Do roads lead to grassland degradation or restoration?

A case study in Inner Mongolia, China*

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This is an online archived appendix of supplementary material for the paper, "Do Roads Lead to Grassland Degradation or Restoration? A Case Study in Inner Mongolia, China". It provides technical details on the remote sensing data and additional analyses that were not included in the text.

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Appendix 1

Data details

In this appendix, we have two parts. The first part describes in detail the nature of the remote sensing data. The second part explains how we measure grassland cover.

Part 1. Technical details on Remote Sensing Data

In our study we use a land use database developed by the Chinese Academy of Sciences (CAS). The original data are from satellite remote sensing data provided by the US Landsat TM/ETM images which have a spatial resolution of 30 by 30 meters [1]. These have been aggregated by CAS into one kilometer by one kilometer picture elements ('pixels') and these are the observations used in this study. The database includes time-series data for two time periods: a) the mid-1990s, including Landsat TM/ETM scenes from 1995 and 1996 (henceforth, 1995); b) the late 1990s, including Landsat TM/ETM scenes from 1999 and 2000 (henceforth, 2000).[1] For each time period more than 500 TM/ETM scenes were used to cover the entire country.[2] The data team also spent considerable time and effort to validate the interpretation of TM/ETM images and land-cover classifications against extensive field surveys [2].[3] A hierarchical classification system of 25 land-use classes was originally applied to the data and we aggregate these further into six classes of land use–cultivated land, forestry area, grassland, water area, built-up area and unused land [3]. In this study we only use information from the data set on grassland cover (primarily as our dependent variable).

Part 2. Using remote-sensing to measure grassland cover

Many studies in the past have applied remote sensing (RS) technology to measure grassland cover. Seaquist *et al.* (2003) profiled a Light Use Efficiency (LUE) model of primary production parameterised with satellite information [4]. Wang *et al.* (2009) detected grassland cover change in the West Songnen Plain of China using remote sensing and GIS [5].

Using satellite images also has been found to be a cost-effective approach to study grassland degradation. Tong *et al.* (2004) combined information from field survey records, existing vegetation maps, and remote sensing data to determine the different degrees of degradation for diverse steppe communities at the local scale and their spatial pattern at the landscape scale [6]. According to the research conclusions of Long *et al.* (2010), integrating remote sensing and geographical information system technologies, the spatial and temporal

[1] In fact, the records kept during the period of time that the data set was created allow us to provide detailed information about the timing of the data. In the case of the mid-1990s, 92 percent of the TM/ETM imagines are from 1995. There was a small share of TM/ETM digital images that were not available during 1995 because Jiangxi frequently is shrouded with clouds. Because of this, a small share of TM/ETM images, 8 percent of the total, were drawn from a 1996 image data base. Because a large majority of images were from 1995, in the rest of the paper we refer the first period as 1995. The same was true for 2000. Most of the images for the latter period are from a 2000 database; only a small fraction is from 1999.

[2] A TM/ETM scene is the unit of area of coverage of digital images that are made by Landsat satellites. In the original Landsat material, which was configured by NASA before they provided the material to CAS, it took about 500 scenes to completely cover all of China's territory.

[3] Additional details about the methodology, which we used to generate the databases of land cover from Landsat TM/ETM, are documented in Liu *et al.* [2] and Deng *et al.* [3].

conditions of the alpine grassland, trend, and projected stocking rates could be forecasted for decision making [7].

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Appendix 2

In this appendix, we describe the grassland cover area and their average area percentages by regions.

Table A1. Total area and average area percentage of grassland cover by regions of Inner Mongolia in 1995 and 2000

Regions	1995		2000	
	Total grassland area (million ha)	Average percent of grassland cover (%)	Total grassland area (million ha)	Average percent of grassland cover (%)
Total	57.22	100.00	52.60	100.00
Middle grassland region	37.82	66.10	36.84	70.04
East forest region	12.28	21.46	12.01	22.83
West desert region	7.12	12.44	3.75	7.13

Appendix 3

Illustration of Assigning Labels to Watersheds and Pixels

To more clearly illustrate the process of assigning labels to watersheds and pixels in our sample, we take a small region of a watershed map of Inner Mongolia that has been overlaid with the highway map and magnify it. In the map we show the number of some watersheds. The numbers of the other watersheds are suppressed for clarity. The map would be too cluttered otherwise.

We start with an explanation of how we label the 5951 watersheds. Referencing the magnified map in figure A1 (below), we can see that expressways (the heavy solid lines) run through some watersheds, but not others. Likewise province-level highways (the heavy dotted lines) run through some watersheds, but not others and other roads (the thinner solid lines) run through some watersheds but not others. Some watersheds have no roads through them. The first step in labeling the watersheds involves identifying all watersheds through which expressways run. All of these are called *expressway watersheds*. In figure A1, watersheds #4281 and #4272 are expressway watersheds. This process is then repeated for province-level highways (for example, watersheds #4111 and #4073 are *province-level highway watersheds* because provincial-level highways is the largest type of roads in these watersheds) and for other roads (for example, watersheds #4174 and #4245 are *other road watersheds* because other roads is the largest type of watersheds). The rest of the watersheds (those without roads) are called *no road watersheds* (for example, watersheds #4177 and #4310).

According to our labeling rules, there can be no watershed with two names. If a watershed is given a label of an expressway watershed, it cannot take on another name. This rule is needed to take care of cases such as watershed #4281. Although watershed #4281 has both expressways and province-level highways running through it, it takes on the name of the largest highway (which in this case makes the watershed an expressway watershed). Likewise, although watershed #4073 has both a province-level highway and an “other road”, it is called a province-level highway watershed.

The process of naming the pixels is relatively trivial. Each and every pixel in the watershed takes on the name of the watershed. In other words, all pixels in the expressway watersheds are called e*xpressway pixels*. Likewise, all pixels in the province-level highway watersheds are called *province-level highway pixels*; and all pixels in the other road watersheds are called *other road pixels*; and all pixels in no road watersheds are called *no road pixels*. We are careful to point this out because this is an assumption of our analysis that all pixels in the watershed are affected by the largest road the runs through it. As seen from figure A1, this means that all pixels in the other road watershed in the example are called other road pixels even though in the case of most of the pixels in the watershed, the road actually does not run directly through it.

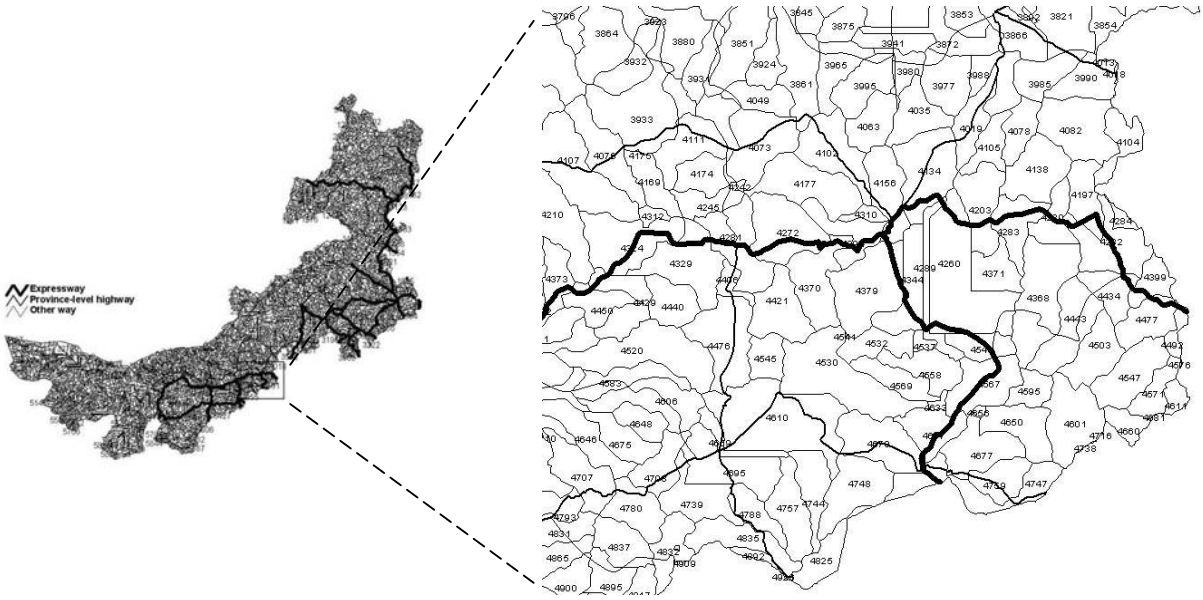

Figure A1. Illustration of assigning labels to watersheds and pixels

Appendix 4

In this appendix, we describe statistics of the variables at pixel level.

Table A2. Descriptive statistics of the variables at the pixel level

Variable	Units	Obs	Mean	Std. Dev.
Dependent variables				
dense grassland cover in 2000	%	563296	29.88	37.93
moderate grassland cover in 2000	%	563296	24.08	34.04
sparse grassland cover in 2000	%	563296	11.87	25.19
QA-grassland cover in 2000	%	563296	32.32	25.16
Change in the dense grassland cover between 1995 and 2000	%	563296	-4.44	27.65
Change in the moderate grassland cover between 1995 and 2000	%	563296	-0.42	29.96
Change in the sparse grassland cover between 1995 and 2000	%	563296	3.27	22.75
Change in the QA-grassland cover between 1995 and 2000	%	563296	-3.07	15.51
Geographic and climatic factors				
Rainfall	mm	563296	308.78	83.96
Temperature	degree centigrade	563296	2.96	2.46
elevation	m	563296	1085.00	383.59
terrain slope	degree	563296	0.63	1.53
Nitrogen	%	563296	0.10	0.08
Phosphorous	%	563296	0.07	0.03
Potassium	%	563296	2.12	0.57
available phosphorous	ppm	563296	1.30	1.26
available potassium	ppm	563296	95.20	116.58
soil pH value	-	563296	7.78	0.58
soil clay	%	563296	16.23	7.13
soil loam	%	563296	19.37	8.74
soil sand	%	563296	64.40	14.59
organic matter	%	563296	1.61	1.34
Demographic and economic factors				
Population	persons per square kilometer	563296	30.28	77.12
GDP	yuan per square kilometer	563296	942.75	4879.37
Measure of distance				
distance to nearest road	km	563296	9.76	8.41
distance to the provincial capital	km	563296	318.07	158.30
distance to the nearest urban core	km	563296	44.54	26.82
Other factors				
Bufferfarmland	%	563296	0.13	0.19
Bufferforest	%	563296	0.05	0.10

dense grassland cover in 1995	%	563296	34.33	38.78
moderate grassland cover in 1995	%	563296	24.50	33.08
sparse grassland cover in 1995	%	563296	8.60	20.75
QA-grassland cover in 1995	%	563296	35.40	25.44

Appendix 5

In this appendix, we report the estimation results of the full regressions for the pixel-specific impacts of roads (1995) on the level of grassland (2000) and the changes in grassland (between 1995 and 2000) for the Middle Grassland Zone of Inner Mongolia, China.

Table A3. OLS estimates with all covariates (Treatment variable: Expressway vs province-level highway—i.e., $(Access\ to\ Roads)_{1.1}$)

	Dependent variable: level				**Dependent variable: change**			
	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland
$(Access\ to\ Roads)_{1.1}$	-1.16 (5.43)***	-3.58 (9.44)***	2.28 (13.49)***	1.75 (8.59)***	-1.21 (14.63)***	-2.84 (20.61)***	-2.71 (18.15)***	0.25 (2.11)**
rainfall	0.03 (24.54)***	0.04 (26.73)***	-0.01 (7.85)***	-0.01 (11.83)***	-7.69e-04 (1.18)	0.01 (11.38)***	-0.02 (18.46)***	-1.84e-03 (1.95)*
temperature	-0.65 (16.16)***	-1.34 (21.89)***	0.42 (6.83)***	1.65 (35.53)***	0.02 (0.91)	-0.09 (2.20)**	-0.08 (1.70)*	0.64 (17.10)***
elevation	1.48e-03 (7.01)***	-1.09e-03 (3.40)***	3.94e-03 (12.32)***	0.01 (30.17)***	2.09e-03 (15.55)***	3.00e-03 (13.72)***	-1.29e-03 (5.33)***	2.69e-03 (13.78)***
terrain slop	0.90 (24.04)***	0.86 (15.10)***	0.50 (8.88)***	0.65 (15.01)***	0.27 (11.43)***	0.28 (7.19)***	0.23 (5.46)***	0.28 (8.05)***
nitrogen	5.38 (0.97)	28.50 (3.38)***	-67.76 (8.06)***	61.77 (9.66)***	3.83 (1.08)	8.29 (1.44)	-9.14 (1.44)	1.95 (0.38)
phosphorous	37.83 (12.39)***	85.90 (18.55)***	-64.40 (13.93)***	-32.46 (9.23)***	1.39 (0.72)	6.56 (2.07)**	-8.09 (2.32)**	8.48 (3.01)***
potassium	0.74 (5.19)***	-0.36 (1.68)*	2.85 (13.31)***	0.057 (0.35)	0.15 (1.67)*	-0.04 (0.29)	0.83 (5.15)***	-0.26 (2.00)**
available phosphorous	0.02 (0.35)	0.44 (4.40)***	-1.37 (13.65)***	1.37 (17.90)***	0.35 (8.22)***	0.79 (11.44)***	-0.80 (10.62)***	0.08 (1.28)
available potassium	2.46e-03 (1.96)*	-4.26e-04 (0.22)	0.01 (7.69)***	-0.02 (12.95)***	-4.32e-03 (5.41)***	-4.04e-03 (3.11)***	2.29e-04 (0.16)	-5.45e-03 (4.71)***
soil pH value	0.90 (7.95)***	0.31 (1.84)*	1.52 (8.92)***	1.03 (7.92)***	-1.43e-03 (0.02)	-2.02e-03 (0.02)	0.06 (0.44)	0.58 (5.58)***
soil clay	0.38 (10.98)***	0.71 (13.62)***	-0.50 (9.56)***	0.15 (3.87)***	0.09 (4.07)***	0.19 (5.42)***	-0.14 (3.61)***	0.08 (2.66)***
soil loam	2.00e-04	0.10	-0.16	-0.02	-0.33	-0.44	0.11	0.32

	(9.51)***	(11.84)***	(10.10)***	(7.29)***	(1.03)	(6.14)***	(2.73)***	(4.75)***
soil sand	0.17	0.34	-0.28	0.07	0.04	0.12	-0.13	0.06
	(11.09)***	(14.75)***	(11.87)***	(4.19)***	(4.52)***	(7.49)***	(7.44)***	(4.38)***
organic matter	-0.21	-1.64	3.95	-2.85	-0.05	-0.31	0.60	0.03
	(0.66)	(3.44)***	(8.28)***	(7.87)***	(0.23)	(0.95)	(1.68)*	(0.12)
population	-0.01	-1.53e-03	-0.01	-0.02	5.83e-04	3.82e-03	-2.99e-03	-0.01
	(5.67)***	(1.13)	(4.00)***	(15.71)***	(1.03)	(4.14)***	(2.95)***	(16.65)***
GDP	-1.94e-06	-2.34e-05	-7.44e-05	3.33e-04	-4.40e-05	-1.16e-04	6.34e-06	3.40e-04
	(0.16)	(1.29)	(4.11)***	(24.21)***	(5.79)***	(9.35)***	(0.47)	(30.87)***
distance to nearest road	-0.14	-0.22	0.04	0.11	-0.04	0.02	-0.21	0.13
	(13.55)***	(14.39)***	(2.66)***	(9.74)***	(6.65)***	(1.46)	(18.21)***	(13.77)***
distance to provincial capital	0.03	0.05	-0.03	2.47e-04	0.01	0.02	-0.02	1.82e-03
	(44.11)***	(53.13)***	(30.88)***	(0.37)	(26.37)***	(36.37)***	(25.40)***	(3.38)***
distance to nearest urban core	0.04	0.03	0.05	-0.01	0.01	-3.75e-03	0.04	-0.01
	(13.86)***	(7.32)***	(11.42)***	(3.54)***	(4.09)***	(1.28)	(12.15)***	(3.03)***
bufferfarmland	-42.65	-42.00	-26.98	-13.67	-2.38	-2.61	-8.00	-7.86
	(121.00)***	(78.60)***	(50.57)***	(33.70)***	(9.88)***	(6.92)***	(19.70)***	(24.13)***
bufferforest	-40.86	-30.03	-47.53	-13.59	-2.59	-0.98	-11.91	-9.19
	(63.34)***	(30.70)***	(48.67)***	(18.30)***	(6.18)***	(1.46)	(16.00)***	(15.43)***
QA-grassland cover in 1995					-0.23			
					(137.70)***			
dense grassland cover in 1995						-0.29		
						(164.90)***		
moderate grassland cover in 1995							-0.32	
							(154.90)***	
sparse grassland cover in 1995								-0.31
								(126.70)***
Constant	-4.45	-26.82	48.64	-10.84	-5.83	-21.82	33.99	-8.36
	(2.36)***	(9.39)***	(17.05)***	(4.99)***	(4.86)***	(11.17)***	(15.80)***	(4.81)***
R-squared	0.22	0.11	0.07	0.31	0.18	0.16	0.12	0.14
N treated	100192	100192	100192	100192	100192	100192	100192	100192
N available controls	49318	49318	49318	49318	49318	49318	49318	49318

Notes: Absolute value of t-statistics in parentheses. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

Table A4. OLS estimates with all covariates (Treatment variable: Expressway and/or province-level highway vs other roads—i.e., (*Access to Roads*)$_{1.2}$)

	Dependent variable: level				**Dependent variable: change**			
	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland
(*Access to Roads*)$_{1.2}$	-1.94	-2.50	1.64	1.42	-0.22	-1.10	2.02	0.87
	(23.76)***	(18.85)***	(3.66)***	(17.79)**	(3.67)***	(9.89)***	(17.17)***	(9.98)***
rainfall	-1.12e-03	0.03	-0.06	3.79e-03	-0.01	2.45e-04	-0.04	0.02
	(1.63)	(23.52)***	(56.49)***	(4.77)***	(27.27)***	(0.29)	(47.57)***	(26.16)***
temperature	-1.42	-1.98	-0.43	1.68	-0.34	-0.38	-0.95	1.31
	(49.84)***	(43.55)***	(9.78)***	(51.12)***	(17.36)***	(10.90)***	(26.00)***	(46.58)***
elevation	-1.37e-03	-1.65e-03	-3.91e-03	9.88e-03	-8.94e-04	1.46e-04	-0.01	0.01
	(9.21)***	(6.96)***	(17.12)***	(57.44)***	(8.69)***	(0.81)	(31.43)***	(61.01)***
Terrain slop	0.76	0.71	0.47	0.56	0.23	0.22	0.34	0.11
	(22.73)***	(13.19)***	(9.16)***	(14.35)***	(9.80)***	(5.42)***	(7.94)***	(3.34)***
nitrogen	75.48	116.90	-36.01	3.09	50.47	84.12	-18.75	-28.68
	(20.01)***	(19.48)***	(6.21)***	(0.71)	(19.35)***	(18.42)***	(3.88)***	(7.70)***
phosphorous	7.70	43.05	-69.40	-2.37	-2.86	0.35	-17.52	17.74
	(3.07)***	(10.78)***	(17.98)***	(0.82)	(1.65)*	(0.12)	(5.44)***	(7.16)***
potassium	1.54	-0.13	4.34	0.89	0.10	-0.90	2.69	0.55
	(12.85)***	(0.66)	(23.61)***	(6.46)***	(1.19)	(6.19)***	(17.53)***	(4.67)***
available phosphorous	0.73	1.22	-0.46	-0.17	1.02	1.78	-0.67	-0.85
	(13.45)***	(14.10)***	(5.54)***	(2.72)***	(27.08)***	(27.01)***	(9.57)***	(15.89)***
available potassium	-7.69e-03	-0.02	0.01	7.89e-03	-0.01	-0.03	0.02	0.01
	(8.97)***	(12.66)***	(9.27)***	(7.97)***	(23.21)***	(26.50)***	(16.86)***	(8.43)***
soil pH value	0.58	0.43	0.58	0.44	0.07	0.42	-0.45	0.13
	(6.08)***	(2.83)***	(3.96)***	(4.00)***	(1.08)	(3.62)***	(3.65)***	(1.34)

soil clay	-0.01	-0.02	-0.04	-4.47e-03	-0.35	-0.47	-0.12	0.37
	(9.06)***	(1.72)*	(2.85)***	(2.41)**	(3.58)***	(1.52)	(1.00)	(1.43)
soil loam	-0.01	-0.20	0.46	-0.13	-0.08	-0.21	0.30	-0.15
	(0.25)	(4.75)***	(11.19)***	(4.22)***	(4.63)***	(6.49)***	(8.84)***	(5.62)***
soil sand	-0.06	-0.16	0.18	-0.03	-0.07	-0.12	0.09	-0.05
	(3.86)***	(6.36)***	(7.43)***	(1.89)*	(6.33)***	(6.28)***	(4.47)***	(3.19)***
organic matter	-4.16	-6.21	1.72	-0.81	-2.92	-4.44	0.63	0.66
	(21.30)***	(20.01)***	(5.75)***	(3.60)***	(21.62)***	(18.82)***	(2.54)**	(3.45)***
population	-0.01	-0.01	2.24e-03	-0.01	-1.11e-03	-1.92e-03	1.00e-03	-0.01
	(12.53)***	(10.05)***	(1.64)	(9.85)***	(1.81)*	(1.79)*	(0.88)	(10.78)***
GDP	5.72e-05	1.06e-04	-1.64e-04	2.78e-04	-3.50e-05	-7.20e-05	-3.53e-05	3.00e-04
	(4.72)***	(5.51)***	(8.77)***	(19.83)***	(4.18)***	(4.90)***	(2.27)**	(25.04)***
distance to nearest road	-0.06	-0.09	0.02	0.03	-3.98e-03	0.03	-0.09	0.02
	(8.69)***	(8.73)***	(2.00)**	(4.48)***	(0.87)	(3.67)***	(10.51)***	(3.65)***
distance to provincial capital	0.03	0.06	-0.04	2.87e-03	0.01	0.03	-0.02	0.01
	(65.93)***	(82.43)***	(61.82)***	(5.77)***	(34.53)***	(48.37)***	(41.69)***	(15.77)***
distance to nearest urban core	-0.05	-0.13	0.12	0.02	-0.06	-0.14	0.12	0.02
	(34.02)***	(52.18)***	(49.86)***	(9.86)***	(56.31)***	(73.49)***	(60.53)***	(10.01)***
bufferfarmland	-41.24	-43.31	-20.19	-13.56	-7.78	-13.79	-2.66	-9.86
	(141.20)***	(93.18)***	(44.97)***	(40.15)***	(37.26)***	(38.46)***	(7.05)***	(34.19)***
bufferforest	-34.30	-30.19	-27.92	-15.06	-1.81	-4.25	-5.04	-13.25
	(67.22)***	(37.19)***	(35.61)***	(25.55)***	(5.08)***	(6.86)***	(7.69)***	(26.31)***
QA-grassland cover in 1995					-0.27			
					(233.00)***			
dense grassland cover in 1995						-0.36		
						(285.80)***		
moderate grassland cover in 1995							-0.42	
							(290.00)***	

sparse grassland cover in 1995								-0.38 (221.90)***
Constant	34.80 (20.84)***	33.49 (12.61)***	29.58 (11.53)***	-5.40 (2.80)***	18.66 (16.16)***	18.99 (9.39)***	22.20 (10.38)***	-8.93 (5.42)***
R-squared	0.23	0.13	0.06	0.31	0.21	0.22	0.14	0.15
N treated	149510	149510	149510	149510	149510	149510	149510	149510
N available controls	212459	212459	212459	212459	212459	212459	212459	212459

Notes: Absolute value of t-statistics in parentheses. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

Table A5. OLS estimates with all covariates (Treatment variable: Expressway and/or province-level highway vs other roads or no roads—i.e., $(Access\ to\ Roads)_{1.3}$)

	Dependent variable: level				**Dependent variable: change**			
	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland
$(Access\ to\ Roads)_{1.3}$	-2.97	-0.53	0.04	1.08	-0.04	-0.66	1.65	1.00
	(6.06)***	(5.54)***	(0.01)	(23.02)***	(0.83)	(6.96)***	(16.07)***	(12.75)***
rainfall	0.01	0.04	-0.07	0.01	-0.01	0.01	-0.05	0.02
	(18.99)***	(48.42)***	(77.28)***	(16.35)***	(29.14)***	(8.22)***	(68.48)***	(41.80)***
temperature	-1.81	-2.26	-0.95	1.78	-0.48	-0.55	-1.13	1.53
	(76.69)***	(60.93)***	(27.00)***	(65.91)***	(29.73)***	(19.69)***	(38.79)***	(65.79)***
elevation	-3.54e-03	-2.95e-03	-8.09e-03	0.01	-2.09e-03	-4.57e-04	-0.01	0.01
	(29.35)***	(15.51)***	(44.71)***	(86.73)***	(25.57)***	(3.45)***	(60.58)***	(90.52)***
Terrain slop	0.74	0.75	0.41	0.30	0.16	0.10	0.44	-0.06
	(26.26)***	(16.79)***	(9.75)***	(9.18)***	(8.19)***	(3.13)***	(12.59)***	(2.00)**
nitrogen	77.96	108.00	-7.90	-2.12	33.22	53.26	1.23	-19.47
	(26.88)***	(23.64)***	(1.82)*	(0.64)	(16.91)***	(15.70)***	(0.34)	(6.79)***
phosphorous	-3.15	33.34	-80.51	0.21	5.49	13.35	-30.24	17.70
	(1.54)	(10.34)***	(26.23)***	(0.09)	(3.96)***	(5.58)***	(11.91)***	(8.75)***
potassium	2.94	1.73	4.62	0.18	0.99	0.47	2.73	0.01
	(29.67)***	(11.11)***	(31.10)***	(1.60)	(14.67)***	(4.05)***	(22.19)***	(0.05)
available phosphorous	0.53	0.84	-0.16	-0.33	0.82	1.32	-0.23	-0.89
	(11.44)***	(11.42)***	(2.23)**	(6.18)***	(26.07)***	(24.24)***	(3.93)***	(19.29)***
available potassium	0.01	1.21e-03	0.01	4.40e-03	-0.01	-0.02	0.02	0.01
	(8.59)***	(1.08)	(12.45)***	(5.42)***	(15.78)***	(19.74)***	(17.63)***	(7.68)***
soil pH value	-0.21	-0.44	0.16	0.49	-0.44	-0.24	-0.59	0.13
	(2.52)**	(3.31)***	(1.28)	(5.02)***	(7.74)***	(2.47)**	(5.64)***	(1.60)
soil clay	-0.22	-0.08	-0.50	0.11	0.03	0.10	-0.31	0.14

	(10.57)***	(2.50)**	(15.79)***	(4.61)***	(1.79)*	(4.22)***	(11.90)***	(6.95)***
soil loam	0.03	-0.03	0.03	-0.01	-0.31	-0.43	-0.05	0.33
	(1.36)	(3.17)***	(2.09)**	(2.82)***	(4.27)***	(2.23)**	(1.55)	(1.70)*
soil sand	-0.18	-0.11	-0.32	0.11	-0.01	0.04	-0.24	0.12
	(19.50)***	(7.67)***	(22.75)***	(10.40)***	(2.24)**	(3.61)***	(20.12)***	(12.44)***
organic matter	-4.01	-5.49	0.53	-0.63	-2.22	-3.21	-0.07	0.23
	(28.26)***	(24.56)***	(2.49)**	(3.86)***	(23.13)***	(19.34)***	(0.39)	(1.67)*
population	-0.01	-0.02	-1.31e-03	-0.01	-1.35e-03	-2.45e-03	5.21e-04	-0.01
	(17.26)***	(12.82)***	(1.04)	(11.01)***	(2.37)**	(2.49)**	(0.50)	(12.27)***
GDP	9.80e-05	1.39e-04	-1.23e-04	2.92e-04	-2.70e-05	-6.30e-05	-2.87e-05	3.13e-04
	(8.47)***	(7.65)***	(7.08)***	(22.01)***	(3.45)***	(4.66)***	(2.00)**	(27.36)***
distance to nearest road	-0.17	-0.17	-0.11	0.02	-0.03	-0.01	-0.10	-4.26e-03
	(44.97)***	(29.66)***	(19.95)***	(3.67)***	(11.44)***	(2.36)**	(22.51)***	(1.16)
distance to provincial capital	0.03	0.06	-0.05	2.63e-03	0.01	0.02	-0.03	0.01
	(72.91)***	(99.77)***	(87.37)***	(6.39)***	(37.50)***	(58.62)***	(60.92)***	(20.36)***
distance to nearest urban core	-0.05	-0.13	0.13	0.03	-0.05	-0.12	0.10	0.03
	(34.90)***	(59.43)***	(61.67)***	(20.50)***	(59.83)***	(76.09)***	(58.82)***	(19.40)***
bufferfarmland	-39.67	-41.65	-19.03	-14.16	-6.48	-11.40	-3.45	-10.51
	(158.60)***	(105.70)***	(50.75)***	(49.35)***	(37.16)***	(38.51)***	(11.07)***	(42.49)***
bufferforest	-36.94	-35.27	-25.09	-13.61	-2.71	-5.00	-6.58	-11.99
	(96.03)***	(58.23)***	(43.52)***	(30.86)***	(10.27)***	(11.07)***	(13.76)***	(31.56)***
QA-grassland cover in 1995					-0.25			
					(275.70)***			
dense grassland cover in 1995						-0.34		
						(342.80)***		
moderate grassland cover in 1995							-0.43	
							(375.40)***	
sparse grassland								-0.39

cover in 1995								(282.70)***
Constant	49.17	26.77	90.93	-21.86	15.33	2.88	62.91	-27.95
	(39.50)***	(13.66)***	(48.73)***	(15.32)***	(18.16)***	(1.98)***	(40.76)***	(22.72)***
R-squared	0.22	0.12	0.06	0.29	0.19	0.23	0.15	0.14
N treated	149510	149510	149510	149510	149510	149510	149510	149510
N available controls	413786	413786	413786	413786	413786	413786	413786	413786

Notes: Absolute value of t-statistics in parentheses. ***significant at 1% level,**significant at 5% level,*significant at 10% level.

Table A6. OLS estimates with all covariates (Treatment variable: Expressway and/or province-level highway and/or other roads vs. no roads—i.e., $(Access\ to\ Roads)_{1.4}$)

	Dependent variable: level				**Dependent variable: change**			
	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland	QA-Grassland	Dense Grassland	Moderate Grassland	Sparse Grassland
$(Access\ to\ Roads)_{1.4}$	-0.41	-0.29	1.60	0.01	-0.11	-0.80	1.65	0.72
	(1.92)**	(0.77)	(4.11)***	(1.04)	(2.06)**	(8.27)***	(15.85)***	(9.03)***
rainfall	0.01	0.04	-0.06	0.01	-0.01	4.87e-03	-0.05	0.02
	(18.64)***	(47.59)***	(76.05)***	(16.22)***	(29.47)***	(7.37)***	(67.15)***	(41.31)***
temperature	-1.81	-2.26	-0.96	1.78	-0.48	-0.54	-1.14	1.53
	(76.68)***	(60.90)***	(27.05)***	(65.98)***	(29.71)***	(19.62)***	(38.88)***	(65.87)***
elevation	-3.60e-03	-3.13e-03	-0.01	0.01	-2.12e-03	-5.87e-04	-0.01	0.01
	(29.88)***	(16.47)***	(43.71)***	(87.29)***	(25.98)***	(4.17)***	(59.76)***	(90.56)***
Terrain slop	0.73	0.70	0.46	0.32	0.15	0.08	0.47	-0.06
	(25.72)***	(15.74)***	(10.91)***	(9.76)***	(7.77)***	(2.33)**	(13.56)***	(2.04)**
nitrogen	76.53	103.80	-3.55	-0.62	32.48	50.86	4.32	-19.65
	(26.41)***	(22.74)***	(0.82)	(0.19)	(16.55)***	(15.01)***	(1.20)	(6.87)***
phosphorous	-4.02	30.77	-77.80	1.08	5.04	11.87	-28.26	17.55
	(1.96)**	(9.55)***	(25.36)***	(0.46)	(3.64)***	(4.96)***	(11.14)***	(8.68)***
potassium	2.95	1.77	4.57	0.18	0.99	0.50	2.68	0.02
	(29.78)***	(11.36)***	(30.75)***	(1.59)	(14.77)***	(4.29)***	(21.83)***	(0.16)
available phosphorous	0.54	0.86	-0.18	-0.34	0.83	1.33	-0.24	-0.89
	(11.62)***	(11.76)***	(2.58)**	(6.38)***	(26.21)***	(24.49)***	(4.22)***	(19.29)***
available potassium	0.01	1.41e-03	0.01	4.41e-03	-0.01	-0.02	0.02	0.01
	(8.67)***	(1.27)	(12.18)***	(5.44)***	(15.70)***	(19.55)***	(17.34)***	(7.78)***
soil pH value	-0.20	-0.40	0.12	0.46	-0.44	-0.22	-0.61	0.13
	(2.33)**	(2.98)***	(0.97)	(4.78)***	(7.61)***	(2.26)**	(5.86)***	(1.55)
soil clay	-0.22	-0.07	-0.51	0.10	0.03	0.11	-0.32	0.15

	(10.33)***	(2.04)**	(16.30)***	(4.42)***	(1.98)**	(4.58)***	(12.35)***	(7.00)***
soil loam	0.01	-0.02	-8.29e-03	-0.03	-0.31	-0.41	-0.15	0.34
	(4.76)***	(11.81)***	(4.03)***	(7.58)***	(16.10)***	(6.22)***	(3.95)***	(5.73)***
soil sand	-0.18	-0.11	-0.33	0.11	-0.01	0.04	-0.24	0.12
	(19.28)***	(7.24)***	(23.23)***	(10.24)***	(2.06)**	(3.96)***	(20.56)***	(12.51)***
organic matter	-3.91	-5.20	0.23	-0.74	-2.17	-3.05	-0.28	0.24
	(27.61)***	(23.30)***	(1.09)	(4.54)***	(22.65)***	(18.39)***	(1.57)	(1.73)*
population	-0.01	-0.02	-1.09e-04	-0.01	-1.55e-03	-3.10e-03	1.38e-03	-0.01
	(17.74)***	(13.69)***	(0.09)	(10.61)***	(2.72)***	(3.15)***	(1.32)	(12.36)***
GDP	9.78e-05	1.39e-04	-1.22e-04	2.92e-04	-2.71e-05	-6.33e-05	-2.85e-05	3.13e-04
	(8.45)***	(7.62)***	(7.06)***	(22.04)***	(3.46)***	(4.68)***	(1.99)**	(27.37)***
distance to nearest road	-0.16	-0.17	-0.09	-0.01	-0.03	-0.02	-0.07	-0.02
	(36.76)***	(24.77)***	(13.69)***	(2.25)**	(9.84)***	(4.28)***	(13.39)***	(5.26)***
distance to provincial capital	0.03	0.06	-0.05	2.59e-03	0.01	0.02	-0.03	0.01
	(73.22)***	(100.40)***	(88.15)***	(6.30)***	(37.76)***	(59.15)***	(61.67)***	(20.57)***
distance to nearest urban core	-0.05	-0.12	0.12	0.03	-0.05	-0.12	0.09	0.03
	(33.87)***	(57.35)***	(59.14)***	(19.84)***	(59.20)***	(74.53)***	(56.49)***	(20.03)***
bufferfarmland	-40.04	-42.72	-17.95	-13.73	-6.66	-11.97	-2.70	-10.53
	(161.60)***	(109.50)***	(48.33)***	(48.36)***	(38.55)***	(40.82)***	(8.75)***	(43.01)***
bufferforest	-37.04	-35.61	-24.68	-13.58	-2.77	-5.22	-6.23	-12.07
	(96.30)***	(58.77)***	(42.79)***	(30.79)***	(10.49)***	(11.54)***	(13.02)***	(31.76)***
QA-grassland cover in 1995					-0.25			
					(275.60)***			
dense grassland cover in 1995						-0.34		
						(342.50)***		
moderate grassland cover in 1995							-0.43	
							(375.00)***	
sparse grassland								-0.39

cover in 1995								(282.90)***
Constant	48.76	25.88	91.27	-20.74	15.19	2.72	62.67	-27.43
	(39.12)***	(13.18)***	(48.84)***	(14.51)***	(17.98)***	(1.87)*	(40.54)***	(22.28)***
R-squared	0.22	0.12	0.06	0.28	0.19	0.22	0.15	0.14
N treated	361969	361969	361969	361969	361969	361969	361969	361969
N available controls	201327	201327	201327	201327	201327	201327	201327	201327

Notes: Absolute value of t-statistics in parentheses. ***significant at 1% level,**significant at 5% level,*significant at 10% level.