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Loss or gain: A spatial regression analysis of switching land conversions between agriculture and natural land

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ABSTRACT

This article comprehensively investigates the gains and losses between agriculture and natural land in the case of the Edmonton–Calgary Corridor, Canada. Using remote sensing data from 2000 to 2012, factors that drive land-use conversions, including environmental and socio-economic characteristics, are explored. This study also adopts spatial techniques to allow for neighborhood effects from land-use activities in neighboring areas. Key findings include the following: higher land suitability hinders the process of agricultural land abandonment; road density prohibits agricultural land conversion to natural land; the implementation of conservation sites protects land in its natural status; and land-use activities have strong neighborhood effects on nearby regions. Incorporating spatial interactions can generate less biased empirical results and provide more accurate policy recommendations. In addition, an investigation of bi-directional land-use transitions helps to better understand the associated gains and losses between agriculture and natural land and offers further insights into the effectiveness of preservation programs that aim to protect wild space and maintain ecological balance.

1. Introduction

In the study of land-use/land-cover changes (LULCCs), the conversion of agricultural land has received considerable attention (Beilin et al., 2014; Di'az et al., 2011; Zhang et al., 2014). Typically, agricultural land conversion can be grouped into three categories: urban encroachment onto agricultural land, farmland conversion to non-agricultural production (e.g., forest), and agricultural land transition to natural landscapes. The transitions differ greatly in their degree of reversibility as well as associated environmental and socio-economic consequences. For example, a shift from agricultural land to development, such as residential uses, is unlikely to be reversed. In contrast, the conversion of agricultural land to natural land, such as grassland and shrubland, may represent a temporary change to preserve current production capability for future purposes (MacDonald et al., 2000).

Losses of agricultural land to developed uses have been widely discussed (Francis et al., 2012; Irwin and Bockstael, 2007), and recent literature has given considerable attention to the issue of agricultural land conversion to a natural land base, which may simply represent farmland abandonment due to unprofitability (Baumann et al., 2011; Gellrich et al., 2007) or wild land preservation as a result of certain conservation programs (Claassen et al., 2008; McGranahan et al., 2015). Although the reasons behind these two types of transitions are quite different, the observed land-use/land-cover changes (in terms of changing the earth's terrestrial surface) are often the same, representing a tract of land that is converted from agricultural uses to a natural land base.

In literature, agricultural land abandonment is found to be associated with a variety of ecological ramifications. For instance, positive impacts include the stabilization of soils and carbon sequestration (Laiolo et al., 2004; Tasser et al., 2003), while negative influences include the gradual loss of landscape complexity and an increased risk of natural disasters (Bielsa et al., 2005; Serra et al., 2008). Meanwhile, agricultural land expansion onto natural or wild land has been increasingly investigated (Hatna and Bakker, 2011; Izquierdo and Grau, 2009). Such land conversions also deserve attention, as they can result in serious ecological and environmental ramifications. For example, the loss of natural land leads to reductions in biodiversity and landscape complexity, increases the probability of flooding and the emergence of desertification (Flez and Lahousse, 2004; Monteiro et al., 2011). The transitions between agricultural land and natural land have therefore led to a key question: What has been gained or lost due to these bi-directional changes?

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Increasingly, policy makers and the general public are particularly concerned with neighborhood effects associated with land preservation programs. Such effects occur when a conservation program influences land-use decisions outside the targeted area. For example, agricultural land of relatively low quality has been removed from production under a conservation program in one region; meanwhile, a substantial amount of land with even lower agricultural suitability has been brought into agricultural production as a result of the conservation program (e.g., to compensate for the decreased farmland supply in the marketplace). Such effects may or may not be able to offset environmental and ecological benefits of the conservation programs. Therefore, the identification of the pattern and location of both transitions of agricultural conversion to natural land and agricultural land expansion onto natural land constitutes a first step for further in-depth analyses. As a second step, following the assessment of detailed transitions, an investigation of the inherent drivers behind these two types of land-use transitions is of significant interest to researchers and policy makers in their attempts to develop corresponding policies and plans regarding sustainable land-use management.

Although recent reviews have incorporated elaborate discussions of agricultural land abandonment (see van Vliet et al., 2015), the majority of these cases were reported in Europe, the United States and South America (e.g., Di'az et al., 2011; Izquierdo and Grau, 2009; Munroe et al., 2013). Few studies have explored the context of Canada, especially the prairie region, where agricultural land conversions commonly occur. In this study, we implement a spatial regression analysis of switching land conversion between agriculture and natural land in the Edmonton–Calgary Corridor of Alberta to better understand the spatial, environmental, and socio-economic factors that drive such land-use conversions. We also contribute to the current literature by quantifying both agricultural land abandonment and agricultural land expansion from natural land in order to investigate underlying mechanisms from a more nuanced perspective. Furthermore, although previous studies related to agricultural land abandonment have been conducted, no empirical work has included spatial interactions to allow for neighborhood effects from neighboring areas' land-use activities. Land conversion is often considered to be spatially auto-correlated due to the similarity of nearby resource attributes such as soil quality and climate conditions, as well as socio-economic determinants including public policies such as taxes and planning and zoning regulations in neighboring areas (Zhang et al., 2014). Ignoring spatial interactions may lead to biased estimates, which may in turn lead to misleading implications and policy recommendations. We therefore utilize three spatial regression models, as opposed to the classic ordinary least squares (OLS) technique, to investigate more detailed drivers of agricultural land conversions incorporating spatial effects.

Combining remote sensing data on land-use/land-cover changes with environmental characteristics and socio-economic attributes between 2000 and 2012, the objectives of this article are twofold: (1) to quantify agricultural land conversion to natural land and agricultural land expansion onto natural land; and (2) to investigate the effects of multiple drivers from both the environmental and socio-economic sides on the two types of land-use transitions, taking spatial interactions into consideration.

2. Literature review

2.1. Transitions between agriculture and natural land

Agricultural land abandonment is driven by a mix of biophysical, ecological and socio-economic factors that can differ based upon local land-use history, climate, and landscape composition (Beilin et al., 2014). MacDonald et al. (2000) reviewed a literature of agricultural land abandonment, and provided a comparative analysis of case studies in Europe (e.g., Austria, Finland, France, Germany, Greece, Italy, Portugal, Spain, Sweden, Switzerland) to assess environmental impacts and policy responses. Renwick et al. (2013) also performed a comprehensive analysis of agricultural land abandonment in the European Union (EU), with a focus on policy reform, and discussed possible solutions to the issue.

More recent studies have investigated the drivers of agricultural land abandonment. For example, Baumann et al. (2011) explored the patterns of post-socialist farmland abandonment in Western Ukraine and considered environmental variables, population impact, and accessibility as potential drivers. Prishchepov et al. (2013) explored the determinants of agricultural land abandonment in post-Soviet European Russia and suggested that biophysical and socio-economic attributes are the key drivers. One specific study conducted by Zhang et al. (2014) focused on cropland abandonment in mountainous areas of China. The process of cropland abandonment was detected at three levels, including parcel, household, and village, with demographic and socio-economic determinants.

In conjunction with the research on agricultural land abandonment, the issue of agricultural land expansion (e.g., conversions from natural land) has also been acknowledged and quantitatively assessed (Hatna and Bakker, 2011; Pazu'r et al., 2014; Sluiter and de Jong, 2007). For instance, Caraveli (2000) explored agricultural intensification and extensification in Mediterranean countries in response to the less favored area (LFA) policy. Storkey et al. (2012) investigated the impact of crop management and the expansion of agricultural land use on the threat status of plants adapted to arable habitats in 29 European countries. Their results indicated a positive association between wheat yields and the number of threatened or recently extinct arable plant species.

Despite the popularity of spatial regression models as tools for investigating impacts caused by certain factors of LULCCs, no study to date has adopted this technique in the context of agricultural land abandonment and expansion especially when investigating the two transitions simultaneously in the same study area.

2.2. Environmental and socio-economic factors associated with specific locations

Previous literature has considered multiple factors that have important influences on agricultural land-use decisions (Hansen and Naughton, 2013; Li et al., 2013). When investigating underlying drivers of agricultural land-use changes in Europe, van Vliet et al. (2015) divided the factors into several groups, among which location factors (such as climate and other topographic elements that are typically associated with specific locations) are most commonly adopted and assessed in the existing studies involving spatial analyses.

Some studies further group location factors into environmental and socio-economic streams. Environmental location factors primarily include land quality or capability (Lubowski et al., 2008; Monteiro et al., 2011), precipitation and temperature (Cabanillas et al., 2012; Marti'nez et al., 2011), and elevation or altitude (Nahuelhual et al., 2012; Trincsi et al., 2014). Land quality or capability acts as a proxy for land's suitability for agricultural uses. In other words, land with higher quality or capability is considered to be more likely to remain in agricultural use (Di'az et al., 2011). In contrast, impacts from elevation, precipitation and temperature may present more mixed effects, varying from region to region (Alix-Garcia et al., 2012; Hatna and Bakker, 2011).

Recognizing the importance of the above environmental constraints does not preclude socio-economic location factors from influencing landowners' decisions regarding the use of agricultural land. Rather, factors associated with human activities are often deemed more direct drivers of LULCCs, such as the loss of agricultural land to urbanization. According to prior studies, population density (Marti'nez et al., 2011) and agricultural land prices (Alix-Garcia et al., 2012; Li et al., 2013; Serra et al., 2008) are regarded as the main socio-economic factors that impact agricultural land-use decisions. Road density is another underlying driver that affects land-use decisions, as it can be viewed as a measurement of market connectedness and accessibility, which is positively associated with urban proximity and better infrastructure (Guiling et al., 2009; Jiang et al., 2012). In general, agricultural land is abandoned under unfavorable environmental conditions (e.g., poorer soils), and also when the land is in remote or isolated areas (MacDonald et al., 2000).

2.3. Policy factors

Based on the research of van Vliet et al. (2015), institutional drivers that include different land-use plans are also a typical cause of agricultural land changes, which has also been frequently reported in prior studies. Among all land-use policies that strive to protect biodiversity and the ecosystem, the direct-creation of protected areas is considered most straightforward (Brooks et al., 2004). For example, Izquierdo and Grau (2009) explored the effects of protected areas on agricultural land use, and their findings indicated that the creation of protected areas failed to protect those eco-regions that were most threatened by current agricultural adjustments in northwestern Argentina. A specific case study by Di'az et al. (2011) investigated the impact of distance to national

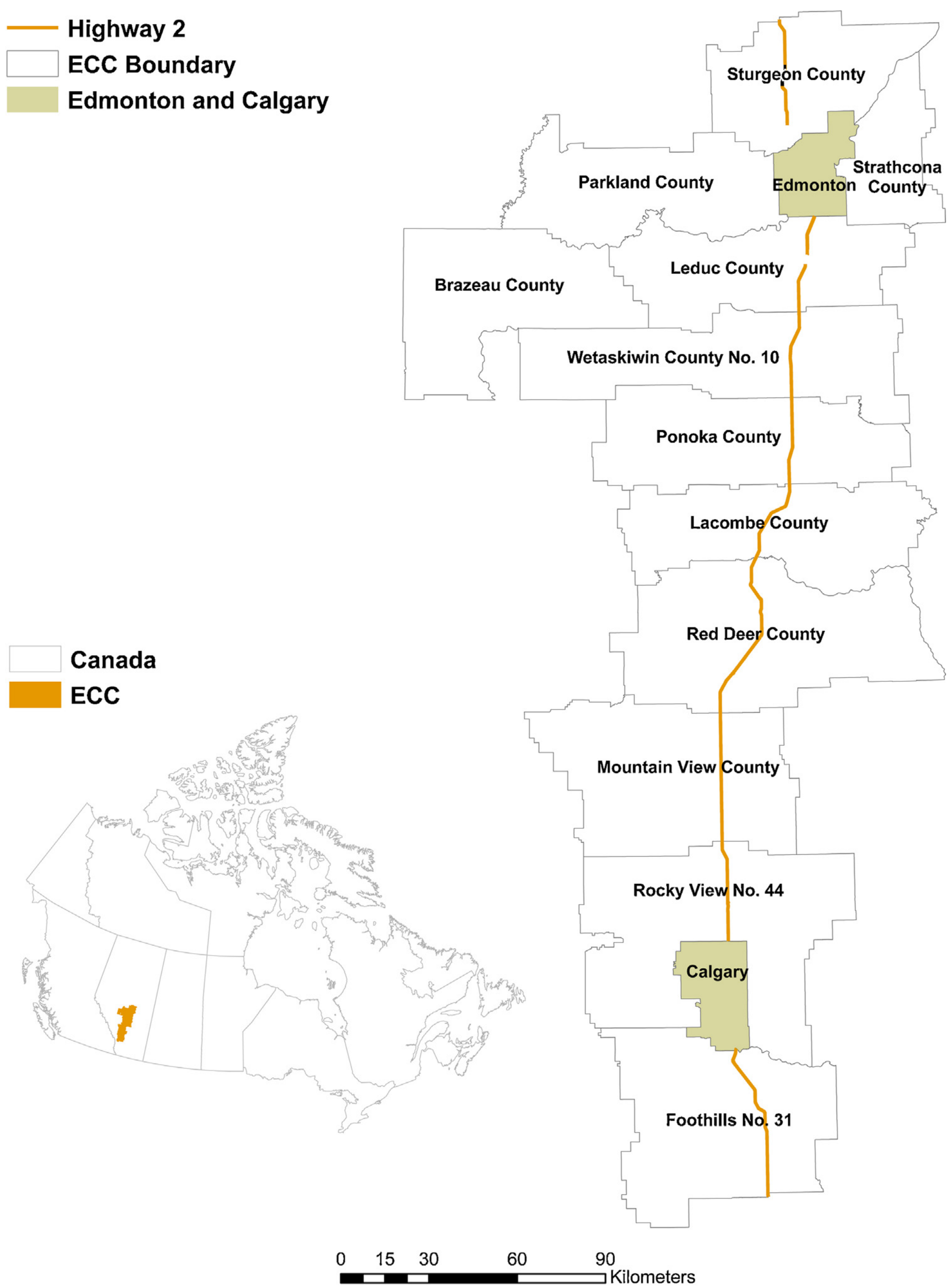

Fig. 1. Geographic location of the Edmonton–Calgary Corridor (ECC), Canada.

Table 1
Definition of land-use/land-cover classification.

Classification	Definition
Built-up Land	
Development	Land predominantly built up or developed. This may include road surfaces, railway surfaces, buildings and paved surfaces, urban areas, parks, industrial sites, mine structures, and farmsteads.
Agricultural land	
Cropland	Annually cultivated cropland and woody perennial crops.
Pasture	Periodically cultivated grasses, hay land or pasture.
Natural land	
Shrubland	Predominantly woody vegetation of relatively low height (generally ±2 m).
Grassland	Predominantly native grasses and other herbaceous vegetation.
Others	
Forest	Mixed coniferous and broadleaf/deciduous forests or treed areas.
Exposed land	Predominately non-vegetated and non-developed, including exposed lands, bare soil, snow, glacier, rock, sediments, burned areas, rubble, mines.
Wetland	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes.
Water	Water bodies (lakes, reservoirs, rivers, streams, salt water, etc.).

parks on agricultural land abandonment in southern Chile. Their results indicated that farmland closer to national parks is more likely to be abandoned to natural land, which further suggests the incentive for natural land protection derived from conservation initiatives.

3. Materials and methods

3.1. Study area

The Edmonton–Calgary Corridor (ECC) lies in the province of Alberta, and has become one of the top urbanized areas in Canada (Statistics Canada, 2012). The ECC spans an area of approximately four million ha and encompasses the two largest cities (Edmonton in the north and Calgary in the south) in the province. According to the census, the capital city of Edmonton had a population of around 0.8 million (City of Edmonton, 2012), and the city of Calgary had an estimated population of 1.1 million (City of Calgary, 2012) in 2012. Queen Elizabeth II Highway (also known as Highway 2) runs through the region from north to south like a central spine, connecting the 12 surrounding counties (Fig. 1).

Agriculture has a long history in the province, spanning more than a century, and Alberta has become the third largest producer and exporter of agri-food products in Canada (Government of Alberta, 2014). Although the ECC only covers about 6% of the total area of the province, it comprises approximately 25% of the province's most suitable land for agricultural uses. Because Alberta has experienced substantial economic and population growth in recent years, which is expected to continue, the province's agricultural land bases, especially those in the ECC, have been significantly challenged by the expansion of residential, recreational, and industrial development. Between 2000 and 2012, approximately 62,500 ha of land within the ECC was converted to developed uses. Of the land converted to development, about 83% came from agricultural land. In addition, approximately 90% of the land converted from agriculture to developed uses was of high-quality soil.[1]

The Government of Alberta is paying particular attention to land-use issues and policies to support a healthy environment, diverse communities, and a thriving economy, which involves extensive planning and collaboration among municipalities. A document called the *Land-use Framework* (LUF) was established in 2008 to serve as a blueprint to align provincial and local initiatives for land-use policies. One of the key strategies is the call to identify ecosystems and the environment as main desired outcomes in the outlined seven regions within the province and to develop a regional plan for each of these regions (Government of Alberta, 2008). Specifically, the use and enjoyment of land and natural resources as well as the protection of land, air, water and biodiversity were highlighted.

3.2. Data

All the response variables and explanatory variables were adapted to the Alberta Township System (ATS) level. The ATS is a comparatively fine lattice network, which divides the entire province into so-called "townships" that are about 9.7 × 9.7 km in size (or 9400 ha) (Government of Alberta, 2010). We conducted the analysis at the township level because existing land-use studies and governmental reports in Alberta have used the ATS system (Alberta Geological Survey, 2015; Qiu et al., 2015). Our results can thus be further compared to prior studies.

3.2.1. Land-use/land-cover changes

The 30-m resolution land-use raster images for 2000 and 2012 were provided by Agriculture Agri-Food Canada (AAFC). The 2000 image contains 11 different land-use classes, including Annual Crops, Hay and Pasture, Developed (or Built-Up), Water, Barren, Shrubland, Wetland, Grassland, Coniferous Trees, Deciduous Trees and Mixed Trees. The 2012 image has nearly 40 land-use classes comprising ten of the above-mentioned classes and detailed crop-type classifications (e.g., wheat, canola, corn). To better compare across data sets, we processed the data into nine land-use/land-cover classes: Annual Crops, Developed (or Built-Up), Exposed, Forests, Grassland, Pasture, Shrubland, Water, and Wetland. Table 1 provides a detailed description of the nine categories, and Fig. 2 presents the land-use/land-cover changes for the ECC from 2000 to 2012.

In our analysis, we primarily focused on the following two conversion cases: agricultural land conversion to natural land and agricultural land expansion to natural land. To enrich the literature, we also separated the agricultural land category into cropland and pasture. As a result, four additional types of conversion cases were presented in detail. The areas of each conversion case were calculated at the township level and served as response variables in the model specification.

[1] These numbers were calculated based on land-cover and soil suitability data obtained from Agriculture and Agri-Food Canada (AAFC) and Alberta Agriculture and Rural Development (AARD).

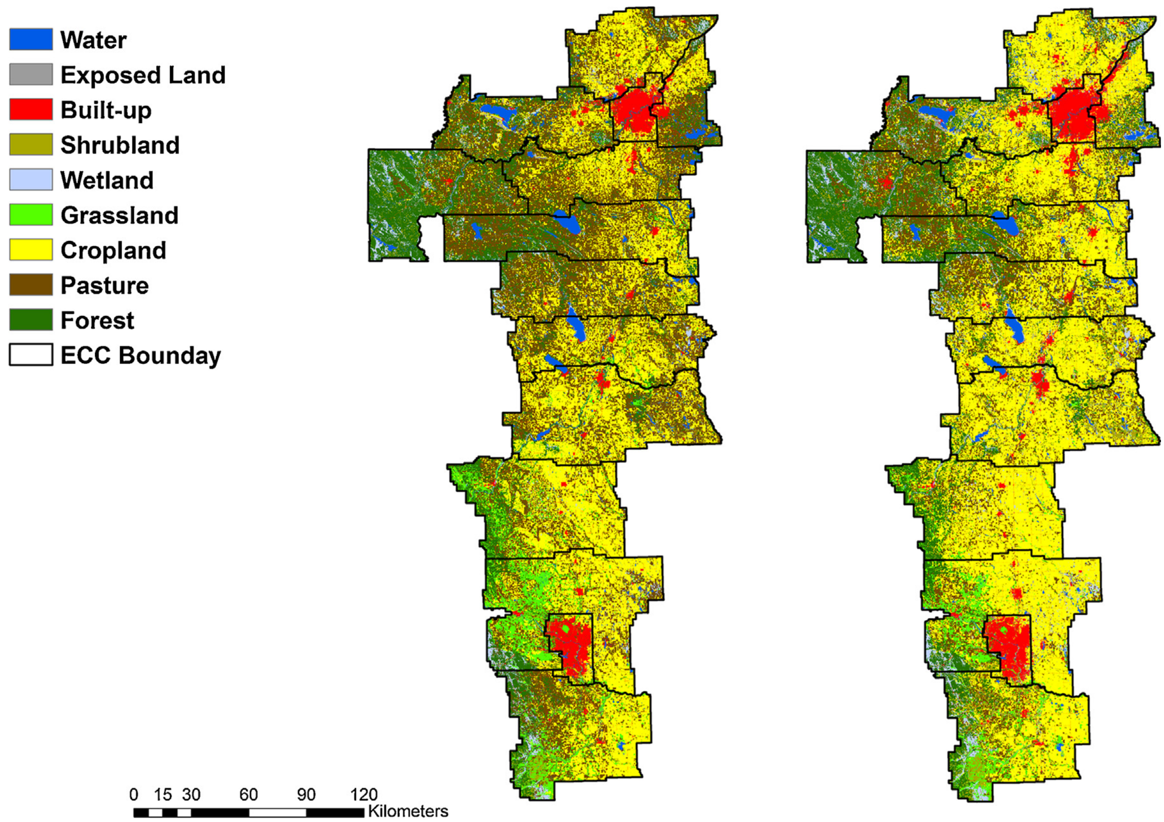

Fig. 2. Land-use/land-cover changes in the ECC: left (2000) and right (2012).

3.2.2. Explanatory variables

Explanatory variables (i.e., environmental and socio-economic location factors as well as conservation activities) are selected primarily based on the literature review that is presented in Sections 2.2 and 2.3. A summary of explanatory variables is presented in Table 2. The 13-year average values of the daily mean temperature and accumulative precipitation for the growing season (April through September) were provided by the Alberta Agriculture and Rural Development (ARD). Land suitability or capability for agricultural uses was generated based on the Land Suitability Rating System (LSRS) provided by ARD as well, which is a 7-class evaluation system. Given Alberta's relatively arid climate and severe winter, the province's highest quality land for the production of annual crops is classified under Class 2 and Class 3, which indicates no significant limitation other than weather conditions. Hence, we calculated the proportion of land with suitability ratings of 2 or 3 within each township.

Road network raster data for 2012 was provided by AltaLIS Ltd., and road density was calculated for each township. The conservation site data was also extracted from AltaLIS Ltd. (20 K Base Features). These conservation sites include natural areas (e.g., natural and near-natural landscapes of regional and local importance for nature-based recreation and heritage appreciation), ecological reserves (e.g., preservation of natural ecosystems, habitats and features), and parks and heritage lands protected for nature appreciation in the study area. The areas of such conservation sites were calculated in each township. Agricultural land value was based on the agricultural land transactions on the market. ARD provided the original land value data at the county level for each land suitability class. We first calculated the proportion of land in each land suitability class and then multiplied this proportion by the initial agricultural land value for each class within the respective county. All of the above explanatory variables were adapted to the township level to conduct regression analysis.

3.3. Empirical models

Recent literature on LULCCs has proposed that spatial distributions of the landscape are endogenously determined, and neighborhoods' land-use decisions may strongly affect the

Table 2
Detailed descriptions of explanatory variables at the township level.

Explanatory Variables	Description	Range	Mean	S.D.
CONSITE	Conservation site area (1000 ha)	0–5.11	0.28	0.54
LAND23	Proportion of land with suitability ratings of 2 or 3	0–1	0.73	0.31
TEMP	Growing season daily mean temperature (°C)	8.79–12.93	11.44	0.69
PRCP	Growing season cumulative precipitation (1000 mm)	0.28–0.48	0.36	0.04
DROAD	Road density (100 m/ha)	0.02–1.16	0.13	0.14
LVALUE	Agricultural land value (1000 CAD$/ha)	0–6.87	3.76	1.92

Note: we investigated the potential multicollinearity problem and found that all of the coefficients of the correlation matrix were relatively small. However, population density was highly correlated with road density at the township level, and elevation was highly correlated with other environmental drivers. To avoid the multicollinearity problem, these two variables were not included in the model.

focal land-use/land-cover changes (Irwin and Bockstael, 2002). Taking agricultural land conversion as an example, farmland abandonment may lead to fragmentation of the agricultural land base, which in turn may discourage nearby agricultural businesses due to an inability to obtain sufficient contiguous farmland to benefit from economies of scale in the future (Gellrich et al., 2007; Qiu et al., 2015). Another aspect that explains the spatial interaction derives from the similarity of biophysical and socio-economic conditions (Hansen and Naughton, 2013). Therefore, scholars have recently begun to consider spatial interactions in the empirical analysis of land-use changes to mitigate bias caused by spatial dependence.

One method of conducting spatial analysis is to make maps that show the spatial distributions and patterns of land-use transitions. Another approach is to build empirical regression models that include a set of covariates representing neighboring conditions (e.g., soil quality, climate conditions, open land availability) (Gellrich et al., 2007; Monteiro et al., 2011). A more advanced method is to incorporate neighborhood-dependent variables and/or unobserved factors into the regression analysis to address spatial autocorrelation and heterogeneity issues. The spatial autoregressive model (SAR), spatial error model (SEM), and spatial autocorrelation model (SAC) have recently gained popularity and have been used in place of the classic OLS regression model. For example, Chomitz and Thomas (2003) and Hansen and Naughton (2013) adopted these spatial econometric models to investigate determinants of land-use/land-cover change issues, though not in the case of agricultural land abandonment.

In this article, we adopted three spatial models (SAR, SEM, and SAC) to explore the influences of multiple factors on agricultural land abandonment and agricultural land expansion, explicitly incorporating spatial effects. We first started with a classic OLS model for comparison purposes as follows:

$$y_i = \alpha + \sum\nolimits_{p=1}^{P} x_{ip}\beta_{ip} + \varepsilon_i \tag{1}$$

where y_i is the area of land conversion at the township i; x_{ip} is a environmental or socio-economic factor in the same township, which can be found in Table 2; β_{ip} is the corresponding coefficient to be estimated; and ε_i is an *i.i.d.* unobserved error term. If $\varepsilon_i \sim N(0, \sigma_i^2 I)$, the OLS estimates are unbiased.

A corresponding SAR model, also known as a spatial lag model, is represented in the following equation:

$$y_i = \alpha + \sum\nolimits_{p=1}^{P} x_{ip}\beta_{ip} + \rho \sum\nolimits_{i \neq j}^{J} w_{ij} y_j + \varepsilon_i \tag{2}$$

where the spatial lag $\sum_{i \neq j}^{J} w_{ij} y_j$ is the weighted average of the neighboring township's land conversion. We are particularly interested in ρ, which is the spatial autoregressive coefficient that measures the overall neighborhood effects. Specifically, ρ describes the land conversion in a township that is influenced by its neighboring townships' land conversions.

Next, an SEM model that allows for spatial dependence in unobserved factors is expressed in Eqs. (3) and (4):

$$y_i = \alpha + \sum\nolimits_{p=1}^{P} x_{ip}\beta_{ip} + \varepsilon_i \tag{3}$$

$$\varepsilon_i = \lambda \sum\nolimits_{i \neq j}^{J} w_{ij}\varepsilon_j + \mu_i \tag{4}$$

where $\sum_{i \neq j}^{j} w_{ij}\varepsilon_j$ is the weighted average of the other townships' residuals. The spatial error coefficient λ captures and quantifies the inherent similarity (when $\lambda > 0$) or dissimilarity (when $\lambda < 0$) of unobserved factors that affect neighboring townships' land-use decisions.

Finally, we estimated an SAC model, also known as a spatial mix model, which includes both spatial lag and spatial error effects:

$$y_i = \alpha + \sum\nolimits_{p=1}^{P} x_{ip}\beta_{ip} + \rho \sum\nolimits_{i = j}^{J} w_{ij} y_j + \varepsilon_i \tag{5}$$

$$\varepsilon_i = \lambda \sum\nolimits_{i \neq j}^{J} w_{ij}\varepsilon_j + \mu_i \tag{6}$$

where if $\lambda = 0$ and $\rho \neq 0$, the SAC model reduces to an SAR model; if $\rho = 0$ and $\lambda \neq 0$, it leads to an SEM model; and if $\lambda = 0$ and $\rho = 0$, it simplifies to a non-spatial linear regression model.

The weight matrix used for all three spatial models is based on queen contiguity. The queen contiguity defines neighbors (i.e., townships in our case) as polygons that share a point and/or length of border. Queen contiguity is less stringent than rook contiguity, which defines neighbors as those who share a border of the same length. For a comprehensive discussion of weight matrices, we refer readers to Anselin (1988) and the reference therein. Contiguity-based weighting matrices have been widely used in land-use/land-cover changes research (Caldas et al., 2007; Hansen and Naughton, 2013; Walker et al., 2000). We chose queen contiguity over rook and distance-based weight matrices based primarily on intuition and goodness-of-fit.

4. Results and discussion

4.1. Descriptive results

Table 3 shows the changes of agricultural land, natural land, and developed uses from 2000 to 2012 in the ECC. The net change of agricultural land between 2000 and 2012 was a loss of about 180 thousand ha, which was the result of a total loss of approximately 1.1 million ha and a total gain of 0.94 million ha. However, if we look at cropland and pasture respectively, the changes and proportions are quite different. In specific, cropland demonstrated a net gain of 473 thousand ha as a result of a total gain of 733 thousand ha and a total loss of 260 thousand ha. While for pasture, a total loss of 856 thousand ha and a total gain of

Table 3
Land-use/land-cover changes (LULCC) in the Edmonton–Calgary Corridor: 2000–2012.

	Developed	Agricultural land			Natural land	Others	Total land
		Subtotal	Cropland	Pasture			
LULCC_2000 (ha)	158,941	2,665,735	1,357,866	1,307,869	289,659	849,537	3,963,872
LULCC_2000 (% of total land)	4.01	67.25	34.26	32.99	7.31	21.43	100.00
LULCC_2012 (ha)	221,477	2,487,227	1,831,071	656,156	334,150	931,018	3,963,872
LULCC_2012 (% of total land)	5.59	62.75	46.19	16.55	8.68	22.98	100.00
Net change (ha)	62,536	−178,508	473,205	−651,713	44,491	81,481	0
Net change (% of total land)	1.58	−4.50	11.94	−16.44	1.12	2.06	0.00

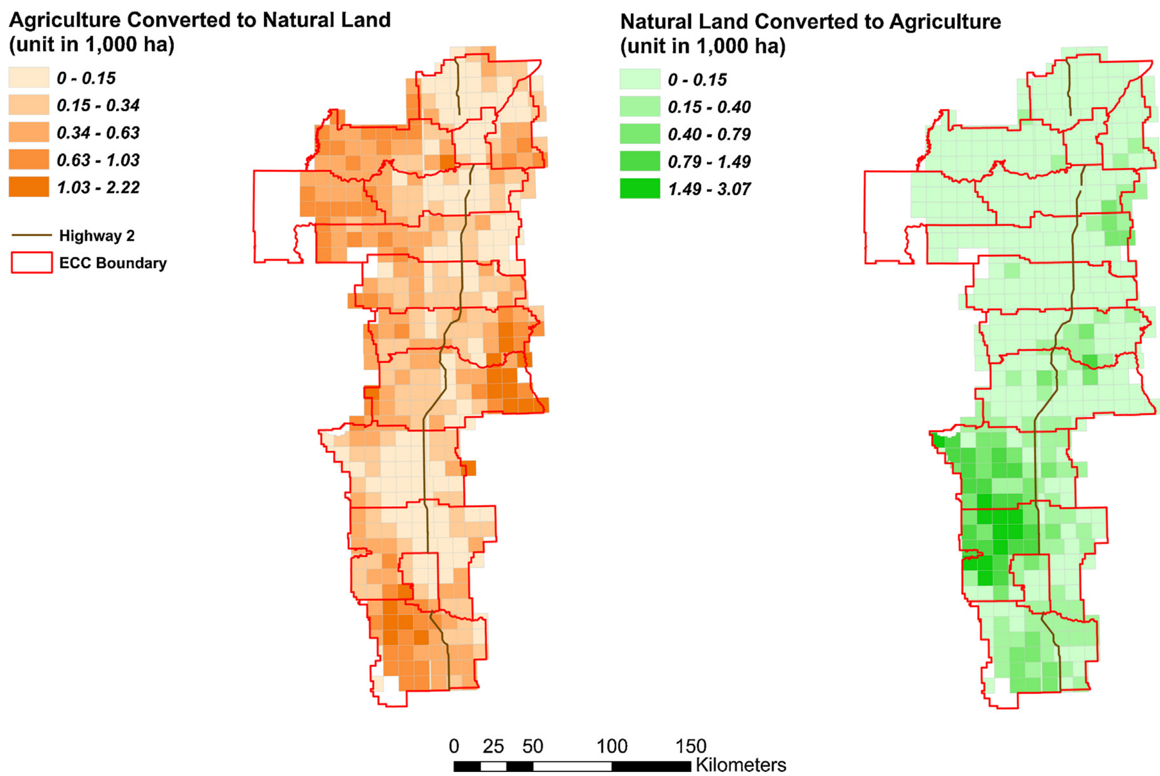

Fig. 3. Areas of agricultural land conversion to natural land (left) and natural land conversion to agricultural land (right) in the ECC (2000–2012).

204 thousand ha led to a net loss of 652 thousand ha over 2000–2012. Meanwhile, for natural land in the same time period, the net change was a gain of nearly 54 thousand ha, with a total gain of 175 thousand ha and a total loss of 121 thousand ha. In terms of transitions between agricultural and natural land, approximately 150 thousand ha of agricultural land was abandoned to natural land, and about 92 thousand ha of agricultural land expanded from natural land. This resulted in a total loss of agricultural land to natural land of about 60 thousand ha.

The above statistics represent the general trend of land-use conversions. Maps at the township level demonstrate a more detailed view of land transitions between agriculture and natural land. Fig. 3 shows the areas of agricultural land conversion to natural land (left) and agricultural land expansion onto natural land (right). As we can see from the maps, agricultural land abandonment primarily occurred in the peripheral regions in the ECC, with counties to the west (i.e., Parkland County) and east (i.e., Strathcona County) of Edmonton most predominant. These two counties are home to several provincial parks and have implemented proactive strategies to conserve land in its natural status in recent years (EALT, 2015; Parkland County, 2015). Such transitions might reasonably be expected as most of these lands are surrounded by existing water and wetland systems and have been designated conservation sites under the land-use strategy of the Alberta Capital Region, Growing Forward (Capital Region Board, 2009). Another document by LandWise Inc. (2013) mentioned the conversion of cultivated annual cropland to native perennial cover in the Parkland region for conservation purposes. In addition to natural land preservation, abandonment of marginal agricultural land also reflects the unprofitability of certain production practices.

For natural land converted to agriculture, Rocky View (the county surrounding Calgary) has demonstrated itself as a "hotspot," especially in the northwestern part of the county. The *Agricultural Context Study* mentioned that the soils in this region of the county are classified as having low to very little limitations for agricultural crop production (Rocky View Municipal District, 2009). These soils are often vegetated with permanent or native pasture and may be used to support livestock grazing. Additionally, these regions have some of the few existing irrigation infrastructures in the ECC, which also create a localized advantage and secure water sources for agricultural activities. Thus, not surprisingly, we observed that a large amount of land in this area has been brought into production since 2000, especially for grazing uses. The motivation behind this transition is quite straightforward. On the one hand, the ECC is experiencing large losses of prime agricultural land around Edmonton and Calgary, as well as areas along the Highway 2, due to urbanization. In addition, the ECC lost substantial farmland due to conservation (and for other purposes) in the northeast region, as previously discussed. On the other hand, farming has become relatively more profitable in recent years, especially since the 2006/2007 world food crisis, and agricultural commodity prices have remained high.

Fig. 4 further illustrates the areas of cropland and pasture converted to natural land over the same period. Areas of natural land conversion to both cropland and pasture can be seen in Fig. 5. Much like the findings regarding agricultural land abandonment, regions such as Parkland County, Strathcona County, and Red Deer County experienced significant cropland and/or pasture abandonment from 2000 to 2012. Among all of these farmland conversions, losses of pasture with marginal soil quality accounted for about 70% of the total agricultural land abandonment. In contrast, these counties rarely saw cropland or pasture expansions onto natural land from 2000 to 2012 (Fig. 5). In accordance with the pattern of natural land conversion to agriculture, as shown in Fig. 3, natural land conversions to both cropland and pasture were most substantial in counties surrounding Calgary, especially in the northwestern of Rocky View County, where the soil is of high quality.

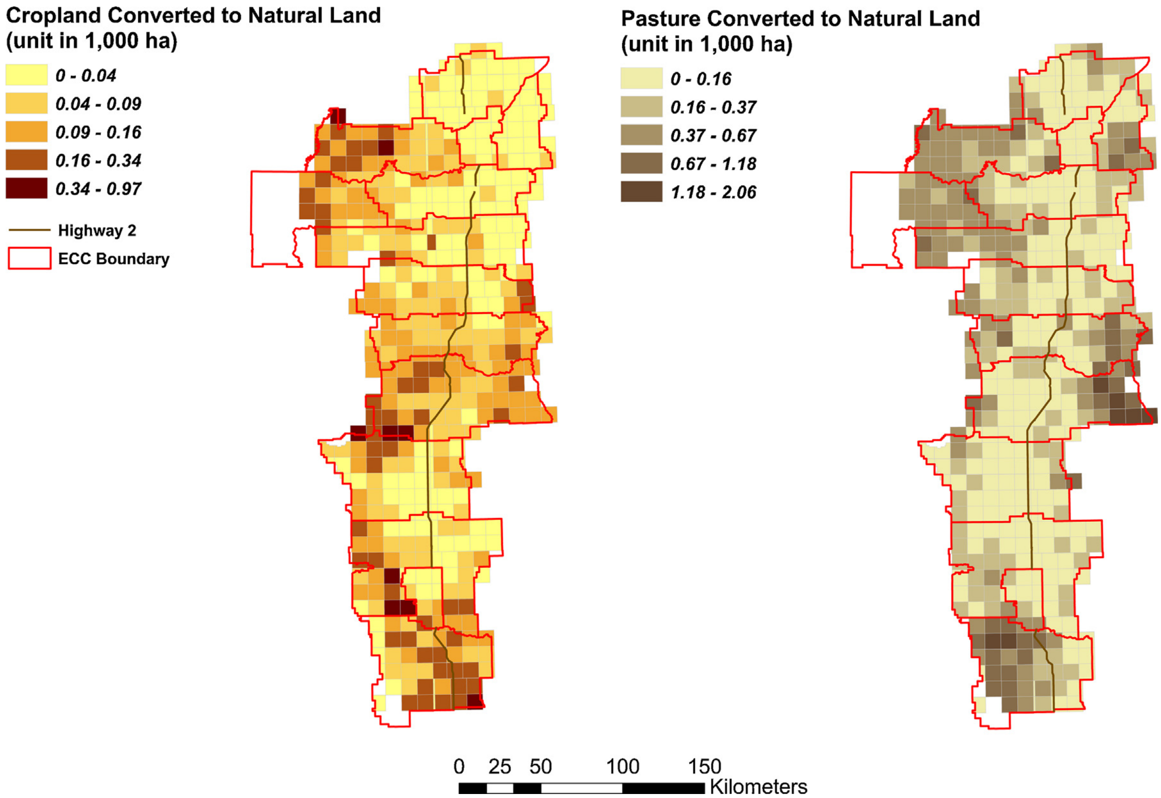

Fig. 4. Areas of cropland conversion to natural land (left) and pasture conversion to natural land (right) in the ECC (2000–2012).

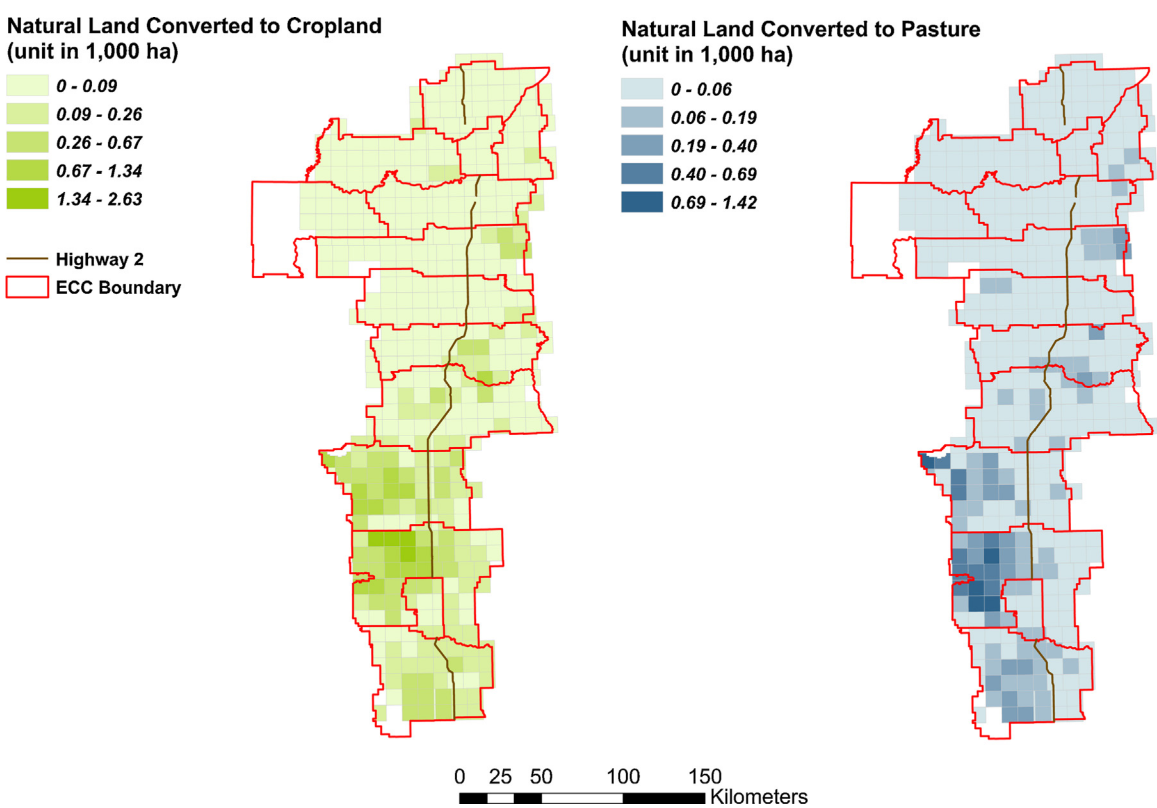

Fig. 5. Areas of natural land conversion to cropland (left) and natural land conversion to pasture (right) in the ECC (2000–2012).

Table 4
Lagrange multiplier (LM) tests for spatial dependence.

	Agricultural land to natural land			Natural land to agricultural land		
	LM (lag)	LM (error)	LM (SAC)	LM (lag)	LM (error)	LM (SAC)
Statistic (*P*-value)	19.958 (0.000)	11.382 (0.001)	23.838 (0.000)	34.101 (0.000)	18.840 (0.000)	37.960 (0.000)
Robust statistic (*P*-value)	12.456 (0.000)	3.880 (0.049)	–	19.120 (0.000)	3.859 (0.050)	–
	Cropland to natural land			Pasture to natural land		
	LM (lag)	LM (error)	LM (SAC)	LM (lag)	LM (error)	LM (SAC)
Statistic (*P*-value)	31.979 (0.000)	17.905 (0.000)	43.141 (0.000)	14.966 (0.000)	10.927 (0.001)	16.028 (0.000)
Robust statistic (*P*-value)	25.236 (0.000)	11.162 (0.001)	–	5.101 (0.024)	1.061 (0.303)	–
	Natural land to cropland			Natural land to pasture		
	LM (lag)	LM (error)	LM (SAC)	LM (lag)	LM (error)	LM (SAC)
Statistic (*P*-value)	28.472 (0.000)	15.849 (0.000)	35.802 (0.000)	3.210 (0.073)	0.852 (0.356)	5.458 (0.065)
Robust statistic (*P*-value)	19.953 (0.000)	7.329 (0.007)	–	4.606 (0.032)	2.248 (0.134)	–

Note: the weight matrix is based on Queen Contiguity, order 1.

4.2. Empirical results

The standard approach in most spatial analyses is to begin with a non-spatial OLS regression model and then test whether or not spatial effects exist. If they do, spatial models such as the spatial error and/or lag model can be further considered. We followed the conventional process developed by Anselin et al. (1996) and conducted Lagrange Multiplier (LM) tests, including the robust LM tests for comparison. The LM tests are presented in Table 4. The results show very strong evidence of spatial effects and indicate lag-type spatial dependence in both cases of agricultural land conversion to natural land and natural land conversion to agricultural land. Table 5 presents the results of switching land conversions between agriculture and natural land. Table 6 further presents the results from cropland and pasture conversion to natural land. Corresponding results from natural land conversion to cropland and pasture are shown in Table 7.

First, we consider the OLS results. For agricultural land abandonment in general, all of the coefficients of environmental drivers (i.e., land suitability, growing season temperature and precipitation) are significant. Consistent with results from Alix-Garcia et al. (2012) and Li et al. (2013), if land is of higher quality or more suitable for agricultural land uses, it is less likely to be abandoned to natural land uses and tends to remain in agricultural production. On the other hand, growing season temperature and precipitation are positively correlated with agricultural land abandonment. This is not a surprising result, because regions with a large amount of farmland abandonment (e.g., the southwestern part of Rocky View County and Foothills County) are located within areas of highest precipitation and temperature (Government of Alberta, 2015). Although the region has high temperature and sufficient rainfall, the dominant land contains rocks and mountains with agricultural land suitability classes of 5–7. Therefore, instead of drawing conclusions on causality, the growing season temperature and precipitation are better interpreted as two factors that are significantly associated with agricultural land conversion in the ECC case. As for the socio-economic drivers, road density imposes a negative impact on agricultural land abandonment. This outcome is consistent with other studies (Alix-Garcia et al., 2012; Li et al., 2013) as well as

Table 5
Regression results from OLS, SAR, SEM and SAC models ($n = 435$).

Variables	Agricultural land to natural land				Natural land to agricultural land			
	OLS	SAR	SEM	SAC	OLS	SAR	SEM	SAC
Constant	−2.436[a]	−1.930[a]	−2.128[a]	−1.944[a]	−3.269[a]	−1.477[b]	−2.334[a]	−1.957[a]
	(0.486)	(0.488)	(0.501)	(0.406)	(0.570)	(0.642)	(0.591)	(0.621)
CONSITE	−0.002	−0.032	−0.018	−0.006	−0.090[a]	−0.071[b]	−0.088[a]	−0.057[c]
	(0.028)	(0.028)	(0.028)	(0.023)	(0.032)	(0.031)	(0.032)	(0.029)
LAND23	−0.451[a]	−0.368[a]	−0.407[a]	−0.366[a]	−0.313[a]	−0.344[a]	−0.341[a]	−0.286[a]
	(0.064)	(0.065)	(0.064)	(0.062)	(0.074)	(0.070)	(0.074)	(0.066)
TEMP	0.187[a]	0.136[a]	0.163[a]	0.140[a]	−0.198[a]	−0.083[c]	−0.134[a]	0.116[a]
	(0.033)	(0.035)	(0.034)	(0.030)	(0.039)	(0.043)	(0.041)	(0.042)
PRCP	2.797[a]	2.167[a]	2.610[a]	2.078[a]	−1.186[b]	−0.221	−0.583	−0.640
	(0.517)	(0.524)	(0.526)	(0.430)	(0.605)	(0.601)	(0.616)	(0.563)
DROAD	−0.611[a]	−0.531[a]	−0.586[a]	−0.486[a]	−0.340[b]	−0.357[a]	−0.356[a]	−0.323[a]
	(0.117)	(0.115)	(0.117)	(0.098)	(0.137)	(0.129)	(0.135)	(0.121)
LVALUE	0.019[b]	0.016[b]	0.019[b]	0.012[c]	−0.017[c]	−0.015	−0.016	−0.015[c]
	(0.008)	(0.008)	(0.009)	(0.007)	(0.010)	(0.009)	(0.010)	(0.009)
ρ	–	0.685[a]	–	0.677[a]	–	0.621[a]	–	0.620[a]
		(0.161)		(0.127)		(0.122)		(0.110)
λ	–	–	0.240[a]	−0.731[a]	–	–	0.367[a]	−0.275
			(0.062)	(0.159)			(0.073)	(0.169)
Adj. R^2	0.187	–	–	–	0.230	–	–	–
Pseudo R^2	–	0.235	0.196	0.230	–	0.316	0.238	0.314

Note: the weight matrix is based on Queen Contiguity, Order 1.
[a] indicate the coefficient is significant at 1% level. Standard errors are in parentheses.
[b] indicate the coefficient is significant at 5% level. Standard errors are in parentheses.
[c] indicate the coefficient is significant at 10% level. Standard errors are in parentheses.

Table 6
Regression results from OLS, SAR, SEM and SAC models ($n = 435$).

Variables	Cropland to natural land				Pasture to natural land			
	OLS	SAR	SEM	SAC	OLS	SAR	SEM	SAC
Constant	−0.638[a]	−0.548[a]	−0.614[a]	−0.342[a]	−1.797[a]	−1.387[a]	−1.515[a]	−1.490[a]
	(0.139)	(0.134)	(0.144)	(0.100)	(0.444)	(0.452)	(0.458)	(0.380)
CONSITE	−0.005	−0.008	−0.006	−0.002	0.003	−0.023	−0.012	−0.003
	(0.008)	(0.008)	(0.008)	(0.006)	(0.025)	(0.026)	(0.025)	(0.022)
LAND23	−0.078[a]	−0.042[b]	−0.058[a]	−0.047[a]	−0.373[a]	−0.321[a]	−0.345[a]	−0.309[a]
	(0.018)	(0.018)	(0.018)	(0.017)	(0.058)	(0.059)	(0.058)	(0.056)
TEMP	0.040[a]	0.032[a]	0.039[a]	0.020[a]	0.147[a]	0.104[a]	0.124[a]	0.114[a]
	(0.010)	(0.009)	(0.010)	(0.007)	(0.030)	(0.032)	(0.031)	(0.029)
PRCP	0.952[a]	0.667[a]	0.884[a]	0.464[a]	1.844[a]	1.454[a]	1.716[a]	1.440[a]
	(0.147)	(0.148)	(0.150)	(0.125)	(0.472)	(0.476)	(0.480)	(0.381)
DROAD	−0.123[a]	−0.103[a]	−0.117[a]	−0.084[a]	−0.488[a]	−0.427[a]	−0.468[a]	−0.396[a]
	(0.033)	(0.032)	(0.033)	(0.024)	(0.107)	(0.106)	(0.107)	(0.092)
LVALUE	0.000	−0.001	−0.001	−0.001	0.018[b]	0.017[b]	0.019[b]	0.013[b]
	(0.002)	(0.002)	(0.002)	(0.002)	(0.008)	(0.008)	(0.008)	(0.006)
ρ	–	0.924[a]	–	0.942[a]	–	0.640[a]	–	0.642[a]
		(0.144)		(0.106)		(0.196)		(0.156)
λ	–	–	0.340[a]	−0.906[a]	–	–	0.233[a]	−0.728[a]
			(0.069)	(0.176)			(0.061)	(0.181)
Adj. R^2	0.138	–	–	–	0.141	–	–	–
Pseudo R^2	–	0.218	0.145	0.208	–	0.183	0.150	0.178

Note: the weight matrix is based on Queen Contiguity, Order 1.
[a] indicate the coefficient is significant at 1% level. Standard errors are in parentheses.
[b] indicate the coefficient is significant at 5% level. Standard errors are in parentheses.

intuition. Higher road density reflects lower transportation costs and thus makes agricultural products more accessible to markets and consumers. As expected, higher land values contribute to the conversion of agricultural land, since the cost of agricultural operations becomes higher.

For the case of natural land conversion to agriculture, environmental drivers such as temperature and precipitation are significantly negative. Such results are in accordance with those from agricultural land conversion to natural land. Although land suitability and road density play the same roles as in agricultural land abandonment, the effects are less significant. Additional explanations for this issue are provided in Section 4.3. One noteworthy point is the significantly negative coefficient estimate of conservation site areas. Such an inverse relationship indicates that maintaining existing natural areas, especially for conservation purposes, protects land in natural status and prohibits agricultural expansion onto natural land.

In order to provide more detailed information, we further explore cropland and pasture conversion to natural land (Table 6) and the reverse cases of natural land conversion to both cropland and pasture (Table 7). In keeping with the results of agricultural land abandonment in general, all of the coefficient estimates of environmental factors are significant with expected signs for both cropland and pasture abandonment. For instance, higher land suitability and road density hinder the process of cropland and pasture conversion to natural land, while land values are positively related to such land

Table 7
Regression results from OLS, SAR, SEM and SAC models ($n = 435$).

Variables	Natural land to cropland				Natural land to pasture			
	OLS	SAR	SEM	SAC	OLS	SAR	SEM	SAC
Constant	−2.179[a]	0.847[c]	1.632[a]	−1.085[b]	0.928[a]	0.720[a]	0.890[a]	0.779[a]
	(0.414)	(0.473)	(0.429)	(0.450)	(0.213)	(0.229)	(0.216)	(0.213)
CONSITE	−0.057[b]	−0.041[c]	−0.055[b]	−0.029	−0.023[c]	−0.022[c]	−0.024[b]	−0.018
	(0.024)	(0.023)	(0.023)	(0.020)	(0.012)	(0.012)	(0.012)	(0.011)
LAND23	−0.121[b]	−0.149[c]	−0.137[b]	−0.105[b]	−0.169[a]	−0.168[a]	−0.169[a]	−0.158[a]
	(0.054)	(0.052)	(0.054)	(0.045)	(0.028)	(0.028)	(0.028)	(0.026)
TEMP	−0.136[a]	−0.050	−0.098[a]	−0.068[b]	−0.052[a]	−0.039[b]	−0.049[a]	−0.044[a]
	(0.028)	(0.032)	(0.030)	(0.030)	(0.015)	(0.016)	(0.015)	(0.014)
PRCP	−0.843[c]	−0.126	−0.510	−0.347	−0.279	−0.183	−0.259	−0.231
	(0.440)	(0.441)	(0.448)	(0.392)	(0.227)	(0.228)	(0.229)	(0.210)
DROAD	−0.164[c]	−0.178[c]	−0.173[c]	−0.147[c]	−0.162[a]	−0.166[a]	−0.165[a]	−0.153[a]
	(0.099)	(0.095)	(0.099)	(0.082)	(0.051)	(0.051)	(0.051)	(0.047)
LVALUE	−0.017[b]	−0.014[b]	−0.016[b]	−0.013[b]	−0.005	−0.005	−0.005	−0.004
	(0.007)	(0.007)	(0.007)	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)
ρ	–	0.726[a]	–	0.739[a]	–	0.304[b]	–	0.338[a]
		(0.143)		(0.119)		(0.129)		(0.115)
λ	–	–	0.332[a]	−0.490[a]	–	–	0.085	−0.302[c]
			(0.074)	(0.187)			(0.087)	(0.174)
Adj. R^2	0.150	–	–	–	0.239	–	–	–
Pseudo R^2	–	0.232	0.159	0.229	–	0.255	0.250	0.253

Note: The weight matrix is based on Queen Contiguity, Order 1.
[a] indicate the coefficient is significant at 1% level. Standard errors are in parentheses.
[b] indicate the coefficient is significant at 5% level. Standard errors are in parentheses.
[c] indicate the coefficient is significant at 10% level. Standard errors are in parentheses.

transitions. Similar results can also be obtained from natural land conversion to both cropland and pasture when compared to agricultural expansion onto natural land. For example, the existence of conservation sites imposes a significantly negative influence on natural land conversion to cropland and pasture.

We next consider the results by taking spatial effects into account, incorporating a spatially-lagged dependent variable (as the SAR model) and a spatial error variable (as the SEM model) and including both spatial lag and spatial error variables (as the SAC model). For agricultural land abandonment (and, respectively, for cropland and pasture abandonment), both spatial lags and errors are significant (Tables 5 and 6). Based on the Robust Statistics shown in Table 4, the SAR model is superior. We thus focus on the discussion of the SAR model. First, taking the spatially-lagged dependent variable into account improves the overall fitness of the model relative to the OLS approach. Results suggest strong neighborhood effects regarding agricultural land abandonment brought by neighboring areas, as the estimate for the spatial lag variable ρ is significantly positive. This indicates that if the mean agricultural land abandonment in all neighboring areas increases by one ha, on average it will result in an additional 0.69 ha of agricultural land being abandoned to natural land in the focal township. Such neighborhood effects are even stronger in the case of cropland abandonment, with 0.92 as the coefficient estimate of ρ. This finding is not surprising in terms of land-use practices. In reality, the implementation of land-use policies (e.g., taxes, bylaws, planning for conservation programs) usually covers the entire municipality. Therefore, land-use decisions are often influenced by nearby land-use activities within the same municipality. Furthermore, agricultural land is always managed in parcels with a certain degree of scale. When the abandonment decision is made at the parcel level (or several parcels together), neighboring farmland is very likely to be influenced and be converted to natural land as well due to factors such as fragmentation (Qiu et al., 2015).

In the case of natural land conversion to agriculture (and, respectively, for natural land conversion to cropland and pasture), neighborhood effects in terms of spatial lags are significant (Tables 5 and 7). Alternatively, a tract of natural land can strongly respond to the surrounding area's conversion to farmland uses. This is consistent with reality as well as intuition. When natural land is brought into agricultural uses, other natural land in nearby areas is more likely to be considered for future conversion as existing farms will seek to expand onto nearby contiguous areas, in order to enjoy economies of scale.

One important finding that merits further discussion is that the two important drivers, high land suitability and road density, are found to have significant and negative effects on agricultural land abandonment and expansion. Intuitively, the two land-use changes represent opposite transitions, and the two drivers are expected to have contrasting impacts on the two conversions. For the land suitability case, the negative effect on agricultural land abandonment indicates that high agricultural suitability contributes to preserving farmland which is consistent with intuition and prior studies. However, the estimated coefficient under the natural land to agricultural land conversion also shows a negative associate between land suitability and agricultural land expansion. Intuitively, the conversion of native grassland for agricultural production will occur at the areas with better soil quality to increase the productivity. The soil quality for farming thus is expected to have a positive influence on farmland expansion.

However, the story is quite different in our ECC case study mainly because of the availability of high suitability land for further conversion. The ECC is a main agricultural region in the province; agricultural land base comprises about 67.3% of its entire area in 2000 (and 62.8% in 2012), while native grassland only consists 5.4% of the land bases in 2000 (and 3.3% in 2012). Almost all of the existing grassland is within the low suitability categories (e.g., in the southwestern region of Rocky View County and Foothills County, which have the poorest soil quality and rocky land), with grassland of high suitability for agricultural uses already converted (e.g., in the northwestern area of Rocky View County). Therefore, further farmland expansion onto native grassland can only occur on these marginal lands that are poorly suited for agricultural uses.

Similarly, the coefficients of road density are also found to be significant and negatively associated with both land-use transitions. This result is in accordance with previous studies in Europe that areas close to roads were found to be associated with both agricultural land abandonment and agricultural land expansion (Hatna and Bakker, 2011). High road density is often considered to reduce the transportation costs for agricultural businesses and enhance the convenient access to the markets. A negative coefficient under the agricultural land abandonment case is consistent with this perception. However, the estimated coefficient under the case of natural land conversion to agricultural land is also found to be negative. The main reason for this seemly counterintuitive result is the same as the land suitability discussion. The ECC is one of the most urbanized areas in Canada and its road construction in the entire region is well-constructed. In most areas of the ECC, soil quality and road density are both high and in favor of agricultural production. However, soil quality and road density in these marginal areas with extensive native grassland are usually fairly low.

In the past two decades, substantial farmland has been converted to development (such as residential, commercial and industrial) uses given the rapid population and economic growth in the ECC. According to a recent report (ALI, 2014), the total developed area in the ECC has increased about 40% since 2000. In addition, more than 80% of the newly developed land was converted from agricultural base and approximately 90% was from land suitability classes 2 and 3. Reduced supply together with the increased demand for agricultural land has amplified the pressure on existing productive land and moved the limit of production onto marginal lands. A considerable amount of low soil quality grassland which is unsuitable for farming has been brought into agricultural production. Although the absolute farmland loss has not been substantial to date, the switches between prime and marginal soil quality land deserve greater attention. To encourage sustainable economic, environmental and social growth, it is important for policy and decision makers to recognize the issue and access the potential impact of such bi-directional changes.

4.3. Discussion

Researchers and policy makers are often interested in exploring the gains and losses associated with agricultural land conversion. One critical aspect is the benefit-cost analysis of urban encroachment onto agricultural land (e.g., Baumann et al., 2011). Meanwhile, interest regarding agricultural land conversion to natural spaces or wild fields and its opposite conversion (i.e., agriculture expansion onto natural land) has increased over the last decade (e.g., Beilin et al., 2014; Caraveli, 2000; Hatna and Bakker, 2011; Prishchepov et al., 2013). An investigation of both types of transitions in the same study area will help policy makers better understand associated gains and losses, which affect not only the economic viability of the agricultural industry, but also environmental sustainability. Exploring switching land conversions may also help to evaluate the effectiveness of current conservation programs (e.g., conservation sites), as they may produce neighborhood effects and encourage further abandonment of farmland in nearby areas. As a result, agricultural expansion onto natural land may occur in other non-targeted areas (e.g., areas with high conservation values) to balance agricultural production.

Similar to other studies in Europe (Caraveli, 2000; Hatna and Bakker, 2011) and South America (Izquierdo and Grau, 2009; Munroe et al., 2013), we observed both types of conversions occurring substantially in the context of ECC, Canada from 2000 to 2012. Agricultural land conversion to natural land is most evident in regions such as Parkland County and Strathcona County. One important reason is that these two counties have implemented active strategies to conserve land in its natural status (e.g., conservation sites). This is confirmed by our empirical results in Tables 5 and 7, which reveal a significantly negative association between areas of conservation sites and natural land conversion to agriculture. Such a relationship implies that the establishment of conservation programs such as conservation sites can protect natural land from being converted to agricultural uses in the entire area. In contrast, agricultural land expansion onto natural land is more active in northwestern region of Rocky View County and other areas surrounding Calgary. Although agricultural land had a net increase of 60 thousand ha from grassland and shrubland, this does not necessarily indicate a gain from the perspective of preservation of wild land/environment. Accompanied by the gain in the west Parkland area, the ECC lost a significant amount of native grassland and shrubland in the southwest area. These lands have been converted to agricultural uses and have caused serious ecological and environmental losses, such as further degradation of the soil and land and the loss and fragmentation of ecological habitats for certain wild animals, including bison, deer and moose, which are common in the study area (Prairie Conservation Forum, 2006). The negative environmental consequences are likely to continue, as these converted agricultural lands will impose pressure on nearby open land and wildlife habitats.

In addition, strong neighborhood effects are found in both cases of agricultural land conversion to natural land and agricultural expansion onto natural land. In general, the conversion between agriculture and natural land in a focal area largely facilitates similar conversions in nearby regions. Such neighborhood effects are most evident with cropland abandonment. As indicated by many prior studies, agricultural land conversion is likely to have positive spatial effects and cause neighboring farmland to be converted (Brady and Irwin, 2011; Drummond et al., 2012; Haarsma and Qiu, 2015). In this article, we also find strong neighborhood effects in natural land conversion to agriculture, which indicate that converting a piece of natural land into agricultural uses will result in further losses of natural land in the adjacent areas. An important message we learn from this piece of result is that decision makers should take this extra cost into consideration, when permitting a new development plan which shifts natural grassland to agricultural production purposes.

Another key finding is that the establishment of conservation sites can help protect natural land from converting to agricultural uses within the area. However, a study in Northwestern Argentina indicated that protected areas were created in regions undergoing a decreasing intensity of land use and thus failed to protect the eco-regions most threatened by current land-use trends (Izquierdo and Grau, 2009). Additionally, the mitigated conversion activities in one area will further contribute to protecting natural land bases in the nearby areas because of the positive neighborhood effects. This is a piece of essential information when evaluating the effectiveness and efficiency of conservation programs, though has often been ignored.

5. Conclusions

This article adopts the spatial regression models as tools to investigate multiple drivers of switching land conversions between agriculture and natural land in the Edmonton–Calgary Corridor, Canada, using remote sensing land-use/land-cover data between 2000 and 2012. Key findings include the following: (1) higher land suitability hinders the process of agricultural land abandonment; (2) road density prohibits agricultural land conversion to natural land; (3) the implementation of conservation sites protects land in its natural status; and (4) strong neighborhood effects are observed in both switching land conversions. In addition, an investigation of bidirectional land transitions helps to better understand the associated gains and losses between agriculture and natural land and offers further insights into the effectiveness of preservation programs that aim to protect wild space and maintain ecological balance.

From an empirical perspective, incorporating spatial interactions can generate less biased results and provide more accurate policy recommendations. Spatial regression models can be used to examine the magnitude and statistical significance of neighborhood effects, which should be particularly useful for policy purposes. The ability of spatial models to quantify the magnitude of the divergence should be of help in public policy evaluation and development.

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