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

W. Mark Brown, Shon Ferguson and Crina Viju

Research Institute of Industrial Economics
P.O. Box 55665
SE-102 15 Stockholm, Sweden
info@ifn.se
www.ifn.se

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

W. Mark Brown[†]

Shon M. Ferguson[‡]

Crina Viju[§]

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Abstract

Using detailed census data covering over 40,000 farms in Alberta, Saskatchewan and Manitoba, Canada, we document the vast and increasing farm size heterogeneity, and analyze the role of farm size in adapting to the removal of an export subsidy in 1995. We find that larger farms were more likely to switch to new labor-saving tillage technologies in response to the large negative shock to grain prices caused by the reform. Small- and medium-sized farms responded to the reform by adopting the more affordable minimum tillage technology. We develop a simple model of heterogeneous farms and technology adoption that can explain our findings. The results suggest that farm size plays a crucial role in determining farm-level adaptation to agricultural trade reform. Consistent with the Alchian-Allen hypothesis, the increase in per-unit trade costs due to the reform was associated with farms shifting their production of crops from low value wheat to higher value canola.

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

Keywords: Agricultural Trade Liberalization, Export Subsidy, Technical Change, Farm Size, Firm Heterogeneity

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[†] Statistics Canada, Ottawa, Canada
[‡] Corresponding author. Research Institute of Industrial Economics (IFN), Box 55665, SE-102 15 Stockholm, Sweden. Email: shon.ferguson@ifn.se
[§] Institute of European, Russian and Eurasian Studies, Carleton University, Ottawa, Canada

Introduction

Understanding the link between trade reform and technical progress at the micro level has been a central question in economic research. In the context of 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 crucial to understand how small versus large farms respond to the removal of government support.

In this paper, we exploit the removal of a railway transportation subsidy on the Canadian Prairies in 1995 to study the farm-level impacts of the reform on cropping patterns and adoption of new farming methods. This CAD700 million per year subsidy (Klein et al 1994) applied to the major export crops and varied spatially such that farms located further from seaport 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 railway freight rate deductions at over 1,000 delivery locations across the prairies, we study how farms across Alberta, Saskatchewan and Manitoba adapted to this transportation cost shock by changing their land use and tillage practices.

We begin by establishing several new stylized facts on farm size heterogeneity, using highly detailed census data on over 40,000 farms covering over 70 million acres of farmland. 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). Adamopolous and Restuccia (2014) find that differences in farm size across countries can explain a great deal of the cross-country differences in agricultural productivity. 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).

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 a new technology that entails a larger fixed machinery cost but smaller variable labor cost of production. Following the insight of Kislev and Peterson (1982), the removal of government support leads to lower farm income and hence a higher opportunity cost of farm labor in the model. The increase in the opportunity cost of labor encourages all but the smallest farms to adopt the new labor-saving technology. The model thus illustrates that larger farms are more likely to adopt new technologies in response to lower output prices if adoption entails a fixed investment cost.

In the regression analysis we find that the within-farm effect of the reform on technology adoption varied along the size dimension, with larger farms more likely to shift away from conventional tillage and, by implication, towards more advanced tillage technologies, and with smaller farms tending to adopt the more affordable minimum tillage technology. The sorting of farms into tillage technologies according to farm size agrees with the predictions from our theoretical model.

This study contributes to a growing literature on how firms upgrade their technology when trade liberalizes, which has focused mainly on non-farm enterprises. Our empirical results are similar to findings of heterogeneous technology adoption by Baldwin and Gu (2004), Lileeva and Trefler (2010) and Bustos (2012), where only larger or more productive firms upgraded technology in response to trade liberalization. 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 liberalization 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 incentivizes 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. (2012), who show that import competition compels firms to improve productivity.

There is a dearth of farm-level studies on the effect of agricultural trade liberalization, 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), uncertainty (Chavas and Holt 1996) and risk aversion (Liu 2012).

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. (2017), 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. Their finding of a dominant within-farm effect motivates our focus on continuing farms.

Background

The Western Grain Transportation Act

The subsidization of railway freight for grain grown on the Canadian Prairies began with the Crow's Nest Pass Agreement of 1897. The subsidized 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.[1]

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.[2] The transportation subsidy thus led to higher grain prices in the prairie region compared to a scenario without

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

[2] 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.

government support. Railway freight rates per tonne were strictly regulated by 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. After the WGTA repeal, the railways were regulated by a revenue cap, but the railway companies were still obliged to report the shipping charges per tonne at each delivery location.

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 subsidized 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 1990's forced the Canadian federal government to cut spending, which initially reduced the subsidy in the 1993-94 and 1994-95 crop years. 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 CAD 1.6 billion, plus an additional CAD 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, Highmoor and Schmitz (2002) find that it did not fully compensate landowners for the loss of the subsidy.

Three other reforms occurred around the same time as 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, which increased the distance to the nearest delivery point for some farmers. 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 by ship from Thunder Bay to the mouth of the St. Lawrence Seaway.[3] Third, Canada and the U.S. gradually eliminated import tariffs for wheat, canola, and other grains over a 9-year period that ended January 1, 1998 as part of the 1988 Canada-United States Free Trade Agreement (CUSFTA) and the 1994 North American Free Trade Agreement (NAFTA) (USDA 2002).[4]

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.

A new seeding technology called zero tillage began adoption in Western Canada in the 1990's. This new seeding method prepared the seedbed and deposited the seed and fertilizer all in one operation while disturbing the soil as little as possible. Zero tillage, also called "no till," has been adopted in several countries (Derpsch et al. 2010). The conventional seeding method was to fertilize and seed in separate operations, which disturbed the soil 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

[3] See Vercammen (1996) and Fulton et al. (1998) for a detailed overview of reforms to the Western Canadian grain transportation system.

[4] The WGTA subsidized exports of grain to non-U.S. locations and thus the repeal of the WGTA increased the cost to ship by rail to Canadian seaports but did not increase the cost to ship by rail 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 made grain exports to the U.S. more attractive ceteris paribus, facilitating more wheat exports through or to the U.S. via Manitoba (Wilson 1995, 2000, 2011). The moderating effect of proximity to the U.S. market for southern Manitoba locations is captured by our railway freight rate data.

every 2nd or 3rd year. This practice of "summerfallowing" allowed for moisture to accumulate for the next year and eased the control of weeds.

Zero tillage has become the dominant seeding technology on the Canadian Prairies, increasing from 8% to 59% of cultivated acres between 1991 and 2011.[5] 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 labor 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.

Data

Census of Agriculture data

The longitudinal Census of Agriculture File (L-CEAG), which is constructed from the 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 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.

The census data also indicates 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 CCS's over time and are illustrated in Figure 1. Over 40,000 continuing farms that are active both in 1991 and 2001 are

[5] Awada (2012) posits that four economic factors hastened the adoption of zero tillage on the Canadian Prairies during the 1990's. 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.

included in the regression analysis. Descriptive statistics in Table 1 indicate that most farms in the sample are located in Saskatchewan, followed by Alberta and then Manitoba. Table 1 also indicates that the sample contains 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.

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.[6] The data includes the railway freight rate (CAD per tonne) for wheat from nearly 1,000 delivery locations spread across Alberta, Saskatchewan and Manitoba.[7] We measure railway 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 railway freight rate.[8] These are then assigned to farms based on the CCS.[9] 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

[6] 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 railway freight rate data.

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

[8] 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.

[9] 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.

distances over time reflects the effect of the branch line abandonment or delivery point closures.[10]

The spatial pattern of railway freight rate increases between 1991 and 2001 is illustrated in Figure A1. 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 A2 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.[11] Finally, Figure A2 also illustrates that wheat prices fluctuated greatly during this period.

Soil and weather data

The weather in each CCS is measured using long-run average August precipitation and average July temperature, assuming that the previous year's weather will influence planting decisions in the subsequent year. The data are derived from the University of East Anglia's high-resolution, global land area, surface climate database (New et al. 2002). The weather data from the centroid of each grid area is matched to its nearest CCS using GIS.

The soil zone data derived from the Soil Landscapes of Canada database (AAFC 2010), is used to measure the proportion of land in each CCS composed of brown, dark brown, black dark gray or gray soil. The color 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-central parts of the prairies. Black soil is found in areas previously covered by long grass and deciduous trees that are moister found in an arc between the brown and gray soil zones (see Figure A3). Gray 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

[10] Figure A1 in the Appendix illustrates how local trucking distance increased between 1991 and 2001 for one particular CCS (South Qu'Appelle No. 157).
[11] 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).

(see Table 1).[12] Table 1 also indicates that the sample contains roughly the same number of farms per size quartile within each soil zone.

Trends in Farm Size Heterogeneity, Land Use and Technology Adoption

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 Figures 2 and 3. The distribution of farm size on the basis of acreage for the years 1991, 2001 and 2011 is provided in Figure 2, while the farm size distribution in terms of gross farm revenue for the same census years is illustrated in Figure 3. 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.

Farm size and land productivity

In Table 2 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 (2014) also find a negative correlation between farm acreage and land productivity using the entire sample of 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. The negative correlation between farm acreage and land productivity is 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 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. 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.

[12] A map of the soil zones is provided in Appendix Figure A3.

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. Even though larger farms use more machinery, the fact that the value of machinery per acre decreases with farm size suggests that there are economies of size in machinery, so larger farms spread their machinery costs over more acres (or revenues).

Trends in land use and conservation tillage

As a first pass at the data we 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 time in Figures 4 and 5. Panel A of Figure 4 illustrates that the share of acres in summerfallow declined more rapidly for the more exposed farms. The results in Panels B and C of Figure 4 suggest that 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 the most. Figure 5 shows how the technology adoption outcome variables changed over time in regions that experienced relatively large or small railway freight rate increases. Trends in zero tillage and minimum tillage 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. 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. Panel C illustrates that 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.

A Model of Heterogeneous Farms and Technology Adoption

As we have noted, The Canadian prairie farm population is highly heterogeneous in terms of size, and the empirical literature suggests a relationship between farm size and productivity and technology adoption, such as minimum tillage. Keeping this in mind, and in order to guide the empirical analysis, we develop a simple model that can explain why lower prices for farm output encourage large farms to invest in new technology. We assume that production requires land (T), labor (L) and machines (M). Furthermore, we assume a continuum of farms i that are heterogeneous with respect to size such that $T_i \in (0, \infty)$.[13] The opportunity cost of labor is denoted by w. In order to simplify the model, we assume that the price of land and machines is exogenous. The price of land per acre is denoted by r, and the price of machines is normalized to unity. We assume that machines are a fixed cost of production, while labor and land are variable costs of production. Labor use per acre is denoted by l_i. Total production costs for continuing farm i is given by:

$$TC_i = M_i + wl_iT_i + rT_i$$

We assume that there are two types of machines that farms can choose between: conventional (C) and high-tech (H). The fixed cost of high-tech machines is higher than conventional machines $(M_H > M_C)$, but the labor cost associated with the high-tech machine is reduced by a factor of $z \in (0,1)$. The conventional technology is thus relatively more labor-intensive. The average cost of production per acre for farms using a conventional machine is denoted as:

$$AC_{i,C} = M_C/T_i + wl_i + r.$$

The average cost of production per acre for a farm using a high-tech machine is denoted as:

$$AC_{i,H} = M_H/T_i + zwl_i + r.$$

We assume that farmers choose the technology that yields the lowest average cost per acre. This decision will depend on the size of the farm, the opportunity cost of labor, the relative cost of conventional and high-tech machines, and the degree of labor-saving attributed to the high-tech technology.

The technology choice of each farm as it relates to its size is illustrated in Figure 6. The presence of fixed costs implies that the average cost per acre is decreasing with farm size. Farms larger than T_H obtain a lower average cost if they use the high-tech machine, while farms smaller than T_H obtain a lower average cost if they use the conventional machine. T_H denotes the size of a farm that is indifferent between using the conventional or high-tech technology.

Following Kislev and Peterson (1982), we assume that a decrease in the price of farm outputs and associated decline in farm income leads to an increase in the opportunity cost of farm labor in terms of off-farm employment. We denote the increase in the opportunity cost of labour as an increase in the opportunity cost wage from w to w'. Since labor is required for both technologies,

[13] We abstract from the exit decision in our model, since our empirical analysis focuses on continuing farmers.

the average cost curves for both conventional and high-tech technologies pivot upward. However, the average cost schedule for conventional technology pivots up relatively more, since conventional technology is more labor-intensive. This increase in the average cost of conventional production relative to high-tech production leads more farms to adopt high-tech technology, and the size of the marginal high-tech adopter decreases to T'_H. The model thus predicts that lower output prices induce sufficiently large farms to upgrade to the more advanced technology.[14]

The model's prediction that lower prices lead to investment in new technology is new in the literature. Standard economic theory would predict that lower net output prices should result in less investment as its marginal benefit declines. The Melitz (2003) model extended to include technology choice (Lileeva and Trefler, 2010; Bustos, 2012) predicts that larger exporting firms adopt new technology in response to trade liberalization. Their mechanism is inherently different, however, since trade liberalization in the Melitz (2003) takes the form of lower trade costs, while trade reform in the context of this study takes of the form of lower output prices. The Melitz (2003) model is also based on the assumption of monopolistic competition, whereas our framework is based on price-taking firms. Our framework is complementary to Kislev and Peterson (1982), who show theoretically that lower prices for farm outputs increases the opportunity cost of farm labor in terms of off-farm employment, which induces farmers to invest in labor-saving machinery. However, their model does not capture farm heterogeneity and does not allow for a fixed cost of machinery.

Empirical Methodology

We employ a first-differenced OLS specification to empirically model the heterogeneous impact of freight costs on farms' technology choice along the farm size dimension:

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

[14] A decline in output prices may also reduce the price of land (r). However, a decline in r will lead the average cost of both technologies to shift downward in equal proportion and will not affect the size of the marginal adopter. For the sake of exposition, we assume here that land prices are independent of output prices.

where $\Delta Y_{i,2001-1991}$ is the change in the outcome variable of interest for farm *i* between the pre-reform census year 1991 and the post-reform census year 2001. $\Delta freight_{i,2001-1991}$ is the change in the railway 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 farm *i* 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[15]. 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 in equation (1), which control 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.

The first-differencing process subsumes farm fixed effects, which capture all time-constant factors that may influence the outcome variables. [16] Adding long-run weather and soil zone controls after the first-differencing process controls for the impact of climate on changes in our outcome variables over time. 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.[17] 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

[15] 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.
[16] Our first-differenced specification yields identical results compared to a two-period panel difference-in-differences specification with panel (CCS) fixed effects.
[17] 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 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 requires 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.

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. The constant in the first-differenced specification is analogous to the post-treatment period dummy in a difference-in-differences specification. This includes 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.

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 as 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 railway freight rate between 1991 and 2001 impacts within-farm technology adoption or production changes. For example, consider two farms belong 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.

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 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.

Regression Results

The main results are summarized in Tables 3 and 4, where we report the impacts of the increase in railway freight rates between 1991 and 2001 on farm-level land use and technology adoption, 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 measure of credit constraints), owning a computer in 1991, and weather and soil zone controls. 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.

Summerfallow, wheat and canola

The effect of increased railway freight rates on the share of land devoted to summerfallow, wheat and canola are 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 1 dollar increase in railway freight rates was associated with a 0.0043 to 0.0062 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 0.011 to 0.013, depending on size quartile. In contrast, the point estimates for the interaction terms in columns (6) suggest that each 1 dollar increase in railway freight rates is associated with an increase in the share of land devoted to canola by 0.0059 to 0.0074, 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 0.04 to 0.06 at the location exposed to the larger railway freight rate shock, depending on its size. The more exposed farm would also reduce its share of land in wheat by an additional 0.11 to 0.13 and increase its share of land in canola by 0.06 to 0.07, depending on its size.

This shift towards production from low-value to high-value export crops due to the reform is akin to the Alchian and Allan (1964) conjecture from the producer's perspective, since the increase in per-unit trade costs increased the relative price of canola compared to wheat. 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 reduction in summerfallow and the shift from wheat to canola occurs across the entire distribution of continuing farms. 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 that we discuss later in the analysis, since newer tillage technologies reduced the need for summerfallow as a method of conserving moisture.

The uninteracted quartile results are not significant across all specifications, which suggests that there were no differences in these land use patterns across size quartiles over time independent of the reform. The local trucking distance control is only statistically significant in the results for canola without the full set of controls in column (5). The province controls suggest that Alberta and Manitoba farmers did not reduce their summerfallow and wheat 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 a weakly negative effect on wheat acreage 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.

Conservation tillage

The effect of increased railway freight rates on the adoption of tillage practices is presented in Table 4. The point estimates for the interaction terms in columns (1) and (2) indicate that farms in the 2nd, 3rd and 4th 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. The point estimates in columns (2) suggest that every 1 dollar increase in railway freight rates was associated with a decrease in the probability of using conventional tillage technology by 0.015 for the 2nd and 3rd size quartile and 0.018 for the 4th size quartile. The results indicate a clear 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.

Given that larger farms are more likely to abandon conventional tillage in response to the reform, we check 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 and 2nd size quartiles. Given that minimum tillage requires a lower fixed investment cost compared to zero tillage, our results that smaller farms adopt minimum tillage are reasonable. Overall, the results suggest that larger farms switch away from conventional tillage and into either minimum tillage or zero tillage, but the results are ambiguous regarding whether large farms favour minimum tillage 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 0.15 at the location exposed to the larger railway freight rate shock, in the case of farms in the 2nd or 3rd size quartile. Comparing farms in the 4th size quartile, the farm exposed to the higher railway freight rate would face a 0.18 decrease in the probability of using conventional tillage.

Our results in Table 4 differ from Ferguson and Olfert (2016) in two fundamental respects. First, our use of farm-level data yields the finding that the reduction of conventional tillage was heterogeneous across the size distribution of farms, which could not be studied using aggregated data. Since switching tillage technology requires a fixed equipment cost, it is reasonable to expect that the smallest farms are unable to afford this investment. Second, our results do not clearly indicate whether farmers switch to zero tillage or minimum tillage, whereas Ferguson and Olfert (2016) and Brown et al. (2017) find a statistically significant increase in zero tillage associated with the reform. Brown et al. (2017) results suggest that the effect of reform on zero tillage acted as much through the reallocation of land towards growing farms as the within farm effect, which explains 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 uninteracted quartile results in Table 4 are significant at the 10% level for the 2nd quartile in the conventional tillage regression using all controls in column (2) but insignificant otherwise, which suggests that there were no 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. 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.

Conclusion

The sudden and spatially differentiated increases 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 analyze this historic agricultural trade reform using highly-detailed farm-level panel data, yielding several new results. 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.

We develop a simple theory of technology choice and heterogeneous farms, where lower output prices reduce farm income, which increases the opportunity cost of farm labor and induces firms to invest in labor-saving technology. The model predicts that larger farms are more likely to adopt high-tech tillage technology, and all but the smallest farms adopt high-tech tillage technology when output prices fall. Our regression results agree the prediction of the model, with all but the smallest quartile of farms abandoning the conventional tillage technology in response to the removal of the subsidy. Smaller farms tend to switch into minimum tillage, with a lower fixed investment cost compared to zero tillage. The results suggest that larger farmers switch into both types of new technologies, but the results are ambiguous regarding whether large farms favour minimum tillage or zero tillage.

Our regression results support the idea that the adoption of new technologies and practices can vary along the dimension of farm size if they require fixed investments that only farms of sufficient size can expoit. 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 emphasize 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. We have tested hypotheses on the response to trade reform along the farm size dimension, but there may be other dimensions of farm heterogeneity that have yet to be explored. Similarly, future research may explore new empirical approaches to study farm-level technology adoption.

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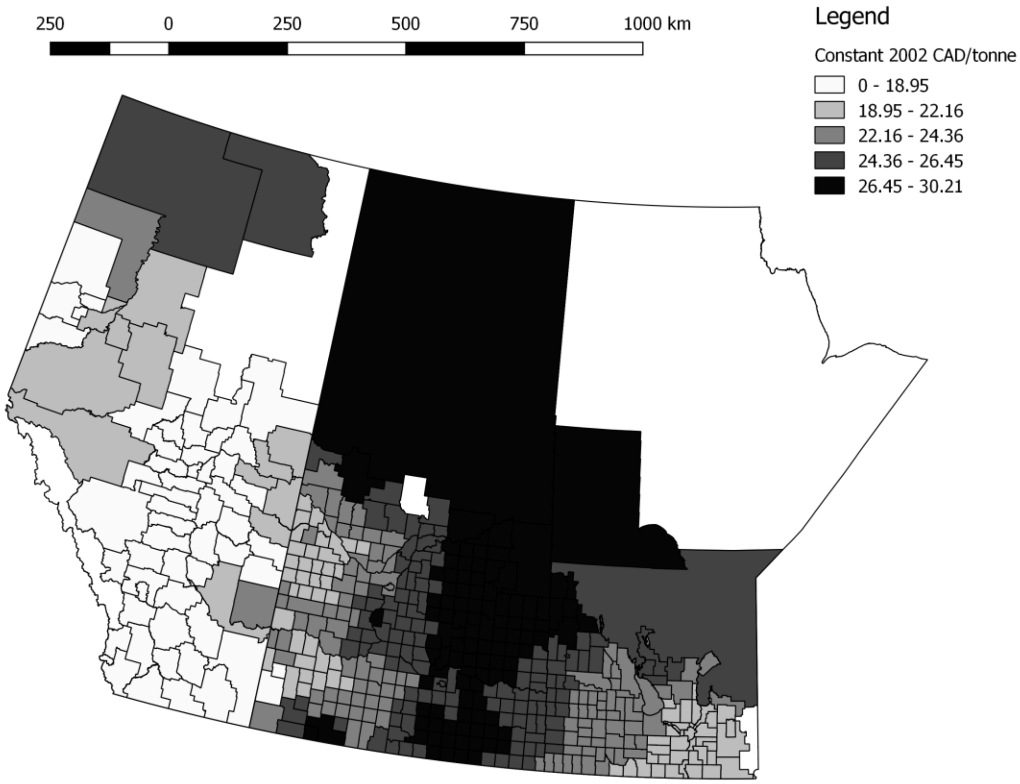


Figure 1. Freight rate changes between 1991 and 2001 and 2011 Census Consolidated Subdivision boundaries for Alberta, Saskatchewan and Manitoba

Notes: Areas with no fill indicate 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*.

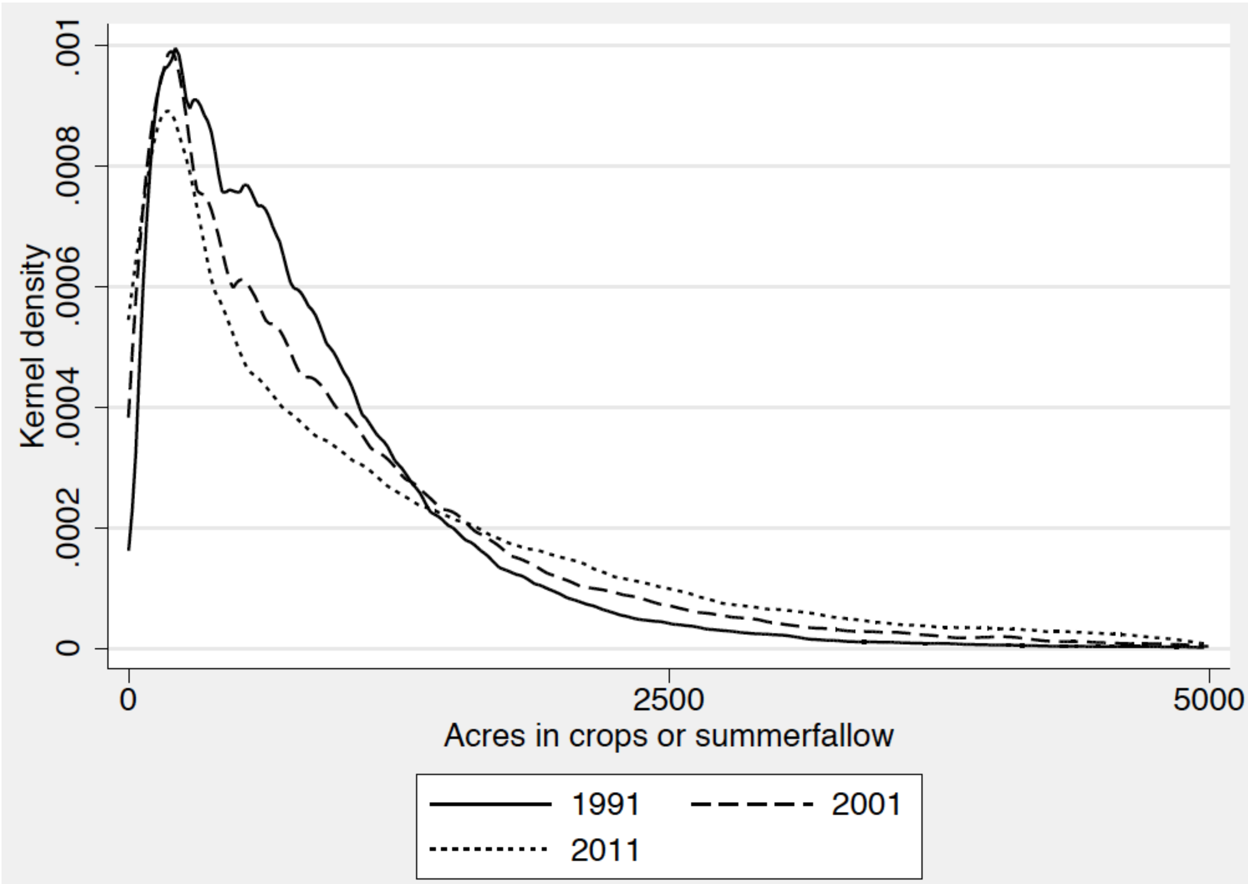


Figure 2. Farm size distribution in terms of acres in crops or summerfallow, 1991, 2001, 2011, all grain and oilseed farms

Source: Statistics Canada, authors' calculations

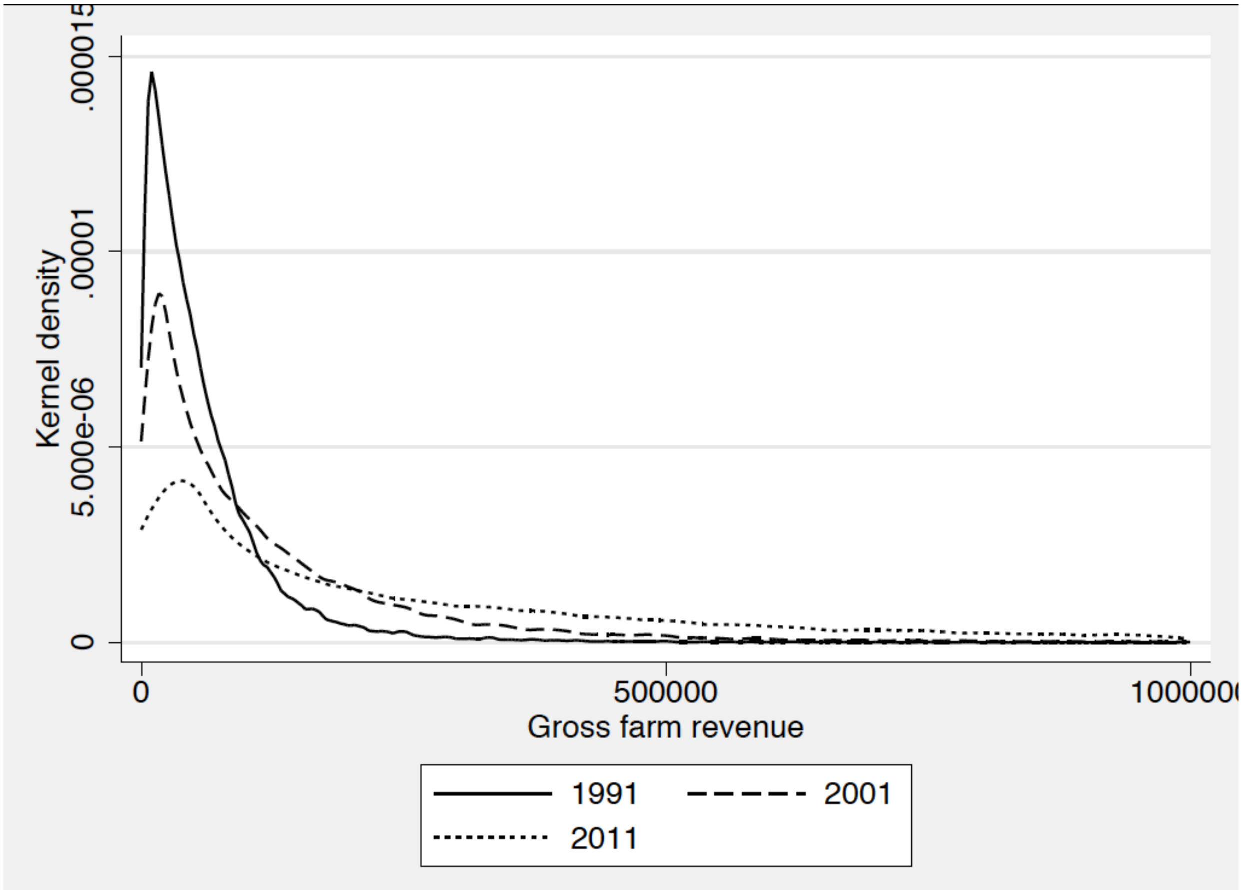
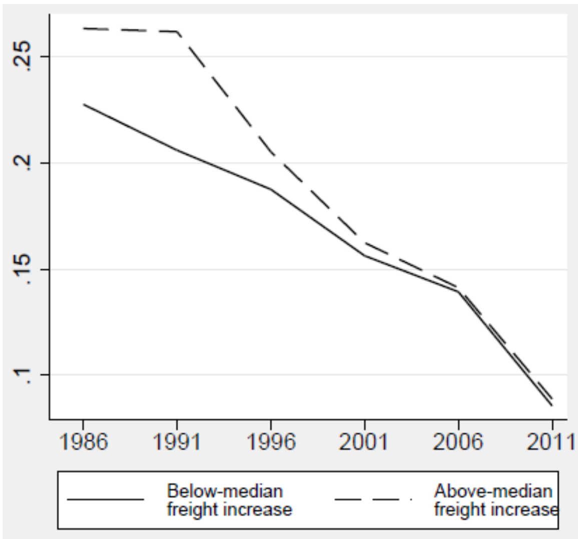


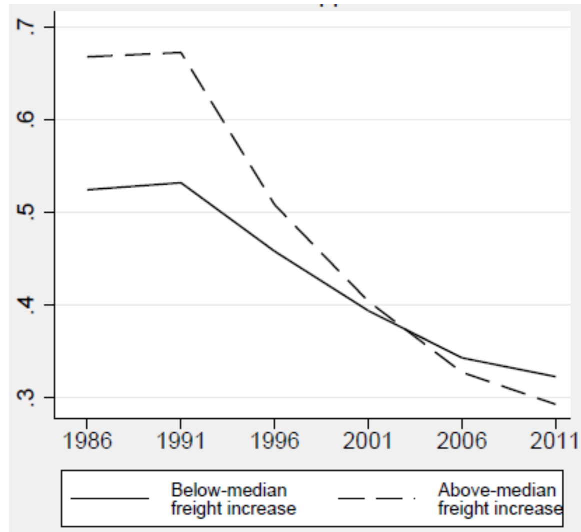
Figure 3. Farm size distribution in terms of gross farm revenue, 1991, 2001, 2011, all grain and oilseed farms

Source: Statistics Canada, authors’ calculations

Panel A: Share of acres in summerfallow



Panel B: Share of cropped acres in wheat



Panel C: Share of cropped acres in canola

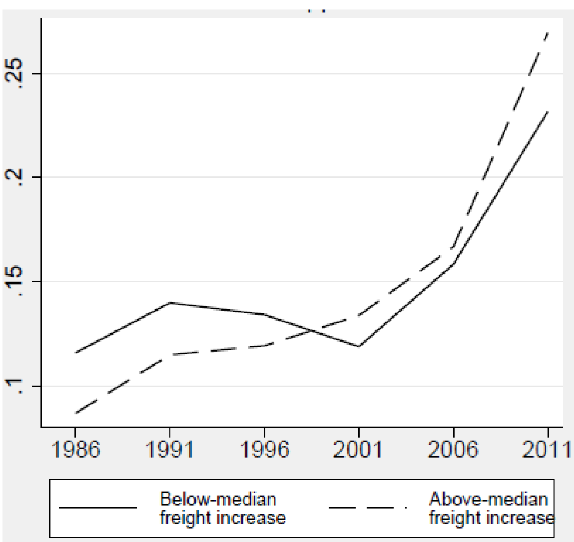
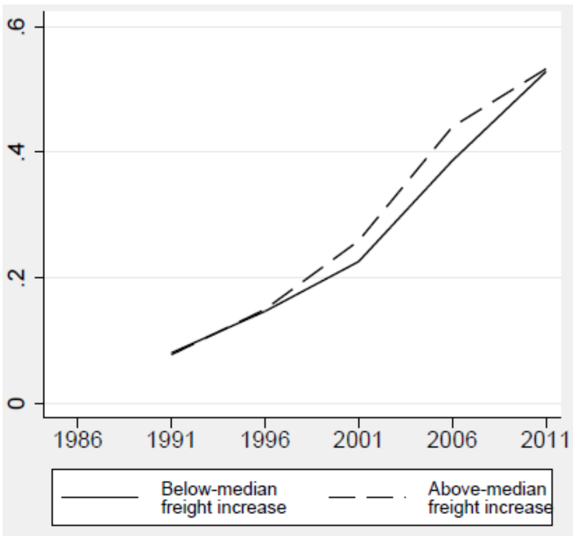


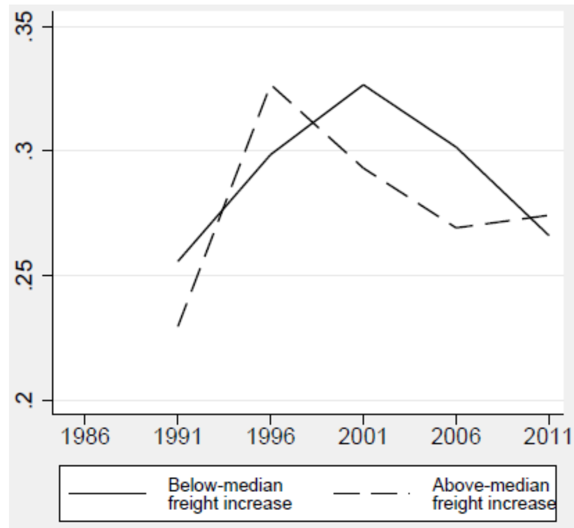
Figure 4. Trends in land use for farms with railway freight rate changes above versus below the median

Source: Statistics Canada, authors' calculations

Panel A: Share of acres zero tillage



Panel B: Share of acres min-till



Panel C: Share of acres conventional

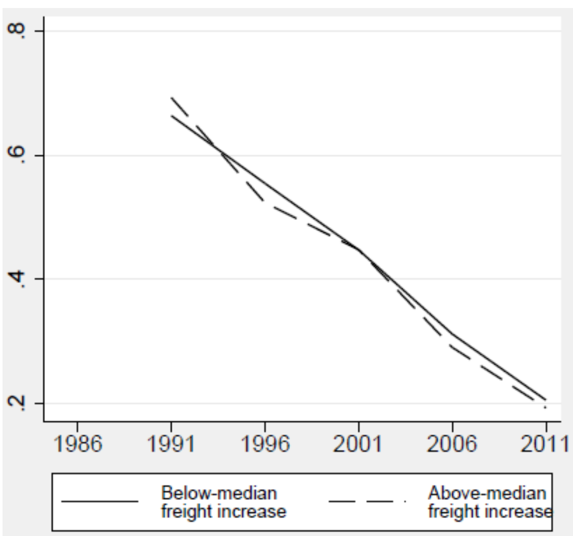


Figure 5. Trends in tillage for farms with railway freight rate changes above versus below the median

Source: Statistics Canada, authors' calculations

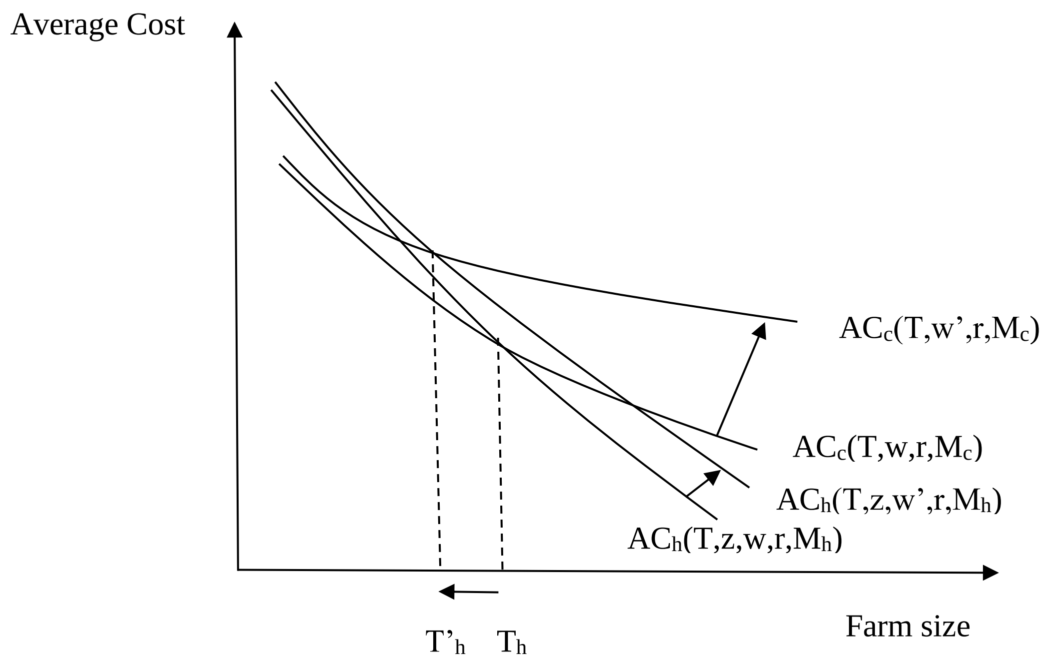


Figure 6: Higher opportunity cost of labor and technology adoption by farm size

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 gray	448	444	471	502
Gray	571	546	469	517

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

Table 2: Correlations between farm size, productivity and machinery intensity, 1991 and 2001

Panel A: 1991	Revenue per acre	Machinery/farmland ratio
Acreage in crops or summerfallow	-0.15*	-0.15*
Gross farm revenue	0.28*	0.02*

Panel B: 2001	Revenue per acre	Machinery/farmland ratio
Acreage in crops or summerfallow	-0.03*	-0.06*
Gross farm revenue	0.03*	-0.01*

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

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

	10 year first difference (2001-1991)					
Dep. variable:	$Summerfallow_{i,01-91}$		$Wheat_{i,01-91}$		$Canola_{i,01-91}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta freight_{i,01-91} \times Q_1$	-0.00700***	-0.00449**	-0.0106***	-0.0115***	0.00649***	0.00605***
	(0.00205)	(0.00169)	(0.00316)	(0.00286)	(0.00229)	(0.00216)
$\Delta freight_{i,01-91} \times Q_2$	-0.00602***	-0.00426**	-0.00985***	-0.0112***	0.00578***	0.00591**
	(0.00211)	(0.00178)	(0.00285)	(0.00261)	(0.00177)	(0.00226)
$\Delta freight_{i,01-91} \times Q_3$	-0.00750**	-0.00618***	-0.00982***	-0.0118***	0.00575**	0.00650***
	(0.00309)	(0.00209)	(0.00319)	(0.00282)	(0.00245)	(0.00230)
$\Delta freight_{i,01-91} \times Q_4$	-0.00554**	-0.00495***	-0.0105***	-0.0128***	0.00607***	0.00744***
	(0.00244)	(0.00173)	(0.00339)	(0.00284)	(0.00189)	(0.00217)
Q_2	-0.0254	-0.00474	-0.0113	-0.000660	0.0277	0.00931
	(0.0178)	(0.0174)	(0.0256)	(0.0254)	(0.0213)	(0.0218)
Q_3	0.00641	0.0364	0.00267	0.0299	0.0279	-0.00611
	(0.0333)	(0.0292)	(0.0323)	(0.0269)	(0.0187)	(0.0206)
Q_4	-0.0318	0.00856	0.0275	0.0639	0.0264	-0.0221
	(0.0316)	(0.0232)	(0.0474)	(0.0461)	(0.0248)	(0.0252)
$\Delta localdist_{i,01-91}$	-0.000590	2.15e-05	0.000414	-0.000707	-0.00157***	-0.000531*
	(0.000552)	(0.000364)	(0.000568)	(0.000546)	(0.000436)	(0.000279)
$Alberta_i$		+		+		-
		(sig)				
$Manitoba_i$		+		-		+
		(sig)				
$Age_{i,1991}$		0.00047***		0.000718***		0.000383***
		(0.000127)		(0.000138)		(0.000101)
$Interest_{i,1991}$		0.0240		-0.0534*		-0.0483*
		(0.0174)		(0.0291)		(0.0282)
$Computer_{i,1991}$		-0.00798**		0.00453		0.00272
		(0.00323)		(0.00467)		(0.00256)
$Constant$	0.102**	-0.187	0.124	0.295	-0.151***	-0.379**
	(0.0465)	(0.126)	(0.0750)	(0.217)	(0.0532)	(0.150)
Weather/soil controls	NO	YES	NO	YES	NO	YES
Observations	40,397	40,397	40,397	40,397	40,397	40,397
R-squared	0.015	0.087	0.021	0.041	0.018	0.059

Notes: This table reports the results of regression equation (1). Robust standard errors in parentheses, clustered at the Consolidated Census Subdivision (CCS) level. *** p<0.01, ** p<0.05, * p<0.1

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

	10 year first difference (2001-1991)					
Dep.variable:	$Conventional_{i,01-91}$		$Mintill_{i,01-91}$		$Zerotill_{i,01-91}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta freight_{i,01-91} \times Q_1$	0.00864*	-0.00890	-0.00326	0.00813**	0.00253	0.00733
	(0.00468)	(0.00538)	(0.00336)	(0.00285)	(0.00265)	(0.00549)
$\Delta freight_{i,01-91} \times Q_2$	0.00114	-0.0148**	-0.00182	0.00886**	0.00103	0.00565
	(0.00529)	(0.00581)	(0.00345)	(0.00290)	(0.00260)	(0.00559)
$\Delta freight_{i,01-91} \times Q_3$	0.00134	-0.0149**	-0.00612*	0.00438	0.00166	0.00678
	(0.00534)	(0.00586)	(0.00340)	(0.00280)	(0.00370)	(0.00559)
$\Delta freight_{i,01-91} \times Q_4$	0.000414	-0.0182***	-0.00562	0.00548	0.00167	0.00832
	(0.00561)	(0.00632)	(0.00508)	(0.00417)	(0.00450)	(0.00612)
Q_2	0.171**	0.120*	-0.0371	-0.0120	0.0331	0.0415
	(0.0663)	(0.0612)	(0.0690)	(0.0671)	(0.0290)	(0.0311)
Q_3	0.112	0.0728	0.0620	0.0934	0.0687	0.0633
	(0.0705)	(0.0666)	(0.0719)	(0.0683)	(0.0507)	(0.0497)
Q_4	0.0798	0.1010	0.0302	0.0506	0.131**	0.0908
	(0.0715)	(0.0619)	(0.122)	(0.120)	(0.0653)	(0.0583)
$\Delta localdist_{i,01-91}$	0.00105	0.000549	-0.00147**	-0.00237***	0.000701	0.000389
	(0.00151)	(0.00112)	(0.000650)	(0.000625)	(0.000982)	(0.000727)
$Alberta_i$		-		+		+
		(sig)		(sig)		
$Manitoba_i$		+		-		-
						(sig)
$Age_{i,1991}$		0.00173***		-0.00101**		-0.00138***
		(0.000273)		(0.000378)		(0.000318)
$Interest_{i,1991}$		0.0197		-0.0623		0.0266
		(0.0224)		(0.0413)		(0.0302)
$Computer_{i,1991}$		-0.0230***		-0.0435***		0.0289***
		(0.00785)		(0.00898)		(0.00828)
$Constant$	-0.414***	-0.740*	0.150*	0.267	0.0497	0.281
	(0.120)	(0.382)	(0.0819)	(0.202)	(0.0709)	(0.373)
Weather/soil Controls	NO	YES	NO	YES	NO	YES
Observations	40,860	40,860	40,860	40,860	40,860	40,860
R-squared	0.007	0.034	0.001	0.008	0.007	0.021

Notes: This table reports the results of regression equation (1). Robust standard errors in parentheses, clustered at the Consolidated Census Subdivision (CCS) level. *** p<0.01, ** p<0.05, * p<0.1

Appendix

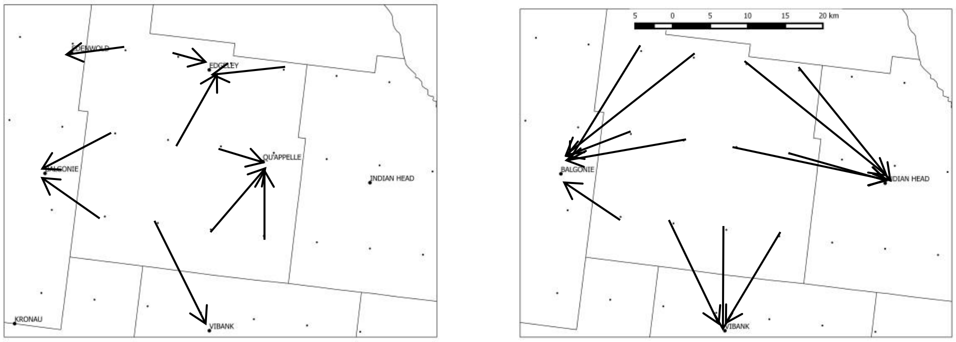


Figure A1. Measurement of local trucking distances in 1991 (left panel) and 2001 (right panel), South Qu'Appelle No. 157. Source: Statistics Canada and *Freight Rate Manager*

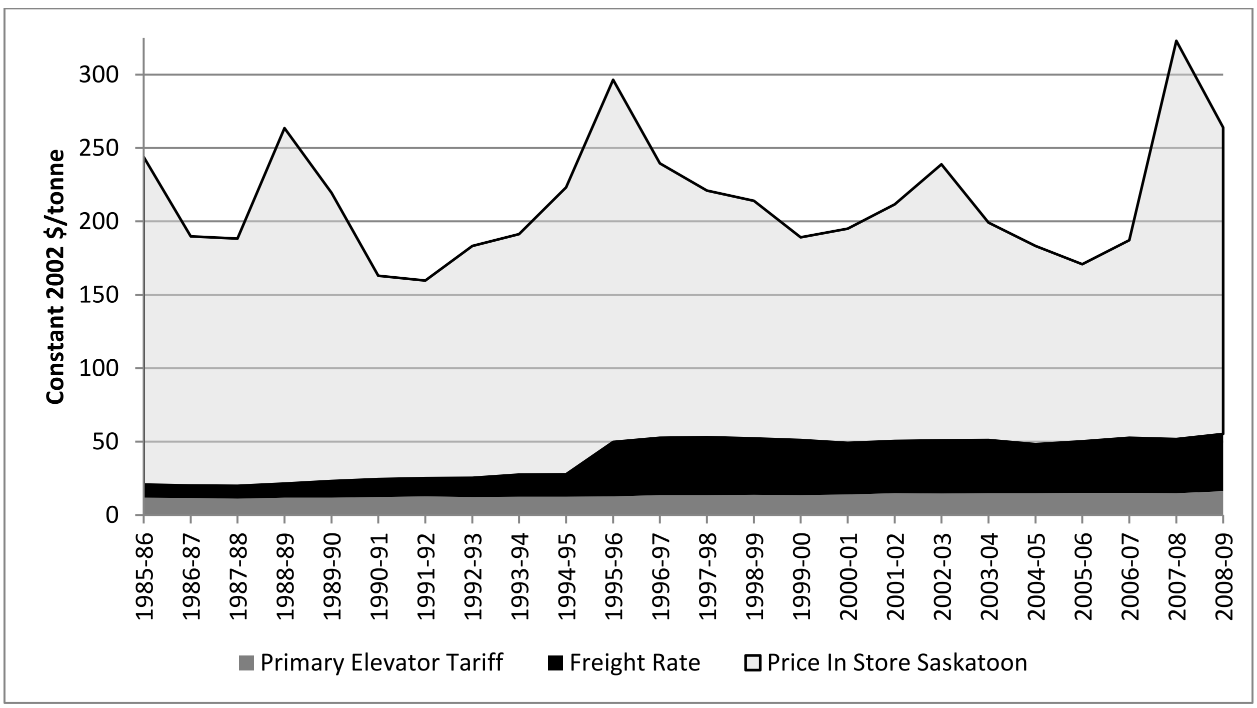


Figure A2. Primary elevator tariff, railway freight rate and price in store, Saskatoon SK, #1 Canada Western Red Spring Wheat, 12.5% protein

Source: Saskatchewan Agriculture and Food

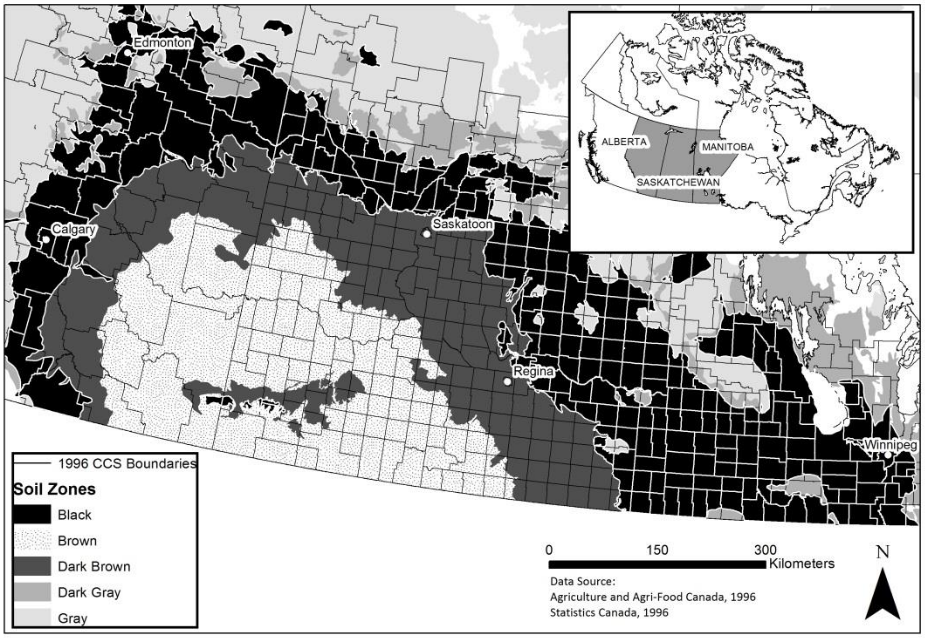


Figure A3. Soil Zones for the Prairie Provinces

Source: Agriculture and Agri-Food Canada, Statistics Canada