Tenure Decentralization and Forest Productivity

Evidence from Northeast China

Tingyu CUI[1] Chen FANG[1] Yushuai ZHANG[2]

[1]School of Economics and Management, Tsinghua University

[2]National School of Development, Peking University

May 11, 2024

Contents

Background: Forest and CFTR

Forest in China

- **Distribution**: Nearly **90%** are located in mountainous areas
  - ◇ overlapping with agricultural population
- **Categories**: state-owned **vs.** collective (more than **60%**)
  - ◇ Majority are natural, **artificial** forests more prevalent in collective lands
- **Problems**
  - ◇ **"Tragedy of Commons"**: Unsustainable-logging, steal and wildfire (Hardin, 1968), (Liu et al., 2017)
  - ◇ **Ambiguous Property**: lack of enthusiasm to manage

(second round) Collective Forest Tenure Reform (CFTR)

- **2003**: **Experimental** & Pilot (e.g. Sanming County in Fujian)
- **2006-2008**: **Nationwide** comprehensive promotion
- the **second large-scale land reform** initiative in rural areas
  - ◇ following the Household Responsibility System (HRS) reform in 1978. (Xu and Hyde, 2019)

Why Northeast China?

Natural Endowment

- 38.75 million hectares, $\approx$ **39.6%** forest coverage rate
- 3.2 billion m^3 timber stock volume, $\approx$ **1/3** of the national total

Good Practice

- **Northeast Forest Region**
  - the largest **natural forest area** in China
  - long history
  - rich experience
- **Enormous contribution**
  - prominent **greening** (Yu et al., 2021)

Staggered Implementation

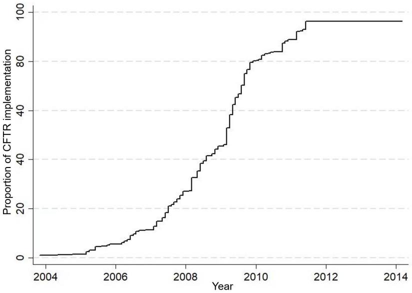

Figure 1: CFTR Coverage Proportion

- Mainly from **2006 to 2010**
- **Almost completely** cover collective forest area

Literature Review

Value of Forest

- **Climate**: **lower surface temperature** (Peng et al., 2014), energy savings (Han et al., 2024), interact with precipitation (Smith et al., 2023)
- **Health**: **infectious diseases** (Berazneva and Byker, 2017), infant (Jones and Goodkind, 2019), emergency room visits (Xing et al., 2023)
- **Agriculture**: cropland expansion **vs.** deforestation (He and Chen, 2022)

Common-Pool Resource Management (Ostrom, 1990)

- **Cropland & Grassland**: downsized corporate farms (Lerman, 1999), rollout of the land titling (Liu et al., 2023), allow to lease out (Chari et al., 2021), privatization (Hou et al., 2023), RCT evidence (Subramanian and Kumar, 2024)
- **Forest Area**: property-rights sharing (Chankrajang, 2019), **contracting** (Abman and Lundberg, 2024)

Controversial Effects of Tenure Reform

- **Positive**: incentive forestry **investment** (Xie et al., 2013), (Yi et al., 2014), healthier and more productive (Chen and Innes, 2013)
- **Caveats**: stability of **property** (Qin and Xu, 2013), ambiguity of **boundary** (Yin et al., 2013), impatience (Xie et al., 2014), democracy practice

Research Questions & Findings

- **Can CFTR incentive the forest quality?**
  - ◇ leverage satellite data to estimate CFTR in a **long-term** and **comprehensive** way
    - ✓ complement traditional research based on regional case study or survey among households
  - ◇ CFTR leads **long-lasting** increase of forest quality
- **What are the impacts of CFTR in different regions?**
  - ◇ Areas with better **agricultural practices** ⇒ higher quality
  - ◇ Areas with more frequent **human activity** ⇒ higher quality
- **What are the possible mechanisms behind this?**
  - ◇ More **agricultural population participation** in forest management
  - ◇ may help response the debates about the **balance between environment and economic development** (e.g. rotational logging) (Rico-Straffon et al., 2023)

Data Sources & Main Variables

A grid-level monthly panel data from 2000-2014 with $7km \times 7km$ spatial resolution. Details

- **Natural**
  - ◇ **GPP** $(g \cdot carbon/(m^2 \cdot d))$: satellite data from [NASA Earth Data]
    - ✓ **Gross Primary Productivity, the amount of organic carbon fixed by organisms, through photosynthesis per unit of time.**
  - ◇ **Land Cover**: 2000 & 2010, ten types [GlobeLand30] (Chen et al., 2017)
    - ✓ our research objective are the grids with forest coverage **over 30%**
  - ◇ **Temperature & Precipitation**: Chinese version downscale from [WorldClim] (Peng, 2020)
- **Socio-Economics**
  - ◇ **Control Group** ("Tianbao" zones): forest under the direct jurisdiction of the government delineated in the **Natural Forest Protection Project** (2000)
  - ◇ **Population** (people per km^2): [WorldPop] (Tatem, 2017)

Treatment & Control Group

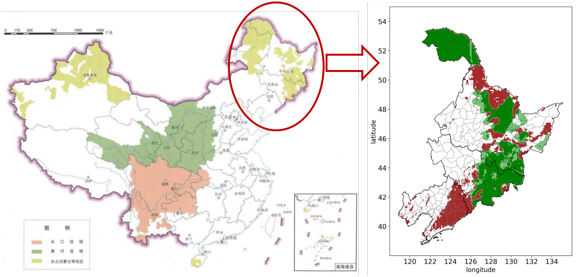

Figure 2: An illustration of **Natural Forest Protection Project (2000)**

Dispersed distribution of two groups

- **darkred Grids**: Collective Forest Area
- **darkgreen Grids**: State-Owned Forest Area

Notes: Thanks for Professor Jintao Xu to provide the shapefile of NFPP area.

Coverage vs. Quality

- **Left**: the **density and coverage** of vegetation
- **Right (GPP)**: the **quality** of vegetation
- **NFPP area**: greener (**higher coverage**) but lower GPP (**worse quality**).

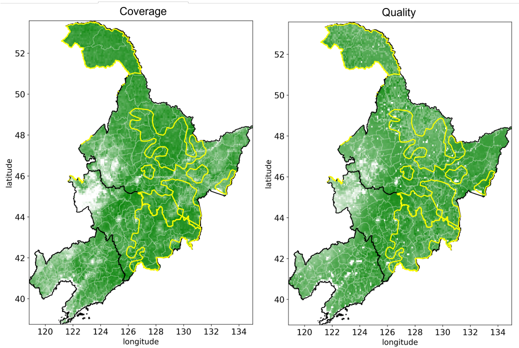

Figure 3: Comparison between **coverage** and **quality** (Yellow lines: NFPP boundary)

Baseline: TWFE DiD Model

the Average Treatment Effect of CFTR on GPP

$$\ln GPP_{ijt} = \alpha + \beta_1 Reform_{jt} \times Manf_i + \beta_2 Reform_{jt} + \gamma X_{it} + \mu_i + \eta_t + \varepsilon_{ijt} \quad (1)$$

- $\ln GPP_{ijt}$: natural logarithm of GPP for **grid i** of **county j** in **month t**
- $Manf_i$: binary, 1 if **grid i** belongs to the reform region in **county j**
- $Reform_{jt}$: binary, 1 if after the reform
- X_{it}: time-varying control variables
  - mainly climate, e.g. temperature, precipitation...
- μ_i: grid FE; η_t: time FE
- β_1: **not guaranteed** to recover an interpretable causal parameter (e.g. heterogeneity) (Goodman-Bacon, 2021), (Callaway and Sant'Anna, 2021), (Athey and Imbens, 2022)
  - using **stacked strategy** introduced by Cengiz et al. (2019) and Deshpande and Li (2019) to emphasize **clean controls** only (Wing et al., 2024)

Baseline: Specification Results

Table 1: Baseline Estimates

	Dependent variable: Log (GPP)			
	Two-way FE		Stacked DiD	
	(1)	(2)	(3)	(4)
Reform×Manf	0.032***	0.034***	0.055***	0.043***
	(0.009)	(0.01)	(0.01)	(0.01)
Controls	Yes	Yes	Yes	Yes
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes			
Group×Year-to-Reform FE			Yes	Yes
Year×Month FE		Yes		Yes
Observations	645,774	645,774	4,044,533	4,044,533
R-squared	0.911	0.933	0.851	0.918

Notes: The dependent variable is the natural logarithm of GPP. Robust standard errors in parentheses, clustered at the county level in column 1 and 2, clustered at the group level in columns 3 and 4. We keep sample **from April to October** to avoid low productivity during cold season.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Baseline: Canonical Event-Study Model

“Dynamic” Variations of the TWFE specification

$$\ln GPP_{ijt} = \alpha + \sum_{y=\underline{y}, y \neq -1}^{\bar{y}} \beta_y Reform_j \times Year_y + \gamma X_{it} + \mu_i + \eta_t + \varepsilon_{ijt} \quad (2)$$

- $[\underline{y}, \bar{y}] = [-4, 5]$ and the **base year** is $y = -1$ $(\beta_y = 0)$
- $Year_y$: binary, 1 when the **grid i** would be treated after y years
- $y \geqslant 0$: **average accumulation of GPP** relative to the former year
- β_y expected to be **positive** when $y \geqslant 0$
- β_y cannot be rigorously interpreted as reliable measures of **“dynamic treatment effects”** (Sun and Abraham, 2021)

Baseline: Stacked Event-Study Model

Estimate ATE for a whole group in a specific year

$$\ln GPP_{ijgy} = \alpha + \sum_{y=\underline{y}, y\neq -1}^{\bar{y}} \beta_y Reform_{jg} \times Manf_{gy} + \gamma X_{iy} + \mu_i + \eta_{gy} + \varepsilon_{ijgy} \tag{3}$$

- g denotes **a group of sample grids** (treated & randomly assigned control)
- **stratified** in the month unit (match by the month)
- $Manf_{gy}$: binary, 1 when the grid in group **group g** would be treated after y years, otherwise 0
- η_{gy}: FE of **group g** with y years forward to be treated
- standard error are clustered at **group** level

Baseline: Dynamic Effects Results

Long-lasting change (to collective forest area)

- **pre**: parallel trends
- **post**: significant, roughly linear treatment effects, no sign of reverting back

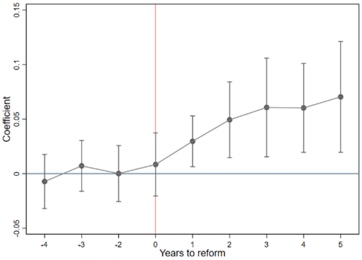

Figure 4: **Panel A** Two-way FE

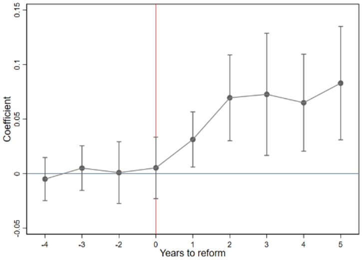

Figure 5: **Panel B** Stacked DiD

Notes: Panel A is estimated using equation (2), Panel B is estimated using equation (3). Scatter plots with error bars of 95% CI.

Robustness: Placebo Test

change the CFTR year (relative to the actual year)

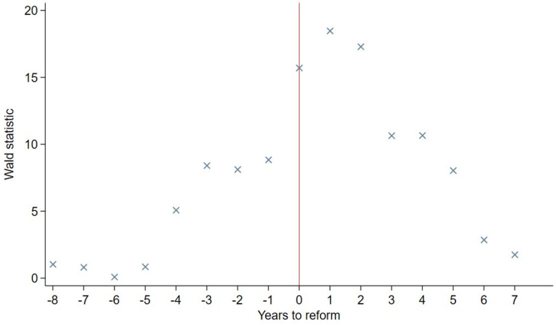

Figure 6: Wald Statistics from Estimates with Placebo Reform Years

Notes: Each cross is a Wald statistic from the t-test of the key coefficient in the stacked DiD specification where a placebo year of reform is used. The x-axis indicates the placebo year relative to the actual year.

Robustness: PSM-DiD

Identification Concerns: Sample Selection Bias

- Whether a grid belongs to treatment or control may be **endogenous**.
- **Matching** by temperature, precipitation and human activity.

Table 2: Baseline Estimates **after PSM**

	Dependent variable: Log (GPP)			
	Two-way FE		Stacked DiD	
	(1)	(2)	(3)	(4)
Reform×Manf	0.033***	0.036***	0.036***	0.037***
	(0.009)	(0.01)	(0.008)	(0.009)
Controls	Yes	Yes	Yes	Yes
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes			
Group×Year-to-Reform FE			Yes	Yes
Year×Month FE		Yes		Yes
Observations	590,595	590,595	4,043,938	4,043,938
R-squared	0.919	0.944	0.926	0.933

Notes: The dependent variable is the natural logarithm of GPP. Robust standard errors in parentheses, clustered at the county level in column 1 and 2, clustered at the group level in columns 3 and 4. We keep sample **from April to October** to avoid low productivity during cold season.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Robustness: PSM-DiD

Dynamic Effects of CFTR after PSM

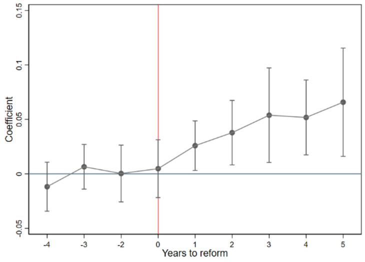

Figure 7: **Panel A** Two-way fixed effects

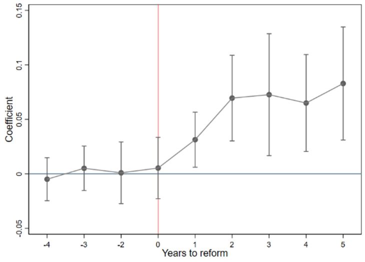

Figure 8: **Panel B** Stacked DiD

Notes: Panel A is estimated using equation (2), Panel B is estimated using equation (3), all after PSM, using only observations between April and October.

Channel: Area & GPP Intensity

Decompose the change of GPP into two elements

- The change of **land area**
- The change of the **"intensity"** of GPP (the quality of vegetation itself)

$$GPP = \sum_{t \in land\ types} Coverage\ Ratio_t \times GPP\ Intensity_t$$
$$land\ types = \{\text{forest, cultivated, grass \& shrub}\} \tag{4}$$

$$\begin{bmatrix} I_f \\ I_c \\ I_g \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix}^{-1} \cdot \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} \tag{5}$$
$$\Rightarrow I = R^{-1} Y$$

- I: the vector of **GPP intensity**
- Y: the vector of **GPP**
- R: the **coverage ratio** matrix of three land types

Channel: Area & GPP Intensity

Table 3: Channel Analysis Based on **Land Cover Types**

	Two-way Fixed Effect					
	Dependent variable: $\ln Area$			**Dependent variable:** $\ln GPP\_Int$		
	(1)	(2)	(3)	(4)	(5)	(6)
	Forest	Cultivated	Grass & Shrub	**Forest**	Cultivated	Grass & Shrub
Reform×Manf	0.207***	-0.022*	-0.180***	0.230***	0.040	0.608
	(0.055)	(0.013)	(0.065)	(0.068)	(0.214)	(1.019)
Reform	-0.218***	0.049***	0.144***	-0.188	0.228	0.249
	(0.045)	(0.016)	(0.040)	(0.787)	(0.772)	(1.062)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Grid FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE				Yes	Yes	Yes
Observations	21,264	21,264	21,264	21,264	21,264	21,264
R-squared	0.993	0.999	0.949	0.829	0.656	0.557

Notes: This table compares 3 different land cover types. The dependent variable is area in column 1-3, and GPP intensity in column 4-6. Robust standard errors in parentheses, clustered at the county level. We keep sample **from April to October** to avoid low productivity during cold season.
** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Human Activities

Table 4: Heterogeneous Effects Based on **Human Activities**

	Dependent variable: Log (GPP)			
	Stacked DiD			
Population Density	$[0, 5]$	$(5, 15]$	$(15, 125]$	> 125
	(1)	(2)	(3)	(4)
Reform×Manf	-0.01	0.009	0.062***	0.072***
	(0.009)	(0.008)	(0.013)	(0.008)
Controls	Yes	Yes	Yes	Yes
Grid FE	Yes	Yes	Yes	Yes
Group×Year-to-Reform FE	Yes	Yes	Yes	Yes
Observations	1,199,750	1,175,020	1,244,489	1,172,890
R-squared	0.963	0.963	0.961	0.962

Notes: The dependent variable is the natural logarithm of GPP. Robust standard errors in parentheses, clustered at the group level. Columns 1-4 are grouped according to the population density interval (people/km^2). We keep sample **from April to October** to avoid low productivity during cold season.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Human Activities

Dynamic Effects of CFTR on Groups Based on Human Activities

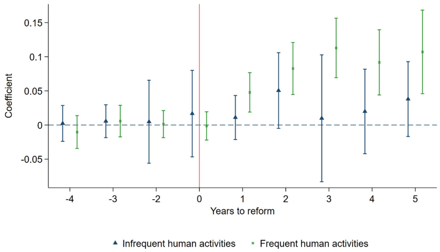

Figure 9: Panel A Group Set 1

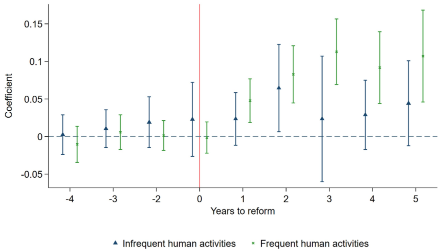

Figure 10: Panel B Group Set 2

Notes: Panel A and B are estimated using equation (3), grouping based on human activities, measured by population density. Two Groups in Panel A are divided with a boundary of **15** (people per km^2). The groups of frequent human activities in Panel A and B are the same, while the population density in the group of infrequent human activities in Panel B is **less than 15 but no less than 1** (person per km^2)

Conceptual Framework

A Modified Model of the Optimal Harvest Decision (Hartman, 2018)

$$V(t) = \int_0^t e^{-rx} F(x)dx + e^{-rt}(G(t) - c) \tag{6}$$

$$V'(t) = 0 \Rightarrow F(t) + G'(t) = r(G(t) - c)$$

- $\mathbf{G(t)}$: stumpage value of the lumber in a forest of age t.
- $\mathbf{F(t)}$: other ecological services value flowing (e.g. carbon sink)

Different Management Scenarios

- **State-owned (After CFTR)**: no harvest (*NFPP*)
- **State-owned (Before CFTR)**: not so optimal governance
- **Collective (1st)**: ignore environmental value (hinder productivity)
- **Collective (2nd)**: **closer to optimal level with human participation**
  - ◇ **Experienced**: more information about the **heterogeneity** of trees
    - ✓ more accurate $\mathbf{G(t)}$ and $\mathbf{F(t)}$
  - ◇ **Cost-saving**: shorter distance access to the trees (**less** $\mathbf{c}$)

CFTR-induced Human Activity

Replace the Outcome Variable as $\ln \text{pop}$

$$\begin{aligned}\ln pop_{ijt} = & \alpha + \beta_1 Manf_i \times Event_{jt} + \beta_2 Reform_{jt} \times Manf_i \times Event_{jt} \\ & + X_{it}\gamma + \psi_i + \theta_t + \varepsilon_{ijt}\end{aligned} \tag{7}$$

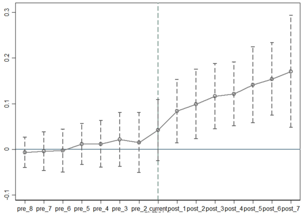

Figure 11: Human activity intensity dynamic effects

- CFTR slows down **population loss** in forest areas
- Simultaneous **growth of forestry GDP** in Northeast China after CFTR

Cultivated/Forest Ratio

Grids with better agricultural practices will achieve more increase in GPP

- $[0, 50\%]$: far away from villages, mountainous area
- $[50\%, 200\%]$: closer to villages, exposed to **more frequent human activity**
- $[200\%, +\infty)$: cultivated fields are not be treated by CFTR

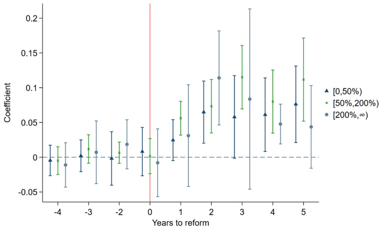

Figure 12: Heterogeneous Effects Based on **Cultivated/Forest Ratio**

Notes: This panel is estimated using equation (3) with groups of different types of land cover, measured by the ratio of cultivated land area to forest area.

Dynamics Multiplier

$$
\begin{aligned}
GPP_{ijt} &= \alpha + n_{-4}\ln(pop_{i,t-4}) + \sum_{k=-3}^{4}[\mathbf{n_k}\Delta\ln pop_{i,t+k}] + \delta_{-4}Manf_i \times \ln pop_{i,t-4} \\
&+ \sum_{k=-3}^{4}[\delta_{\mathbf{k}} Manf_i \times \Delta\ln pop_{i,t+k}] + v_{-4}Manf_i \times \ln pop_{i,t-4} \times Reform_{j,t-4} \\
&+ \sum_{k=-3}^{4}[\mathbf{v_k} Manf_i \times \Delta\ln pop_{i,t+k} \times Reform_{j,t+k}] + X_{it}\gamma + \psi_i + \theta_t + \varepsilon_{ijt}
\end{aligned} \tag{8}
$$

- **base year**: $t-4$, net change of $\ln pop$ every year
- $\mathbf{n_k}$: absorb the ATE of all the human activity intensity on the all forest area
- $\delta_{\mathbf{k}}$: absorb the effects of additional effect by human activity intensity change on collective forest lands **vs.** state-owned
- $\mathbf{v_k}$: additional effect based on $\delta_{\mathbf{k}}$, but after CFTR

Dynamics Multiplier

CFTR transforms the conventional dynamic between human activities and forest ecosystems.

- **No adverse causality**: the change of human activity has no effects on earlier GPP
- **Before**: the increase of human activity **decreases** the GPP level
- **After**: the increase of human activity **increases** the GPP level

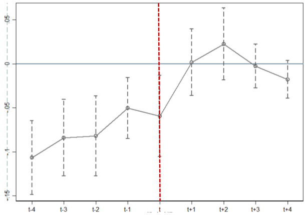

Figure 13: **Panel A** Before CFTR

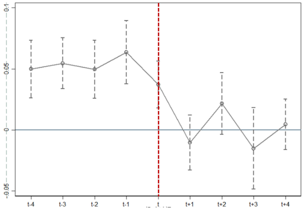

Figure 14: **Panel B** After CFTR

Notes: Panel A and B are estimated using equation (8).

Takeaways & Discussion

Findings

- CFTR leads **long-lasting** increase of GPP level (about **3% to 5%**)
- Significant in areas with better **agricultural practices** and more frequent **human activities**
- More **agricultural population participation** is a possible mechanism

Policy Implications

- **Role of Management**: Managing **existing** trees better is more efficient to capture carbon than **planting new**
- **Role of Human Activities**: Complement previous research on **human-induced degradation** with positive evidence

Applications: "win-win" in the new-round forest tenure reform *(started from Sep. 2023)*

- More **Productivity** (Release huge carbon sink potential for **neutrality**)
- More **Employment** (Develop "Under-forest Economy")

Thank You!

- *Thank You!*
- We appreciate any comments:
  - cuity23@mails.tsinghua.edu.cn
  - fangc23@mails.tsinghua.edu.cn
  - yszhang2019@nsd.pku.edu.cn

Appendix: GPP Change in Northeast China

Gross Primary Productivity (GPP): the amount of organic carbon fixed by organisms, through photosynthesis per unit of time.

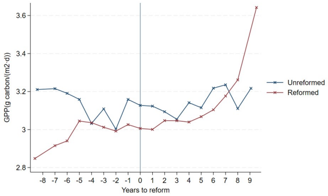

Figure 15: Trends in GPP of Reformed and Unreformed Land

- **prior**: average GPP of collective forests was **lower**
  - ◇ natural forests have higher biodiversity and better ecosystem function
- **post**: increased and **surpassed** state-owned after 7th year since CFTR
  - ◇ **improvement in management stimulates productivity?**

Appendix: More Details about CFTR

Basic Mandate

- Clarify forest tenure, Reduce taxation and fees
- Activate management, Standardize transfer

Achievements

- **Collective Forest stock**: 4.60 to 6.99 billion m^3
- **New Business Entities**: 283k, operating more than 300 million *mu*
- more than **80% of domestic timber** and **80% of economic forest products**
  - ◇ Camellia oleifera, walnut, pepper, goji berries and Ganoderma lucidum

Challenges

- Low comprehensive benefit
- Fragmentation of forest land

Notes: This is the formal document unveiled by the State Council in 2008. For more information, please click here. About the plan for new-round deepening CFTR started from 2023, please click here.

Appendix: Achievements of CFTR

- e.g. **Liaoning Province**
  - ◇ By March 2008, Liaoning had completed CFTR, over 72 million mu of land rights confirmed, accounting for 92% of the total
  - ◇ Over 4 million households and more than 13 million farmers benefit from the reform
  - ◇ in *Benxi* City, forestry accounted for 59% of farmers' per capita income, reaching 2,367 yuan (2006)

Appendix: Case 1

一番努力后，超采、盗伐、毁林等现象，得到了有效遏制；森林资源，得到有效保护。鉴于伊春对森林资源保护做出的突出贡献，前不久，联合国授予该市“绿色伊春”称号，授予市长“森林使者”称号。

林要保护，人要吃饭。那么，怎样才能从根本上保住资源，同时又可解决林区职工奔小康难题？新班子认为：关键是要解决林业职工与森林资源责权利不统一的矛盾，进行林权改革，让林业职工家家有其山，户户有其林。

目前，此项改革，已在该市桃山林业局开始实验。结果表明，林权活了，希望有了。

林权改革，不仅使林区职工奔小康有了保障，也使他们在森林培育及管护上更加精心。职工栾德利补植落叶松1．25万株，成活率达98％，使每公顷林木株数，由原来的800多株，增加到4000多株，且由于每天精心管护，林中至今没少一棵树。

替代产业迅速发展。五营林业局今年仅绿色食品产业中的黑木耳一项，产量就高达2500吨，实现销售收入1．2亿元，木耳栽培户户均纯收入超2万元。以都柿、山葡萄、五味子等山野果为原料的果酒、饮料生产企业，也迅速发展到7家，实现产值近亿元。

Notes: This is the snapshot of news reported by *Sina* in 2005.

Appendix: Case 2

徐长思在发展林上经济的同时，发展了各种短期的林下经济，他希望到期将有上千万的回报。

徐长思现在几乎全天泡在林子里：每天早上4点起床去林子里，下午5点多才回家，午饭也是自带，在山上解决。“自己的东西就不能再祸害了，得精心地侍弄。”

在老徐的规划中，林地被划分为用材林、种子林和经济林三个林区。目前，用材林栽植落叶松11.5万株，杨树1万株，云杉0.3万；种子林种植红松0.5万株；经济林种植五味子5万株，种植林下人参5亩。

“神树的五味子很出名，都出口到韩国、日本，现在湿的每公斤在10元左右，干的每公斤可以买到70—80元”徐长思的妻子张喜英是该林业局科技科科长，懂得五味子的经济价值。

Notes: This is the snapshot of news reported by *Sina* in 2006.

Appendix: Land Coverage Distribution

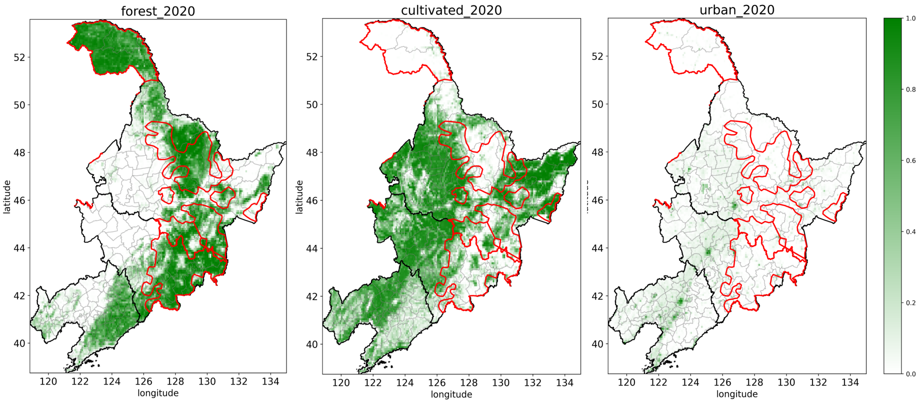

Figure 16: Land Coverage from GlobeLand30 (**Red lines**: NFPP boundary)

Appendix: Population Distribution

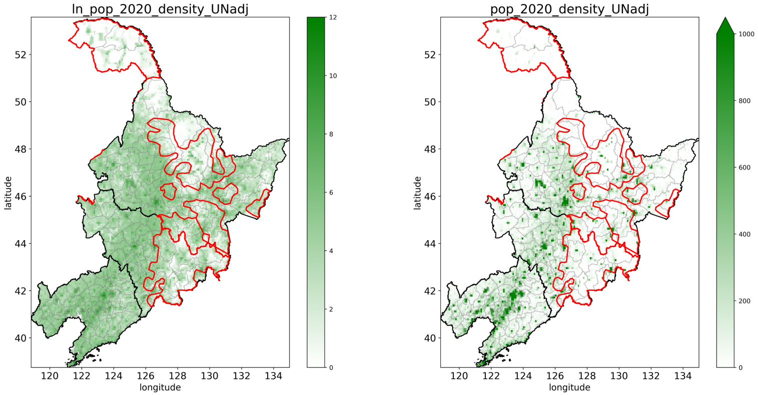

Figure 17: Population data from WorldPop (**Left**: $\ln(pop + 1)$; **Right**: Raw Data)

Appendix: More Details about Population data

Calculation

- **Resource**: **census-based** population count data from UNPD
- **Method**: **random forest**-based dasymetric redistribution

Why grid-level data?

- align with our **natural variable**
- **high resolution** in space and time (frequently update)
- convenient for **visualization and spatial analysis**

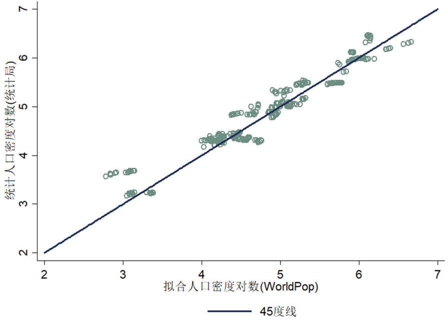

Figure 18: comparison of population data

Notes: This figure shows the difference of population data is small enough between the Worldpop (used by us) and National Bureau of Statistics in China (most dots are around the 45 degree line).
For more information about the accuracy of WorldPop dataset, please click here.

Appendix: More Details about GPP data

Calculation Method Data

- **Derived** from original satellite remote sensing data provided by ORNL DACC
- **Inverted** using the Monteith Light Use Efficiency Model (LUE) equation
- **Represented** various climate, landscape, and vegetation factors
- **Yields** highest GPP estimation accuracy compared to other methods

Reasons for choosing GPP

- **Coverage**: Wide spatial range, making analysis easier compared to labor-intensive field measurements
- **Representation**: directly related to biological carbon and representing various forest parameters
- **Dynamic insight**: dynamic assessment of forest productivity (forest health and ecosystem dynamics)

Appendix: Directions for Future Research

Other Consequences from CFTR

- Reduced **air pollution**
  - Revisit the effects of **Great Green Wall** (or "Three-North" Shelter Belt)
  - whether tree-planting program effective enough?
- Better **biodiversity**
- Less **secondary forests** $\Rightarrow$ more livable **habitats**

Unbalanced Effects

- locally absorbing heat (artificial forests) to mitigate the global warming
- **Local**: Costs $>$ Benefits $\Leftrightarrow$ **Global**: Costs $<$ Benefits

Community Management

- extension to other emerging economies (e.g. Colonial independent countries)

Abman, Ryan and Clark Lundberg, "Contracting, market access and deforestation," *Journal of Development Economics*, 2024, p. 103269.

Athey, Susan and Guido W Imbens, "Design-based analysis in difference-in-differences settings with staggered adoption," *Journal of Econometrics*, 2022, *226* (1), 62–79.

Berazneva, Julia and Tanya S Byker, "Does forest loss increase human disease? Evidence from Nigeria," *American Economic Review*, 2017, *107* (5), 516–521.

Callaway, Brantly and Pedro HC Sant'Anna, "Difference-in-differences with multiple time periods," *Journal of econometrics*, 2021, *225* (2), 200–230.

Cengiz, Doruk, Arindrajit Dube, Attila Lindner, and Ben Zipperer, "The effect of minimum wages on low-wage jobs," *The Quarterly Journal of Economics*, 2019, *134* (3), 1405–1454.

Chankrajang, Thanyaporn, "State-community property-rights sharing in forests and its contributions to environmental outcomes: Evidence from Thailand's community forestry," *Journal of Development Economics*, 2019, *138*, 261–273.

Chari, Amalavoyal, Elaine M Liu, Shing-Yi Wang, and Yongxiang Wang, "Property rights, land misallocation, and agricultural efficiency in China," *The Review of Economic Studies*, 2021, *88* (4), 1831–1862.

Chen, Juan and John L Innes, "The implications of new forest tenure reforms and forestry property markets for sustainable forest management and forest certification in China," *Journal of Environmental Management*, 2013, *129*, 206–215.

Chen, Jun, Xin Cao, Shu Peng, and Huiru Ren, "Analysis and applications of GlobeLand30: a review," *ISPRS International Journal of Geo-Information*, 2017, *6* (8), 230.

Deshpande, Manasi and Yue Li, "Who is screened out? Application costs and the targeting of disability programs," *American Economic Journal: Economic Policy*, 2019, *11* (4), 213–248.

Goodman-Bacon, Andrew, "Difference-in-differences with variation in treatment timing," *Journal of econometrics*, 2021, *225* (2), 254–277.

Han, Lu, Stephan Heblich, Christopher Timmins, and Yanos Zylberberg, "Cool cities: The value of urban trees," Technical Report, National Bureau of Economic Research 2024.

Hardin, Garrett, "The tragedy of the commons: the population problem has no technical solution; it requires a fundamental extension in morality.," *Science*, 1968, *162* (3859), 1243–1248.

Hartman, Richard, "The harvesting decision when a standing forest has value," in "Economics of Forestry," Routledge, 2018, pp. 295–302.

He, Xi and Zhenshan Chen, "Weather, cropland expansion, and deforestation in Ethiopia," *Journal of Environmental Economics and Management*, 2022, *111*, 102586.

Hou, Lingling, Pengfei Liu, and Xiaohui Tian, "Grassland Tenure Reform and Grassland Quality in China," *American Journal of Agricultural Economics*, October 2023, *105* (5), 1388–1404.

Jones, Benjamin A and Andrew L Goodkind, "Urban afforestation and infant health: Evidence from MillionTreesNYC," *Journal of Environmental Economics and Management*, 2019, *95*, 26–44.

Lerman, Zvi, "Land reform and farm restructuring: What has been accomplished to date?," *American Economic Review*, 1999, *89* (2), 271–275.

Liu, Can, Sen Wang, Hao Liu, and Wenqing Zhu, "Why did the 1980s' reform of collective forestland tenure in southern China fail?," *Forest policy and economics*, 2017, *83*, 131–141.

Liu, Shouying, Sen Ma, Lijuan Yin, and Jiong Zhu, "Land Titling, Human Capital Misallocation, and Agricultural Productivity in China," *Journal of Development Economics*, October 2023, *165*, 103165.

Ostrom, Elinor, *Governing the commons: The evolution of institutions for collective action*, Cambridge university press, 1990.

Peng, S, "1-km monthly precipitation dataset for China (1901–2017). National Tibetan Plateau Data Center," 2020.

Peng, Shu-Shi, Shilong Piao, Zhenzhong Zeng, Philippe Ciais, Liming Zhou, Laurent ZX Li, Ranga B Myneni, Yi Yin, and Hui Zeng, "Afforestation in China cools local land surface temperature," *Proceedings of the National Academy of Sciences*, 2014, *111* (8), 2915–2919.

Qin, Ping and Jintao Xu, "Forest land rights, tenure types, and farmers' investment incentives in China: An empirical study of Fujian Province," *China Agricultural Economic Review*, 2013, *5* (1), 154–170.

Rico-Straffon, Jimena, Zhenhua Wang, Stephanie Panlasigui, Colby J Loucks, Jennifer Swenson, and Alexander Pfaff, "Forest concessions and eco-certifications in the Peruvian Amazon: Deforestation impacts of logging rights and logging restrictions," *Journal of Environmental Economics and Management*, 2023, *118*, 102780.

Smith, Callum, JCA Baker, and DV Spracklen, "Tropical deforestation causes large reductions in observed precipitation," *Nature*, 2023, *615* (7951), 270–275.

Subramanian, Arjunan and Parmod Kumar, "Property rights, factor allocation and household welfare: Experimental evidence from a land titling program in India," *Journal of Development Economics*, 2024, *167*, 103238.

Sun, Liyang and Sarah Abraham, "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects," *Journal of econometrics*, 2021, *225* (2), 175–199.

Tatem, Andrew J, "WorldPop, open data for spatial demography," *Scientific data*, 2017, *4* (1), 1–4.

Wing, Coady, Madeline Yozwiak, Alex Hollingsworth, Seth Freedman, and Kosali Simon, "Designing difference-in-difference studies with staggered treatment adoption: Key concepts and practical guidelines," *Annual Review of Public Health*, 2024, *45.*

Xie, Yi, Peichen Gong, Xiao Han, and Yali Wen, "The effect of collective forestland tenure reform in China: does land parcelization reduce forest management intensity?," *Journal of Forest Economics*, 2014, *20* (2), 126–140.

—, **Yali Wen, Yaoqi Zhang, and Xiaoyong Li**, "Impact of property rights reform on household forest management investment: An empirical study of southern China," *Forest Policy and Economics*, 2013, *34*, 73–78.

Xing, Jianwei, Zhiren Hu, Fan Xia, Jintao Xu, and Eric Zou, "Urban Forests: Environmental Health Values and Risks," Technical Report, National Bureau of Economic Research 2023.

Xu, Jintao and William F Hyde, "China's second round of forest reforms: Observations for China and implications globally," *Forest Policy and Economics*, 2019, *98*, 19–29.

Yi, Yuanyuan, Gunnar Köhlin, and Jintao Xu, "Property rights, tenure security and forest investment incentives: evidence from China's Collective Forest Tenure Reform," *Environment and Development Economics*, 2014, *19* (1), 48–73.

Yin, Runsheng, Shunbo Yao, and Xuexi Huo, "China's forest tenure reform and institutional change in the new century: What has been implemented and what remains to be pursued?," *Land Use Policy*, 2013, *30* (1), 825–833.

Yu, Lingxue, Yongkang Xue, and Ismaila Diallo, "Vegetation greening in China and its effect on summer regional climate," *Science bulletin*, 2021, *66* (1), 13–17.