Chapter 7
Global Drivers of Land Degradation and Improvement

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Abstract Identification of factors catalyzing sustainable land management (SLM) could provide insights for national policies and international efforts to address land degradation. Building on previous studies, and using novel datasets, this chapter identifies major drivers of land degradation at global and regional levels. The findings of this study confirm the earlier insights in the literature on the context-specific nature of the drivers of land degradation. This context-dependence explains the previous contradictions in the literature on the effects of various socio-economic and institutional factors on land degradation. It also calls for the localized diagnostic of the drivers of land degradation. The drivers of land degradation are predominantly local, so actions to address them should be based on the understanding of the local interplay of various factors and how they affect land degradation.

Keywords Drivers of land degradation · Endogeneity · Land degradation hotspots

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Introduction

Land degradation has occurred on about 30 % of global land area between 1982 and 2006 (Chap. 4), resulting in substantial economic impacts on agricultural livelihoods and national economies (Chap. 6), especially in developing lower income countries. The drivers of land degradation are numerous, complex and interrelated (Nkonya et al. 2011; von Braun et al. 2013; Pender et al. 2009), with often context-dependent characteristics. Therefore, identification of the important drivers of land degradation is crucial for national and international efforts to reduce, and optimally, prevent land degradation and promote land restoration and improvement. Based on this problem definition, this chapter seeks to answer the following research question: what are the major drivers of land degradation at the global and regional levels?

While answering this research question, the present study intends to make the following contributions. Many previous studies have used raw values of the Normalized Difference Vegetation Index (NDVI) as a proxy for land degradation (Nkonya and Anderson 2014; Nkonya et al. 2011). These raw values may be significantly biased by such factors as rainfall dynamics (Bai et al. 2008) and atmospheric or chemical fertilization (Vlek et al. 2010). This chapter uses a new global dataset of land degradation hotspots (Le et al. 2014, Chap. 4) as its dependent variable, which corrects for the above mentioned sources of potential biases. Moreover, many previous studies at the global level (cf. Nkonya et al. 2011 for a review) explore the drivers of land degradation by grouping countries within geographic regions, i.e. Sub-Saharan Africa, Asia, etc. However, the same geographic region may contain countries with very differing conditions. For example, Asia contains both Japan and North Korea, putting such very different countries together may make the results more ambiguous. A more theoretically motivated approach would be to run sub-global regressions for groupings of countries with similar socio-economic, agro-ecological and institutional features. The study makes use of such a country clustering (Table 7.8), developed in Nkonya et al. (2013) and Chap. 2, by making the sub-global regressions more easily interpretable along the major socio-economic and institutional characteristics of the countries. Furthermore, the dependent variable in the present study includes not only degraded and non-degraded categories, but also a category designating areas where land improvement has occurred. Most previous studies confound improved areas with non-degraded areas. To illustrate, land degradation is often considered under dichotomous representation whether land degradation has occurred or not (e.g. usually using a dummy variable with categories 0—land degradation, and 1—no land degradation). However, this ignores the fact that the “no land degradation” category consists of two distinct groups: one group where there has been no change in land quality, and the second group where land quality has improved. The present study disentangles “no land degradation” and “land improvement” as two distinct categories. Fourthly, we seek to further minimize potential omitted variable bias by including some relatively new global level datasets, such as night time lighting intensity series (Elvidge et al. 2001), which were found to be good proxies of institutional development and poverty (Ebener et al. 2005; Sutton et al. 2007; Michalopoulos and Papaioannou 2013). Moreover, the inclusion of regional, country, and agro-ecological zone fixed effects also minimizes the omitted variable bias. Finally, previous work is challenged by the endogeneity of some of the variables in the global models; the present study makes a step forward in addressing this issue.

Literature Review

The causes of land degradation are numerous and complex (Table 7.1). Quite often, the same causal factor could lead to diverging consequences in different contexts because of its varying interactions with other proximate and underlying causes of land degradation.

The effects of proximate drivers of land degradation—such as topography, climate, and soil characteristics—are well understood as causes of land degradation and there is a broad consensus about their causal mechanisms. For example, steeper slopes are more vulnerable to water-induced soil erosion (Wischmeier 1976; Voortman et al. 2000) and soils with high silt content are naturally more prone to degradation (Bonilla and Johnson 2012). There are also a large number of available SLM technologies developed to address soil and land degradation (Liniger and Schwilch 2002; Liniger and Critchley 2007). However, there is an on-going debate on the role of various underlying drivers of land degradation (von Braun et al. 2013; Nkonya et al. 2011) and why many existing SLM technologies are not adopted by landusers (for example, Pender et al. 2009, for Central Asia). For instance, as summarized in Mirzabaev et al. (2015), some well-known points of debate on the drivers of land degradation include: whether higher population causes land degradation (Grepperud 1996), or leads to SLM (Tiffen et al. 1994); whether poverty is a primary driver of land degradation (Way 2006; Cleaver and Schreiber 1994; Scherr 2000) or not (Nkonya et al. 2008); and whether higher market access leads to SLM (Pender et al. 2006), or to land degradation (Scherr and Hazell 1994). Table 7.1 elaborates on these underlying drivers and on the theoretical intuitions behind their cause-and-effect mechanisms.

The conclusions reached have been quite diverse and often contradicting depending on the datasets used, methodologies applied, timeframes considered, and locations studied (Mirzabaev et al. 2015). The purpose of the present analysis is not to give the final word on this debate: the nature of available datasets and of methodological challenges would not allow it. However, our objective is to bring the debate a step forward, both by using more advanced datasets which became available at this scale relatively recently and through methodological upgrades to the previous studies.

The diversity of the results implies that targeting one underlying factor is not, in itself, sufficient to address land degradation. Rather, a number of underlying and

Table 7.1 Proximate and underlying drivers related to land degradation and their potential cause-effect mechanisms (selective)

Drivers	Type	Examples of causality	References
Topography	Proximate and natural	Steep slopes are vulnerable to severe water-induced soil erosion	Wischmeier (1976), Voortman et al. (2000)
Land cover change	Proximate and natural/anthropogenic	Conversion of rangelands to irrigated farming with resulting soil salinity. Deforestation	Gao and Liu (2010), Lu et al. (2007)
Climate	Proximate and natural	Dry, hot areas are prone to naturally occurring wildfires, which, in turn, lead to soil erosion. Strong rainstorms lead to flooding and erosion. Low and infrequent rainfall and erratic and erosive rainfall (monsoon areas) lead to erosion and salinization	Safriel and Adeel (2005), Barrow (1991)
Soil erodibility	Proximate and natural	Some soils, for example those with high silt content, could be naturally more prone to erosion	Bonilla and Johnson (2012)
Pest and diseases	Proximate and natural	Pests and diseases lead to loss of biodiversity, loss of crop and livestock productivity, and other forms of land degradation	Sternberg (2008)
Unsustainable land management	Proximate and anthropogenic	Land clearing, overgrazing, cultivation on steep slopes, bush burning, pollution of land and water sources, and soil nutrient mining are among the major causes of land degradation	Nkonya et al. (2008, 2011), Pender and Kerr (1998)
Infrastructure development	Proximate and anthropogenic	Transport and earthmoving techniques, such as trucks and tractors, as well as new processing and storage technologies, could lead to increased production and foster land degradation if not properly planned	Geist and Lambin (2004)

(continued)

Table 7.1 (continued)

Drivers	Type	Examples of causality	References
Population density	Underlying	No definite answer Population density leads to land improvement	Bai et al. (2008), Tiffen et al. (1994), Boserup (1965),
		Population density leads to land degradation	Grepperud (1996)
Market access	Underlying	No definite answer Land users in areas with good market access have more incentives to invest in sustainable land management	Pender et al. (2006),
		High market access raises opportunity cost of labor, making households less likely to adopt labor-intensive sustainable land management practices	Scherr and Hazell (1994)
Land tenure	Underlying	No definite answer Insecure land tenure can lead to the adoption of unsustainable land management practices	Kabubo-Mariara (2007)
		Insecure land rights do not deter farmers from making investments in sustainable land management	Besley (1995), Brasselle et al. (2002)
Poverty	Underlying	No definite answer There is a vicious cycle between poverty and land degradation. Poverty could lead to land degradation while land degradation could lead to poverty	Way (2006), Cleaver and Schreiber (1994), Scherr (2000),
		The poor heavily depend on the land, and thus, have a strong incentive to invest their limited capital into preventing or mitigating land degradation if market conditions allow them to allocate their resources efficiently	De Janvry et al. (1991), Nkonya et al. (2008)

(continued)

Table 7.1 (continued)

Drivers	Type	Examples of causality	References
Access to agricultural extension services	Underlying	No definite answer Access to agricultural extension services enhances the adoption of land management practices	Clay et al. (1996) Paudel and Thapa (2004)
		Depending on the capacity and orientation of the extension providers, access to extension services could also lead to land-degrading practices	Benin et al. (2007), Nkonya et al. (2010)
Decentralization	Underlying	Strong local institutions with a capacity for land management are likely to enact bylaws and other regulations that could enhance sustainable land management practices	FAO (2011)
International policies	Underlying	International policies through the United Nations and other organizations have influenced policy formulation and land management	Sanwal (2004)
Non-farm employment	Underlying	Alternative livelihoods could also allow farmers to rest their lands or to use nonfarm income to invest in land improvement	Nkonya et al. (2008)

Proximate drivers are biophysical factors and unsustainable land management practices. Underlying drivers are social, economic and institutional factors that lead to unsustainable land management practices. See Chap. 2 for more detailed discussion
Source von Braun et al. (2013)

proximate factors need to be taken into account when designing policies to prevent or mitigate land degradation (ibid.). For the analysis of land degradation, it is necessary to explicitly model nonlinearities and interactions between the variables, and to address potential biases emanating from omitted variables and reverse causalities. It is likely that such diversity and contradictions will remain in future studies, since these contradictions may simply be reflecting the diverging and context-dependent causal interplays of factors affecting land management, i.e. the same factor (e.g. population pressure) may lead to land degradation or land improvement depending on its interactions with other factors (such as poverty, access to markets and extension, etc.) (ibid.).

Methods and Data

This study is guided by the ELD conceptual framework presented in Chap. 2. The ELD conceptual framework classifies the drivers of land degradation into two categories: (1) proximate and (2) underlying (Table 7.2). Biophysical factors, such as precipitation, agro-ecological zones, land use and land cover, are classified as proximate drivers. Whereas such socio-economic and institutional factors as rule of law, land tenure security, GDP per capita, and infant mortality rates, are classified as underlying drivers of land degradation. The econometric model to identify the drivers of land degradation is specified as follows:

$$\begin{aligned}
&\boldsymbol{P}(\boldsymbol{SLM} = 0|\boldsymbol{x}_1,\boldsymbol{x}_2,\boldsymbol{z}) = \boldsymbol{\Phi}[\boldsymbol{\mu}_1 - (\boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3\boldsymbol{z}_i)]\\
&\boldsymbol{P}(\boldsymbol{SLM} = 1|\boldsymbol{x}_1,\boldsymbol{x}_2,\boldsymbol{z}) = \boldsymbol{\Phi}[\boldsymbol{\mu}_2 - (\boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3\boldsymbol{z}_i)] - \boldsymbol{\Phi}[\boldsymbol{\mu}_1 - (\boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3\boldsymbol{z}_i)]\\
&\boldsymbol{P}(\boldsymbol{SLM} = 2|\boldsymbol{x}_1,\boldsymbol{x}_2,\boldsymbol{z}) = 1 - \boldsymbol{\Phi}[\boldsymbol{\mu}_2 - (\boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3\boldsymbol{z}_i)] = \boldsymbol{\Phi}(\boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3\boldsymbol{z}_i - \boldsymbol{\mu}_2)
\end{aligned} \tag{7.1}$$

where, of land degradation (e.g. precipitation, length of growing period, land cover/use); density, GDP per capita, land tenure security, rule of law, etc.);

SLM a categorical variable, where, 0—land degradation, 1—no change, 2—land improvement, with the baseline in 1982–84 and the endline in 2004–06

x_1 a vector of proximate drivers of land degradation (e.g. precipitation, length of growing period, land cover/use);

x_2 a vector underlying drivers of land degradation (e.g. population density, GDP per capita, land tenure security, rule of law, etc.);

z_i vector of fixed effect variables, including administrative divisions (region, country, etc.);

μ_1, μ_2 model constants;

$\Phi(.)$ the standard normal cumulative distribution function.

Taking into account that the dependent variable has three ordered categories, the present study uses an ordered probit model in the estimation. The ordered probit model assumes that a latent variable (not explicitly modeled above) underlying the state of land degradation is normally distributed, while the effects of the independent variables on the ordered outcomes are restricted to be monotonous. The coefficients are then estimated via the maximum likelihood (ML) method. As can be seen from the model equations, if the independent variables have a positive average effect on the probability that "land degradation" will be the outcome, they will unambiguously reduce the probability that "land improvement" will occur. Formally, it means that if

Table 7.2 Description of the variables

Variable name	Description	Source
SLM: sustainable land management	A categorical variable, where, 0—degraded land, 1—no change, 2—improved land. The baseline 1982–84 and the endline 2004–06	Le et al. (2014), Chap. 4 of this volume
Precipitation	Total annual precipitation (mm) during the baseline period of 1982–84	Climate research unit (CRU), University of East Anglia, through Nkonya and Anderson (2014)
AEZ	Length of growing period (LGP). Categorized into six regions: LGP1: 0–59 days, LGP2: 60–119 days, LGP3: 120–179 days, LGP4: 180–239 days, LGP5: 240–299 days, and LGP6: more than 300 days	Source: Alexandros (1995), through Nkonya and Anderson (2014)
Distance to markets	Travel time to urban areas with 50,000 people or more. Most of the underlying data layers are from around baseline period or do not change over time	Uchida and Nelson (2010), through Nkonya and Anderson (2014)
Population density	The data is for 1990. The data is only for one period because using the population density data for some later period as well could have an endogeneity problem with the dependent variable	CIESIN (2010)
Infant mortality rate	Mortality of children below 5 years per 1000 of live births. Baseline: 1982–82, endline: 2005	Baseline: World development indicators, World Bank. Endline: Source: CIESIN http://sedac.ciesin.columbia.edu/povmap
GDP per capita	For the baseline period of 1982–1984	World development indicators, World Bank
DMSP-OLS nighttime lights time series	Remotely sensed intensity of night time lighting for 1992 (i.e. at the basic level shows the availability of electricity during the night time. Should not be confounded with natural day time brightness). Here used as a proxy for broad socio-economic development and availability of non-farm sector	Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency. http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
Land tenure security	Global Land Tenure Master Database. 2007. Has four categories: good—1, moderate concern over the security of land tenure—2, severe concern—3, and extremely severe concern—4. The database was developed in 2004–2006, based on subjective expert evaluations. Closeness to the endline period and	USAID and ARD, Inc. (2008)

(continued)

Table 7.2 (continued)

Variable name	Description	Source
	subjective nature of the evaluation causes potential problems, specifically, endogeneity through reverse causality and measurement error. Though, theoretical reasons for the reverse causality with the dependent variable are thin, i.e. land degradation may not have affected the way experts evaluate the security of land tenure in a specific country. Despite these shortcomings, this is a very important variable that should rather be not missed in the model. Moreover, it is likely that the land tenure situation changes, in most cases, gradually, and this dataset also depicts well the baseline period (perhaps, except for Eastern Europe and the former USSR). To check for sensitivity of the results, we run the global regression with and without this variable to see any influence on other variables	
Rule of law	"Perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular, the quality of contract enforcement" (Kaufmann et al. 2010), property rights, the police, and the courts, as well as the likelihood of crime and violence, baseline of 1996–1998, endline 2002–2004	Worldwide Governance Indicators: http://info.worldbank.org/governance/wgi/index.asp, through Nkonya and Anderson (2014)
Land use/cover	Globcover 2005–2006 data (interpretation should be only as association, not causality). The regressions are run with and without to see any biasing effects of this variable	Bicheron et al. (2008)

$$\frac{\partial P(SLM = 0)}{\partial x_j} = -\beta_j \phi(\mu_1 - \mathbf{X\beta}) < 0 \tag{7.2}$$

it follows that

$$\frac{\partial P(SLM = 2)}{\partial x_j} = \beta_j \phi(\mathbf{X\beta} - \mu_2) > 0 \tag{7.3}$$

where ϕ denotes the standard normal density and $\mathbf{X\beta} = \boldsymbol{\beta}_1\boldsymbol{x}_1 + \boldsymbol{\beta}_2\boldsymbol{x}_2 + \boldsymbol{\beta}_3 z_i$. In contrast, it is generally not clear how the independent variables affect the probability of the "no change" state.

Data

A major shortcoming of many previous global studies is that they do not address the endogeneity between dependent and explanatory variables. For example, poverty may lead to land degradation, but at the same time, land degradation may lead to poverty. If one does not account for such a reverse causality between the dependent and independent variables the model estimates will be biased. To avoid this problem, only variables corresponding to the baseline period (1982–1984) are used as explanatory variables in the model, i.e. the NDVI changes in the future could not have any causal effect on the past values of the explanatory variables (Table 7.2).

However, not all variables are available for the period of 1982–1984, therefore some variables, such as night-time lighting intensity, are taken for the earliest year available, 1992 in this case. There is very little theoretical basis for concluding that land degradation would affect night time lighting intensity, but night time lighting intensity can serve as a proxy for some variables which affect land degradation (e.g., availability of non-farm sectors in the area). At the same time, the use of variables too close to the endline period is minimized, because then the econometric model would not make much sense, since the future cannot cause past: at best, any relationship would be associative, not causal (Table 7.2).

NDVI has well-known limitations as a proxy for land degradation (Le et al. 2014, Chap. 4). However, it can be a good estimate of global vegetation change over a long period of time. Le et al. (2014) address some of the caveats related to using raw values of NDVI by addressing potential distorting effects of rainfall dynamics, atmospheric and chemical fertilization (ibid). The comparison of land degradation results emerging from the work of Le et al. (2014) and the results of land degradation when raw NDVI values are used directly (Nkonya and Anderson 2014), shows considerable and statistically significant discrepancies (Table 7.3).

Both indicators agree on the land degradation status of 63 % of pixels (Table 7.3). However, they disagree on the remaining 37 %, especially concerning the location of degraded areas. The Le et al. (2014) database does not consider a pixel to be degraded if the NDVI value decreases by less than 10 %, as values less than 10 % are not distinguishable from expected measurement errors and noise in the NDVI dataset (Le et al. 2014). In 11 % of areas, the Le et al. (2014) dataset points at degradation, whereas the raw NDVI values do not show degradation. This is due to the fact that Le et al. (2014) also accounts for the masking effects of rainfall, atmospheric and chemical fertilization. For example, the soils may have been completely degraded, but application of chemical inputs may result in similar

Table 7.3 Comparison of land degradation by Le et al. (2014) with the one based on raw NDVI change used by Nkonya and Anderson (2014)

Land degradation categories		Nkonya and Anderson (2014)	
		Degraded (%)	Not degraded (%)
Le et al. (2014), Chap. 4	Degraded	8	11
	Not degraded	25	55

Note Pearson $chi^2(1) = 1.5e+04$ Pr = 0.000. The correlation coefficient 0.096

levels of NDVI as before degradation. The overall coefficient of correlation between these two sets of land degradation indicators is 0.096, indicating that these datasets are very divergent.

The descriptive statistics of the variables in the model are given in Table 7.4. All of the variables are in the pixel format ($8 \times 8\ km^2$). Some variables, such as rule of law, land tenure security, do not vary by pixel but vary by country. So in the case of these variables, the same value is attached to all the pixels within a single country.

Most of the descriptive statistics in Table 7.4 are self-explanatory. However, some of the variables warrant more elaboration. Specifically, night time lighting intensity measures the luminosity of night time lighting emitted from the Earth surface during the night, i.e. this measures artificial night time lighting, and can serve as a proxy for the spread and magnitude of electricity use. The potentially distorting effect of the clouds, sun and moonlight interferences are excluded from the data.[1] The higher the number the brighter is the location. Number zero signifies a dark pixel during the night. The rule of law variable is an index number from the World Bank's World Governance Indicators database.[2] The higher number means a better rule of law. Land tenure security variable varies between 1 and 4, with 1 indicating good land tenure security and 4-extremely severe concern over land tenure security.

Results

The results of the analyses are presented in Tables 7.5, 7.6 and 7.7. The theoretical intuitions behind these findings are discussed on more detail further below after the presentation of the full results.

Table 7.5 presents the global level findings. The model results are checked for robustness by testing several model specifications. The first is the full model, in which all variables described in the data section are included. The second model excludes the variables that are taken from periods closer to the endline period due to

[1] http://ngdc.noaa.gov/eog/gcv4_readme.txt.

[2] http://info.worldbank.org/governance/wgi/index.aspx#doc.

Table 7.4 Descriptive statistics of the variables used

Variable	Mean	Standard deviation	Median	Min	Max
Precipitation, baseline (in mm)	772	660	553	1	6901
Population density, baseline	37	181	2	0	35,662
Distance to market (in minutes)	1106	1522	463	0	27,584
Night time lighting intensity 1992[a]	1.19	5.35	0	0	63
GDP per capita (in USD), baseline	9365	10,228	2816	0	55,221
Rule of law, baseline	0.21	1.11	−0.24	−2.19	1.93
Rule of law, change to endline	−0.06	0.22	−0.07	−1.08	1.08
Infant mortality rate, baseline	41	37	26	6	171
Infant mortality rate, change	9	16	5	−132	146
Land tenure security	1.45	0.92	1	1	4.00

[a]The urban areas are excluded from the analysis

their unavailability for the baseline period (their interpretation being associative, not causal). The third model excludes country dummies, the fourth model is without squared terms, the fifth model is without interaction terms, and the last model is without change variables (i.e. those variables showing the change between the baseline and endline periods). The major finding of this sensitivity analysis is that the same results persist throughout the models, pointing at the robustness of the findings. This also shows that endogeneity or omitted variables are not likely to be an issue in the full model. The check for multicollinearity also shows no problem, with the overall variance inflation factor (VIF) being below 10, and even this is mostly driven by the presence of both level and squared terms. Since model 4, where the squared terms are excluded, does not give results different from the full model, it is concluded that multicollinearity is unlikely to have any tangible effects on the model results. For these reasons, below the results are interpreted based on the full model—our preferred specification.

Most of the variables in the model are statistically significant at 1 % and the overall Pseudo R^2 of the full model is equal to 28 %. The key variables that positively influenced sustainable land management are precipitation and longer distance to markets, including when it interacted with crop production. However, the relationship between distance to markets and sustainable land management is concave, meaning that after a certain distance the effect levels out. Moreover, it is found that higher population density and more intense night-time lighting (a proxy for higher socio-economic development) is positively associated with higher land degradation, though in the case of night time lighting intensity the relationship is convex. However, the interaction of night time lighting intensity and higher

Table 7.5 Global level regression

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full	No endline variables	No country dummies	No squared terms	No interaction terms	No change variables
Precipitation	0.000139***	0.00024***	0.000216***	0.000151***	0.000142***	0.000144***
Population density	−0.000376***	−0.00057***	−0.000488***	−0.000508***	−0.000339***	−0.000346***
Population density, squared	1.24e−09	3.27e−09	6.03e−09*		1.40e−08***	9.84e−10
Distance to market	0.000379***	0.00045***	0.000428***	0.000197***	0.000377***	0.000379***
Distance to market, squared	−3.55e −08***	−4.51e−08***	−4.48e−08***		−3.52e−08***	−3.57e−08***
Night time lighting intensity	−0.0247***	−0.0308***	−0.0335***	−0.0134***	−0.0283***	−0.0248***
Night time lighting intensity, squared	0.000308***	0.00041***	0.000477***		0.000470***	0.000307***
GDP per capita	1.38e−07	0.0000236	9.51e−05***	9.30e−06	2.77e−06	1.24e−05
GDP per capita, squared	2.40e−10	−2.64e−10	−2.43e−09***		1.81e−10	−0
Rule of law	0.0960*	0.0481726	−0.0747***	0.0870	0.0950*	0.0699
Change in Rule of Law	0.118		0.328***	0.115	0.106	
Infant mortality rate	0.00325***	0.0050***	0.00444***	0.00345***	0.00358***	0.00430***
Change in infant mortality rate	0.00257***		0.00403***	0.00240***	0.00234***	
Distance to market with cropland	0.0446***		0.0207***	0.0665***		0.0413***
Night time lighting intensity with population density	7.78e−06***	0.000011***	8.40e−06***	1.18e−05***		7.38e−06***
Distance to market with population density	−2.93e −06***	−2.98e−06***	−4.91e−06***	−2.43e−06***		−3.05e−06***
Land use, cropland-base						
Mosaic vegetation—crop	0.662***		0.453***	0.788***	0.442***	0.637***
Forest	1.101***		0.878***	1.255***	0.886***	1.076***

(continued)

Table 7.5 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full	No endline variables	No country dummies	No squared terms	No interaction terms	No change variables
Mosaic forest—shrub	0.724***		0.450***	0.872***	0.507***	0.708***
Shrublands	0.729***		0.415***	0.882***	0.512***	0.711***
Grassland	0.694***		0.413***	0.856***	0.479***	0.664***
Sparse vegetation	0.796***		0.619***	0.937***	0.580***	0.775***
Bare surface or water	0.590***		0.549***	0.722***	0.379***	0.572***
Land tenure security, base—good						
Moderate concern	0.729***		−0.0320***	0.718***	0.723***	0.853***
Severe concern	−0.850***		−0.0444***	−0.903***	−0.920***	−0.966***
Extremely severe concern	−0.166		0.0783***	−0.218**	−0.176*	−0.256***
Missing values for land tenure	−0.404**		0.175***	−0.397**	−0.540***	−0.290*
Regional dummies, base—SSA						
LAC	1.549***	1.41***	−0.381***	1.613***	1.729***	1.450***
North America	1.574***	1.38***	0.142***	1.657***	1.762***	1.438***
NENA	1.593***	1.35***	0.426***	1.571***	1.775***	1.529***
Asia and Pacific	0.115	−0.66***	0.0954***	0.114	0.113	0.222***
Europe	0.710***	−0.74	0.427***	0.703***	0.733***	0.703***
Length of growing period—LGP1						
LGP2	−0.0454***	−0.071***	−0.0784***	0.00323	−0.0461***	−0.0468***
LGP3	−0.0766***	0.01***	−0.127***	−0.0638***	−0.0842***	−0.0655***
LGP4	−0.413***	−0.35***	−0.642***	−0.426***	−0.436***	−0.375***

(continued)

Table 7.5 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full	No endline variables	No country dummies	No squared terms	No interaction terms	No change variables
LGP5	−0.486***	−0.46***	−0.817***	−0.496***	−0.521***	−0.465***
LGP6	−0.453***	−0.39***	−0.753***	−0.460***	−0.497***	−0.437***
Country dummies	Yes	Yes	No	Yes	Yes	Yes
$\mu 1$	0.797***	0.58***	0.253***	0.901***	0.616***	0.938***
$\mu 2$	4.858***	4.57***	4.125***	4.933***	4.677***	4.981***
Observations	1,572,534	1,585,096	1,572,534	1,572,534	1,572,594	1,585,096

Notes Country dummies are also included, but not reported here due to space limits. LGP1: 0–59 days, LGP2: 60–119 days, LGP3: 120–179 days, LGP4: 180–239 days, LGP5: 240–299 days, and LGP6: more than 300 days. *,** and ***Mean associated coefficient is statistically significant, respectively, at 0.10, 0.05 and 0.01 %, respectively. *Blank cells* mean the associated variable was not reported in the corresponding region or that it had only one value. For example, rule of law and land tenure security had the same value in North America. Robust standards errors are applied.

Table 7.6 Regression by major geographic regions

Variables	SSA	LAC	North America	NENA	Asia	Europe
Precipitation	0.000592***	0.000125***	0.000347***	0.000497***	−8.21e−05***	0.000312***
Population density	−1.79e−05	−0.000517***	−0.000208	−0.000828***	−0.000658***	−8.06e−05
Population density, squared	1.13e−08	−2.70e−08***	7.80e−08***	3.07e−08	7.87e−09**	4.30e−10
Distance to market	0.00107***	0.00121***	0.000885***	0.000724***	0.000231***	0.00100***
Distance to market, squared	−2.86e−07***	−2.33e−07***	−1.12e−07***	−1.09e−07***	−8.74e−09***	−1.46e−07***
Night time lighting intensity	−0.0611***	−0.0562***	−0.0439***	−0.0160***	0.00617***	−0.0108***
Night time lighting intensity, squared	0.000998***	0.000831***	0.000624***	0.000156*	−0.000225***	0.000260***
GDP per capita	0.000327**	−0.000926	−3.18e−05	−0.000482	0.000220	3.17e−05
GDP per capita, squared	−3.06e−08**	1.21e−07		1.01e−07	−5.26e−09	5.52e−11
Rule of law	0.391***	0.449		−0.00900	2.31e−05	−0.402***
Change in rule of law	0.316**	−1.239		0.302	−0.0970	−0.623*
Infant mortality rate	0.00400*	0.00678		0.00324	0.00468***	0.00345
Change in infant mortality rate	−0.00231***	0.0141***	0.0942***	−0.00470***	0.00576***	0.00572***
Distance to market with cropland	0.115***	−0.0187	0.127***	0.192***	0.0939***	−0.240***
Night time lighting intensity with population density	4.95e−06**	1.63e−05***	1.62e−06	1.28e−05***	9.20e−06***	1.73e−06*
Distance to market with population density	−9.61e−06***	−9.99e−06***	−5.79e−06***	−5.27e−06***	−2.17e−06***	−1.50e−06***
Land use, Cropland-base						
Mosaic vegetation—crop	0.383***	0.326**	1.186***	1.448***	0.930***	−0.495***
Forest	0.654***	0.683***	1.803***	1.733***	1.352***	−0.0412
Mosaic forest—shrub	0.247**	−0.0776	1.292***	1.419***	0.802***	−0.159***
Shrublands	0.0779	−0.00660	1.437***	1.391***	0.875***	−0.290***
Grassland	0.199*	−0.0383	1.329***	1.390***	0.861***	−0.405***
Sparse vegetation	0.558***	0.694**	1.076***	1.708***	0.793***	−0.271***

(continued)

Table 7.6 (continued)

Variables	SSA	LAC	North America	NENA	Asia	Europe
Bare surface or water	1.339***	2.386***	1.014***	2.335***	0.645***	0.278*
Land tenure security, base—good						
Moderate concern	0.836***	−0.259	−1.820**			
Severe concern	0.555***	2.013**		−0.487*		
Extremely severe concern	0.512***	0.158		0.0569	0.130	−0.679
Missing values for land tenure	1.560***	0.164		−0.339		
Length of growing period—LGP1						
LGP2	−0.0267*	−0.165***	−0.116***	−0.652***	−0.00234	0.552***
LGP3	−0.0871***	−0.569***	−0.536***	−0.645***	−0.0172	0.770***
LGP4	−0.154***	−0.419***	−1.262***	−0.651***	−0.464***	0.803***
LGP5	−0.369***	−0.405***	−1.161***	−0.909***	−0.371***	0.765***
LGP6	−0.346***	−0.482***	−0.646***	−1.098***	−0.303***	1.199***
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
μ1	1.301***	−0.920	−0.854	−0.484	1.571	0.0552
μ2	4.974***	3.530*	4.283***	3.886***	4.933***	4.901***
Observations	175,919	33,631	354,118	173,015	299,334	461,666

Notes Country dummies are also included, but not reported here due to space limits. LGP1: 0–59 days, LGP2: 60–119 days, LGP3: 120–179 days, LGP4: 180–239 days, LGP5: 240–299 days, and LGP6: more than 300 days. *,** and ***Mean associated coefficient is statistically significant, respectively, at 0.10, 0.05 and 0.01 %, respectively. Blank cells mean the associated variable was not reported in the corresponding region or that it had only one value. For example, rule of law and land tenure security had the same value in North America. Robust standards errors are applied. Europe includes Russia.

population density has a positive relationship with sustainable land management.[3] Those areas which have both higher population and good socio-economic development[4] are found to be likely to manage their land resources more sustainably. Better rule of law is significant at 10 % and positively related to SLM in the full model. Another key variable found to be positively associated with SLM is secure land tenure. Those areas with serious and severe concerns over land tenure security are associated with land degradation. Among various land covers and uses, cropland was found to be more associated with land degradation. Longer length of the growing period is found to lead to more land degradation. At the same time, the results do not find a statistically significant impact of GDP per capita. Of course, a lack of statistical significance does not mean a lack in significance of GDP per capita in general. In general, it would mean that lower GDP per capita, and hence, poverty, does not have to lead to land degradation. This finding is also corroborated by the fact that those countries with higher infant mortality rates (a classic proxy for poverty) in 1982–1984 have managed their lands more sustainably than those countries with lower infant mortality rates. Infant mortality rate is a strong proxy for poverty. These results signify that poorer locations are not necessarily associated with land degradation. The causal mechanism driving this could be that since dependence on agriculture and land is higher in poorer locations, landusers in these areas are more motivated to manage land sustainably (Nkonya et al. 2011). At the same time, it should be noted that those countries which made more progress towards reducing infant mortality during the studied period, also made more progress in terms of sustainable land management.

Table 7.5 presents the results of the regression run separately for major global regions. The sub-global regressions are broadly consistent with the global model results, even though there are some region-specific divergences. Precipitation, similarly, is positively associated with land improvement in all regions, except Asia. One potential explanation for this could be that Asia has much higher reliance on irrigated agriculture, with a lower role for rainfall in crop production. Population density has negative association with sustainable land management in Asia, Near East and North Africa (NENA) and Latin America and Caribbean (LAC). However, in other regions, the regressions do not show statistically significant results for the effect of population density. The distance to markets has a concave relationship with SLM in all regions. The night time lighting intensity has convex relationship with SLM in most regions, except in Asia, where the relationship is concave. GDP per capita does not show statistical significance, but only in Sub-Saharan Africa (SSA) where it has a concave relationship with SLM. Similarly, better rule of law is positively related to SLM in SSA, but not in Europe. Those countries with higher

[3]Land degradation hotspots database by Le et al. (2014) used here excludes urban areas from its analysis, so our night time lighting intensity and population density variables are not biased by urban areas.

[4]For example, availability of non-farm sector. The night time lighting intensity variable at its basics also stands for availability of electricity, which may imply having better access to broader development opportunities.

infant mortality rates (i.e. here used as a proxy variable for poverty) in Asia and SSA were associated with less land degradation, whereas in other regions the effect is non-significant. The reductions in infant mortality rates (a proxy for poverty reduction) have led to higher land degradation in SSA and NENA, but to lower land degradation in other regions. As we said earlier, infant mortality rate is taken as a proxy for poverty. The explanation for this seemingly surprising finding can be that those areas with higher economic development achieved reductions in infant mortality rates, but also the opportunity costs of labor might have increased as a result of economic growth. Consequently, making the application of labor-intensive SLM measures more costly. Other surprising results from Table 7.5 are that less secure land tenure does not seem to be associated with higher land degradation in SSA. In most regions higher levels of land degradation occur in croplands, but not in Europe, where other land uses, such as shrublands, forests, grasslands, have experienced more land degradation. In all regions a longer period of growing days is associated with more land degradation.

The results of the analyses are further nuanced by Table 7.7, where separate regressions are run for each cluster of countries with similar socio-economic and institutional conditions. The characteristics of these clusters are explained in detail in Table 7.8, however, what needs to be borne in mind is that the higher the number of the cluster, the higher the level of economic, institutional and technological development of the countries making up that cluster. For example, Cluster 1 is made up of the least developed countries (so called, "the bottom billion", Collier (2007)), whereas cluster 8 is comprised of the most advanced countries, mostly OECD countries. The major characteristics of the clusters are shown in Table 7.8. The results presented in Table 7.7 are also broadly consistent with global findings, but also have their specific insights. The positive association of precipitation with land improvement is present for the least developed and most developed countries, but not for those countries in the middle. Population density is negatively related to SLM in lower income countries, but positively for higher income countries. Distance to markets seems to lead to more SLM all across the clusters and higher night time lighting intensity to less SLM.

The results of these three tables are summarized in Table 7.9. The variables showing a larger consistency across all the regression models are distance to markets and the interaction of distance to markets with population density. The longer distance to markets means less land degradation (both in croplands and non-cropped areas). However, higher population densities combined with longer distance to markets seem to mean more land degradation. At first sight, it is understandable that remote areas have lower chances then areas closer to major urban centers of being deforested, overgrazed, and used in crop production (unless they are densely populated). For example, in Central Asia, it was found that most of rangeland degradation happens in areas near population settlements, as the costs of moving livestock to more remote pastures are high (Pender et al. 2009). However, as we have seen in the literature review section, higher market access could also give more incentives for sustainable land management as the opportunity cost of fertile soil is higher in areas closer to markets (Pender et al. 2006). On the other

Table 7.7 Regression by clusters

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Precipitation	0.000297***	0.000132**	−0.000137***	−1.12e−05	0.000440***	−4.56e−05***	0.000570***	0.000463***
Population density	−0.000430***	−0.00893***	−0.000496***	0.000148**	−0.000835***	−0.000378***	−0.000322	0.000683***
Population density, squared	2.97e−08***	1.19e−05***	7.19e−09**	9.08e−09	−5.13e−09	6.74e−08***	2.44e−07***	−1.82e−08**
Distance to market	0.000798***	0.000650***	0.000299***	0.00123***	0.000695***	0.000763***	0.00128***	0.00170***
Distance to market, squared	−1.88e−07***	−1.75e−07***	−1.49e−08***	−3.89e−07***	−1.00e−07***	−9.91e−08***	−1.63e−07***	−3.13e−07***
Night time lighting intensity	−0.0169***	0.131**	0.00788***	−0.0139***	−0.0145***	−0.0287***	−0.0232***	−0.0191***
Night time lighting intensity, squared	0.000253**	−0.00187	−0.000232***	0.000246***	9.94e−05	0.000367***	0.000547***	0.000291***
GDP per capita	0.000184*	0.000204	0.000181**	7.98e−05	−0.00136*	0.000143	−1.67e−06	−5.84e−05
GDP per capita, squared	−1.94e−08**	−3.54e−09	−8.61e−09	−3.11e−09	2.67e−07*	−2.39e−09	1.29e−10	1.58e−09
Rule of law	0.166*	0.0138	0.154	−0.219*	0.318	−0.423**	−0.386**	−0.390
Change in rule of law	0.236*	−0.392	−0.332	−0.0343	0.807***	−0.406	−0.739**	0.228
Infant mortality rate	0.00454**	0.00260	0.00418**	−0.00130	0.00453	−0.00584*	0.0333***	−0.0343**
Change in infant mortality rate	−0.00201***	−0.0145***	0.00523***	0.00794***	−0.00660***	0.00940***	−0.113***	−0.00356
Distance to market with cropland	0.101***	−0.0906	0.0667***	−0.0866***	0.183***	−0.105***	−0.0223	−0.0469***
Night time lighting intensity with population density	5.52e−06*	−0.00314***	6.27e−06***	−3.38e−06	1.69e−05***	3.30e−06*	−1.21e−05***	−7.81e−06***

(continued)

Table 7.7 (continued)

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Distance to market with population density	−5.80e−06***	−8.49e−06***	−1.87e−06***	−4.52e−06***	−7.29e−06***	−4.25e−06***	−4.76e−06***	−8.28e−06***
Land use, cropland-base								
Mosaic vegetation—crop	0.640***	−0.826*	0.759***	−0.0499	1.372***	0.0233	0.420***	0.284***
Forest	0.917***	−0.731*	1.137***	0.226***	1.644***	0.694***	0.997***	0.827***
Mosaic forest—shrub	0.458***	−1.038**	0.594***	−0.255***	1.388***	0.555***	0.462***	0.229***
Shrublands	0.226***	−1.208***	0.665***	−0.241***	1.426***	0.505***	0.384***	0.272***
Grassland	0.184**	−1.148***	0.803***	−0.00128	1.516***	0.461***	0.297**	0.141***
Sparse vegetation	0.739***	−0.414	1.107***	0.209***	1.790***	0.528***	0.359**	0.241***
Bare surface or water	1.875***	0.793*	1.784***	1.551***	2.669***	0.254***	2.168***	1.438***
Land tenure security, base—good								
Moderate concern	0.638***	1.044	−0.134	−1.240***	−1.816***		−2.981***	
Severe concern	0.0222	0.370		−1.447***	−0.865**	−0.296	−1.718***	
Extremely severe concern	0.397***	1.408*	0.0510	−0.481***	−0.504***	0.740***		
Missing values for land tenure	0.948***	0.977*		−1.290***	−0.858***	−1.045***	−0.660**	−2.032***
Length of Growing Period—LGP1								
LGP2	0.359***	0.322***	−0.0586***	−0.311***	−0.426***	0.0892***	−0.437***	−0.225***
LGP3	0.467***	1.548***	−0.0847***	−0.665***	−0.716***	0.351***	−0.612***	−0.997***
LGP4	0.560***	1.174***	−0.402***	−0.566***	−0.682***	0.417***	−1.010***	−1.347***
LGP5	0.407***	0.925***	−0.371***	−0.195***	−0.985***	0.451***	−0.782***	−1.314***

(continued)

Table 7.7 (continued)

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
LGP6	0.476***	0.799***	−0.278***	−0.247***	−1.102***	0.512***	−0.931***	−0.934***
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$\mu 1$	1.846***	0.0298	1.271***	−1.109***	−2.367***	−0.222	−1.700***	−2.470**
$\mu 2$	5.226***	4.252***	3.545***	1.993***	1.999**	4.810***	2.814***	1.949**
Observations	126,716	24,677	161,004	94,401	161,812	769,961	23,508	210,455

Notes Country dummies are also included, but not reported here due to space limits. LGP1: 0–59 days, LGP2: 60–119 days, LGP3: 120–179 days, LGP4: 180–239 days, LGP5: 240–299 days, and LGP6: more than 300 days. *,** and ***Mean associated coefficient is statistically significant, respectively, at 0.10, 0.05 and 0.01 %, respectively. *Blank cells* mean the associated variable was not reported in the corresponding region or that it had only one value. For example, rule of law and land tenure security had the same value in North America. Robust standards errors are applied.

Table 7.8 The socio-economic and institutional characteristics of clusters

Clusters	GDP per capita	Government effectiveness	Population density	Agricultural intensification	Maximum changes in NDVI values between the baseline (1982–84) and endline (2003–06)*	Cereal yields	Share of agriculture in GDP	Share of rural population in total
1	Lower	Lower	Higher	Lower	Highest dispersion, both biggest decreases and increases	Lower	Higher	Higher
2	Mid	Mid	Higher	Higher	Smaller decreases	Mid	Mid	Higher
3	Mid	Mid	Higher	Mid	Smaller decreases	Mid	Mid	Mid
4	Mid	Mid	Lower	Mid	Larger decreases	Mid	Mid	Lower
5	Mid	Mid	Lower	Lower	Smaller decreases	Lower	Mid	Mid
6	Higher	Higher	Mid	Higher	Larger decreases	Mid	Mid	Lower
7	Higher	Higher	Higher	Higher	Smaller decreases	Higher	Lower	Lower

Source Chap. 2

Notes *The NDVI time-series comes from GIMMS dataset, which is driven from NOAA AVHRR satellite data (http://glcf.umd.edu/). The NDVI changes here-calculated have not been corrected for the effects of inter-annual rainfall variation, atmospheric fertilization and human application of mineral fertilizer.

hand, the opportunity cost of labor is also higher in high market access areas, thus, was suggested to be a barrier for implementing labor-intensive SLM measures in those areas (Sherr and Hazell 1994). In this regard, even the interaction of distance to markets with croplands has a negative association with SLM in a majority of the models used. It means that, in most cases, the areas closer to markets have higher chances of being degraded. The incentive effect of nearness to markets for SLM seems to be working only in more advanced economies and not in lower income countries. The reason for this might be (in addition to physical access to the area) that in lower income countries the higher opportunity cost of labor in high market access areas is preventing the application of SLM measures, which are necessarily labor-intensive as the capital-intensive measures are even less affordable. Whereas in more advanced economies, the capital may be more affordable than labor, and the capital is certainly cheaper in areas with higher market access than in remote areas, so farmers cultivating croplands closer to urban centers in advanced countries are more able to implement SLM measures through more intensive use of capital (satellite guided precise fertilization, drip irrigation, etc.).

Another more consistent finding is the lack of significance of GDP per capita in explaining SLM. As stated earlier, this lack of significance should not be considered

Table 7.9 Summary of findings in global, regional and cluster-based regressions

Variables affecting SLM	Global	Regional	Cluster	Exceptions from the dominant sign
Precipitation	+	+/−	+/−	Asia, Clusters 3 and 6
Population density	−	−	+/−	Clusters 4 and 8
Distance to market	+	+	+	
Night time lighting intensity	−	+/−	+/−	Asia, Clusters 2 and 3
GDP per capita	.	.	.	SSA(+), Clusters 1 and 3 (+), Cluster 5(−)
Rule of law	+	+/−	+/−	Clusters 4, 6, 7, Europe
Change in rule of law	.	+/−	+/−	Europe
Infant mortality rate	+	+	+/−	Clusters 6 and 8
Change in infant mortality rate	+	+/−	+/−	SSA, NENA, Clusters 1, 2, 5 and 7
Distance to market with cropland	+	+/−	+/−	Europe, Clusters 4, 5, 6 and 8
Night time lighting intensity with population density	+	+	+/−	Clusters 2, 4, 7 and 8
Distance to market with population density	−	−	−	
Land use (most degradation)	Cropland	Cropland	Cropland	Europe, Cluster 2 and 4
Land tenure insecurity	−	+/−	+/−	SSA, Clusters 1 and 2
Length of growing period	−	+/−	+/−	Clusters 1, 2 and 6

Note Plus means positively associated with SLM, minus—negatively, dot—not significant. In regional and cluster-based regressions, if there are differences between groups, more prevalent sign is depicted in bold.

unimportant except in a few isolated cases. For example higher GDP per capita seems to be positively associated with SLM in SSA, but overall these two variables are not significant in other regions. The lack of significance of GDP may also hint at the fact that the impact of GDP is already captured by other variables indicating economic performance, which are available on a smaller geographic level, such as night-time light intensity. While night lights per se may represent a cruder measure of economic development than GDP, they do not ignore its spatial variability.[5] This stresses the importance of including the variables in the analysis that contain information on a more detailed level, since land degradation may also be a highly dispersed phenomenon not limited to country borders or within-country boundaries. The conclusion we can draw is that GDP per capita is not a major factor influencing sustainable land management in many cases. Moreover, higher infant mortality rate, used as a proxy for poverty, has not prevented SLM in most regions of the world. Poorer households are expected to have higher reliance on natural resources, including land, for the livelihoods. Thus, they have more incentives to manage land sustainably. Moreover, the opportunity cost of labor in poorer locations is lower, thus allowing for its use in implementing labor-intensive SLM measures. This finding is also agrees with the results of Nkonya et al. (2008). On the other hand, those countries which have reduced infant mortality rates more than others seem to be also making more efforts toward SLM.

Higher population density is also found to be leading to more land degradation, except in the most advanced countries and some middle income countries (Clusters 4 and 8). Supporting this finding, most estimations show that night time lighting intensity interacted with population density is leading to SLM. Night-time light intensity can be used as a proxy for socio-economic development of the area, the higher prevalence of non-farm sectors, and easier access to capital. More economically dynamic areas with larger populations, thus, can provide more incentives and opportunities for SLM adoptions and innovations (a la Boserup 1965), information costs can be assumed to be lower and technology spillover effects are more likely. However, densely populated, but economically backward areas seem to be following a more Malthusian scenario, where higher population is translating to more land degradation. It is also found that in advanced economies with higher night time lighting intensity, the effect of population density on promoting SLM is decreasing. This may be due to the overall higher level of night time lighting intensity in advanced economies, where even relatively less densely populated areas have high night time lighting intensity (and also high share of non-farm sectors).

Rule of law was found to be positively associated with SLM in most cases, especially in SSA and other developing lower income countries, but not in Europe, and the countries of Clusters 4, 6 and 7. First of all, this may be due to nonlinearities in the effect of rule of law on SLM outcomes. Any increases from very low

[5]This is highlighted by the fact that night lighting and GDP have a moderate correlation on country level (0.44), but only a weak one on pixel level (0.13), which points at substantial variation of night lights within countries.

levels of rule of law to higher levels may have huge positive effects for SLM. However, further changes in already high levels of rule of law may have a marginally lower or no effect.

Land tenure, a measure of security, also shows interesting results. Insecure land tenure seems to be a deterrent for SLM in middle income and advanced economies, but not for the lowest income countries, especially in Sub-Saharan Africa. Secure land tenure may provide additional benefits and opportunities with relatively well-functioning markets, including output, input and financial markets. Credible land property rights expand the planning horizon of agricultural entrepreneurs and make costly innovations in SLM with large mid- to long term benefits more profitable in expectations. Where markets do not function well or are very thin, secure land tenure may have much less effect on SLM. It should also be noted that a credible and stable rule of law is a precondition for secure land tenure, so that the effect of rule of law on SLM supersedes the one of land right security.

Conclusions

There have been numerous studies on the drivers of land degradation in the past with often contradicting results. It is believed that the contradictions are due to differences in applied methods and the datasets. Although these differences in methods and datasets play a crucial role in explaining the diverging findings on the causal mechanisms of the factors affecting land management, these differences are also due to context-specific nature of the interactions between various drivers of land degradation, where socio-economic, institutional and technological particularities of the location shape the nature of the interactions between the drivers of land degradation. SLM is positively associated with land tenure security, especially in middle-income and advanced economies. In lower income countries a lack of secure land tenure is not associated with less SLM. Shortening the time to reach markets may have many other desirable outcomes but not necessarily a decrease in land degradation, especially in low income countries. Population pressure may lead to land degradation unless public policies provide for increases in non-farm jobs. The findings of this study call for localized diagnostic of the drivers of land degradation and for elaborating policy actions targeting the local interplay of major drivers of land degradation.

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