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Change of vegetation cover in the US–Mexico border region: illegal activities or climatic variability?

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Abstract
This study explores both human activities and climatic factors to examine the change of vegetation cover in the US Southwest border region—a region that is almost 2000 miles long and with rich natural resources but mostly a sensitive semi-arid/arid ecosystem. It is the first study that integrates large-scale remote-sensing data with multiple layers of socio-economic data and aims to inform critical policy issues related to natural resources management and border security enforcement in the region. A fixed effects panel data regression model is deployed to control for spatial heterogeneities and macro trends in vegetation cover distribution. The results show that both illegal and legal activities have statistically significant impacts on the border region vegetation cover between 2008–2017. Within a 3 mile buffer of the border, a one-standard-deviation increase in illegal border-crossings would lead the vegetation cover index (measured between 0–100) to decline by 4.1% of its standard deviation. A one-standard-deviation increase in border patrol agent staffing would lead the vegetation cover index to decline by 19.0% of its standard deviation. Employment density (a proxy for the dominant local economic activities) in the border county economies and growing season monthly mean temperature are also statistically significant in driving the change of vegetation cover. These findings provide important implications for natural resources management and border security policy in the region, as well as for the quality of life in the local border communities.

1. Introduction
Vegetation cover plays critical roles in various biophysical processes related to global climate and terrestrial biogeochemistry in the evolution of natural ecosystems (Nemani et al 1996, Verburg et al 2009). In the meantime, human activities have been influencing and reshaping the land cover since the beginning of history (Lambin et al 2001, Briggs et al 2002, 2007, Barger et al 2011, Hostert et al 2011). For a long time, the impact of human activities on vegetation cover had been understudied, especially from an interdisciplinary perspective (Meyer and Turner 1992, Lambin 1997, Bonilla-Moheno et al 2012). One of the main reasons for the lack of attention on the driving forces of vegetation cover change was the availability of precise spatial data measuring land covers. The rise of remote-sensing data in the recent decades has provided the opportunities for researchers worldwide to investigate the change of vegetation cover at much finer resolutions and much larger scales (Townshend et al 1991, Currit 2009). The high-resolution remote-sensing data have seen widespread applications in many industries, especially in agricultural and environmental management. Up until recent years, however, integrating remote-sensing data with socio-economic objects is still a challenge to many researchers (Verburg et al 2009, Blaschke 2010). Such an integration process becomes a bottleneck of many otherwise valuable remote-sensing applications.

This study demonstrates the possibility of integrating large-scale remote-sensing datasets with multiple layers of socio-economic data to inform public debates and critical policy issues. In particular, this study focuses on the US Southwest border region—an area known for its rich natural resources and unique landscapes, but also for its sensitive semi-arid/arid ecosystem. In recent years, illegal activities (e.g.
unauthorized trails, trash left behind, and unattended campfires in the US–Mexico border region have seriously disturbed local vegetation cover and the ecosystem (Jacoby-Garrett 2018). Because of the semi-arid/arid climate and spatially limited water resources, the ecosystem in the region is sensitive to drought and warmth (Williams et al 2010, Villarreal et al 2016). Some of the severely affected areas will have great difficulty recovering or may never return to the original vegetation cover. One noticeable trend is the woody encroachment near the southeast part of the border region (Brown and Archer 1999, Briggs et al 2005). In those affected areas, brushy and woody species have increased in density and cover over the last century (Van Auken 2000). Warming of the climate, overgrazing, and human activities are the main contributing factors to the change (Van Auken 2000, Kupfer and Miller 2005, Briggs et al 2007, Williams et al 2010).

Two streams of evidence show that the vegetation cover in the US Southwest border region has gone through a significant change in recent decades. One stream is the statistical evidence from remote-sensing data on land cover (e.g. McIntyre and Weeks 2002), which is explored in this study. Another stream is the anecdotal evidence collected by different organizations located in the border region, for example, the National Park Service and the Bureau of Land Management (Goodwin 2000, Terrell 2006, Meierotto 2014). In general, two categories of drivers of vegetation cover change have been identified in the literature: human activities and climatic variability. In the Southwest border region, illegal border-crossings make up a substantial part of the human impact on the natural ecosystem. The critical research question is: illegal activities or climatic variability? Or more generally, what is driving the change of vegetation cover in the Southwest border region?

The illegal border-crossings have been a subject of both research and policy debate since the late 1960s, following the end of the Bracero Program in 1964. Up until the early 1990s, popular crossing points were all next to major cities such as San Diego and El Paso. After the implementation of Operation Gatekeeper in 1994, illegal aliens started choosing more remote routes into areas previously covered with dense natural vegetation cover—a so-called spatial displacement effect (Rossmo et al 2008). Figure 1 shows that the number of illegal alien apprehensions (as a proxy for illegal crossings) has declined gradually since the late 1990s except for one sector—Rio Grande Valley. The number of border patrol agents has increased during the same time period (figure 2). Presumably, the technologies deployed by the border patrol agents have improved over the same period. A critical question to ask here is: what is the environmental impact of this spatial displacement effect? For instance, the Rio Grande Valley region is known for its remoteness and rich vegetation cover. The increase in the number of apprehensions in the Rio Grande Valley sector since the late 2000s could be an indication of potential environmental impact due to the spatial displacement effect.

The literature finds that this shift of illegal crossings flow has imposed serious impacts on the border region vegetation cover (Orrenius 2001, McIntyre and Weeks 2002, Sundberg and Kasperman 2007). Most of the existing studies, however, focus on a small area with mainly anecdotal evidence. The literature lacks a border-wide quantitative analysis of the potential impact of illegal crossings. This study aims to make such a contribution. In the meantime, climatic variabilities have also been identified as significant drivers.
of vegetation cover change (Diouf and Lambin 2001, Park and Sohn 2010). In the Southwest, the changing climate has had significant impacts on the agricultural system (MacDonald 2010, Wang 2016). It is reasonable to expect that the natural ecosystem is not immune to such impacts. This study takes into account variations in both precipitation and temperature. Other important control variables include: (1) the employment density that reflects the intensity of local economic activities in the region; and (2) the number of border patrol agents in the region. Presumably, such (legal) activities can also have an impact on the vegetation cover (e.g. Meierotto 2012).

Overall, this study integrates human activities (legal and illegal) and climatic factors to examine the change of vegetation cover in the Southwest border region between 2008 and 2017. To control for spatial heterogeneities and macro trends in the change of vegetation cover, a fixed effects panel data regression model is deployed. The findings provide important implications for natural resources management and border security policy in the region, as well as for the quality of life in the local border communities.

2. Methods

2.1. Regression model
Change of vegetation cover on a parcel of land is a spatial-temporal process. This paper deploys a two-way (spatial and temporal) fixed effects panel data model to identify the drivers of vegetation cover change in the Southwest border region. The dependent variable (VegCover) is an index measuring the canopy density/greenness of the vegetation cover (discussed in the Vegetation Cover Data section). Independent variables include station-level number of agents (Staffing), station-level number of illegal alien apprehensions (Apprehensions), county-level employment density (Employment) as an indicator of the intensity of economic activities, parcel-level growing season average monthly precipitation (PPT) and temperature (Tmean). Specifically, the following model is estimated:

\[
VegCover_{it} = \beta_1 Staffing_{it} + \beta_2 Apprehensions_{it} + \beta_3 Employment_{it} + \beta_4 PPT_{it} + \beta_5 Tmean_{it} + \alpha_i + \delta_t + \epsilon_{it},
\]

where \(\alpha_i\) represents time-invariant parcel-level fixed effects, and \(\delta_t\) represents time-varying year fixed effects. The fixed effects control for both spatial heterogeneities and any macro trends in the change of vegetation cover. \(\epsilon_{it}\) is an idiosyncratic error. The model can be estimated using a standard approach as suggested in Baltagi (2013). Other specifications are discussed in the results section.

2.2. Study area
The study area covers the US Southwest border region. According to the US Geological Survey (USGS), the US–Mexico border is estimated to be 1,933 miles long.\(^1\) This study considers an up-to 30 mile buffer of the boundary on the US side, which covers 33 counties in California, Arizona, New Mexico, and Texas. There are 72 US border patrol stations in these four states, 40 of them are within 30 miles of the border (figure 3). Most of the region has a semi-arid/arid climate and has experienced increased heat/droughts in recent decades.\(^2\) The changing climatic conditions have been identified as a major factor influencing both the

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\(^1\) https://fas.org/sgp/crs/misc/RS21729.pdf (Accessed: 30 October 2018).
\(^2\) https://nca2014.globalchange.gov/report/regions/southwest (Accessed: 30 October 2018).
natural ecosystem and the agricultural system in the region (MacDonald 2010, Wang 2016). Figure 3 shows the overlay of the 30 mile buffer, border patrol stations in the Southwest sectors, and the US counties on/near the border. In the following analysis, different buffer sizes ranging from 3 mile to 30 mile are considered.3

2.3. Vegetation cover data
Most of the remote-sensing vegetation cover data are developed from raw satellite imagery (e.g. Landsat 8). Among many land cover datasets (e.g. USGS—global land cover characterization, USDA—cropland data layer (CDL), MODIS Vegetation Indices such as NDVI and EVI), this study uses the CDL data to derive a vegetation cover index for two reasons: (1) the CDL data have a high-resolution of 30-by-30 meter; and (2) CDL is the best existing dataset that classifies agricultural land use (especially cropland) from land cover in the US. In this study, it is important to remove the agricultural system from the natural system so that the impact of human activities on natural vegetation cover can be accurately estimated.

The majority of the land cover in the Southwest border region is shrubland which makes up more than 70% of the total land cover. Figure 4 shows the proportions of different land covers in a 3 mile buffer belt of the border. Following shrubland, the other major land covers are grassland/pasture, barren, and forest/wetlands. Figure 4 reveals that there has been a decline in forest and grassland during the study period (2008–2017), while barren and shrubland have increased. The increase in the proportion of shrubland has been statistically significant. Figures A1 and A2 in the appendix show the proportions of land cover with buffer sizes of 10 mile and 30 mile, respectively. The trends of vegetation cover change are very similar across data samples with different buffer sizes.

This study removes all cropland, developed land, and water bodies.4 Among the remaining vegetation covers, the following numeric values are assigned to compute an aggregate vegetation cover index. Barren is assigned a value of zero; shrubland is assigned a value of 0.5; grassland/pasture and forest/wetlands are assigned a value of one. 30-by-30 meter CDL pixels are aggregated by averaging to a cell size of 4-by-4 km (PRISM climate data grid), resulting in a vegetation cover index between zero and one. The aggregation process ignores all of the CDL pixels with NA values and all of the removed CDL pixels. Figure 5 illustrates the data aggregation process. The selected PRISM cell centered at geographic coordinates (31.169, −105.750) represents an area of active cropland as indicated in the Google Maps view. This aggregation (resampling) of data is necessary for two reasons. First, it effectively reduces the computational burden and makes a fixed effects panel data regression feasible. Second, all of the independent variables are measured at a resolution that is either at or beyond the PRISM cell size. No new information can be learned by estimating a model at the CDL resolution. To facilitate the regression analysis and the interpretation of results,

3 Given that this study’s climatic data (PRISM) resolution is at 4-by-4 km, 3 mile is the smallest buffer size that can be chosen while getting a continuous set of parcels (4-by-4 km as well) along the border.

4 Depending on the buffer size of the sample, 9%–18% of the CDL pixels (cropland, developed land, and water bodies) are removed. For example, for the 30 mile buffer sample, on average 9.38% of the pixels are removed. For the 3 mile buffer sample, on average 17.55% are removed.
the vegetation cover index is then linearly scaled to the range between 0 and 100. The unit of analysis is the 4-by-4 km PRISM cell.

2.4. Illegal crossings data
Data on illegal border-crossings have been difficult to compile (Argueta 2016). In this study, illegal crossings at each PRISM cell are approximated by the number of illegal alien apprehensions made by nearby border patrol stations. The USCBP only publishes illegal alien apprehension data at the sector level. The station level data are generated based on a simple average (total sector apprehensions/number of stations within the sector). The simple average could potentially lead to an over/underestimation of illegal crossings and

Note that the value of the index does not have to be restricted to [0,100]. For instance, a value of 105 can still be interpreted as improved vegetation cover. If it is otherwise restricted to [0,100], then a generalized linear model with a logit link may be used.

5 A Freedom of Information Act request has been submitted to access both the apprehension data and the staffing data at station level. At the time of this writing, the request has not been approved.
introduce an attenuation bias. To some extent, the large sample size in this study can help counterbalance the attenuation bias and improve identification. A similar procedure is followed to approximate the station level border patrol agent staffing variable.

Given the station level apprehension and staffing data, the nearest three stations are used to compute the corresponding Staffing and Apprehensions variables (as a weighted average) for each PRISM cell. Due to the non-homogeneous landscape and topography in the region, illegal crossings occurring at a given location may not necessarily get caught by patrol agents from the nearest station. The reciprocal of the squared distance from the PRISM cell to a given station is used as a weighting factor. A similar approach using distance as weights has been adopted in other studies (e.g. McDougal et al. 2015). It is uncertain whether the observed number of apprehensions can be used to approximate the actual but unobserved number of illegal border-crossings. The uncertainty is diminished if the probability of apprehension is stable. Espen-shade and Acevedo (1995) showed that the estimated monthly apprehension probability across all the Southwest sectors is fairly stable and was around 30% from the 1970s to 1980s. This is supporting evidence for using the number of apprehensions to approximate the volume of illegal border-crossings. This study maintains the assumption that the apprehension probability is stable during the study period.

2.5. Climatic data
The climatic data (average precipitation and temperature) used in this study are assembled from the monthly PRISM data for recent years developed by Oregon State University. The data are model-generated using climatologically-aided interpolation which consists of a long-term average pattern as a first-guess of the spatial pattern of climatic conditions for a given month and a refinement based on actual weather observations. Since the Southwest region has a relatively long growing season and the natural vegetation is usually less sensitive to weather conditions compared to crops, we choose a 10 month growing season from February to November in the study year. The average precipitation (PPT) and the average temperature (Tmean) are computed as the average of the mean values from the 10 growing-season months. Given that the climate data are already at the PRISM grid, no aggregation is needed.

2.6. Data on other control variables
Another important control variable is the employment density in the local economies. Presumably, local economic activities as measured by employment density have a large and dominant impact on the natural vegetation cover through various processes including land development, production, transportation, recreation, and etc. The employment data are drawn from the US Census County Business Pattern (CBP) database. The CBP data report three main indicators of economic activities: the number of business establishments, total employment, and the total payroll amount. The three indicators are highly correlated (with correlation coefficients larger than 0.9 in the study area). This study chooses employment density to represent the intensity of local economic activities. The variable (Employment) is computed as the employment per square mile at the county level. All the PRISM cells inside a county share the same employment density. For a few cells that span over multiple counties, a simple average of employment densities from all overlapped counties is used. To account for the fact that the CBP data are collected in the middle of the year and the potential delay in the feedback between human activities and the ecosystems, one-year lagged employment density is used. Table A1 in the appendix presents the summary statistics of variables for the 3 mile buffer area.

3. Results
To gauge the robustness of the results, samples with different buffer sizes (3 mile, 6 km, 5 mile, 10 mile, 20 mile, 25 mile, 30 mile) are analyzed. Intuitively, one may expect that the illegal crossings only affect the vegetation cover that is very close to the border. However, empirical studies have found that the impact on vegetation cover due to illegal border-crossing activities can persist far into US territory. Billington et al. (2010, pp 109–122), for example, shows that Ironwood Forest National Monument suffered from serious environmental degradation due to illegal border-crossing activities including illegal entrants and drug trafficking even though it is more than 100 km from the border. Therefore, the up-to 30 mile buffers can be considered a reasonable choice of the study area.

The variables of key interest in the regression analysis are Staffing and Apprehensions. Figure 6 plots the point estimates along with their 95% confidence intervals for both variables at different buffer sizes. Both variables have a statistically significant and negative impact on the vegetation cover. This finding echoes with two major results in the literature. First, illegal crossings can significantly damage the vegetation and the ecosystem in the border area (Carter et al 1996, McIntyre and Weeks 2002, Meierotto 2014). Second, the increasingly enforced border security involves more and more off-road vehicle use. Such security-related activities can also cause serious damage to the sensitive vegetation and ecosystem in the Southwest border region (Meierotto 2012, Esque et al 2016, Villarreal et al 2016). Lenihan (2016) synthesized both impacts as a compounding environmental effect.
jointly caused by illegal activities and border security enforcement.

Referring to figure 6 and table 1, a one-unit increase in illegal crossings (1000 apprehensions) can cause vegetation cover to decline by 0.0721 units (in the index range of [0, 100], hereinafter), which is statistically significant. To put this in context, a one-standard-deviation increase in illegal crossings (7900 apprehensions) would lead the vegetation cover to decline by 0.57 units, which is 4.1% standard deviation of the dependent variable. A one-unit increase in border patrol agent staffing (one additional agent) can cause vegetation cover to decline by 0.0186 units, which is statistically significant. To put this in context, a one-standard-deviation increase in border patrol agent staffing (142 agents) would lead the vegetation cover to decline by 2.64 units, which is 19% standard deviation of the dependent variable. Given the potential trade-off between border security enforcement and reduction in illegal border-crossing, is increasing border patrol agents an environmentally effective way to control illegal crossings? The current study suggests a tentative answer, though contingent on the limited data. A thorough answer to the question requires knowledge of the spatial-temporal distribution of border patrol agents at a finer scale, which points to a fruitful direction of future research. Also, it is worth noting that since the statistical distributions of Staffing and Apprehensions are not necessarily the same, any comparisons of the estimated marginal effects should be made with caution.

Table 1 presents all of the coefficient estimates for the 3 mile buffer sample area. As one would expect, the intensity of economic activities as measured by lagged employment density has a negative impact. Looking at column (4), an estimate of $-0.1648$ implies that for a one-standard-deviation increase in employment density (63.38 per square mile) the vegetation cover index declines by 10 units, which is a dramatic change. This result is expected given that local (legal) economy is supposed to be the dominant human activity. It is worth stressing that it is important to control such a major effect when estimating the impact of illegal crossings. The estimated impacts of precipitation level are not very robust across samples with different buffer sizes (table 1 and tables A2–A4 in the appendix). The insignificance of precipitation level is consistent with the literature on climate change impact on crop

![Figure 6. The impacts of border patrol staffing and illegal crossings on natural vegetation.](image)

Table 1. Two-way fixed effects panel data model estimation results (3 mile buffer).

| Buffer size | Variables | (1)       | (2)       | (3)       | (4)       |
|-------------|-----------|-----------|-----------|-----------|-----------|
| 3 Mile      | Staffing  | $-0.0208^{***}$ (0.0021) | $-0.0193^{***}$ (0.0021) | $-0.0189^{***}$ (0.0021) | $-0.0186^{***}$ (0.0021) |
|             | Apprehensions | $-0.1014^{***}$ (0.0107) | $-0.0958^{***}$ (0.0107) | $-0.0746^{***}$ (0.0113) | $-0.0721^{***}$ (0.0112) |
|             | Lagged employment | $-0.0962^{***}$ (0.0166) | $-0.1154^{***}$ (0.0168) | $-0.1534^{***}$ (0.0183) | $-0.1648^{***}$ (0.0183) |
|             | PPT       | $0.2093$ (0.1424) | $0.0150$ (0.0129) | $0.0150$ (0.0129) | $0.0150$ (0.0129) |
|             | PPT$^{-2}$ | $0.0150$ (0.0129) | $0.0150$ (0.0129) | $0.0150$ (0.0129) | $0.0150$ (0.0129) |
|             | Tmean     | $4.7537^{***}$ (0.7017) | $5.2611^{***}$ (0.7142) | $5.2611^{***}$ (0.7142) | $5.2611^{***}$ (0.7142) |
|             | Tmean$^{-2}$ | $-0.0903^{***}$ (0.0146) | $-0.1076^{***}$ (0.0148) | $-0.1076^{***}$ (0.0148) | $-0.1076^{***}$ (0.0148) |
| $R^2$ (w/o FEs) | 0.0336 | 0.0414 | 0.0420 | 0.0499 |
| $R^2$ (with FEs) | 0.9345 | 0.9351 | 0.9351 | 0.9356 |

Note: throughout the article, asterisks (*, **, ***) indicate statistical significance at 10%, 5%, and 1% level, respectively, unless otherwise noted.
production (e.g. Schlenker and Roberts 2009). One possible explanation is that the permanent vegetation covers (e.g. phreatophytes) in a semi-arid/arid ecosystem like the Southwest depend more on the groundwater resources. Studies have reported that the southwestern US is rich of phreatophytes (Robinson 1958, Busch et al 1992, Stromberg 2013). On the other hand, a statistically significant nonlinear effect of temperature change has been consistently identified across the different samples. As figure 7 (corresponding to results in column (4)) suggests, once the growing season mean temperature goes beyond 22 °C–25 °C it starts having a negative impact on the vegetation cover. Such a temperature threshold has been identified in the literature (e.g. Porter and Gawith 1999, Schlenker and Roberts 2009). Overall, the proposed model explains 93.6% of the variation observed in the vegetation cover controlling for spatial and temporal fixed effects. The estimation results are robust across data samples with different buffer sizes.

4. Discussion

The findings in this study have important implications for natural resources management and border security policy. Vegetation cover plays a fundamental role in every natural ecosystem. A decline of vegetation cover can lead to biodiversity loss because of the disturbances to wildlife habitats. In some cases, serious damage to vegetation cover can cause degradation or even disappearance of habitats (Liverman et al 1999). Unauthorized trails and roads created by illegal crossings can lead to habitat fragmentation which affects wildlife populations in the long run. Trash and litter left behind by illegal activities, once accumulated in large amounts, can cause serious pollution to water resources. In a sensitive and water-stressed ecosystem like the Southwest border region, such pollutions can lead to quick degradation of wildlife habitats (Terrell 2006).

Meanwhile, it should be stressed that border security enforcement related activities can also have a significant impact on the vegetation cover. This is particularly true when heavy vehicles and off-road vehicles are used (Meierotto 2012, Villarreal et al 2016). As far as the unintended consequences of any border security policies are concerned, such an environmental impact should be taken into consideration. Ultimately, as argued by Lenihan (2016), the border region should be treated as a system to manage and steward. Policies related to border security should coordinate with policies and initiatives on natural resources management. And then, a key stakeholder in the border region—the local communities should be involved in the policymaking processes. Without their participation and consideration of their interests, no policy or strategy can go far in creating a well-managed and environmental-friendly border region. The quality of life in the border communities is a complicated function of safety, economic opportunities, as well as environmental quality. How it has been affected by different driving forces is an interesting direction for future research.

This study is in no way meant to answer every question related to the vegetation cover in the Southwest border region. Several unanswered questions (due to data limitation and the scope of the study) point to fruitful directions for future research. First, the spatial-temporal distribution of wildlife is impossible to detect with the remote-sensing data. It requires dedicated efforts and technologies to do field data collection. Nevertheless, the impact of human activities (legal or illegal) on wildlife in the border region should be an important input in policymaking. Second, related to the estimation of the extent of illegal crossings, this study relies on a simplified assumption that the apprehension probability is stable over a relatively
short timeframe. However, as the border security technology improves and more illegal crossings shift to remote routes the apprehension probability may become more spatially-varying. This could introduce measurement errors into independent variables and weaken the significance of the results. As we enter the era of data revolution, another research direction related to this is to coordinate data collection and analytical capacity among researchers, government agencies, and local stakeholders.

5. Concluding remarks

This study explores both human activities (legal and illegal) and climatic factors to examine the change of vegetation cover in the Southwest border region. It is the first study that integrates large-scale remote-sensing datasets with multiple layers of socio-economic data and aims to inform critical policy issues related to natural resources management and border security enforcement in the region. It finds that both illegal and legal activities have a statistically significant impact on the border region vegetation cover. Among all factors, local economic activities as measured by employment density have the largest impact as expected. A one-standard-deviation increase in illegal crossings would lead the vegetation cover index (measured between 0–100) to decline by 4.1% of its standard deviation. A one-standard-deviation increase in border patrol agent staffing would lead the vegetation cover index to decline by 19.0% of its standard deviation. Growing season mean temperature is also significant in driving the change of vegetation cover.

Along with the projected population growth in the US–Mexico border region and given the differences in the priorities of residents on two sides of the border (Sprouse 2005, US EPA 2016), it can be challenging to manage both the natural resources and border security effectively. The findings in this study should be able to shed some light on finding a solution that could integrate the stewardship of the natural environment and a secure border. As being pointed out by Andreas (1996), the status of the US–Mexico border region reflects a deep conflict between economic freedom and border security. Therefore, a forward-looking solution to the environmental problem that we are facing in the border region can only become effective in the context of binational economic integration.

Appendix. Supplementary figures and tables

Figure A1. Proportion of different land covers in the Southwest border region (10 mile buffer). Data source: computed directly from CDL, 2008–2017.
Figure A2. Proportion of different land covers in the Southwest border region (30 mile buffer). Data source: computed directly from CDL, 2008–2017.

Table A1. Summary statistics of variables.

| Buffer size | Variable | Mean   | Min    | Max    | Std. Dev |
|-------------|----------|--------|--------|--------|----------|
| 3 mile      | Vegcover (0–100, unit-free) | 53.78  | 0.00   | 100.00 | 13.89    |
|             | Staffing | 247.56 | 35.08  | 529.88 | 142.13   |
|             | Apprehensions (in 1000) | 6.24   | 0.31   | 39.71  | 7.90     |
|             | Lagged employment (per square mile) | 29.69  | 0.02   | 292.42 | 63.38    |
|             | Average monthly PPT (cm) | 2.88   | 0.09   | 11.16  | 1.92     |
|             | Average monthly $T_{\text{mean}}$ (°C) | 22.61  | 13.50  | 27.30  | 2.88     |

Study period 2008–2017
Number of PRISM cells 681

Table A2. Two-way fixed effects panel data model estimation results (10 mile buffer).

| Buffer size | Variables | (1)       | (2)       | (3)       | (4)       |
|-------------|-----------|-----------|-----------|-----------|-----------|
| 10 Mile     | Staffing  | $-0.0170^{***}$ (0.0011) | $-0.0158^{***}$ (0.0011) | $-0.0162^{***}$ (0.0011) | $-0.0157^{***}$ (0.0011) |
|             | Apprehensions | $-0.0729^{***}$ (0.0054) | $-0.0686^{***}$ (0.0054) | $-0.0591^{***}$ (0.0056) | $-0.0573^{***}$ (0.0056) |
|             | Lagged employment | $-0.0761^{***}$ (0.0079) | $-0.0877^{***}$ (0.0081) | $-0.1072^{***}$ (0.0086) | $-0.1151^{***}$ (0.0086) |
|             | PPT        | $-0.1948^{***}$ (0.0710) | $-0.0040$ (0.0065) | $-0.1237$ (0.0765) | $-0.0148^{***}$ (0.0067) |
|             | $T_{\text{mean}}$ | $3.2333^{***}$ (0.3351) | $3.4733^{***}$ (0.3421) |
|             | $T_{\text{mean}}^2$ | $-0.0651^{***}$ (0.0070) | $-0.0756^{***}$ (0.0072) |
| $R^2$ (w/o FEs) | 0.0245 | 0.0287   | 0.0292   | 0.0342   |
| $R^2$ (with FEs) | 0.9497 | 0.9499   | 0.9499   | 0.9502   |
Table A3. Two-way fixed effects panel data model estimation results (20 mile buffer).

| Buffer size | Variables | (1)          | (2)          | (3)          | (4)          |
|-------------|-----------|--------------|--------------|--------------|--------------|
| 20 Mile     | Staffing  | $-0.0175^{***}$ (0.0007) | $-0.0165^{***}$ (0.0007) | $-0.0170^{***}$ (0.0007) | $-0.0166^{***}$ (0.0007) |
|             | Apprehensions | $-0.0869^{***}$ (0.0035) | $-0.0828^{***}$ (0.0035) | $-0.0781^{***}$ (0.0036) | $-0.0762^{***}$ (0.0036) |
|             | Lagged employment | $-0.0581^{***}$ (0.0052) | $-0.0673^{***}$ (0.0053) | $-0.0785^{***}$ (0.0056) | $-0.0848^{***}$ (0.0056) |
|             | PPT        | $-0.1520^{***}$ (0.0472) | $-0.0038$ (0.0044) | $-0.0124^{***}$ (0.0506) | $-0.0123^{***}$ (0.0506) |
|             | PPT$^{-2}$ |              |              |              |              |
|             | $T_{mean}$ |              |              |              |              |
|             | $T_{mean}^{-2}$ |              |              |              |              |
|             | $R^2$ (w/o FEs) | 0.0297       | 0.0328       | 0.0327       | 0.0366       |
|             | $R^2$ (w/ FEs) | 0.9547       | 0.9549       | 0.9549       | 0.9551       |

Table A4. Two-way fixed effects panel data model estimation results (30 mile buffer).

| Buffer size | Variables | (1)          | (2)          | (3)          | (4)          |
|-------------|-----------|--------------|--------------|--------------|--------------|
| 30 Mile     | Staffing  | $-0.0156^{***}$ (0.0006) | $-0.0146^{***}$ (0.0006) | $-0.0150^{***}$ (0.0006) | $-0.0146^{***}$ (0.0006) |
|             | Apprehensions | $-0.0760^{***}$ (0.0029) | $-0.0719^{***}$ (0.0029) | $-0.0691^{***}$ (0.0029) | $-0.0673^{***}$ (0.0029) |
|             | Lagged employment | $-0.0556^{***}$ (0.0043) | $-0.0639^{***}$ (0.0043) | $-0.0725^{***}$ (0.0045) | $-0.0770^{***}$ (0.0045) |
|             | PPT        | $-0.1745^{***}$ (0.0374) |              |              | $-0.1240^{***}$ (0.0399) | $-0.0052$ (0.0036) |
|             | PPT$^{-2}$ | 0.0019 (0.0035) |              |              |              |              |
|             | $T_{mean}$ |              |              |              | $1.8134^{***}$ (0.1610) | $1.8831^{***}$ (0.1644) |
|             | $T_{mean}^{-2}$ |              |              |              | $-0.0365^{***}$ (0.0034) | $-0.0416^{***}$ (0.0035) |
|             | $R^2$ (w/o FEs) | 0.0241       | 0.0264       | 0.0264       | 0.0287       |
|             | $R^2$ (w/ FEs) | 0.9583       | 0.9584       | 0.9584       | 0.9585       |

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