# Modelling dynamic effects of multi-scale institutions on land use change: Electronic Supplementary Material 1

Regional Environmental Change

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# Model Regions

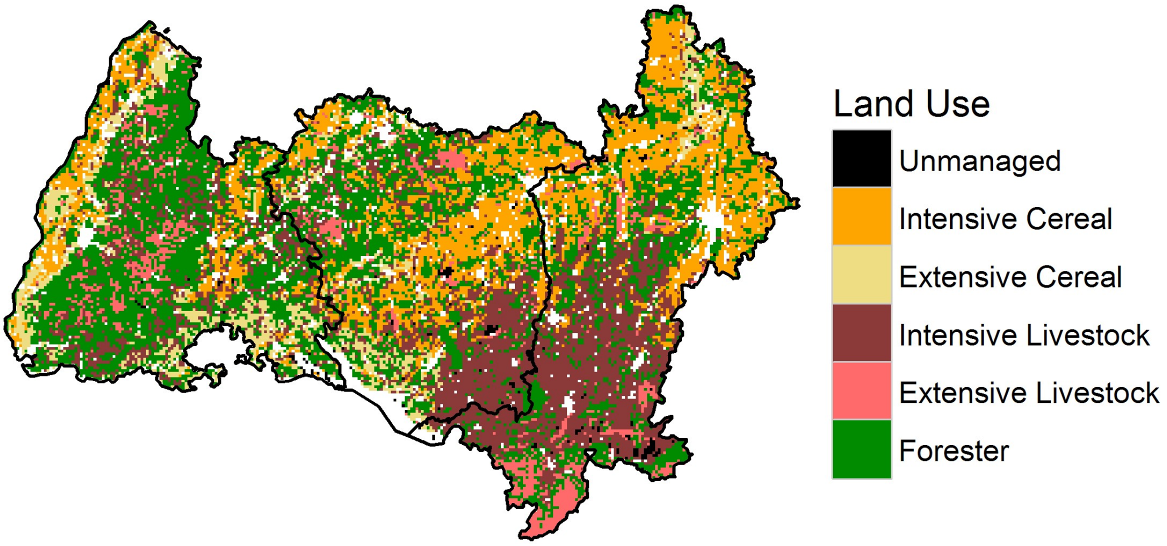



Figure 1: Model region with initial land use. Region A is on the left, Region B in the middle, and Region C on the right (divided by black lines on map).

# Agent Functional Types (AFT) Parameters

| AFT | GI | GIDistMean | GIDistSD | GU | GUDistMean | GUDistSD | Noise |
|---|---|---|---|---|---|---|---|
| **C_Cereal** | 0.1 | 0.1 | 0.3 | 0 | 0 | 0.3 | 0.1 |
| **NC_Cereal** | 1.0 | 1.0 | 0.3 | 0 | 0 | 0.3 | 0.1 |
| **C_Livestock** | 0.1 | 0.1 | 0.3 | 0 | 0 | 0.3 | 0.1 |
| **NC_Livestock** | 1.0 | 1.0 | 0.3 | 0 | 0 | 0.3 | 0.1 |
| **Forester** | 1.0 | 1.0 | 0.3 | 0 | 0 | 0.3 | 0.1 |

Table 1: AFT parameters. GU is Giving up, GI is giving in. Noise describes the maximum value of a uniform distribution (of mean 'DistMean' and standard deviation 'DistSD') which is added to the AFT's default optimal production.

# Agent Functional Types (AFT) Production

### *C_Cereal*

| X | Cprod | Fprod | Infra | Lprod | Nat | Econ | Production |
|---|---|---|---|---|---|---|---|
| **Meat** | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.000000 |
| **Cereal** | 0.8 | 0.2 | 0.5 | 0.2 | 0 | 0.5 | 1.229431 |
| **Timber** | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.000000 |

Table 2 Capital sensitivities and productivities for AFT C_Cereal (intensive cereal farming)

### *NC_Cereal*

| X | Cprod | Fprod | Infra | Lprod | Nat | Econ | Production |
|---|---|---|---|---|---|---|---|
| **Meat** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000000 |
| **Cereal** | 0.5 | 0.1 | 0.3 | 0.1 | 0.05 | 0.2 | 0.7376588 |
| **Timber** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000000 |

Table 3: Capital sensitivities and productivities for AFT NC_Cereal (extensive cereal farming)

### *C_Livestock*

| X | Cprod | Fprod | Infra | Lprod | Nat | Econ | Production |
|---|---|---|---|---|---|---|---|
| **Meat** | 0.6 | 0.2 | 0.4 | 0.5 | 0 | 0.4 | 0.8124785 |
| **Cereal** | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0000000 |
| **Timber** | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0000000 |

Table 4: Capital sensitivities and productivities for AFT C_Livestock

### *NC_Livestock*

| X | Cprod | Fprod | Infra | Lprod | Nat | Econ | Production |
|---|---|---|---|---|---|---|---|
| **Meat** | 0.3 | 0.1 | 0.2 | 0.4 | 0.05 | 0.1 | 0.4874871 |
| **Cereal** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000000 |
| **Timber** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000000 |

Table 5: Capital sensitivities and productivities for AFT NC_Livestock

### *Forester*

| X | Cprod | Fprod | Infra | Lprod | Nat | Econ | Production |
|---|---|---|---|---|---|---|---|
| **Meat** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000 |
| **Cereal** | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0000 |
| **Timber** | 0.2 | 0.6 | 0.1 | 0.2 | 0.05 | 0.1 | 8.4190 |

Table 6: Capital sensitivities and productivities for AFT Forester

# Capitals

| Capital | Identifier | Data source |
|---|---|---|
| **Crop productivity** | Cprod | DynaCLUE (Verburg and Overmars 2009)– Cropland productivity |
| **Livestock productivity** | Lprod | DynaCLUE (Verburg and Overmars 2009) – Grassland productivity |
| **Forest productivity** | Fprod | CLIMSAVE Integrated Assessment Platform (Harrison et al. 2015) – Potential wood yield |
| **Infrastructure** | Infra | DynaCLUE (Verburg and Overmars 2009) – Infrastructure |
| **Economic** | Econ | DynaCLUE (Verburg and Overmars 2009) – Economic capital |
| **Natural capital** | Nat | CLIMSAVE Integrated Assessment Platform (Harrison et al. 2015) – Natural capital |

Table 7: Capitals, their identifiers, and data source.

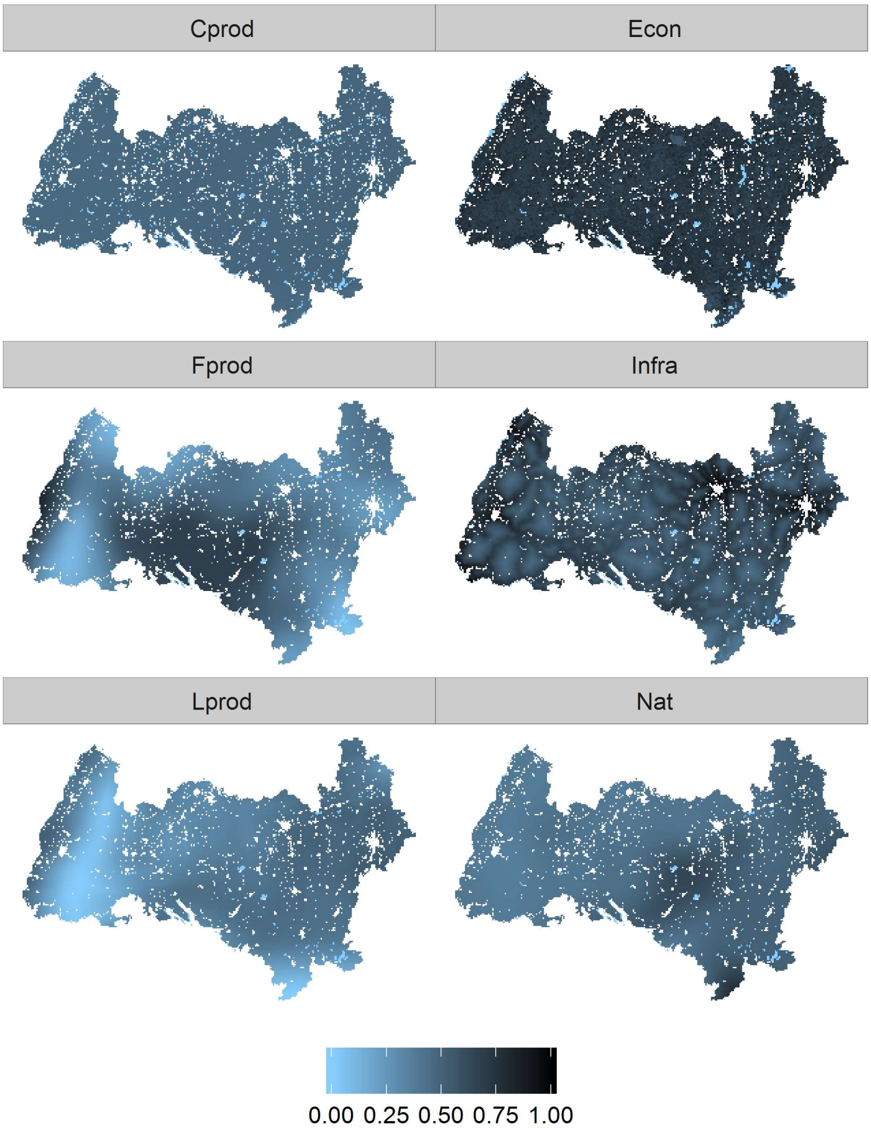



Figure 2: Initial levels of capitals. See Table 7 for description and data sources.

# Benefit Functions

| Service | Function |
|---|---|
| **Meat** | 5.90x + 0.014 |
| **Cereal** | 3.26x + 0.025 |
| **Timber** | 1.0x + 0 |

Table 8: Benefit functions (of linear form *a*x + *b*) for each considered service.

# Service Demands

Service demands for each region were set to roughly match service supply of the initial land use (based on given production functions in Table 2 to Table 6 and capitals data in Figure 2) and change over time in response to a set of scenario assumptions based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) B1.

## *Region A*

| Tick | Region | Cereal | Meat | Timber |
|---|---|---|---|---|
| **2010** | A | 1300.000 | 330.0000 | 9000.000 |
| **2011** | A | 1283.988 | 323.1846 | 9058.054 |
| **2012** | A | 1267.976 | 316.3693 | 9116.107 |
| **2013** | A | 1251.964 | 309.5539 | 9174.161 |
| **2014** | A | 1235.952 | 302.7386 | 9232.215 |
| **2015** | A | 1219.940 | 295.9232 | 9290.268 |
| **2016** | A | 1203.927 | 289.1079 | 9348.322 |
| **2017** | A | 1187.915 | 282.2925 | 9406.375 |
| **2018** | A | 1171.903 | 275.4771 | 9464.429 |
| **2019** | A | 1155.891 | 268.6618 | 9522.483 |
| **2020** | A | 1139.879 | 261.8464 | 9580.536 |
| **2021** | A | 1136.270 | 265.1137 | 9594.993 |
| **2022** | A | 1132.661 | 268.3809 | 9609.451 |
| **2023** | A | 1129.051 | 271.6481 | 9623.908 |
| **2024** | A | 1125.442 | 274.9154 | 9638.365 |
| **2025** | A | 1121.833 | 278.1826 | 9652.822 |
| **2026** | A | 1118.224 | 281.4498 | 9667.279 |
| **2027** | A | 1114.614 | 284.7170 | 9681.736 |
| **2028** | A | 1111.005 | 287.9843 | 9696.193 |
| **2029** | A | 1107.396 | 291.2515 | 9710.651 |
| **2030** | A | 1103.787 | 294.5187 | 9725.108 |
| **2031** | A | 1102.616 | 292.5863 | 9725.510 |
| **2032** | A | 1101.446 | 290.6539 | 9725.912 |
| **2033** | A | 1100.275 | 288.7215 | 9726.314 |
| **2034** | A | 1099.105 | 286.7891 | 9726.716 |
| **2035** | A | 1097.934 | 284.8567 | 9727.118 |
| **2036** | A | 1096.763 | 282.9243 | 9727.520 |
| **2037** | A | 1095.593 | 280.9919 | 9727.921 |
| **2038** | A | 1094.422 | 279.0595 | 9728.323 |
| **2039** | A | 1093.252 | 277.1271 | 9728.725 |
| **2040** | A | 1092.081 | 275.1947 | 9729.127 |

Table 9: Demands for Services per year in region A. Values for 2010 are chosen to approach the supply of initial land use, and trends resemble those of IPCC scenario B1.

### *Region B*

| Tick | Region | Cereal | Meat | Timber |
|---|---|---|---|---|
| **2010** | B | 950.0000 | 550.0000 | 9400.000 |
| **2011** | B | 938.2989 | 538.6411 | 9460.634 |
| **2012** | B | 926.5977 | 527.2821 | 9521.268 |
| **2013** | B | 914.8966 | 515.9232 | 9581.901 |
| **2014** | B | 903.1954 | 504.5643 | 9642.535 |
| **2015** | B | 891.4943 | 493.2054 | 9703.169 |
| **2016** | B | 879.7932 | 481.8464 | 9763.803 |
| **2017** | B | 868.0920 | 470.4875 | 9824.437 |
| **2018** | B | 856.3909 | 459.1286 | 9885.070 |
| **2019** | B | 844.6898 | 447.7696 | 9945.704 |
| **2020** | B | 832.9886 | 436.4107 | 10006.338 |
| **2021** | B | 830.3511 | 441.8561 | 10021.438 |
| **2022** | B | 827.7136 | 447.3015 | 10036.537 |
| **2023** | B | 825.0761 | 452.7469 | 10051.637 |
| **2024** | B | 822.4385 | 458.1923 | 10066.737 |
| **2025** | B | 819.8010 | 463.6376 | 10081.836 |
| **2026** | B | 817.1635 | 469.0830 | 10096.936 |
| **2027** | B | 814.5260 | 474.5284 | 10112.036 |
| **2028** | B | 811.8885 | 479.9738 | 10127.135 |
| **2029** | B | 809.2509 | 485.4192 | 10142.235 |
| **2030** | B | 806.6134 | 490.8646 | 10157.335 |
| **2031** | B | 805.7580 | 487.6439 | 10157.755 |
| **2032** | B | 804.9026 | 484.4232 | 10158.174 |
| **2033** | B | 804.0472 | 481.2026 | 10158.594 |
| **2034** | B | 803.1918 | 477.9819 | 10159.014 |
| **2035** | B | 802.3364 | 474.7612 | 10159.434 |
| **2036** | B | 801.4810 | 471.5406 | 10159.854 |
| **2037** | B | 800.6256 | 468.3199 | 10160.274 |
| **2038** | B | 799.7702 | 465.0992 | 10160.693 |
| **2039** | B | 798.9148 | 461.8786 | 10161.113 |
| **2040** | B | 798.0594 | 458.6579 | 10161.533 |

Table 10: Demands for Services per year in region B. Values for 2010 are chosen to approach the supply of initial land use, and trends resemble those of IPCC scenario B1.

### *Region C*

| Tick | Region | Cereal | Meat | Timber |
|---|---|---|---|---|
| **2010** | C | 950.0000 | 630.0000 | 10000.00 |
| **2011** | C | 938.2989 | 616.9889 | 10064.50 |
| **2012** | C | 926.5977 | 603.9777 | 10129.01 |
| **2013** | C | 914.8966 | 590.9666 | 10193.51 |
| **2014** | C | 903.1954 | 577.9555 | 10258.02 |
| **2015** | C | 891.4943 | 564.9443 | 10322.52 |
| **2016** | C | 879.7932 | 551.9332 | 10387.02 |
| **2017** | C | 868.0920 | 538.9221 | 10451.53 |
| **2018** | C | 856.3909 | 525.9109 | 10516.03 |
| **2019** | C | 844.6898 | 512.8998 | 10580.54 |
| **2020** | C | 832.9886 | 499.8886 | 10645.04 |
| **2021** | C | 830.3511 | 506.1261 | 10661.10 |
| **2022** | C | 827.7136 | 512.3635 | 10677.17 |
| **2023** | C | 825.0761 | 518.6010 | 10693.23 |
| **2024** | C | 822.4385 | 524.8384 | 10709.29 |
| **2025** | C | 819.8010 | 531.0758 | 10725.36 |
| **2026** | C | 817.1635 | 537.3133 | 10741.42 |
| **2027** | C | 814.5260 | 543.5507 | 10757.48 |
| **2028** | C | 811.8885 | 549.7882 | 10773.55 |
| **2029** | C | 809.2509 | 556.0256 | 10789.61 |
| **2030** | C | 806.6134 | 562.2630 | 10805.68 |
| **2031** | C | 805.7580 | 558.5739 | 10806.12 |
| **2032** | C | 804.9026 | 554.8848 | 10806.57 |
| **2033** | C | 804.0472 | 551.1957 | 10807.02 |
| **2034** | C | 803.1918 | 547.5065 | 10807.46 |
| **2035** | C | 802.3364 | 543.8174 | 10807.91 |
| **2036** | C | 801.4810 | 540.1283 | 10808.36 |
| **2037** | C | 800.6256 | 536.4392 | 10808.80 |
| **2038** | C | 799.7702 | 532.7500 | 10809.25 |
| **2039** | C | 798.9148 | 529.0609 | 10809.69 |
| **2040** | C | 798.0594 | 525.3718 | 10810.14 |

Table 11: Demands for Services per year in region C. Values for 2010 are chosen to approach the supply of initial land use, and trends resemble those of IPCC scenario B1.

## Institutional Preferences

| | Institution's preference weight | Regional Institution's preference weight |
|---|---|---|
| **LOW_COST** | 0.4 | 0.5 |
| **GLOBAL_DEMAND_MATCHING** | 1.0 | 1.0 |
| **SOCIAL_APPROVAL** | 0.9 | 0.9 |

Table 12: Institutional agents' preference weights.

# Actions

| Action | Effect | Preferences | Calculation | Annotations |
|---|---|---|---|---|
| **GlobalSubsidyPa (_Cereal / _Clivestock / _NCCereal / _NCLivestock / _Forester)** | Increase all land managers competitive-ness by {subsidy rate} | LOW_COST | 0.5 / 0.5 / 0.3 / 0.3 / 0.5 | Fixed |
| | | GLOBAL_DEMAND_MATCHING | $\frac{1}{\lvert S_{sub}\rvert}\sum_{s\in S_{sub}} w_{pc}\frac{n_{pc}}{n_g}+\left(\frac{d_s^g-s_s^g}{d_s^g\max_{z\in S}\left(\frac{d_z^g-s_z^g}{d_z^g}\right)}\right)c_s^{sub}f^{sub}\frac{\sum_{f\in FR_{sub}}p_s^f}{\sum_{f\in FR}p_s^f}$ | Average of subsidised services of proportion of all cells that potentially could take over when subsidised (reach) plus demand supply gap (importance) times subsidies times proportion of optimal production of subsidised (effect) |
| | | SOCIAL_APPROVAL | $\min\left(1,\frac{n_{pc}}{n_w}\right)\{0.5/0.7/0.5/0.7/0.5\}$ | The more land manager benefit, the higher, multiplied by AFT-specific factor |
| **RegionalSubsidyPa (_Cereal / _Clivestock / _NCCereal / _NCLivestock / _Forester)** | Increase regional land managers competitiveness by {subsidy rate} | LOW_COST | 0.6 | Fixed |
| | | REGIONAL_DEMAND_MATCHING | $\frac{1}{\lvert S_{sub}\rvert}\sum_{s\in S_{sub}} w_{pc}\frac{n_{pc}}{n_R}+\left(\frac{d_s^r-s_s^r}{d_s^r\max_{z\in S}\left(\frac{d_z^r-s_z^r}{d_z}\right)}\right)c_s^{sub}f^{sub}\frac{\sum_{f\in FR}}{\sum_{f\in F}}$ | Average of subsidised services of proportion of regional cells that potentially could take over when subsidised plus demand supply gap times subsidies times proportion of optimal production of subsidised FR |
| | | SOCIAL_APPROVAL | $\min\left(1,\frac{n_{pc}}{n_w}\right)0.5$ | The more land manager benefit, the higher |
| **DoNothing** | No effect | LOW_COST | 1 | Fixed |
| | | REGIONAL_DEMAND_MATCHING | 0 | Fixed |
| | | SOCIAL_APPROVAL | 0.4 (global) / 0.3 (regional) | Fixed |

Table 13: Institutions' potential actions, the action's effect when performed, the way their utilities towards institutions' preferences are calculated, and according explanation. Terms in parenthesis in the first column indicate that there is one action for each term, in these cases functional roles of land managers.

## Evaluation of Potential Actions

| | | **Global Subsidy (int. Cereal)** | | **Global Subsidy (ext. Cereal)** | |
|---|---|---|---|---|---|
| | Institution's preference weight | Current utility | Weighted utility | Current utility | Weighted utility |
| **LOW_COST** | 0.4 | 0.400 | 0.160 | 0.300 | 0.120 |
| **GLOBAL_DEMAND_MATCHING** | 1.0 | 0.868 | 0.868 | 0.697 | 0.697 |
| **SOCIAL_APPROVAL** | 0.9 | 0.181 | 0.162 | 0.687 | 0.618 |
| **Sum** | | | 1.190 | | 1.435 |

Table 14: Example evaluation of two potential actions. For each preference, the actions' current utility is multiplied by the institution's preference weight. The column sum represents the actions' scores.

## Parameter Overview

| **1st RunID** | **Last RunID** | **Random seeds** | **Experiment** |
|---|---|---|---|
| 743 | 743 | 0-99 | Coefficient of variance |
| 720 | 735 | 0-19 | DoE: Triggering threshold, subsidy rate, action runtime, precedence |
| 740 | 780 | 0-19 | Sensitivity analysis for subsidies rate (0 to 1.0) |
| 800 | 824 | 0-19 | Sensitivity analysis for triggering threshold (0.01/.02/.03/.04/.05/.06/.07/.08/.1/.11/.12/.13/.14/.15/.16/.17/.18/.19/.2/.22/.24/.26/.28/0.3) |

Table 15: All parameters and input data are available at https://bitbucket.org/geoslurg/pub_serios. RunIDs specify which runs were conducted for particular experiments reported in the paper.

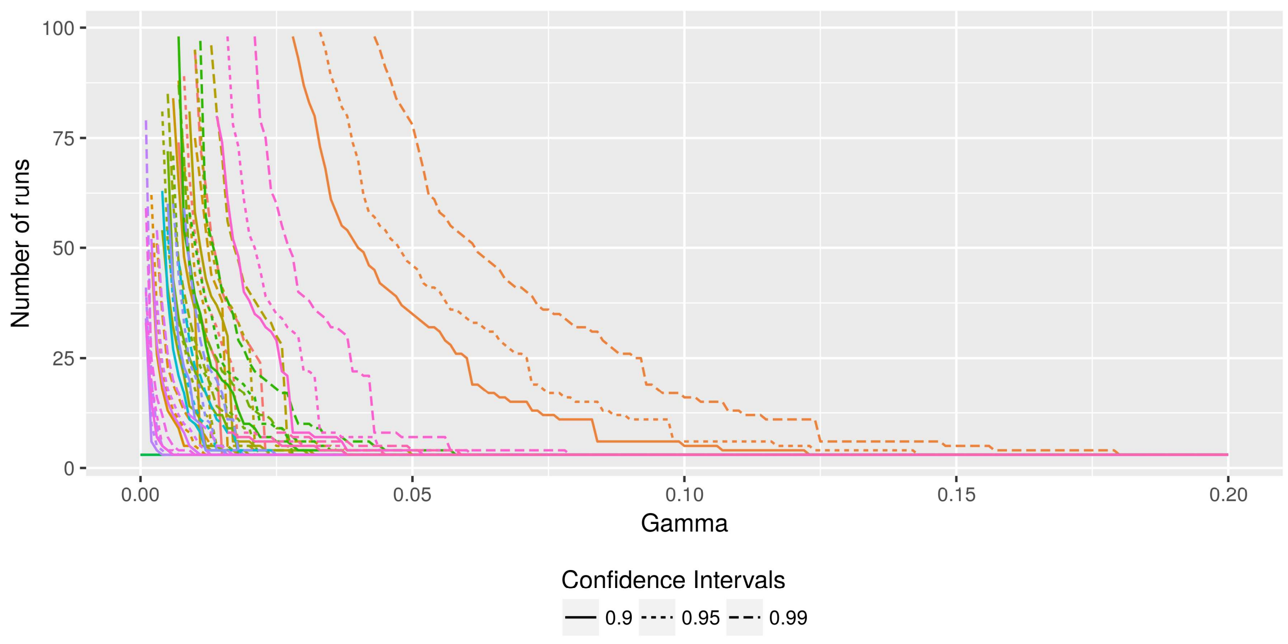
## Metrics

| **Key** | **Ref.** | **Description** | **Interpretation** | **craftyR function** | **Aggregation** |
|---|---|---|---|---|---|
| **Number of LU changes** | - | Number of changes in land use (if a cell changes multiple times it is counted several times) | Variability: Area under change | `metric_rasters_changedcells` | sum of all ticks |
| **Number of LU changed cells** | - | Number of cells whose land uses changes somewhen during simulation | Variability: Volatility in land use | `metric_rasters_changes` `metric_celldata_changes` | sum of all ticks |
| **Maximum undersupply (% demand)** | - | Maximum value of demand-supply gap during simulation when supply falls short of demand [MAX(0,demand – supply], relative to each service's demand | Service supply: Severity of worst mismatch | `metric_agg_supplydemand_maximum` | maximum of ticks |
| **Maximum oversupply (% demand)** | - | Maximum value of demand-supply gap during simulation when supply exceeds demand [MAX(0, supply – demand], relative to each service's demand | Service supply: Severity of worst mismatch | `metric_agg_supplydemand_maximum` | maximum of ticks |
| **Mean undersupply (% demand** | **-** | Demand for cereals/meat/ timber minus the amount that is supplied when under- | Service supply: Average mismatch | `metric_agg_supplydemand_percentage` | mean of all ticks |

| | | | | | |
|---|---|---|---|---|---|
| **cereal/meat/timber)** | | supplied, given as percentage relative to demand. Oversupply is considered 0. | | | |
| **Mean reg. undersupply (% demand cereal)** | - | Regional demand for cereals/ meat/timber minus the amount that is regionally supplied when undersupplied, given as percentage relative to demand. Oversupply is considered 0. Averaged across regions. | Service supply: Average mismatch per region | `metric_agg_supplydemand_percentage` | mean of all ticks |
| **Mean oversupply (% demand cereal/meat/timber)** | **-** | Supply for cereals/meat/ timber minus the demand when oversupplied, given as percentage relative to demand. Undersupply is counted as 0. | Service supply: Average mismatch | `metric_agg_supplydemand_percentage` | mean of all ticks |
| **Mean reg. oversupply (% demand cereal)** | - | Regional supply for cereals/ meat/timber minus the regional demand when oversupplied, given as percentage relative to demand. Undersupply is considered 0. Averaged across regions. | Service supply: Average mismatch per region | `metric_agg_supplydemand_percentage` | mean of all ticks |
| **Number of ext. managed patches** | Hijmans (2016) | Number of patches (cells connected via at least one of their 8 (Moore) neighbours) whose cells are managed extensively. | Conservation: Landscape connectivity of land uses | `metric_rasters_global_patches` | mean of all ticks |
| **Proportion of ext. managed cells** | Brown et al. (2016) | Simple proportion of extensively managed cells in all cells | Conservation: Extent of conservation | `metric_aggaft_proportions` | mean of all ticks |
| **Connectivity of ext. land uses** | Brown et al. (2016) | Mean proportion of neighbouring cells (Moore neighbourhood) that are managed by the same type. Cells with fewer neighbours are excluded. | Conservation: Micro connectivity of land uses | `metric_celldata_connectivity_global` | mean of all ticks |
| **Number of performed actions** | - | Number of all actions that are performed by any institution during a simulation. In case of action runtimes > 1, actions are counted for each tick. | Efficiency: Number of interventions | `metrics_agg_actions_number` | sum of all ticks |
| **Number of performed ext. LU targeted actions** | - | Number of all actions which subsidise extensive land uses that are performed by any institution during a simulation. In case of | Efficiency: Number of interventions that support extensive land use | `metrics_agg_actions_number` | sum of all ticks |

| | | | | | |
|---|---|---|---|---|---|
| | | action runtimes > 1, actions are counted for each tick. | | | |
| **Supply consistency across regions** | Brown et al. (2016) and Simpson (1949) | Proportions of each service in total landscape-scale service supply across landscapes. Maximum if each landscapes produces the same level $\frac{1}{\lvert R\rvert}\sum_{r\in R}\left(1-\sum_{s\in S}\left(\frac{p_r^s}{\sum_{s\in S} p_r^s}\right)^2\right)$ | Diversity: Similarity of service delivery levels across regions | `metric_agg_supplyaccrossreg_simpson` | mean of all ticks of all services |
| **Shannon Diversity Index** | Caillault et al. (2013) and O'Neill et al. (1988) | Negated sum of proportions of land use multiplied by ln(proportion). Alternative to Level of landscape-scale ecosystem service delivery | Diversity: Measures: diversity in land uses | `metric_aggaft_diversity_shannon` | |
| **Regional supply diversity** | Brown et al. (2016) and Simpson (1949) | Simpson's Index of Diversity to combine level and evenness of service delivery per landscape. Maximum if each landscapes produces all services equally $1-\sum_{s\in S}\left(\frac{p_s}{\sum_{s\in S} p_s}\right)^2$ | Diversity: Level of delivery of all services at regions | `metric_agg_supplyperreg_simpson` | mean of all ticks of all regions |
| **Regional LU diversity** | Brown et al. (2016) and Simpson (1949) | Diversity per region defined via Simpson's Index to take account of diversity and evenness. Maximised where many land uses are practiced, each in the same number of cells $\frac{1}{\lvert S\rvert}\sum_{s\in S}\left(1-\sum_{r\in R}\left(\frac{p_r^s}{\sum_{r\in R} p_r^s}\right)^2\right)$ | Diversity: Number and evenness of land uses | `metric_aggaft_diversity_simpson` | mean of all ticks of all regions |
| **Service delivery efficiency** | Brown et al. (2016) | For each service, the mean of non-zero quantities produced across all cells divided by the mean under initial conditions (at start of simulation). | Efficiency: Change in mean per-cell production of given service | `metric_agg_regionalsupply_efficiency` | mean of all ticks of all services |

Table 16: Metrics applied by the simulation to characterise land use dynamics. craftyr is an R package for the post-processing of CRAFTY results and can be installed with R commands 'devtools::install_bitbucket("S-Holzhauer/shbasic")' and 'devtools::install_bitbucket("geoslurg/craftyr@sirios_rec1")' (see package's vignettes for further information).




Response Variables

- Number of changed cells
- Number of land use changes
- Shannon Diversity Index
- Number of ext. managed patches
- Number of int. managed patches
- Connectivity of ext. land uses
- Proportion of ext. managed cells
- Proportion of int. managed cells
- Maximum Undersupply (% demand)
- Mean Undersupply (% demand cereal)
- Mean Undersupply (% demand meat)
- Mean Undersupply (% demand timber)
- Mean Oversupply (% demand total)
- Mean Oversupply (% demand cereal)
- Mean Oversupply (% demand meat)
- Mean Oversupply (% demand timber)
- Regional supply diversity (Simpson)
- Supply consistency across regions (Simpson)
- Regional land use diversity (Simpson)
- Service delivery efficiency
- Mean reg. Undersupply (% demand cereal)
- Mean reg. Undersupply (% demand meat)
- Mean reg. Undersupply (% demand timber)

Figure 3: Required number of runs based on the coefficient of variance for confidence intervals .9/.95/.99 for each response variable. The y axis gives the number of runs which are required to keep the response variable within the confidence interval with an error denoted at the x axis.

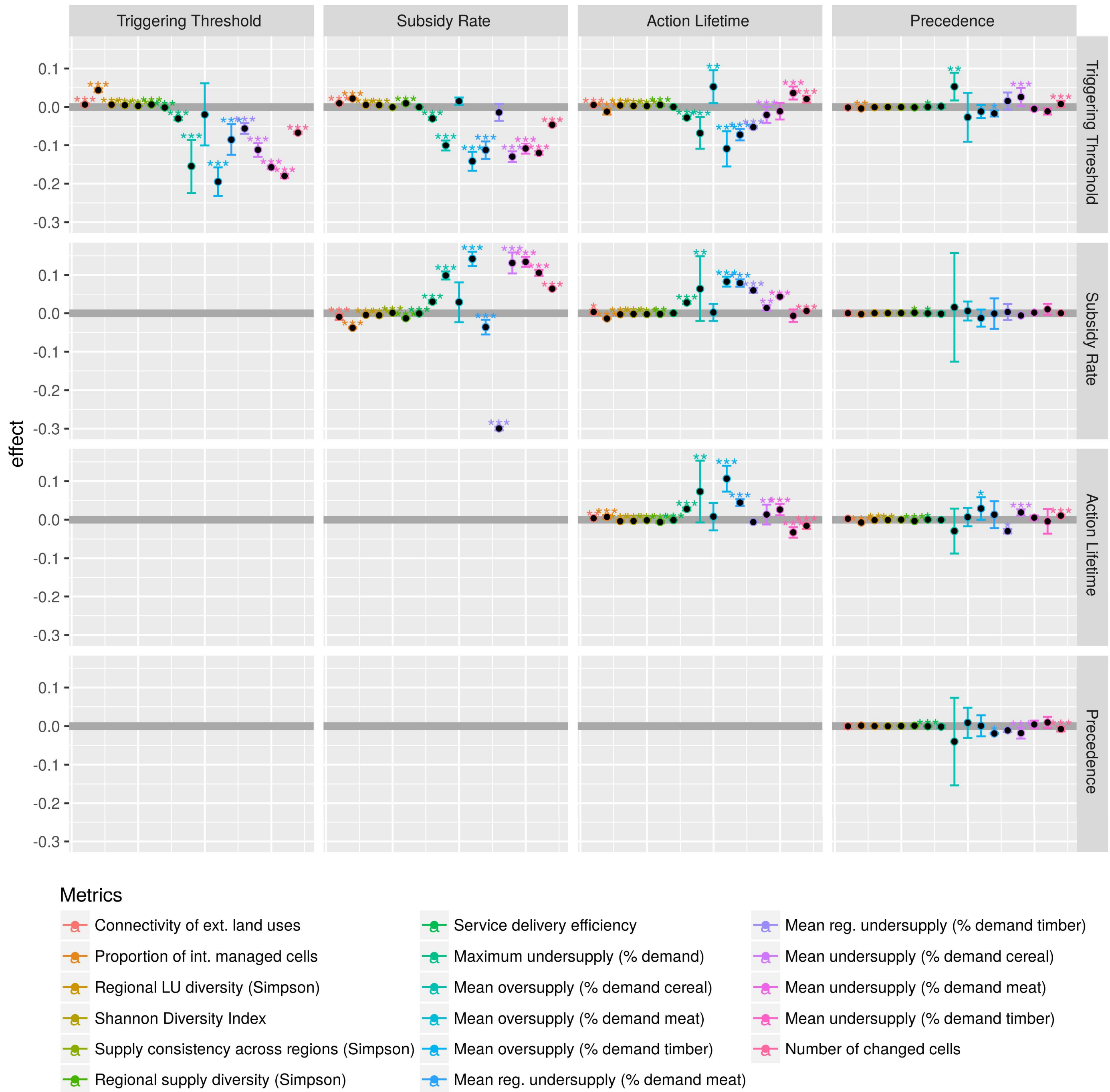



Figure 4: Effects of four parameters (triggering threshold determines when institutions act, the subsidy rate represents the magnitude of subsidies, action lifetime is how long actions are in place, when precedence is on global institutions act first, followed by regional institutions the next time step) on a set of land use metrics from Design of Experiments runs (see article) including interaction effects. Error bars show the 90% confidence interval. Stars above error bars denote levels of significance: ***⇨ 0.001; **⇨ 0.01; *⇨ 0.05.

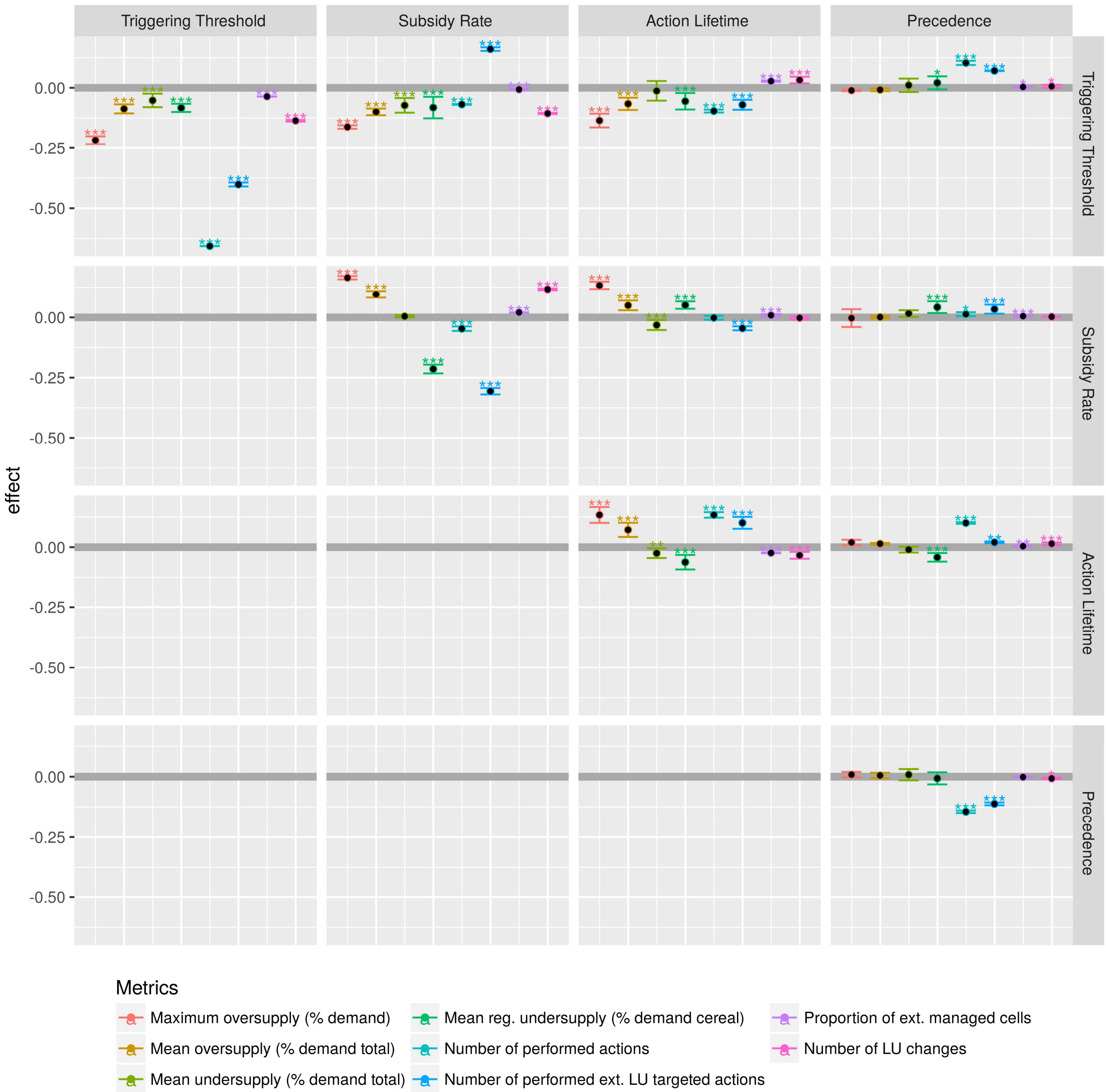



Figure 5: Effects of four parameters (triggering threshold determines when institutions act, the subsidy rate represents the magnitude of subsidies, action lifetime is how long actions are in place, when precedence is on global institutions act first, followed by regional institutions the next time step) on another set of land use metrics from Design of Experiments runs (see article) including interaction effects. Error bars show the 90% confidence interval. Stars above error bars denote levels of significance: ***⇨ 0.001; **⇨ 0.01; *⇨ 0.05.

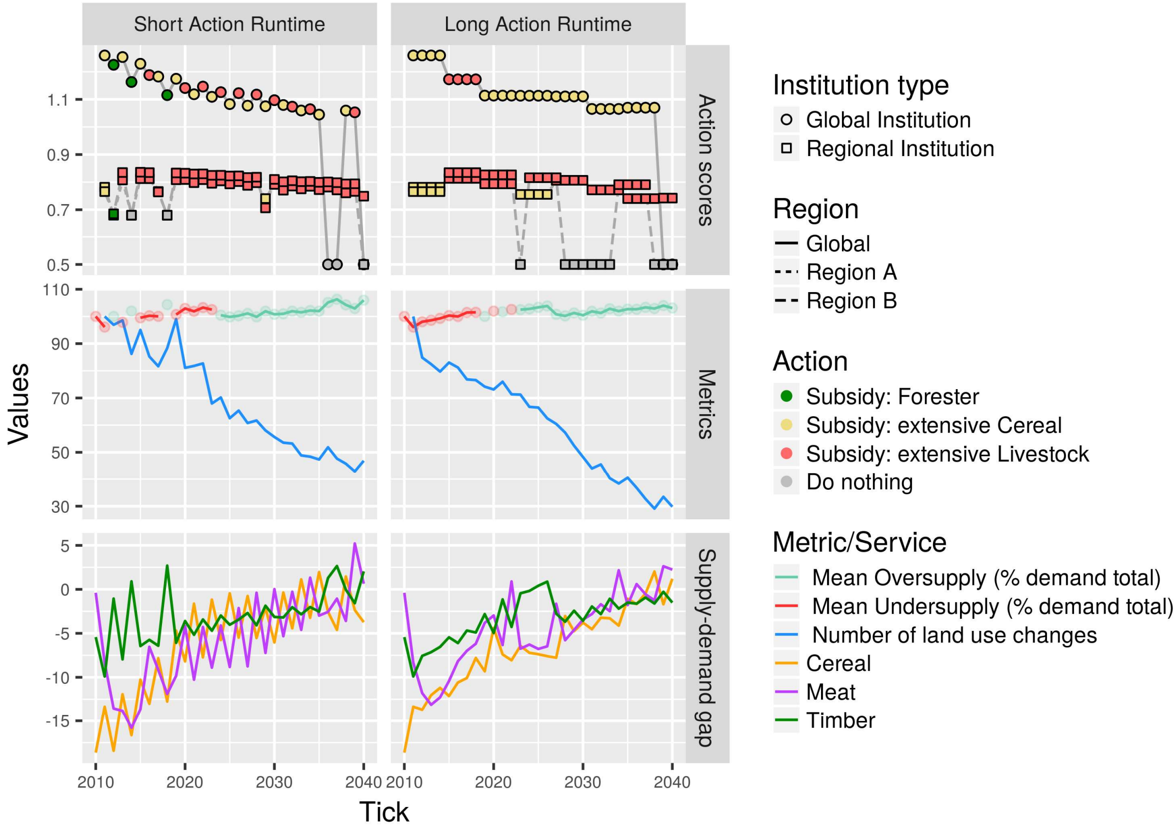



Figure 6: Performed actions and their score (upper panels), mean oversupply, mean undersupply, and number of land use changes (middle panels), as well as global supply demand gaps for cereal, meat and timber (in percentage of their demand levels; bottom panels) for a single run with short actions lifetime (1 time step) compared to a run with long action lifetimes (4 time steps). Subsidies rate is 0.2 (low), triggering threshold is 0.06 (low), and there is no precedence between institutions. Dots show actions performed by the global institutions, squares the ones performed by regional institutions. For reasons of clarity only two of three regions are presented (upper panels). Metrics are divided by their initial value (middle panels).

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