,* 2003). See Ferguson and Olfert (2016) for a more detailed background of the WGTA reform.

[4]Until 2012, farmers were required to sell wheat and barley destined for human consumption via the Canadian Wheat Board (CWB). In this case, farmers received a 'pooled' price, which reflected the average price fetched by the CWB over the August 1st – July 31st crop year, adjusted for quality and adjusted at each delivery location for the freight rate deduction for wheat or barley.

[5]See Brewin *et al.* (2017) for a more detailed description of grain transportation policy reform in Western Canada.

the Canadian federal government to cut spending, which initially reduced the subsidy in the 1993–1994 and 1994–1995 crop years.[6] 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.

Owners of farmland were partially compensated for the increase in railway freight rates with a one-time payment of $1.6 billion, plus an additional $300 million to assist farmers that were most severely affected. In addition, payments were also made to rural municipalities to invest in roads. While this compensation was equivalent to approximately two years of the annual subsidy amount, Schmitz *et al*. (2002) find that it did not fully compensate landowners for the loss of the subsidy.[7]

2.2. Conservation tillage on the Canadian Prairies

Tillage is necessary in order to plant the seeds in grain production systems and was also used to control weeds before the advent of herbicides. The North American Great Plains have historically been susceptible to soil erosion, and technologies and management practices developed over time to reduce the loss of topsoil due to wind and water erosion. The main principle of these so-called 'conservation tillage' methods is to till the soil in a way that leaves the previous year's crop residue undisturbed on the surface of the field. Conservation tillage also conserves moisture, which is often a limiting factor in non-irrigated grain production that predominates the Canadian Prairies.

Beginning in the early 1990s, farmers on the Canadian Prairies began adopting a seeding technology called zero till, which deposited the seed and fertiliser all in one operation while disturbing the soil as little as possible.[8] The conventional seeding method involved disturbing the soil several times and led to moisture loss and erosion problems under windy conditions. The moisture conservation benefits of zero tillage allowed farmers to sow a crop every year in their fields instead of leaving them to lie fallow every 2nd or 3rd year. This practice of 'summerfallowing' allowed for moisture to accumulate for the next year and eased the control of weeds.

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[6]In the analysis, we use the 1991 census year as the pre-treatment year, which pre-dates the initial subsidy reductions that started in 1993.

[7]Three other grain transportation reforms occurred around the same time as the WGTA repeal. First, the federal government and railways accelerated the process of abandoning inefficient prairie branch rail lines, which increased the distance to the nearest delivery point for some farmers. Second, the federal government amended the pricing regime for grain sold via the Canada Wheat Board (CWB) so that the price of grain shipped eastward incorporated the cost of transport from Thunder Bay to the mouth of the St. Lawrence Seaway. Third, Canada and the US gradually eliminated import tariffs for several grains over a 9-year period that ended 1 January 1998 as part of the 1988 Canada–United States Free Trade Agreement (CUSFTA) and the 1994 North American Free Trade Agreement (NAFTA) (USDA, 2002). See Ferguson and Olfert (2016) for more detail.

[8]Zero tillage, also called 'no till' has been adopted in several countries (Derpsch *et al*. 2010).

Zero tillage has become the most widely used seeding technology on the Canadian Prairies, increasing from 8% to 59% of cultivated acres between 1991 and 2011.[9] At the same time, the use of 'minimum tillage' technology was relatively stable between 1991 and 2011 at 25% of cultivated acres. Minimum tillage technology involved less tillage than conventional methods (often seeding in one operation) but disturbed the soil more than zero tillage technology. Minimum tillage also saved labour and fuel 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.

3. Data

3.1. Census of Agriculture data

The longitudinal Census of Agriculture File (L-CEAG), which is constructed from the Canadian Census of Agriculture and spans from 1986 to 2011 at five-year intervals, permits the analysis of continuing farms for census years before and after the 1995 reform. We use 1991 as the pre-treatment census year and 2001 as the post-treatment census years in our baseline estimations. The data cover a rich set of information, including gross farm revenues, interest expenses, the acreage of different crops and land uses, the use of different tillage technologies and fertiliser 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.

The census data also indicate the location of each farm at the Census Consolidated Subdivision (CCS) level, equivalent to a Rural Municipality in the case of Saskatchewan and Manitoba and a County in the case of Alberta. Constant 2011 CCS boundaries are used to control for changes in boundaries between years and amalgamations of CCSs over time and are illustrated in Figure 1. Over 30,000 continuing farms that are active both in 1991 and 2001 are included in our regression analysis. Descriptive statistics in Table 1 indicate that most farms are located in Saskatchewan, followed by Alberta and then Manitoba. Table 1 also indicates that there are roughly the same number of farms per size quartile within each province.

The Census of Agriculture definition of agricultural operation includes many operations where gross farm revenues are very small, such as small acreages. In an effort to exclude hobby and lifestyle farms from the analysis, we restrict our sample to farms with a gross farm income of CAD 30,000 (constant 2002 dollars) in 1991, which is the average income for Canadian low-income grain and oilseed farms during the period we study (Statistics Canada, 2016). We also restrict the sample to only 'grain and oilseed farms' (Longitudinal NAICS 17 to 22) that are defined by Statistics Canada using the derived market value of commodities reported.

[9]Awada (2012) posits that four economic factors hastened the adoption of zero tillage on the Canadian Prairies during the 1990s. First, the zero tillage seeding technology 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. Interest rates also decreased, making it easier for farmers to finance the cost of the new technology. Finally, the price of fuel increased during this time, which increased the relative benefits of adoption.

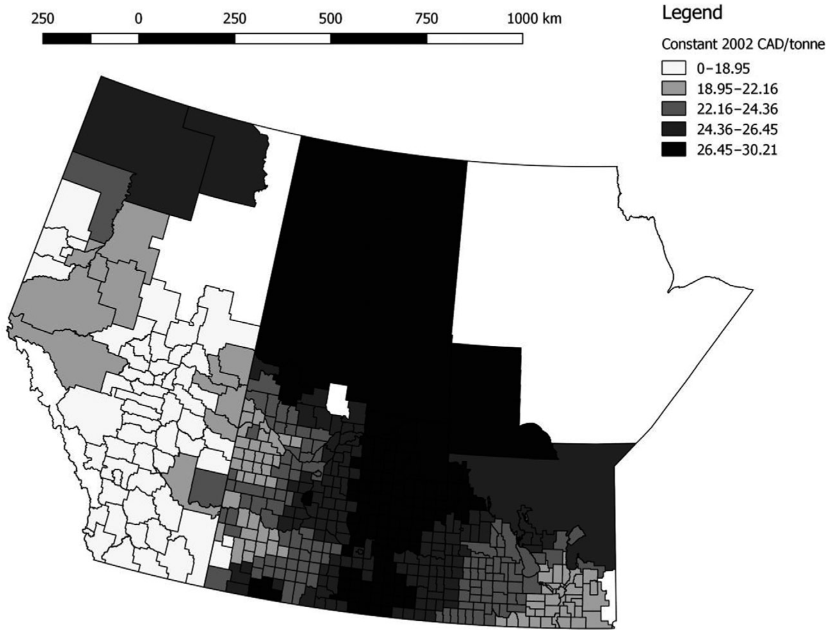

Figure 1. Freight rate changes between 1991 and 2001, and 2011 Census Consolidated Subdivision boundaries for Alberta, Saskatchewan and Manitoba.***Notes***: Areas with no fill indicate CCSs without Census data or CCSs where data were amalgamated with neighbouring CCSs for confidentiality reasons.*Source*: Statistics Canada and Freight Rate Manager.

Table 1
Descriptive statistics by farm size quartile

	Number of farms per quartile			
Farm size quartile, based on 1991 gross farm revenue:	1st	2nd	3rd	4th
Province				
Alberta	1,624	1,581	1,770	2,316
Saskatchewan	5,058	5,077	4,656	3,739
Manitoba	1,088	1,111	1,350	1,708
Soil zone:				
Brown soil	1,352	1,367	1,297	974
Dark brown soil	1,916	1,881	1,808	1,506
Black soil	3,102	3,161	3,397	3,858
Dark grey	448	444	471	502
Grey	571	546	469	517

Notes: A farm is considered as belonging to a particular soil zone if that soil type covers at least 50% of the area of the Census Consolidated Subdivision (CCS) in which the farm is located.

3.2. Railway freight rate data

Data on farm outcomes from the L-CEAG are combined with railway freight rate data supplied by *Railway Freight Rate Manager*, a service provided by a consortium of government, academic and farmer organizations.[10] The data include the rail freight rate (CAD per tonne) for shipping wheat from 1,000 delivery locations spread across Alberta, Saskatchewan and Manitoba to seaport.[11] We measure freight rates from each crop-growing grid point within each CCS to its nearest delivery point, using a 0.1 degree grid of the earth's surface. The average across the grids in each CCS is then taken as our measure of each CCS's average freight rate.[12] These are then assigned to farms based on the CCS.[13] We measure average local trucking costs from the farm to the delivery location using the average distance measure from each crop-growing grid point to the nearest delivery location, which is calculated for each CCS. The change in local trucking distances over time reflects the effect of the branch line abandonment or delivery point closures.[14]

The spatial pattern of railway freight rate increases between 1991 and 2001 is illustrated in Figure 1. Although railway freight rates increased for all prairie locations between 1991 and 2001, there was large variation in the magnitude of this increase, even within individual provinces. Figure A1 (online) illustrates the abrupt increase in railway freight rates in the 1995–1996 crop year at 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 study period.[15] Finally, Figure A1 (online) also illustrates that wheat prices fluctuated greatly during this period.

3.3. Soil and climate data

The climate averages in each CCS are measured using long-run average August precipitation and average July temperature. The data are derived from the University of East Anglia's high-resolution, global land area, surface climate database (New *et al.*, 2002). The climate data from the centroid of each grid area are matched to the nearest CCS using GIS.

The soil zone data derived from the Soil Landscapes of Canada database (AAFC, 2010) are used to measure the proportion of land in each CCS composed of brown, dark brown, black dark grey or grey soil. The colour of the soil determines the level of organic matter that, in turn, is driven by long-run climate conditions. Hence, brown soil is associated with previously grassland ecosystems found in the most arid, south-

[10]See http://freightratemanager.usask.ca/index.html for more details on the source of the railway freight rate data.

[11]Using shipment volume data from the Canadian Grain Commission (2014) for each station, we exclude stations that report total train deliveries per year of 1,000 metric tonnes or less.

[12]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 (online) for an example of how grid points are matched to delivery locations.

[13]It is unknown where each farm in the census delivers its grain. Hence, average railway freight rates are measured at the CCS-level and assigned to farms on that basis.

[14]Figure A2 in the Appendix (online) illustrates how local trucking distance increased between 1991 and 2001 for one particular CCS (South Qu'Appelle No. 157).

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

central parts of the prairies. Black soil is found in areas previously covered by long grass and deciduous trees, which are moister and found in an arc between the brown and grey soil zones (see Figure A3 online). Grey soil is found in more northern areas previously covered by coniferous forest. Farms in the black soil zone are most represented in the sample, which is due to the fact that the black soil zone is the largest soil zone in the study area (see Table 1).[16] Table 1 also indicates that the sample contains roughly the same number of farms per size quartile within each soil zone.

4. Trends in Farm Size Heterogeneity, Land Use and Technology Adoption

4.1. *Farm size heterogeneity*

Kernel density plots of the evolution of the farm size distribution for all Census grain and oilseed farms in Manitoba, Saskatchewan and Alberta are presented in Figures A4 and A5 (online).[17] These figures illustrate the high degree of size heterogeneity among Census farms. The distribution of farm size follows a lognormal distribution that is highly skewed to the right, a pattern also found in the firm size distributions of other industries. This skewness has increased over time, as the share of farms at the top of the size distribution has been rising between 1991 and 2011, while the share of small farms has been declining.

4.2. *Farm size and performance*

In Table 2 we show that gross farm revenues per acre in 1991 are negatively correlated with farm size area, but positively correlated with farm size in terms of gross farm revenues. Adamopoulos and Restuccia (2014) also find a negative correlation between farm acreage and value added per acre using the entire sample of farms from the 2007 US Census of Agriculture. In contrast, using gross farm revenues as the proxy for farm size suggests that larger farms have a higher output per acre. The negative correlation between farm acreage and output per acre is likely driven by the fact that farms tend to be larger (in term of acreage) in regions where value added per acre is lower due to soil quality or climatic constraints. Revenue or value added per acre in the brown soil zone, for example, is arguably lower than the black soil zone due to differences in precipitation. Farms thus tend to be larger in the brown soil zone in terms of acreage, but not necessarily larger in terms of total gross revenues. Since gross farm revenues appear to be a more geographically neutral proxy for farm size than acreage, we use gross farm revenues as our proxy for farm size throughout the rest of the analysis.

Table 2 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.[18] Even though larger farms use more machinery, the fact that the value of machinery per acre

[16]A map of the soil zones is provided in Appendix Figure A3 (online).

[17]Gross farm revenue is defined by the Census of Agriculture as the gross receipts from all agricultural products sold, programme payments and custom work receipts. Sales from capital items or from any goods bought only for retail sales are excluded. We also exclude receipts from the sale of forest products.

[18]The value of machinery per acre is defined as the total present market value of all farm machinery and equipment, both owned and leased.

Table 2
Correlations between farm size, gross farm revenue and machinery intensity, 1991 and 2001

	Revenue per acre	Machinery/farmland ratio
Panel A: 1991		
Acreage in crops or summerfallow	−0.15*	−0.15*
Gross farm revenue	0.28*	0.02*
Panel B: 2001		
Acreage in crops or summerfallow	−0.03*	−0.06*
Gross farm revenue	0.03*	−0.01*

Notes: Asterisks indicate statistically significant pairwise correlations at the 5% level.

decreases with farm size suggests that there are economies of size in machinery such that larger farms spread their machinery costs over more acres (or revenues).

4.3. Trends in land use and conservation tillage

We first compare several characteristics in 1991 for regions that subsequently experienced relatively large and small railway freight rate increases. We divide farms into two groups: farms that experienced an above-median versus below-median increase in railway freight rates between 1991 and 2001. We illustrate the changes in the outcome variables over the 1986–2011 period in Figures A6 and A7 (online). The share of acres in summerfallow declined more rapidly for the more exposed farms, while the shares of cropped acres planted to wheat and canola were trending parallel for both groups, and then farms experiencing the largest shock to transportation costs reduced their wheat acreage and increased their canola acreage more. Similarly, farms exposed to an above median increase in railway freight rates had a faster adoption of zero tillage and moved into and out of minimum tillage at an earlier time than farms less exposed to the railway freight rate shock (Figure A7, online). However, the use of conventional tillage declined steadily over time for both groups, and little difference between the groups can be discerned dividing farms along the median (Figure A7, Panel C, online).

5. Conceptual Framework

The change in freight rates can affect both the choice of crops and the tillage practices. First, a shift towards production from low-value to high-value export crops due to higher per-unit transportation cost may reflect the Alchian and Allan (1964) conjecture from the producer's perspective, since the increase in railway transportation costs per tonne increased the relative price of canola (a relatively high-value, low volume crop) compared to wheat. Since farmers incur little or no fixed cost to shift from low-value per tonne to high-value per tonne production, the Alchian-Allen effect would hold for any farm size, small or large.

Second, in general, large farms are more likely to have the size economies required to justify the fixed cost of zero tillage seeding equipment (Davey and Furtan, 2008; Awada, 2012), while the empirical literature suggests a relationship between farm size and technology adoption. We thus suggest a simple model of heterogenous farms and technology adoption, building on the Kislev and Peterson (1982) assumption that lower output prices encourage the use of labour-saving machines by increasing the opportunity cost of on-farm labour.[19] The theoretical model is provided in the online Appendix. The model assumes a continuum of price-taking farmers that vary in farm size. Farmers then choose the technology that minimises their costs, given their size.[20] This model predicts that all but the smallest farms invest in new technology in response to a lower output price, while farms below a certain size do not invest in the labour-saving technology because the fixed cost of equipment is prohibitive.

Our model's prediction that lower prices lead to investment in new technology is novel. Alternative theories of technology adoption in response to a negative price shock do not necessarily predict the same pattern of adoption as our theoretical model. Standard economic theory predicts that lower net output prices result in less investment. The Melitz (2003) model extended to include technology choice (Lileeva and Trefler, 2010; Bustos, 2011) predicts that larger exporting firms adopt new technology in response to reduced trade costs, while trade reform in the context of this study takes the form of lower output prices. Prospect theory (Kahneman and Tversky, 1979, 1984) would predict that farmers with the greatest probability of bankruptcy are most likely to make investments in response to a negative price shock, which does not necessarily correlate with farm size.[21]

6. Empirical Methodology

We employ a first-differenced OLS specification to estimate the heterogeneous impact of freight costs on farms' technology and crop choices along the farm size dimension. We begin with the model of farm i in year $t \in \{1991, 2001\}$ before taking first differences:

$$Y_{it} = \alpha_i + \sum_{r=1}^{4} \beta_r \left(\text{freight}_{it} \times Q_{i,r}\right) + \text{post}_t + \omega_{it} + \varepsilon_{it}, \tag{1}$$

where

$$\omega_{it} = \gamma(\text{localdist}_{it}) + \text{post}_t \times \left[\sum_{r=2}^{4} Q_{i,r} + \text{prov}_i + \text{soilclim}_i + \delta(1991\,\text{controls}_i)\right]. \tag{2}$$

Y_{it} is the outcome variable of interest for farm i in year t, while α_i represents farm fixed effects. We interact the freight rate variable freight_{it} with farm size indicator variables, $Q_{i,r}$, that take a value of 1 if farm i belongs to the rth quartile of the farm

[19]In Kislev and Peterson (1982), lower prices for farm output increase the opportunity cost of labouring on-farm versus off-farm, which encourages farmers to invest in labour-saving machinery. Lower prices for agricultural commodities thus lead to higher farm capital-labour ratios, which they observe in historical US data. However, their model is of a single representative farm, and does not distinguish responses by farm size.

[20]Since we study continuing farms that are present in both the 1991 and 2001 censuses, the model abstracts from the entry and exit decision.

[21]Lower output prices encouraged a reallocation of production from smaller and less modern farms towards larger and more modern farms. However, evidence provided by Brown *et al.* (2019) suggests that the so-called 'within-farm effect' was a more important factor than reallocation for explaining crop choice and technology change due to the reform during the 1991–2001 period.

size distribution, and takes a value of 0 otherwise. We use 1991 gross farm revenue as our proxy for farm size, as explained above.[22] Farms are divided into quartiles using the 25th, 50th and 75th percentiles of the farm size distribution in the entire sample. post_t takes a value of 1 in 2001 and takes a value of 0 in 1991. ω_{it} represents all covariates that vary over both farms and time, and ε_{it} is the error term.

The time-varying covariates, ω_{it}, include the local trucking distance (localdist_{it}). We also control for time-constant factors in the first differenced specification, which prior to first-differencing can be interpreted as being interacted with the time indicator variable. Specifically, we interact the post-reform dummy with the farm size quartile indicator variables, the province dummies, CCS-level soil and climate characteristics, and several farm-level characteristics in the 1991 pre-reform period. Without these provincial dummies, soil zone and climate variables, it is very likely that the simple first difference equation would suffer heavily from omitted variable bias. To minimise omitted variable bias, we therefore include as controls geographically specific variables that are likely to have an important impact on crop and tillage choice. These variables control for the effect of local transportation costs and trends in land use or tillage which are farm size-specific, province-specific, driven by soil and climate characteristics or by pre-existing farm-level characteristics. For example, it may be the case that the largest farms or farms in a certain province or soil climatic zone adopted new technology at a faster rate than small farms, and these phenomena are accounted for by these controls. The province and climate controls also help to control for land use changes in response to pests or disease, such as wheat midge or fusarium, since the pattern of these infestations over time tends to be correlated with climatic factors. Long-run weather averages are likely to affect the return to technology adoption or production changes and thus affect the rate at which new technologies are adopted.[23] 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 fertiliser. 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 railway freight rate measure.

Substituting (2) into (1) and first-differencing yields the following regression specification that we use throughout our analysis:

$$\Delta Y_i = \Delta\text{post} + \sum_{r=1}^{4} \beta_r\left(\Delta\text{freight}_i \times Q_{i,r}\right) + \gamma(\Delta\text{localdist}_i) + \sum_{r=2}^{4} Q_{i,r} + \text{prov}_i + \text{soilclim}_i + \delta(1991\text{controls}_i) + \Delta\varepsilon_i. \tag{3}$$

[22]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.

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

where ΔY_i, $\Delta\text{freight}_i$ and $\Delta\text{localdist}_i$ are the change in the outcome variable of interest railway freight rates and local trucking distance for farm i between the pre-reform census year 1991 and the post-reform census year 2001.

The first-differencing process subsumes the farm fixed effects, which capture all time-constant factors that may influence the outcome variables.[24] The first-differenced post-reform dummy becomes a constant term in (3), and its estimated coefficient represents the change in the dependent variable that is due to factors that affect all farms identically. The constant controls for the effect of world prices, the effect of tariffs negotiated at the WTO or regionally via the CUSFTA or NAFTA, the advent of new technologies such as herbicide-tolerant canola or any technological innovation that became available to all farms at the same time. The purpose of the controls in equation (3) are to control for as many factors that affect the growth in adoption as possible, and in so doing, avoid bias in the β_r s caused by omitted variables.

We estimate equation (3) 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 $\beta_r = 0$. The regression coefficients in the first-differenced specification reflect how the explanatory variables affect the growth in the outcome variable. 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 rth quartile of the farm size distribution.

The size of the coefficient β_r can be interpreted as a measure of inter-regional differences in the impact of the reform on 1991–2001 change in land use or tillage choice for a particular farm size quartile. In other words, the coefficient β_r indicates how a \$1/tonne increase in freight rate between 1991 and 2001 affects within-farm technology adoption or production changes. For example, consider two farms belonging to the same size quartile r but in different locations on the Prairies, where railway freight rates rise between 1991 and 2001 by \$15/tonne and \$25/tonne, respectively. Given that the increase in railway 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.

We emphasise that our identification strategy is able to tease out the marginal impacts of the policy change across regions but does not identify the total impact of the policy. All locations experienced higher railway 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.

7. Regression Results

We report the impacts of the increase in railway freight rates between 1991 and 2001 on farm-level land use (Table 3) and tillage practice (Table 4), including only continuing farms that were present in the census in both 1991 and 2001. All specifications control for local trucking distances, and even-numbered columns include a full set of controls for province, farmer age, 1991 interest payments as a share of total costs (a

[24]Our first-differenced specification yields identical results compared to a two-period panel difference-in-differences specification with panel (CCS) fixed effects.

Table 3
The impact of higher railway freight rates on farm-level land use

	10-year first difference (2001–1991)					
	$\text{Summerfallow}_{i,01-91}$		$\text{Wheat}_{i,01-91}$		$Canola_{i,01-91}$	
Dep. variable	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\text{freight}_{i,01-91} \times Q_1$	−0.005***	−0.003*	−0.010***	−0.012***	0.006***	0.006***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
$\Delta\text{freight}_{i,01-91} \times Q_2$	−0.008***	−0.006***	−0.010***	−0.012***	0.005**	0.006**
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
$\Delta\text{freight}_{i,01-91} \times Q_3$	−0.007**	−0.006***	−0.011***	−0.013***	0.007***	0.008***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
$\Delta\text{freight}_{i,01-91} \times Q_4$	−0.005**	−0.005**	−0.010***	−0.013***	0.006***	0.008***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Q_2	0.052**	0.062**	0.004	0.009	0.009	0.006
	(0.026)	(0.025)	(0.030)	(0.028)	(0.024)	(0.025)
Q_3	0.036	0.054	0.041	0.058	−0.018	−0.040**
	(0.037)	(0.035)	(0.041)	(0.039)	(0.017)	(0.016)
Q_4	0.001	0.033	0.0358	0.066	0.010	−0.024
	(0.033)	(0.028)	(0.042)	(0.044)	(0.023)	(0.020)
$\Delta\text{localdist}_{i,01-91}$	−0.001	0.000	0.000	−0.001	−0.002***	−0.001*
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Alberta_i		+		+		+
		(sig)				
Manitoba_i		+		-		+
		(sig)				
$\text{Age}_{i,1991}$		0.0005***		0.0007***		0.0003***
		(0.0001)		(0.0001)		(0.0000)
$\text{Interest}_{i,1991}$		0.066**		−0.149***		−0.130***
		(0.033)		(0.033)		(0.034)
$\text{Computer}_{i,1991}$		−0.009**		0.003		0.000
		(0.003)		(0.005)		(0.003)
Constant	0.063	−0.234	0.109	0.316	−0.124***	−0.360**
	(0.043)	(0.123)	(0.069)	(0.207)	(0.044)	(0.140)
Climate/soil controls	NO	YES	NO	YES	NO	YES
Observations	32,216	32,216	32,216	32,216	32,216	32,216
R-squared	0.016	0.104	0.022	0.046	0.019	0.062

Notes: This table reports the results of regression equation (3). The dependent variables are the area devoted to each land use as a share of total acreage in crops and summerfallow. Robust standard errors in parentheses, clustered at the Census Division level.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

measure of credit constraints), owning a computer in 1991, and climate and soil zone controls. We cluster all regressions at the Census Division level, which are larger geographical units composed of several CCSs and provides the most conservative standard errors. This provides us with up to 54 clusters, depending on the specification.

7.1. Summerfallow, wheat and canola

The effect of increased railway freight rates on the share of land devoted to summerfallow, wheat and canola is presented in Table 3. The main variables of interest are the interaction between the change in railway freight rates and the farm size quartile indicators. The point estimates for the interaction terms in columns (1) and (2) indicate that farms in all size quartiles reduced the share of land devoted to summerfallow, with very little difference across size quartiles with or without extra controls. The point estimates in column (2) suggest that every dollar increase in railway freight rates was associated with a 0.003 to 0.006 decrease in the share of acres devoted to summerfallow, depending on size quartile. The point estimates for the interaction terms in column (4) suggest that an additional 1 dollar increase in railway freight rates is associated with a decrease in the share of land devoted to wheat by 0.012 to 0.013, depending on size quartile. In contrast, the point estimates for the interaction terms in column (6) suggest that each dollar increase in railway freight rates is associated with an increase in the share of land devoted to canola by 0.006 to 0.008, depending on size quartile.

The effects of higher railway freight rates on land use are quantitatively large. Comparing two farms that experience a CAD 15/tonne versus CAD 25/tonne increase in railway freight rates, the point estimates suggest that the share of land in summerfallow would decline by an additional 0.03 to 0.06 at the location exposed to the larger railway freight rate shock, depending on farm size. The more exposed farm would also reduce its share of land in wheat by an additional 0.12 to 0.13 and increase its share of land in canola by 0.06 to 0.08, depending on farm size. The shift towards production from low-value to high-value export crops is highly suggestive of an Alchian-Allen effect. Ferguson and Olfert (2016) document the same pattern using data aggregated at the CCS level, although they find smaller impacts on canola and larger impacts on summerfallow.

The results suggest that the shift from wheat to canola occurs across the entire distribution of continuing farms to a similar extent. This result is intuitive given that there is very little if any fixed cost associated with changing these land use practices, which could otherwise impede adaptation by smaller farmers. The reduction in summerfallow is likely driven by the shift away from conventional tillage, since newer tillage technologies reduced the need for summerfallow as a method of conserving moisture. The fact that farmers in the 1st size quartile reduced summerfallow to a lesser extent compared to the larger size quartiles would be consistent with smaller farms being less likely to adopt conversation tillage practices compared to larger farms.

The uninteracted quartile results, with a few exceptions, were not significant across the specifications, which suggests that there was little difference in these land use patterns between size quartiles over time independent of the reform. The local trucking distance control is only statistically significant in the results for canola (columns (5) and (6)). The province controls suggest that Alberta and Manitoba farmers did not reduce their summerfallow acreage to the same extent as Saskatchewan farmers independent of the reform. Operator age has a strongly statistically significant and positive effect on all columns. Credit constraints have weakly negative effects on wheat and canola acreages but is otherwise not robust. Owning a computer in 1991 is associated with a negative effect on summerfallow but has no effect on wheat or canola. The estimates of the climate control variables are reported in Table A1 in the online Appendix. Neither average precipitation nor average July temperatures had a statistically significant effect on the growth of acreage in summerfallow, wheat or canola between 1991 and 2001. Summerfallow and wheat acreage tended to decline in areas with higher January average temperatures, although the effect was weakly significant.

Table 4
The impact of higher railway freight rates on farm-level tillage choice

	10-year first difference (2001–1991)					
	$\text{Conventional}_{i,01-91}$		$\text{Mintill}_{i,01-91}$		$\text{Zerotill}_{i,01-91}$	
Dep.variable:	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\text{freight}_{i,01-91} \times Q_1$	0.001	−0.017**	−0.002	0.011***	0.001	0.007
	(0.005)	(0.007)	(0.003)	(0.003)	(0.002)	(0.006)
$\Delta\text{freight}_{i,01-91} \times Q_2$	0.002	−0.016**	−0.004	0.007***	0.000	0.005
	(0.005)	(0.006)	(0.003)	(0.003)	(0.003)	(0.006)
$\Delta\text{freight}_{i,01-91} \times Q_3$	0.002	−0.017**	−0.005	0.007**	0.003	0.009
	(0.005)	(0.007)	(0.004)	(0.003)	(0.004)	(0.006)
$\Delta\text{freight}_{i,01-91} \times Q_4$	0.000	−0.021***	−0.007	0.006	0.002	0.010
	(0.006)	(0.007)	(0.006)	(0.005)	(0.005)	(0.007)
Q_2	−0.069	−0.076	0.068	0.082*	0.067	0.065
	(0.073)	(0.075)	(0.047)	(0.048)	(0.050)	(0.050)
Q_3	−0.089	−0.078	0.073	0.088	0.026	0.005
	(0.090)	(0.086)	(0.054)	(0.054)	(0.052)	(0.048)
Q_4	−0.106	−0.029	0.086	0.095	0.113	0.053
	(0.089)	(0.070)	(0.120)	(0.118)	(0.086)	(0.078)
$\Delta\text{localdist}_{i,01-91}$	0.001	0.000	−0.001*	−0.003***	0.000	0.000
	(0.002)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Alberta_i		−		+		+
		(sig)		(sig)		
Manitoba_i		+		-		−
						(sig)
$\text{Age}_{i,1991}$		0.002***		−0.001**		−0.001***
		(0.000)		(0.000)		(0.000)
$\text{Interest}_{i,1991}$		0.042		−0.188***		0.065
		(0.076)		(0.063)		(0.057)
$\text{Computer}_{i,1991}$		−0.022**		−0.048***		0.029***
		(0.009)		(0.009)		(0.009)
Constant	−0.232*	−0.734*	0.109	0.335*	0.066	0.396
	(0.131)	(0.406)	(0.077)	(0.194)	(0.067)	(0.398)
Climate/soil Controls	NO	YES	NO	YES	NO	YES
Observations	32,573	32,573	32,573	32,573	32,573	32,573
R-squared	0.006	0.036	0.001	0.009	0.008	0.023

Notes: This table reports the results of regression equation (3). The dependent variables are dummy variables taking a value of 1 if the majority of a farm's land is tilled with a given technology, and zero otherwise. Robust standard errors in parentheses, clustered at the Census Division level.
***$p < 0.0$,
**$p < 0.05$,
*$p < 0.1$.

7.2. *Conservation tillage*

The effects of increased freight rates on the adoption of tillage practices are shown in Table 4. The point estimates for the interaction terms in columns (1) and (2) indicate that farms across all size quartiles reduced their use of conventional tillage in response to the reform once all controls are added. Our tillage measures are indicator variables taking a value of one if the majority of land is tilled with a particular technology, and zero otherwise. Our specification in this case is thus a linear probability model. The point estimates in column (2) suggest that every dollar increase in railway freight rates was associated with a decrease in the probability of using conventional tillage technology by 0.016 to 0.017 for the 1st to 3rd size quartile and 0.021 for the 4th size quartile. The results suggest a relationship between farm size and the tendency to abandon conventional tillage in response to the reform, which implies that farmers switched to either minimum tillage or zero tillage technology.

We also investigate whether the adoption of minimum tillage or zero tillage varies across the farm size dimension. While the point estimates for the interaction terms in columns (3)–(6) of Table 4 are all positive once controls are added, there is only a positive impact on adoption of minimum tillage for the 1st through 3rd size quartiles. Given that minimum tillage requires a lower fixed investment cost compared to zero tillage, our results that relatively small farms adopt minimum tillage are reasonable. Overall, our results suggest that all farms switch away from conventional tillage, with the largest point estimate for the 4th size quartile. Our evidence suggests that all but the largest farms switch to minimum tillage, although the results are ambiguous for whether large farms favour minimum or zero tillage.

Comparing two farms that experience a CAD 15/tonne versus CAD 25/tonne increase in railway freight rates, the point estimates in Table 4 suggest that the probability of tilling with conventional methods would decline by an additional 16 to 17 percentage points at the location exposed to the larger railway freight rate shock, in the case of farms in the 1st to 3rd size quartiles. Comparing farms in the 4th size quartile, the farm exposed to the higher railway freight rate would face an additional 21 percentage point decrease in the probability of using conventional tillage.

The uninteracted quartile results in Table 4 are significant for the 2nd quartile in the conventional tillage regression (columns (1) and (2)) and for the 4th quartile in the zero tillage regression without controls (column (5)), but insignificant otherwise, which suggests that there were no significant differences in tillage adoption across size quartiles over time independent of the reform. The local trucking distance control is positive and statistically significant in the results for minimum tillage in columns (3) and (4). The province controls suggest that Alberta farmers switched from conventional tillage to minimum tillage at a faster pace than Saskatchewan farmers independent of the reform. Older operators were less likely in general to convert from conventional tillage to zero tillage and minimum tillage. Our credit constraint proxy has no statistically significant impact on tillage choice with the exception of minimum tillage. 1991 computer usage is associated with a negative effect on the use of conventional tillage and minimum tillage but a positive association with zero tillage adoption. The estimates of the climate control variables are reported in Table A2 in the online Appendix. Changes in conventional tillage between 1991 and 2001 were positively related to average precipitation and negatively related to January temperatures. Long-run climate appears to have at best a statistically weak impact on growth in minimum tillage and zero tillage.

7.3. Additional robustness

We also check whether our results are robust to controlling for distance to the nearest canola crushing plant and for the distance to the nearest agricultural research station, both in km.[25] Farms closer to a crushing plant would experience higher local prices for canola and so may have responded by increasing the share of land devoted to growing canola and decreasing land use in other crops such as wheat. If canola production is complementary to conservation tillage, then proximity to a canola crushing plant may also affect tillage choice. Proximity to a research station may also increase adoption rates for conservation tillage, as found by Awada (2012). The regression results including these additional control variables are reported in Table A3 and A1 in the online Appendix. In Table A4 we find that our main results for land use are robust to controlling for proximity to canola crushing plants and research stations. Distance to the nearest research station had no impact on our land use outcomes, while distance to canola crushing plants had an unexpected positive impact on wheat acreage. In Table A4 we find that our main results are largely unchanged, with the exception that for zero tillage our freight interaction terms for the third and fourth quartiles are now positive and statistically significant at the 10% level when we include these additional controls. Farms further away from canola crushers were less likely to switch from conventional tillage in favour of adopting minimum tillage and zero tillage over the 1991–2001 period. Farms further away from research stations were less likely to switch away from conventional tillage and were more likely to switch to minimum tillage.

8. Discussion

Studying the impact of the 1995 WGTA reform using farm-level data allows us to control for a host of farm-level covariates, including farm size, and provides several new perspectives on the underlying mechanisms driving technology adoption. Since shifting production to higher-value crops entails no fixed cost, the nearly identical point estimates for wheat and canola land use shares across farm size quartiles, driven by the Alchian-Allen effect, are reasonable. In contrast, the point estimates across summerfallow and tillage choice exhibited more variation across size quartiles, with smaller farms tending to respond to a lesser extent than larger farms. In terms of the theoretical predictions regarding tillage choice and farm size, the results for summerfallow and tillage tend to favour the fixed cost explanation over prospect theory, although both explanations are plausible.

While our results clearly show a movement away from conventional tillage and towards minimum tillage, the estimates for zero tillage are positive but imprecise. In contrast, Ferguson and Olfert (2016) and Brown *et al*. (2019) find a statistically significant increase in zero tillage associated with the reform. Brown *et al*. (2019) find that the effect of the reform on zero tillage also acted through the reallocation of land towards growing farms, albeit to a lesser extent than the within-farm effect. The role of reallocation may explain why the Ferguson and Olfert (2016) aggregate findings differ from those presented here, an example of the benefits of using longitudinal farm-level micro data. The lack of precision in the point estimates regarding the choice of minimum tillage or zero tillage in the largest farm size quartile suggests that this group of farms are themselves a highly heterogeneous group, which poses challenges to modelling their behaviour.

[25]The data on the location of the canola crushing plants are derived from Pikard *et al*. (1986) and from communications with Chris Vervaet, Canadian Oilseed Processors Association, 12 November 2019. The data on the location of agricultural research stations are based on Awada (2012).

9. Conclusion

The sudden increase in railway freight rates for grain exports from Western Canada after 1995 serves as a useful natural experiment that allows us to evaluate the heterogeneous impact of agricultural trade reforms on farm-level land use and technology adoption. We analyse this historic agricultural trade reform using highly-detailed farm-level panel data, yielding several new stylised facts on farm size. We find that prairie farms were highly heterogeneous with respect to size during the period we study, and that size heterogeneity has grown over time.

Our conceptual framework posits that the Alchian-Allen effect will induce farmers to produce higher-value crops in response to an increase in per-unit transportation costs per tonne, an option that farms of any size may pursue. Adopting new technologies can be driven by a combination of prospect theory, which would encourage marginal farms to adopt, while an increase in the opportunity cost of off-farm labour induces farms of sufficient size to pay the fixed cost to adopt new labour-saving tillage technologies.

Our results suggest that tillage adoption and the subsequent reduction in summerfallow are more consistent with the presence of fixed costs than by the prediction of prospect theory. This implies that the most efficient way to encourage technology adoption requiring a fixed investment is to identify and target farms on the technology adoption margin. In contrast, the reform-induced shift in production from low-value to high-value exports was an adaptation that farms of any size could pursue, since changes in this cropping pattern required no fixed cost investments. Our results are in line with studies in other sectors where technology adoption in response to trade reform is heterogeneous with respect to size and productivity. Overall, our findings emphasise the importance of considering the heterogeneous effects of farm policy. In particular, our results suggest that farm size is an important factor in determining the impact of agricultural subsidy reforms on technical change.

Our study represents a first attempt to study the farm-level effects of trade reform on land use and technology adoption using highly-detailed longitudinal data on the entire population of farms across a large geographic region. There are, however, many aspects of the farm-level data that we do not explore in this study and we leave for future research.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure A1. Primary elevator tariff, railway freight rate and price in store, Saskatoon SK, #1 Canada Western Red Spring Wheat, 12.5% protein.

Figure A2. Measurement of local trucking distances from 0.1 degree grid to nearest delivery point in 1991 (left panel) and 2001 (right panel), South Qu'Appelle No. 157.

Figure A3. Soil zones for the prairie provinces.

Figure A4. Farm size distribution in terms of acres in crops or summerfallow, 1991, 2001, 2011, all grain and oilseed farms.

Figure A5. Farm size distribution in terms of gross farm revenue, 1991, 2001, 2011, all grain and oilseed farms.

Figure A6. Trends in land use for farms with railway freight rate changes above versus below the median

Figure A7. Trends in tillage for farms with railway freight rate changes above versus below the median.

Figure A8. Higher opportunity cost of labour and technology adoption by farm size.

Table A1. Weather controls, land use outcomes..

Table A2. Weather controls, tillage choice outcomes.

Table A3. Robustness to additional controls, land use outcomes.

Table A4. Robustness to additional controls, tillage choice outcomes.

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