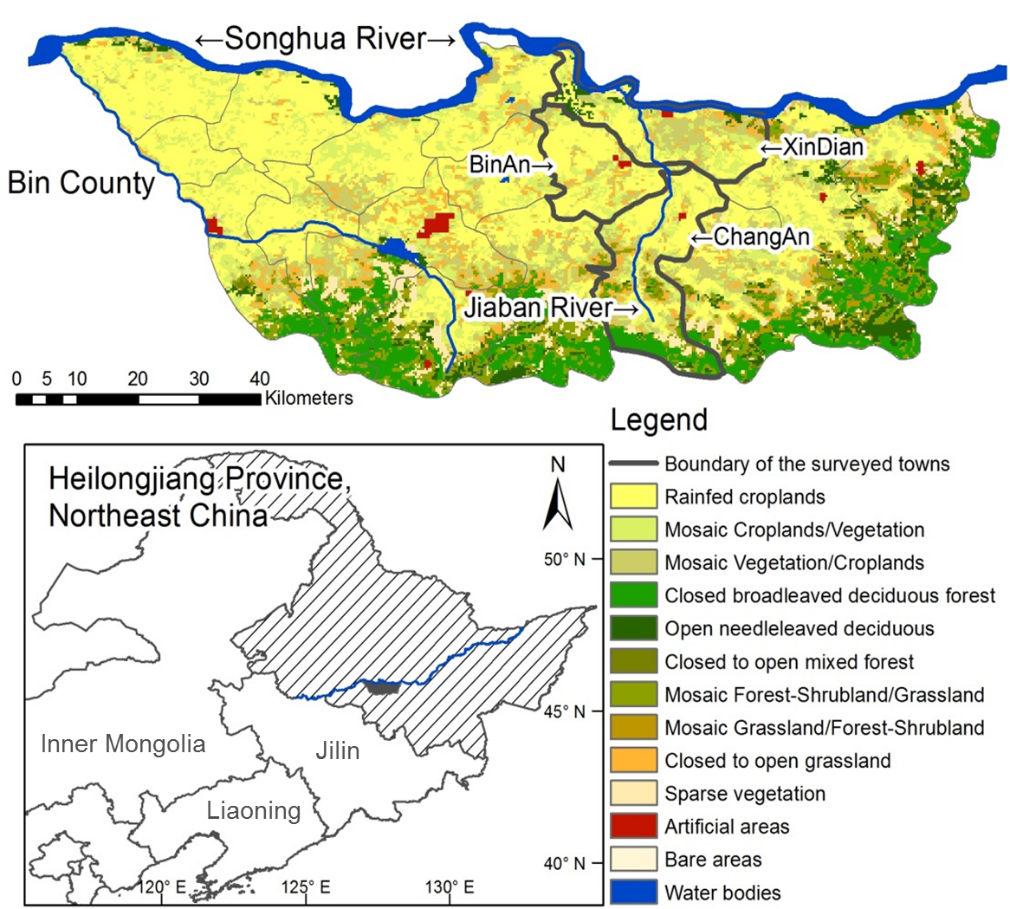
**Title:** Environmental cognitions mediate the causal explanation of land change

**Operationalization of the PAD measurements in a case study in Northeast China**

The operationalization of PAD measurement is illustrated by reconciling two related case studies on farmers’ decision-making processes from the same region, specifically, in three towns (namely XinDian, BinAn, and ChangAn) in Bin County, Heilongjiang Province (Figure S1) (Yu et al. 2013, Yu et al. 2014).



**Figure S1.** Location and land use of the case study area.

Evidence obtained from a detailed household survey – carried out in April 2012, covering all 24 villages in the three towns, with a final 384 farmer household samples – was selected to present the perceptions, attitude, and decisions respectively. The survey questionnaires regarding these aspects are compiled in Table S1.

The measurement for perceptions was qualitative and only required farmers to report his/her perception on changes of those variables from past to present, e.g., increased/decreased/unchanged. Regarding attitudes, one question was whether this factor (any item from Table S1) has affected decision-making and how important is it? We distinguished two aspects of attitude (i.e. land use right transfer and crop choice) and applied a semi-quantitative measurement to obtain farmers’ attitudes by assigning points, corresponding to different levels of importance. Decisions in the case study are in accordance to land transfer decisions and crop selection/replacement, as they are the most important agricultural land use decisions in the study region.

**Table S1.** Possible factors and their corresponding attitudes that may influence decisions, in addition to the variables selected for the assessment of perception (marked with “#”).

|  |  |  |
| --- | --- | --- |
| Category | Factor | Abbr. name |
| Internal | (1) Education of the family head and the average level of the family | *Education* |
|  | (2) Agricultural labourers in the family | *Labor* |
|  | (3) Age of the family head and the structure of the family | *Age* |
|  | (4) Distributed land area got from the village cooperative | *DistriAcreage* |
|  | (5) General land quality of the farmland of the household | *LandQuality* |
|  | (6) Actual farming land area that is currently managed by the household | *CurrentAcreage* |
|  | (7) The balance of income and expenditure of the family | *FamilyBal* |
|  | (8) The income structure of the family | *IncomeStruc* |
| Biophysical | (1) Local temperature characteristics | *Temperature#* |
|  | (2) Local precipitation characteristics | *Precipitation#* |
|  | (3) Local characteristics of the length of growing degree days | *GDDs#* |
|  | (4) Local characteristics of agricultural disasters | *AgriDisaster#* |
|  | (5) Accessibility for advanced cropping systems and technology | *CropSystem* |
|  | (6) The yield for crops | *CropYield#* |
| Socioeconomic | (1) The price and costs for agricultural material input | *InputPrice* |
|  | (2) The condition of local infrastructure, including irrigation accessibility | *Infrastructure* |
|  | (3) The activities organized by local agricultural cooperatives | *AgriCoop* |
|  | (4) The price for crops | *CropPrice* |
|  | (5) Market accessibility and marketing channel | *Market* |
|  | (6) Accessibility for policy and subsidy | *Policy* |

The evidence is compiled following the PAD sequence, and the main interpretations are presented in the main text.

Perceptions: The survey assessed the farmers’ perceptions of four environmental conditions in relation to observed changes between 1980 and 2010. Temperature increase, precipitation decrease, and increased length of the growing season were correctly perceived by 76%, 67%, and 70% of the farmers, respectively (see Table S2). In contrast, the increase in frequency of disasters was perceived correctly by only 42% of the local farmers.

**Table S2.** Comparison between observed and perceived climate change in Bin County, China.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | From meteorological/statistical data | | | From survey data | |
|  | 1980s | 2010s | Δ | Correct perception | Percentage |
| Temperature (°C) | 3.2 | 4.6 | 1.4 | Increased | 76% |
| Growing Season (°C) | 1253 | 1428 | 175 | Prolonged | 70% |
| Precipitation (mm) | 620 | 510 | -110 | Decreased | 67% |
| AgriDisaster (%) | 0.41 | 0.49 | 0.083 | Increased | 42% |

Attitudes: Farmers’ attitudes towards the factors that may influence their decisions related to land transfer and crop choice were subsequently examined. The importance of a number of potential factors for individual farmers, categorized into internal factors, biophysical factors and socioeconomic factors, were assessed using a five-point scale. These measurements are hereafter referred to as “attitude scores”, as they express the attitude of the farmer towards these factors. Higher scores indicate that factors were more important to farmers in their decision-making. When aggregating scores for the three different categories, all have a higher influence on land transfer than on crop choice decisions. This indicates that most farmers in the region care more about whether to engage in agricultural activities and less about which crop they choose (Table S3 and Table S4).

**Table S3.** Aggregated analysis of attitude scores.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Score average | | Standard deviation | | Correlation coefficient  (between land transfer and crop choice) | *p*-value |
|  | Land transfer | Crop choice | Land transfer | Crop choice |
| Internal | 2.18 | 1.50 | 0.37 | 0.29 | 0.34 | 0.415 |
| Biophysical | 2.66 | 2.18 | 0.72 | 0.45 | 0.92 | 0.010 |
| Socioeconomic | 2.35 | 1.61 | 0.90 | 0.84 | 0.92 | 0.009 |

Decisions: Environmental conditions and attitudes towards various factors eventually yield two types of decisions: leasing more land to expand production and selecting the mix of crops grown on this land. These correspond to land transfer and crop choice, respectively. A quantitative binary-logit analysis was applied to check the relationships between the farmers’ stated attitude scores and their actual decisions (Table S4). The attitude scores with significant coefficients in the logit model are marked with “\*” Figure 3 in the main text. These are generally the scores that have a relatively high average attitude score.

**Table S4.**  Average attitude scores for land transfer and crop choice in relation to the actual decisions. Attitude scores significantly related to the actual decision in a logit model are indicated with asterisk(s).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Land transfer | | |  | Crop choice | | | | |
| Variable | Average  score | exp (*β*) values  in logit model |  | Variable | Average  score | exp (*β*) values in logit model | | |
| Rice | Beans | Tobacco |
| 1 | CropYield | 3.78 | 1.265 |  | CropPrice | 3.07 | 0.714 | 1.1 | 1.058 |
| 2 | **CropPrice** | 3.47 | **0.651\*** |  | **CropYield** | 2.91 | **0.434\*** | 0.96 | 1.609 |
| 3 | CropSystem | 3.34 | 0.852 |  | **CropSystem** | 2.49 | 1.049 | 1.27 | **0.182\*\*** |
| 4 | Policy | 3.02 | 0.88 |  | **FamilyBal** | 2.16 | **1.754\*** | 1.133 | 1.329 |
| 5 | **DistriAcreage** | 2.55 | **1.381\*** |  | **GrowingSeason** | 2.08 | **2.36\*** | 0.99 | 1.696 |
| 6 | **Infrastructure** | 2.52 | **1.625\*\*** |  | Temperature | 2.05 | 0.576 | 0.99 | 0.495 |
| 7 | CurrentAcreage | 2.47 | 1.411 |  | **Policy** | 1.89 | **2.215\*\*** | 0.8 | 1.275 |
| 8 | **Education** | 2.46 | **0.685\*\*** |  | **AgriDisaster** | 1.81 | 0.671 | 0.9 | **0.184\*\*** |
| 9 | FamilyBal | 2.41 | 1.25 |  | Precipitation | 1.72 | 1.269 | 1.221 | 1.011 |
| 10 | Precipitation | 2.29 | 1.339 |  | LandQuality | 1.63 | 0.858 | 1.143 | 0.775 |
| 11 | LandQuality | 2.29 | 1.198 |  | Education | 1.52 | 1.81 | 0.763 | 1.932 |
| 12 | AgriDisaster | 2.23 | 0.762 |  | IncomeStruc | 1.48 | 1.233 | 0.969 | 1.738 |
| 13 | InputPrice | 2.18 | 1.025 |  | InputPrice | 1.44 | 0.95 | 0.769 | 1.005 |
| 14 | Temperature | 2.16 | 0.947 |  | **Infrastructure** | 1.39 | **5.066\*** | 1.265 | 3.525 |
| 15 | GrowingSeason | 2.15 | 0.753 |  | **Market** | 1.37 | **0.145\*\*** | 1.335 | 0 |
| 16 | Market | 2.03 | 0.934 |  | DistriAcreage | 1.35 | 1.74 | 0.76 | 0.902 |
| 17 | Labor | 1.88 | 0.794 |  | CurrentAcreage | 1.35 | 0.661 | 0.993 | 3.308 |
| 18 | Age | 1.77 | 1.014 |  | Labor | 1.29 | 0.45 | 1.098 | 0 |
| 19 | IncomeStruc | 1.61 | 0.868 |  | Age | 1.25 | 1.057 | 0.963 | 1.683 |
| 20 | AgriCoop | 0.86 | 0.759 |  | AgriCoop | 0.54 | 0.167 | 1.04 | 2.203 |
| ROC statistic | | | 0.823 |  | ROC statistic | | 0.898 | 0.665 | 0.897 |
| Nagelkerke R Square | | | 0.351 |  | Nagelkerke R Square | | 0.53 | 0.103 | 0.521 |

\* implies significance at *p*＜0.1 and \*\* implies significance at *p*＜0.05 level

**A collection of underlying driving forces of agricultural land change in Northeast China**

By applying the literature searching engines, e.g. Web of Science, Google Scholar, etc., a number of studies have sought to explain the causality in agricultural land systems in Northeast China (i.e. Heilongjiang, Jilin, and Liaoning Province), given its importance in becoming the major breadbasket for the country. Climate variables, especially changes in temperature and precipitation, are considered to be the most important factors determining changes in agricultural land systems (e.g., cropland conversions and crop pattern changes) in Northeast China given the recent global warming trend. At the same time, socioeconomic factors such as population, investment, off-farm employment and new policy implementation during the recent institutional reforms are also believed to impact land changes. The 23 relevant studies are listed in Table S5.

The temporal-spatial scales, research questions, and analytical frameworks of these studies are not necessarily consistent to each other, thus the collection and straightforward presentation of reported evidence of case studies only gives a general impression on the identified causes in the focused region. While these studies indicated the great impact brought by the factors from the underlying conditions, the role of human activities and decision-making have not been considered explicitly.

**Table S5.** Studies presenting underlying driving forces of agricultural land change in Northeast China.

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Time period | Major drivers | Reference |
| 1 | 1975-2006 | Infrastructure, precipitation, agricultural population, per capita GDP, settlements | (Cui et al. 2014) |
| 2 | 1958-2010 | Climate warming | (Gao and Liu 2011) |
| 3 | 1900-1980 | Population increase, food production, natural disasters, government policies | (Ge and Dai 2005) |
| 4 | 1989-2005 | Urban wages, failure of agricultural investment | (Jiang et al. 2012) |
| 5 | 1730-1910 | Climate, population | (Lee 2014) |
| 6 | 1980-2010 | Climate change, policy regulation, economic driving forces | (Liu et al. 2014) |
| 7 | 2000-2005 | Climate warming, agricultural policy, agronomic technology | (Liu et al. 2010) |
| 8 | 1995–2000 | Production conditions, economic benefits, climatic conditions | (Liu et al. 2003) |
| 9 | 2000-2008 | Policy, urbanization | (Qin et al. 2013) |
| 10 | 1970s-2000s | Indicators of heat, water resources | (Shi et al. 2014) |
| 11 | 1976-2005 | Institutional strategies, market policies | (Song et al. 2014) |
| 12 | 1976-2005 | Climatic changes, population, groundwater harvesting, fertilizer application | (Song et al. 2012) |
| 13 | 1996-2008 | Extensive use of fertilizers, machinery and pesticide, increased labour and capital input | (Wang et al. 2015b) |
| 14 | 1954-2008 | Climate warming, precipitation decreasing, population, gross domestic product | (Wang et al. 2011) |
| 15 | 1986-2000 | Climate warming, population augment, regional economic development, national and provincial policies | (Wang et al. 2009a) |
| 16 | 1954-2000 | Climatic changes, population, GDP | (Wang et al. 2009b) |
| 17 | 1980-2010 | Climate change | (Xia et al. 2014) |
| 18 | 1999-2008 | Agricultural inputs including fertilizer inputs, pesticide inputs and agricultural plastic sheeting | (Xie et al. 2014) |
| 19 | 1700s-2000s | Migration, wars, regime shift | (Ye et al. 2009) |
| 20 | 1976–2001 | Industry structure, population | (Zang and Huang 2006) |
| 21 | 1900-2000 | Population pressure | (Zhang et al. 2003) |
| 22 | 1990-2009 | Off-farm employment of rural labour force, commercialization of agricultural product, regional comparative advantage | (Zhao et al. 2012) |
| 23 | 1999-2005 | Fragmental terrain, soil salinization, deficiency of water resources, and loss of labour | (Zuo et al. 2013) |

**A collection of actor characteristics on agricultural land change in China**

There are few publications focusing on actors’ characteristics and environmental cognitions in Northeast China. We assume that the influence of actors’ characteristics would have limited disparities across regions. Therefore, we expand the searching coverage to entire China, and we found 18 relevant publications focusing on actors’ characteristics (Table S6).

**Table S6.** Studies presenting actor characteristics on agricultural land change in China.

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Survey time | Major drivers | Reference |
| 1 | 2009 | Education, labor, farming size | (Yan and Huo 2016) |
| 2 | 2012 | Labor, household size, cropland area per labor, income, wage | (Yan et al. 2016) |
| 3 | 2009 | Age, labor, household size, cropland area, total income, income structure | (Hao et al. 2015) |
| 4 | 2011 | Age, labor, labor average age | (Zhang et al. 2014) |
| 5 | 2005 | Gender of household head, income structure | (Yang and Xu 2014) |
| 6 | 2000 | Household size, labor, off-farm labor, cropland area per capital, on-farm income | (Tan et al. 2006) |
| 7 | 2012-2014 | Farming size | (Zhang et al. 2016) |
| 8 | 2013 | Age, female ratio, farming size, off-farm income | (Yang et al. 2016b) |
| 9 | 2014 | Age, Gender of household head, livestock income | (Yang et al. 2016a) |
| 10 | 2014 | Age, agricultural equipment, off-farm income per capital | (Wang et al. 2016) |
| 11 | 2013 | Off-farm labor, female labor, off-farm income | (Hua et al. 2016) |
| 12 | 2007 | Age | (Chen et al. 2016) |
| 13 | 2012 | Age, household children and elderly, education, labor, tractor, cattle, | (Wang et al. 2015c) |
| 14 | 2010 | Education, value of agricultural assets | (Wang et al. 2015a) |
| 15 | 2007-2009 | Household children and elderly, female labor, cropland area, off-farm income, | (Tian et al. 2015) |
| 16 | 2011 | Age, longevity, household size, migrant farmer, land rent farmer, cropland area, plot number, net income per capital, subsidy received | (Bai et al. 2015) |
| 17 | 2000/2008 | Cropland area | (Deininger et al. 2014) |
| 18 | 2009 | Education, cropland area, farming size, off-farm income | (Lu et al. 2012) |

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