Anonymous Referee #2

Summary of the paper This paper uses gcamland/GCAM to calibrate/estimate/tune the land distribution parameters of a nested logit land allocation function used in this model. In the lack of econometrically estimated values for these parameters, it is an important effort to accomplish this task. However, the paper suffers from some important deficiencies and lack of clarity, in particular for those who do not know this mode.

Author Response: Thank you for your detailed review of our paper. Your comments have pointed out a number of places where we did not clearly describe our methodology.

Author Changes: We have made a number of changes to the paper in response to your comments and those of another reviewer. Those changes are detailed below.

Response: Thanks for your attention. Your responses helped me to understand your work better. However, in some cases your responses were not convincing. In what follows I highlight my comments using green fonts after each response.

Author Response: Thank you for your detailed review of our paper.

Author Changes: We have made a number of changes to the paper in response to your comments. Those changes are detailed below in red. Note that in response to many of the comments we have added several tables and figures to the Supplementary Material. We note these additions in the individual responses, but are including a list here to facilitate the review. Note that we are using the new table and figure numbering and not the numbering used in the previous submission. All other tables and figures are still included in the paper, but with new numbers.

Figure S1: Nesting diagram showing all land types included in gcamland and how they are grouped for the logit
Table S1: List of all gcamland land types, including a list of crops/categories included, and the data used for initialization, simulation, and observations.
Table S2: List of the gcamland node names (from the nesting diagram), along with the plain language description used in the paper and the logit exponent used in the analysis
Table S4: Absolute error, percentage error, and NRMSE for all crops and expectation types
Figure S10: Change in land area for forest, grassland, and shrubland in both the gcamland simulations and the observations
Figure S11: Change in land area for all gcamland land types

Some important comments:
1. I am not a GCAM modeler but is seems gcamland operates under GCAM. For nonGCAM community the links and interactions between these two models are not clear. How they linked and interact. A simple chart can help.

Author Response: GCAM and gcamland are completely separate models. GCAM includes representations of energy, water, land, and climate. It includes a land allocation mechanism where land use and land cover are calculated based on changes in profit. gcamland only includes this land allocation calculation. gcamland is not run when GCAM is run; GCAM is not run when gcamland is run. Instead, gcamland replicates the land allocation equations used in GCAM so that we can isolate that part of the code for analysis and uncertainty quantification. See also response to comment #19.

Author Changes: We have added a footnote to the methodology section clarifying the relationship between GCAM and gcamland: "GCAM and gcamland are separate models.While gcamland replicates the land allocation mechanism in GCAM, it is not run within GCAM. Similarly, GCAM is not run as a part of gcamland. gcamland only includes a representation of land allocation. GCAM includes representations of agricultural supply and demand, land allocation, and other sectors (energy, water, economy, climate). The land allocation mechanism within gcamland uses price, yield, cost, subsidy, logit exponents, expectation parameters, and initial land area as exogenous inputs and endogenously determines land area in subsequent years. Changes in demand are explicitly represented in GCAM. In gcamland, changes in demand are captured through changes in price. For example, the increase in demand for corn and soybean due to biofuels policy is captured through changes in the prices of these goods."

Thanks, it seems the CGAM model plays no role in the estimation process of the estimated parameters and only the gcamland with no demand side has been used. If that is the case, then the paper needs revisions to make sure that CGAM has not been used in the estimation process. For example, here are a few places that need attention:
- Table 2, Description of Arable Land should refer to "gcamland" not "GCAM", as noted in footnote 5.
- Change title of 2.1.2 to "Economic approach in gcamland"
- Change title of section 2.3 to "Evaluation gcamland model performance"
- Change the end of line 204 to "… focused on annual time step in gcamland"

Author Response: That is correct. GCAM is only relevant here because it is where we derived the land allocation equations and data, and because we could use the parameters estimated in this paper in GCAM. Note that in order to use the parameters derived in this paper in GCAM, we would also need to estimate parameters for 31 other geopolitical regions and estimates of parameters governing demand since GCAM includes both supply and demand. See also response to #29

Author Changes: We have made the changes suggested by the reviewer.

2. The model clearly uses a nesting logit format, perhaps three nests. Equation 1 of the paper shows only on nest. The formula should be replaced with a formula for the full nest.

Author Response: We have added information on how profit and shares are calculated for the other nests.

Author Changes: We have added additional text and an equation "In the three-level nest version, land allocation at each level is determined by a modified version of equation 1, whereY is

replaced by the land allocated to that particular nest. The land allocated to a particular nest is dynamic and varies over time. Profit rates (rj) at the lowest level of the nest are computed based on price, cost, yield, and subsidy (if included) for land use types (crops, pasture, commercial forest); profit rates for land cover types are input into the model and are based on the value of land. Profit rates for higher levels of the nest (rnode) are determined by:
𝑟𝑟𝑛𝑛𝑛𝑛𝑛𝑛𝑛𝑛=[Σ(𝜆𝜆𝑗𝑗𝑟𝑟𝑗𝑗𝑛𝑛𝑗𝑗=1)𝜌𝜌]1𝜌𝜌⁄

The revision mentioned here is helpful, but it provides a broken formulation and misrepresent your work. To be fully transparent and to make sure that the readers understand that three exponent parameters (distribution parameters) and there sets of share parameters were estimated, I propose to use the following format:
𝑋𝑋𝑗𝑗𝑗𝑗𝐶𝐶=(𝜆𝜆𝑗𝑗𝑗𝑗𝑐𝑐𝑟𝑟𝑗𝑗𝑗𝑗𝑐𝑐)𝜌𝜌𝐶𝐶Σ(𝜆𝜆𝑗𝑗𝑗𝑗𝑐𝑐𝑟𝑟𝑗𝑗𝑗𝑗𝑐𝑐)𝜌𝜌𝐶𝐶𝑗𝑗∙𝑌𝑌𝑡 𝐶𝐶 where "C" represents the crop nest including rice, wheat, ……
𝑋𝑋𝑗𝑗𝑗𝑗𝐴𝐴=(𝜆𝜆𝑗𝑗𝑗𝑗𝐴𝐴𝑟𝑟𝑗𝑗𝑗𝑗𝐴𝐴)𝜌𝜌𝐴𝐴Σ(𝜆𝜆𝑗𝑗𝑗𝑗𝐴𝐴𝑟𝑟𝑗𝑗𝑗𝑗𝐴𝐴)𝜌𝜌𝐴𝐴𝑗𝑗∙𝑌𝑌𝑡 𝐴𝐴 where "A" represents the ag-forestry nest including cropland, forest, ….
𝑋𝑋𝑗𝑗𝑗𝑗𝑅𝑅=(𝜆𝜆𝑗𝑗𝑗𝑗𝑅𝑅𝑟𝑟𝑗𝑗𝑗𝑗𝑅𝑅)𝜌𝜌𝑅𝑅Σ(𝜆𝜆𝑗𝑗𝑗𝑗𝑅𝑅𝑟𝑟𝑗𝑗𝑗𝑗𝑅𝑅)𝜌𝜌𝑅𝑅𝑖𝑖∙𝑌𝑌𝑡 𝑅𝑅 where "R" represents the arable land nest including …..
The members of each nest should be clearly mentioned. In particular, for the crop nest all members of this nest including unused land, cropland pasture, CRP, other idled land should be specified. The information that presented in Table 2 is incomplete and very misleading. Of course, the names of variables should be described fully and maintain this convention through the paper.

Author Response: Please note that the equation did not transfer well from the PDF of the review and thus appears strangely in the comment and response above. We have used the original PDF with the correct formatting when reading and reacting to this comment. The same equation is used in all three places; given the confusion this seems to have caused, we have now repeated it as suggested by the reviewer. Given the number of crop categories in gcamland, listing all crops in Table 2 made it difficult to read the table, so we have opted to provide the full list in a footnote. We also include a complete nesting diagram with all information in the same figure in the SM. To facilitate readability, we have opted to use plain language descriptors in the paper rather than the abbreviated terminology used with the gcamland code. However, we do agree that we need to specify the mapping between plain language and terminology, so we have added a table to the SM.

Author Changes: We have repeated the logit equation as suggested by the reviewer. We have added information on what is contained in the nests, using the node names (now defined in Table S2) in the main text and the complete list of crops in footnote 6. We have added a nesting diagram to the SM (Figure S1) which indicates which members are in which nests. We have added a table to the SM (Table S2) that maps the plain language descriptors used in the main text of the paper to the precise terminology in the gcamland model.

3. How the land constraint/constraints is/are defined? Does a simple land constraint directly add all types of land: Total land =forest + pasture + corm + soy+ etc.? or each nest has its own land constraint?

Author Response: The only explicit constraint on land in the model is on total land. That is, we require the sum of all land types (forest, pasture, grassland, shrubland, urban, crops, etc.) to equal the total area in the United States. We parameterize the model to prevent expansion of cropland into non-arable lands (urban, tundra, and rock/ice/desert).

Author Changes: We have clarified this in section 2.1.2: "The land allocated to a particular nest is dynamic and varies over time."

Thanks for the clarifications that: 1) only one land constraint is used and 2) land transformation from non-arable lands to cropland is prohibited. However, these clarifications raised the following important concerns:
- First, when it goes to crops how do you distinguish between harvested area and planted area? There is no information for planted area for all crops. If harvested area is used for each crop, then what do you do with multiple cropping, crop failure. You cannot simply add up harvested area and say that the sum is total cropland. Please be very specific in your response.
- According to your response, non-arable land cannot be converted to cropland. You said some kinds of parameterizations were used. Please explain it more transparently and be very specific in your response. How about the revers land transformation: conversion of cropland to non-arable land? How do you model that? Please, again be precise in your response and avoid the general statement of based on profitability.

Author Response: gcamland tracks both harvested area and planted area. We have a fixed ratio of harvested to planted area for each crop, estimated in the base year and held constant throughout the simulation. We have focused our results on harvested area since that is the comparison data we used from FAO. Planted area is used in the constraint on total land.

To limit the transformation of non-arable land (urban, tundra, and rock/ice/desert) to cropland, we set the logit exponent above that nest to zero. With a logit exponent of zero, land shares are held constant at their base year values. Such a parameterization also means that cropland cannot be converted to non-arable land.

Note that I have continued to use "arable" and "non-arable" in this response. However, based on our response to your comment #6, we are no longer using these terms in the paper.

Author Changes: We have added a couple of sentences to 2.1.2 describing the gcamland approach to planted and harvested area: "gcamland tracks both planted and harvested area for crops. Planted area is determined by the logit-base land allocation scheme described in this section. Harvested area is calculated using planted area and a fixed harvested-to-planted area ratio, estimated in the base year, and held constant in the future."

In response to the second point, we have elaborated on the footnote, which now states: "This land is held constant throughout the simulation time period by setting the logit exponent dictating competition between these land types to zero. Such a parameterization means that no cropland can be converted to urban, rock/ice/desert or tundra and no urban, rock/ice/desert or tundra can be converted to cropland."

4. It is not clear how the estimation process is defined to estimate these parameters. Does the process estimate all the distribution parameters (s) simultaneously or individually?

Author Response: We are using Latin Hypercube Sampling, which estimates all parameters simultaneously.

Author Changes: We have added the following note to section 2.2: "Latin Hypercube Sampling draws all parameters simultaneously from uniform distributions."

Thanks, for this clarification. Please let me concentrate on the three logit distribution parameters and use the notation mentioned above. Based on this response and the response to my next comment, it seems the implemented process uses the following steps:
- Randomly selects three values for the three distribution parameters of $\rho\rho RR$,$\rho\rho AAaaaaaa$ $\rho\rho CC$ from three uniform distributions (each ranged between 0.01 to 3).
- Given the selected parameters of $\rho\rho RR$,$\rho\rho AAaaaaaa$ $\rho\rho CC$, land allocation for the whole time period is determined
- The above two steps repeated for 10,000 collections for each expectation type.
- A collection, including three distribution parameters, that minimizes the size of NRMSE is selected as the best estimate for the distribution parameters under each examined expectation type.

Author Response: Please note that the equation did not transfer well from the PDF of the review and thus appears strangely in the comment and response above. We have used the original PDF with the correct formatting when reading and reacting to this comment. This is mostly correct. For the first step, we are drawing three distribution parameters plus parameters governing how expectations are formed for the non-Perfect expectation models. Additionally, given subsequent comments, we do think we should elaborate on the second and fourth steps. For the second step, "Land allocation for the whole time period is determined" *by running gcamland over the historical period with each set of randomly chosen parameters.* For the fourth step, NRMSE is calculated by comparing simulated land area from gcamland over time with observations of land area (that is, we calculate land area in the historical period with gcamland and compare those outputs to observations to determine NRMSE). We have separated this step into two to make this clearer in the paper.

Author Changes: We have added an elaborated version of these steps to the beginning of the methodology section and are using these steps to help the reader navigate the subsections of the methodology:

"The overall methodology used in this paper is as follows:

1. Randomly select a set of parameters from uniform distributions (see Table 2 for list of parameters and their values, Section 2.2 for how the parameters are selected, and Sections 2.1.2 and 2.1.3 on how those parameters are used in gcamland).
2. Land allocation for the whole time period is estimated by running gcamland over the historical period with each set of randomly chosen parameters (see 2.1 for a description of gcamland and how it simulates land allocation and section 2.4 for the data used in gcamland).

3. Repeat steps 1 and 2 for 10,000 parameter draws (see Section 2.2).
4. Calculate a variety of metrics of goodness of fit from simulated land allocation from gcamland and observations of land allocation (see Section 2.3 for the metrics used and Section 2.4.3 for a description of the observation data).
5. Determine the "best" set of parameters by choosing the set that minimizes a given goodness of fit metric."

5. How distribution parameters () were perturbed? Are they coming from given distribution? If yes, what type of distribution? Is this a random selection of three values limited between 0.01 and 3?

Author Response: The parameters were sampled assuming a uniform distribution. For logit exponents, we choose values for each of the three exponents randomly between 0.01 and 3. Each of the three exponents can have a different value and we do 10,000 samples for each expectation type and model configuration.

Author Changes: We have added the following note to section 2.2: "Latin Hypercube Sampling draws all parameters simultaneously from uniform distributions."

Thanks for this clarification. See my previous response.

6. Over time total area of agricultural land in the US has declined sharply, due to conversion to non-agricultural uses of land (urbanization, infrastructure, ...). How gacamland handles conversion of land to non-forestry-ag land. How land availability land has been taken care off over time? Is it an exogenous variable in each year?

Author Response: While urban land has grown over time, the definition of urban land in gcamland accounts for only 1% of total land area in the United States. We hold this area constant in the simulations presented here (equal to 1975, 1990 or 2005 values depending on the calibration year used in the simulation). Allowing this to change over time would not have a noticeable impact on results given how small the area is. Similarly, we hold tundra and rock/ice/desert constant in time, but they account for very small amounts of land in the United States (2.6% and 0.4%, respectively). All other land is included in the economic competition.

Author Changes: We have added a footnote to the methodology section: "A small amount of land (~4%) is considered non-arable in gcamland in the United States, including urban, tundra, rock, ice, and desert. This land is held constant throughout the simulation time period."

Thanks for this clarification. However, it does not help and makes further confusion.

- The paper does not provide a clear picture of the land categories in the model. While you are talking about non- arable land as a part of land use modeling, the logit nesting structure does not cover it. If this type of land is not modeled, why it is described in the paper.

- Table 1 introduces three nests: Arable land; Ag land. Forest, and other; and Cropland (or crops). This plus other information provided in the tale bring in mind the following nesting structure:

Rice wheat corn soy, ….
\ \ | /
\ \ | /
\ \ | /
Forest Ag land other
\ | /
\ | /
Arable land

However, there is no "cropland" in the middle nest. What is the relationship between Ag land, cropland, and pasture land? It seems a nest is missing.

- It is noted FAO data with some modification is used to determine land data. If that is the case, then something is not correct. Please let me explain. Arable land is a subset of cropland in the FAO data. For example, in the FAO data for 2018, area of US cropland is 160,437 thousand hectares with sub component of 157,737 thousand hectare of arable land. This is in a sharp contrast with the nesting structure defined in the paper. Also, area of US Ag land is 2.6 times of its arable land. How Ag land could be a subset of arable land? The paper should make proper clarifications on this issue.

Finally, let us follow the nesting structure outlined in the paper. According to the FAO data, total area of US arable land has declined from 180,630 thousand hectares in 1961 to 157,727 thousand hectares in 2018, a decline by 22,893 thousand hectares. How this reduction has been handled? It is not a small reduction.

Author Response: In terms of the nesting, we had focused this part of methodology section on the aspects of gcamland that we perturbed in this experiment. It is clear from the reviewer's response that this has caused confusion.

For "arable", we were using this word in the colloquial sense ("suitable for growing crops") and not in the way that FAO defines it ("areas under temporary crops, temporary meadows and pastures, and land with temporary fallow"). We can see that this caused confusion and given the paper's dependence on FAO data we have decided to remove the word "arable" in almost all instances in the paper. The one exception is when we define the categories in gcamland; in this case, we think it is important to use and define the terminology in gcamland. gcamland only uses the word "arable" in the name of "OtherArableLand" category, so this is the only case in which "arable" will appear in the paper. Note that throughout the paper we have on occasion used plain language descriptions or lengthier titles for categories and names in gcamland to make the paper easier to read; within gcamland, we use shorthand and abbreviations. We have now added a table to the SM (Table S2) mapping the precise terminology used in gcamland to the plain language descriptors used in the paper.

For your question about reduction of arable land in the USA, that is captured in gcamland within the nest where changes in land are dynamic and determined by the logit exponent. We think this question arose from confusion over the word "arable" and is now resolved by our decision to change that word.

Author Changes: We have added a nesting diagram to the SM (Figure S1) that shows all nests in the model, including all land types within each nest. We have added an additional table to the SM (Table S2) that indicates which logit exponents are perturbed in this paper (and which are not). We've also revised Table 2 to better describe what each parameter is doing. We have removed the word "arable", with the exception of places listing the names used within gcamland. Instead, we are using the word "dynamic land" for the name of the logit parameter since the only land types not included in this nest are those held constant during the simulation (urban, rock/ice/desert, tundra). In all other places, we've opted for lengthier descriptions of what is being included, rather than a short hand name, for clarity. We have also added a table to the SM (Table S2) mapping the terminology in gcamland to the words/descriptions used in the paper. This should facilitate understanding for any user who downloads and runs gcamland or looks at the raw outputs of the model. Lastly, we have revised the discussion on the nested logit in the methodology for clarity (see also response to comment #2).

7. A big issue in land use modeling is marginal cropland (idled land under CRP, cropland pasture, other types of idled). Area of idled cropland in the US have changed a lot. The definition of "cropland pasture" has also changed over time. How idled land is treated?

Author Response: Idled land is called "Other Arable Land" in gcamland. The amount of land in this category can change over time based on economic signals. Since idled cropland does not produce a product, its profit rate is exogenously specified like other land cover types (see response to comment #12). Note that this exogenous value is similar to a CRP payment, as it represents a marginal benefit of keeping land fallow.

Author Changes: We have added a footnote to the methodology section: "Fallow cropland (called other arable land in gcamland) is also included in this nest." We have also added text to the supplemental material indicating that idled cropland is included in gcamland.

This is a misleading response. FAO data base does not have other arable land. Please at least, provide a table and put all types of included land in each nest at list for three years, including cropland and its components.

Author Response: We derive the OtherArableLand category from harvested area data from FAO and total cropland area data from the land use harmonization (LUH) product. LUH provides total land cover classified as cropland. We assume the difference between land planted in crops and land cover of crops is idled land. See also the response to #3. We are unclear what the reviewer meant by 'at list [least?] for three years' and thus have not responded directly to that.

Author Changes: We have added a nesting diagram (Figure S1) and two tables to the SM (Table S1 and S2). These figures and tables include all land types in gcamland, where they are nested, what we call them in the paper, and where we get the initialization and simulation data. We believe that this provides full transparency for readers in clear, easy-to-understand forms.

8. It is noted that harvested area from FAO is used. FAO is missing many feed crops since 2011, including million hectares of those crops. without proper steps to cover missing crops in FAO, the estimated parameters will be subject to major issues and biases. Figure three suggest that those feed crops is missed. That is a major issue.

Author Response: gcamland includes fodder and feed crops, using data from FAO prior to 2011. We have excluded it from the comparison and statistics because the data is not available after 2011 as you noted, but it is included in the modelled results.

Author Changes: We have revised the Figure 3 caption to clarify this: "Note that fodder crops are included in gcamland but are excluded from total cropland area in this figure due to data limitations." We have also added figures to the supplemental material showing all crops, including fodder.

This is a misleading response. If you fixed the data (for after 2011) by estimating the missing data items, then that should be reported and included in your figures. Transparency is the key.

Author Response: We did not fix the data. gcamland only needs land cover data in the base year (1975, 1990, or 2005 depending on the historical time period to be simulated); FAO has data on fodder crops for all three of those years. With that quantity for use as a base year, we then simulate fodder crop land cover throughout the simulation time horizon (1975-2015, 1990-2015, or 2005-2015 depending), but we do not use FAO data in our simulations after the base year and we do not fix the FAO data at all. Therefore, while we have simulated fodder crop land cover for the entire simulation time horizon, including years beyond 2011, we cannot compare the later years of the simulation to observations because they are not provided by FAO after 2011. This is why fodder crops are excluded from the NRMSE calculations.

Author Changes: We have added a table to the SM (Table S1) that lists all gcamland types, along with the source of data for initialization and for comparison.

9. GCAM is using commodity price to model land allocation. It seems wholesale farm prices is used. That is a bad proxy for exporting crops such as cone and soybeans. For example, half of soybean is exported at much higher price farm price.

Author Response: The producer price is the relevant price signal to be used for planting decisions. The market price, and thus the producer and consumer prices, is a function of the demand sectors as well, which includes domestic demand and exports. However, the resulting equilibrium price paid to producers is the relevant price regardless of how the demand is determined. Therefore, we feel that producer price is the right input into gcamland for this analysis.

Author Changes: We have revised the manuscript to better document what is included in gcamland. See also the responses to comment #1 and comment #19.

Yes, as it is noted in this response “price paid to producers is the relevant price”, but the FAO whole sale price does not reflect the price received by farmers. You need to address this as a major limitation of your work clearly. Please explain what revision you have made? And be more specific.

Author Response: We are not using wholesale prices. We are using producer prices from FAO, which FAO defines as “prices received by farmers” for the reasons above. We are not clear on what in the manuscript led the reviewer to think we were using wholesale price, but we are using producer prices (as indicated by the reference to the FAO producer price dataset).

Author Changes: We have added “producer” as a qualifier on “price” in section 2.4.2 to clarify this.

10. In this paper, in one case, subsidy has been examined in a sensitivity test. Subsidy is the key item in deriving land use, land rent, and the price received by farmers. The distribution parameters of the logit should be evaluated with subsidies. Sensitivity test is meaningless. The key here is to capture all types of subsidies paid to famers in the estimation processes.

Author Response: As noted in the manuscript, the subsidy data does not improve the estimation either because these subsidies do not affect cropland area (as suggested by Weber and Key 2012 and discussed in Section 5.1) or due to the quality of the data. There are not continuous, complete, and consistent data sets for all types of subsidies paid to farmers. Additionally, we only found crop-specific information on direct payments, making the inclusion of other types of subsidies difficult.

Author Changes: We added more information to Section 2.4.2 describing the limitations of the data: “Subsidies are a reality of crop agriculture in the United States. However, there are not continuous, complete, and consistent data sets for all types of subsidies paid to farmers. Additionally, crop-specific information (of the type needed for gcamland) is only available for direct payments, making the inclusion of other types of subsidies difficult” and our choice to make this a sensitivity “Because this data is inconsistent and incomplete, we only use it as a sensitivity in this paper and do not include it in the primary analysis.”

Thanks for this response. However, it is incomplete. The paper should clearly acknowledge that improper inclusion of subsidies could make major biases in the outcome of the estimation process and that a sensitivity test is not a proper way of fixing this issue.

Author Response: We agree with the reviewer that including subsidies (or any changes to the calculation of profit or the equations determining land allocation) could alter the error-minimizing parameters resulting from this analysis. However, the simulations that included subsidies did not result in a change in different estimates of error-minimizing parameter values but did increase NRMSE for those parameter sets relative to the simulations without subsidies. Finally, sensitivity tests are a common way in modeling studies to test whether a particular factor matters. In this case, our sensitivity test concluded it did not. Furthermore, we have found previous literature that supports this finding (noted in section 5.1). Thus, while it is possible that including subsidies could change results or lead to biases, it is not guaranteed.

Author Changes: We have added information clarifying the effect of subsidies in this study and indicating that the inclusion of subsidy data *could* result in different parameters, though that did not happen here. In particular, we've expanded footnote 9 to say (added text in italics): "Note that our choice to use it as a sensitivity and not the default is because it does not improve NRMSE *and did not alter the parameter set that minimized NRMSE between simulated and observed land allocation* (as discussed in Section 5).".

We've revised the sentence describing the results of this sensitivity in Section 5.1 to clarify what does and doesn't change with subsidies: "Varying these assumptions results in differences in cropland area (Figure 4) and in parameters for the "Same Parameters" sensitivity; however, the parameters for the "With Subsidies" sensitivity are identical to the Default model (Table S2)."

To the discussion, we have added: "In theory, any change in the data or in the profit calculation, like the inclusion of subsidies, could alter the error and the set of parameters that minimize error (i.e., conversely, the exclusion of those factors could introduce biases in the estimated parameters). However, in our study, we found that the inclusion of subsidies increased NRMSE, but did not alter the parameters that minimized NRMSE."

11. How biofuels were included in the simulations? Biofuels and biofuel policies were major drives of land use. How that included in your simulations

Author Response: Biofuels and biofuels policy are reflected in our model through changes in producer prices of crops.

Author Changes: We have added this to the footnote explaining differences between GCAM and gcamland: "Changes in demand are explicitly represented in GCAM. In gcamland, changes in demand are captured through changes in price. For example, the increase in demand for corn and soybean due to biofuels policy is captured through changes in the prices of these goods."

This response makes me more concern. I am not convinced that your work properly identifies source of piece changes. You approach only consider changes in the prices and send that as a signal to the land supply tree, without identifying the sources of price change. The source of price change could be demand shock (e.g. biofuels) or supply shock (reduction in yield or land supply). You approach does not distinguish these sources and simply consider price changes as signals to the land supply. Can you convince the readers that you do not need to identify the source of price change?

Author Response: Our model was not designed to identify the source of price changes as we focus on supply responses. However, we do represent supply and demand shocks differently. The direct effect of a supply shock (e.g., a yield change) is explicitly represented in gcamland; demand shocks (e.g., biofuel policy) are signaled by changes in prices. This information is enough for landowners to make land allocation decisions based on the relative rental profits, particularly under perfect foresight. In the cases with imperfect expectations (e.g., adaptive expectation), we allow a different expectation coefficient for biofuel crops (i.e., Corn and OilCrop) to reflect that the price expectations of these biofuel crops could be different than other crops. In other words, biofuel shocks in our model indirectly affect price signals and/or expectation schemes. As discussed in Section 4.1, the results indicate that Corn and OilCrop rely less on past information than other crops in the Adaptive expectations.

Author Changes: None.

12. Th dapper highlights that gcamland uses commodity prices in land allocation. But the model allocates land across land cover items. What prices are used for forest products, livestock products, etc.? The paper is silent on these prices. What prices were used for land cover items

Author Response: We calculate land rental prices for commercial forest and pasture using their product (forest or livestock products) prices and related productivity and cost information. For non-commercial land cover only items, effective profit rates are derived during the calibration process to ensure that the amount of land area in the base year predicted by the logit equation matches the read in value. For subsequent years, these effective profit rates are held constant. This estimation is described in detail in Wise et al. (2014).

Author Changes: We have added this information to the methodology section: "Profit rates (rj) at the lowest level of the nest are computed based on price, cost, yield, and subsidy (if included) for land use types (crops, pasture, commercial forest); profit rates for land cover types are input into the model and are based on the value of land."

- This response makes no clarification. For example, it is said that: "We calculate land rental prices for commercial forest and pasture using their product (forest or livestock products) prices and related productivity and cost information." Please be very specific and answer the following: What are the prices of livestock products? How about prices of forest products? How do you measure yield for forest? How about yield for pasture land?
- If only arable land is modeled, why do you need profit rates for non-commercial land. As noted in my earlier comments, providing a table including all nests and their members could help.
- What is the effective rate for unmanaged forest? How do you determine it in the calibration prices? Calibration to what?
- The paper should clearly explain the above points

Author Response: We estimate the yield for forest from its vegetation carbon density and the yield for pasture is set to the yield of hay. Forest prices are calculated from FAO's export data. Pasture price data is not available; instead, we set these prices to 70% of the alfalfa price (used for FodderHerb).

For arable land, as noted in our response to #6, the choice of this word has caused confusion. We include all land use and land cover categories in gcamland and thus need profit rates for each.

The effective profit rate is the profit rate that would be needed to return the land allocation in the base year. The calibration process ensures that land allocation in the base year exactly matches the input values. To do this, we determine what the profit rate would need to be for the logit to predict the input (referred to as the "effective profit rate" above). For non-commercial land, we hold these effective profit rates constant in the future. As noted above, this procedure is described in Wise et al. (2014). We cannot repeat everything from that paper; thus, we refer the reader to that paper for a discussion of the calibration procedure, as is common in science.

Author Changes: We have added a nesting diagram (Figure S1) and a table (Table S1) that specifies each land type in gcamland to the SM. This table includes the type and sources of all input and comparison data used.

13. Regarding forestry, how gcamland treats forest land. Is it operates based on managed forest? Managed + unmanaged? How it treats unmanaged forest with no economic output.

Author Response: We include both managed and unmanaged forestland. For managed forestland, we use price and yield to calculate profit. For unmanaged, see response to comment #12.

Author Changes: See response to comment #12.

What are the price and yield of managed forest? How do you determine them? Based on what data do you calculate price of forest and yield of managed forest? The paper should explain these.
See also my response to comment 12 as well.

Author Response: The yield of managed forest is derived from its carbon density. The price is derived from its export value and volume, as reported by FAO.

Author Changes: We have added a table to the SM (Table S1) with information on data sources for all gcamland land types.

14. GCAM and gcamland are not forestry models. Forestry is not an annual crop. How these models take care of forestry in a dynamic setting. Do these models treat forestry as an annual crop?

Author Response: GCAM, gcamland, and other similar models assume that you need to set aside land at every timestep to ensure that you will have enough commercial forestland to meet harvest demand at the time the forest matures. To do this in GCAM, we assume that the amount of land needed for forest is equal to the wood product demand divided by the yield times the rotation length. So, if you need 1 Ha of land to meet wood product demand in a given year and the rotation length is 25 years, we set aside 25 Ha of land in that year. gcamland uses a similar paradigm, only we don't model demand, just yield and area. So, gcamland uses a yield that is equal to the harvest yield divided by the rotation length.

Author Changes: We have added this information to the methodology section: "Note that, since forestland is not an annually planted and harvested commodity, GCAM, gcamland, and other similar models assume that land must be set aside at every timestep to ensure enough commercial forestland is available to meet harvest demand at the time the forest matures. To do this in gcamland, we assume that the amount of land allocated to forest depends on the harvest yield and the rotation length."

Sorry for my ignorance. But I do not know any model that follow the assumption mentioned above. In your revision, please name some well-knows models that follow this approach. If I understand correctly, what mentioned above can be replicated by the following formula:
Forest area in year t = yield of forest in t * demand for forest in t * 25.
This formula over simplifies the way that a forest model works and has no root in real world. You need to put this formula in the paper and justify it to be transparent.

Author Response: First, the discussion above was about "commercial forestland" (also referred to as managed forest in these models) as indicated in that response and in the text added to the paper. Second, as noted in Grassi et al. (2021, https://doi.org/10.1038/s41558-021-01033-6), models like GCAM (e.g., IMAGE, MESSAGE, AIM, REMIND) calculate managed forest area based on: "(1) forest product demand (mostly based on FAO statistics and then projections into the future), (2) carbon density of forests and/or timber that can be harvested per hectare increments and (3) estimates on length of rotation cycles and/or year to maturity." These calculations assume "the area of managed forest represents the area required to provided historic and future demand for wood products in continuous harvest rotations". This approach was (and still is) described in Section 2.1.2 of the paper.

Author Changes: We have added a footnote to the SM table (Table S1) describing data sources indicating how managed forest area is calculated in gcamland.

15. In each case, the model is solved for a range of parameters. Then a set of parameters that minimizes NRMSE is selected. But NRMSE is defined for a single crop. How this variable is aggregated over crops? How NRMSE is calculated for non-cropland (e.g. forest, pasture, grass land, and etc.)? How cropland and non-cropland aggregated?

Author Response: We take the average of crop-specific NRMSE to get the aggregated NRMSE. As noted in the manuscript, we do not include non-cropland in our calculation of NRMSE.

Author Changes: We have clarified this in the methodology by adding "For NRMSE and RMSE" before the sentence that describes the averaging across crops.

Thanks for these clarifications. I have difficulties to find out in what part of the manuscript it is noted that you do not include non-cropland in the calculation of NRMSE. Please clearly mention this point at the beginning of section 2.3 so that the reader can see this important limitation. Also, it is important to explain why you do not include non-cropland in the calculation. This is a surprise for me? Why you do not follow the same approach for other nest that you determine their distribution parameters. Indeed, as I mentioned before, you determine a selection of three parameters of $\rho\rho RR$,$\rho\rho AAaaaaaa$ $\rho\rho CC$. But it seems you ignore how good are your estimated for $\rho\rho RR$ $aaaaaa$ $\rho\rho AA$ and only care about $\rho\rho CC$. In fact, you select a mix of $\rho\rho RR$,$\rho\rho AAaaaaaa$ $\rho\rho CC$ to minimize NRMSE over the crop nest. So, this means that you may get bad errors for the other two nests while you minimize only over crops. This is a serous problem. Indeed, you do not optimize for two nests out of three nests. This could cause major errors in the projection of land use changes in the non-cropland nests, compared to the observed data.

Author Response: In a nested logit model, all logit exponents above a particular leaf play a role in determining the land area of that leaf. That is, the amount of land allocated to a particular crop depends on the cropland logit, as well as the two logits in the nests above cropland. For this reason, we have to vary all three logits to do a sensitivity on the area for an individual crop.

As for why we did not include non-cropland, we had included land types where we have complete time series of observation data, covering the entire simulation period, in our default NRMSE calculations. We do not have land cover data for the entire time series since the satellite data record does not go that far back in time. We have done a sensitivity where we include land cover to demonstrate the effect of it on NRMSE and the parameters that minimize NRMSE. However, we are keeping this as a sensitivity since we do not have a complete time series of observation data.

Author Changes: We have added a nesting diagram (Figure S1) which shows which nests and logits affect the area allocated to crops. We have also revised the discussion of the nested logit in the methodology section adding additional equations and description: "In a nested logit, the area of a particular land type is determined by not just the logit of its nest, but also by the logit of the nests above that".

We have added a discussion of a sensitivity simulation which includes land cover types to Section 5.2.2: "Finally, including all dynamic land cover types where observations are available for any period of the simulation years (e.g., non-fodder crops, grassland, shrubland, and forest) in the calculation of NRMSE increases the NRMSE substantially (from 1.4 to 75) due to definitional differences in land cover types. The change in land area for land cover types is reasonably consistent with observations (Figure S10); however, the absolute value for grassland and shrubland differs substantially (Figure S9). Despite the increase in NRMSE, the inclusion of land cover types does not alter the parameter sets that minimize NRMSE."

We have also added a sentence to the methodology section clarifying our choice to focus NRMSE calculations on crops: "By default, we include any land type where we have observations for the full time series of the simulation, which effectively means all crops excluding fodder crops (see Section 2.4.3 and Table S1); however, we include a sensitivity on the set of land types included in Section 5.2.2.". Finally, we've added text on the availability of observation data in both Section 2.4.3 and Table S1.

16. How productivity of non-cropland is measured?

Author Response: We include productivity of pasture and forest, but not of other non-cropland types.

Author Changes: We have added this information to the methodology section: "Profit rates (rj) at the lowest level of the nest are computed based on price, cost, yield, and subsidy (if included) for land use types (crops, pasture, commercial forest); profit rates for land cover types are input into the model and are based on the value of land."

Thanks for this clarification, but you did not answer the question completely. Please explain how did you calculated productivity of forest and pasture land? It is an important piece of information and the reader should know it.

Author Response: We calculate productivity of forest from its vegetation carbon density and the yield for pasture is set to the yield of hay.

Author Changes: We have added information on the source of yields for all land types to a table in the SM.

17. GCAM aggregates crops into some specific categories? How prices were generated for those categories. In many cases there is no data on crop prices?

Author Response: We use the weighted average of producer prices for aggregated commodities, weighting by the production.

Author Changes: We have added this information to Section 2.4.2: "Data was aggregated from individual crops to the GCAM/gcamland commodity groups, weighting crops by their production quantity"

Thanks for the clarification, but for some crops, such as fodder crops, no data is available for quantity of production. Please explain what you did for those crops.

Author Response: The reviewer is correct that our previous answer was incomplete. For most crops, we use the weighted average of producer prices as the aggregate commodity price, weighting by production. For fodder crops, we do not have complete time series of price or production data. Instead, we use alfalfa prices from USDA for FodderHerb prices and we set the FodderGrass prices at 70% of the FodderHerb prices.

Author Changes: We have added a table to the SM that includes the data sources for prices. We explain how prices are weighted for most crops and include the source for the fodder prices.

18. The paper provides mixed messages on endogenous and exogenous variable. In determining targeted distribution parameters, what variables were targeted and what variables were determined in the model. It seems prices, areas, and yields were exogenous. Be more specific.

Author Response: Within gcamland, prices, costs, yields, subsidies, logit exponents, and expectation parameters are exogenous. In addition, the land area in the calibration year is exogenous. Areas in subsequent years are endogenous. Within the experiment in this paper, we also varied logit exponents and expectation parameters as part of the ensemble sampling.

Author Changes: We have added this information to a footnote in the methodology section: "The land allocation mechanism within gcamland uses price, yield, cost, subsidy, logit exponents, expectation parameters, and initial land area as exogenous inputs and endogenously determines land area in subsequent years."

Thanks for this clarification.

19. The whole practice implicitly assumes that other model parameters are accurate and valid. This is a strong assumption. The land supply parameters were determined while demand parameters held constant. The estimated supply parameters will be entirely wrong if the demand parameters (e.g. income and price elasticities for crops, livestock products, and forestry) are not valid. Any change in the demand parameters could alter your estimated parameters for the land supply. Can you test sensitivity of your results with respect to changes in other elasticities of the model?

Author Response: As noted in our response to comment #1, gcamland does not include a representation of demand for the exact reason you note here. We have chosen to isolate the land allocation mechanism in gcamland to ensure we get the right parameters for the right reasons and do not have cancelling errors. We cannot do a sensitivity on demand elasticities since they are not included in the model at all. Price is the only link to demand and we are using observed prices from FAO to ensure that demand-side sensitivity and errors do not affect the parameter estimation on the supply-side.

Author Changes: See response to #18.

Please see my response to item # 11

20. The results are counterintuitive. Let me explain using figure 2. In the adaptive case, for the first two nests the values are about 0.4 and for the last nest (cropland) the value of is about 0.6. Given that limited land movements among land cover items occurred at national level in the US and lots of change occurred in the crop nest, one could justify this outcome. However, for the other three cases (hybrid, linear, and perfect) the ranking is of values shows revers. Meaning that land conversion is easier at the land cover nests than the cropland land nest. These outcomes do not make sense. Am I missing something?

Author Response: Those outcomes also get lower NRMSE than the adaptive expectations, indicating that they do not explain historical land allocation as well as adaptive expectations. The parameter sets for hybrid, linear, and perfect minimize NRMSE if those expectation types are assumed, but the model with the lowest NRMSE includes adaptive expectations and parameters that match our intuition.

Author Changes: An explanation of the results and intuition is provided in section 4.1.

Thanks for this clarification.

21. In showing the results, level variables were used to show errors. For example, figure 2 compares estimated harvested areas with their observations for four types of expectations. This

hides the errors involved. It is better to calculate errors as percent difference between the estimated and observed areas.

Author Response: Thank you for the suggestion. We have considered adding a figure on percentage difference to the paper (attached). However, we feel that showing absolute values compared to observations is more informative since it gives a sense of scale, which differs significantly across crops in the USA.

Author Changes: We have added figures comparing model results to observations for all commodities to the supplemental material, but have opted not to add figures showing percentage difference.

This is not an appropriate response. It is an essential task to inform the readers regarding the percent errors between projections and observed values. Comparing the level variables in a chart hides those errors. to be transparent and informative you need to provide data on errors. If it is hard to show it in charts, please show them in a table in the appendix. This is an essential validation check.

Author Response: See response to comment #24

Author Changes: See changes in response to comment #24

22. The main manuscript only presents comparison of the projected and observed harvested areas and provided no comparison for other land types.

Author Response: The comparison of projected and observed area for other land types is included in the supplemental material for types where observations are available.

Author Changes: The comparison of projected and observed area for other land types is included in the supplemental material for types where observations are available. We have also added a paragraph to the supplemental material stating which land types are in gcamland and explaining our choice of what to show where: "The main text of this paper focuses on four commodity groups (Corn, Wheat, OtherGrain, and OilCrop), as these four commodities represent the largest land area in the United States. However, gcamland includes twelve commodity groups in total, representing all crops reported by the FAO, and fallow or idled cropland (referred to as other arable land in gcamland). In addition, gcamland includes commercial forest and pasture, as well as several other land cover types, including forest, grassland, shrubland, tundra, rock/ice/desert, and urbanland. We include results for other agricultural commodities and the land cover types where observations are available in this section"

Sorry, I do not consider this as a satisfactory response. The paper and its supporting material provide inconstant and confusing information about the land cover types, land uses, and components of each of the three nests included in the model. Simply revise table 2 and clearly put all land types and land uses in that table for each nest.

For example, in the main text in table 2 pasture land is not a part of middle nest. But it appears in the SI in Figure 7 as a component in the mix of grassland, shrubland, and pasture. Very confusing.

The main text should clearly represent the nesting structure and the component of each nest. Do not refer to another paper. This is an essential information for this paper.

Figure S7 should show data for each land cover item including managed forest, unmanaged forest, pasture, grassland, shrubland, any other components of the non-cropland nest, and cropland as one land cover type. If your model does not trace changes in some land types, that type of land should not be included in the model nor in the paper.

As a subcategory of cropland, the projections for unused cropland and their corresponding observations should be presented and compares.

Author Response: We have added a nesting diagram and a table to the SM with information on every land type included in the paper. We have also included a figure in the SM with model results and observations (where available) for all land types. We have included this an additional figure rather than an expansion of the original Figure S7 (now Figure S9) because in some cases the observations we have are for a sum of two gcamland land types. The new figure shows land by type for each individual type included in gcamland.

Author Changes: We have added a nesting diagram (Figure S1) and a table to the SM (Table S1) with information on every land type included in the paper. We have also included a figure in the SM (Figure S11) with model results and observations (where available) for all gcamland land types. We have also clarified when observations are available and when they are not, including the information in Table S1 and a description of what is included in the various figures and why: "Finally, Figures S6-S10 and Table S4 focus on comparing gcamland simulation results to observations for categories or sums of categories where observation data is present. However, there are other land types included in gcamland (see Figure S1 and Table S1). Figure S11 shows the evolution of all individual land categories in gcamland for the default simulations, with observation data plotted when it is available for the individual category."

23. Results are highly aggregated into four groups of crops. how about the 12 categories of crops in GCAM?

Author Response: The main manuscript shows four of the 12 crop categories. We have included figures showing the other categories to the supplemental material.

Author Changes: The main manuscript shows four of the 12 crop categories. We have included figures showing the other categories to the supplemental material. We have also added an explicit reference to these figures in the main text.

Please, add changes in unused land. That is an important piece of information.

Author Response: I am not clear on what the reviewer means by "unused land", but we have added information on all land types included in gcamland.

Author Changes: We have added information and results for all land types included in gcamland, including a nesting diagram (Figure S1), a table with data sources (Table S1), and a figure showing changes in land allocation for all gcamland land types (Figure S11).

24. The figure S5 of SI shows major errors for the change in forest area. This show that the model fails to represent changes in forest area correctly.

Author Response: Figure S5 had included the net change from 1990 to 2015 for the modeled data and the net change from 1992 to 2015 for observations for forest. Figure S7 shows the whole time series. As shown in S7, the time series tracks the observations fairly closely for the adaptive expectations. We do not think it is correct to say that the model fails to represent changes in forest area; however, we do think that Figure S5 was confusing given the unit used and the differences in time horizon.

Author Changes: We have removed Figure S5 as it did not add any new information and was confusing (see response to comment #25).

First thanks for adding figure S7. Adding this figure is a step forward. As I mentioned in comment # 23 you need to extend this figure for all land cover items. In particular, it is important to show errors in %, not in levels. Level variables hide errors. Please show the percent errors, then we can judge the model performance in land cover items. Also remember that you failed to calculate the goodness of fit (in your language NRSME) for land cover items.
Figure S7 shows bad performances for land cover items that already are included in this figure. In particular, I see very large differences in level variables between the performance and observed items. You also could alter the scale of this figure to better see the errors for forest. You should show the errors in percent to show the model performance. I believe it is straight forward to calculate NRSME for these items. Why not?

Author Response: We have added a calculation of NRMSE including dynamic land cover types. As noted in our response to comment #15, we are keeping this as a sensitivity since we do not have a complete time series of observations for land cover types.

As for percentage errors, percentage errors can mask as much as absolute errors (like an unnormalized rms) for this sort of multi-target work. Percentage errors often overemphasize errors in land types with small land allocations. For example, the largest error in percentage terms in any of the gcamland simulations is for PalmFruit. In absolute terms, this error is virtually zero. NRMSE uses the standard deviation of observation to normalize errors rather than using percentage errors to address this point. For this reason, many model validation studies rely on NRMSE as a measure of error. We have now added a table showing absolute error, percentage error, and NRMSE; we have also included a discussion on our choice to focus on NRMSE instead of percentage errors.

Author Changes: We have added a calculation of NRMSE including dynamic land cover types where observation data is available (see also response to comment #15). We have added a table to the SM (Table S4) showing absolute error, percentage error, and NRMSE, as well as a discussion on the different metrics: "Finally, Table S4 summarizes the error (simulation minus observation) in both absolute (million km^2) and percentage terms, as well as including NRMSE for each expectation type and crop. We include all three metrics in this table; however, in this study, we primarily use NRMSE. Normalized measures of error are key for interpreting whether a simulated data set acceptably replicates available observational data. While normalizing to present errors in terms of percentages is common, this can result in large magnitude percentage errors when dealing with multiple variables (land types) with a wide range of magnitudes. Given the significant difference in land historically allocated to different uses in the United States (e.g, the PalmFruit vs Corn commodities in gcamland) and the fact that we are seeking parameter sets to minimize error measures across these commodities, this can lead to misleading results. Rather, we follow the literature normalizing by the standard deviations of observations (Nash and Suttcliff 1970; Willmott 1981; Legates and McCabe 1999; Willmott et al 2012; Tebaldi et al 2020), captured in our NRMSE. This allows a benchmark of whether the discrepancies between simulated and observed data fall within the natural variability of the observed data, giving a statistically justifiable benchmark to determine whether those discrepancies are acceptably sized."

25. The figure S5 show increases in all land cover types and harvested areas. How that could be possible?

Author Response: Figure S5 shows the ratio of land in 2015 to land in 1990. Values less than 1 indicate a reduction in land area over time. There are several land types where area declined and those land types have values less than 1. However, we do think the unit used in this figure was confusing and all of the information contained in this figure is also shown in Figure S7, so we have removed this figure.

Author Changes: See response #24.

Thanks, see my responses to item # 24

26. Figure S7 shows no results for land cover items including grassland and shrubland for three types of expectations. Why?

Author Response: These results are included but they are covered by the line for adaptive expectations. All four expectation types produce similar values.

Author Changes: We have improved the figure so that the other expectation types are visible and added a note to the caption indicating they are overlapping.

Thanks

27. Figure S7 shows major errors for grassland and shrubland in the adaptive approach project huge errors. Why?

Author Response: This is due to differences in the definition of grass and shrubland between gcamland and the CCI land cover product. Most notably, gcamland includes a large portion of what is categorized as grass or shrub in CCI land cover as pasture.

Author Changes: This was already stated in the paragraph immediately preceding figure S7: "Due to differences in definitions of land cover between gcamland and the CCI land cover product, Grassland and Shrubland do not match in absolute value between gcamland and the observation data." We have also added a panel to this figure showing the sum of pasture, shrubland and grassland; this summation improves upon the data mismatch.

Sorry, but this response does not make sense. If you used different definitions in your modeling practice, you should adjust the actual observations based on your definition as well. please revise accordingly. Even the combined panel shows large differences. We are talking about millions of km2.

Author Response: We do not think it is appropriate to adjust the observation data. However, we agree that it makes it difficult to compare results. We cannot initialize gcamland to the observation data because the CCI data is not available for all possible gcamland base years (1975, 1990, 2005). The initialization data we do use (now reported in Table S1) is a reconstruction based on potential vegetation and land use data; since it is not a single data product, we did not think it was a good source of observation data.

Author Changes: As noted, we do not think it is appropriate to adjust observation data, but we have added a figure (Figure S10) showing changes in land area for land cover types to compare the model to observations. In addition, we've added sources for initialization and observation data to the new table in the SM (Table S1), along with an explanation of why we do not use the CCI data for initialization: "The CCI satellite data is only available starting in 1992. For this reason, we cannot use it as initialization data since we need that data for 1975, 1990, and 2005."

28. It seems the whole practice has failed to take care of land cover changes.

Author Response: Land cover changes are included in gcamland and are compared to observations in the Supplemental Material. Therefore, we do not think it is correct to say that we have failed to take care of land cover changes.

Author Changes: See changes in response to comments 12, 13, 16, 22, 24, 25, 26, 27.

I already responded to these. Your work fails to calculate the goodness of fit for land cover items. That should be highlighted in the main manuscript, as I highlighted in several places in my responses. Also, errors should be presented in % differences. This is an essential item to validate this work. given the size of land items, even 5% error is huge. We are talking about million hectares of land.

Author Response: We have addressed these comments in our responses to 21, 24, and 27.

Author Changes: See changes in response to comments 21, 24, and 27

29. The examined practice estimated a few parameters of the model for land use. A good way to test the outcomes of this practice is to run the GCAM model with the estimated parameters and compare the model results for land use changes, land cover changes, changes in crop prices, and changes in yield with actual observations over the examined period.

Author Response: We agree that this is a useful test and intend to do it in subsequent work. However, this paper is focused on parameter estimation and we think that adding those simulations to this paper would unnecessarily complicate the existing text and analysis.

Author Changes: None.

I am glad that you consider this test as a useful test. But it is not only useful. This is an essential task. Validation of estimated parameters is a crucial task. Indeed, without this test you do not know how good the estimated parameters for projection are. Running a validation test may require more work, but it is an essential task.

I observe that the revised version noted that: "we have focused on the historical period. However, these models and parameter estimates could be used in a simulation of future land use and land cover change to better understand their implications." Even you have not shown how your model project historical data. You only used historical data to estimate the logit parameters. But failed to test how good are the estimated parameters to replicate the historical. That should be clearly acknowledged in the paper.

If you choose not running this test, then the paper should clearly acknowledge that you have not examined the validity of your practice in the abstract, discussion section, and conclusion.

Author Response: We believe the reviewers response to our previous answer stems from the confusion between gcamland and GCAM, as discussed in comment #1. We have used the parameters in gcamland, re-run the model, and compared the results to observations. That is, we have shown how gcamland simulates land area in the historical period using the new parameters (see Figures 3-6). We have not run GCAM, which would require us to replicate this analysis for 31 other regions (GCAM includes 32 regions). In addition, GCAM includes models of agricultural demand and links to the energy system, all of which will affect land allocation. We do think running the updated parameters through GCAM is useful future work, but it is outside the scope of this paper.

Author Changes: We have revised the final paragraph clarifying what we have done and why we are leaving the GCAM analysis to future work. The first sentence now reads (new text in italics): "In this paper, we have focused on the historical period, *simulating land allocation in gcamland over this period and comparing it to observations*." And, we've added this sentence about the potential GCAM validation test: "However, for such a study, we would need parameter estimates for all thirty-two GCAM regions and not just the United States." We have also added an overview of the methodology, including the simulation of historical land using gcamland and comparison with observations to the beginning of Section 2 (see response to comment #4).

30. Finally, the whole work could be a valuable practice for the CGAM community. It uses "hindcast" to estimate the logit distribution parameters for this model. Hindcast Is not a new approach. The outcome of this practice may help the GCAM community to improve their work on land use modeling. However, the results of this practice may be not useable for other models. As they may follow very different modeling structure and assumptions. The author of this paper should make this point very carefully.

Author Response: We agree with the reviewer's notes here. Other models can use from our methodology and some of the takeaways from this paper (e.g., the choice of metric and which crops to include can alter the resulting parameters and model performance); however, other models are unlikely to be able to use these parameters directly.

Author Changes: We've added this caveat to the discussion.

Thanks

31. The abstract provides trivial information. It is not an abstract of this paper.

Author Response: We have revised the abstract.

Author Changes: We have revised the abstract.

With all due respects, the revised abstract needs a major work. The fist six lines provide a lecture to justify this work. Those should be included in the main text not in the abstract. Then it is noted that: "We run gcamland simulations with these parameter sets over the historical period in the United States to quantify land use and land cover, determine how well the model reproduces observations". This is not what you did. you have not quantified "land use and land cover" over time. You used historical data to estimate some model parameters. You have not determined how your model produces actual observations for the estimated parameters. This is the validation test that you refused to accomplish. You have not highlighted your findings on the sizes of the estimated parameters. You have not highlighted the limitations of this work. You need to revise the abstract.

Author Response: First, we are following the guidance provided by the Nature journals on how to write an abstract or summary paragraph (https://www.nature.com/documents/nature-summary-paragraph.pdf). Such guidance recommends providing an introduction to the field (both general and specific) to motivate the work before describing the specific contribution of the paper. It does not include limitations of the work in the abstract, instead that is included in the discussion.

Second, we have quantified land use and land cover in the historical period (see also response to comment #29). The statement in the abstract is correct as written. For each randomly sampled set of parameters, we initialize gcamland to a base year of data (e.g. 1990) and then use the parameter sample set to simulate land use and land cover in subsequent years (e.g. 1991-2015) without incorporating additional historical data. We then compare the gcamland simulated historical data to available observational historical data for each random parameter set and select the error-minimizing parameter set.

Author Changes: We have added a summary of our methodology to the beginning of Section 2 to clarify what we have done (see response to comment #4).

32. Following a summary of land use change at the global scale, the second paragraph of the introduction begins with: "Similar trends occurred in the United States". This is not an accurate statement. The US land use change did not follow the global land use changes in terms of land conversion to crop production. No expansion in cropland has been observed for the cases of US.

Author Response: We have removed that sentence.

Author Changes: We have removed that sentence.

Sorry, why you removed this part. You have to correct your statement and say that the United States have not followed the common trends in other countries and inform the reader why not.

Author Response: We removed that sentence because the entire next paragraph elaborates on the trends in the United States: "In the United States, crop production has increased substantially in the last several decades, but much of that increase in production is due to increases in yields (Babcock, 2015; Fuglie, 2010). Total cropland area in the United States has remained relatively constant between 1975 and 2015. Instead, there has been a shift in crop distribution, with an increasing share of corn and soybeans and a decreasing share of wheat and other grains (Figure 1, (FAO, 2020a; Taheripour and Tyner, 2013))."

Author Changes: No changes.