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Investigating the role of spatial spillovers as determinants of land conversion in urbanizing Canada

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Abstract

Although the impacts of income, population growth, and other important determinants of land-use change have been widely studied, there is less understanding of how spatial spillovers matter. Utilizing a spatial econometric approach, we investigate the main determinants of natural landscape conversion, focusing on quantifying local and global spatial spillovers. The empirical investigation applies to the Edmonton Metropolitan Region and the Calgary Regional Partnership in Canada. Key results include: (1) determinants of land conversion have significant spillover effects; (2) income, population density, road density, natural land endowment and land suitability for agriculture are all found to have influences on natural land conversion both in the own and neighboring areas; and (3) local (i.e., within the immediate neighboring areas) and global (in the entire study region) spillovers are different in strength and direction. Our work provides useful information for understanding the spillover issues in land conservation, resource governance, and optimal conservation design.

Keywords: global spillover; land conservation; local spillover; natural land loss; resource governance; spatial econometrics

JEL classifications: C21; Q24

1. Introduction

In recent decades, due to population growth, urbanization/suburbanization and economic development, lots of natural landscapes have been or are being converted to various development uses, including residences, infrastructures, industry and recreation. A great deal of literature has investigated drivers of land conversion and land conservation (e.g., Blackman *et al.*, 2008; Ferraro and Simorangkir, 2020). There is also a specific line of empirical research, the so-called environmental Kuznets curve (EKC) analysis (e.g., Carson, 2009; Wang *et al.*, 2020). The EKC hypothesizes that environmental degradation and income growth exhibit an inverted U-shaped relationship. Degradation increases with income growth, but once a specific income threshold is reached, environmental quality improves as income grows further.

Dedicated research from various disciplines has been devoted to studying the impact of economic development, population growth and poverty alleviation programs on natural land conversion (e.g., Alix-Garcia *et al.*, 2013; Ferraro and Simorangkir, 2020). Seto *et al.* (2011) have conducted a global meta-analysis of urban land expansion drivers from agricultural and natural landscapes using remote sensing land cover data. Their results indicate that population growth, GDP growth and automobile-oriented economic growth are the most relevant and significant drivers globally, despite the large regional differences. Research also shows that the increase in income brought about by poverty alleviation projects can have both positive and negative impacts on land protection. For example, Alix-Garcia *et al.* (2013) find in their Mexico case study that income transfers increase deforestation in specific populations. The main reason is that the cash received allows households to increase their consumption of land-intensive commodities such as milk and meat. On the other hand, through a case study in Indonesia, Ferraro and Simorangkir (2020) find that the cash-transfer programs for the poor reduce deforestation as a side benefit, in addition to poverty alleviation.

A closely related field of research is devoted to the spillovers from land conservation programs. Programs such as the Conservation Reserve Program are designed to protect forests and other types of natural landscapes in the target zones. However, studies have shown that such programs exhibit spillover effects, leading to land conversion in untreated areas (e.g., Wu, 2000; Alix-Garcia *et al.*, 2012; Ford *et al.*, 2020). Such spillover effects are often known as leakage or slippage effects. Fuller *et al.* (2019) conducted a systematic review of 1,615 papers on deforestation spillovers in protected areas (PA). The authors find that 11.8 per cent of the PAs that effectively limit deforestation have leakages that spill over to the nearby regions. Spillovers from conservation programs might also be positive, which means less land conversion outside the untreated PAs. Fuller *et al.* (2019) report more than 50 per cent of PAs in their review exhibit some blockage effects.

In addition to direct land-use change in the surrounding areas, spillovers from conservation programs can have broader implications. For example, Runyan *et al.* (2015) investigate the economic impacts of spillovers from deforestation. Lichtenberg and Smith-Ramirez (2011) examine land conservation programs spillovers and find such programs can harm the share of vegetation cover within a farm. Robalino (2007) examines the impact of land conservation policies on income distribution. The author finds that conservation policies can have significant distributional effects through changes in rents and wages. Robalino and Villalobos (2015) investigate the impact of PAs (national parks) on local workers' wages using survey data and find positive effects. We refer readers to Pfaff and Robalino (2017) for a more general discussion on such spillovers.

Despite abundant research devoted to exploring the spillover effects of land conservation programs, little is known about the impact of spatial spillovers of other key determinants (e.g., income and population growth) on land conversion. Does income growth in the neighboring regions influence land protection in the focal place? Are the influences positive or negative? Compared with economic growth in distant areas, will the income increase in those closer neighbors have a greater impact? These are all practical and crucial questions. However, existing research cannot answer them as these questions require explicit quantifications of spatial spillovers at both local and global levels.

This work aims to investigate the spatial spillovers associated with key factors driving the natural land-to-development conversion. The empirical investigation applies to the Edmonton Metropolitan Region (EMR) and the Calgary Regional Partnership (CRP) in Alberta, Canada. We make three contributions to the literature. First, we examine spillovers of key determinants at both local (i.e., within the immediate neighboring areas) and global (in the entire study region) levels. Existing studies with a spatial spillover component usually focus on quantifying local impacts (e.g., Alix-Garcia *et al*., 2013), and do not explicitly examine global influences. As will be explained in the next section, it is important to distinguish between these two levels, which has implications on resource governance at different jurisdictional levels.

Second, we propose a three-channel framework to explain spatial spillovers in land conservation and land conversion. Existing empirical work often focuses on using individual behaviors (e.g., changing consumption and/or production behaviors) to explain the observed spatial spillovers (e.g., Alix-Garcia *et al*., 2013; Ford *et al*., 2020). We generalize the channel discussion to include government and other institutional efforts seeking local optimization and spillovers due to intrinsic ecological-geographic links.

Finally, by comparing two metropolitan areas in the same province in a developed country with similar economic development and population growth but with different natural endowments and different development strategies, we illustrate the importance of resource endowments and policy interventions for nature conservation. Our findings will help to better understand the spillover issues related to land conversion and nature conservation. Our work also provides useful information for resource governance (such as government cooperation at different levels) to deal with spillovers. The idea of incorporating different levels of spatial spillovers into modeling can also add value to the optimal conservation design (e.g., Albers *et al*., 2020) with broader applications.

The rest of this article is structured as follows. Section 2 discusses the three channels of spatial spillovers and spillovers at local versus global levels. Section 3 provides some background of the study area. The methods and data are presented in section 4, and the results and discussion are presented in section 5. Section 6 concludes.

2. Channels and levels of spatial spillovers

2.1 Three channels for spatial spillovers

Why do drivers that affect land conversion and land conservation have spatial spillovers? Using relevant economic theories and intuition, we discuss the three channels leading to observed spatial spillovers: (1) individual decisions and behaviors, (2) the efforts of governments and other organizations to seek constrained (local) optimization or sustainability, and (3) intrinsic ecological-geographic links.

In a review article, Pfaff and Robalino (2017) summarize five channels for spillovers from conservation programs: input reallocation, market prices, learning, nonpecuniary motivations and ecological-physical links. Our channel discussion is different from their work in two ways. First, they investigate spillovers from conservation programs (i.e., unintended consequences of conservation programs). We focus on the impact of spatial spillovers on land conversion (i.e., spillovers as a determinant of land conversion). Second, their scope of spillovers is broader than ours. We focus on spatial spillovers only and their definition of spillovers beyond 'spatial'. For example, when explaining their second channel (i.e., market prices), they argue that a conservation program can affect the supply and demand of agricultural and forest goods, which can shift the demand for input factors such as labor and capital. Shifts in supply and demand can potentially affect

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the market equilibrium prices of these commodities and production factors, which can further cause a series of spillovers like out-migration due to decreased demand for labor and wage rate. On the other hand, our channel discussion is solely based on the 'spatial' aspect and emphasizes the importance of relative proximity (e.g., local versus global) in quantifying the spillover effects.

In the following discussion, we take the impact of personal income increase on natural land conservation as an example to illustrate the three channels we proposed. The first, channel #1, is spillovers related to individual decisions and behaviors. When an individual's income increases, the income effect may increase the person's demand for various consumer goods, including housing and infrastructure. This may have a negative impact on land conservation. The demand for housing and infrastructure will increase land conversion from natural to development uses; this increase will often happen in the area (e.g., the city or neighborhood) where the individual resides. At the same time, the income effect will increase the demand and willingness to pay (WTP) for leisure and environmental goods (e.g., better air quality and more open space) (e.g., Irwin, 2002). Thus, income growth may increase land conservation demand for amenity and recreational uses such as hunting and sightseeing. Locations protected for such recreational services are not necessarily the same as the individual's residential location. Generally speaking, the recreational activities' geographic areas will not be too far away from the person's living environment; the sites are likely to be within a reasonable travel distance. Such a location mismatch between individual decisions/behaviors (e.g., the increased demand and WTP for land conservation) and the land conservation outcome is one channel of spatial spillovers.

The above example shows an individual's WTP for use values associated with environmental goods. In addition to use values, the environment and ecosystems also have nonuse values to human beings. Freeman (2003, chapter 5) discussed and summarized four reasons for people's positive WTP for nonuse values: indirect use values, bequest values, altruistic attitude toward other people's use of a resource, and ethical or altruistic concerns for non-human species. Hanley and Perrings (2019) provide a recent review of the economic value of biodiversity, focusing on the valuation of nonmarket environmental goods and ecological system services. In our land conservation case, if a person is concerned about land protection, his WTP for nonuse value will also increase as his income increases. Note that land conservation not only reflects people's interest in land protection. Natural land is also the habitat for many rare species and is closely related to essential ecosystem services. Therefore, land conservation also reflects a broader interest in protecting the environment and ecosystems and supporting sustainable development. For nonuse values, because people do not need to consume the relevant resources, it is normal that the spatial locations between the protected land and the (locations of) individuals who pay for the protection do not match. In theory, the extent of spillovers, from a geographical perspective, from nonuse values is greater than those from use values. People's WTP may be used more efficiently in distant places through the government and other organizational efforts, as will be discussed below.

In addition to the consumer/demand perspective, we may also explain the impact of income on land conversion from the perspective of individual producers. For example, when income is low, farmers may choose to put undeveloped marginal land into production to increase income or consumption. As income increases, the conversion of such marginal land may decrease, which helps natural land conservation in nearby areas. Ferraro and Simorangkir's (2020) research on the impact of cash transfer on deforestation provides evidence in this regard.

The second channel of the observed spillover, channel #2, is the conservation strategies and efforts of the government and other organizations. As personal income increases, the government's tax revenue also increases. The government's ability and intention to protect natural resources and supply more public open space have also increased. Research on sustainability has increasingly recognized that ecosystems and the environment play an irreplaceable role in sustainable development (Wang *et al.*, 2019; Chen *et al.*, 2020; Wu *et al.*, 2020; Quintero-Angel *et al.*, 2021). Accordingly, governments worldwide have made tremendous efforts in protecting the environment and ecosystems. Such conservation efforts usually do not match the geographical distribution of income or other socio-economic indices. The governments' targets are often to protect those locations with high ecological value, low economic costs (or high economic benefits) and high social acceptance (Brown *et al.*, 2019). In conservation science, location selection is a widely studied topic. The early focus of the literature is on identifying locations with the highest ecological value. More recent literature emphasizes the importance of multi-dimensional criteria related to public acceptance and people's responses (Brown *et al.*, 2019; Albers *et al.*, 2020). The optimal conservation design and the collective efforts can explain part of the spatial spillovers that researchers observe from real data.

The third channel for spatial spillovers, channel #3, is the ecological-physical links as discussed in Pfaff and Robalino (2017). Such spillovers are inherent within ecological or physical processes. The authors give examples of species diversity and oil extraction to illustrate spillovers through such a channel. They explain that ecological spillovers can occur due to factors such as species migration and reproduction behaviors. For example, when species richness increases in one (e.g., if conservation programs successfully target an area), the biodiversity in nontargeted areas can also benefit. Ecosystem interactions can propagate the effects of conservation programs to neighboring regions. Purely physical processes can also have spillovers. Underground extraction of oil is subject to the laws of pressure. Extraction in one location shifts marginal costs of extraction and thus shifts extraction elsewhere.

Unlike the previous two channels, this type of spillover does not require human involvement and can be seen as feedback caused by natural laws. Pfaff and Robalino (2017) emphasize that this channel does not involve human behavior. In our discussion of spillovers caused by the ecological-physical connections, we allow human behavior/participation as long as natural laws are the dominant reasons. In the land conservation case, take the spillover effect of soil quality on agricultural land use as an example. The soil quality of adjacent land is highly correlated. Severe soil degradation on one farm can also affect the fertility of neighboring farms. This may reduce productivity in a larger area, affecting land-use decisions accordingly (for example, planting different crops or shifting land from agriculture to other uses). Consider another example of land fragmentation – a research topic that has attracted much attention in ecology, biology, and conservation science. The values and quality of land are interrelated. Suppose a small piece of land on a large natural land area is converted to other uses, such as industrial use. Then, the value (for example, measured as biodiversity) of the surrounding natural land can also decline. Sometimes, such land fragmentation can lead to fragmentation of biodiversity and critical habitats, which can be severe to ecological conservation (Fahrig, 2003). We refer interested readers to Albers *et al.* (2018) for a recent review on habitat fragmentation. Due to such ecological-physical characteristics, many factors affecting focal land use, such as soil quality, will naturally affect surrounding land use and land-use change.

2.2 Local versus global spatial spillovers

From the above discussion of the three channels, especially the ecological-physical links, it is not difficult to see that spatial spillovers are likely to be stronger in closer regions than in distant ones. The locality nature of spatial spillovers is also indicated by Tobler's First Law of Geography, which says 'everything is related to everything else, but near things are more related than distant things' (Tobler, 1970). Looking back at our channel #1, although an individual's WTP for use value is not restricted to the community in which he lives, it is usually limited to a reasonable distance range depending on the uses (e.g., hunting vs. scenic view). Even with nonuse values, existing survey studies (e.g., see Wang and Swallow, 2016; Brown *et al.*, 2019) have shown that people are more willing to pay for conservation closer to their living environment. In addition, local taxation is more dedicated to providing local public goods and services (Williams III, 2012). Therefore, governments and other organizations often prioritize or only consider finding the best solution in a specific geographic region. In other words, the local optimum replaces the global optimum.[1] Therefore, quantifying local spillovers separately from global ones is important and provides an in-depth understanding of the spatial spillover effects. We provide a diagram for illustration of local versus global spillovers in section 4.2 when discussing the measurement of spatial spillovers.

3. Study area and background

The study applies to the EMR and CRP, the two most densely populated areas of Alberta in Canada. Details on the study area and some background are provided in section A1 of the online appendix.

4. Methodology and data

4.1 Model specification

This paper quantifies the spillovers from drivers of natural land conversion by using a spatial econometric method. Commonly used spatial regression models are the spatial autoregressive model (SAR), spatial error model (SEM), spatial lag of X model (SLX) and spatial Durbin model (SDM). This study employs an SDM, which is often believed to be superior among various options, due to its favorable attributes for potential econometric issues such as the omitted variable bias (LeSage and Pace, 2009). The choice of SDM is based on relevant statistical tests that will be further explained in section 5.1 when we present the estimation results. The SDM model can be expressed as:

$$y = \alpha \iota_n + \rho W y + X\beta + WX\theta + \gamma Z + \varepsilon, \tag{1}$$

where y is an $n \times 1$ vector of the dependent variable, and X is an $n \times k$ matrix carrying key explanatory variables. The term ε stands for a vector of *i.i.d.* disturbances, ι_n is an $n \times 1$ vector of ones with the associated scalar parameter α, and Z is a vector of other controls. Parameters ρ, β, θ and γ are coefficients to be estimated, and W is an $n \times n$ weights matrix representing the spatial relationship between observations. Specifically,

[1]Depending on the topic being studied, the local and global definitions may differ substantially. For example, Gan and McCarl (2007) develop an analytical framework to analyze cross-country spillover results from forest conservation. In that setting, a specific county represents a focal area. Shobe (2020) provides a review of resource governance issues, spillover effects and different jurisdictions levels.

$W_{ij} > 0$ if j is a defined a neighbor to i, and $W_{ij} = 0$ otherwise. Section A2 of the online appendix, 'Additional information on model specification', provides more details about the model specification and explanation in the current land conversion context.

4.2 Measurement of spatial spillovers

To serve the purpose of this study, global and local spillovers are measured by employing different post-estimation calculations for the SDM. Global spillovers are obtained from the decomposition of total marginal effects, as suggested by Lesage and Pace (2009). To illustrate the point, we first rewrite the SDM into its data generating process,

$$y = (I_n - \rho W)^{-1}(X\beta + WX\theta + \gamma Z + \iota_n \alpha + \varepsilon). \tag{2}$$

Equation (2) can also be further rearranged to:

$$\begin{aligned} y &= \sum_{r=1}^{k} S_r(W)x_r + V(W)(\gamma Z + \iota_n \alpha) + V(W)\varepsilon \\ S_r(W) &= V(W)(I_n\beta_r + W\theta_r) \\ V(W) &= (I_n - \rho W)^{-1} = I_n + \rho W + \rho^2 W^2 + \rho^3 W^3 + \ldots \end{aligned} \tag{3}$$

where $S_r(W)$ is an $n \times n$ matrix carrying all possible marginal effects from a unit change of a key variable r such as income. $S_r(W)$ can also be illustrated as:

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix} = \sum_{r=1}^{k} \begin{pmatrix} S_r(W)_{11} & S_r(W)_{12} & \ldots & S_r(W)_{1n} \\ S_r(W)_{21} & S_r(W)_{22} & \ldots & S_r(W)_{2n} \\ \vdots & \vdots & \ddots & \ddots \\ S_r(W)_{n1} & S_r(W)_{n2} & \ldots & S_r(W)_{nn} \end{pmatrix} \begin{pmatrix} x_{1r} \\ x_{2r} \\ \vdots \\ x_{nr} \end{pmatrix} + V(W)\iota_n\alpha + V(W)\varepsilon. \tag{4}$$

The i, jth element $S_r(W)_{ij}$ is the partial derivative of y_i to x_{jr}, measuring the marginal effects on the dependent variable in location i from a change of the explanatory variable r in location j. Applied to this study, for example, if r denotes income, $S_r(W)_{ij}$ stands for location i's change of natural land area converted to the developed land due to a unit increase of income in location j. We define the average total effects (ATE), average direct effects (ADE), and average indirect or spillover effects (AIE) based on LeSage and Pace (2009: 34–39).

The AIE obtained here are the average global spillover effects, which come from the fact that changes in one region impact all regions' outcomes because the spillovers will pass to other higher neighbors (i.e., from neighbors to the neighbors of neighbors) through the spatial multiplier $(I_n - \rho W)^{-1}$. The AIE of income can be interpreted as the aggregated change of natural land area converted for development uses on a representative focal area, arising from a unit change of income in all locations except itself (i.e., global spillover effects).

To ease the description, we provide a simplified diagram with small samples to illustrate local spillover effects and global spillover effects. In figure 1, A_0 represents the focal area of interest. A_1 to A_6 are local/immediate neighbors of A_0 if we define neighbors

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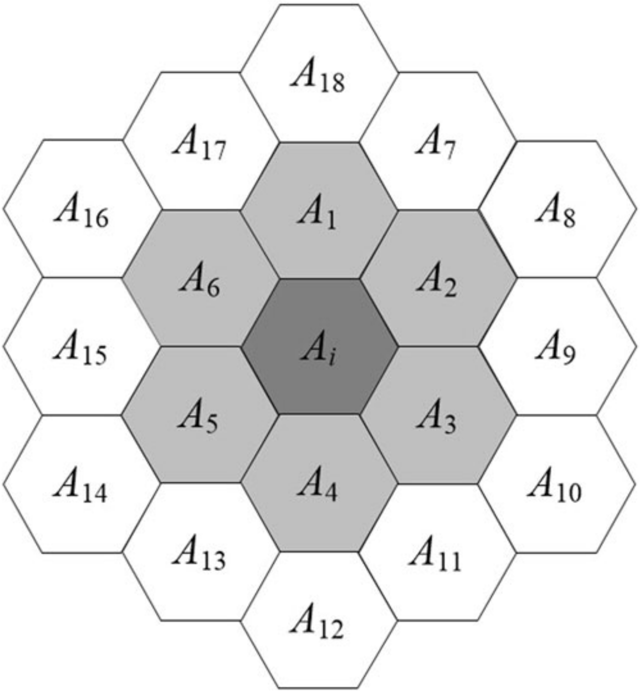

Figure 1. Simplified diagram for illustration of the spillover effects.

using a Queen's contiguity definition.[2] Any location other than itself can be defined as a global neighbor. Suppose we use the regression method to conduct an impact analysis. For the dependent variable y in the focal area A_0 with respect to a certain explanatory variable x, the direct/own effects can be represented as $\partial y_0/\partial x_0$, the total/global spillover effect is $\sum_{j=1}^{18} \partial y_0/\partial x_j$, the local spillover effect is $\sum_{j=1}^{6} \partial y_0/\partial x_j$[3] and the total effects can be written as $(\partial y_0/\partial x_0) + \sum_{j=1}^{18} \partial y_0/\partial x_j$, or $\sum_{j=0}^{18} \partial y_0/\partial x_j$.

Distinguishing the local and global spillover effects provides more detailed information from the resource governance perspective. For example, for local collaboration purposes, policymakers at nearby geographic units are likely to be more interested in quantifying local spillovers, which will directly affect their jurisdiction levels. Meanwhile, the central government at the federal level is probably more interested in knowing the total spillovers across the entire country or region due to local action in a specific area. Recent studies (e.g., see Shobe, 2020) discussed some emerging issues in resource governance when there are spillovers among vertical and horizontal jurisdictions.

Obtaining local spillovers in the estimation based on a general SDM is straightforward. Without considering the passing paths through W and its higher orders such as W^2 and W^3, the local spillover effects on the dependent variable can be calculated as

[2]Local/immediate neighbors can be defined in other ways (such as threshold distances and social networks) depending on the definitions of the spatial weights matrices.

[3]It should be noted that the local spillovers here are immediate, which means higher-order feedback paths (e.g., impact from A_2 through $A_2 \to A_3 \to A_0$) are ignored.

$\rho W I_n \beta_r + I_n W \theta_r$ from equation (3). Therefore, the average local spillover effects for the variable r can be expressed as $(1/n) \sum_{i=1}^{n} \sum_{j=1}^{n} (\rho W I_n \beta_r + I_n W \theta_r)$. Given that W is row-standardized and all diagonal elements are zero, this term can be simplified as the estimated coefficient $\rho \beta_r + \theta_r$. Again, if r denotes income, the area of natural land converted to development land on location i will change by $\rho \beta_r + \theta_r$ if its immediate neighbors see a unit change in income (i.e., local spillover effects).

4.3 Data and description

The 2000 and 2016 land-use/land-cover data (30-meter resolution raster images) are obtained from Agriculture and Agri-Food Canada. Four types of land are grouped and classified as the natural land in this study: Shrubland, Wetland, Grassland, and Forest. Therefore, the dependent variable is represented by the total area of the natural land in 2000 that has been converted to the developed land in 2016. As for explanatory variables, the road density is calculated using road network data from the AltaLIS Ltd. The land suitability information is provided by the Alberta Agriculture and Rural Development. According to the Canadian Land Suitability Rating System, larger rating scores represent lower suitability for agricultural uses. Since Alberta does not have Class 1 land due to the harsh climate, Class 2 or 3 land is the most suitable for agriculture. The 2016 population data are collected from the 2016 Canadian Census Program, while the 2000 population information use 2001 Census data as a proxy. Road network data are obtained from the CanMap Content Suite purchased by the University of Alberta.

For the empirical investigation, a grid of 5-km diameter hexagons is overlaid on each metropolitan area to divide the study area into the hexagonal regions of the same size. The choice of 5 km is a compromise between the observational unit of the dependent variable and the key independent variables. The dependent variable land conversion is observed at a high-resolution $30\,\text{m} \times 30\,\text{m}$ ($= 900\,\text{m}^2$) level. However, key explanatory variables (i.e., median income and population) are only observed at the Census dissemination area (DA) level, which is the smallest standard geographic unit in the Canadian Census Program. The average DA sizes are 7.4 and $11.0\,\text{km}^2$ in EMR and CRP, respectively. However, DAs in some rural areas are quite large. Therefore, we chose to use a 5-km hexagon (about $16.2\,\text{km}^2$) to balance the heterogenous DA sizes in rural and urban areas. In a similar setting, Stone and Wu (2014) choose to use a grid of 2-mile (i.e., 3.2 km) diameter circles for their empirical analysis. Their independent variables are at the census block level, smaller than our DA unit, so our diameter selection is also bigger than theirs.

The final dataset includes 872 observations for the EMR and 1,197 for the CRP. To conduct the spatial regression analysis, all variables are adapted to the hexagonal level. Table 1 presents the summary statistics of the variables. Figure 2 displays the distribution of natural land converted to development uses for the study area. The results show that for the EMR, the natural land loss is mainly distributed on the east and west outside of the city of Edmonton; while for the CRP, most loss occurs in the northwest of Calgary city. Also, the CRP has more units with over 200 ha natural land loss to development than the EMR.

5. Results and discussion

5.1 Model estimation results

Before proceeding to the empirical analyses, we test spatial correlations for natural land conversion among hexagonal units. The global Moran's I statistics are 0.226 and 0.267

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Table 1. Summary statistics of the variables

Variable name	Definition	EMR ($n = 872$) Mean	EMR ($n = 872$) S.D.	CRP ($n = 1,197$) Mean	CRP ($n = 1,197$) S.D.
Natural2DevLand	The area of natural vegetation land converted to developed land (ha)	15.82	24.35	18.06	43.90
Income	Natural logarithm of median individual income in $	10.64	0.17	10.61	0.29
PopulationGrowth	The change of population density (person/km^2)	26.96	138.21	24.86	145.05
RoadDensity	The road density (m/ha)	19.44	18.08	14.13	18.58
NaturalLand2000	Total area of natural vegetation land in 2000 (ha)	326.46	320.12	609.39	587.71
LandSuitability	Proportion of land with suitability ratings of 2 or 3 (%)	76.94	28.98	47.11	43.68
Elevation	The average elevation of the area (100 m)	7.07	0.58	11.78	3.19
Distance_Inverse	The reciprocal of road network distance (km) to the Edmonton/Calgary city core	0.02	0.02	0.02	0.02

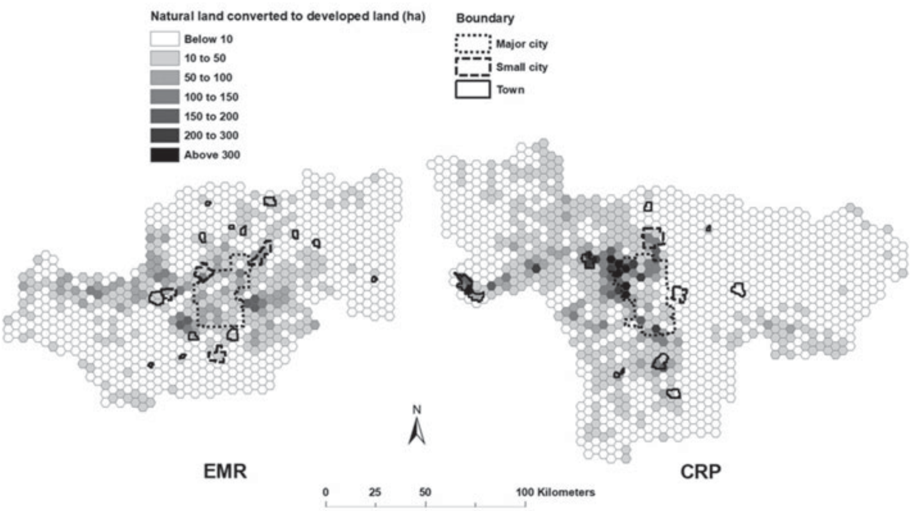

Figure 2. Natural land converted for development uses in EMR and CRP (2000–2016).

for the EMR and CRP, respectively. The p-values are both far below 0.001, indicating significant global autocorrelations. Additionally, according to the local Moran's I statistics, the spatial distribution and spatial patterns suggest the existence of strong local autocorrelations (see figure A2 in the online appendix). To sum up, both global and local spatial statistics indicate the necessity of considering the spatial dependence of natural land conversion in the empirical investigation.

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Table 2. Different types of marginal effects on natural land conversion for the EMR and CRP

	Own effects (ADE)	Local spillover effects ($\rho\beta+\theta$)	Total/Global spillovers (AIE)	Total effects (ATE)
EMR				
Income	27.939***	−19.942***	−41.618	−13.679
PopulationGrowth	−0.004	−0.139***	−0.289	−0.293
RoadDensity	0.303***	1.386***	2.893**	3.196**
NaturalLand2000	0.034***	−0.023***	−0.047**	−0.013
LandSuitability	−0.008	−0.351***	−0.733*	−0.741*
Elevation	4.997	−0.239	−0.498	4.498
CRP				
Income	14.690***	−2.193***	−11.913	2.777
PopulationGrowth	0.089***	0.171***	0.924*	1.013*
RoadDensity	0.905***	0.919***	4.974	5.879*
NaturalLand2000	0.032***	−0.029***	−0.157**	−0.126*
LandSuitability	0.004	−0.416***	−2.255**	−2.252**
Elevation	−2.449**	−0.087	−0.468	−2.917

Notes: The weights matrix is based on a threshold distance of 24 km and 20 km for EMR and CRP, respectively. The effects are computed using the trace created by powering a sparse matrix of distance weights. The tests for the impacts are based on 5,000 times simulations from a multivariate normal distribution (MND). ***, ** and * denote significance at 1%, 5% and 10% level, respectively.

Given that the SDM model allows spatial interactions among both the dependent and independent variables, it nests many other spatial model specifications. To ensure the appropriateness of adopting the SDM, we conduct multiple likelihood ratio tests for the SDM against the SAR and SEM. For both regions, EMR and CRP, the results reject the null hypotheses $\theta = 0$ and $\theta = -\rho\beta$, indicating that the SDM cannot be simplified to either a SAR or an SEM. Furthermore, the SLX specification can also be abandoned because of the significant spatial autocorrelation coefficient ρ. In addition, the SDM has the smallest Akaike information criterion (AIC) and largest pseudo R^2 (Efron, 1978) among the four models (SAR, SEM, SLX, and SDM). The regression results of spatial models are provided in the online appendix (tables A1–A5).

5.2 Marginal effects and spillovers for the EMR

Table 2 presents the marginal effects obtained from the selected SDM model. Marginal effects for estimates using different W, as a robustness check, are provided in the online appendix (tables A6 and A7).

According to table 2, income is found to play an important role in natural land loss and conservation. Our results indicate that income increase in a specific area has a positive impact on the loss of the natural landscape in its own area; however, if income levels in all of the immediate neighbors increase, natural land losses will actually decrease (may be viewed as an increase in land conservation). In other words, own- and immediate-neighbor- influences of income growth are in opposite directions. Specifically, with an increase of 10 per cent in median income in one specific area and no change in other areas, such isolated income growth will cause a loss of 2.8 ha of natural landscapes in

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its own area. The conversion of land is likely to be related to the increased demand for housing, better infrastructure facilities, and recreational sites such as shopping centers (e.g., due to the income effect). It may also relate to more development for industrial and commercial land uses. On the other hand, if there is an increase of 10 per cent in income in each of the immediate neighbor areas (i.e., the local neighbors), it will reduce natural land conversion in the focal area by 2.0 ha. These results are consistent with our discussion of the spillover mechanism in section 2. In particular, the results indicate that, as predicted by channel #1, individual demand for housing and infrastructure increase with income growth, causing land in their own areas to be converted for development purposes. However, an increase in income also increases the demand for environmental amenities and may also increase the WTP for nonuse values related to land conservation; therefore, we have observed a decline in land conversion in neighboring areas.

To provide a bit of local context, the median income in the EMR was 23,144 Canadian dollars (CAD) in 2000 and 43,900 CAD in 2015 (Statistics Canada, 2021). Therefore, the annual income growth rate is about 5.6 per cent, based on the simple arithmetic average. Using this rate as a proxy for future economic growth, the yearly natural land loss in the EMR, only considering its own impact, is about 1,367 ha,[4] which is 2 per cent of the area of the city of Edmonton. However, if we further consider the benefits of local spillovers, the results show that the total net loss of natural landscape is only about 391 ha, *ceteris paribus*. Furthermore, using the same scenario, the non-spatial OLS results (shown in online appendix table A1) predict a net loss of 2,002 ha per year, which is a severe overestimation and will lead to very different conclusions about the impact of income growth on land conversion.

These results from spatial regression are consistent with our discussion of channels #1 and #2 in section 2. As income increases, people's affordability and WTP for better environments and open space conservation (both due to use and nonuse values) increase. According to a recent study (Wang and Swallow, 2016), Albertans showed tremendous interest in preserving various types of open space (e.g., urban agricultural land, large scale of grassland and shrub land in rural areas) using private funds. The government has also shown a growing interest in preserving open space and environmentally-sensitive lands. The growing (tax) revenues also allow for better pursuing such an avenue. The central government has been providing significant financial benefits to individuals and companies that protect natural lands through various programs, such as the Ecological Gift Program (Environment Canada, 2010). Moreover, the provincial and municipal governments also adopt financial tools such as property tax reduction and the exemption for green space conversation when developing residential properties (City of Edmonton, 2001). With the efforts of the government and organizations, the choice of conservation sites may be different from the geographic distribution of the high income. However, such efforts will still have strong local preference, as we discussed previously.

As for population growth, the direct effect is insignificant, while the local spillover effects are negative and significant at the 1 per cent level. Specifically, an increase of population density of 10 persons/km^2 in all of the immediate neighbors will lead to an average of 1.4 ha natural land conservation (i.e., reduction of conversion) in a representative area. This is likely reflecting the efforts from the government side and the changing perspectives of the general public regarding sustainable development and smart growth. With the rapid population growth, in large cities with high population density like Edmonton,

[4] 1,367 ha =5.6*0.28 ha*872 hexagons.

the local government has been continuously advocating changes to the growth strategy to support sustainability: from the low-density to the high-density since the 2000s. A series of new residential land use regulations and policies have been proposed and implemented (for example, the 'Residential Landfill Guidelines' approved in 2009).

Another noteworthy finding is the significant and positive effect of road density on natural land losses in both direct and spillover forms. The results are in line with prior findings in urban study literature, which suggest that transportation improvement such as denser highways contributes to more land development for residential housing and business location selection due to lower transport and travel costs (Holl, 2004; Kim *et al*., 2005). Both types of spillover effects are greater than the direct (own) effects. The main channel for spillovers is through individual decisions and activities (e.g., the residential and job location decisions and traveling activities). Due to the movement of people, externalities are almost always imposed on neighboring areas. Expanding the road system in neighboring areas can help alleviate congestion. Reduced commuting time and decreased transportation costs make an area a better place for both residential and business uses.

Existing natural landscape available for conversion in the own/focal area is positively linked to more conversion of natural land to development uses. Each 100-ha of extra natural land in a specific area can encourage a 3.4-ha conversion. The reason behind this might be the substantially increased supply/availability of land, which reduces the conversion cost. However, as discussed in section 2, channel #3, the natural land endowment can generate significant and negative local/global spillovers because of the ecological-physical connections. Our results are consistent with this hypothesis. Specifically, each 100 ha of extra natural land in all of the immediate neighbors and all other areas except itself can protect 2.3 ha and 4.7 ha of a focal area, respectively. Land suitability has no significant own effect. However, with an increase in good soil by 10 per cent in all of the immediate neighbors, the conversion from natural land to development will drop by 3.5 ha. Higher suitability means higher expected return from agricultural uses, which has higher values for conservation.

5.3 Marginal effects and spillovers for the CRP

Next, we take a look at the results from the CRP. Overall, the signs of marginal effects (i.e., own, local, and global effects) are consistent with the Edmonton case; however, some of the spillovers' magnitude/strength are quite different. Like the EMR case, income growth in one single area leads to more natural land conversion in the same place in CRP. However, suppose income increase happens in all of the immediate neighboring areas. In that case, each 10 per cent income growth will promote approximately 0.2 ha of natural land protection in the focal area. The marginal spillover impact is much smaller than that in the EMR case. One explanation is the heterogeneous land markets in the two regions. Given the same amount of budget for land conservation in the two regions (for example, due to the same level of income increase), more land can be protected in the EMR because of its relatively lower land prices. According to the housing market statistics, the average house price in Calgary is higher than in Edmonton, and the average difference can be 100,000 CAD for single-family detached houses (RBC Economics, 2016). The median income of the CRP was 25,670 CAD in 2000 and 43,974 CAD in 2015 (Statistics Canada, 2021), and the annual growth rate was roughly 4.4 per cent. Using this rate to make future predictions, considering only its own impact, the total annual loss of the CRP is about 790 ha, which is close to 1 per cent of the city of Calgary. When also considering the local spillover, the predicted total net loss of the natural landscape drops to 658 ha. Using the same scenario, the OLS results (shown in online appendix table A1) predict a net loss of 822 ha per year, which is again overestimated, but the deviation is much smaller compared with the EMR case.

Similarly, population growth in a focal area contributes to its own natural land losses; moreover, population growth in all immediate neighbors can cause further natural land conversion. Explicitly, an increase in population density of 10 persons/km^2 will increase land development in the same area by 0.9 ha. At the same time, a 10-person/km^2 increase in the population density in all immediate neighbors can lead to natural land conversion by an average of 1.7 ha in a specific area. The increased demand for residential land may explain the positive own effect due to the increased population density. In contrast, the positive local spillovers might be explained by the dense population density of the CRP. The population density of the CRP is approximately twice that of the EMR. As the population grows, because its population density is already high, the natural land in its immediate vicinity is more likely to be converted into development uses (such as housing) to accommodate the increasing population.

Recall the Edmonton case; road density plays a dominant role both locally and globally. Similarly, it is found to have positive own and local spillover effects in the CRP. Construction of more roads in its own or local neighboring areas leads to loss of natural landscapes. Like the EMR case, the availability of natural landscape has a positive direct impact and negative spillover effect on land conversion in the CRP. However, the global spillover for the CRP is so large that it is able to generate negative and significant total effects. The difference may reflect the distinct conservation values associated with the natural land in these two regions. The natural landscapes in the CRP are largely high-value international/national parks and PAs such as part of the Jasper National Park. Due to the sustainability and agglomeration effects of nature conservation and the significant economic and cultural value associated with tourism, they are more likely to be conserved (City of Calgary, 2003). On the other hand, most natural lands in the Edmonton metropolitan area are grassland, hayland, and shrubland with fewer amenity values. A substantial part of the current natural lands is abandoned farmlands, which are no longer profitable in agricultural production. Therefore, the conservation values and nonuse values are considerably different in the two regions, leading to different global/total conversion results. The observed spillover is the result of a combination of individual, government and natural channels. As in the EMR case, land suitability helps preserve the land from development, although it may result in converting natural land to agricultural use. Finally, to statistically test the heterogeneous impacts, we conduct a test for the significance of the differences in own effects and spillover effects. The results are provided in the online appendix (table A8). These results confirm the substantial difference in marginal effects, especially the total indirect (spillover) effects.

6. Concluding remarks

Using data on two developed regions in Alberta, Canada, this study examines the impacts of economic development and other associated factors on natural landscape conversion. The empirical work adopts an SDM to quantify spatial spillovers in both local and global settings. The results show that economic development and the degree of natural land conversion are negatively associated in the context of spillovers. A non-spatial regression can lead to biased and misleading results. In addition, other determinants such as road

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density, nature land owned, proximity to the central city, and land suitability for agriculture are found to have influences on natural landscape conservation both in the own and neighboring areas. Our study demonstrates that allowing spatial spillovers is important in explaining reality. For people interested in contributing to land protection, it may not always be possible to find a piece of land to conserve in his/her own community. Alternatively, contributing to conserving land in specific areas under specific programs and government efforts seems more realistic and has been practiced commonly in reality. In our case of the two metropolitan regions, if spillover effects are not allowed in the empirical analysis, as many previous studies have done, we will not be able to find the correct answer, nor can we provide evidence of people's effort in land conservation. To make matters worse, when using non-spatial regression models, we mistakenly assume spillovers (particularly local spillovers) are zero, and believe that income growth is positively related to the results of natural land conversion. Consequently, inappropriate policy recommendations may be suggested, such as the purposeful selection of areas to strategically slow economic development to protect nature.

We demonstrate that key drivers of natural land conversion and conservation, such as income, population growth, road construction, and the natural endowment, all have strong spillover effects. The magnitudes of spillovers vary between local and global settings. It is vital to distinguish and quantify the local versus global neighbor influences. One important implication is that, to design or implement effective strategies (e.g., conservation and smart growth), policymakers at different locations and jurisdiction levels need to collaborate and coordinate with each other. Any attempts to isolate one area from neighboring activities and central decisions may lead to inefficiencies and ineffective results. In addition to local and regional cooperation, the central government may also have a role to play given the 'global' nature of spillovers in a broader context. When there are spatial spillovers, the benefits of decentralized resource management tend to diminish. This is because local governments strive to achieve local optima without fully considering the costs beyond their jurisdiction (Shobe, 2020). Without the high-level government intervention, localized collaborations may not lead to the socially-optimal land conservation (other activities alike), and externalities are likely to exist. The idea of incorporating different levels of spatial spillovers into modelling can also add value to the optimal conservation design with wider applications.

This study also contributes to the empirical literature on the EKC hypothesis. Our results show that an increase in income in a single (small) area does not result in a decline in environmental degradation at the local, regional or global scales. This finding seems to go against the EKC hypothesis. However, if one allows global interactions and examines the impact of income growth in the entire region on nature degradation in a specific area, then in that case, it becomes obvious that economic growth does slow down the natural land conversion. The results provide evidence to support the EKC hypothesis. This finding and the underlying approach intuitively make sense. As the overall regional income increases, the willingness and ability to pay for better environmental quality will be raised to a level that can improve the status quo, resulting in enhanced environmental quality through public or policy efforts.

Finally, although the two metropolitan areas are located in the same province and have lots of similarities in terms of population growth, per capita income levels and development rates, the impacts of income and population growth as well as other relevant factors on nature preservation are significantly different. Our results illustrate the importance of policy interventions and regional endowments on development and land protection. Although geographic large-scale – such as the county level – research can give an overall impression, it will overlook the heterogeneities at the disaggregated levels which is essential for in-depth understanding of the issue, design of tailored local strategies and promotion of global collaborations.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X21000346

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