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The Impact of Agriculture on Waterfowl Abundance: Evidence from Panel Data

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Because there are potential externality benefits, it is important to specify an appropriate statistical model when analyzing the conflict between agriculture and migratory waterfowl in Canada's pothole region. Unlike non-spatial panel models, our use of a spatial autoregressive panel model identifies indirect impacts of agricultural activities on wetlands and waterfowl. In particular, we find that programs to restore wetlands in one location will result in enhanced duck productivity of wetlands and habitat in other locations within the study region. Even so, costs of protecting ducks could range from \$107 to \$204 per bird.

Key words: GIS; land use conflict; migratory waterfowl; spatial econometrics; wetlands protection

Introduction

Canada's Prairie Pothole Region (PPR) represents a mere 10% of North America's waterfowl breeding habitat (figure 1), but produces over 50% of the continent's ducks (e.g., Baldassarre, Bolen, and Saunders, 1994). As this region also accounts for roughly 60% of Canada's agricultural output (Statistics Canada, 2006), intense competition exists between private economic interests and public benefits. Not surprisingly, therefore, wetlands and waterfowl numbers have declined. North American waterfowl populations have fallen by at least 40% since monitoring began in the mid 1950s (U.S. Fish and Wildlife Service, 2010).

Already in the early 1970s, it was shown that wetlands area and waterfowl populations were less than optimal, even if wetlands only provided benefits to U.S. duck hunters the situation has deteriorated (Brown and Hammack, 1973; Hammack and Brown, 1974).[1] For instance, van Kooten, Whitey, and Wong (2011) found wetlands and duck numbers to be well below socially optimal levels, with climate change (higher temperatures and less precipitation) and efforts to mitigate carbon dioxide emissions through biofuel policies exacerbating the problem (Withey and van Kooten, 2011). Duck populations continue to experience periods of sharp decline and limited recovery.

To arrest declines, various wetland conservation activities have been undertaken by public and private agencies since the 1890s (e.g., see Porter and van Kooten, 1993), with the establishment of the North American Waterfowl Management Plan (NAWMP) in 1986 constituting the first continental effort to restore waterfowl populations. By providing funds for NAWMP, the United States explicitly recognized that American hunters benefitted from waterfowl habitat and wetlands protection in Canada (e.g., van Kooten, 1993). A major objective of NAWMP is to restore wetlands (CWS, 2004).

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[1] In their models, the objective function included a term to account for the annual opportunity cost of providing waterfowl habitat and wetlands.

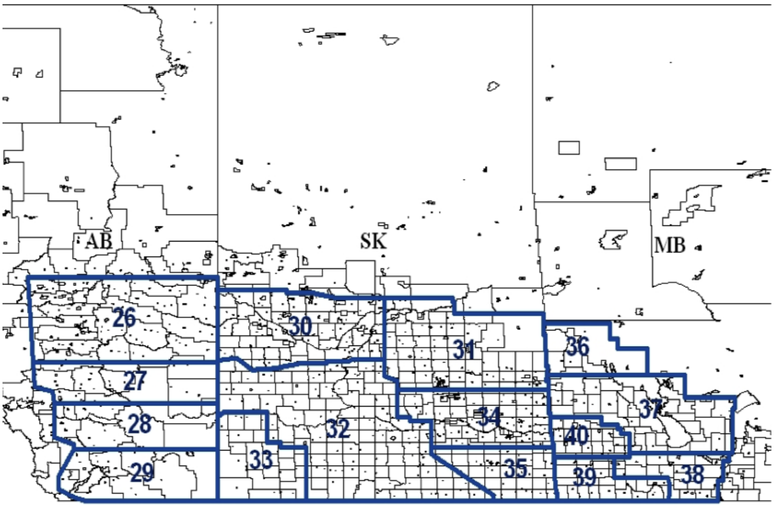

Figure 1: Strata of the Waterfowl Breeding Population and Habitat Survey (thick lines) and Census Consolidated Subdivision Boundaries of the Census of Agriculture (thin lines)

Despite having spent more than $800 million on conservation efforts in Canada's Prairie Provinces, wetlands remain below the NAWMP target (NAWMP Committee, 2009). A key reason is the large overlap (as high as 91% in the PPR) between waterfowl habitat and agricultural lands (Bethke and Nudds, 1995). The primary strategy of establishing long-term land conservation agreements are expensive and fraught with pitfalls related to the principal-agent problem of contracting. As a result, less upland habitat and wetlands are protected with programs often targeted at habitat of poorer quality and wetlands that are less likely to be developed (e.g., van Kooten and Schmitz, 1992; van Kooten, 1993).

Key to the success of any programs that aim to tradeoff agricultural use against waterfowl protection is an understanding of the relationship between land use and waterfowl density. Our goal is to contribute to this understanding. We use a spatial panel econometric model to investigate the extent to which agricultural intensification negatively impacts waterfowl populations. A crucial aspect of our study is that our models allow for the fact that migratory waterfowl can choose to breed where wetlands are more plentiful if wetlands at one location are lost or reduced. This suggests that wetlands conservation or restoration in one location can impact wetlands productivity at another location. Related large-scale ecological studies have not been undertaken due to their high costs (Mitsch et al., 2009), but positive spillovers at the local level have been well researched (e.g., see Murkin, Murkin, and Ball, 1997; Naugle et al., 1999, 2001; Whigham, Chitterling, and Palmer, 1988).

Background

Waterfowl benefits range from aesthetic enjoyment for birdwatchers to the support of multi-billion dollar industries for hunting and eco-tourism; waterfowl are also studied for their scientific value and usefulness as indicators of environmental health (NAWMP Committee, 2009). Thus, changes in waterfowl populations have been widely researched, with several studies having examined the impact of climate and agriculture on specific species. One such study uses random coefficient models, fixed effects models and various mixed specifications to examine the response of northern pintail ducks to changes in wetlands and agriculture in the PPR from 1961-1996 (Podruzny et al., 2002). Their regressions specify pintail density as a function of wetland density, climate variables (soil moisture and precipitation), and measures of agricultural land use intensity (percentages of improved farmland, pasture, cropland, etc.). Additionally, the analysis is conducted at various spatial scales (provincial-, stratum- and transect-levels) to obtain an understanding of possible multiple scale effects.[2]

Although the title of Podruzny et al. (2002, 's) paper suggests otherwise, they are not interested in determining the magnitude of the impact of agriculture and wetlands on pintail populations, perhaps because this species only accounts for approximately 5% of the total duck population in the PPR. They find that, in general, pintail density is positively related to pond density, precipitation and land in summerfallow, and negatively related to cropland and improved pasture. With the exception of pintails and a few other minor species, ducks rarely nest in crop or fallow land (Baldassarre, Bolen, and Saunders, 1994); thus, although Podruzny et al. (2002) find a positive relationship between pintails and summerfallow, this result cannot be generalized and should be negative for waterfowl as a whole.

Bethke and Nudds (1995) also study the effects of climate and land use variables on ten species of duck populations. Although they do not report model specifications, it is apparent that they examine climate and land use effects separately and run separate regressions for each species and stratum. With regards to the impact of agricultural land use, they find that habitat loss accounted for 65% and 80% of the variation in mallard and northern pintail population deficits, respectively. As noted, northern pintail are a minor species, while mallards account for about one-quarter of all ducks. No significant relationship was detected for the other species.

In an examination of mallards, Miller (2000) uses a log-transformed index of production (the ratio of immature to mature mallards) as the dependent variable in his regressions, instead of population density or numbers. His regressors are similar to those chosen by Bethke and Nudds (1995) and Podruzny et al. (2002), and he considers all of the United States. Miller (2000) employs models specified at two spatial scales—the stratum (specific region) scale and the continental (Canada's PPR) scale. Similar to Bethke and Nudds (1995), Miller also finds a negative relationship between cropland and mallard production at the stratum level; however, at the continental level, the relationship is positive. He views this latter relationship as spurious, resulting from random error.

Although we do not follow the unit-by-unit approach used by Bethke and Nudds (1995), the variables used in their study are similar to those chosen by Podruzny et al. (2002), Miller (2000), and for the current study, and are thus useful for comparing results. In addition, as it is most likely that relevant variables are omitted, we extend the single equation methods and pooled OLS approach to a panel framework allowing for omitted variables via unit and period effects. We also adopt spatial panel models that account for the impacts of changes in wetlands at one location on duck productivity at another, in our belief that conservation in one region may impact duck productivity in another, spatially located, region.

Data

The cross-sectional units used in the analysis are the U.S. Fish and Wildlife Service's strata 26-40 (figure 1). Data are compiled from surveys of waterfowl populations and pond counts, drought indices derived from meteorological data, and agricultural data from Canada's agricultural censuses. Although data on waterfowl and ponds are available for the period 1955-2010, we limit attention to 1961-2006, as these are the years when Canadian agricultural census data are available. Table 1 describes variables and table 2 presents summary statistics.

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[2] The U.S. Fish and Wildlife Service created 'census regions' throughout North America for measuring migratory waterfowl populations and habitat. A single region is referred to as a stratum, a term that we adopt; strata are indicated in figure 1 for Canada's PPR.

Table 1: Variables and the Expected Effect on Waterfowl Density

Variable	Definition	Expected Effect
Y	Log of duck counts per square kilometer (dependent variable)	
lPND	Log of the pond counts per square kilometer	+
SPI	1-month Standardized Precipitation Index	+
CPL	Percentage of farm area in cropland	-
SMF	Percentage of farm area in summerfallow	-
PST	Percentage of farm area in improved pasture	-
Fixed Effects	Unobserved cross-sectional or temporal controls	+ or -

Table 2: Panel Summary Statistics, 1961-2006

Variable		Mean	Std. Dev.	Min	Max
Y	Overall	2.09	1.67	−3.04	5.25
	Between		1.66	−1.82	4.61
	Within		0.42	0.87	3.01
lPND	Overall	0.89	1.47	−2.59	3.55
	Between		1.42	−1.93	2.88
	Within		0.52	−0.91	1.98
CPL	Overall	37.70	14.45	6.27	67.87
	Between		13.51	8.93	61.95
	Within		6.11	22.63	48.90
SMF	Overall	11.86	7.57	0.31	28.95
	Between		6.20	1.74	23.70
	Within		4.60	−1.08	23.00
PST	Overall	3.47	2.21	0.28	12.51
	Between		1.45	0.97	7.33
	Within		1.71	−2.31	8.66
SPI	Overall	−0.13	0.98	−3.72	1.91
	Between		0.20	−0.42	0.20
	Within		0.96	−3.46	1.83

Notes: Each variable has 150 total observations across 15 strata over 10 time periods.

Waterfowl and Wetlands Data

Beginning in 1955, the U.S. Fish and Wildlife Service (USFWS) and the Canadian Wildlife Service (CWS) have conducted annual ground and aerial surveys in May that provide counts of ponds and various waterfowl species. May pond counts can vary significantly from year to year because they include both ephemeral and permanent ponds. Fields covered with ponds in May are not usually planted to crops (although there are exceptions), but are used for pasture. The more ephemeral ponds, which are most likely to be drained and converted to crop production, provide important nutrients for breeding ducks. Thus, May pond counts tend to better predict migratory waterfowl numbers than

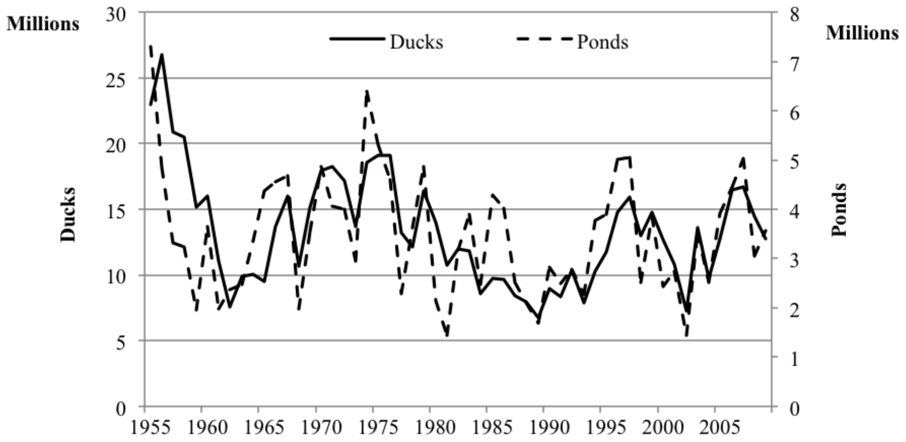

Figure 2: Duck Population and Pond Count Time Series, 1955-2009

Notes: Source: U.S. Fish and Wildlife Service (2010).

more permanent July pond counts (e.g., Hammack and Brown, 1974). This led the USFWS to stop reporting July counts.

For our purposes, the PPR is divided into 15 strata or regions, denoted as strata 26-40 in figure 1. Figure 2 displays the time series for duck populations and pond counts for the entire PPR. These two series are highly correlated, and duck population movements appear to follow pond count movements for the reason noted above. Recall that our interest is to determine whether wetlands moderate the effect of agricultural land use on duck populations, rather than the effect of wetland numbers on duck populations.

Agricultural Data

Agricultural land use data were obtained from the Census of Agriculture, conducted by Statistics Canada every five years since 1961; 2006 is the latest available census data. Data for individual Census Consolidated Subdivisions (CCS) were assigned to survey strata using the ArcGIS software package and aggregated to obtain three measures of agricultural land use intensity: proportions of farm area used as cropland, summerfallow and improved pasture (tables 1 and 2).[3] Figure 3 presents time series of cropland acreage and waterfowl numbers for the PPR appear. This figure illustrates a possible negative relationship, especially after the 1970s.

The overlay of Statistics Canada's CCSs and the USFWS's waterfowl strata boundaries dictate the assignment of CCS data to each stratum, as indicated in figure 1. When a CCS overlies two or more strata, the acreage data were multiplied by the proportion of the CCS that falls within the stratum under consideration. To ensure consistency between years, we only consider CCS with observations in every census year, unless the missing observation was due to an amalgamation, for confidentiality reasons, with a neighbouring CCS. As the numeric identifiers for the CCS were changed by Statistics Canada in 1981, we recoded the earlier years prior to performing ArcGIS database procedures.[4] We found 446 CCSs that coincided with the PPR. We assume that CCS boundaries did not change over time, consistent with Podruzny et al. (2002), who indicate that this was true for 95% of the CCSs.

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[3] While recognizing that different crops impact migratory waterfowl differently (e.g., winter wheat can provide nesting habitat on par with native grasses), we consider only three categories to ensure sufficient observations in each stratum and year (e.g., winter wheat is a minor crop and is only planted in limited areas).

[4] The names of the CCSs were also inconsistently formatted from year to year, so could not be used as a key.

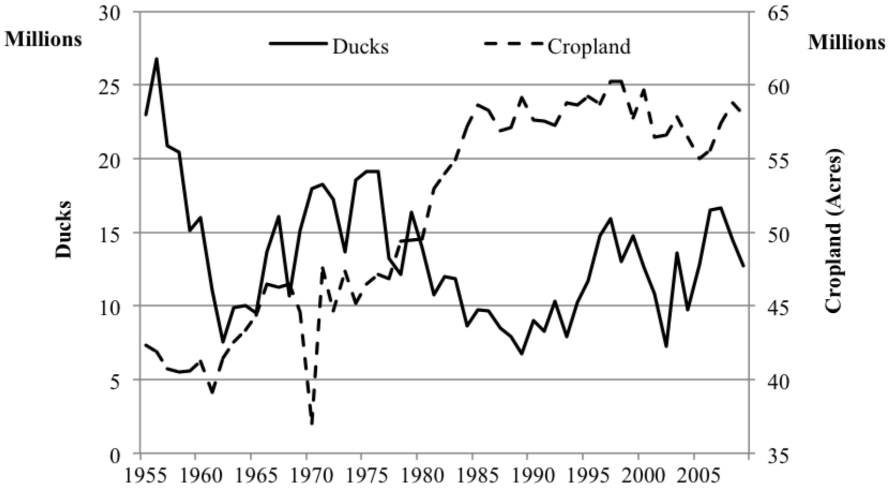

Figure 3: Cropland Acreage and Duck Count Time Series, 1955-2009

Upon examining the spatiotemporal variation of the agricultural variables, we find that cropland intensification has generally occurred across the PPR since the 1960s, with the exception of the southeast corner of Alberta, the southwest corner of Saskatchewan, and parts of central Manitoba. Southeast Alberta and adjacent southwest Saskatchewan are the most arid regions in the PPR, while the portion of central Manitoba that has witnessed no agricultural intensification contains large bodies of water. Cropland area in the pothole region increased by roughly 56% from 1961 to 2006. At the same time, while area in summerfallow declined dramatically from an average of 24% of cropland in 1961 to under 7% in 2006, the average proportion of improved pasture increased by only 5%.

Standardized Precipitation Index

The standardized precipitation index (SPI), obtained from the North American Drought monitor,[5] is available from various weather stations across the prairies. We used data for the month of May from the weather station closest to the center of each survey region, selecting a short-term one-month index for our analysis.[6] The SPI takes on values from -4 to +4; a value of 0 indicates average wetness conditions as determined for the 1951-2001 standardizing period. Positive (negative) values indicate wet (dry) conditions. We chose data from May to coincide with the month when planting generally occurs (and choice is made as to fallow or crop) and the month in which waterfowl breeding and habitat surveys are conducted.

Models and Estimation Methods

Spatial Panel Models

Our models contain both temporal and unit (stratum) fixed effects.[7] Geographic and biological differences across strata likely affect the response of waterfowl to agricultural land use changes, leading to different responses across units that may not be modeled by our included regressors;

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[5] http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/

[6] A longer-term twelve-month SPI was also considered, but estimation results did not differ substantially.

[7] Unit and stratum are used interchangeably as our cross-sectional units are the fifteen strata of the USFWS waterfowl survey.

this justifies a time-invariant unit-specific effect. Similarly, unit-invariant economic incentives, such as commodity prices, potentially affect land use decisions and waterfowl abundance, motivating inclusion of a temporal fixed effect. Statistically, F-tests support the inclusion of both temporal and unit fixed effects over a pooled ordinary least square (OLS) regression. However, as the fixed effects model essentially demeans the variables before applying OLS, we are unable to estimate the impacts of observable variables of interest that are slow moving or time-invariant (e.g., Wilson and Butler, 2007). Procedures outlined in Plümper and Troeger (2007) would overcome this issue, but application of their technique is left for future research.

In controlling for unobserved unit heterogeneity, standard fixed effects panel models account for regional characteristics but not spatial dependence or interaction, the omission of which may render estimators inconsistent. Fortunately, spatial panel models can be specified to account for both unit heterogeneity, captured by pure fixed effects, and interactive heterogeneity, captured by the impact coefficients of the model (e.g., Debarsy and Ertur, 2010). Estimation by (quasi) maximum likelihood (QML) and generalized method of moments (GMM) are most common for spatial panel models (e.g., Elhorst, 2010); we employ QML.

Various specifications are feasible, with the spatial autoregressive model (SAR) and the spatial error model (SEM) frequently adopted to account for spatial effects. The SAR model, also known as the spatial lag model, is typically used when the dependent variable for a given region is jointly determined with that of its neighbors, whereas the SEM model has a standard panel specification but views the error terms as correlated across space (e.g., Anselin, Le Gallo, and Jayet, 2006). Both specifications can be combined to construct a higher-order spatial model (SARAR) that can be used to test whether a SAR, SEM or SARAR specification is more appropriate. For time period t, the SARAR specification is:

$$(1) \qquad \boldsymbol{Y}_t = \rho \boldsymbol{W}_N \boldsymbol{Y}_t + \boldsymbol{X}_t \boldsymbol{\beta} + \boldsymbol{\alpha} + \gamma_t \boldsymbol{\iota}_N + \boldsymbol{\varepsilon}_t; \boldsymbol{\varepsilon}_t = \lambda \boldsymbol{M}_N \boldsymbol{\varepsilon}_t + \boldsymbol{v}_t; \boldsymbol{v}_t \sim N(0, \sigma_v^2 \boldsymbol{I}_n),$$

where $\boldsymbol{Y}_t$ is the $N \times 1$ lagged dependent variable, $\boldsymbol{X}_t$ is the $N \times 5$ matrix of explanatory variables (see table 1 for descriptions), $\boldsymbol{\beta}$ is the 5×1 vector of coefficients, $\boldsymbol{\alpha}$ is an $N \times 1$ vector of unit effects, γ_t is the scalar time effect, $\boldsymbol{\iota}_N$ is an $N \times 1$ vector of ones, $\boldsymbol{W}$ and $\boldsymbol{M}$ are row-normalized spatial weight matrices, ρ is the spatial autoregressive coefficient, and λ is the spatial autocorrelation coefficient.[8] Here, the data are sorted first by time and then by spatial units - strata 26, 27, etc. for 1961 followed by strata 26, 27, etc. for 1966, and so on.

The spatial weight matrices $\boldsymbol{W}$ and $\boldsymbol{M}$ are $N \times N$ and assumed to remain constant over time. The elements are non-negative and specify the strength and structure of the relationship between a region and its neighbors. The row elements represent the effect of all other regions on a particular stratum and the column elements represent the effect of a particular stratum on all other regions (e.g., Elhorst, 2010). The choice of weight matrix is rather arbitrary; thus, we consider a Queen-based contiguity as well as an inverse distance matrix, both of which are common in the spatial econometrics literature. For Queen-based contiguity, all regions sharing a border or vertex are considered neighbors and the corresponding element in the weighting matrix is set to 1; all other elements are 0. For inverse distance, we use the inverse of the arc distance separating the strata centroids. Thus, all regions are neighbors, but the strength of the relationship is weaker for regions that are farther away. We do not allow for the possibility of self-influence; therefore, all diagonal elements are zero.

For computational reasons, the weighting matrices are row-standardized so that each row sums to 1. Finally, for stationarity, $\frac{1}{\omega_{min}} < \rho < \frac{1}{\omega_{max}}$ and $\frac{1}{\omega_{min}} < \lambda < \frac{1}{\omega_{max}}$, where ω_{min} and ω_{max} are the smallest and largest eigenvalues of the weight matrix. However, the smallest eigenvalue of a row-standardized weight matrix could be less than -1 (e.g., Elhorst, 2010).

From equation (1), it is clear that the SAR and SEM models are special cases of the SARAR model, in which λ or ρ is restricted to be zero, respectively. Following the procedures outlined in

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[8] Note that $\boldsymbol{Y}_t$ appears on both sides of the equation because we model a spatial effect where the waterfowl populations in neighboring regions are also explanatory variables.

Anselin, Le Gallo, and Jayet (2006), or Debarsy and Ertur (2010), Lagrange multiplier (LM) tests are constructed to determine the most appropriate specification. However, Debarsy and Ertur differ from Anselin, Le Gallo, and Jayet with regard to the method adopted to demean the variables to eliminate the fixed effects. Anselin, Le Gallo, and Jayet (2006) employ a traditional within transformation, whereas Debarsy and Ertur follow a method outlined in Lee and Yu (2010). Lee and Yu note that the traditional within transformation applied to SARAR models causes the ML estimators to be inconsistent unless N is large. In addition, although Lee and Yu's Monte Carlo results suggest that estimator bias for $\boldsymbol{\beta}$ is small regardless of which method is used to transform the data, they find that the bias of the variance estimator is roughly ten times larger using the standard within transformation when N and T are both small. As this estimator plays a crucial role in inference, such a bias may be problematic for traditional tests on the mean function coefficients. Since $N = 15$ and $T = 10$ in our study, such issues are relevant. Consequently, we obtained estimates for both types of transformed data and compared them.

In order to choose between spatial panel models, we consider several LM tests. Specifically, we undertake an LM test proposed by Anselin, Le Gallo, and Jayet (2006) that tests for a spatially lagged dependent variable and spatial autocorrelation in cross-sections and an LM test suggested by Elhorst (2010) that tests for the presence of a spatial lag or spatial error term when the other is assumed to be present. Both of these LM tests are extensions of tests proposed originally by Anselin et al. (1996). Debarsy and Ertur (2010) test similar hypotheses with variables transformed according to the Lee and Yu (2010) method.

Our spatial panel models are estimated using Matlab routines created by Elhorst (2010) and Debarsy and Ertur (2010).[9] The spatial weight matrices were created using ArcGIS. Because Debarsy and Ertur's code only models unit-specific effects, we modified their code following the procedure outlined in Lee and Yu (2010) to account for additional temporal fixed effects. As Monte Carlo simulations that we undertake yield results similar to those presented in Lee and Yu, we assume that our modifications are appropriate.

Empirical Results

Empirical results and various sensitivity tests are provided in this section; greater details are available in Wong, van Kooten, and Clarke (2011). In general, the coefficient estimates have the expected signs (see table 1) and appear to be robust to various specifications and assumptions.

Spatial Panel Models

Table 3 presents the LM test results for choosing between SAR, SEM and SARAR; they indicate that spatial effects are relevant and a preference for either the SAR or SEM specifications, but not the SARAR model. Irrespective of the weight matrix, the Debarsy and Ertur (2010) tests support a SAR model whereas the Anselin, Le Gallo, and Jayet (2006) tests are inconclusive. In addition, likelihood ratio (LR) tests for the significance of two-way fixed effects provide support for the inclusion of both unit and temporal effects. Support for the SAR specification is somewhat stronger than for the SEM specification, especially since Jarque and Bera (1987) tests suggest the likelihood that errors are not normally distributed under the direct approach, thereby perhaps calling into question the reliability of the QML estimates and subsequent LM tests. Accordingly, we proceed with the SAR specification; table 4 reports the estimated SAR models.

The coefficient estimates suggest that, for a one percentage point increase in cropland (at the expense of uncultivated land), duck density is predicted to decline by 5%. For summerfallow or pasture, the predicted decrease is 6%. The direct and transformation approaches in the SAR model produced virtually identical estimates of $\boldsymbol{\beta}$. Other than different estimates for ρ and σ_V^2, the only

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[9] The spatial econometrics toolbox is available at http://www.spatial-econometrics.com.

Table 3: Tests to Detect Spatial Effects

	Queen Contiguity		**Inverse Distance**	
	AE[a]	**DE**[b]	**AE**[a]	**DE**[b]
(1) LMJ	–	30.07	–	28.79
$H_0 : \rho = \lambda = 0$		(0.00)		(0.00)
(2) LM_{ρ}	27.47	19.57	22.86	15.97
$H_0 : \rho = 0$	(0.00)	(0.00)	(0.00)	(0.00)
(3) LM_{λ}	27.92	29.81	22.14	28.47
$H_0 : \lambda = 0$	(0.00)	(0.00)	(0.00)	(0.00)
(4) $LM_{\lambda\|\rho}$	1.07	0.07	0.24	0.42
$H_0 : \lambda = 0$, with ρ possibly different from 0	(0.30)	(0.80)	(0.63)	(0.52)
(5) $LM_{\rho\|\lambda}$	0.62	105.12	0.96	96.70
$H_0 : \rho = 0$, with λ possibly different from 0	(0.43)	(0.00)	(0.34)	(0.00)
Chosen model	*SAR or SEM*	*SAR*	*SAR or SEM*	*SAR*
LR test for two-way effects	273.38	276.07	264.09	271.04
	(0.00)	(0.00)	(0.00)	(0.00)

Notes: p-values are in parentheses from a χ^2 limiting null distribution. SAR refers to the spatial lag model; SEM refers to the spatial error model.

[a] Anselin, Le Gallo, and Jayet (2006) and Elhorst (2010) tests - standard within transformation.

[b] Debarsy and Ertur (2010) tests - Lee and Yu (2010) pseudo-within transformation.

Table 4: Effect of Agricultural Land Use on Duck Populations, Spatial Panel Models

	Queen Contiguity		**Inverse Distance**	
	Direct[a]	**LY**[b]	**Direct**[a]	**LY**[b]
lPND	0.412	0.400	0.415	0.398
	(0.06)***	(0.07)***	(0.07)***	(0.07)***
SPI	0.031	0.025	0.032	0.022
	(0.03)	(0.03)	(0.03)	(0.03)
CPL	−0.049	−0.045	−0.054	−0.052
	(0.02)***	(0.02)***	(0.02)***	(0.02)***
SMF	−0.059	−0.055	−0.066	−0.061
	(0.02)***	(0.02)***	(0.02)***	(0.02)***
PST	−0.056	−0.055	−0.039	−0.029
	(0.02)***	(0.03)**	(0.02)*	(0.03)
P	0.457	0.599	0.461	0.681
	(0.07)***	(0.08)***	(0.09)***	(0.10)***
σ^2	0.0576	0.0663	0.0616	0.0710
Jarque-Bera[c]	12.025	0.475	11.364	0.224
	(0.00)	(0.79)	(0.00)	(0.89)

Notes: Except where noted, standard errors are in parentheses. Single, double, and triple asterisks (*, **, ***) represent significance at the 10%, 5% and 1% level using a two-sided test for ρ and λ; one-sided test for all other coefficients.

[a] Direct maximum likelihood in which the common parameters and fixed effects are jointly estimated.

[b] Lee and Yu (2010) data transformation with quasi-maximum likelihood estimation.

[c] $\chi^2(2)$ p-values are in parentheses.

notable difference is the coefficient estimate for PST. With inverse distance as the spatial weight matrix, PST is not significant under the LY approach, whereas it is significant at the 10% level under the direct approach. Again, this is likely an issue with including time-invariant effects while also trying to model a slow-moving variable. Interestingly, the coefficient estimates for the land use variables appear to be influenced more by the weight matrix than the estimation approach, whereas the strength of the spatial autocorrelation is influenced more by the estimation approach.

However, interpreting the coefficients as marginal effects neglects the simultaneous feedback characteristic of the SAR model and any potential indirect effects (LeSage and Pace, 2009). By expanding equation (1) and setting λ equal to zero, the SAR specification is:

$$(2) \qquad \boldsymbol{Y}_t = \rho \boldsymbol{W}_N \boldsymbol{Y}_t + \beta_1 \boldsymbol{lPND}_t + \beta_2 \boldsymbol{SPI}_t + \beta_3 \boldsymbol{CPL}_t + \beta_4 \boldsymbol{SMF}_t + \beta_5 \boldsymbol{PST}_t + \boldsymbol{\alpha} + \gamma_t \boldsymbol{\iota}_N + \boldsymbol{\varepsilon}_{it}.$$

Any spillover effects can be obtained by expressing equation (2) in its reduced form:

$$(3) \qquad \begin{aligned} \boldsymbol{Y}_t = {} & (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_1 \boldsymbol{lPND}_t + (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_2 \boldsymbol{SPI}_t + (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_3 \boldsymbol{CPL}_t + \\ & (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_4 \boldsymbol{SMF}_t + (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_5 \boldsymbol{PST}_t + \\ & (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} (\boldsymbol{\alpha} + \gamma_t \boldsymbol{\iota}_N) + (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \boldsymbol{\varepsilon}_{it}. \end{aligned}$$

By deriving the matrix of partial derivatives of $\boldsymbol{Y}_t$ with respect to the land use variables, we can determine the direct and indirect effects of agricultural land use changes on waterfowl populations:

$$(4) \qquad \frac{\partial \boldsymbol{Y}_t}{\partial \boldsymbol{CPL}_t} = (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_3, \frac{\partial \boldsymbol{Y}_t}{\partial \boldsymbol{SMF}_t} = (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_4, and \frac{\partial \boldsymbol{Y}_t}{\partial \boldsymbol{PST}_t} = (\boldsymbol{I}_N - \rho \boldsymbol{W})^{-1} \beta_5.$$

The diagonal elements of the matrices in equation (4) are the direct effects, whereas the off-diagonal elements are indirect effects (Debarsy and Ertur, 2010). Using $\frac{\partial \boldsymbol{Y}_t}{\partial \boldsymbol{CPL}_t}$ as an example, let c_{ij} denote the matrix elements where $i, j = 26, \ldots, 40$. Then c_{ij} is the effect of a one percentage point increase in cropland in stratum j on waterfowl populations in stratum i. Using summary measures described in LeSage and Pace (2009, 2010), we can calculate an average total impact, an average direct impact and an average indirect impact. Table 5 presents these measures and their associated t-statistics. Empirically simulated values of ρ and β are used to generate empirical distributions for the impact measures (see LeSage and Pace, 2009); the t-statistics are based on 10,000 sampled raw parameter estimates.

The average total impact for each variable is derived by averaging the row-sums of the appropriate matrix in equation (4). Again, using $\frac{\partial \boldsymbol{Y}_t}{\partial \boldsymbol{CPL}_t}$ as an example, the average total impact is calculated as $\frac{1}{N} \sum_j \sum_i c_{ij}$. The average direct impacts are obtained by taking the average of the diagonal elements (e.g., $\frac{1}{N} \sum_i c_{ii}$). The indirect impact is the difference between the total and direct impacts or the average of the row-sums of the off-diagonal elements (e.g., $\frac{1}{N} \sum_j \sum_{i \neq j} c_{ij}$).

To explain the interpretation of the impact measures, we consider the impact measures for cropped land (CPL) for the direct ML approach with Queen contiguity spatial weights. From table 5, the average direct impact of a one percentage point increase in cropped land on duck density is -5.2%. The corresponding coefficient estimate from table 4 is -4.9%. The difference of -0.03% represents the feedback effects that return after passing through neighboring strata. Since this difference is small, it is unlikely to be of practical significance.

The indirect impacts are also considered spatial spillovers (LeSage and Pace, 2009). They can be interpreted as the impact on a typical stratum if cropped land through-out the entire PPR increased by one percentage point. Since the indirect impact for CPL is negative, this indicates that duck density in a typical stratum would decrease by 3.7%. All else equal, the indirect impacts are larger using an inverse distance weight matrix because there are more neighbors—an increase in CPL leads to a larger reduction in waterfowl numbers as more neighbors are considered in the weighting matrix used to account for spatial autocorrelation.

Table 5: Impact Measures

Queen Contiguity

	Direct			LY		
	CPL	SMF	PST	CPL	SMF	PST
Direct	−0.052	−0.063	−0.060	−0.052	−0.062	−0.062
	(−3.05)***	(−3.76)***	(−2.41)***	(−2.63)***	(−3.13)***	(−2.11)**
Indirect	−0.037	−0.046	−0.043	−0.061	−0.074	−0.074
	(−2.14)**	(−2.37)***	(−1.84)**	(−1.59)*	(−1.48)*	(−1.31)*
Total	−0.090	−0.109	−0.103	−0.113	−0.136	−0.136
	(−2.75)***	(−3.24)***	(−2.23)**	(−2.06)**	(−2.10)**	(−1.67)**

Inverse Distance

	Direct			LY		
	CPL	SMF	PST	CPL	SMF	PST
Direct	−0.057	−0.069	−0.041	−0.060	−0.071	−0.034
	(−3.28)***	(−4.01)***	(−1.62)*	(−1.83)**	(−2.02)**	(−0.94)
Indirect	−0.044	−0.053	−0.032	−0.102	−0.121	−0.057
	(−2.01)**	(−2.17)**	(−1.30)*	(−0.29)	(−0.31)	(−0.24)
Total	−0.101	−0.122	−0.073	−0.163	−0.192	−0.091
	(−2.79)***	(−3.22)***	(−1.52)*	(−0.43)	(−0.45)	(−0.34)

Notes: t-statistics in parentheses are based on 10,000 sampled raw parameter estimates of the SAR model. Single, double, and triple asterisks (*, **, ***) represent significance at the 10%, 5% and 1% level.

Additionally, the magnitude of the spatial autocorrelation coefficient ρ is much larger using the Lee and Yu (2010) transformation, leading to larger average indirect impacts. It is a mistake, however, to interpret the magnitude and significance of ρ as representing the spatial spillover effect. For example, the indirect impacts of the Lee and Yu approach with an inverse distance matrix are not significantly different from zero, whereas ρ is significant. If we interpret ρ as the spatial spillover effect, we would incorrectly infer that the agricultural variables exert even larger negative impacts on duck density.

Conclusions

Our aim was to determine the impact of agricultural land use changes on waterfowl abundance in the Canadian Prairie Pothole Region. Recognizing that empirical results and conclusions are highly contingent on the strategies and methods used to obtain them, we examined various spatial panel models to ascertain the robustness of the empirical results. In general, the conclusions hold up fairly well.

Spatial autoregressive models allow the derivation of measures for assessing direct and indirect impacts. The estimated direct impacts are similar to estimates obtained from standard panel models (see Wong, van Kooten, and Clarke, 2011), but estimated impacts exceed those predicted by the standard model when spillover effects are also included.

Results suggest that when wetlands are lost at one location ducks do not compensate by breeding in other locations, or, if they do, there is an overall reduction in fecundity. If indeed duck populations are below those considered socially optimal (as noted in the introduction), this makes programs to retain or create wetlands all the more worthwhile, as additional wetlands in one location will result in enhanced productivity of ducks in another. It would appear that there are economies of scale for ducks in wetlands provision.

Because geographically referenced data are used to answer the research question, the use of a spatial model is most logical. In this particular case, the bias resulting from not explicitly modeling

Table 6: Estimates of Conservation Dollars Spent Per Duck in 2006

Item	Standard[a]	Spatial A[b]	Spatial B[c]
Δ Duck Density	+0.44	+0.67	+0.85
Δ Ducks in PPR	254,438	385,538	486,881
Expenditure per Duck	$204	$135	$107

Notes: The Canadian Prairie Pothole Region is roughly 575,000 km^2.
[a] Standard panel specification without interaction effects (see Wong, van Kooten, and Clarke, 2011).
[b] Spatial lag model using a Queen contiguity weight matrix and demeaned data.
[c] Spatial lag model using a Queen contiguity weight matrix and data transformed according to the Lee and Yu (2010) method.

spatial dependencies may not be practically significant, but neglecting possible indirect impacts only gives researchers a partial picture of how agricultural land use changes affect waterfowl populations. For example, one spatial model estimates that the direct impact of a 1% increase in cropland will result in a 5% decline in duck density for a typical stratum, although the total impact is much larger (9%) because land use changes in one region not only affect the waterfowl population for that stratum, but also impact the population in surrounding regions. Thus, the standard approach that ignores spatial interdependence underestimates effects.

One possible application for the results of this study is assessing conservation program efficiency. As a crude illustration, consider the $1.2 billion that the North American Waterfowl Management Plan has spent from 1986-2008 to secure 25,500 km^2 of land in the Canadian Prairie Pothole Region. Simply averaging over this 23-year period, we determine that 1,100 km^2 of farmland was secured annually at a cost of $52 million. In 2006, 1,100 km^2 constituted 0.25% of farm area and waterfowl density was roughly thirty ducks per square kilometer. The conservation dollars spent securing habitat to increase the waterfowl population by a single duck can be estimated using these figures and the results from the various models. These calculations are presented in table 6.

For further simplicity, we assume that the 1,100 km^2 of secured land came entirely from cropland. In that case, the estimates range from $107 to $204 per duck, although these estimates are on the high side because land taken from summerfallow or pasture to maintain or create wetlands would be less costly to secure. These estimates support earlier work by van Kooten and Schmitz (1992), and van Kooten (1993), who found that NAWMP spent large sums of money with little increase in waterfowl numbers. In many cases, subsidies to landowners were spent protecting questionable wetlands and habitat.

Perhaps the most important conclusion from our empirical analysis is that, when determining the benefits of conserving wetlands, biologists need to look beyond the impact on nearby duck numbers and measure population increases in neighboring strata as well. By considering these indirect or spillover impacts of wetlands protection, the costs of preventing declines in waterfowl numbers or enhancing populations are also lower.

Admittedly, the models employed in this study were not complex. For example, we did not examine higher-order dynamic processes or explore hierarchical models.[10] More importantly, the spatial unit chosen for this analysis can be improved upon. Given that waterfowl data are available at the transect level and agricultural data are available for census consolidated subdivisions, it would be interesting to examine spatial interactions at a finer spatial resolution. There is room to incorporate these aspects into future analyses to provide stronger inferences about the impact of anthropogenic activity on waterfowl populations.

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[10] We considered simple dynamic versions of the models in this study, but the results were not much different from those reported here (and thus not reported); however, we did not examine higher-order and nonlinear dynamic processes.

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