Agricultural Trade Reform, Reallocation and Technical Change: Evidence from the Canadian Prairies[1]

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Abstract

We decompose the impact of trade reform on technology adoption and land use to study how aggregate changes were driven by reallocation versus within-farm adaptation. Using detailed census data covering over 30,000 farms in Alberta, Saskatchewan and Manitoba, Canada we find a range of new results. We 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. In the longer run, however, reallocation of land from shrinking and exiting farms to growing and new farms explains more than half of the aggregate changes in technology adoption and land use between 1991 and 2011.

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

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Introduction

The impact of trade liberalization on the reallocation of resources and aggregate technical progress continues to be an important area of study. At the same time, many countries maintain tariff and non-tariff barriers aimed at preserving small farms that are identified by many commentators as impediments to trade agreement negotiations. It is thus crucial to understand the distributional impacts of trade reform across the farm population and their combined implications for aggregate outcomes such as technology adoption and land use adaption.

In this paper, we exploit the removal of a railway transportation subsidy on the Canadian Prairies in 1995 to study the relative contribution of reallocation versus within-farm changes due to the reform on aggregate technology adoption and land use. The subsidy, worth CAD700 million per year (Klein et al. 1994) applied to the main export crops, and the impact of the reform was location-dependent, with locations farthest from seaport experiencing the greatest increase in transportation costs when the subsidy was removed. The export-dependent nature of grain production on the Prairies, combined with the unique institutional features of the grain marketing and transportation system at the time, imply that the increase in freight rates translated directly into a decrease in the price of grains at the farm gate.[5] Ferguson and Olfert (2016) exploited this large regional variation in this historic reform in order to identify the causal effects of the subsidy loss on the aggregate adoption of new technologies for sowing grain crops and several other aspects of land use. Ferguson and Olfert (2016) used data aggregated at the Census Consolidated Subdivision (CCS) level, which allowed for a comparison in average technology adoption across regions, but the limitations of their data meant that they could not investigate the distributional impact of the reform within each region over time.

Using a detailed farm-level panel, we decompose the aggregate technology adoption and land use in each region into several components, which capture adaption through within-farm change

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

and the reallocation cropland between incumbent and entering and exiting farms. We find that the 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. While the reallocation of cropland played a minor role in the shorter time horizon, it plays a larger role over the 1991-2011 period, accounting for over half of aggregate technology adoption and land use changes. Although technology adoption and land use changes occurred across the Prairies, the pace of change was much stronger in those areas where transportation costs rose through the within-farm and reallocation effects—both are economically, and statistically, significant channels by which the farm population adapt to economic shocks.

This study contributes to a growing literature on the impact of trade liberalization and reallocation on aggregate technical change. Melitz (2003) showed theoretically that trade liberalization raises aggregate productivity by reallocating production from low-productivity firms to high-productivity firms, with strong empirical support by many studies that exploited historical trade reforms, including Chile (Pavcnik 2002) and Canada (Trefler 2004). Our results also contribute to a related empirical literature positing that trade liberalization or competitive pressure induces technology adoption and efficiency improvements within farms (Paul et al. 2000) or firms in other industries (Galdon-Sanchez and Schmitz 2002, Schmitz 2005, Lileeva and Trefler 2010, Bustos 2011, Bloom et al. 2012).

The idea that reallocation of acreage from smaller farms and exiters to larger farms and entrants leads to aggregate technical change is motivated by several studies. A survey of the literature by Sumner (2014) suggests a positive relationship between farm size and productivity in developed countries such as the U.S. 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, in particular, zero tillage (Awada 2012).

Our work contributes to a broader literature that focuses on the impact of technology diffusion on farm size, including Olmstead and Rhode (2001).[6] Our work is also complementary to recent

[6] See Sunding and Zilberman (2001) for a comprehensive literature review of technology adoption in agriculture and see Olmstead and Rhodes (2008) for a historical background of innovation in the U.S. context.

research by Collard-Wexler and De Loecker (2015) that emphasizes the role of technology adoption in driving the reallocation process and within-firm efficiency improvements that together raised aggregate productivity in the U.S. steel industry.

Our methodology builds on Foster et al. (2001, 2008), who decompose aggregate TFP growth into separate components, but we depart from the literature by performing the decomposition within each finely detailed spatial unit and then using these components as separate outcome variables in regressions where the variable of interest is the change in railway freight rates. Our regression approach allows us to determine the impact of the reform on each component of aggregate technology adoption and land use change, which, to the best of our knowledge, is a unique contribution to the literature.

Background

We begin with a brief overview of the grain transportation subsidy and its reform, as well as a description of the grain market in Western Canada. Finally, we discuss the advent of zero tillage technology in the region.

The Western Grain Transportation Act and Structural Change

In 1995, the Canadian Government eliminated a transportation subsidy on railway shipments of grain from the Canadian Prairies to seaport, known as the Western Grain Transportation Act (WGTA).[7] The decision ended one of the longest-running agricultural subsidies in the world, first known as the Crow's Nest Pass Agreement of 1897.[8] These subsidized freight rates were commonly referred to as the "Crow Rate." The removal of the transportation subsidy increased the cost of exporting grain from the Canadian Prairies by $17-$34/tonne, equivalent to 8%-17% of its value.[9] These increased transportation costs translated directly into lower grain prices at the farm-gate since grain was exported almost exclusively by rail.[10]

[7] The announcement came in February of 1995 to be effective August 1995 (Doan, Paddock and Dyer 2003).
[8]See Vercammen (1996) for a detailed overview of reforms to the Western Canadian grain transportation system.
[9] This assumes an average grain price of $200/tonne.
[10] In the case of export or CWB grains at the time, farmers deliver their grain to the grain companies' "elevator," a short-term storage facility usually located along a rail line. The grain is then loaded onto rail cars for transport to ports in on Canada's west coast (Vancouver or Prince Rupert), the Lakehead (Thunder Bay) or Hudson's Bay (Churchill), and then loaded on boats for export; grain destined for the eastern U.S. market to enters via rail to Minneapolis.

The subsidization of railway freight rates to move Western Canadian grains to export position was a vital part of the National Policy of the late 19th century to settle the Prairie Provinces and develop the so-called "wheat economy." While the subsidized grain producers benefitted from the subsidy, livestock producers and processors were disadvantaged by the resulting higher local prices of grains, and the Crow Rate was seen as contributing to dependence on a very narrow range of crops whose export was subsidized (Klein and Kerr 1996). Removal of the transportation subsidy was expected to have large impacts on the grains and livestock industries in the region (Kulthreshra and Devine 1978).

While the repeal of the WGTA affected farmers in all locations across the Prairies to some extent, there was substantial geographical heterogeneity in the size of this impact. Prior to the reform, railway freight rates for shipping wheat from the Prairies to export position (Vancouver, BC or Thunder Bay, ON) ranged from $8 to $14/tonne, depending on location. After the reform, the freight rates increased to $25-46/tonne, with the highest freight rates in locations that were farthest from the seaports. It is this spatial heterogeneity that Ferguson and Olfert (2016) used to untangle the impact of the WGTA repeal from other concurrent changes in the production and marketing of wheat that affected all locations equally or did not share the same geographical pattern as the shock to railway freight rates.[11]

The timing of the WGTA removal is attributable to two external factors that were beyond the control of the grain industry in Western Canada. First, a recession in the early 1990's forced the Canadian federal government to cut spending. Second, the GATT deemed the WGTA to be a trade-distorting export subsidy and the Canadian government faced international pressure to reduce export subsidies during the Uruguay Round.[12]

Farmers were partially compensated for the higher freight rates resulting from the repeal of the WGTA, with a one-time payment of $1.6 billion, and an additional $300 million to assist producers that were most severely affected and to invest in rural roads. Payments were based on a formula that considered each farm's acreage of eligible land, productivity, and distance to seaport. This compensation was equivalent to approximately two years of the annual subsidy amount, and

[11] For example, grain handling and transportation innovations such as high-throughput elevators and unit-trains were gradually being adopted across the Prairies, possibly resulting in adaptations by farmers, but these were generally the same in all locations and not differentiated by distance to the nearest seaport.

[12] In particular, the Uruguay Round's Agriculture Agreement stipulated that export subsidies were to be reduced by 36 percent of what was spent in 1991/92 by the year 2000. Moreover, this reduction was to apply to at least 21 percent of the volume shipped in 1991/92 (Kraft and Doiron 2000).

Schmitz, Highmoor and Schmitz (2002) calculated that the payment was not large enough to fully compensate farmers for the loss of the subsidy.

Two other reforms occurred around the same time as the WGTA repeal. First, the federal government began to speed up the process of abandoning prairie branch rail lines that were too inefficient to maintain. Second, the federal government also amended the Canada Wheat Board (CWB) Act in order to change the point of price equivalence to St. Lawrence/Vancouver, rather than Thunder Bay/Vancouver. The new pricing regime accounted for the cost to ship grain on lake freighters from Thunder Bay to the mouth of the St. Lawrence Seaway.[13]

It is important to note that the WGTA subsidized exports of grain to non-U.S. locations and thus the repeal of the WGTA made it relatively more attractive to export to the U.S. In the case of grains exported by the CWB (wheat and barley for human consumption), the CWB's catchment area for exports to the U.S. was located in southern Manitoba. The WGTA repeal would have increased the U.S. catchment area, resulting in more wheat exports to the U.S. via Manitoba. The increase in exports to the U.S. moderated the freight increase after 1995 observed in southern Manitoba locations, and is captured by our freight rate data.

Overall, it was expected that some farmers would adapt to the new environment by shifting away from low-value (wheat) exports and towards high-value export crops such as canola (Doan, Paddock and Dyer 2003, 2006). It was also expected that farmers would produce more feed grain for the local livestock industry. Finally, the lower farmgate prices were expected to encourage farmers to pursue economies of size in grain production.

It is important to note, however, that the 1990's were a dynamic time for grain production on the Canadian Prairies for several reasons, not just because of the repeal of the WGTA. Improvements in farm equipment encouraged larger and more efficient farms, and the development of herbicide-resistant canola varieties led to their increasing popularity (Beckie et al. 2011). World prices for agricultural commodities also varied widely during this period, which likely affected farmers' production and technology adoption decisions. It is thus a challenging empirical question to determine how much of the aggregate changes in land use and technology

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

adoption stemming from within-farm changes and reallocation that were caused by the trade reform. To the best of our knowledge such an empirical investigation has not been undertaken to date.

The advent of zero tillage in Western Canada

The 1990's marked the beginning of large-scale adoption of a new seeding technology called zero tillage in Western Canada. The technology was a seeding method that could prepare the seedbed and deposit the seed all in one operation while disturbing the soil as little as possible. The conventional seeding method involved tilling the soil several times, which dried the soil and removed the previous year's crop residue from the surface, hence leading to erosion problems under windy conditions. The benefits of zero tillage were to reduce fuel use, conserve soil moisture, decrease soil erosion and reduce labor requirements. Zero tillage technology was an extension of existing "minimum tillage" technology, which involved less tillage than conventional methods (often seeding in one operation) but disturbed the soil more than zero tillage technology.

The moisture conservation benefits of zero tillage allowed many farms to sow a crop every year in their fields instead of leaving them to lie idle every 2nd or 3rd year, a practice commonly referred to as "summerfallowing". This practice allowed for moisture to accumulate for the next year and allowed for the control of weeds using tillage. Planting a crop every year also meant that more fertilizer needed to be applied, since leaving the soil idle increased plant-available nitrogen levels through the natural soil process of mineralization. Zero tillage depends on the use of herbicides to control weeds.[14]

Zero tillage became the dominant seeding technology on the Prairies, increasing from 8% to 59% of cultivated acres between 1991 and 2011. At the same time, the use of "minimum tillage" technology was relatively stable between 1991 and 2011 at 25% of cultivated acres. Zero tillage has been adopted in many countries (Derpsch et al. 2010).

[14] Awada (2012) posits four factors hastened the adoption of zero tillage in Western Canada during the 1990's in general. First, the zero tillage seeding equipment improved substantially during this time. Second, the price of "Roundup" herbicide decreased to a point where it became economical to use it as a primary weed control method. Third, interest rates decreased, making it easier for farmers to finance the cost of the new technology. Finally, the price of fuel increased during this time.

Data

We combine freight rate data with a unique new farm-level dataset derived from the Census of Agriculture. This section explains the data sources and how they were combined.

Census of Agriculture microdata

The analysis is based on the longitudinal Census of Agriculture File (L-CEAG), which is constructed from the quinquennial Census of Agriculture (CEAG). Stretching from 1986 to 2011, the L-CEAG traces the evolution of the farm population over five-year intervals, permitting the longitudinal analysis of continuing farms and their operators as well as the identification of entering and exiting farms.

The census data also indicates the location of each farm at the Census Consolidated Subdivision (CCS) level. A CCS is equivalent to a Rural Municipality in the case of Saskatchewan and Manitoba and a County in the case of Alberta. We use data for several years before and after the 1995 reform in order to identify the effect of the WGTA repeal on farm outcomes. We therefore use data from 1991 and 2001 census years in the baseline estimations.

The data includes a rich set of information such as farm size and the number of acres devoted to different crops and summerfallow. We also use census data on the use of different tillage technologies. Constant 2011 CCS boundaries were used to control for changes in boundaries between years and amalgamations of CCS's over time. The CCS boundaries are illustrated in Figure 1.

The definition of agricultural operation used by the Census of Agriculture includes many operations where farming is not the main occupation of the operator and gross farm revenues are very small. Small acreages, for example, are included in the definition of a "census farm". Since we want to focus on the behavior of grain farms of sufficient size to avoid including hobby or lifestyle farms, we restrict our sample to farms with a gross farm income of CAD30,000 (constant 2002 dollars) in 1991, which is the average income for Canadian low-income grain and oilseed farms during the study period (Statistics Canada 2016). We also restrict the sample to only farms that self-report as "grain and oilseed farms" (Longitudinal NAICS 17 to 22).

Freight rate data

We combine data on farm outcomes from the Census of Agriculture with railway freight rate data supplied by *Freight Rate Manager*, a service provided by a consortium of government, academic and farmer organizations.[15] The freight rate data encompass the freight rate (price per tonne) for wheat from almost 1,000 delivery locations spread across Alberta, Saskatchewan and Manitoba.[16] Since we do not know where each farm in the census delivers its grain, we measure average railway freight rates for each CCS in the data using the nearest delivery point available each census year. We measure freight rates from several grid points within each CCS, using a 0.1 degree grid of the earth's surface, then take the average freight rate for all grid points within a given CCS as our measure of each CCS's average freight rate.[17]

We measure average local trucking costs from the farm to the delivery location using the average distance measure from each grid point to the nearest delivery location. The change in distances over time reflects the effect of the branch line abandonment and the consolidation of delivery points that occurred at the same time as the subsidy repeal.

The pattern of freight rate changes between 1991 and 2001 by CCS is illustrated in Figure 1. Note that while freight rates increased for all locations between 1991 and 2001, there was large variation in the size of this increase, even within individual provinces. The largest freight increases were in Northeastern Saskatchewan, which is the most remote location in terms of distance to both the west coast and Thunder Bay.

Figure 2 illustrates the abrupt increase in freight rates in the 1995-1996 crop year, using data for Saskatoon, Saskatchewan, a location in the middle of the Canadian Prairies. On a constant dollar basis, rates were effectively constant across the other years. Hence, we are confident that the changes in observed freight rates are due to the policy change, rather than any endogenous

[15] This service provides farmers with information on the cost of shipping various crops by rail, depending on their location. See http://freightratemanager.usask.ca/index.html for more details on the source of the freight rate data.
[16] Using shipment volume data from the Canadian Grain Commission (2014) for each station, we exclude stations that report total train deliveries per year of 1000mt or less.
[17] 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 Ferguson and Olfert (2016) for an example of how grid points are matched to delivery locations.

relationship between farm production and freight rates.[18] The figure also illustrates that primary elevator tariffs for wheat, which is the fee charged by grain companies to store and load grain onto railway cars, were generally constant over the 1986-2009 period.[19] Figure 2 also illustrates that wheat prices fluctuated greatly during this period.

Soil and weather data

The weather data includes long-run average annual precipitation and average July temperature in each CCS. The weather data are taken from the University of East Anglia's high-resolution (10') data set of surface climate over global land areas (New et al. 2002). We match the weather data from the centroid of each grid area to its nearest CCS using GIS techniques.

The soil data describes the percentage of each CCS that is brown, dark brown, black dark gray or gray soil. The color of the soil is determined by the level of organic matter it contains, which is itself related to the vegetation and hence by long-run weather. Brown soil is found most arid parts of the Prairies were previously a grassland ecosystem. Black soil is found in moister areas of the Prairies were previously covered by long grass and deciduous trees. Gray soil is found in areas with coniferous forest. The soil data originates from the Soil Landscapes of Canada database (AAFC 2010).

Defining entering, exiting and continuing farms

As with any longitudinal firm population, a full understanding of their dynamics depends on the rules that are imposed to identify continuing, entering and exiting farms. The L-CEAG identified agriculture operations[20] (hereafter farms) using a longitudinally consistent code that is maintained across census years and is largely based on the headquarters location of the farm. Of course, decisions have to be made when farms change hands or are merged into larger operations as to

[18] Freight rates and production are inherently endogenous, because freight rates influence the equilibrium level of production, while production through transportation density and fronthaul and backhaul effects can influence freight rates (see Behrens and Brown, 2017)

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

[20] An agriculture operation is a "…farm, ranch or other agriculture operation producing agriculture products"(http://www.statcan.gc.ca/eng/ca2011/gloss and see http://www.statcan.gc.ca/pub/95-629-x/2007000/4123857-eng.htm for a more detailed discussion).

whether they are continuers, exiters or entrants.[21] These are based on a set of basic rules that allow the farm population to be classified into these three groups.

Continuing farms

Mechanically, farms are considered to be continuers if their response to the subsequent census is under the same identifier. The identifier is maintained if the farm is an on-going operation[22] and has the same headquarters location. This is the case even if the farm is sold as long as it continues to be associated with the original headquarter's location and the new operator's information is available (i.e., name and age). The rule holds regardless of whether the sale is an inter-generational transfer or the farm is sold to someone outside of the family.

Exiting farms

If the respondent indicates the farm is no longer operating (i.e., selling agriculture products for sale or the intent for sale) the farm has exited and its identifier is terminated. Furthermore, if the farm is purchased by an on-going operation farm, under most circumstances it will be treated as an exit, and all of its land and assets will be combined with the purchasing farms operations. The purchasing farms identifier is maintained and the purchased farm identifier is terminated.

Entering farms

If a new farm is identified on the Farm Register and qualifies as an operating farm based on the census response, then it is a new farm and given a unique farm identifier. The farm is also considered to be an entrant if the farm is sold to a new operation, and the headquarters location cannot be associated with the farm under the previous owner.[23] The farm is given a new identifier and the old identifier is terminated.

It is, in the end, likely impossible to codify every possible scenario to discern whether a farm is continuing or is an exit or an entrant. Nevertheless, farms are generally treated as continuers if they are taken over and maintained as on-going and independent operations, but are exits if they cease operation or are taken over by another farm that continues to operate. They are entrants if

[21] See also Nagelschmitz et al. (2016) for a similar, but more in depth discussion.
[22] An on-going operation is one that produces agricultural products for sale or with the intent to sale.
[23] In the case of a dissolved partnership, where the farm is split and begins operations as separate entities, the old farm identifier is terminated and new operations are treated as entrants.

they are new to the Farm Register or it is not clear that the farm that has been sold is identifiable as a continuing farm.

Farm dynamics and technological change

We decompose the change in the composition of farmland, either in its land use (*wheat*, *canola* and *summerfallow*) or in the application of the type of tillage (*conventional*, *conservation* and *zero till*), resulting from the contributions of the *continuing*, *entering* and *exiting* farms. In so doing, the decomposition provides a means to measure how the competitive process influences these outcomes. There are several ways that these outcomes can be decomposed into the contributions of entering, exiting and continuing farms.[24] We adopt the Foster et al. (2001) approach, but do so with an eye to its limitations.

Defining L_{gt}^{o} as the percentage share of land accounted for by outcome *o* (i.e., land use or tillage type) in region *g* ($\in$ Prairies, CCS) at time *t*, we can decompose the percentage point change in share of cropland (ΔL_{gt}^{o}) between year $t-\tau$ and *t* into the contributions of continuing (*C*), entering (*E*) and exiting (*X*) farms (*f*):

$$\begin{aligned}\Delta L_{gt} &= \sum_{f\in C} s_{ft-\tau}\Delta L_{ft} + \sum_{f\in C}\left(L_{ft-\tau} - L_{gt-\tau}\right)\Delta s_{ft} + \sum_{f\in C}\Delta L_{ft}\Delta s_{ft} \\ &+ \sum_{f\in E} s_{ft}\left(L_{ft} - L_{gt-\tau}\right) - \sum_{f\in X} s_{ft-\tau}\left(L_{ft-\tau} - L_{gt-\tau}\right)\Delta L_{ft},\end{aligned} \tag{1}$$

where to simplify the notation the outcome index *o* is dropped. The first three terms in the decomposition capture the effect of the continuing farm population (*C*). The first term is the *within* farm effect and measures the contribution of change in the intensity of the land use/till technology while holding the share of land accounted for by the farm to its level at the start of the period. The second term captures the *between* farm effect, where the farm makes a positive contribution if it is growing and its share is above average at the start of the period. The third term is the *cross* effect and is positive if growing farms are also more intensively using a land use/till technology.

[24] For a review of various decomposition methods as applied to productivity see Baldwin and Gu (2006).

While the first three terms tell us the extent to which change is driven by incumbent farms, it is only the *within* term that measures the extent to which incumbent farms drive change independent of shifts in farm land. The *between* and *cross* terms capture the effect of shifts in acreage between growing and declining farms on outcomes and, therefore, measure an aspect of how the reallocation of resources across farms drive overall change. Their contributions are positive if farms that have higher than average intensity in year $t-\tau$ increase their share (*between*) or because there was concomitant growth in both intensity and shares (*cross*) over t years.

The fourth and fifth terms capture the effects of *entry* (*E*) and *exit* (*X*). Entry has a positive effect if entrants use the technology more intensively than the farm population at the start of the period, while exit has a positive effect if they use technology less intensively at the start of the period compared to the overall farm population.

The Foster et al. (2001) decomposition is not without limitations, but it likely provides a reasonable representation of the effect of changes in the farm population on outcomes. One concern is the potential bias in the continuing farm components resulting from regression to the mean (Baldwin and Gu, 2006). That is, farms with initially large sizes (e.g., because of an expansion of rented land to produce more of a particular crop) are more likely to see subsequent decline in both size and the share of acreage in a particular land use/technology in the subsequent period. Hence, the use of initial farm shares and outcome variable shares in the three incumbent farm components may be correlated because of these transitory effects rather than some underlying economic process. However, in this instance we are less concerned about this effect, because we have chosen to focus the analysis on longer-term trends that are less sensitive to transitory shocks associated with regression to the mean (Baldwin and Gu, 2006).

A second concern[25] surrounds the implicit assumption of who is replacing whom in the farm population. The Foster et al. (2001) decomposition assumes entering farms are replacing the average farm at the start of the period, while the average farm at the start of the period is replacing exiting farms. In other sectors of the economy that are imperfectly competitive, this assumption may not hold. For instance, in many manufacturing industries entry and exits tend to replace each other as the churn involves small firms that are often less productive than larger firms and compete

[25] A third concern is that the Foster et al. (2001) decomposition is sensitive to bias stemming from measurement error (see Foster et al, 2001). We don’t believe this particular form of error, which is more likely to occur when measuring output and employment in productivity decompositions, is a major concern here.

for the same small market segments (Baldwin 1995 and Baldwin and Gu, 2006). Here it isn't apparent *a priori* that entering farms are taking land from exits or declining incumbents. We believe it is reasonable, at least as a starting point, to assume entering farms are replacing the average farm and the average farm is replacing exiting farms.

Decomposing the Sources of Aggregate Changes in Technology Adoption

We begin the analysis by decomposing aggregate changes in technology adoption and land use patterns into the contributions by exiting, entering and continuing farms between 1991 and 2001 (Table 1) based on the Foster et al. (2001) decomposition expressed in (1). For the change in the adoption rate (outcome) and its decomposition, the farm population is divided into two groups: farms experiencing changes in railway freight rates above and below that of the median farm. Splitting the sample this way allows us to test initially on an informal basis and subsequently on a formal basis the relationship between transport costs and shifts in the farm population. However, before reviewing the decomposition results, we first set the scene by describing the basic pattern in the data.

A First Glance at the Data

In term of land use, there is an overall shift in the share of land devoted to wheat and summerfallow and towards canola between 1991 and 2001 (see Table 2). This is the case irrespective of whether the farm incurs below or above median changes in railway freight rates. For instance, the share of land devoted to the production of wheat fell by 25 percentage points (66 to 41%) for farms with above median freight rate increases and 11 percentage points (55 to 43%) for farms with below median freight rate increases. Consistent with expectations, however, the change is stronger for farms with above median transport costs. This basic pattern holds for both canola and summerfallow, albeit both grew in their share of land over the period.

The growing importance of summerfallow, as we have noted, is related to the shift away from conventional till towards conservation and especially zero till technology observed over the period (see Table 1). In particular, the share of land where zero till was used rose by 29 percentage points (9 to 38%) for farms with above median freight rate increases and 24 percentage points (8 to 31%) for farms with below the median freight rate increases. Conventional till saw a similar and opposite shift, while minimum till saw little change. Again, there appears to be a stronger effect across all three technologies for farms with above median changes to freight rates. Of course, the 1991 to 2001 period allows only five years of the farm population to adapt to the change in transportation costs, whose effect is partially cushioned by a one-time payout to farms in partial compensation for the change. Moreover, while individual farms may have the capacity to shift their crops and technology relatively quickly, it may take longer for this changes to play out in terms of farm dynamics as those farms that are better able to adapt enter/expand and those less able exit/contract. Therefore, it is also necessary to look over a longer time frame.

As a result, we extend the analysis by a further ten years from 1991 to 2011 (Table 2). Over this longer period the changing land use and related technological change is even more apparent. In particular, the shift towards the production of canola and away from wheat is more pronounced and so too is the adoption of zero till technology instead of conventional till.[26] Minimum till is the one exception as it becomes less popular by the end of the period, as it is apparently eclipsed by zero-till technology that was only in its infancy in 1991. Still, the essential pattern of greater change for those farms with above median and below median freight rate shocks remains, essentially confirming Ferguson and Olfert's (2016) descriptive findings, but with micro data instead of aggregate farm level data. Left open to question, of course, is whether these outcomes are the result of the incumbent farm adapting to the price shock and/or the reallocation of land from declining incumbent and exiting farms to growing incumbent and entering farms. And, following from this, whether the apparent association between transportation costs and these changes stands up to more rigorous statistical testing. We address these questions in turn.

Decomposition of Farm Outcomes

Overall, we find that the within-farm effect, which isolates the incumbent farm adoption of technology holding farm size constant, is the largest contributor to aggregate changes in technology and land use for the time period 1991-2001. As per Table 1, the within-farm effect for zero till adoption explains about 16 percentage points of the total 29 percentage points of aggregate change for farms with above median transport costs and 14 percentage points out of the total 24 percentage point change for farms with below median transport costs. A strong within-farm effect

[26] The 1991 adoption rates reported in Tables 1 and 2 are not identical, which is due to small differences in the median freight rate for the two time horizons.

can be observed in the decline of conventional till technology, accounting for 20 percentage points out of the total change of 33 percentage points for farms with above median transport costs and 18 percentage points of the total of 29 percentage point change for farms with below average median transport costs. The within-farm effect is also strong when looking at land use, explaining around 19 percentage points of the total of 25 percentage point decline in land used for wheat production for farms with above median transport costs and 9 percentage points out of a total of 11 percentage points for farms with below median transport costs.

The decomposition was performed again for the period 1991 to 2011 to examine whether the same effects are important over a long period of time (Table 2). Over this longer period, the within-farm effect is losing importance and the cross and entry terms combined become the most important component. For example, Table 2 shows that from the total 57 percentage point change in zero till adoption, the within-farm effect explains 22 percentage points, while the cross and entry effects together explain 35 percentage points for farms with above median transport costs. In contrast, for the farms with below median transport costs, of the total of 54 percentage points, the within term explains 22 percentage points and cross and entry terms sum to 32 percentage points. The same trend can be observed for the other technology and land use variables. Thus, the reallocation of land through the expansion of incumbent farms and the entry of new farms gain importance in the long-run. Competitive reallocation matters for understanding aggregate technology adoption.

Casual inspection of Tables 1 and 2 suggests that the effect of transportation costs varies substantially across the components. By focusing, for example, on zero till technology, its adoption is stronger for farms with above median transport costs. For the period 1991 to 2001, the entry term does not play an important role, thus the adoption of zero till technology in higher transport cost areas is associated with farms that have adopted the technology and are expanding and not from new entrants. The situation changes for the period 1991 to 2011 when the entry gains importance and thus, in the long run, the adoption of zero till technology in higher cost areas is explained by both, farms that have adopted the technology and expand, and new entrants. Hence, entry would have occurred only after incentives had changed. These dynamics hold true for all variables considered.

Regression Analysis

Overall, the preliminary results in Tables 1 and 2 suggest that the increase in transportation costs has a within-farm effect in the short run, while reallocation becomes more important in the long run. In order to test this hypothesis more formally we now perform the decomposition analysis at the CCS-level and apply a regression analysis. The following first-differenced model is used to estimate the effect of transport costs on the five decomposition effects: Within, Between, Cross, Entry and Exit. The regression is run for two periods of times, 1991-2001 and 1991-2011, at the CCS level.

The model for the periods 1991-2001/2011 is specified as follows:

$$\Delta L^{c}_{gt} = \alpha + \beta \Delta \text{freight}_{gt} + \delta \Delta \text{dist}_{gt} + \gamma \text{controls}_{g} + \varepsilon_{gt} \quad (2)$$

where ΔL^{c}_{gt} is the change in the outcome variable of interest for the components *c* ($c \in$ Total change, Within, Between, Cross, Entry and Exit) for CCS location *g* between the pre-reform year 1991 and post-reform years 2001 and 2011. The independent variables $\Delta \text{freight}_{gt}$ and Δdist_{gt} represent the change in average freight cost per ton of grain shipped from CCS *g* to port between 1991 and two different years, 2001 and 2011, and the change in average distance from each CCS to its nearest delivery point over the same two periods of time, respectively. The various control variables include January and July temperatures, annual precipitations, dummy variables for the provinces of Alberta and Manitoba and dummy variables for soil types (black, gray, dark gray, brown and dark brown). We run the model with just $\Delta \text{freight}_{gt}$ and Δdist_{gt} (Model 1) and with the controls added (Model 2). First-differencing subsumes CCS fixed effects, yet allows us to control for long-run weather as an explanatory variable for changes in the decomposition components. The constant term captures any effects that are constant across all CCS's, and is analogous to the post-treatment period dummy in a difference-in-differences specification.

The model is run on a balanced panel of 464 CCSs. A CCS is included in the estimation if we are able to measure the total change in all of the outcome variables and the independent variables over both the 1991 to 2001 and 1991 to 2011 periods. This means there will be different set of farms represented in the sample compared to the one used to produce tables 1 and 2. Nevertheless, as Table 3 demonstrates, there is no qualitative difference between the change in the outcome variables for the 1991 and 2001 periods and 1991 and 2011 periods and those reported in Tables 1 and 2 (after taking the mean of the above and below median transport costs).

The main results are summarized in Figures 3 and 4, where we report the point estimates and the 90 percent confidence intervals for the railway freight rate coefficient (β) for the 1991-2001 and 1991-2011 periods. The effect of increased freight rate on crop production is presented in Figure 3. We find evidence that an increase in the freight rate resulted in positive changes for most components (within, cross and entry) explaining changes in canola production, and a decrease of these same components related to wheat production and summerfallow. The within-farm effect reacted the most to the change in transportation costs, meaning that the policy change created a strong incentive for incumbent farms in areas with high transport costs to reallocate land from wheat production and summerfallow to canola production or to other uses not tested in this paper (such as cattle production). The point estimates for the within-farm term over the 1991-2001 period with controls suggest that every one dollar per tonne increase in transportation costs increased the absolute value of the within-farm component by 0.8 percentage points for canola, 1.9 for wheat, and 0.9 for summerfallow.

The impacts of changes in railway freight rates on reallocation are sustained and even larger in some cases over the longer period of time, as the results for the period 1991-2011 show. The effect of changes in railway freight rates on the cross component is (in relative terms) becoming larger during the period 1991-2011, showing that over the longer period of time, incumbent farms that reallocated their land to production of other crops or uses are the ones that increased in size. Thus, they are the ones that adapt to the change and buy out farms that could not survive without the subsidy. The change in the entry and exit components are not statistically significant except for wheat and this does not hold when controls are added. Hence, in the longer run the effect of transportation costs on adaption runs through the incumbent farm population, rather than being associated with the exit of farms that may not have adapted or the entry of farms that are better than the average. The inclusion of controls does not qualitatively change the results.

The increase of freight rate on tillage technology adoption is presented in Figure 4. We find evidence that an increase in railway freight rates resulted in a positive change in most components explaining zero tillage adoption (except for the entry effect) and a negative change in most components related to conventional tillage (except for the entry effect). The results on minimum tillage are mixed and the point estimates are sensitive to the inclusion of controls. The zero tillage results show that the within-farm effect is responsive to the increase in railway freight rates, thus incumbent farms from high transport cost areas are the ones that implement this technology. However, the change in the cross component is as large as the change in the within term and the cross term is the largest in the 2011 horizon. Thus, in places hardest hit by the loss of the transportation subsidy, farms that adopted the zero tillage technology are the ones that increased their size. The same picture can be drawn based on the conventional tillage results, with farms that are moving away from this technology being the ones that expand in size, while the results for minimum tillage are not robust.

Conclusion

The sudden and spatially differentiated increases in freight rates experienced in Western Canada after 1995 serves as a useful natural experiment that allows us to evaluate the relative contribution of reallocation versus within-farm change to understand aggregate changes in technology adoption and land use. The results suggest that the reform induced a within-farm effect in the short-run, while reallocation occurred in the longer-term. Hence, the competitive process plays an important role in aggregate technological change and in land use change, albeit one that focuses on the reallocation of land amongst growing and declining incumbent farms rather than through the entry and exit process. These results, therefore, are consistent with the literature that finds competitive pressure induces technology adoptions within the farms sector (Paul et al. 2000) and a broader set of industries (see Collard-Wexler and De Loecker, 2015). To the extent that this competitive reallocation leads to productivity growth either through the adoption of technology or through the shift to larger farm sizes, these results are also in line with Melitz’s (2003) theoretical findings.

Methodologically, these findings suggest moving from the aggregate to the micro-level through the development of farm-level panel datasets, has the potential to provide insight. This paper has focused on developing a better understanding of a price shock on both within farm changes and competitive reallocation, with both being important. A natural next step is to focus on the incumbent farm population at the micro-level to examine how farms have adapted to change and whether this is conditioned on farm size as these result points to the effects of shifts in farm land towards growing and likely large farms.

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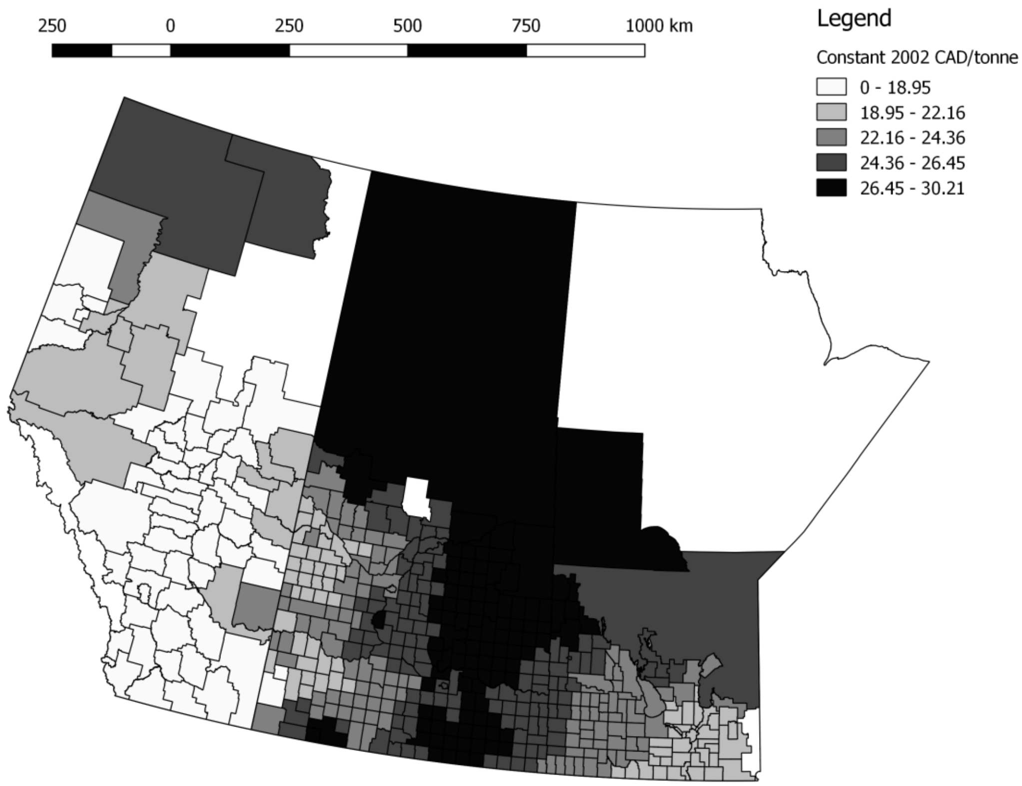

Figure 1. Freight rate changes between 1991 and 2001 and 2011 Census Consolidated Subdivision boundaries for Alberta, Saskatchewan and Manitoba

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*.

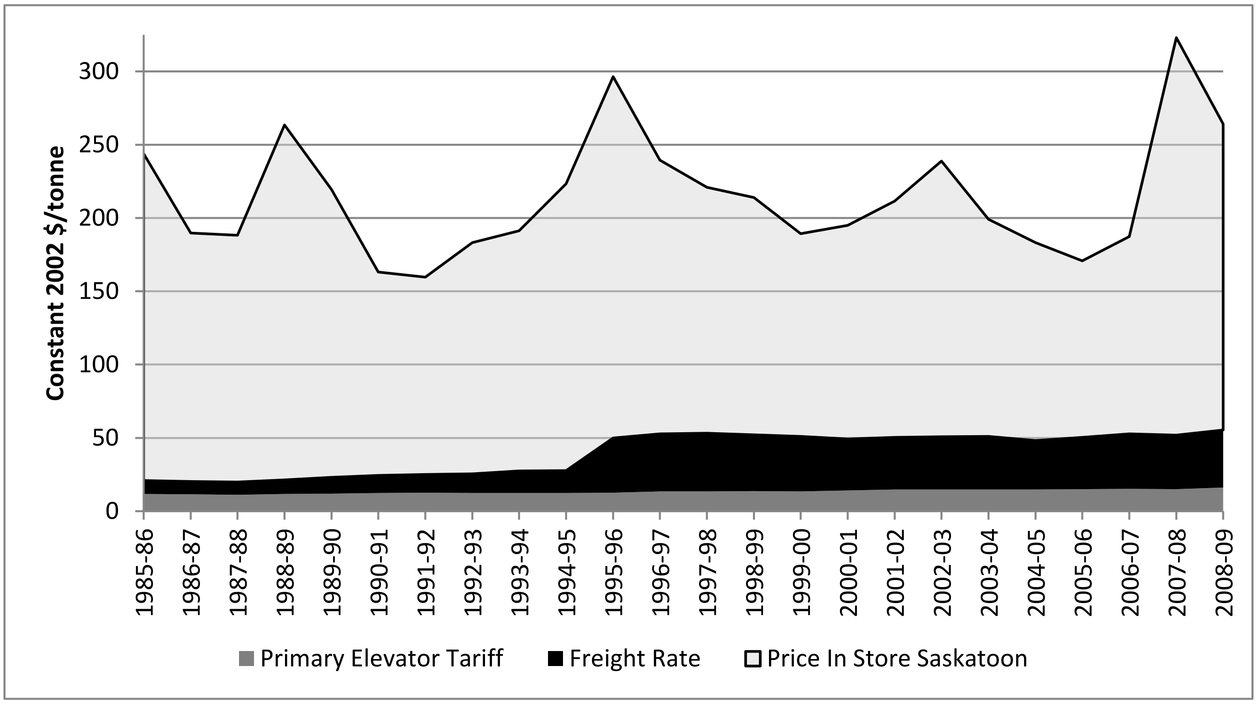

Figure 2. Primary elevator tariff, freight rate and price in store, Saskatoon SK, #1 Canada Western Red Spring Wheat, 12.5% protein
Source: Saskatchewan Agriculture and Food.

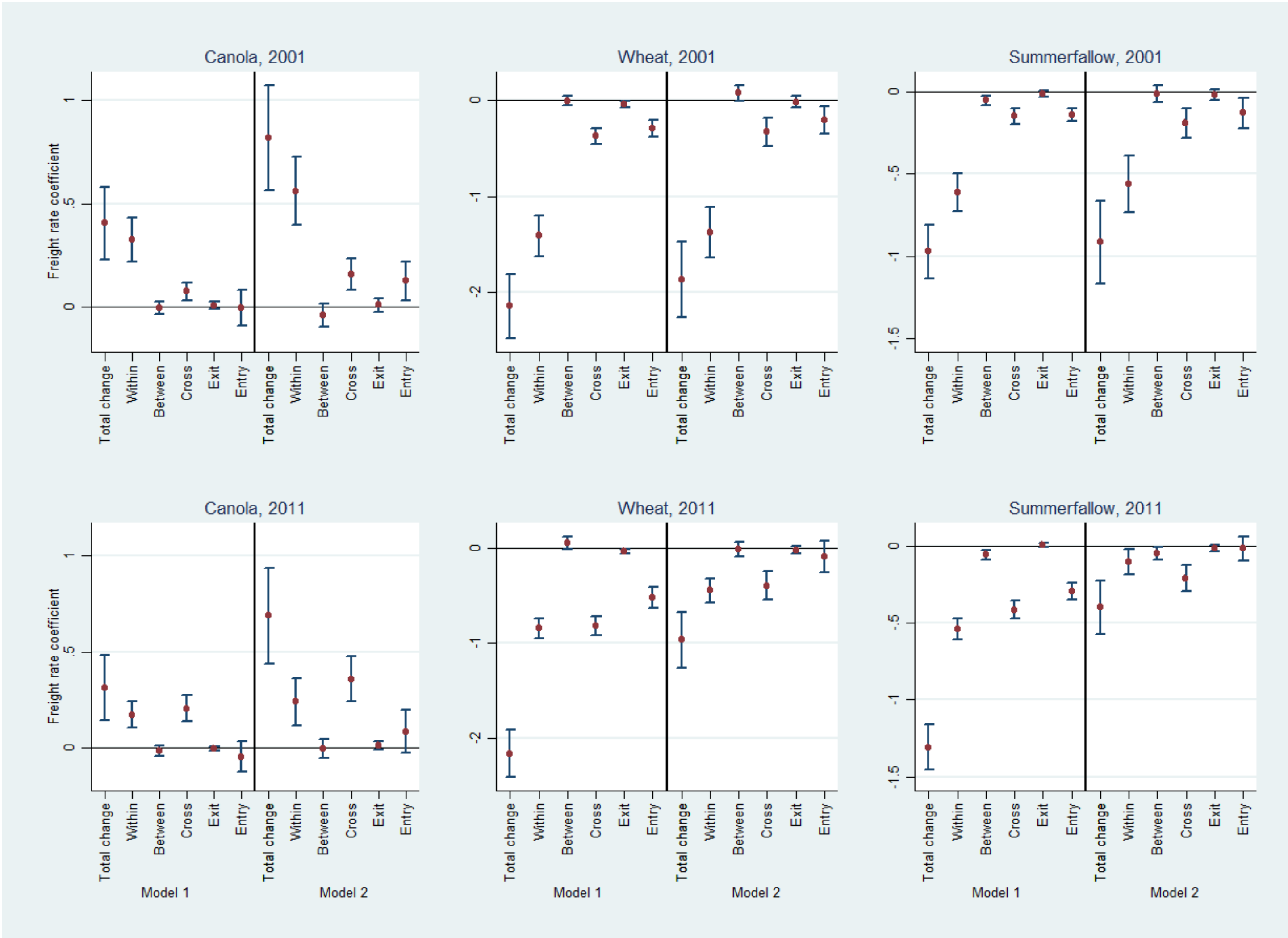

Figure 3. Freight rate coefficient ($\hat{\beta}$) by land use type and period, without controls (Model 1) and with controls (Model 2).

Notes: All models are estimated using a balanced panel of 464 CCSs. The dependent variables are the change in acres in percentage points and its components (within, between, cross, exit and entry) derived from the Foster et al. (2001) decomposition. Presented are the coefficients on *freight* and their 90 percent confidence interval based on robust standard errors. The coefficients represent the total change (or its components) of the share of land in percentage points with respect to a 1$ change in transportation costs incurred per tonne shipped.
Source: Statistics Canada, authors' calculations

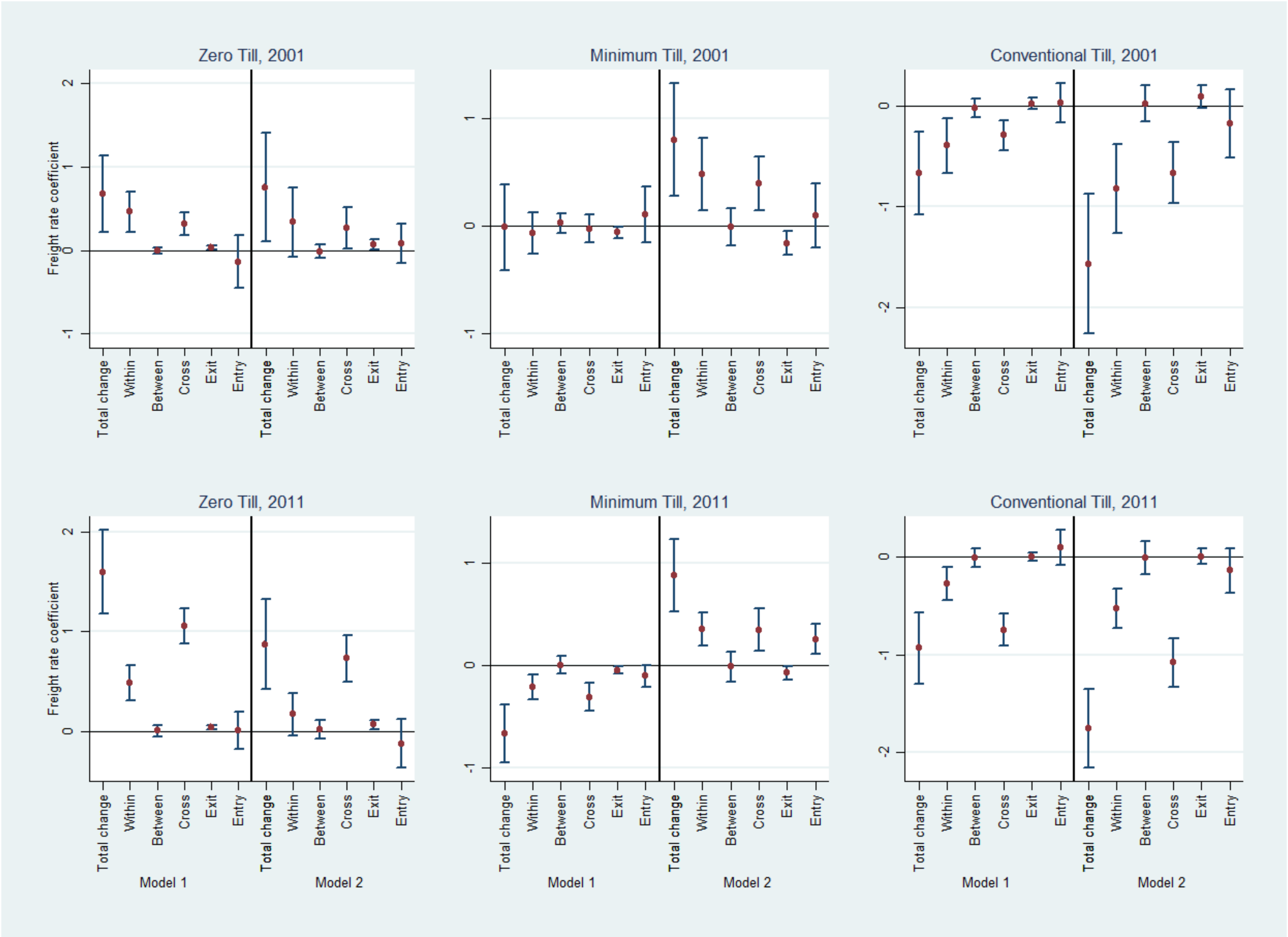

Figure 4. Freight rate coefficient ($\hat{\beta}$) by tillage type and period, without controls (Model 1) and with controls (Model 2).

Notes: All models are estimated using a balanced panel of 464 CCSs. The dependent variables are the change in acres in percentage points and its components (within, between, cross, exit and entry) derived from the Foster et al. (2001) decomposition. Presented are the coefficients on *freight* and their 90 percent confidence interval based on robust standard errors. The coefficients represent the total change (or its components) in the share of land in percentage points with respect to a 1$ change in transportation costs incurred per tonne shipped.
Source: Statistics Canada, authors' calculations

Table 1. Decomposition of the change in land use/tillage type adoption rates between 1991 and 2001 for farms with above and below median changes in railway freight rates

Type	Transport cost	Adoption rate 1991	Adoption rate 2001	Total change	Total change decomposition: Within	Between	Cross	Exit	Entry
Canola	Above median	0.12	0.16	0.03	0.02	-0.01	0.01	0.00	0.01
	Below median	0.15	0.15	0.00	-0.01	0.00	0.01	0.00	0.00
Total wheat	Above median	0.66	0.41	-0.25	-0.19	0.02	-0.03	0.00	-0.04
	Below median	0.55	0.43	-0.11	-0.09	0.01	-0.01	0.00	-0.02
Summerfallow	Above median	0.26	0.13	-0.13	-0.09	-0.01	-0.01	0.00	-0.02
	Below median	0.21	0.15	-0.06	-0.05	-0.01	0.00	0.00	-0.01
Zero till	Above median	0.09	0.38	0.29	0.16	0.01	0.08	0.00	0.04
	Below median	0.08	0.31	0.24	0.14	0.00	0.06	0.00	0.04
Minimum till	Above median	0.26	0.30	0.04	0.03	0.00	0.00	0.00	0.00
	Below median	0.28	0.34	0.06	0.04	0.00	0.01	0.00	0.00
Conventional till	Above median	0.66	0.32	-0.33	-0.20	-0.01	-0.08	0.00	-0.05
	Below median	0.64	0.35	-0.29	-0.18	-0.01	-0.06	0.00	-0.04

Notes: Acres of crops, summerfallow and by tillage type are measured as a proportion of total land in crops in 1991 and 2001 (the adoption rate) for farms classified to Longitudinal NAICS 17 to 22. Entrants and exits and incumbent farms are identified using the longitudinal farm identifier derived from each farm's longitudinal identifier. The restricted sample excludes farms with revenues of $30,000 or less. The decomposition is adapted from Foster, Halitwanger and Krizan (2001). The *within* component measures the contribution of incumbent farms to the aggregated change based on their initial share in acres. The *between* component captures the effect of growth in the measured adoption rate of crops/tillage relative to the average weighted by the change in the farm's share of crop land. The *cross-product* (cross) term measures whether farms with changes in their share of land in crops also experience change in their adoption rate. The last two terms measure the effect of *entrants* and *exits* on the adoption rate. The effect of *exits* will be positive if they have lower than average adoption rates, while the effect of *entrants* will be positive if they have above average adoption rates.

Source: Statistics Canada, authors' calculations.

Table 2. Decomposition of the change in land use/tillage type adoption rates between 1991 and 2011 for farms with above and below median changes in railway freight rates

Type	Transport cost	Adoption rate 1991	Adoption rate 2011	Total change	Total change decomposition: Within	Between	Cross	Exit	Entry
Canola	Above median	0.10	0.29	0.19	0.08	0.00	0.06	0.00	0.05
	Below median	0.17	0.33	0.15	0.06	0.00	0.04	0.00	0.05
Total wheat	Above median	0.70	0.35	-0.35	-0.17	0.02	-0.09	-0.01	-0.10
	Below median	0.51	0.36	-0.15	-0.09	0.01	-0.02	0.00	-0.05
Summerfallow	Above median	0.30	0.09	-0.21	-0.09	-0.01	-0.05	0.00	-0.06
	Below median	0.17	0.05	-0.12	-0.05	-0.01	-0.02	0.00	-0.04
Zero till	Above median	0.11	0.69	0.58	0.22	0.00	0.20	0.00	0.15
	Below median	0.06	0.60	0.54	0.22	0.00	0.15	0.00	0.17
Minimum till	Above median	0.26	0.22	-0.05	-0.01	0.00	-0.03	0.00	-0.01
	Below median	0.28	0.25	-0.03	0.00	0.00	-0.02	0.00	-0.02
Conventional till	Above median	0.63	0.10	-0.53	-0.21	0.00	-0.18	0.00	-0.14
	Below median	0.67	0.15	-0.51	-0.22	-0.01	-0.14	0.00	-0.15

Notes: Acres of crops, summerfallow and by tillage type are measured as a proportion of total land in crops in 1991 and 2011 (the adoption rate) for farms classified to Longitudinal NAICS 17 to 22. Entrants and exits and incumbent farms are identified using the longitudinal farm identifier derived from each farm's longitudinal identifier. The restricted sample excludes farms with revenues of $30,000 or less. The decomposition is adapted from Foster, Halitwanger and Krizan (2011). The within component measures the contribution of incumbent farms to the aggregated change based on their initial share in acres. The between component captures the effect of growth in the measured adoption rate of crops/tillage relative to the average weighted by the change in the farm's share of crop land. The cross-product(cross) term measures whether farms with changes in their share of land in crops also experience change in their adoption rate. The last two terms measure the effect of entrants and exits on the adoption rate. The effect of exits will be positive if they have lower than average adoption rates, while the effect of entrants will be positive if they have above average adoption rates.

Source: Statistics Canada, authors' calculations.

Table 3. Average change in share of acreage in crops and till technology across Consolidated Census Subdivisions, 1991 to 2001 and and 1991 to 2011 (percentage points)

Period	Land use/Technology	Average	Standard deviation
1991-2001	Canola	2.6	7.2
	Wheat	-20.3	14.5
	Summerfallow	-8.9	8.4
	Zero till	23.1	17.5
	Minimum till	4.5	13.9
	Conventional till	-27.6	16.9
1991-2011	Canola	17.7	10.3
	Wheat	-27.8	16.9
	Summerfallow	-15.5	11.3
	Zero till	50.4	25.0
	Minimum till	-1.6	17.8
	Conventional till	-48.8	19.0

Notes: Reported is the average total change, and its standard deviation, in the share of acreage in the crop or where the till technology is applied across 464 Consolidated Census Subdivisions (CCSs). These form a balanced panel for both the 1991 to 2001 and 1991 to 2011 periods, and match the sample used in the regression estimates.

Source: Statistics Canada, authors calculations