

LANDPARAM: A tool to compute land use change parameters

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Abstract

This article introduces a web-accessible tool LANDPARAM that provides land use change related parameters. This tool allows users to aggregate the parameter of interest at self-defined resolutions (e.g. national and regional). Users only need to upload a mapping file indicating the area of interest and its mapping to the geographical coordinates. For a given area, LANDPARAM returns the following outputs: 1) the own-price land supply elasticity and land transformation elasticity, 2) cropland areas converted from forest, grassland, and shrubland, 3) a visualization of the grid-cell level land cultivation probabilities, and 4) a comparison of the results from multiple simulations.

Keywords: land use change, cropland supply, spatial data

1 Introduction

Land supply elasticity is a key parameter in assessing the land use response to changing environment, market conditions and policies. It reflects the fact that cultivation decisions depend on land profitability as well as on land suitability. However, the latter is often ignored in disaggregated empirical studies due to the unknown site-specific land returns. One approach to overcome this data difficulty, so that land profitability can be explicitly controlled for in the cultivation decision process, is to assume the homogeneous land returns within a larger-scale area. This solution appears to be viable because land returns, although site-unknown, can be well documented at the more aggregated level (e.g. state or national level). For this reason, previous studies often grossly estimate or extrapolate land supply elasticity using aggregated data, and assume that the entire region shares the same parameter value (Hertel et al., 2014; van Meijl et al., 2006; Gurgel et al., 2007).

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In spite of its practical importance, the assumption of uniformity has obvious drawbacks. For large areas with complex natural and socio-economic characteristics, a coarsely-estimated uniform parameter is not surprisingly less precise. It can also mask the geographical heterogeneity within the area. In the case that the disparity drives the spatially differentiated land use change response through land supply elasticities, the reliability of an integrated assessment model using these parameters would be weakened. Even worse, the model may render misleading conclusions. All these concerns lead to a demand for the elasticities to be estimated from high-resolution data. Furthermore, the parameters can be aggregated to any geographical scope to accommodate users' demand. These needs have motivated the creation of LANDPARAM.

LANDPARAM is designed as an open source online simulation tool run on myGeoHub (<https://mygeohub.org>). For a given area, the tool generates cropland supply elasticities, land transformation elasticities, and cropland conversion in physical areas. The intended target users include integrated assessment modelers and scholars who are interested in economic and policy analysis regarding land use issues. Having a better understanding of these parameters can certainly increase the accuracy and reliability of research. The tool can also be useful from the teaching perspective. Since it is open-source, users can download the source code via Subversion from the site and modify it for their own purposes. The source code file was written in R. Users with a good knowledge of the software can easily customize the functions of the tool to distribute and promote their own research.

2 Methods

This section briefly discusses the computation of land supply and transformation elasticities. The information helps the users to understand the methodology supporting the tool, although the users do not need to handle the computation and data complexity themselves. For a complete description of the method, users are advised to consult [Villoria and Liu \(2015\)](#).

2.1 Updated predicted cultivation probability

In this analytical framework, the grid-cell level cultivation status is specified as a spatial Logit model (Equation 1), in which the dependent variable Z_i is one if the grid is cultivated and zero otherwise. The independent variables to explain the cultivation status include a set of natural factors S_i and market access A_i .

$$P(Z_i = 1|A_i, S_i) = \Lambda(\alpha_0 + \alpha_1 A_i + \alpha_2 \log(S_i) + \varepsilon_i), \quad (1)$$

Estimating this model gives the elasticity of cultivation probability ϵ_i with respect to market access A_i while holding other factors unchanged. Equation 2 shows that the predicted cultivation is affected by the grid's access to market changes. A larger elasticity ϵ_i indicates a higher probability of cropland conversion for a given level of change in market access.

$$\epsilon_i = \frac{\partial \hat{P}(Z_i = 1)}{\partial A_i} \times \frac{A_i}{\hat{P}(Z_i = 1)} = \lambda[\alpha_0 + \alpha_1 A_i + \alpha_2 \log(S_i)] \times \alpha_1 \times \frac{A_i}{\hat{P}(Z_i = 1)}. \quad (2)$$

The transition elasticity ϵ_i infers the updated predicted cultivation probability $\hat{P}'(Z_i = 1)$, which finally determines the land use change after the market access perturbation. It is assumed that if this updated probability $\hat{P}'(Z_i = 1)$ surpasses a certain threshold, pixel i will be converted to cropland. Summing over all the converted pixels area gives the total physical hectares of new cropland. Repeating this procedure at different levels of returns A_i will trace out the cropland supply schedule (in Million hectares).

$$\hat{P}'(Z_i = 1) = \hat{P}(Z_i = 1) \times \left[1 + \frac{\partial \hat{P}(Z_i = 1)}{\hat{P}(Z_i = 1)} \right] = \hat{P}(Z_i = 1) \times \left[1 + \epsilon_i \times \frac{\partial A_i}{A_i} \right]. \quad (3)$$

2.2 Elasticity parameters

Own-price cropland supply elasticity $\epsilon_{c,c}$ is defined as the percent change of cropland supply for one percent change in land returns represented by market access. It is important to note that the percent change of cropland supply is computed based on physical area obtained as above explained. $\epsilon_{c,c}$ is not directly estimated from the equations in the previous section. Instead, the set of equations estimate the cross-price cropland supply elasticity $\epsilon_{nc,c}$ (nc, c for “from non-crop land” to “cropland”). Further, the own-price cropland supply elasticity $\epsilon_{c,c}$ is computed from $\epsilon_{nc,c}$, using Equation 4.

$$\epsilon_{c,c} = \frac{1 - \theta_c}{\theta_c} \times \epsilon_{nc,c} \quad (4)$$

Elasticity of transformation in the CET production function can be calibrated as Equation 5. Again, refer to Villoria and Liu (2015) for the theoretical illustration of the derivations.

$$\sigma = -\frac{\epsilon_{c,c}}{1 - \theta_c} = -\frac{1}{\theta_{nc}} \left(-\frac{\theta_{nc}}{\theta_c} \right) \times \epsilon_{nc,c} = \frac{\epsilon_{nc,c}}{\theta_c}, \quad (5)$$

3 Demonstration

3.1 Workflow

LANDPARAM 1.0 allows users to aggregate the selected parameters to countries and regions. In this section, we demonstrate an example of land use change induced by increased market access in sub-Saharan Africa (SSA). The goal is to obtain the own-price cropland supply elasticities for SSA sub-regions, given a certain level of change in market access. These output parameters will further be used in a computable general equilibrium model which is focused on and explicitly models SSA sub-regions. In this example, the area of interest covers 47 SSA countries. These countries are further grouped into four regions - East, South, West and Central Africa.

Figure 1 illustrates the workflow of LANDPARAM. Basically, this tool combines fine-scale (the grid-level) information with user’s aggregation requirement to deliver the related parameters at a more aggregated level. The present version provides land supply elasticity, land transformation elasticity, and physical areas of cropland conversion. These are so far the most often referred parameters in a computable general equilibrium model such as GTAP.

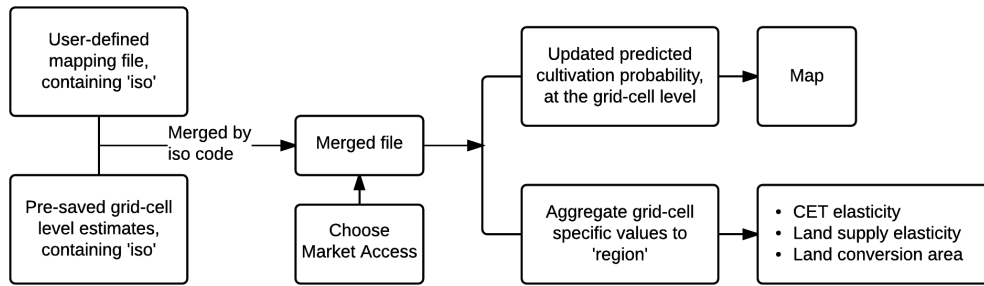


Figure 1: LANDPARAM workflow.

The output also includes the visualization of the grid-cell level information for the purpose of illustration and presentation. The grid-cell level estimation involves sophisticated spatial modeling and data management. However, with the tool, the users can skip these complexities and obtain the information they are interested. Each of the input and output elements will be explained in details below.

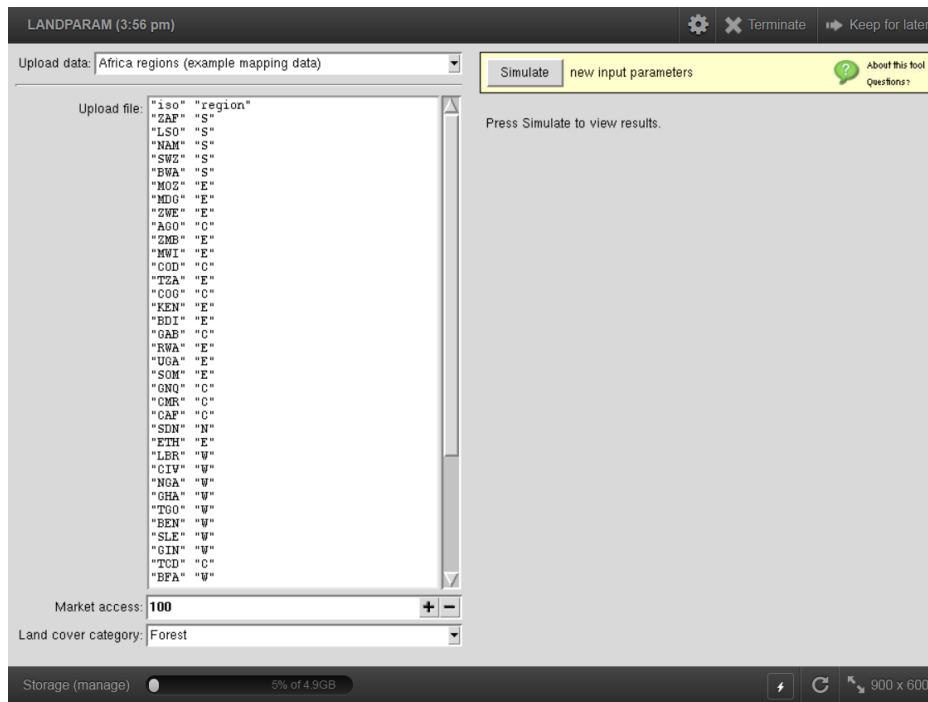


Figure 2: Launch the tool

3.2 Inputs

3.2.1 Embedded gridded data

When the tool is published, a pre-saved database containing grid-cell level information is already embedded as the building bricks for further aggregation computations. In particular, this database contains grid-cell coordinates (longitude and latitude), the grid-specific predicted cultivation probability, transition elasticity (of cultivation probability with respect to market access), total physical area of the grid, and the grid’s associated land cover (Forest, Grassland, Shrubland) and country code. For more information about the grid-specific baseline cultivation status, how the predicted cultivation probability and transition elasticity are estimated and their roles in computing the land supply elasticities, readers are advised to consult [Villoria and Liu \(2015\)](#). Listing 1 displays part of this embedded data.

Listing 1: Embedded grid-level information

z	iso	elasticities	predicted.prob	garea	lon.x	lat.x	cover
0	ZAF	1.40751730	0.03933182	7013.961	18.87500	-34.29167	S
1	ZAF	0.94551657	0.04290682	7013.961	19.29167	-34.29167	S
1	ZAF	1.16318353	0.02752699	7013.961	19.62500	-34.29167	S
1	ZAF	0.99264317	0.04098887	7013.961	20.04167	-34.29167	S
1	ZAF	0.29351333	0.02159603	7013.961	20.37500	-34.29167	S
1	ZAF	0.19919020	0.03423147	7013.961	20.79167	-34.29167	S
1	ZAF	0.14811586	0.07978316	7013.961	21.12500	-34.29167	G
1	ZAF	0.08479935	0.06793731	7013.961	21.54167	-34.29167	G
1	ZAF	0.30468389	0.03919911	7013.961	21.87500	-34.29167	S
0	ZAF	1.89298940	0.04122557	7041.669	18.54167	-33.95833	G

3.2.2 User inputs

Users need to prepare a .txt file that has two columns: one contains the countries of interest and the other indicates the region to which each country is mapped. Columns need to be named exactly “iso” and “region”. Both strings are case sensitive, although the order does not matter. Listing 2 displays the first ten rows of an example .txt file. The country code needs to be in the ISO ALPHA-3 Code format for it to be successfully read into the tool. For a complete list of countries and their ISO ALPHA-3 Code, refer to <http://unstats.un.org/unsd/methods/m49/m49alpha.htm>.

Listing 2: User-defined country-region mapping

iso	region
ZAF	S
LSO	S
NAM	S
SWZ	S
BWA	S
MOZ	E
MDG	E
ZWE	E
AGO	C
ZMB	E

Uploading a mapping file can be done either by choosing “Upload...” from the drop-down menu

(Figure 3), or by right-clicking the “Upload file” area and choosing “Upload...”. After this self-defined mapping text file is uploaded into the tool, the “iso” index is then used to merge the user’s input into the tool. The mapping file used to illustrate the SSA sub-region example in this instruction is set as default for the convenience of testing. Once the file is successfully loaded, it should appear in the “Upload file” area.

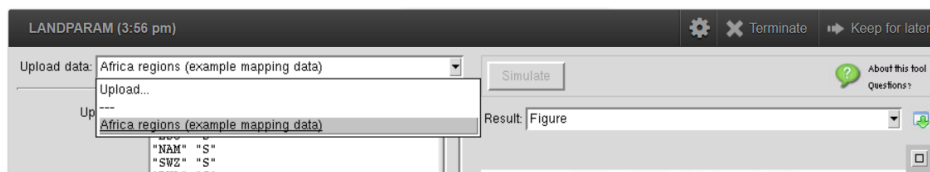


Figure 3: Upload user-defined mapping file

Next, users need to select the level of market access change they are interested. In this tool, market access plays a role of equilibrium shock, which triggers cropland expansion. Intuitively, better market access increases the profitability of cropland, and thus encourages the land to be used for farming activities.

If the interest is centered on the area of land use change induced by the increasing market access, the tool differentiates land conversion from three land cover categories. In particular, the new cropland can come from the area which used to be forest, grassland or shrubland. Since these three covers feature different carbon emission factors, cropland conversion from each of them would imply different levels of carbon emissions. This option can be useful in identifying the associated environmental cost of land use change.

3.3 Outputs

After uploading the user-defined file and clicking simulate, the tool returns a set of outputs. All these are available by changing the “Results” drop-menu options (Figure 5). All the outputs can be downloaded.

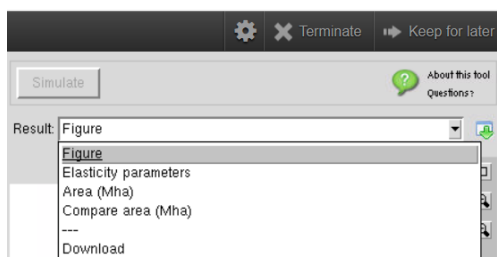


Figure 4: LANDPARAM output

Elasticity parameters contains land supply elasticity and land transformation elasticity aggregated to the SSA sub-regional level. These are respectively the $\epsilon_{c,c}$ and σ parameters mentioned

in the previous section. *Cropland conversion* returns the physical area of cropland converted from forest, grassland or shrubland (in Mha). All the output tables can be downloaded as .csv files. *Figure* provides a visualization of the updated predicted cultivation probability after selecting a specific level of increase in market access, or the $\hat{P}(Z_i = 1)$ (see Methods). This variable directly determines the new cultivation status and subsequently the total area of cropland supply.

Finally, the tool allows users to perform multiple simulations (under different levels of market access) and compare the results. Clicking the “All” button, the output area displays a scatterplot of the physical area resulted from each simulation. The slider can be used to switch between simulations. Above the slider, users can also select a condition to filter out the results they would like to compare and display.

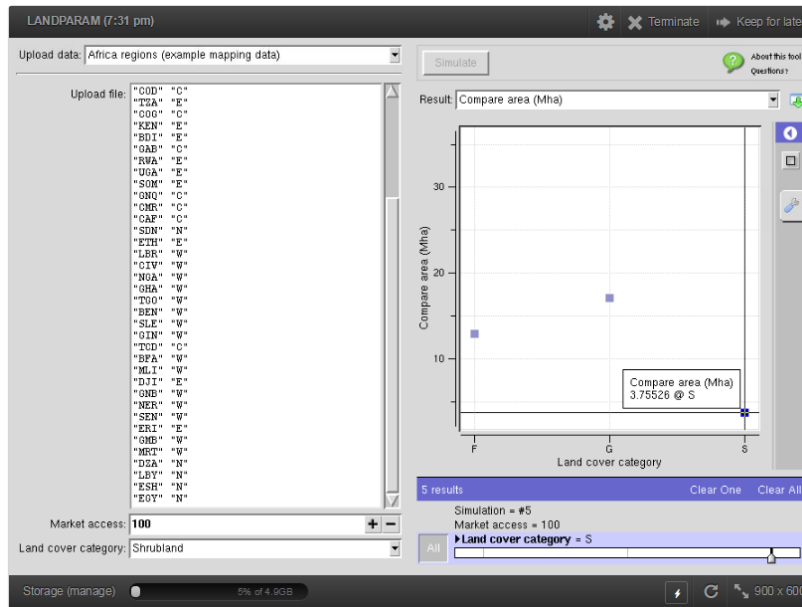


Figure 5: Compare simulation results

4 Extensions

LANDPARAM 2.0 plans to introduce the following improvements.

1. Extend the geographical scope from Africa to also Americas.
2. Allow the aggregations to be done from geographical coordinates.
3. Add climate shocks on top of the market access shock.

References

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