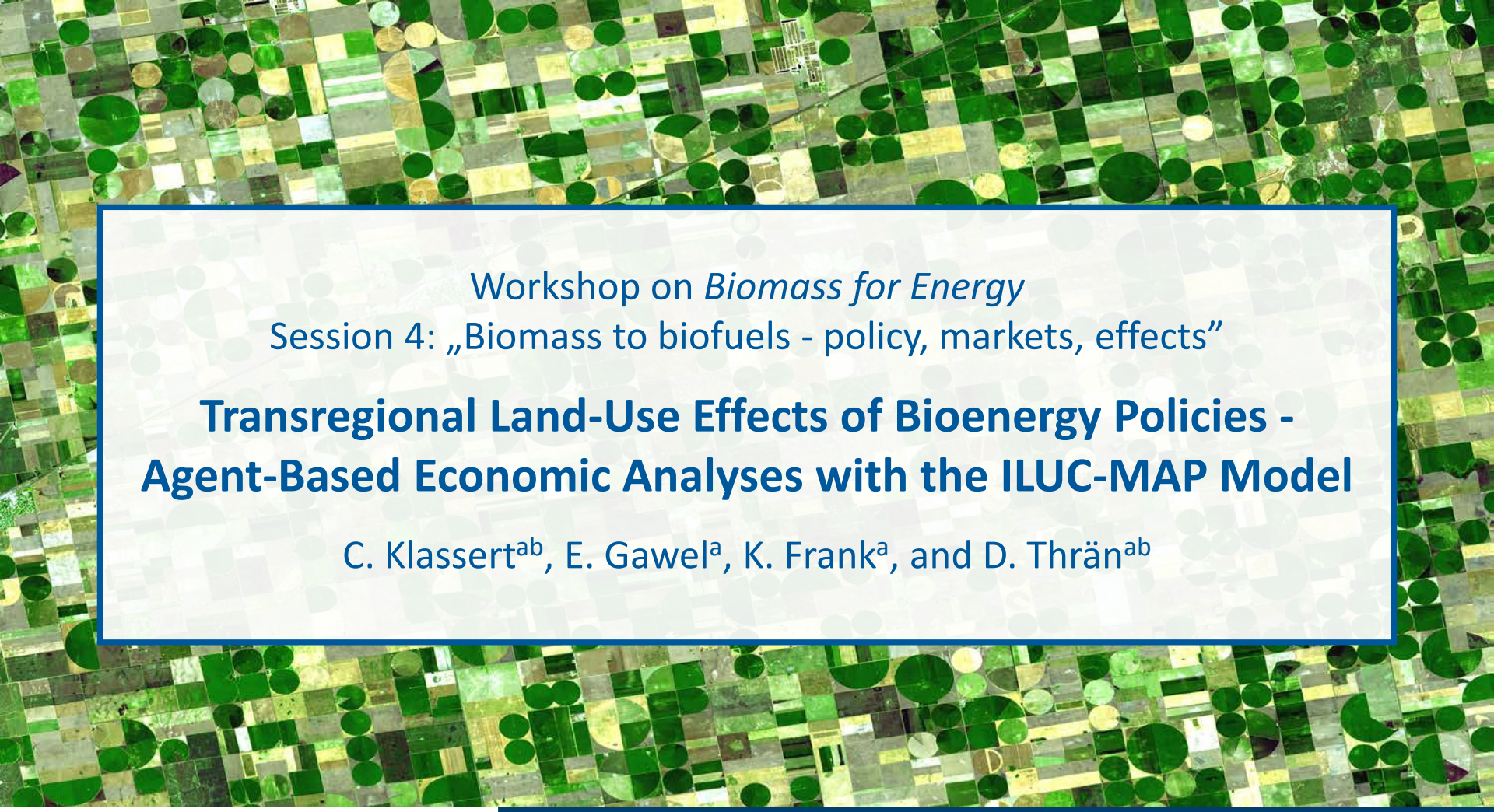

Workshop on *Biomass for Energy*
Session 4: „Biomass to biofuels - policy, markets, effects”

Transregional Land-Use Effects of Bioenergy Policies - Agent-Based Economic Analyses with the ILUC-MAP Model

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Leipzig, November 24th 2014, Helmholtz Centre for Environmental Research – UFZ, Leipzig
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1. Background and Motivation

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1.1 Background: Bioenergy (BE) and Global Land-Use Change (LUC)

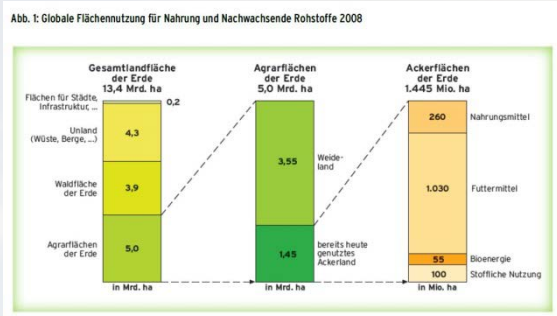
Status Quo:

- In 2011, **50 countries** had biofuel (BF) blending mandates (Rossi and Cadoni (2012)).
- In 2008, **2,2 % of global cropland** was used for BFs (Fargione et al. (2010)).

Trend:

- EU-RED and US-RFS2 have led to a **strong increase in trade with BE-products** (Lamers et al. (2011)).
- This may cause **increased LUC** (OECD/IEA (2011)).

→ *Decisions about BE-policy and governance instruments require information about (in-)direct LU-effects of altern. policy mixes at home and abroad!*



Source: Raschka (2012) in UBA (2012).

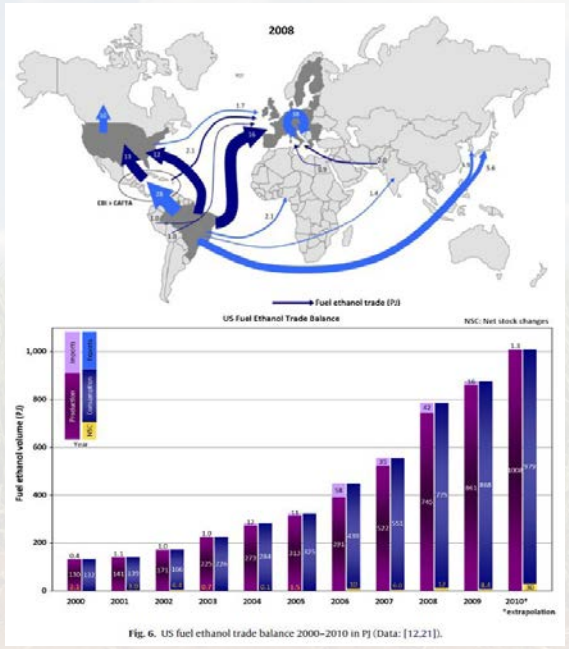


Fig. 6. US fuel ethanol trade balance 2000–2010 in PJ (Data: [12,21]).

Source: Lamers et al. (2011).

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1.2 Research Need and Challenge

Shortcomings of current models:

- Current CGE-, PE-, and integrated assessment models used to assess the effects of BE policy mixes (Edwards et al. (2010), Witzke et al. (2009), Wise et al. (2009)) are closely related to the trade and environment (T&E) literature of 1990's – making them **very suitable for modeling international GHG** issues.
- However, their standard economic (SE) assumptions make it difficult to accommodate some aspects important for the analysis of LUC, such as **spatial interactions**, **temporal dynamics**, and **producer heterogeneity** (Van Beers and van den Bergh (1997)). BE policy features both climate and LUC aspects!

→ Challenge: *How to capture the LUC-specific aspects of BE-policy (space, dynamics, heterogeneity) withouth loosing the explanatory power of SE models?*

1.3 Solution and Research Questions

Solution:

- Epstein (2006) found that within the social sciences, representing **space**, **dynamics** and agent **heterogeneity** are comparative advantages of agent-based models (ABMs). Tesfatsion (2006) recommends ABMs for testing the "**robustness of standard economic theories** to relaxations of their assumptions".
- Based on such considerations, Rounsevell et al., (2013, 2014) **propose to combine ABMs with CGE models** for modeling the LU-effects of BE policies!

→ Research questions: *Since the difficulty to accommodate LUC aspects in CGE and PE models comes from the theoretical level, our research objective is to analyze the possibility to integrate SE T&E models with an LU ABM in a conceptual model, to answer the overarching research questions and purposes:*

(1) ***System understanding:*** *Which transregional land-use dynamics can be caused by BE promotion and related governance instruments? How can negative effects be mitigated?*

(2) ***Current models:*** *How reliable are current model-based BE policy evaluations to relaxations of their assumptions?*

(3) Contribute to the ***theoretical basis*** *for the* ***integration of ABMs in CGE-/PE-frameworks****.*

2. Model Implementation

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Multi-**A**gent **P**latform for the Analysis of **I**nternational Trade and **L**and-**U**se **C**hange (ILUC-MAP):

1. Starting point: Conceptual model closely based on the **SE assumptions** of analytical PE models in the T&E literature, consisting of:
   a) A partial equilibrium framework
   b) A land-use decision model
   c) The market structure
2. Implementation: Based on this, we have implemented a computational laboratory on the agent-based modeling platform NetLogo, Version 5.0.3 (Wilensky (1999)).
3. Testing: We have tested the model via the **replication of** a number of **theorems** from the environmental economics and the T&E literature (Hoel (2001), Baumol (1972), Krutilla (1991)).
4. Policy Analyses: We extend the basic ILUC-MAP setup through **incremental deviations from SE assumptions** in terms of spatial interactions, temporal dynamics and heterogeneity and compare how these deviations affect the environmental and economic performance of a number of policy mixes (BF promotion + gov. instr.).

2.1 Research Strategy

Purpose: Close link to the theoretical foundations of BE policy models. Starting from an analytical PE model of the T&E literature (Krutilla (1991))

Markets: Extension for the 2-country (*Home* and *Foreign*) and 2-product case (generic food and BF crops). Up to 8 market partitions can be targeted by different policy instruments (product taxes/subsidies, land input taxes/subsidies, certification, etc.).

Welfare: Usage of the term welfare to indicate only the partial welfare provided by agriculture (with/without environmental costs).

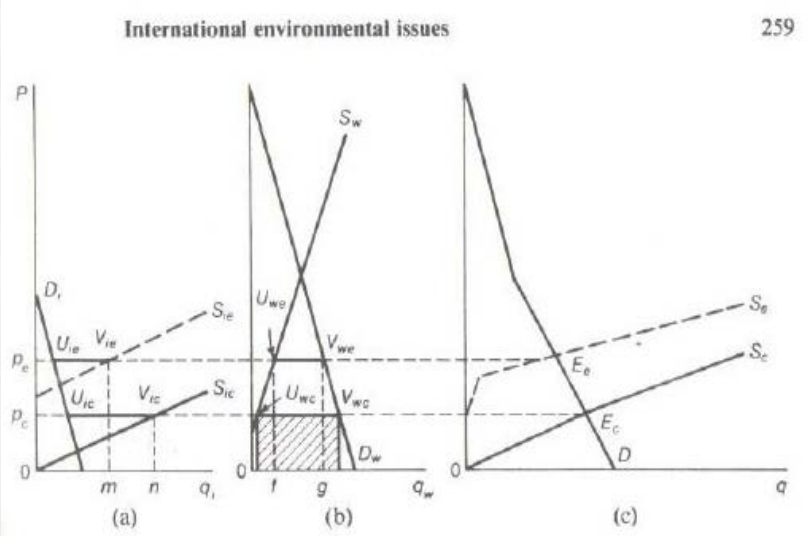


Figure: T&E PE model, Baumol and Oates (1988).

$$Equilibrium\ condition\ (i = f, b):\ \ Y_S^{Hi}\left(P_S^{Hi}\right) - Y_D^{Hi}\left(P_D^{Hi}\right) = Y_D^{Fi}\left(P_D^{Fi}\right) - Y_S^{Fi}\left(P_S^{Fi}\right)$$

$$Global\ Welfare\ (Agricultural\ Contribution):\ \ W = \sum_{j=\{Hf,Hb,Ff,Fb\}} W^j$$

$$W^j = \int_{P_D^j}^{\infty} Y_D^j\left(P_D^j\right) dP_D^j + \left[P_S^j + \tau_p^j\right] Y_S^j\left(P_S^j\right) - C_S^j\left(Y_S^j\left(P_S^j\right)\right) - E_S^j\left(Y_S^j\left(P_S^j\right)\right) + \tau_m^j\left[Y_S^j\left(P_S^j\right) - Y_D^j\left(P_D^j\right)\right]$$

2.2 Partial Equilibrium Framework

Purpose: Linking the SE partial equilibrium framework to a more detailed representation of land-use decisions.

Assumptions:

1. Supply sector disaggregated into farm agents:

- Farms decide for which market to produce (food/BF, domestic/export), on which of their land cells, and at which degree of intensification
- Method: Myopic, non-linear optimization

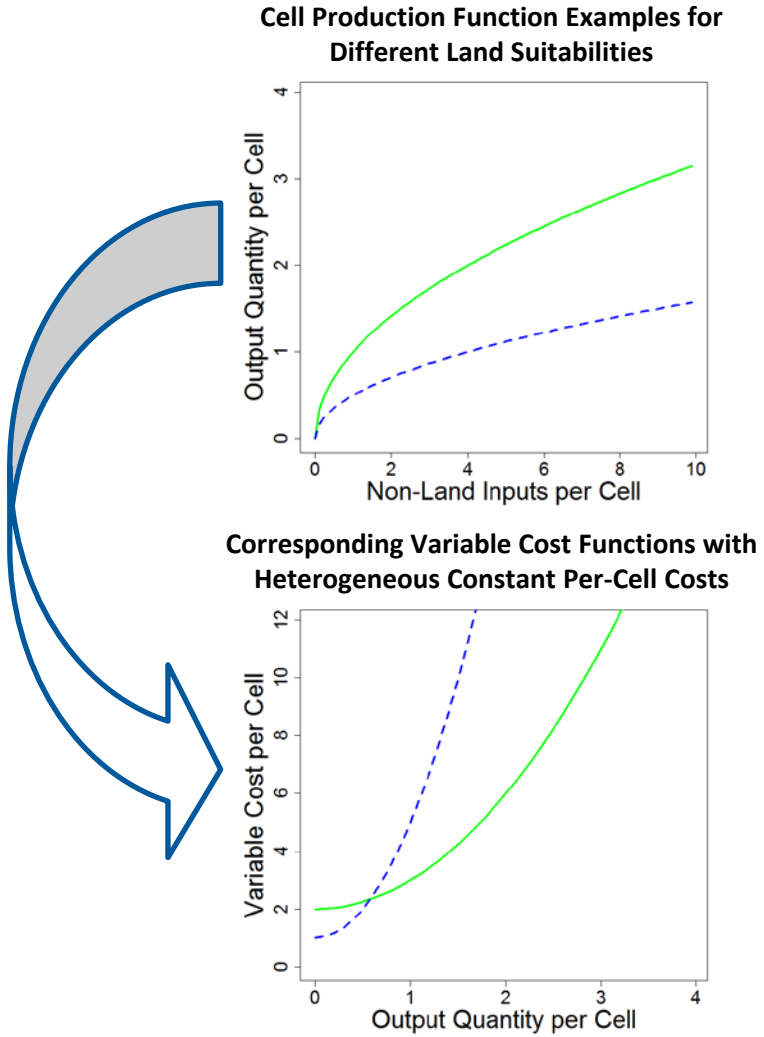
2. Land cells have:

- A **cost function**, derived from a production function with diminishing returns (determined by the cell's land suitability and the farm's managerial ability) and transport costs, etc.
- A **land-use state** (forest, "empty", food, BF)

3. Simplifying assumptions:

- Destruction of ecosystems („forest") is irreversible in the relevant time frame.
- „Empty" land has no ecological value.

Production and cost functions for one cell:



2.3 Land-Use Decision Model

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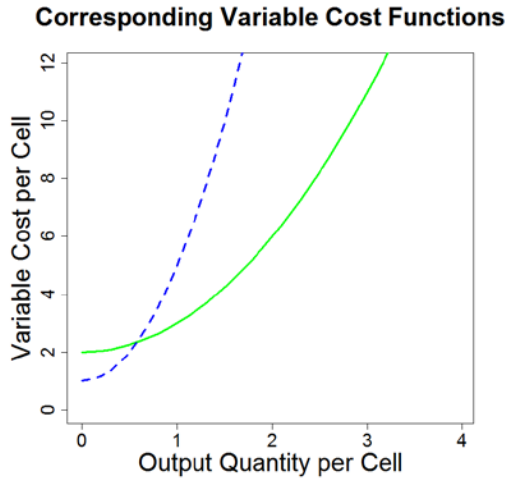

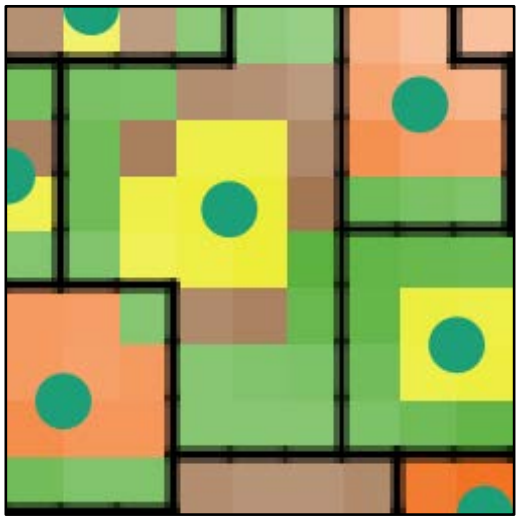

Farm Optimization Problem – Solution Strategy:

- A profit function across all cells controlled by a farm is derived from the cell-specific cost functions (including land and product taxes) and the revenue function
- The Kuhn-Tucker conditions are used to derive an optimal solution in the form of a cubic function, which is then solved with Cardano's method (Polyanin and Manzhirov, 2007: 158)
- When constant per-cell cost parameters (e. g.: deforestation tax) are active, the non-linear programming problem becomes a mixed integer programming problem, which is solved by an heuristic algorithm based on the Kuhn-Tucker solution
- Solutions are calculated for all markets accessible to the farm
- Subsequently, the most profitable solution is implemented by changing the land-use states of the farm's cells (green = forest, brown = "empty", yellow = food, orange = BF; lighter shades indicate higher land suitability)

2.3 Land-Use Decision Model

Purpose: (1) Adapting the model to the dynamic context of an agent-based model and (2) creating a framework in which the (path-dependent) dynamics of land-use change can be meaningfully analyzed.

Assumptions:

- Dynamics: Farm agents act sequentially and make binding contracts. Between decisions, the demand sectors update supply quantity information for all markets.
- Expectations: The demand sector assumes that those agents that have not decided in this time step will produce exactly what they have produced in the last time step (similar to cobweb model)

Consequences:

- Advantages: Representation of market dynamics between the cobweb model and the Walrasian auctioneer. The markets approach competitive equilibrium, but with dynamic path. Avoiding the market instability of cobweb models, especially when there are several markets.
- Disadvantages: When there are too few agents, market power becomes significant – producer surplus is higher, optimal tax levels lower than they should be. Thus the model needs to be run with a sufficient number of agents.

2.4 Market Structure

2.5 Agent-Based Implementation

Purpose: Making the agents production and land-use decisions in the two countries interact.

Structure: Replacing the sectoral supply function with LU agents, similar to those in existing agricultural ABMs (Happe et al., 2006; Gotts et al., 2009), but with non-linear optimization.

Initialization: Allocation of cell control to farms from regular grid or maps from external landscape generator (LG) by Engel et al. (2012). Random initialization of agent parameters and cell states.

Model run:

- **Phase 1:** Model runs until food equilibrium
- **Phase 2:** BF promotion and LU governance instruments are introduced

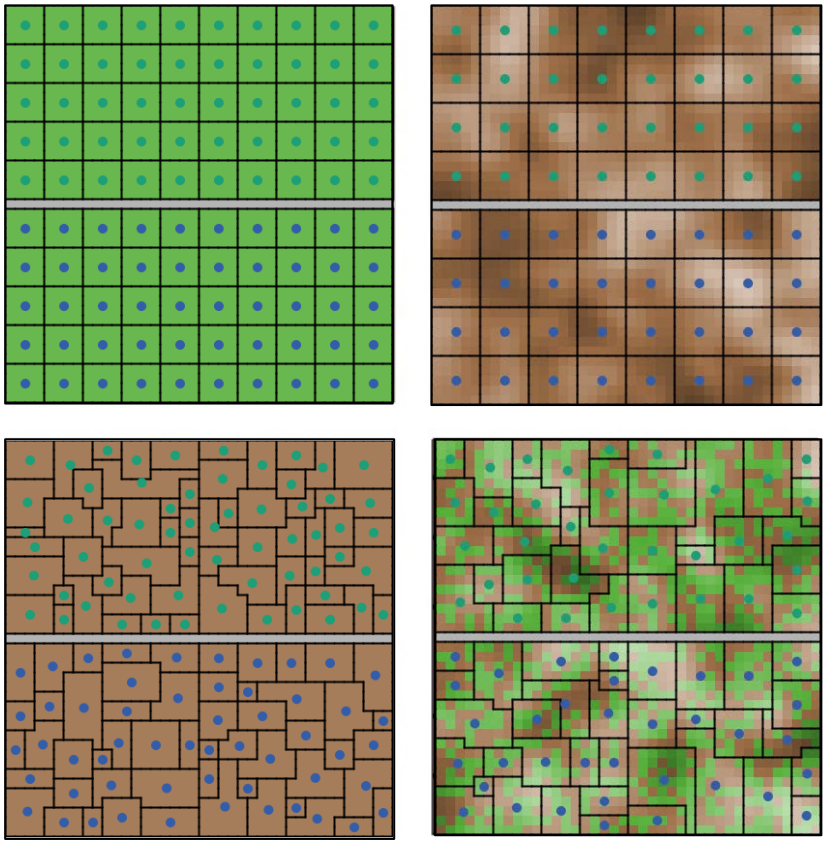

Figure: Grids with mesh-sizes of 4x4 and 5x5 and imported LG maps (Engel et al., 2012). Green color indicates forest cells, lighter shading higher land suitability, black lines cells allocated to one farm.

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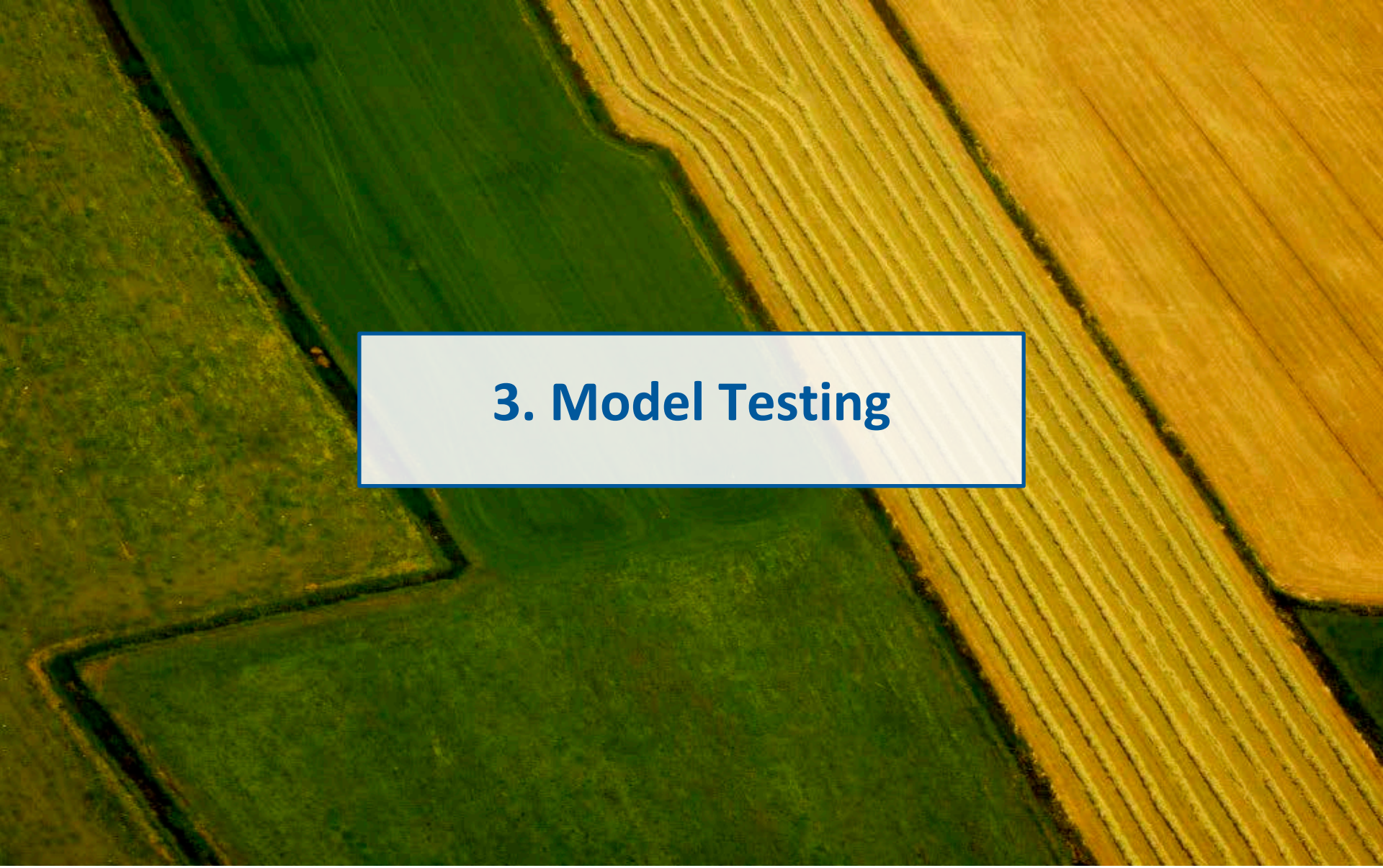

3. Model Testing

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3.1 Model Testing: Assumptions

Approach: Pattern-Oriented Modeling (POM, Grimm et al., 2005)

Assumptions:

- The basic model setup without any extensions is used for the analyses.
- We conducted sensitivity- and spatial analyses for the basic model: In the basic model, qualitative behavior is the same for all parameter sets for which the land constraints are not binding.
- We have chosen a fixed set of basic parameter values (e. g. for agent parameterization) for which we know that most land constraints are not binding.
- Only the treatment parameters necessary for the experiment are changed, such as externalities, taxes and the distribution of demand among countries.

3.2 Model Testing 1: Replication of Lit. Theorems (1)

Pigouvian tax optimality: *Ceteris paribus,* a Pigouvian tax rate equal to the marginal environmental costs (MEC) will be welfare optimal (Baumol (1972)).

Hypothesis 1: The tax rate equal to the MEC rate leads to significantly higher welfare than either higher or lower rates. (Null Hyp.: It will not lead to significantly higher welfare.)

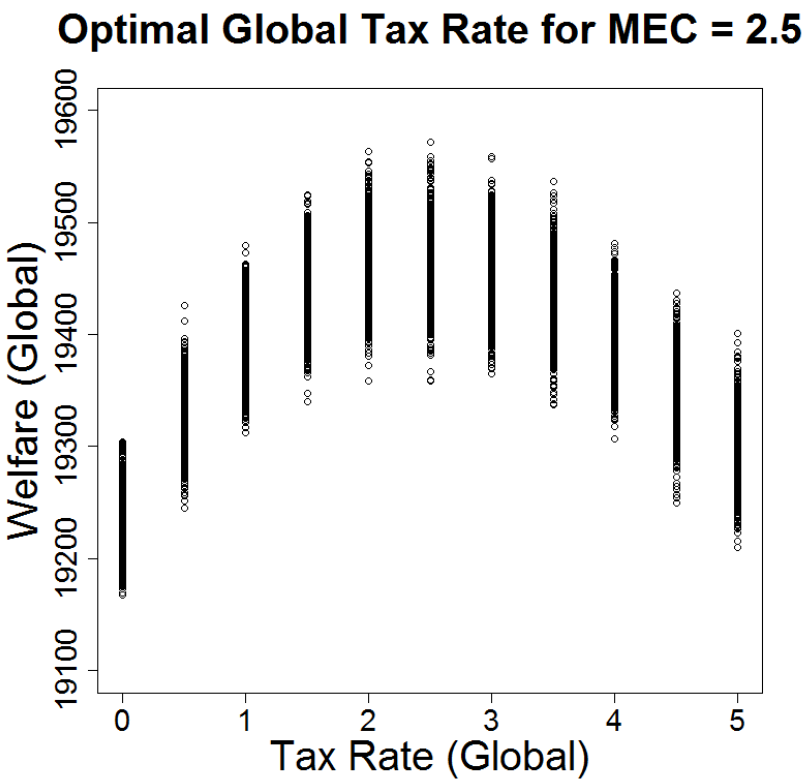

Figure: Distribution of global welfare as a function of the applied global product tax rate under the standard parameter set. Shown are 1000 model runs for 11 tax rates.

3.2 Model Testing 1: Replication of Lit. Theorems (1)

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Hypothesis 1: The tax rate equal to the MEC rate leads to significantly higher welfare than either higher or lower rates. (Null Hyp.: It will not lead to significantly higher welfare.)

Test: Both countries are parameterized identically and production creates a local environmental externality. We analyze global welfare as a function different global product tax rates. Pair-wise heteroscedastic t-tests with Bonferroni-correction show differences between adjacent rates significant at the 99.9 percent level (***), respectively.

→ *We, therefore, confirm hypothesis 1!*

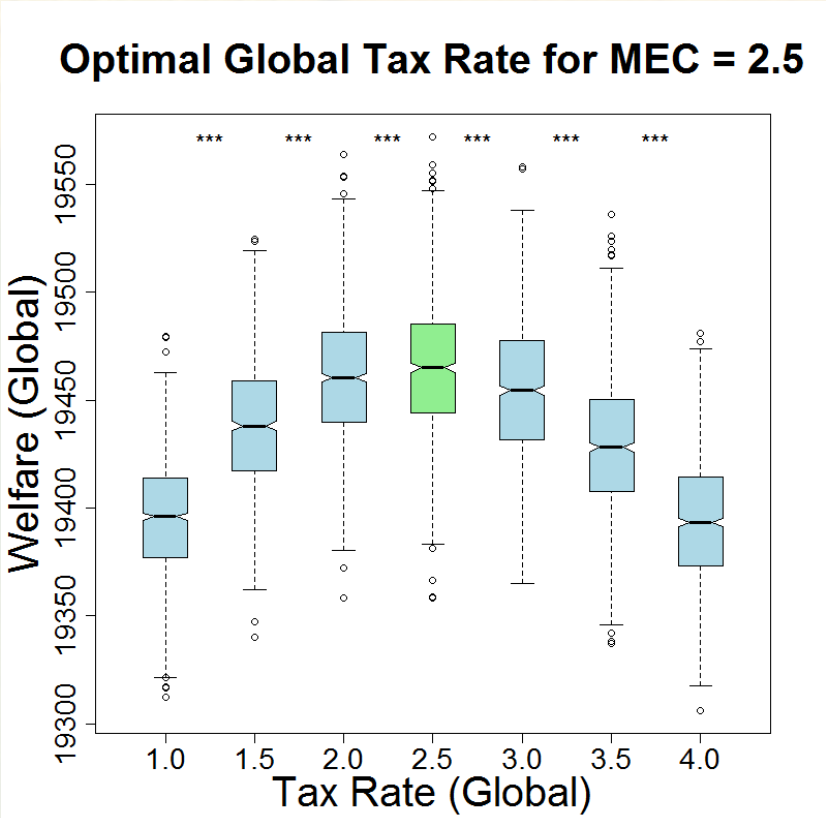


Figure: Distribution of global welfare as a function of the applied global product tax rate under the standard parameter set. Shown are 1000 model runs for 7 selected tax rates around MEC.

3.3 Model Testing 2: Replication of Lit. Theorems (2)

Trade considerations: A large exporting country that is prohibited from using tariffs will maximize welfare by setting the environmental tax rate above MEC (Krutilla (1991)).

Hyp. 2: If all demand comes from Foreign, Home's welfare will be maximized by a tax rate that is higher than the MEC rate. (Null Hyp.: No tax rate above MEC causes sign. higher welfare.)

Test: The setup is identical to the previous test, except that all demand is shifted to Foreign. We analyze Home's welfare as a function different tax rates in Home. Pairwise, heteroscedastic T-tests with Bonferroni-correction show that welfare for the rate equal to MEC is lower than for the one to the right of it, significant at 99.9 percent (***).

→ *We, therefore, confirm hypothesis 2!*

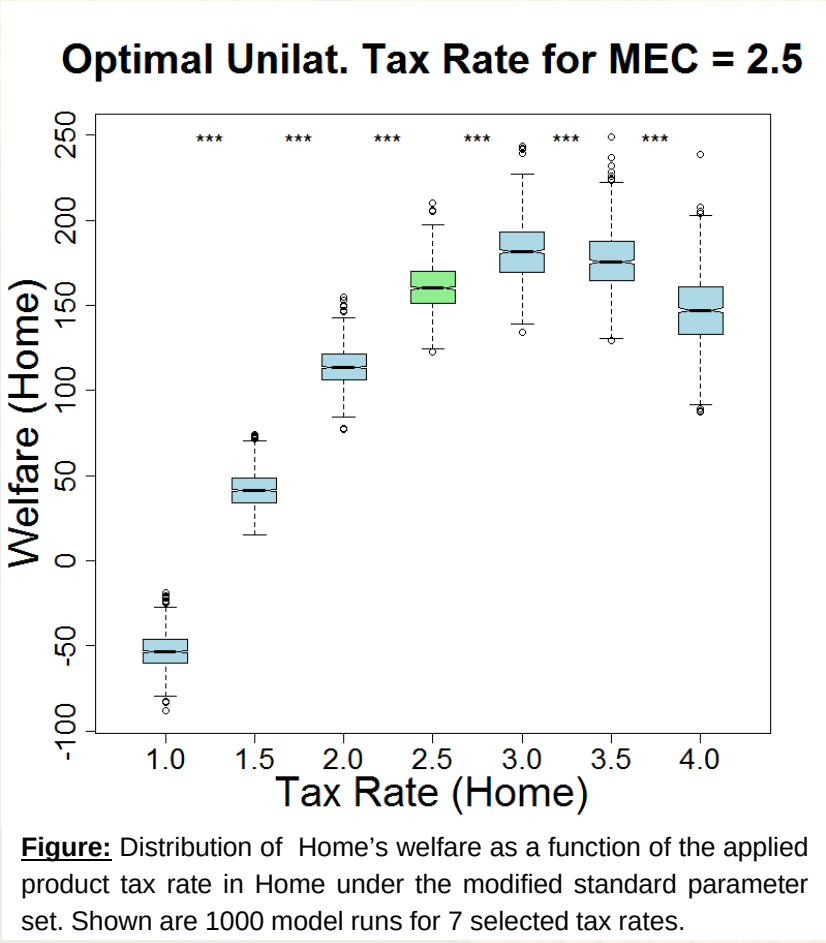
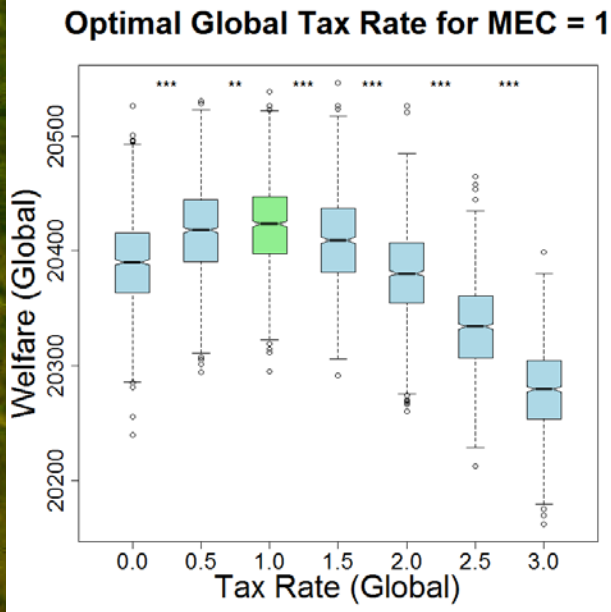
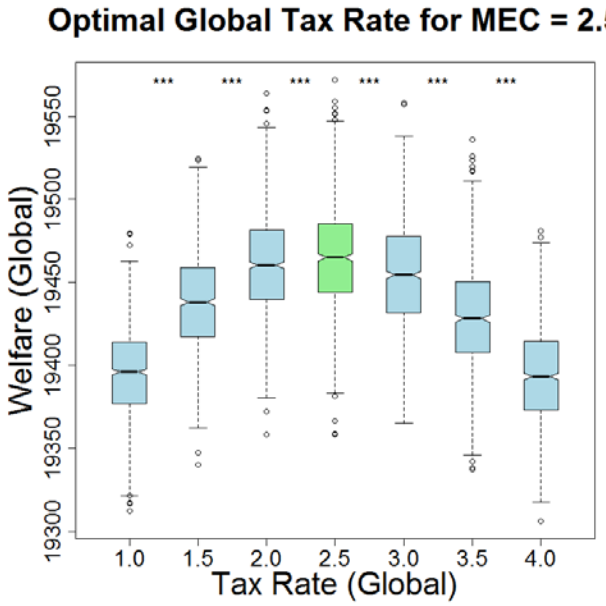
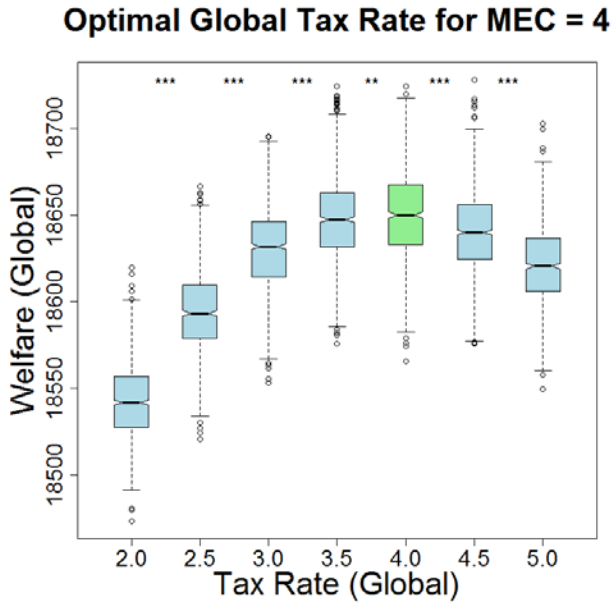


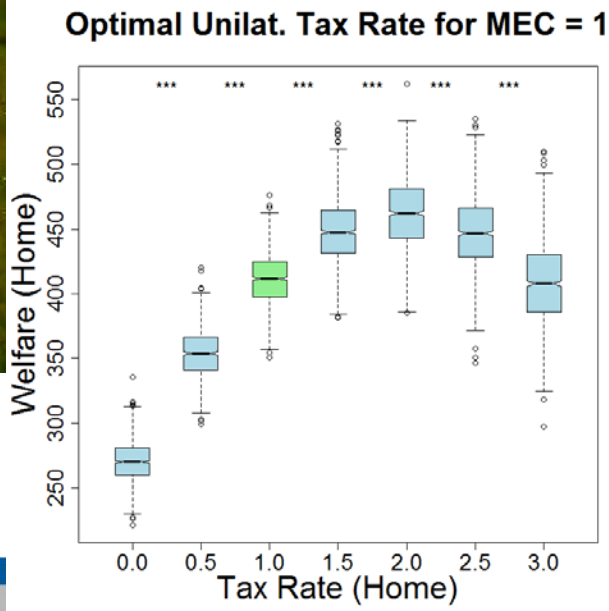
Figure: Distribution of Home's welfare as a function of the applied product tax rate in Home under the modified standard parameter set. Shown are 1000 model runs for 7 selected tax rates.

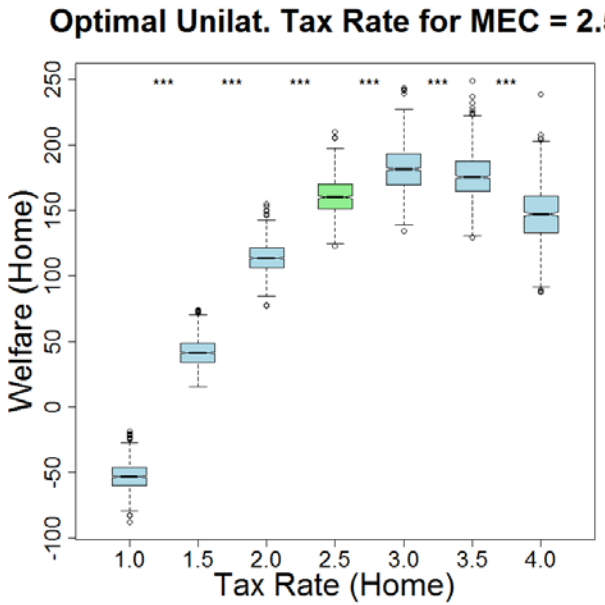
3.4 Result Comparison: Pigou (top) and Krutilla (bottom)

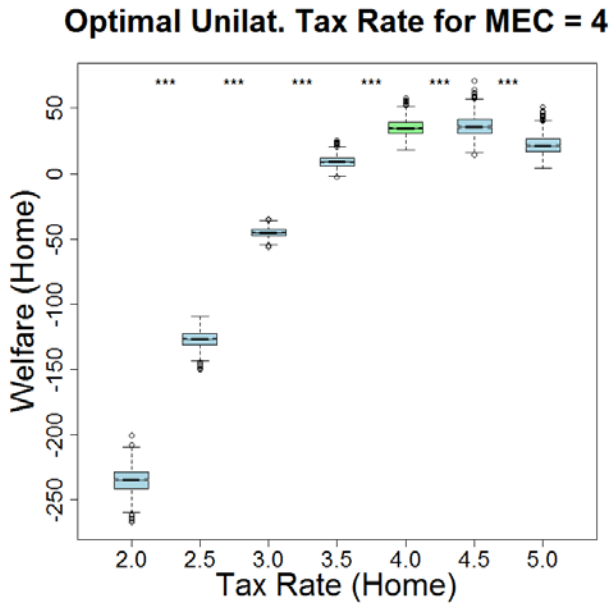












4. Policy Analyses 1: Deforestation Dynamics

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4.1 Policy Instrument Comparison 1

Question: How welfare efficient are different unilateral policy instruments in mitigating the transregional deforestation effects of unilateral BF promotion?

→ *Especially: Unilateral sustainability certification (e. g.: Art. 17 RED), which has only been subject to a limited number of theoretical analyses*

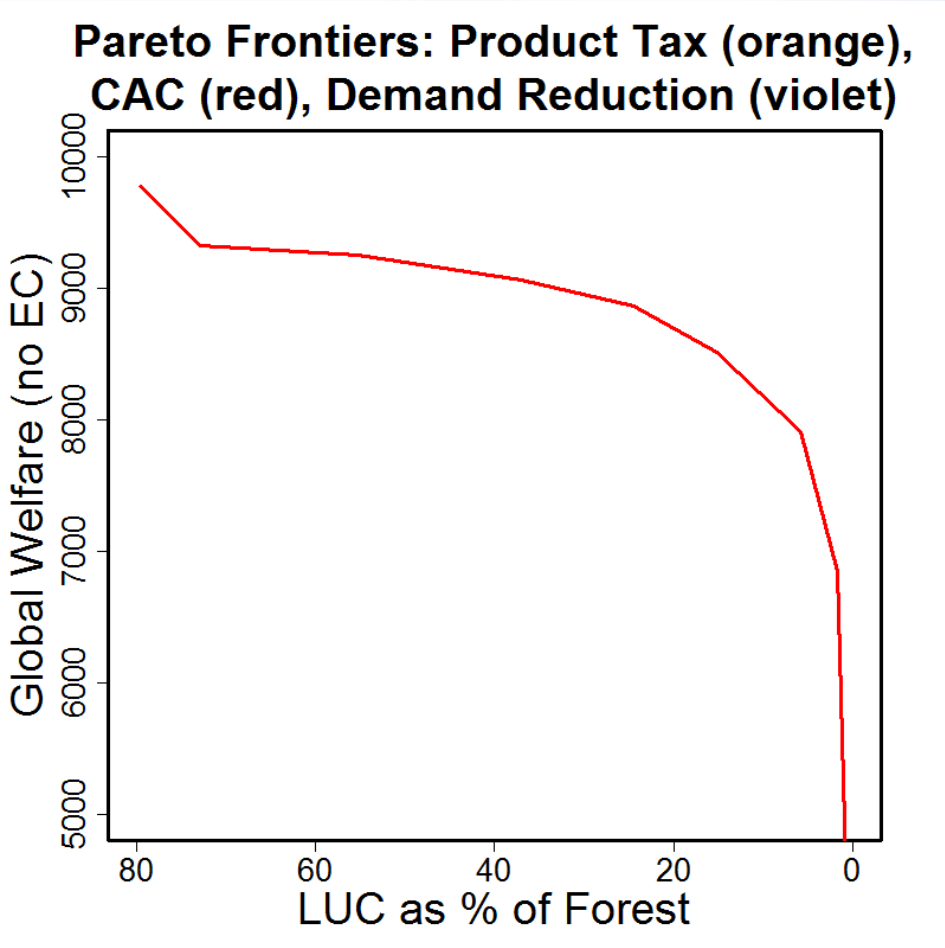
Reference Point: Global command-and-control (CAC) regulation to prevent deforestation:

- Example: Brazilian *Código Florestal*, requiring land-owners to maintain "legal reserve" of 50-80 % percent forest
- Expectations:
  - One-size-fits-all → effective, but not the most efficient instrument
  - Pareto frontier between forest conservation and welfare
  - Also constrains food production

4.1 Policy Instrument Comparison 1

Expectations:

1. CAC: global, high effectiveness, low efficiency, negative effect on food production
2. BF demand reduction: unilateral, high effectiveness, even lower efficiency, reduces pressure on food production



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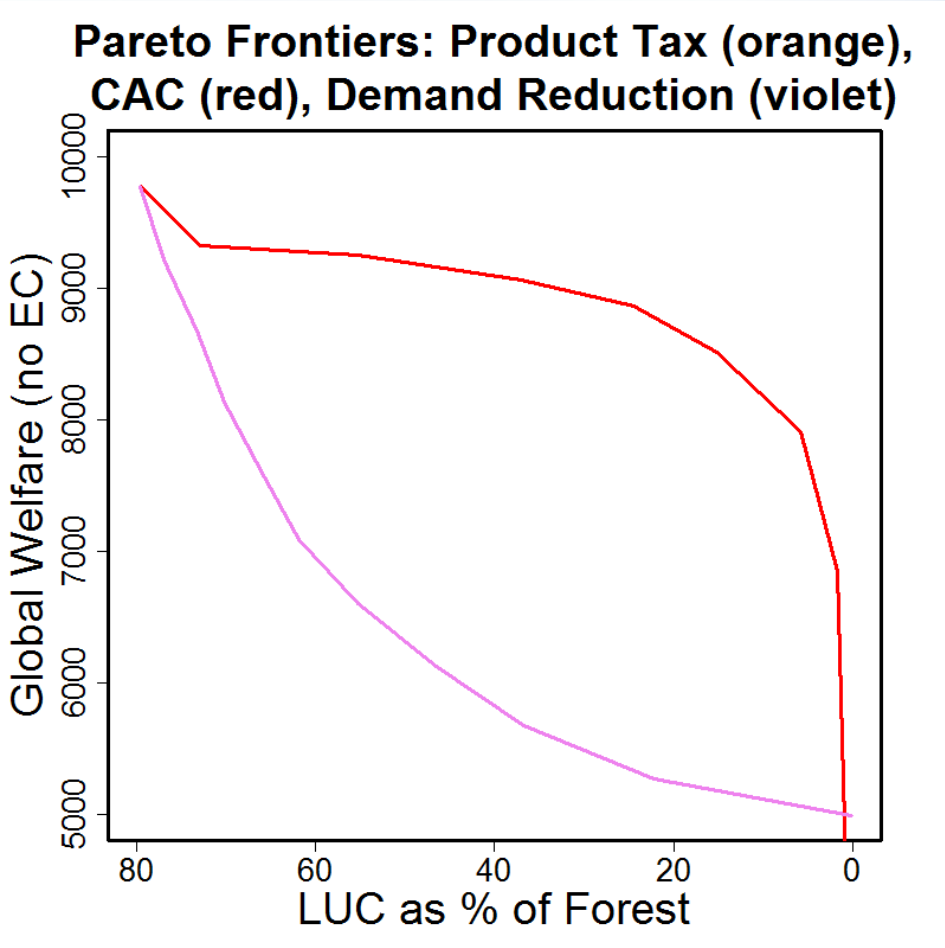
Expectations:

1. CAC: global, high effectiveness, low efficiency, negative effect on food production
2. BF demand reduction: unilateral, high effectiveness, even lower efficiency, reduces pressure on food production
3. Product tax: unilateral, limited effectiveness, higher efficiency (cost heterog.), slightly reduces pressure on food production



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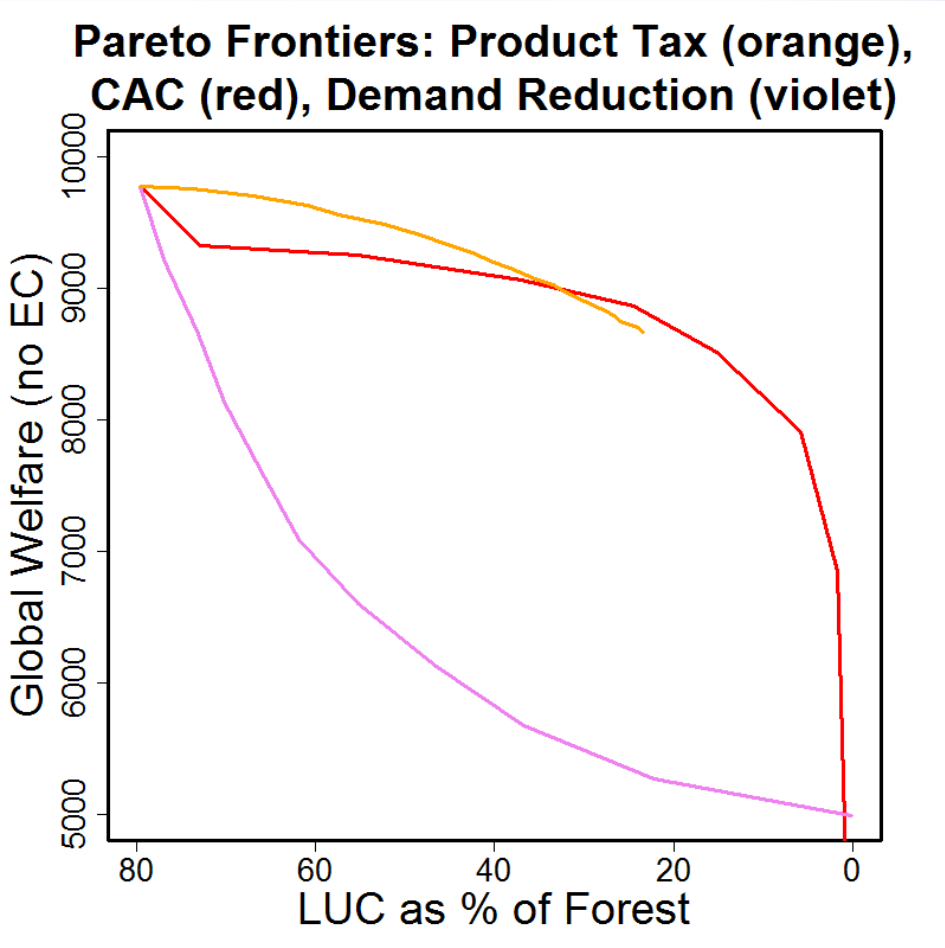
→ *Now, using the product tax as a reference …*



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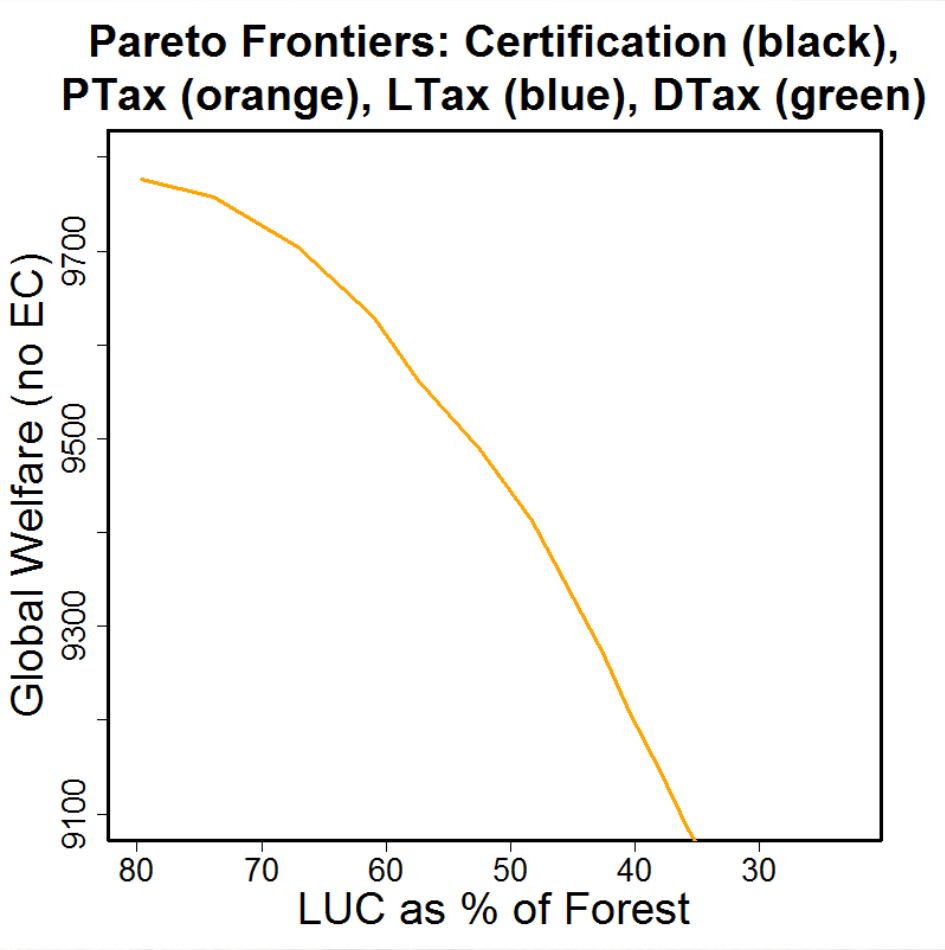
4.2 Policy Instrument Comparison 2

… we can look at additional <u>unilateral</u> policy instruments:

1. <u>Land tax:</u> Similar to product tax, but more targeted at the problem → higher efficiency



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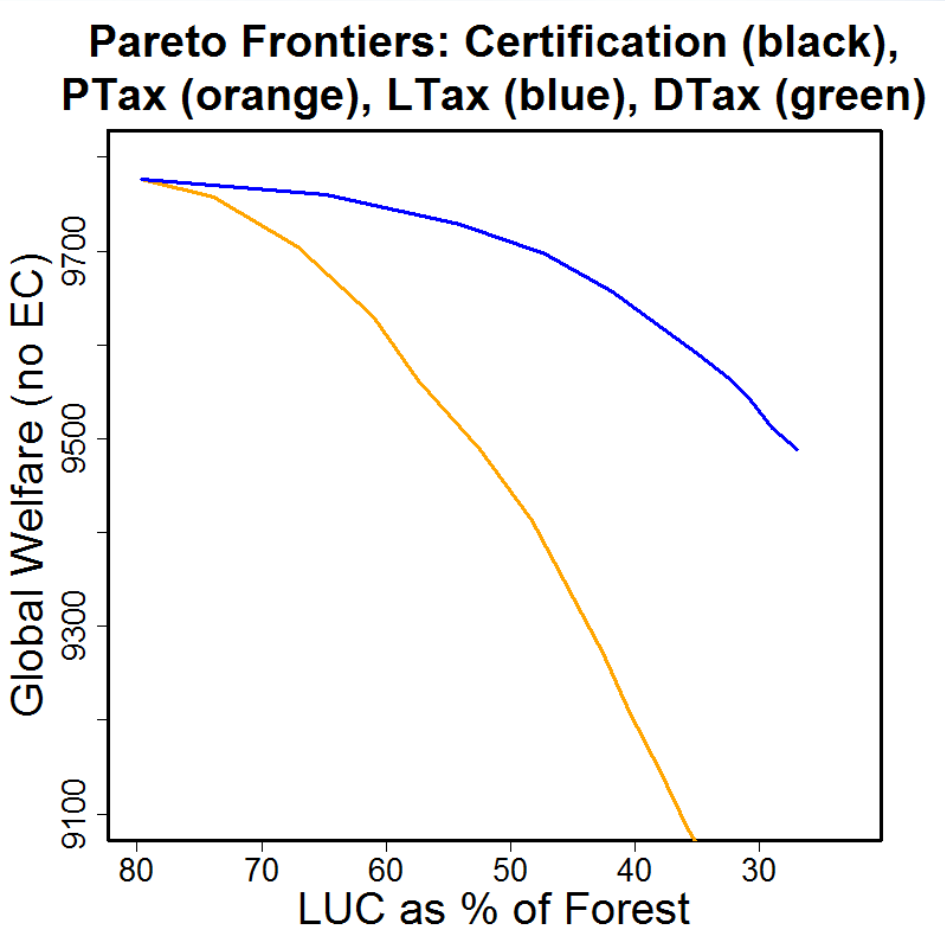
2. <u>Certification:</u> Highly targeted, but has elements of CAC (one-size-fits all) → low efficiency, little effect (iLUC)?



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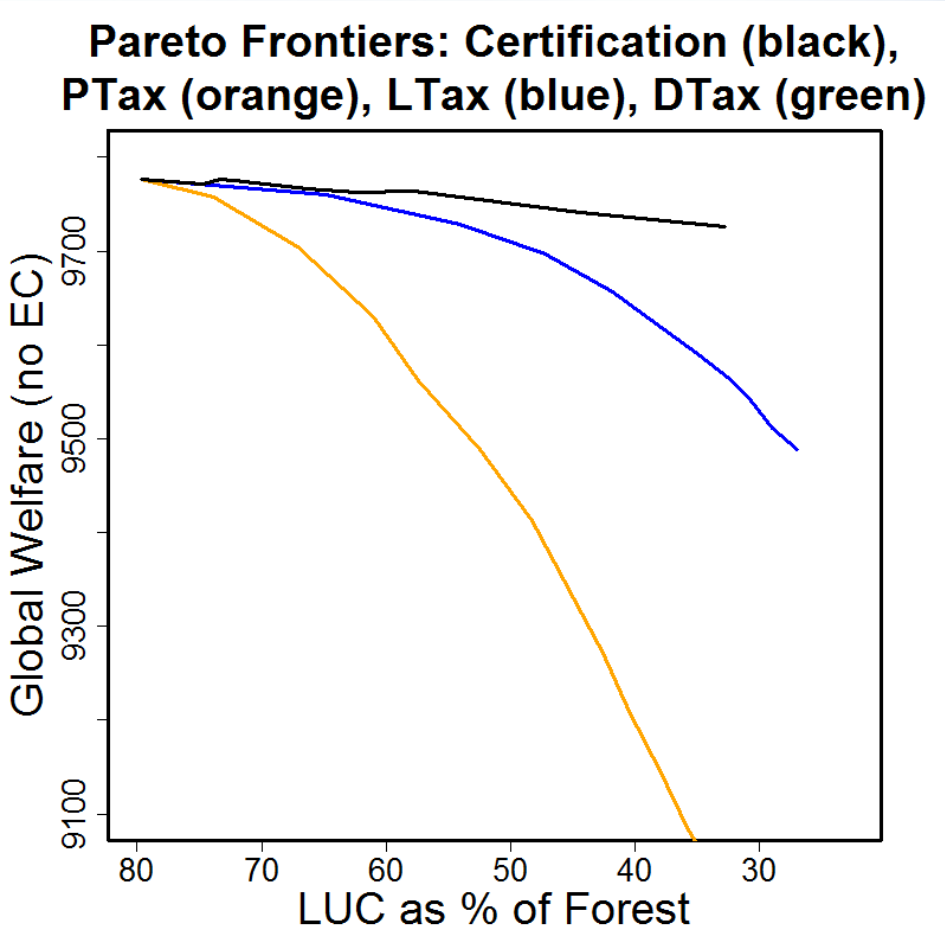

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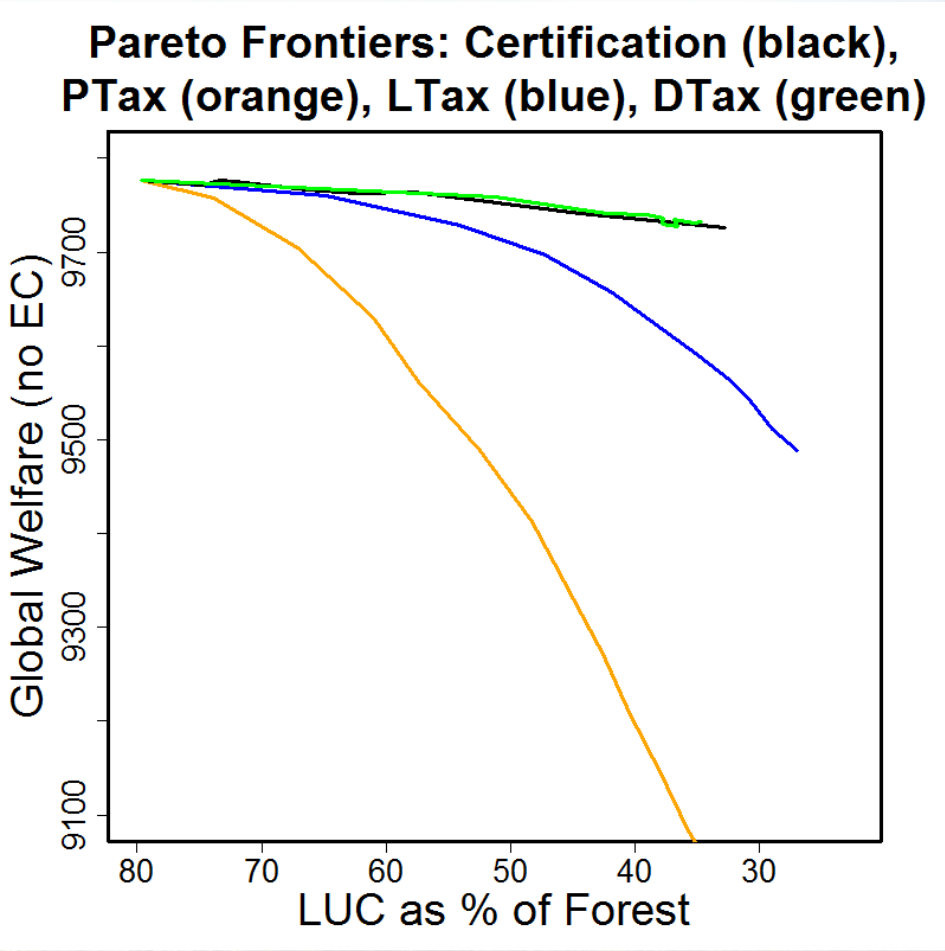
2. <u>Certification:</u> Highly targeted, but has elements of CAC (one-size-fits all) → ~~low efficiency, little effect (iLUC)?~~ → ***efficiency is higher than for most taxes!***
3. <u>Deforestation tax:</u> Highly targeted tax → highest efficiency (as expected)



4.3 Policy Instrument Comparison: Main Result

<u>Result:</u> If well implemented, sustainability certification can be effective and surprisingly efficient!

→ *<u>But:</u> Where does this efficiency come from?*

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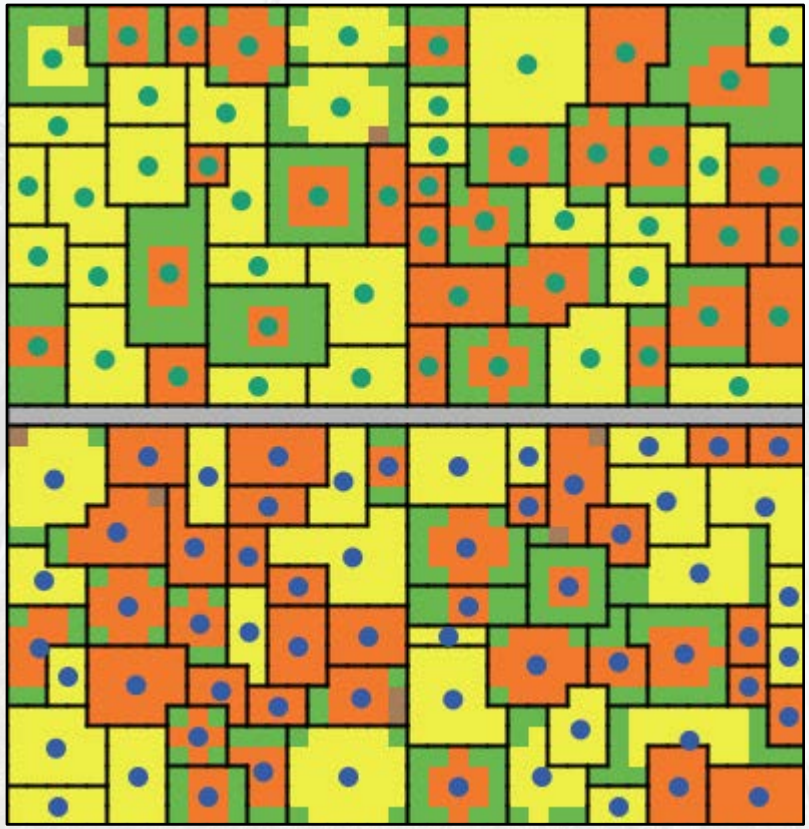
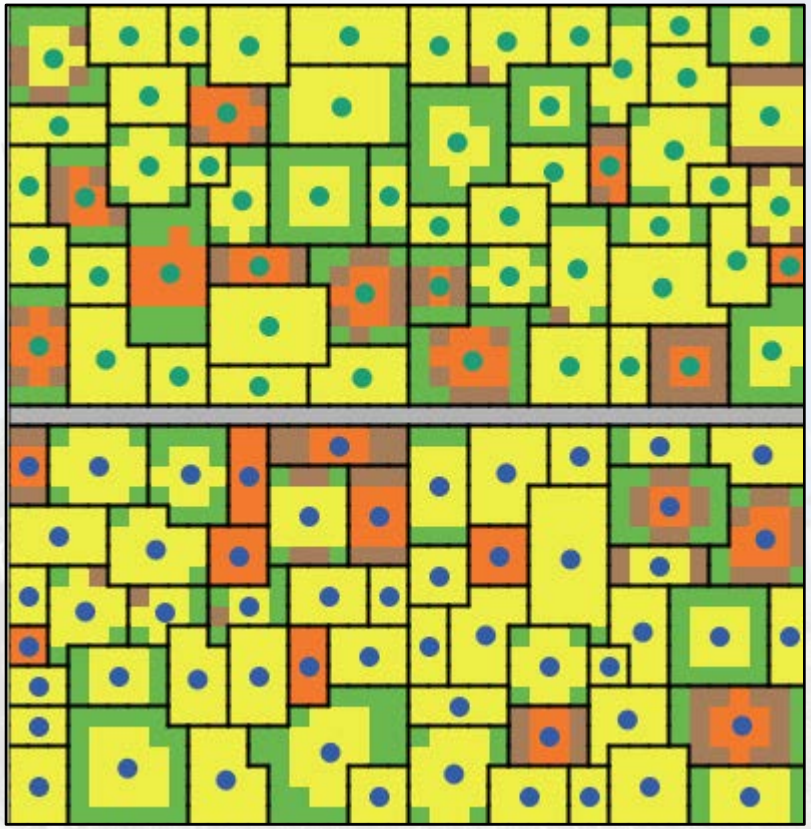
4.4 Explanation 1: Empty Land Cells

Observation: Certification causes fewer empty land cells (brown) than land tax.

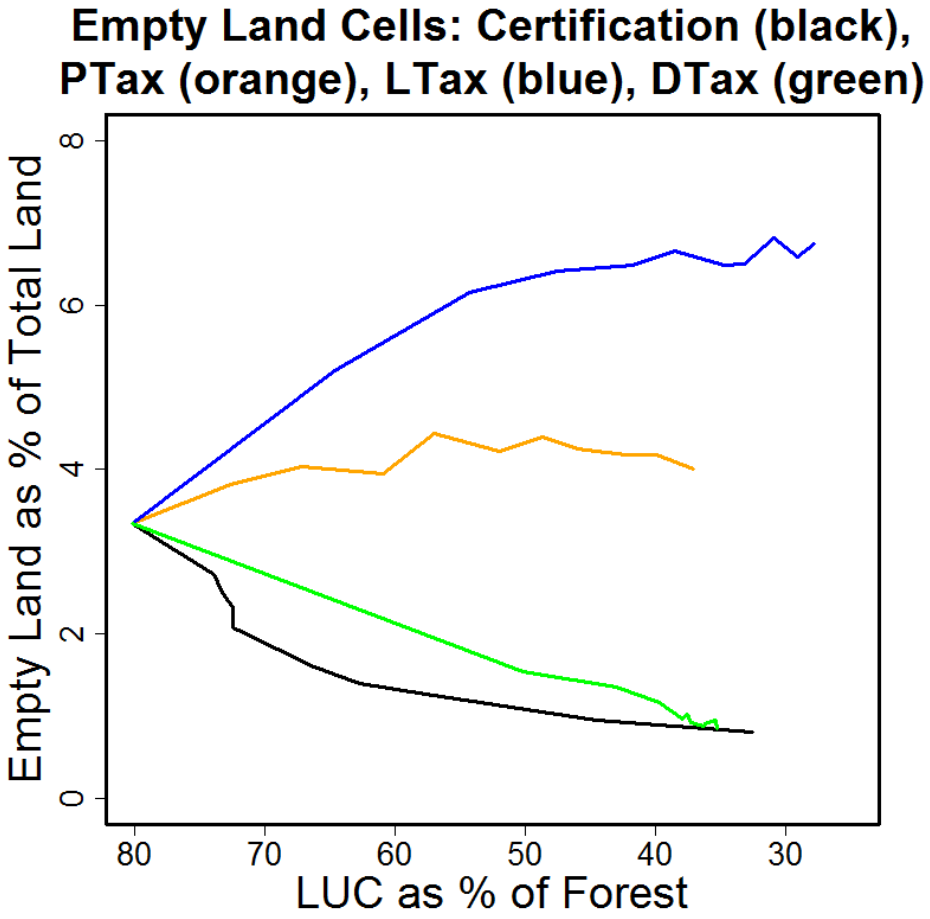


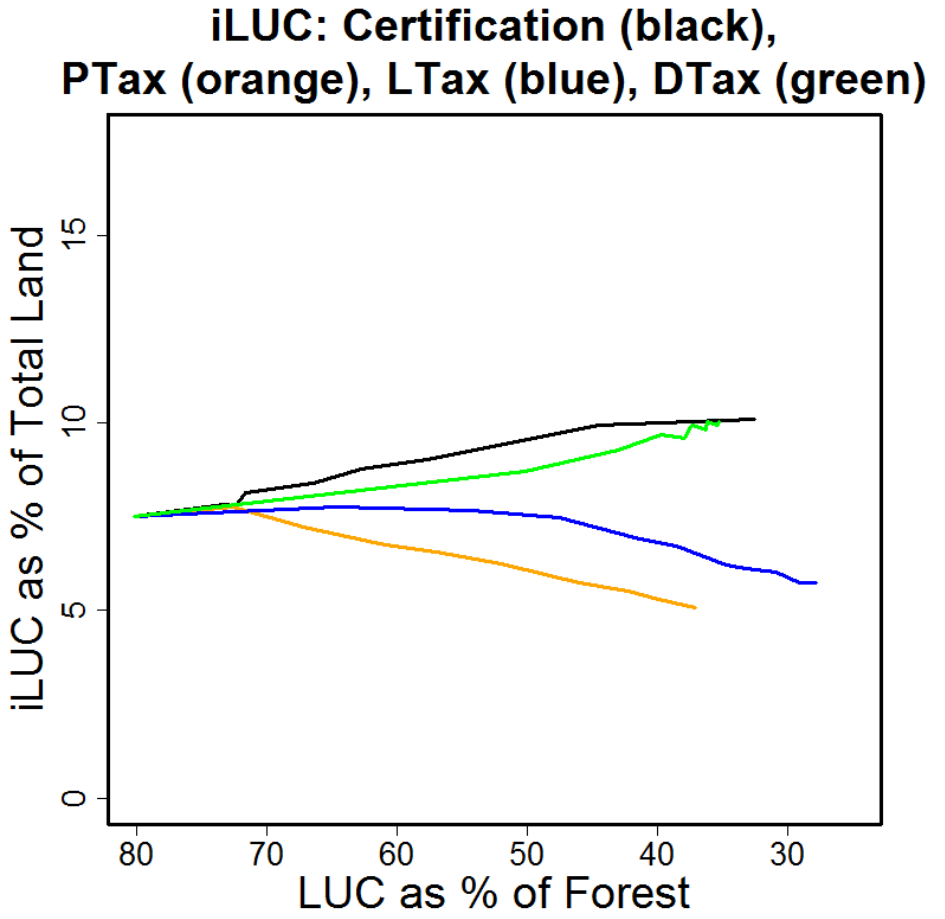
Sustainability Certification



Land Tax

4.4 Explanation 1: Empty Land Cells





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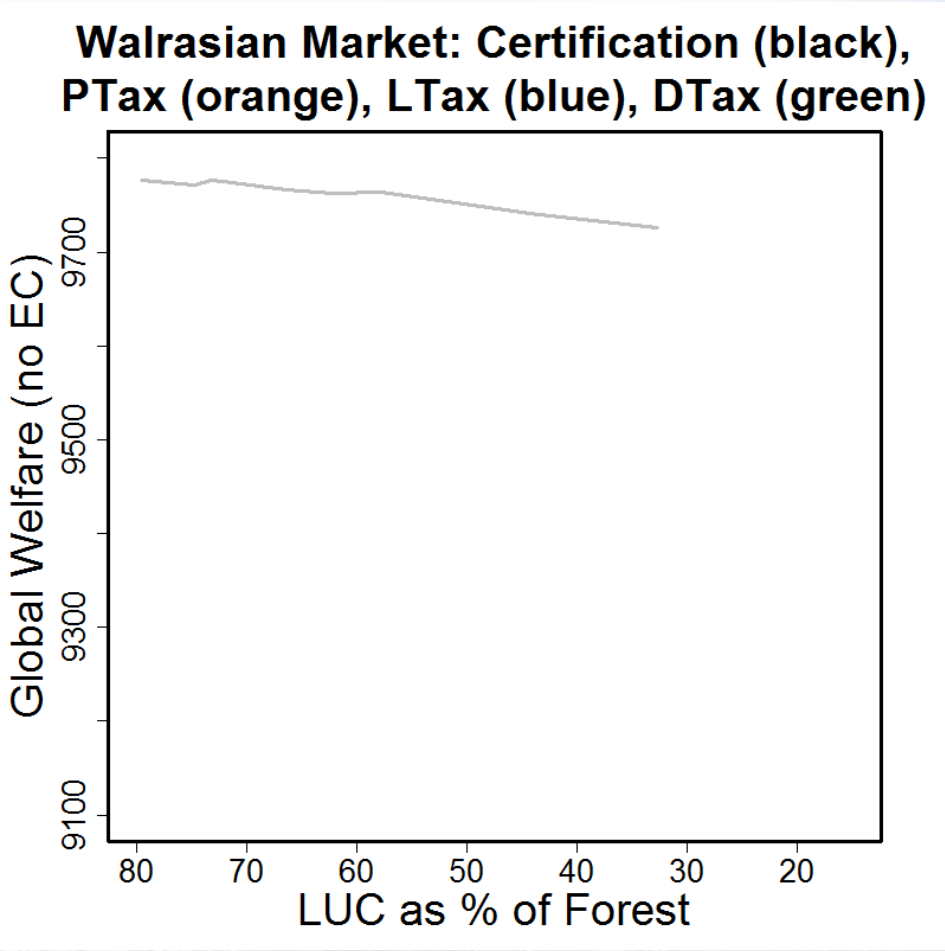
4.5 Explanation 2: Comparison of Market Mechanisms

Does this result depend completely on our assumptions about the market mechanism?

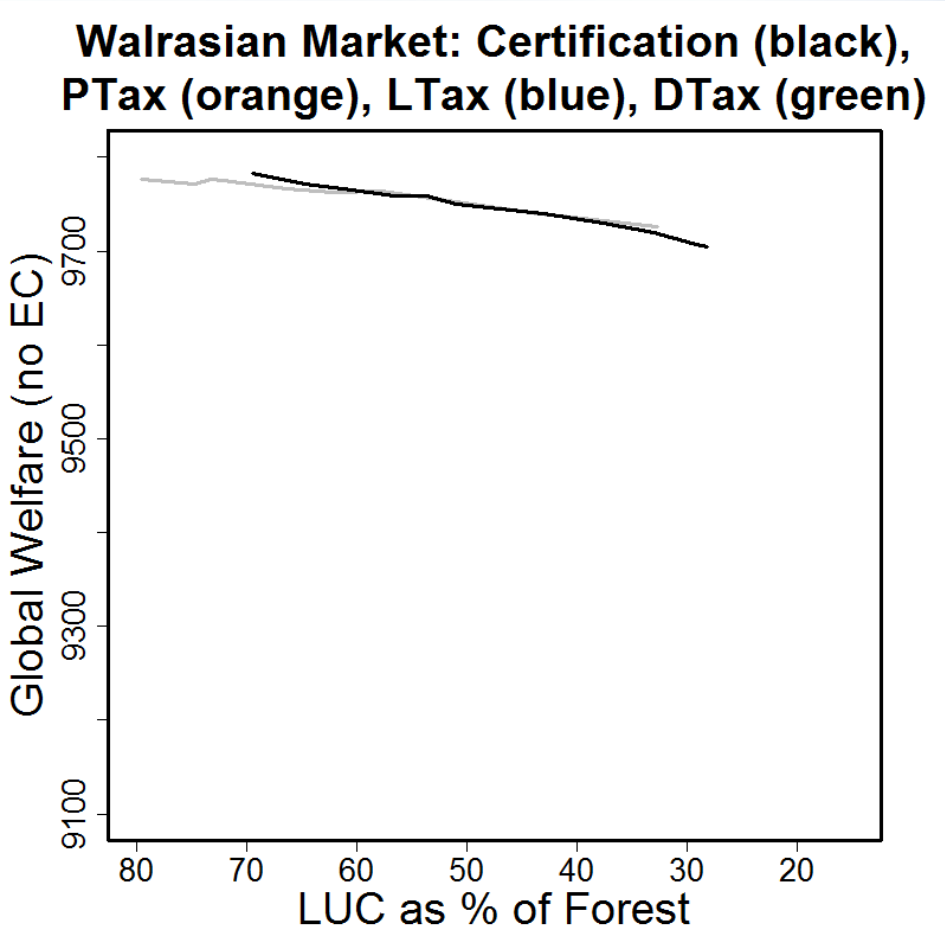
1. Certification under the sequential market mechanism as a reference point (gray)



4.5 Explanation 2: Comparison of Market Mechanisms

Does this result depend completely on our assumptions about the market mechanism?

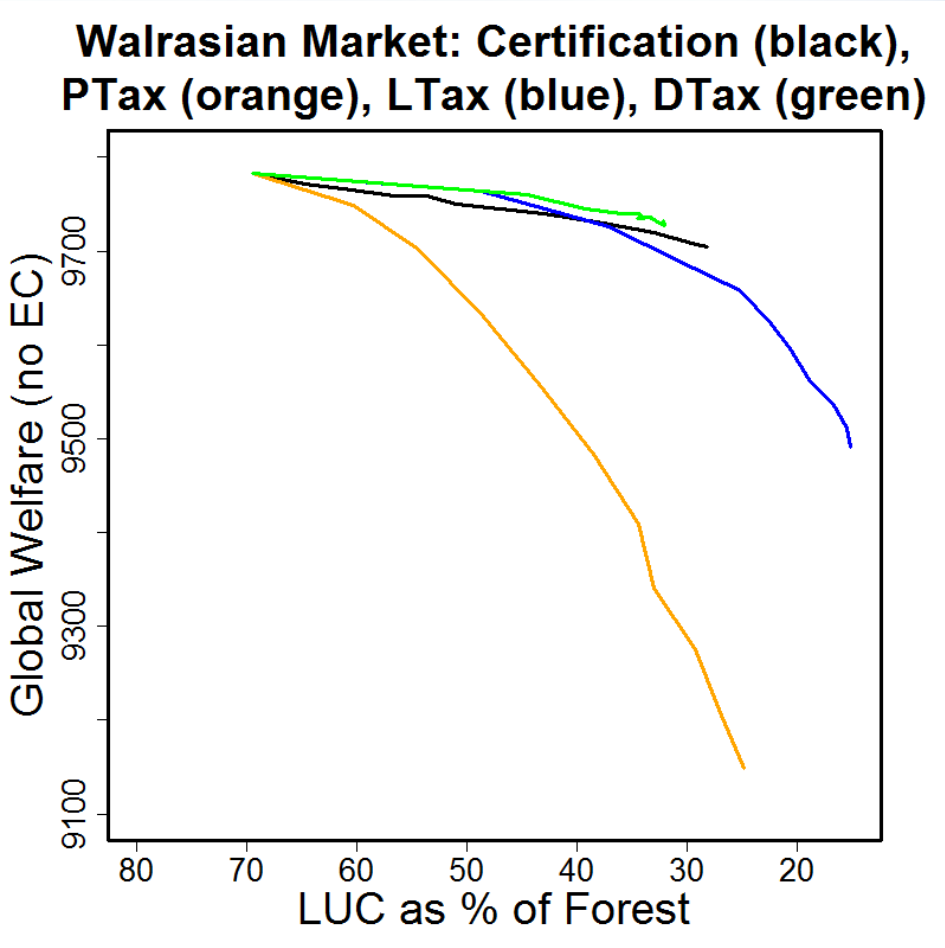
1. Certification under the sequential market mechanism as a reference point (gray)
2. Certification under a Walrasian market mechanism (black): Baseline LUC is lower, but the effect seems similar



4.5 Explanation 2: Comparison of Market Mechanisms

Does this result depend completely on our assumptions about the market mechanism?

1. Certification under the sequential market mechanism as a reference point (gray)
2. Certification under a Walrasian market mechanism (black): Baseline LUC is lower, but the effect seems similar
3. Comparison to other instruments
   → *Market mechanism is not a necessary assumption for certification efficiency, but contributes to it!*



5. Policy Analyses 2: Land Market

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5.1 Land Market: Simple vs. Art. 17 Certification

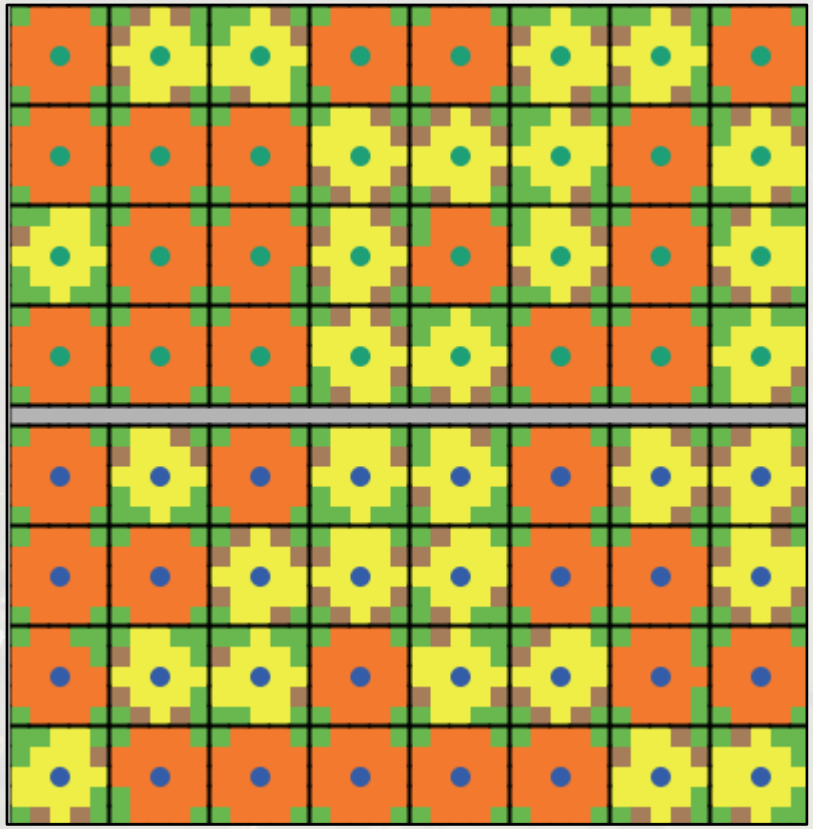
Question: How do two certification designs differ in their effect on land-use interactions?

1. Simple certification: No access to BF market, if deforestation in this time step
2. Article 17 RED certification: No access to BF market, if deforestation after a pre-specified date (here: time step of equilibrium before BF introduction)

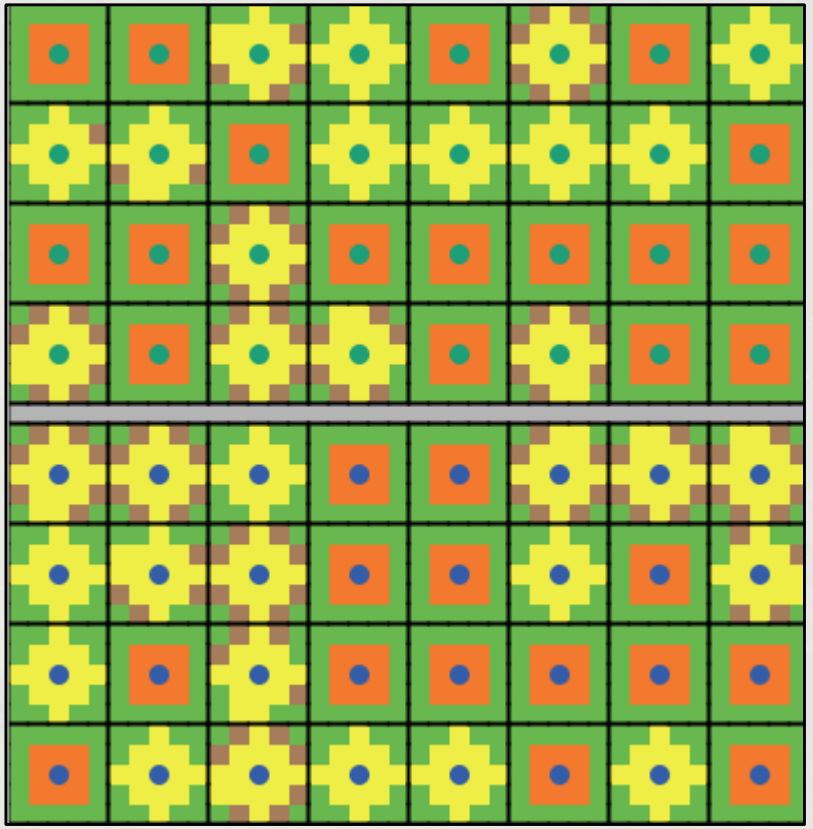
Assumptions:

- Land market: After each production period, agents can buy land cells from other agents via an endogenous auction mechanism
- Parameterization: BF has larger optimal farm scale

5.1 Simple vs. Art. 17 Certification: Before Land Market

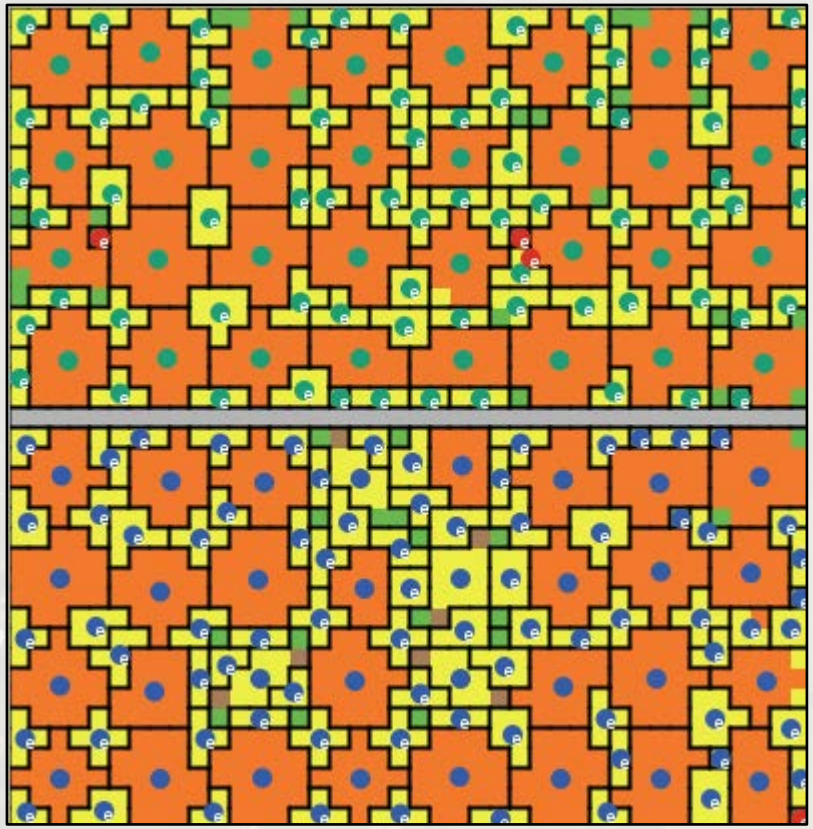


Simple Certification

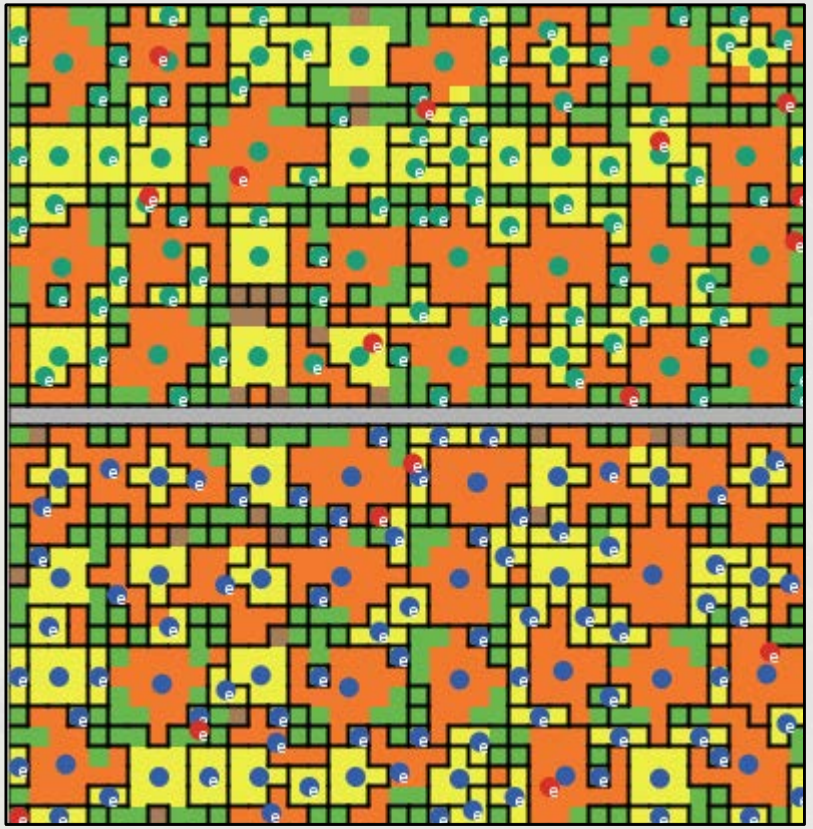


Article 17 RED Certification

5.2 Simple vs. Art. 17 Certification: After Land Market



Simple Certification



Article 17 RED Certification

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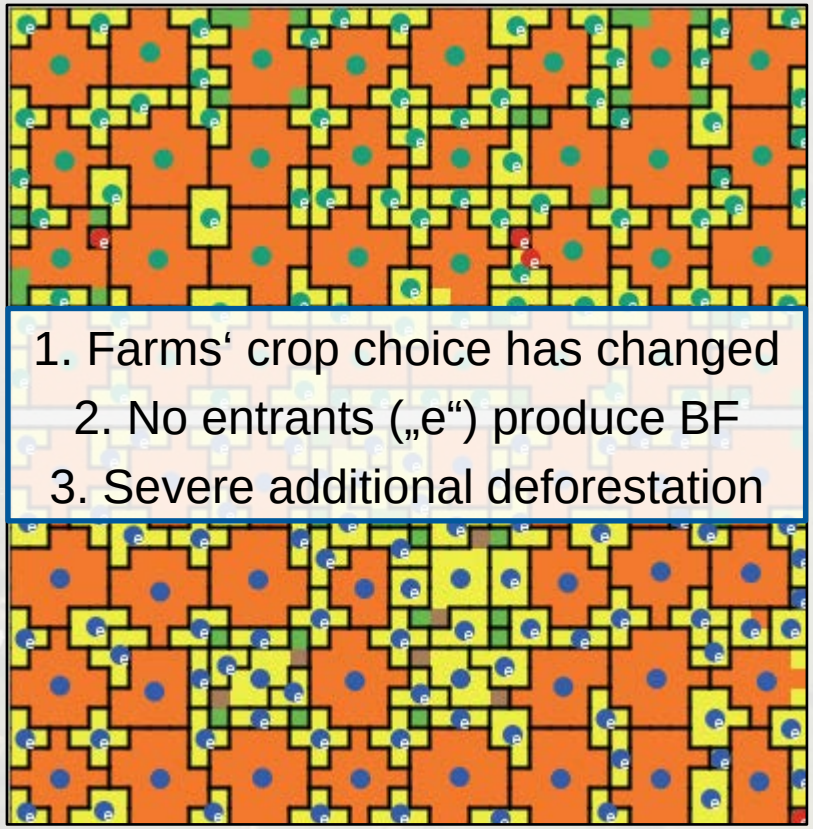
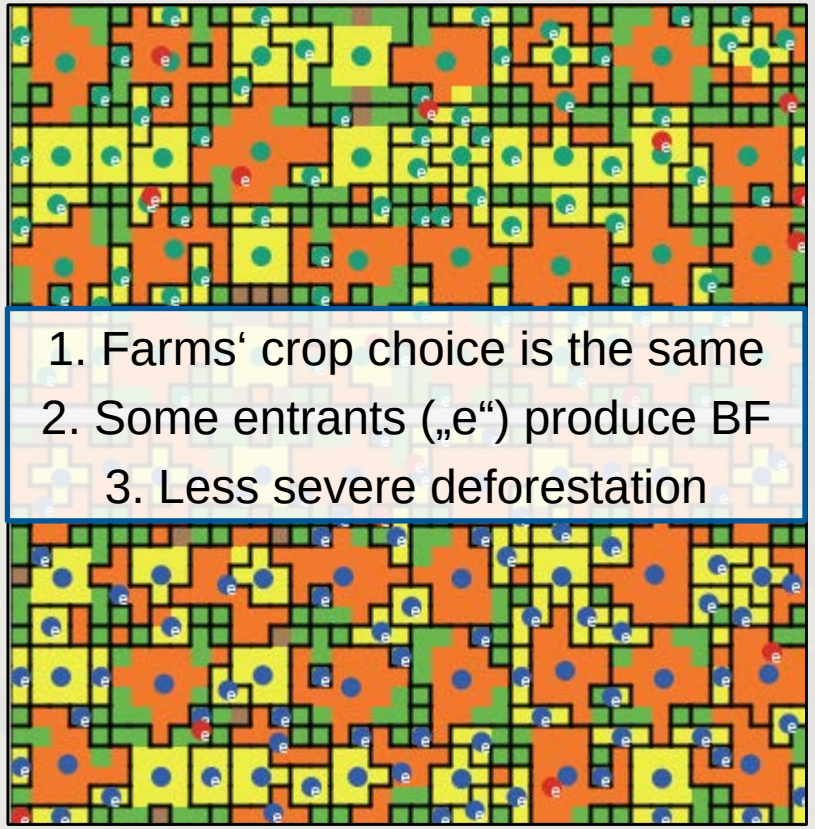
5.2 Simple vs. Art. 17 Certification: After Land Market



1. Farms‘ crop choice has changed
2. No entrants („e“) produce BF
3. Severe additional deforestation

Simple Certification



1. Farms‘ crop choice is the same
2. Some entrants („e“) produce BF
3. Less severe deforestation

Article 17 RED Certification

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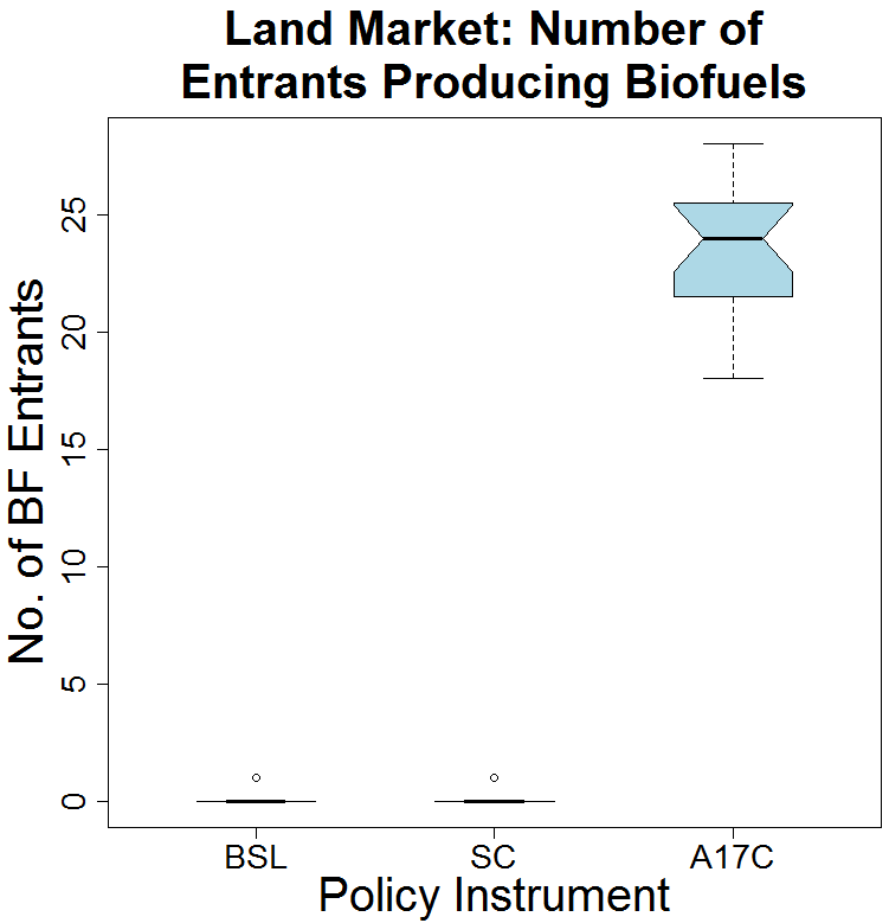
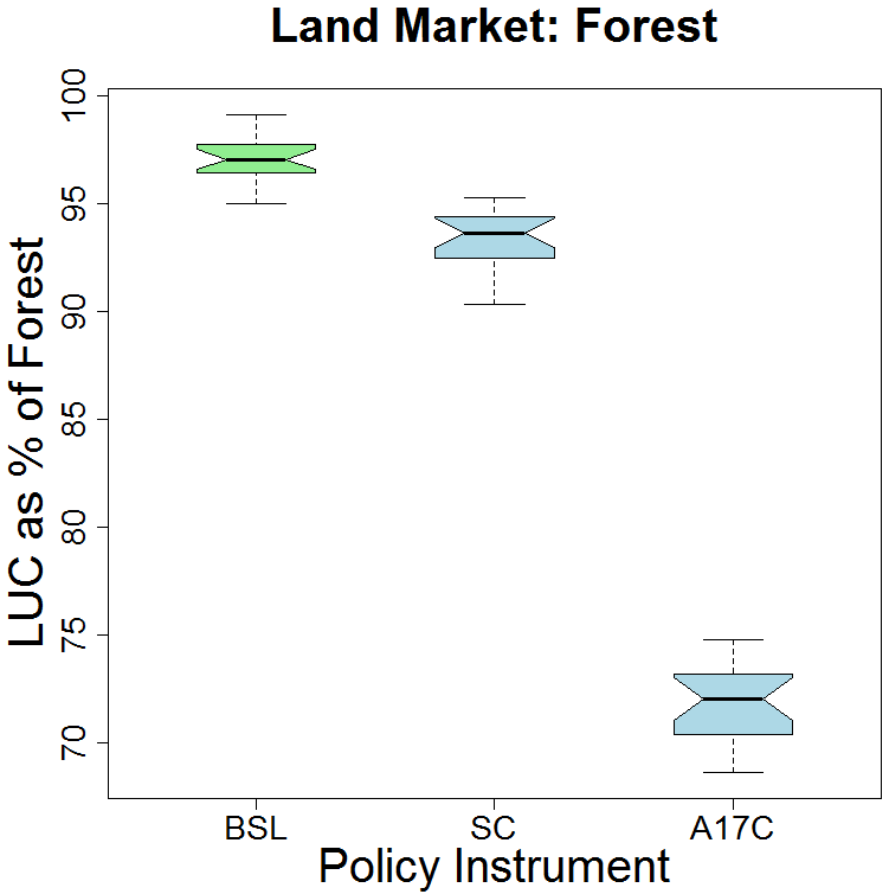
5.3 Simple vs. Art. 17 Certification: Evaluation





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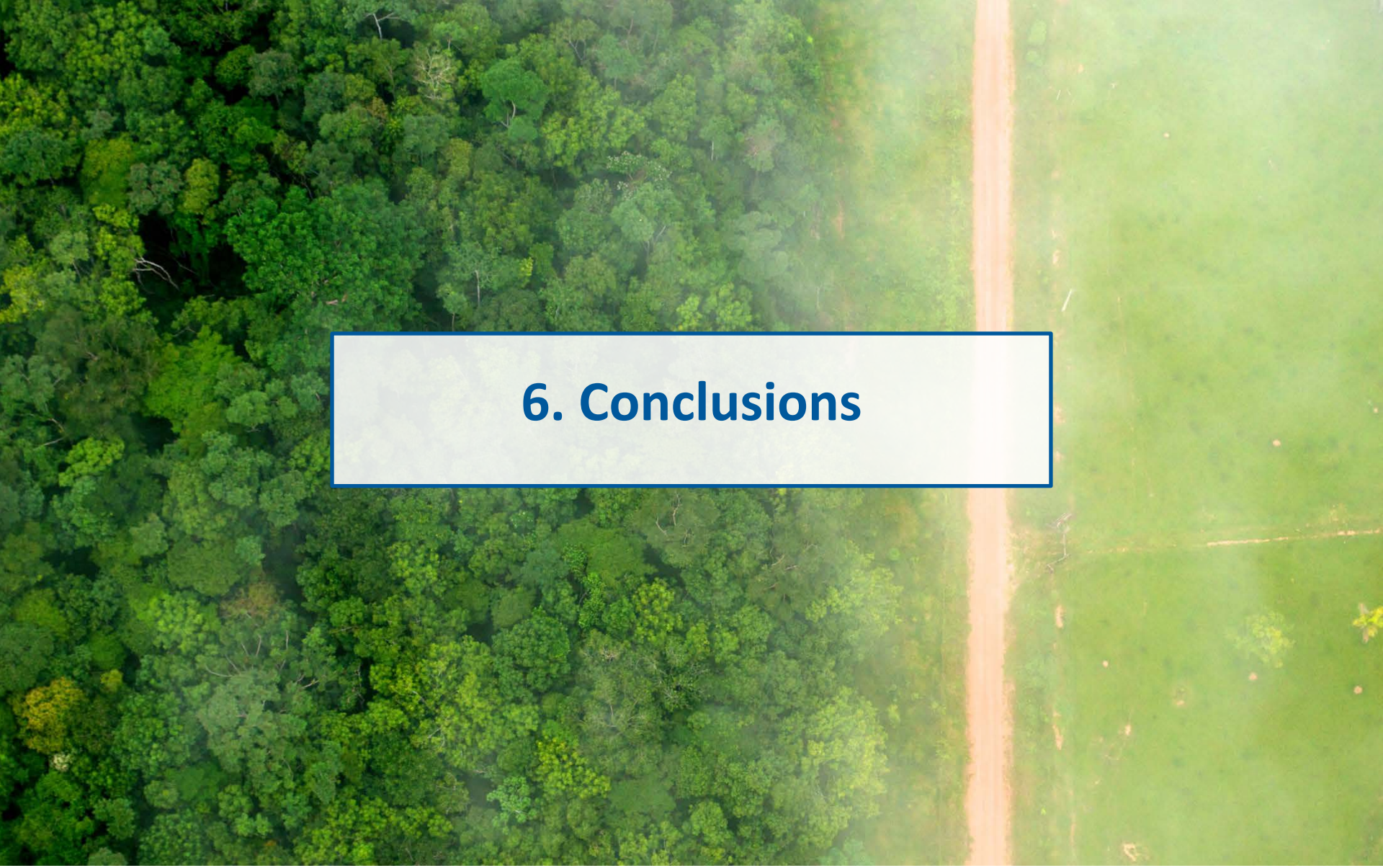

6. Conclusions

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6. Conclusions

1. Systems understanding: ILUC-MAP's agent-based representation of land-use decisions allows for detailed assessments of policy mixes that are otherwise difficult to analyze. This buttresses the recommendation by Rounsevell et al. (2013, 2014) to integrate ABMs with large-scale economic models.
2. Reliability of current policy assessments: The results suggest that the effects of BE policy mixes strongly depend on the assumptions made. Even rather small and very plausible deviations from SE assumptions might influence the hierarchy of some policy instruments.
3. Theory development: ILUC-MAP is used for additional systematic analyses of the role of dynamic market structures, heterogenous national governance environments, and spatial interactions, contributing to theory development for the integration of more realistic LUC dynamics into large-scale economic models.

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