Crop production, cropland use, and land intensification in economic models

By

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1. Introduction

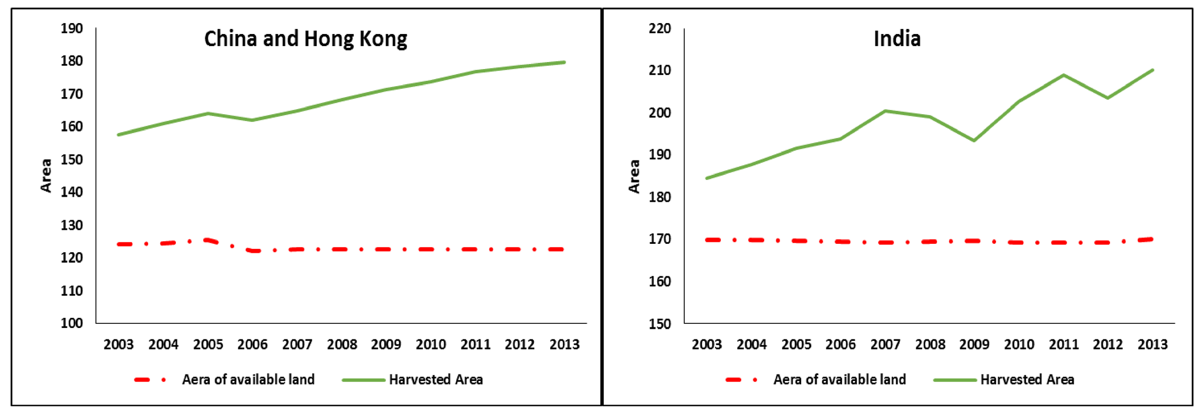
Several recent publications have shown that land intensification in crop production (defined as harvest frequency and measured by the ratio of harvested area (H) over area of available cropland (L)) has increased across the world due to expansion in multiple cropping and/or conversion of unused cropland to crop production (for example see Ray and Foley (2013)).

The expansion in harvest frequency, if persists in the future, could absorb a portion of future increases in demand for cropland. To evaluate the potential economic and land use impacts of improvements in harvest frequency, we need to introduce this source of land intensification in the existing economic models which currently misrepresents it.

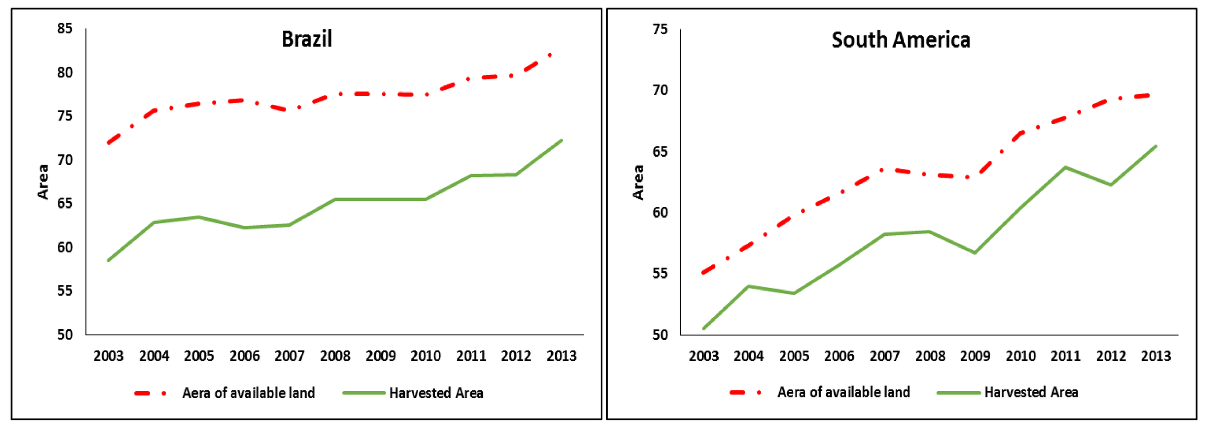
2. Objectives

The existing economic models, in particular the large scale global Computable General Equilibrium (CGE) models are not designed to properly represent improvements in land intensification in crop production and capture their economic and land use implications. This poster discusses this issue, offers a method to introduce land intensification in CGE model, and makes some simulations to represents its economic and land use impact.

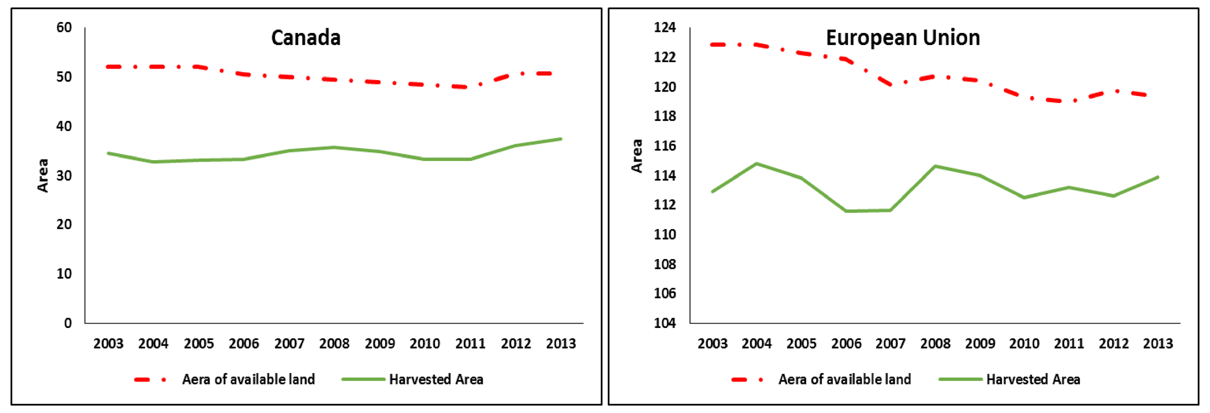
3. Intensification in Cropland: Recent Evidence



China and India: Harvested is larger than available cropland and H/L followed an increasing path over time



Brazil & S. America: Harvested area is less than available cropland but H/L followed an increasing path over time



Canada and European Union: Harvested area is less than available cropland but H/L followed an increasing path over time due to reduction in area of available cropland

4. Intensification in Economic Models

- Regardless of all differences among computable economic models, they usually take into account intensification in crop production in three ways:
  - Intensification due to using more of non-land inputs,
  - Hick's neutral technical shock (TFP),
  - Biased productivity shocks in land input.
- The above demand side approaches can be used to handle improvements in harvest frequency only in those models which aggregate all crop activities in one sector. We refer to these models as G1,
- The economic models which represents several crop sectors, cannot represent improvements in harvest frequency using the demand side approaches, We refer to these model as G2,
- Examples for G1 group:
  - MIT's Emissions Prediction and Policy Analysis (EPPA) model, which is General Equilibrium (GE) model (Paltsev et al., 2005),
  - Simplified International Model of agricultural Prices, Land use and the Environment (SIMPLE) model, which is a partial equilibrium (PE) model (Hertel et al., 2014).
- Examples for G2 group:
  - GTAP-BIO model, which is a GE model (Hertel et al. (2010) and Taheripour and Tyner (2013)),
  - MIRAGE model, which is a GE model (Laborde et al. 2011).

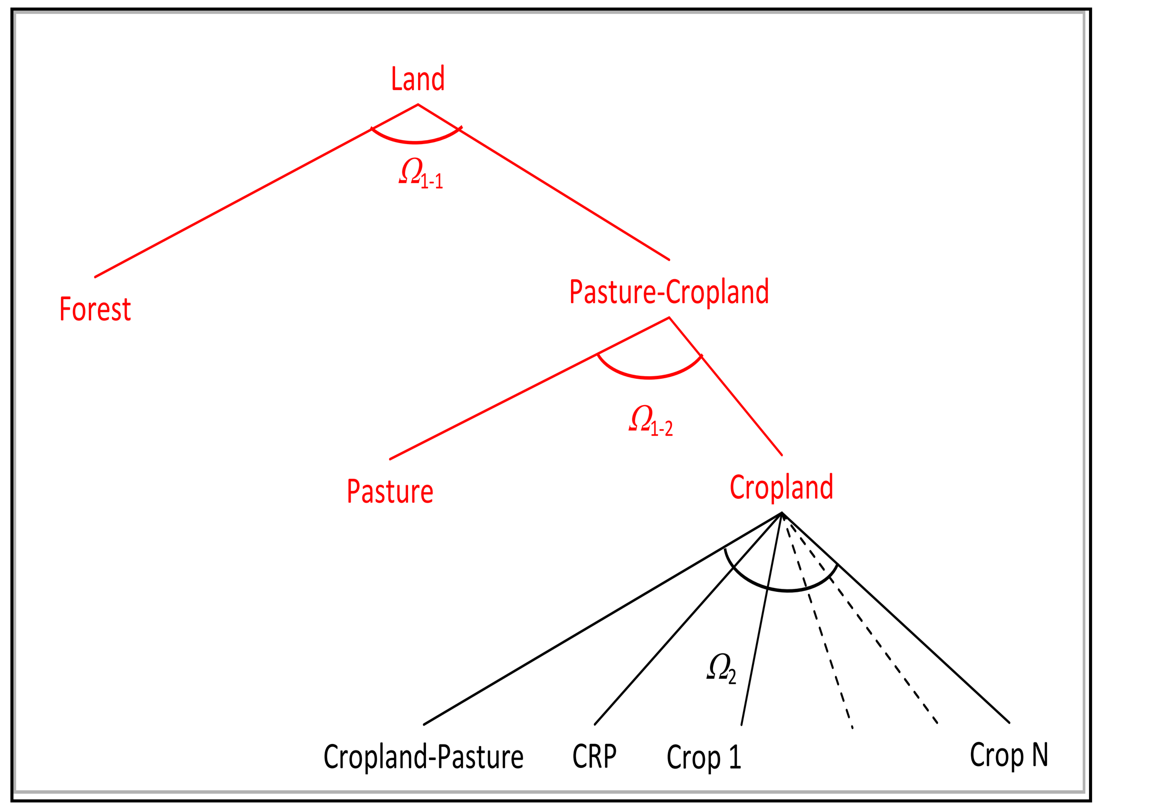
5. Why traditional demand approaches can be implemented to represent improvements in harvest frequency in G1 models, but not in G2 models

- An improvement in harvest frequency occurs due to:
  - Expansion in multiple cropping,
  - Returning idled cropland to crop production,
  - Reduction in crop failure.
- Hence, an improvement in harvest frequency increases harvested area, but it reduces demand for cropland, other factors being constant.
- A typical G1 model which represents all crops under an aggregated sector uses a production function to handle crop production,
- For simplicity consider a general production function with two inputs of land and capital:
  $Y = Af(aL, bK)$,
  Here *Y*, *L*, and *K* stand for production, land, and capital, and *A*, *a*, and *b*, represent productivity variables.
- A typical G1 model could use data on cropland area in its crop production function and quantifies the relationship between production and available land, ignoring harvested area.
- It is trivial that in these models an improvement in harvest frequency can simply be implemented using the demand side approaches outlined above.
- In contrast, a typical G2 model only can use harvested area of each crop to quantify the relationship between land and production of that crop.
- In a typical G2 model a general production function for crop *i* is:
  $Y_i = A_i f_i(a_i H_i, b_i K_i)$
- Since an improvement in harvest frequency increases harvested area, one cannot use in A_i or a_i to represent this improvement
- In addition, an improvement in harvest frequency is not a crop specific improvement.
- An improvement in harvest frequency just increases the pool of available land for crop production on the existing land.
- Farmers can chose to allocate the larger pool among crops.

6. An option to introduce improvements in harvest frequency in a G2 model

- Since an improvement in harvest frequency increases the pool of land on the existing cropland, an option is to introduce this type of improvement on the supply side of land.
- Including a productivity factor in the supply side of a typical G2 models is an appropriate remedy to solve the problem.
- As an example we introduce multiple cropping into the GTAP-BIO model which is a typical G2 model

7. Land supply nesting structure in GTAP-BIO Model



8. Cropland supply in GTAP-BIO with no multiple cropping and no idled land

- A nested Constant Elasticity of Transformation (CET) function allocates land among its alterative uses in this model.
- The following relationship represent the supply of cropland to the alternative crops:
  $lc_i = lc + \Omega_2[pc - pc_i]$
  Here $lc_i, lc, pc, and\ pc_i$ represent changes in: land supply to crop i, area of cropland, price of cropland, and price of cropland under crop i. And Ω_2 is the lands transformation elasticity.

9. Cropland supply in GTAP-BIO with multiple cropping and idled land

- To introduce improvements in harvest frequency a new variable, *afs*, which measures this change is defined and added to the cropland supply nest:
  $lc_i = lc + afs + \Omega_2[pc - pc_i]$
- The model determines the size of *afs* endogenously using:
  - An intensification parameter, γ, obtained from historical trends in land intensification by region,
  - The ratio of total harvested area over cropland by region.
- Improvement in harvest frequency affects other nests of the land supply three and land prices as well. The model is revised to handle the price impacts as well.

10. Simulation Scenarios

- To show the importance of including improvements in harvest frequency on demand for new cropland the following simulations were tested using the GTAP-BIO model with and without intensification using the GTAP-BIO 2011 database as presented in Taheripour et al (2017):
  - Expansion in US corn ethanol by 1.07 BGs (from 13.93 BGs in 2011 to 15 BGs);
  - Expansion in Brazilian sugarcane ethanol by 1 BGs;
  - Expansion in US soybean biodiesel by 0.5 BGs;
  - Expansion in EU rapeseed biodiesel by 0.5 BGs;
- Induced land use changes for these biofuel experiments were calculated in the presence and absence of improvements in harvest frequency.

11. Simulation Results

Description	Without intensification		With intensification	
	Change in harvested area	Change in cropland cover	Change in harvested area	Change in cropland cover
USA	153.4	153.4	147.3	30.2
European Union	35.0	35.0	33.7	6.7
Brazil	117.1	117.1	65.1	26.6
Canada	37.0	37.0	34.8	6.8
Japan	5.4	5.4	5.6	5.6
China	82.3	82.3	12.4	0.0
India	11.6	11.6	6.9	0.0
Central Amer.	5.6	5.6	4.9	1.0
South Amer.	55.7	55.7	48.5	46.3
East Asia	1.7	1.7	1.7	1.7
Mala-Indo	2.2	2.2	2.4	2.4
Rest of S. E. Asia	14.8	14.8	13.6	10.7
Rest of S. Asia	24.8	24.8	13.9	3.1
Russia	11.7	11.7	12.4	12.4
Other CEE-CIS	29.8	29.8	28.1	5.6
Other Europe	0.5	0.5	0.5	0.5
Mena-N. Afr.	23.6	23.6	22.3	4.6
Sub Saharan Afr.	446.2	446.2	422.0	343.3
Oceania	18.3	18.3	18.2	3.5
World	1076.5	1076.5	894.3	510.9

Changes in harvested area and cropland for corn ethanol (in 1000 hectares) : Less cropland needed with intensification

Description	Brazil sugarcane ethanol		US Soybean biodiesel		EU biodiesel rapeseed	
	Without int.	With int.	Without int.	With int.	Without int.	With int.
USA	7.1	1.4	23.2	4.5	4	0.8
EU27	9.2	1.8	3.4	0.7	29	5.8
Brazil	224	52.5	10.1	2.2	4.5	1
South America	10.2	7.7	9.3	8.1	5.9	5.4
Sub Saharan Africa	89.4	69.2	46.3	34.4	109.9	86.8
Others	44.8	9.9	22.5	12.4	68.9	16.8
Total	384.7	142.6	114.8	62.2	222.2	116.7

Changes in cropland for other biofuels (in 1000 hectares): Less cropland needed with intensification

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