

Structural Change, Land Use and Urban Expansion

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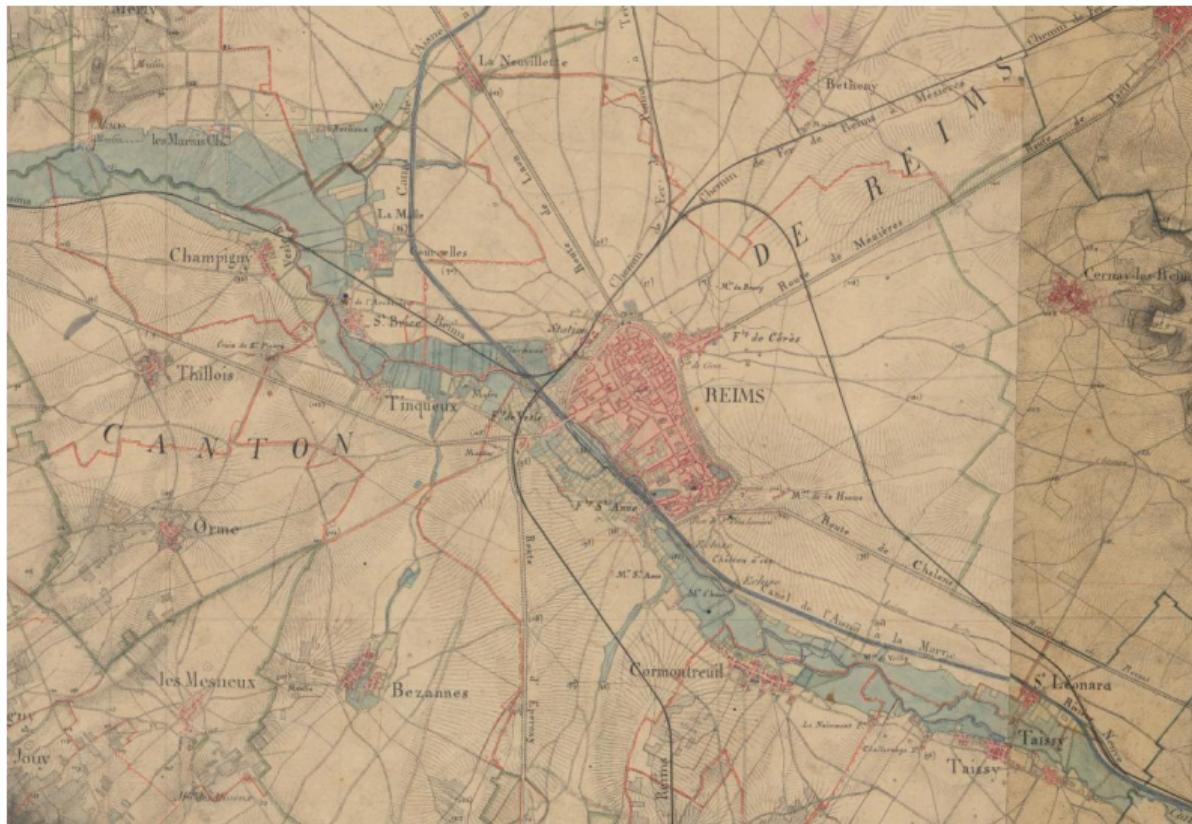
Florian Oswald (SciencesPo)

Marc Teignier (U. Barcelona)

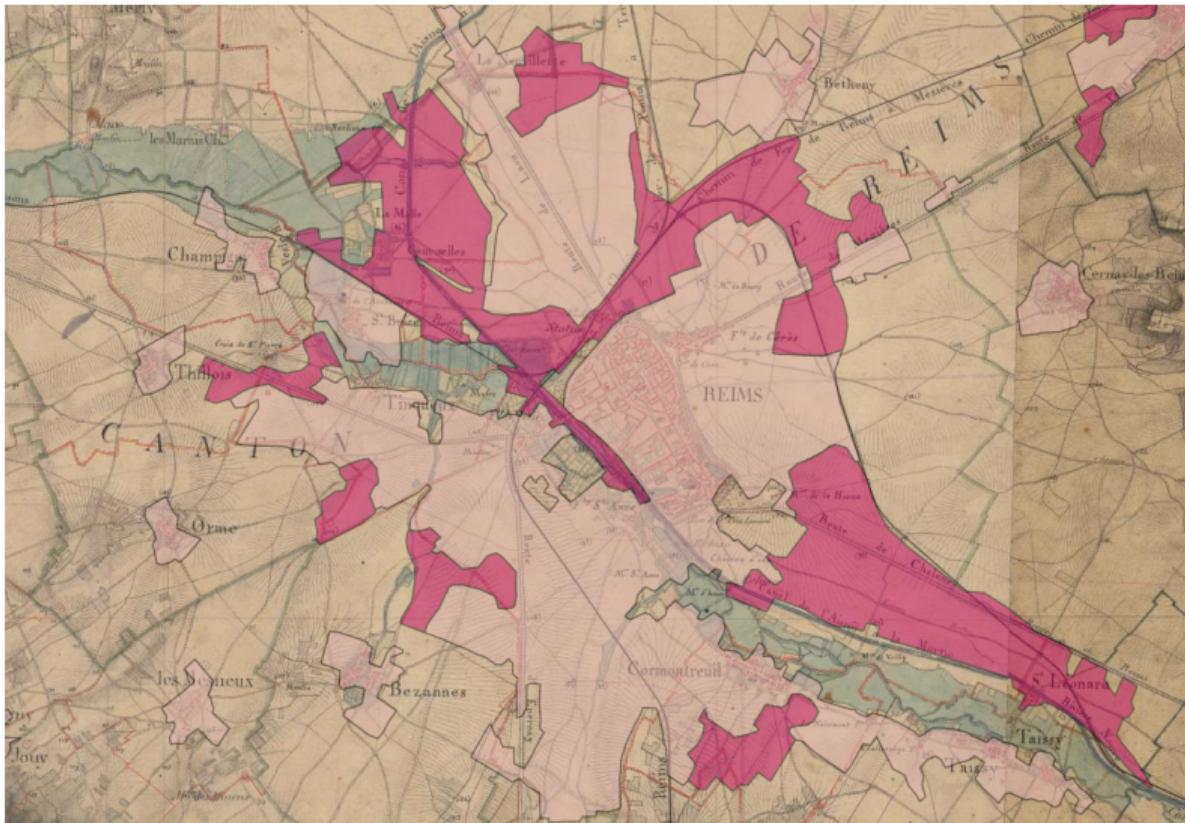
<https://floswald.github.io/publication/landuse/>

September 2023

Motivation: Reims in 1866



Motivation: Reims in 1866 vs IGN Buildings in 2017

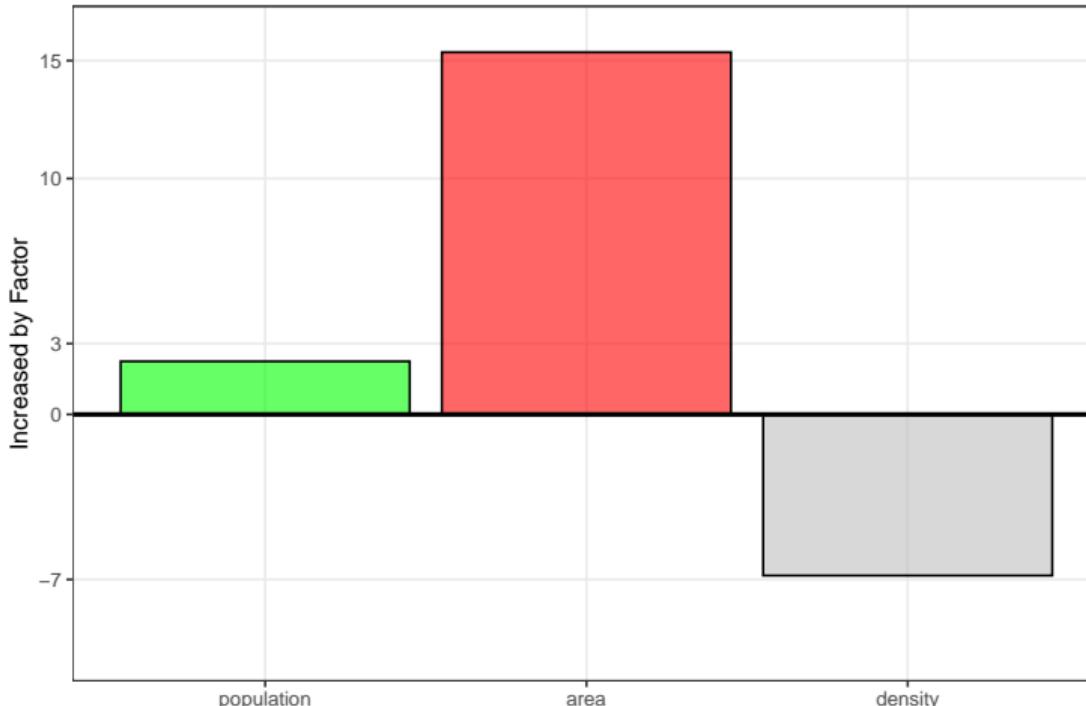


Motivation: Reims in 1950 vs IGN Buildings in 2017



Motivation: Fall in Urban Density

Reims from 1866 to 2015



- ▶ 50% work in Agriculture in 1866, 2% in 2015.
- ▶ Urban Surface increased about 15 fold.
- ▶ Density fell about 7 fold.
- ▶ Why?

Urban Expansion: Different Views

1. Urban Economics:

- ▶ Decline in commuting cost over time allows residing further away from city centre.
- ▶ New technologies (🚗 🚒 🚎) enable suburbanisation. 🏠

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This paper: Try to reconcile 🤝 both views in a unified framework.

Preview of Main Mechanisms

Transitory Dynamics with Rising Productivity and Falling Commuting Costs

- ▶ **Early Period:** Land is scarce. High values of farmland with respect to income due to low productivity ('food problem'). Small homes, low opportunity cost of time. Very small and dense, *walkable* cities.

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- ▶ **Nowadays:** Reallocation of factors/land use slows down. Cities expand less and land prices increase more with rising productivity.

Why Do We Care?

A general equilibrium spatial model of land use

- ▶ Understanding land/housing prices across space and time in the long-run.
 - ▶ Housing Affordability crisis.
- ▶ Understanding sprawling and soil artificialization.
 - ▶ Environmental impact (IPCC (2019)).
- ▶ Implications for welfare and aggregate productivity of land use restrictions. [not there yet]
 - ▶ Is sprawling 'excessive'? Benefits of compact cities?
 - ▶ General equilibrium implications of lowering commuting costs.

Related literature

(Traditional) Macro and Land Values

- ▶ Ricardo (1817), Nichols (1970), Grossman and Steger (2016). Measurement. Morris and Heathcote (2007), Piketty and Zucman (2014), Knoll, Schularick and Steger (2017), Miles and Sefton (2020)

(Macro) Structural Change

- ▶ Survey: Herrendorf, Rogerson and Valentinyi (2014). Theory: Kongsamut et al. (2001), Gollin et al. (2002), Boppart (2014), Acemoglu and Guerrieri (2008), Ngai and Pissarides (2007)...
Structural change and urbanization. Lewis (1954), Michaels et al. (2012). Eckert and Peters (2018).
- ▶ Agricultural Productivity Gap. Gollin et al. (2014), Lagakos and Waugh (2013), Young (2013), Restuccia et al. (2008).

Urban — Size and Expansion of Cities

- ▶ Theory. Alonso-Mills-Muth. Surveys by Duranton and Puga (2014, 2015). Brueckner (1990), Brueckner and Lall (2014), ...
Quantitative Spatial Economics. Redding and Rossi-Hansberg (2017). Sprawl/Density. Glaeser et al., Ahlfeldt et al. (2015), Angel et al. (2010)
- ▶ Land Prices and Rents. Combes et al. (2021), Combes et al. (mimeo 2021), Albouy (et al.) (2016, 2018), Glaeser et al. (2005).

Outline

1. Facts about Land use and Urban Expansion in France since 1840.
2. Theory
 - ▶ A general equilibrium model of structural change and land use
3. Quantitative analysis
 - ▶ Simple Version to generate intuition
 - ▶ Extended Quantitative Model to Match French data since 1840

Urban Expansion in France: Facts

Data Sources: France 1840–2016

- ▶ Land use and employment in agriculture across French regions
 - ▶ Historical: mostly from Toutain (1993) based on Recensement Agricole. Post-1950, Ministry of Agriculture.
- ▶ Employment and spending across sectors
 - ▶ Insee, Toutain (1993), Villa (1996), Herrendorf et al. (2014).
- ▶ The expansion of cities
 - ▶ Carte Etat-Major (1866), IGN (1950), Satellite Data post-1975 (GHSI data). Census for Population.
- ▶ Housing and Land Prices
 - ▶ Aggregate Historical: Piketty et al. (2014), Knoll et al. (2017). Farmland across regions: Ministère de l'Agriculture since 1950. Housing/Farmland Transactions: Base des Notaires.

Land and labor reallocation: Aggregate France

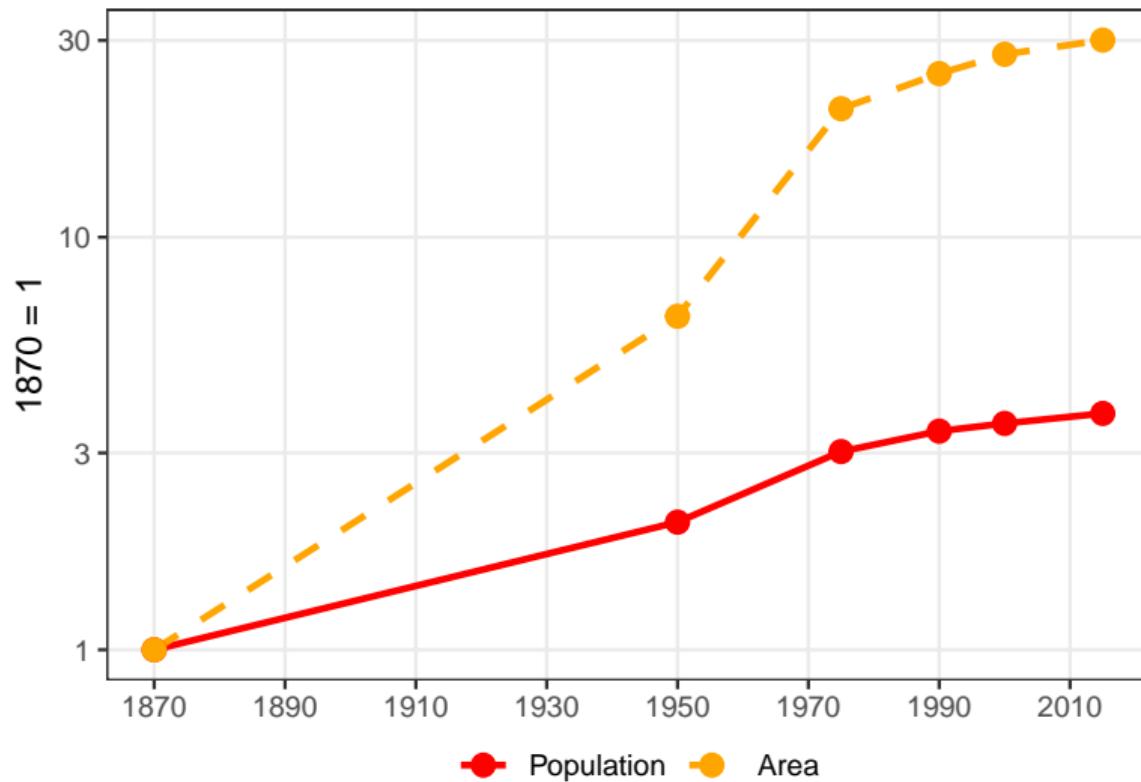


Sources:

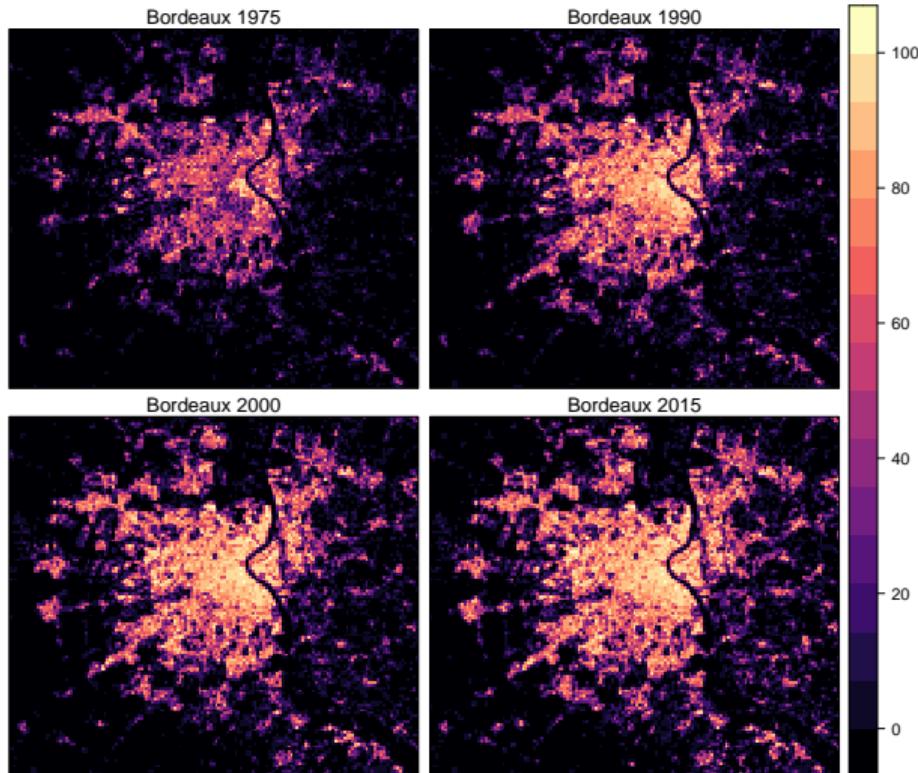
1. Toutain (1993)
2. Recensement Agricole (Ministry of Agriculture)
3. INSEE
4. Villa (1996)

Urban Expansion

Top 100 Cities in France



City Area and Population Measurement

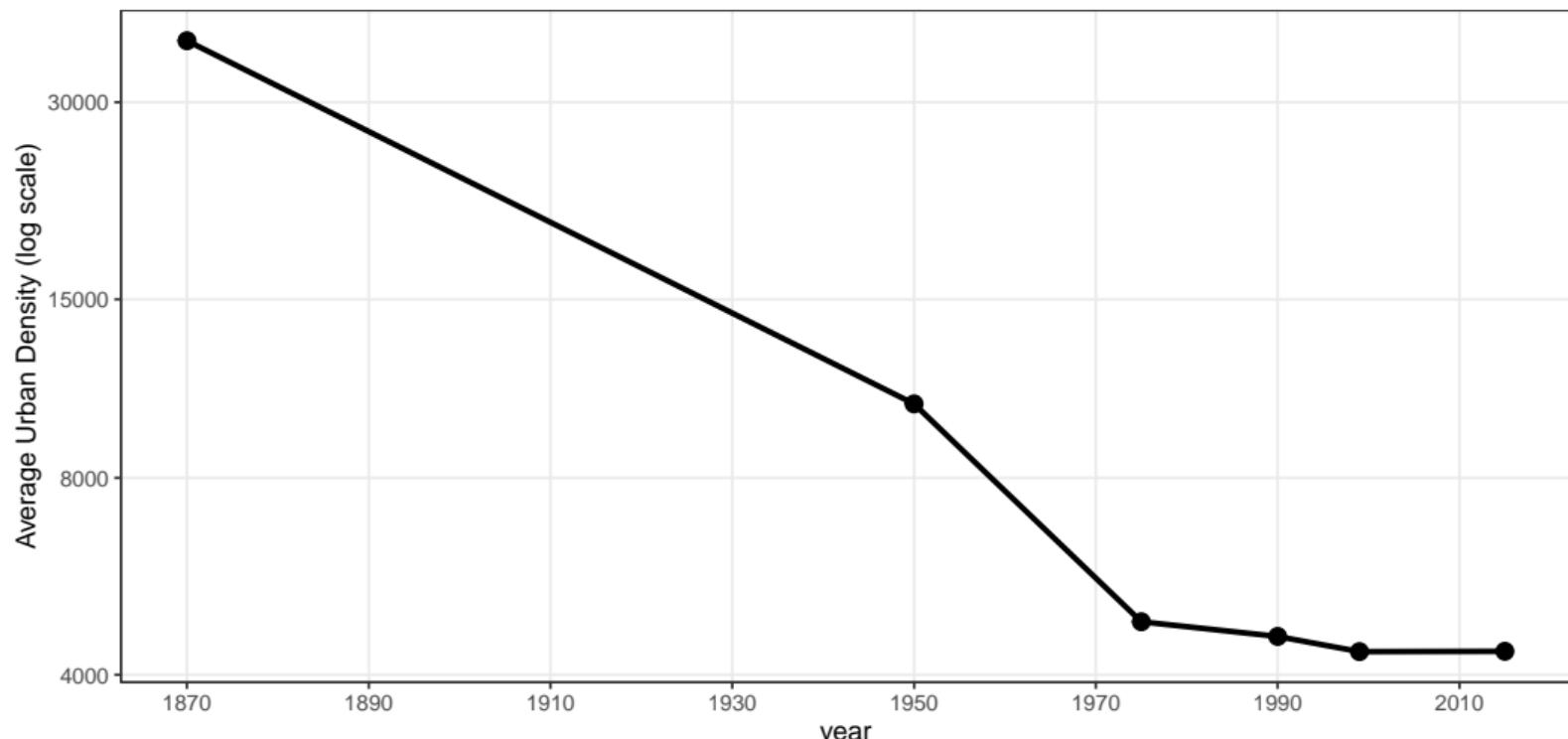


- ▶ 1866: Manual + Census
- ▶ 1950: Manual + Census
- ▶ 1975, 1990, 2000, 2015: GHSL
- ▶ More details please!

The Historical Fall in Urban Density

Mean Urban Density in France fell by Factor 9

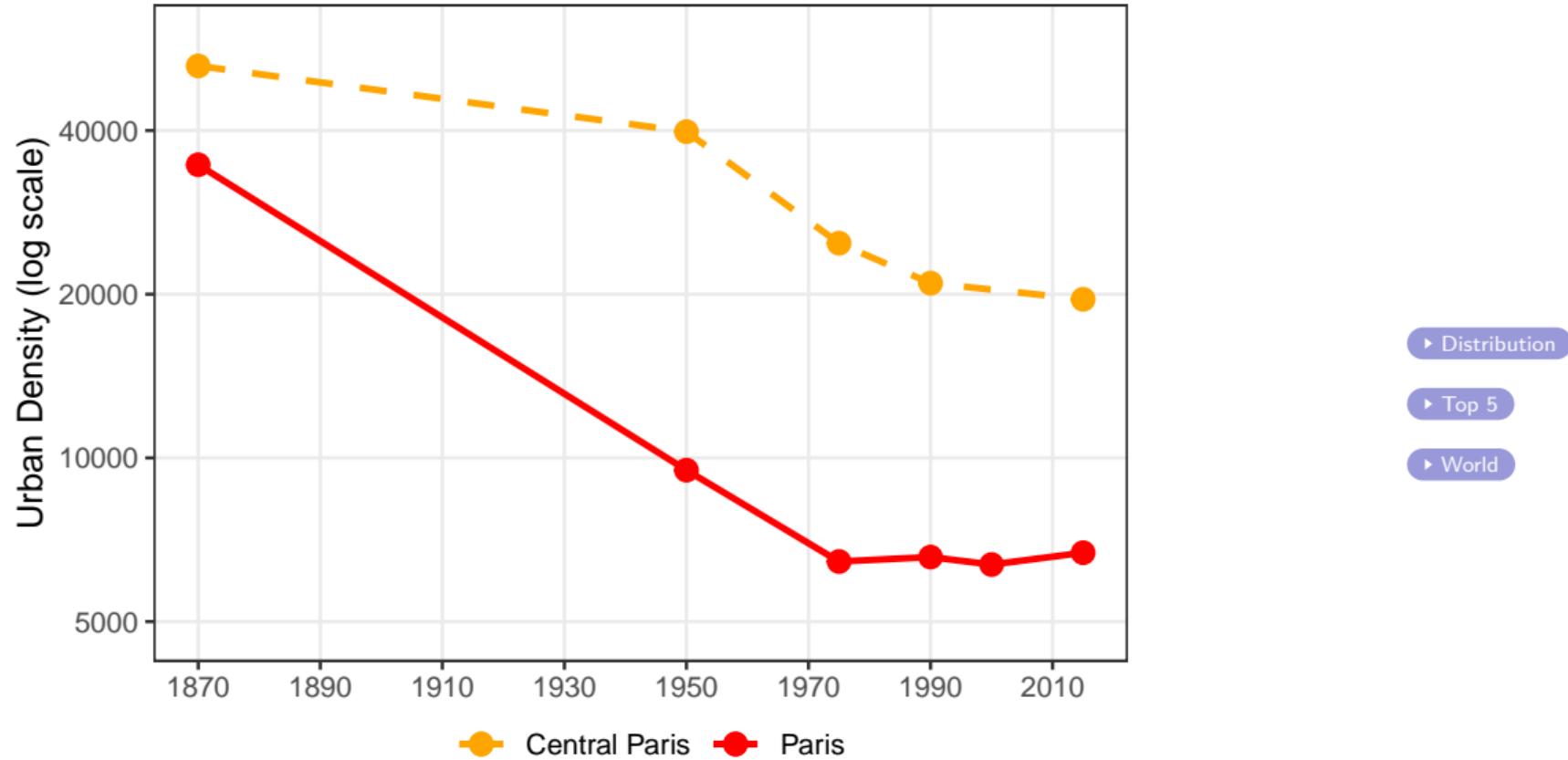
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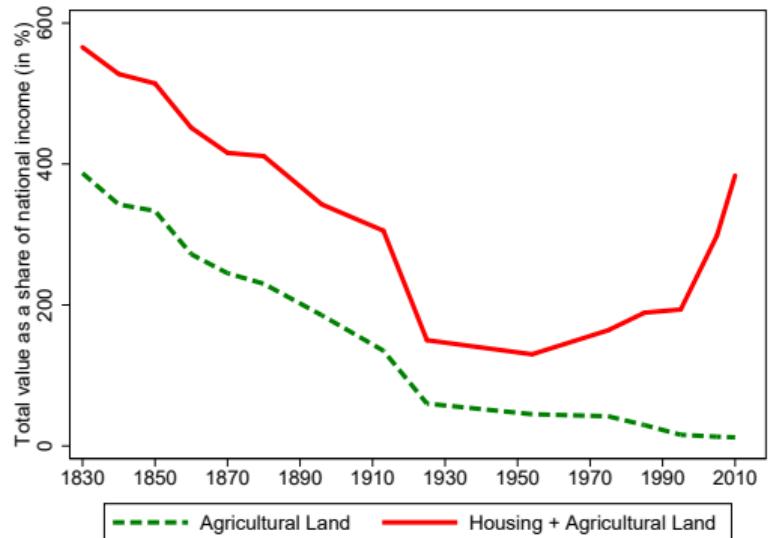
mean weighted by population in 1975



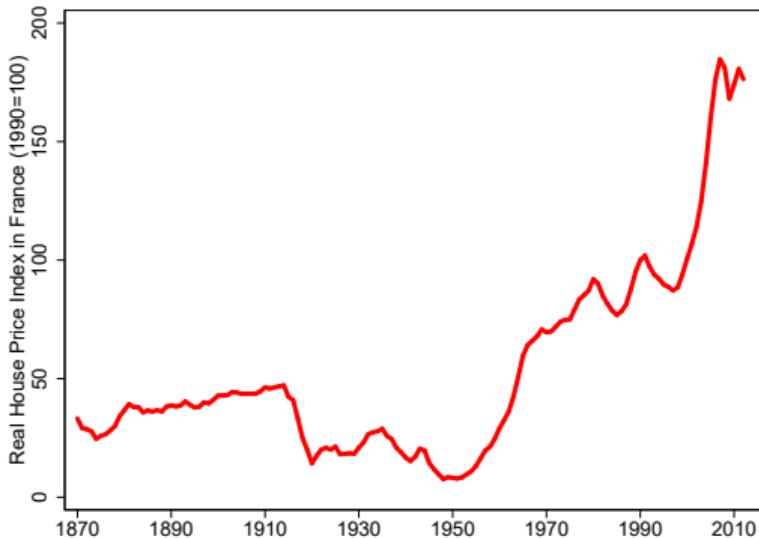
The Historical Fall in Urban Density: Within Paris



Fall in Agricultural Value Share and *Hockey-stick* in Housing Prices



(a) Picketty and Zucman (2014)



(b) Hockey Stick: Knoll et al. (2017)

Model

A general equilibrium model of land use

Set-up

- ▶ Three sectors and goods: rural (r), urban (u) and housing (h).
 - ▶ Different intensity in the use of land as input
 - ▶ Rival Land Use: Agriculture *or* Housing
 - ▶ Fixed Supply of Land
- ▶ Urban versus Rural Land: (Endogenous) commuting costs for urban workers.
- ▶ Drivers of Structural Change
 - ▶ Non-homothetic preferences for the rural good.
 - ▶ Increases in productivity during transition.

Technology

Urban and Rural goods Production

- ▶ For the urban good, only labor for simplicity,

$$Y_u = \theta_u L_u.$$

- ▶ For the rural good,

$$Y_r = \theta_r (L_r^\alpha \cdot S_r^{1-\alpha}).$$

- ▶ θ_i = TFP in sector i , L_i = labor used in i , S_r = land used in r .
- ▶ Rural good more intensive in land.
- ▶ Stronger decreasing returns to labor in (r).

Factor Payments

Urban wage,

$$w_u = \theta_u,$$

with (u) good numeraire.

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Rural wage w_r and rental price of rural land ρ_r ,

$$w_r = \alpha p \theta_r \left(\frac{S_r}{L_r} \right)^{1-\alpha},$$

$$\rho_r = (1 - \alpha) p \theta_r \left(\frac{L_r}{S_r} \right)^{1-\alpha}$$

where p the relative price of the rural good.

Preferences and budget constraint

- ▶ Non-homothetic preferences for an individual in location ℓ

$$C(\ell) = (c_r(\ell) - \underline{c})^{\nu(1-\gamma)} (c_u(\ell) + \underline{s})^{(1-\nu)(1-\gamma)} h(\ell)^\gamma,$$

$c_i(\ell)$ = consumption of $i = \{r, u\}$, housing consumption $h(\ell)$.

c, s subsistence consumption and initial endowment of urban good.

- ▶ Budget constraint,

$$pc_r(\ell) + c_u(\ell) + q(\ell)h(\ell) = w(\ell) + \mathbf{r},$$

$q(\ell)$ the (rental) price of one unit of housing in location ℓ .

\mathbf{r} rental income per capita, equally distributed.

Spatial Structure: Wage Function $w(\ell)$

Wages Net Of Commuting Costs in Spatial Equilibrium: $C(\ell) = \bar{U}$

1. Space $\ell \in [0, 1]$



Spatial Structure: Wage Function $w(\ell)$

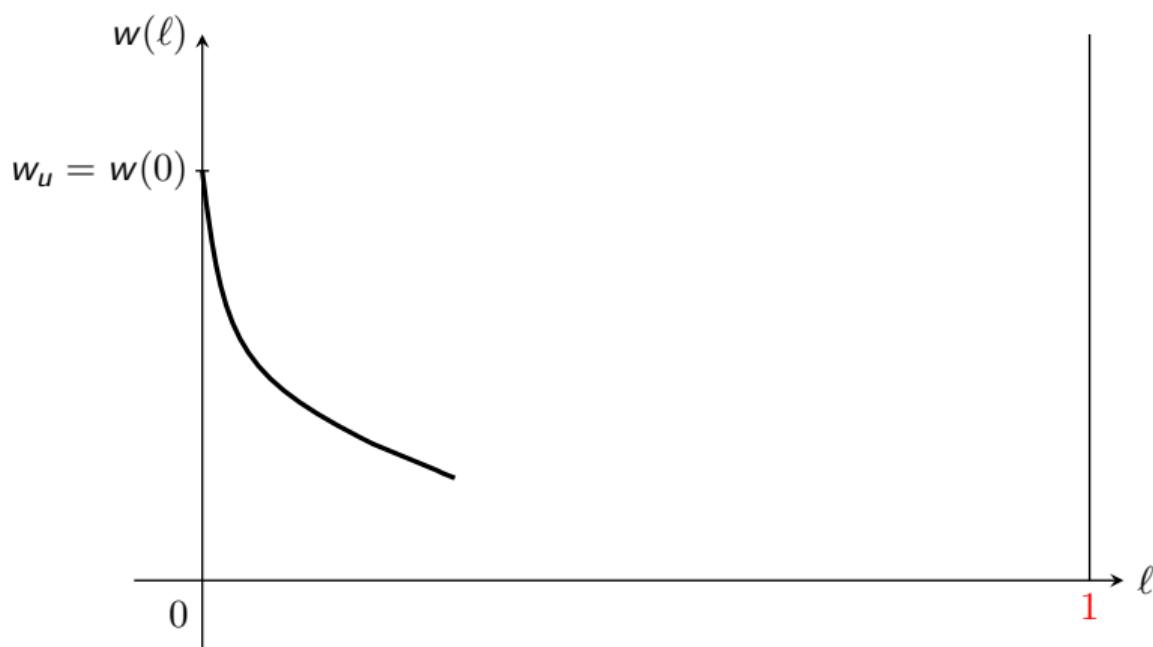
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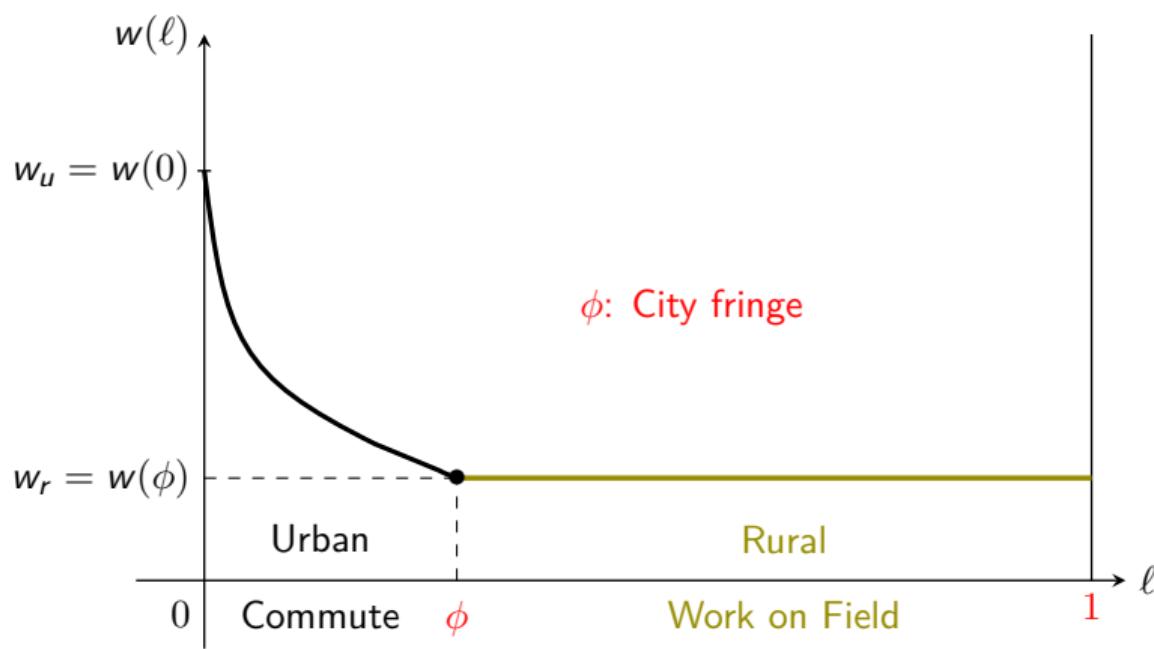
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4. $\tau(\ell)$: commuting cost from ℓ
5. $w_u - \tau(\ell)$ urban wage

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6. ϕ denotes urban fringe.

Commuting Costs in units of Numeraire Good

Based on DeSalvo and Huq (JUE 1996)

- ▶ Commuters choose best mode of transport.
- ▶ Opportunity cost of time (i.e. wage) and location matter.
- ▶ High urban wage → demand faster commute.



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- ▶ Balance marginal cost/benefit of faster mode:

$$\tau(\ell) = a \times (w_u \ell)^\xi$$

1. Faster commutes for people further away.
2. Speed increases with wage (opp. cost of time).
3. Elasticity of $\tau(\ell)$ wrt wage is strictly less than unity

Location Sorting

Spatial Equilibrium

- ▶ Indifference conditions across locations,

$$\bar{C} = C(\ell) = \kappa \frac{w(\ell) + \mathbf{r} + \underline{s} - p\underline{c}}{q(\ell)^\gamma}.$$

- ▶ Same house price q_r at ϕ and in the rural area, $q(\ell \geq \phi) = q_r$.
- ▶ Indifference at the fringe,

$$w(\phi) = w_u - \tau(\phi) = w_r$$

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- ▶ The last urban worker has same net wage as rural worker.
- ▶ Higher commuting costs deter rural workers to move into urban sector.

Equilibrium

- ▶ Land developers buy land and numeraire good to provide residential floorspace.
► Details!
- ▶ Arbitrage across land use at the fringe pins down land values and house prices:

$$\rho_r = \frac{q_r^{1+\epsilon}}{1+\epsilon} = (1-\alpha)p\theta_r \left(\frac{L_r}{S_r}\right)^\alpha$$

- ▶ Land Market Clearing.
- ▶ Labour Market Clearing.
- ▶ Land Rents consistently defined.

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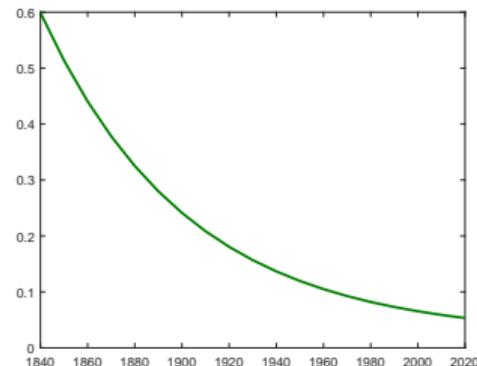
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- ▶ **Recent Times:** Reallocation of factors/land use slows down. Cities expand less and land prices increase more with rising productivity. Land particularly scarce in some locations.

Results:

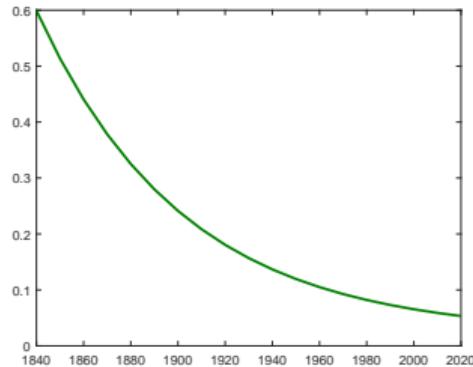
- 1. Toy Model**
- 2. Full Quantitative Model**

Toy Model: Identical Growth (1.25%) in Both Sectors

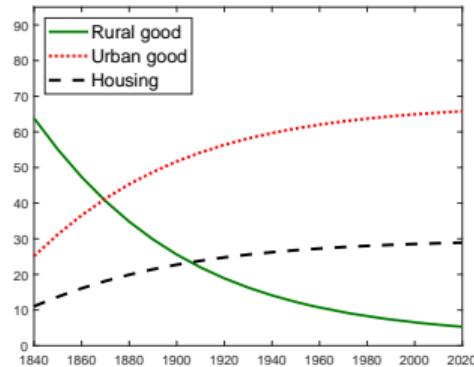


(a) Rural Employment share.

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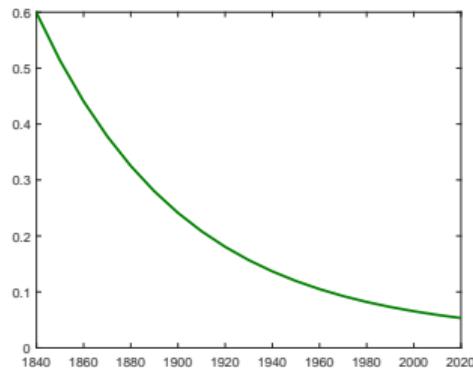


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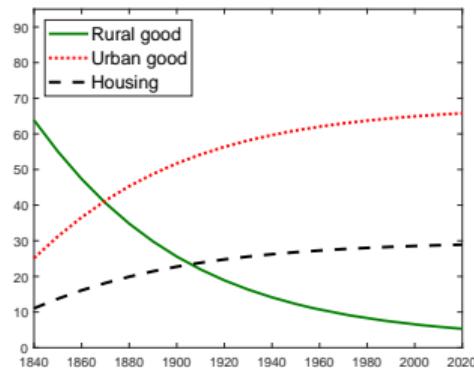


(b) Expenditure Shares.

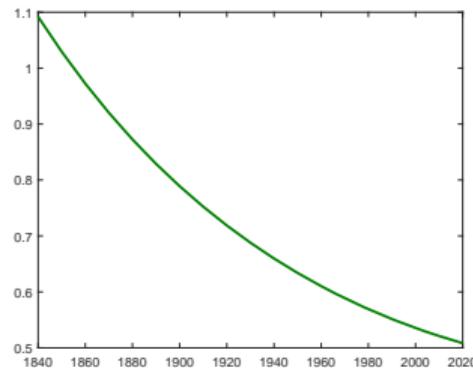
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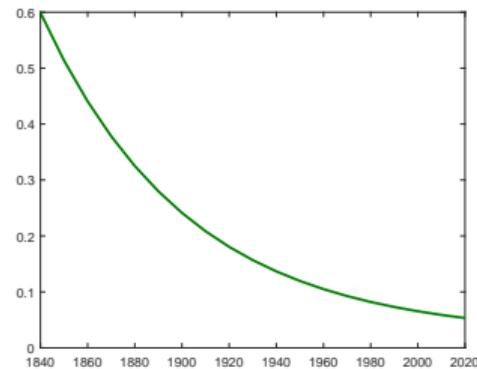


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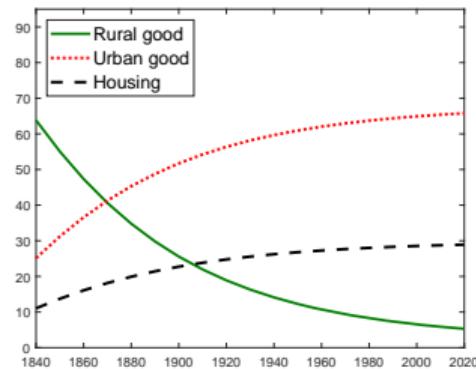


(c) r -price

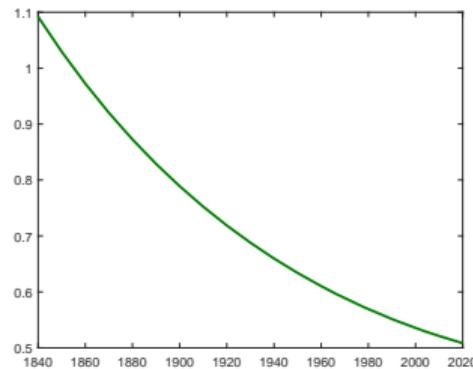
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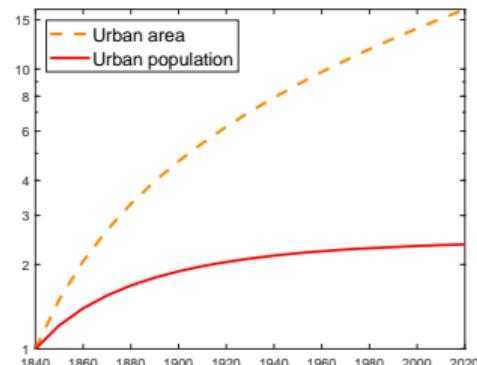
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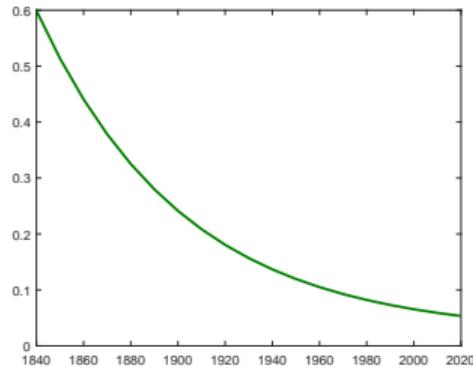


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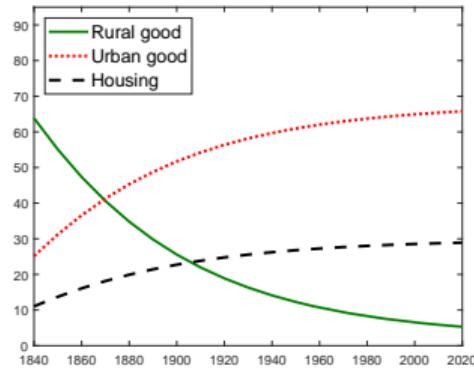


(d) City size (Index, 1840=1)

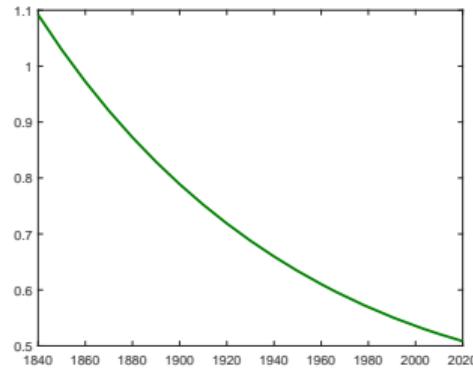
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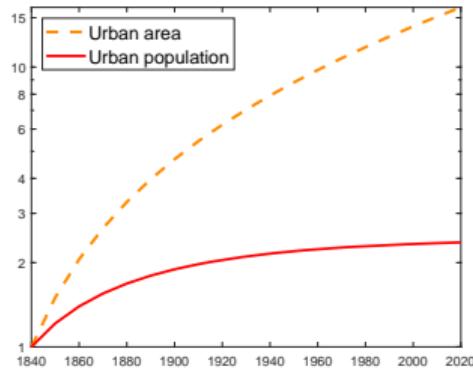
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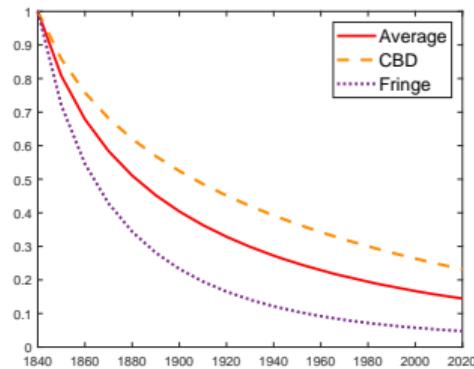
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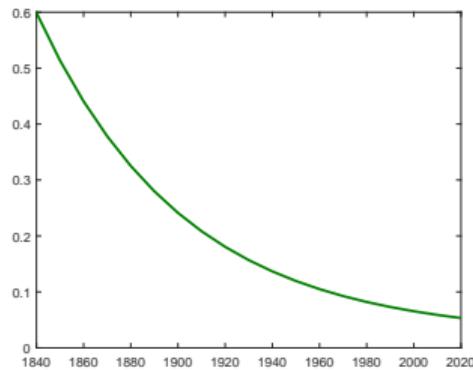


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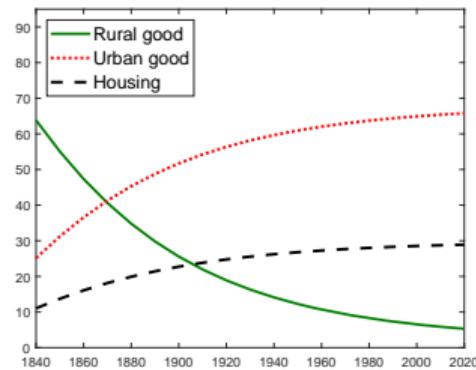


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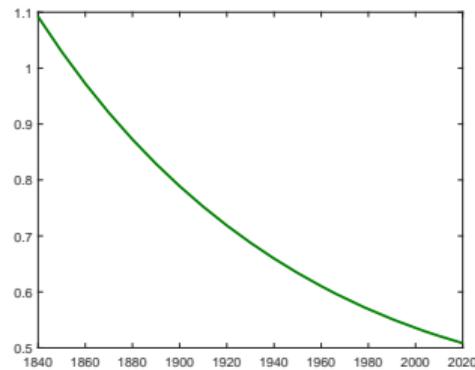
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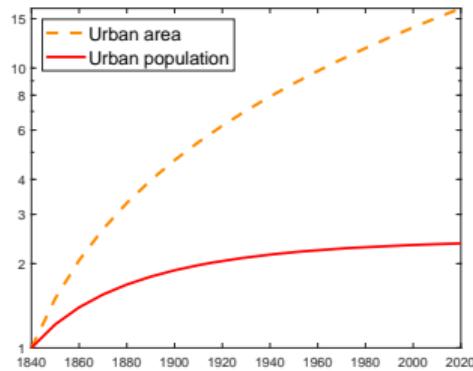
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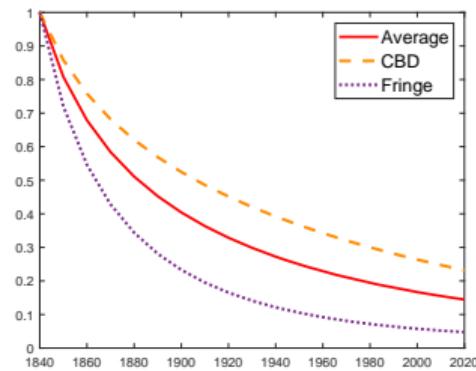
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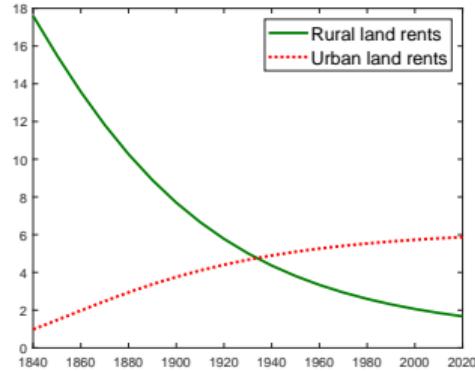
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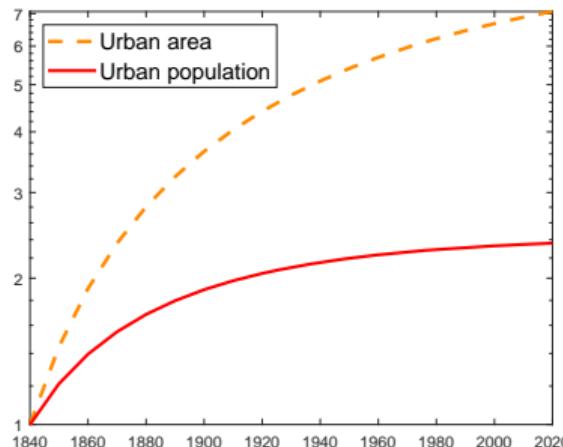
(e) Densities (Index, 1840=1)



(f) Land rents (%).

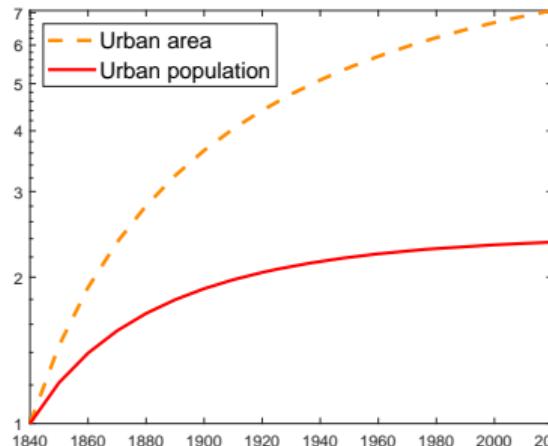
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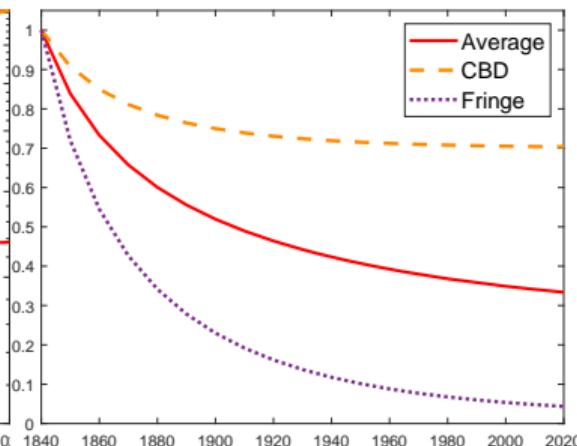


(a) Urban Population and Area

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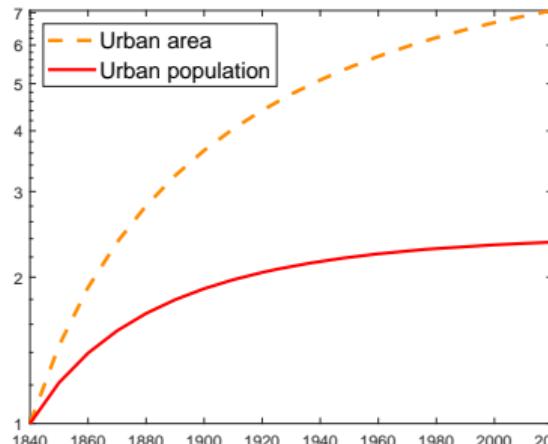


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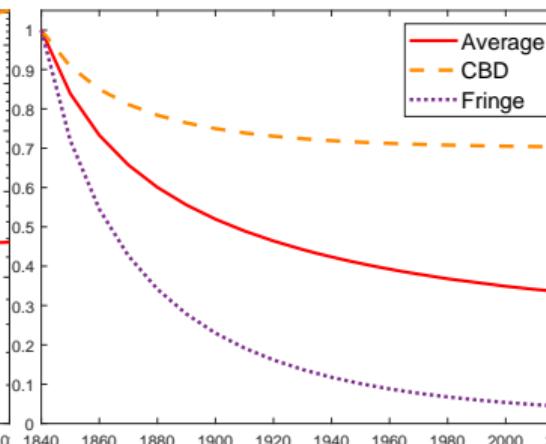


(b) Urban Densities

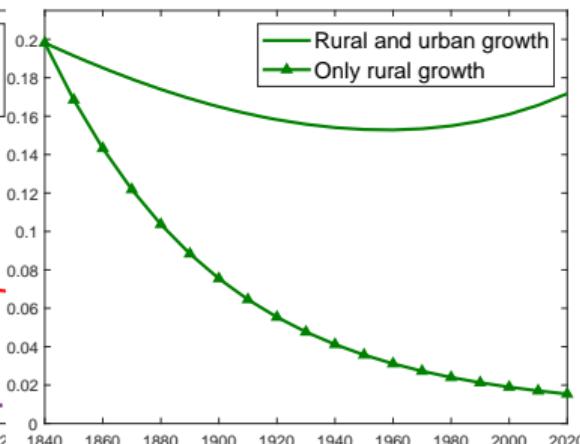
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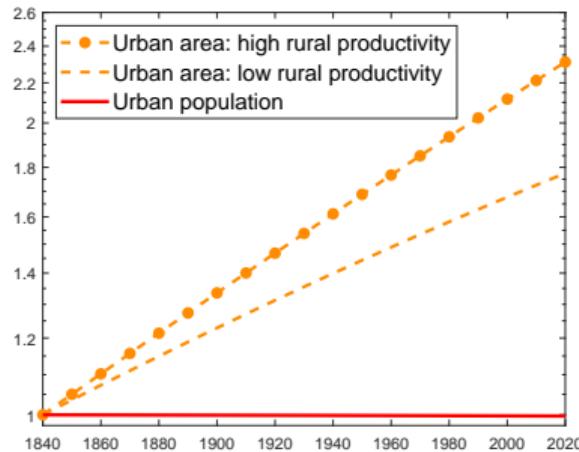
(b) Urban Densities



(c) Farmland Price

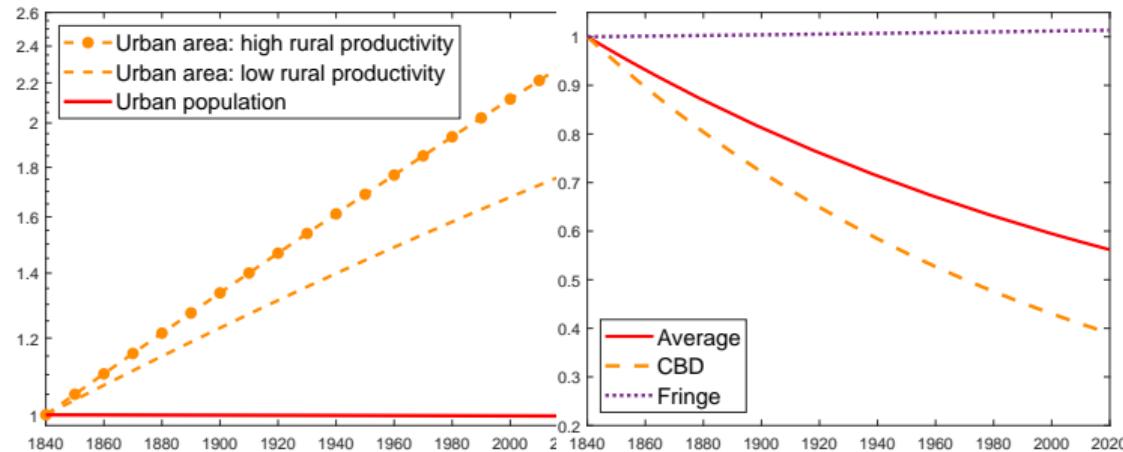
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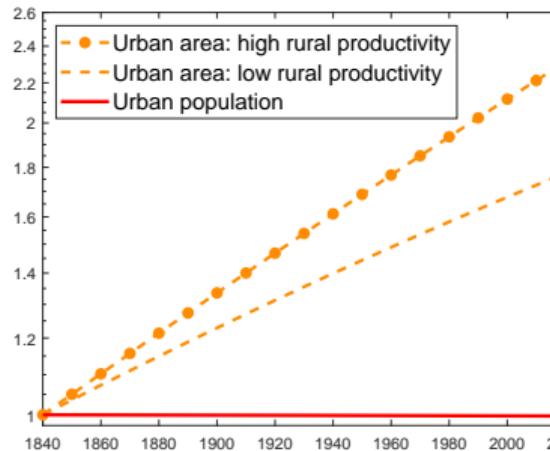
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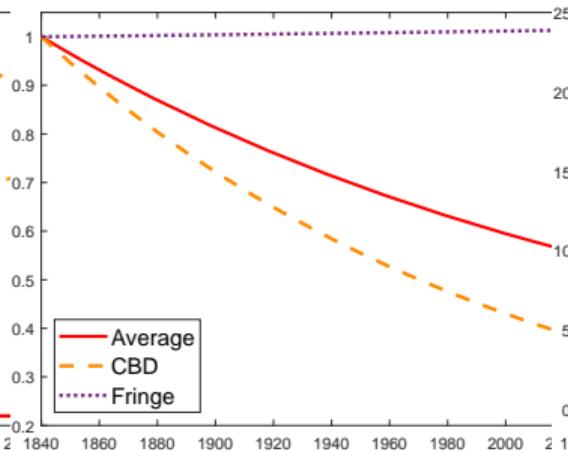
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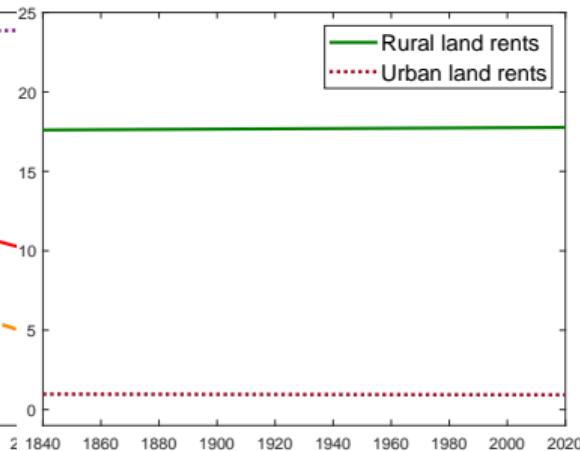
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(a) Urban Population and Area



(b) Urban Densities

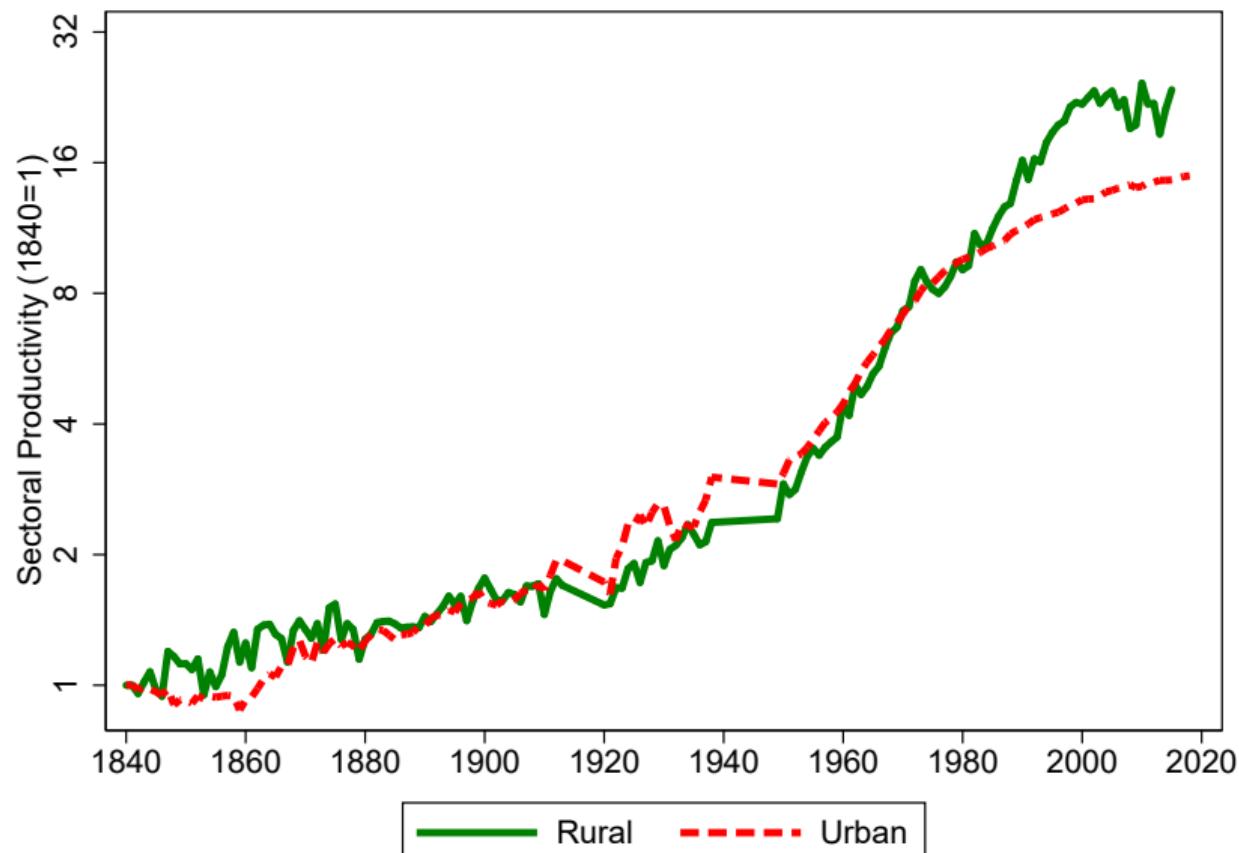


(c) Land rents over income

Full Quantitative Model and Parameterization

1. We estimate the *aggregate* θ_r, θ_u series from data.
2. We use observed population growth.
3. We use individual commuting data to directly calibrate the τ parameters. ▶ How?
4. Jointly estimate preference parameters to match set of moments.
5. We extend model to K regions/cities to take advantage of cross-sectional data.

Estimated θ 's



Full Quantitative Model: K Cities

- ▶ To leverage cross-sectional data, we extend the model to K regions with one city each.
- ▶ Each region/city has a different (exogenous) path of productivities in each sector s , i.e.

$$\theta_{s,k,t} = \theta_{s,t} \cdot \theta_{s,t}^k$$

where $\theta_{s,t}^k = 1$ collapses to the one-city model presented above.

- ▶ We impose that the aggregation reconstructs the *average* French city.
- ▶ Fit Population distribution and land value distributions across regions.

Estimation and Identification

We target the following moments:

Aggregate:

- ▶ L_{rt}/L_t : Aggregate employment share in each period.
- ▶ Average City is 18% of rural area in 2015.
- ▶ Aggregate spending share on housing 1900 and 2010.

Regional:

▶ Illustrate Identification

- ▶ L_{ukt}/L_{u1t} : Urban pop in city k rel. to city 1 (Paris) $\Rightarrow \{\theta_{u,t}^k\}$
- ▶ ρ_{kt}/ρ_{1t} : Farmland value outside city k rel. to city 1. $\Rightarrow \{\theta_{r,t}^k\}$

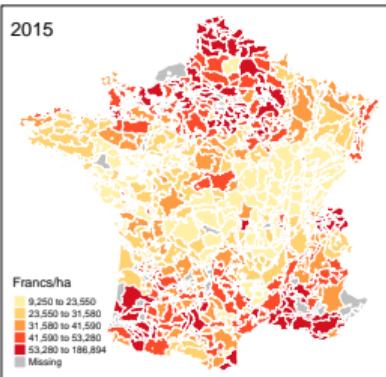
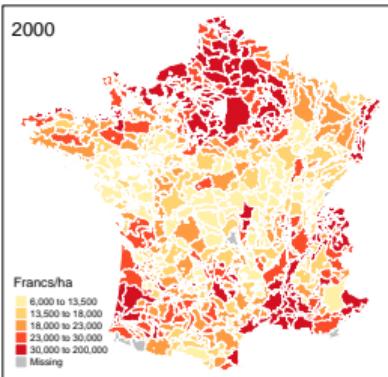
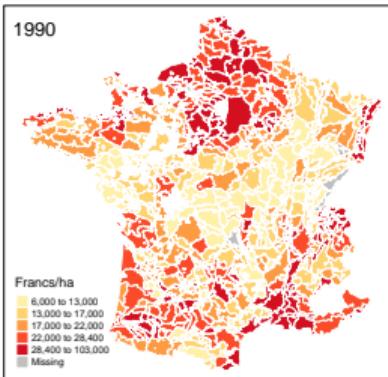
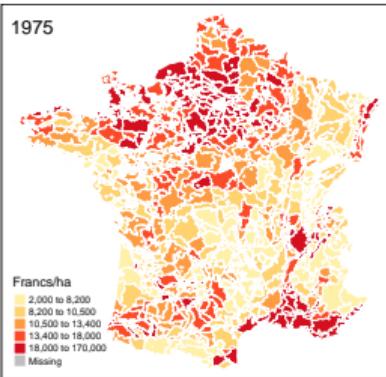
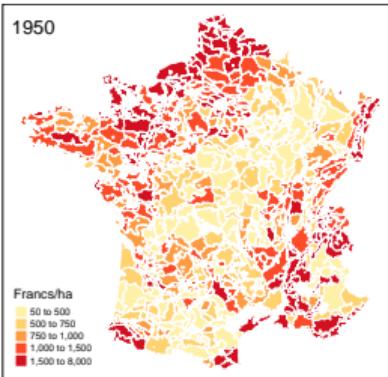
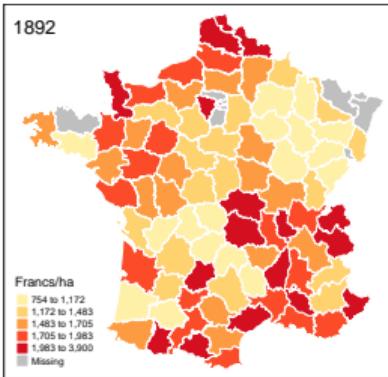
Internal city structure, density fall, commuting speed, house price: not targeted!

TABLEAU A-1 /suite)
EVOLUTION DU PRIX DES TERRES LABOURABLES DE 1950 A 1968 PAR REGION AGRICOLE

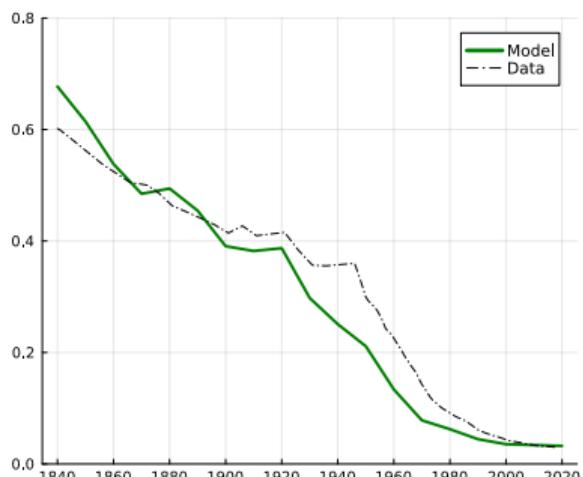
(Francs à l'hectare)

		1950	1953	1958	1960	1962	1963	1964	1965	1966	1967	1968	
26 463-RI	BARONNIES	DOM MINI MAXI	900 800 1000	900 800 1000	2200* 700 3000	2200* 700 4500	4500 1000 5000	4500 1000 5000	5000 2000 6000	5000 2000 6000	5000 1500 7000	5500 1000 11000	
26 464-KI	TRICASTIN	DOM MINI MAXI	2000 1000 4000	2000 1000 4000	2500* 700 3000	2500* 700 4500	6700* 2500 8000	6700* 2500 8000	6800 2500 8000	7500 2000 10000	7500 2000 11000	8000 1500 13000	
	ENSEMBLE DROME	MOYENNE INDICE	2500 39	2500 39	4100 63	4100 63	5900 93	6100 95	6100 95	6700 105	7000 109	7300 113	
ISERE													
38 199-EI	BAS DAUPHINE	DOM MINI MAXI	1000* 700* 3000*	1300 1000 4000	2750 1600 4000	2750 1600 4000	3000 2200 3500	5000 3500 5000	7000 3500 7000	8000 4000 13000	8500 5000 13000	9000 6000 15000	
38 217-AI	GRESIVAUDAN	DOM MINI MAXI	1500 1000* 4000*	2000 1200 5000	3000 2000 4500	3200 2000 5500	4000 4500 5000	7000 5000 9000	10000 6000 15000	11000 7000 15000	12000 6000 17000	12500 8000 18000	
38 453-PI	PREALPES	DOM MINI MAXI	500* 200* 2000*	600 250 2000	2500 1500 3500	2500 1500 3500	3500 1500 3000	3500 1500 4500	3600 1000 4000	4000 1000 4000	4000 1000 7000	5000 2000 8000	
38 457-JI	REGION HAUTE ALPINE	DOM MINI MAXI	300* 100* 800*	400 100 1000	2500 1500 3500	2500 1500 3500	2500 1500 3000	3500 1500 4500	3600 1000 4000	4000 1000 4000	4000 1000 7000	5000 2000 8000	
38 465-SI	VALLEE DU RHONE	DOM MINI MAXI	2000* 1000* 4000*	2500 1500 5000	3000 2000 4500	3200 2000 5500	4000 4500 5000	7000 5000 9000	10000 6000 15000	11000 7000 15000	12000 6000 16000	12500 8000 17000	
	ENSEMBLE ISERE	MOYENNE INDICE	1000 14	1300 18	2800 37	2800 37	3100 42	5200 69	7100 94	7900 106	8500 114	8800 118	
LOIRE													
42 168-AI	MT DU JAREZ ET BASSIN HOUILLER ST EPHANOIS	DOM MINI MAXI	750 400 1100	800 250 1300	1750* 700* 3000*	2400* 1000* 4000*	3300* 1500* 5500*	3300* 2000* 6000*	3500* 2000* 6000*	3500* 2500* 6000*	4100* 3000* 7000*	4500 3500 8000	5000 3500 10000
42 170-BI	MTS DU PILAT	DOM MINI MAXI	550 400 900	600 250 1100	1300* 500* 3000*	1800* 1000* 4000*	2400* 1200* 4000*	2400* 1200* 4000*	2600* 1500* 4000*	2650* 1500* 4500*	3000* 1500* 5000*	3200 1700 6000	3800 1700 6500
42 189-BI	PLATEAUX DE NEULISSE	DOM MINI MAXI	500 300 850	500 250 1100	1400* 700* 2500*	1800* 1000* 3000*	2550* 1500* 4500*	2550* 1500* 5000*	2750* 1500* 5000*	2800* 1500* 5000*	3200* 1500* 7000*	3500 1800 7500	4000 1800 7000

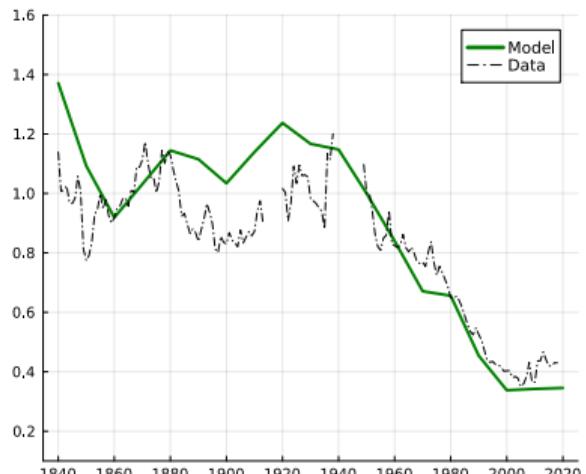
Novel Data on Land Values!



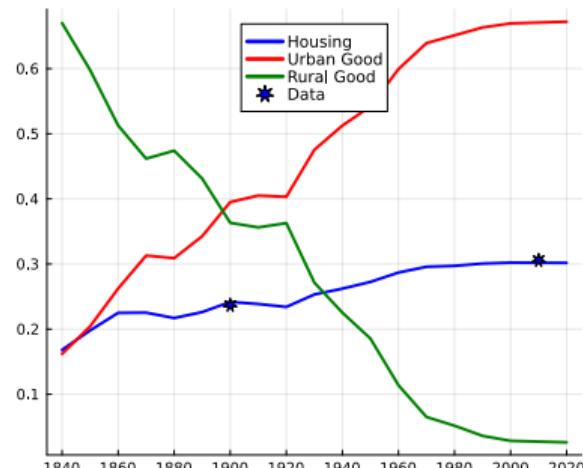
Aggregate Results: Structural Change



(a) Rural employment share.



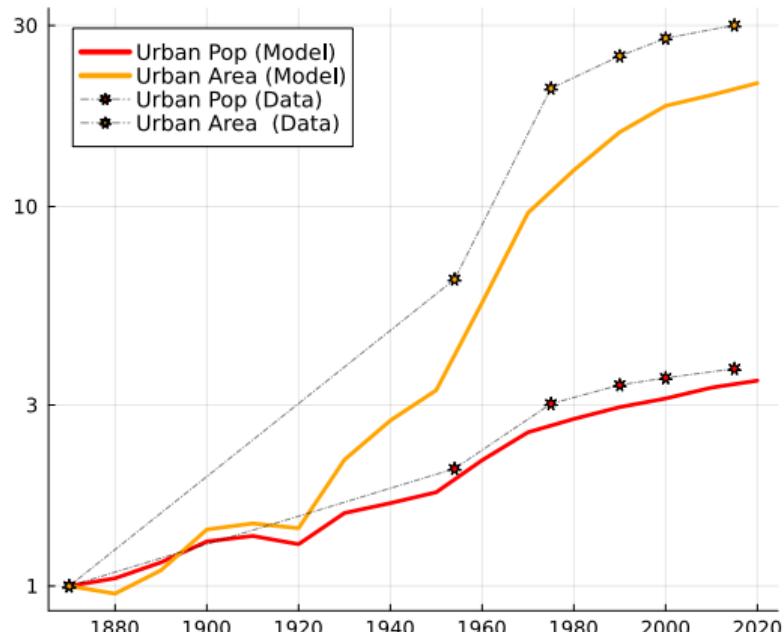
(b) Relative price of rural good.



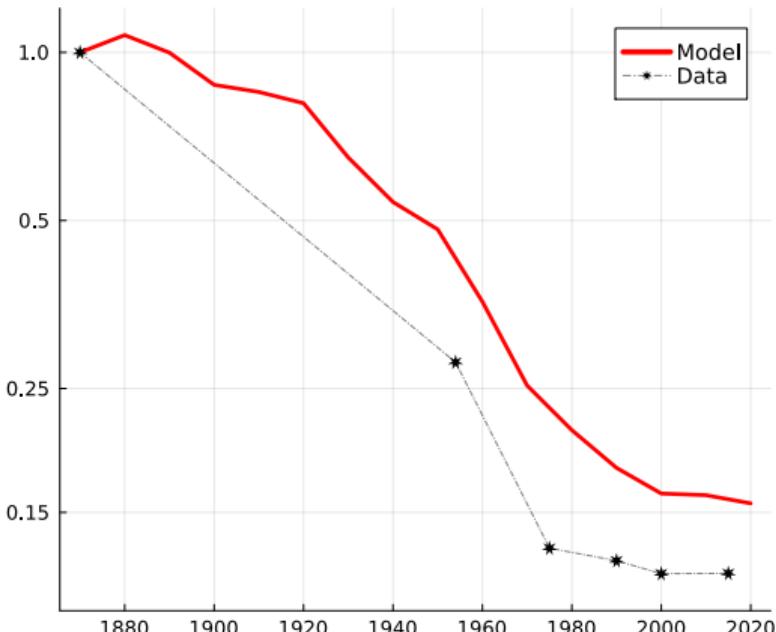
(c) Spending shares.

Figure: Structural change aggregated over K cities.

Aggregate Results: Urban Expansion



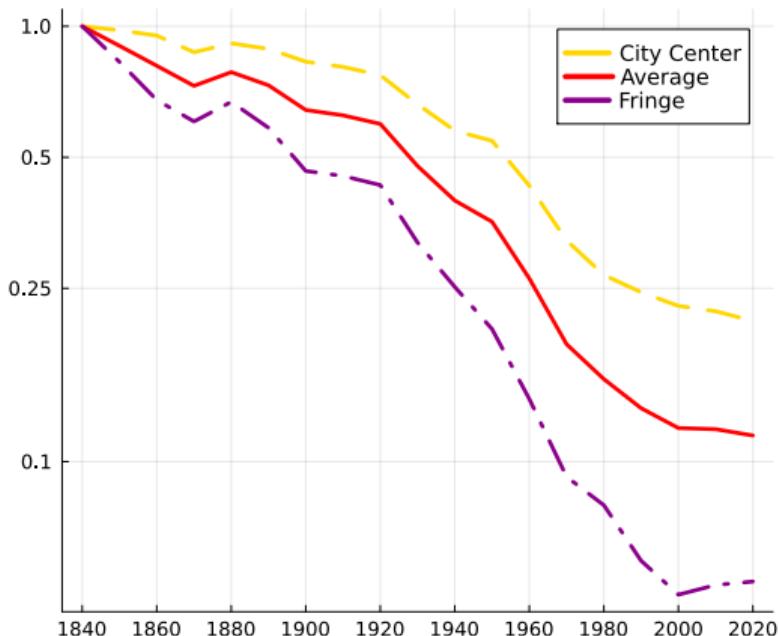
(a) Urban Area and Population (1870=1)



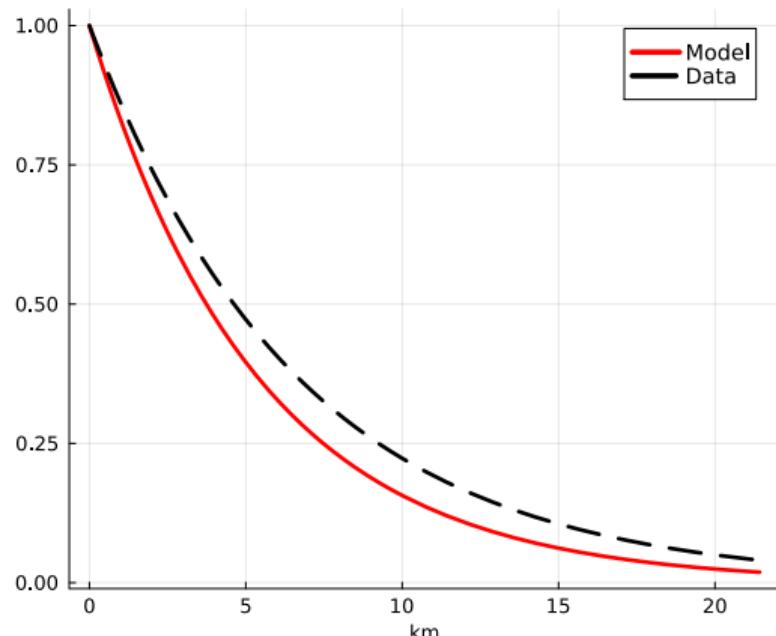
(b) Average urban density (1870=1)

Figure: Urban expansion aggregated over K cities.

Aggregate Results: Urban Structure



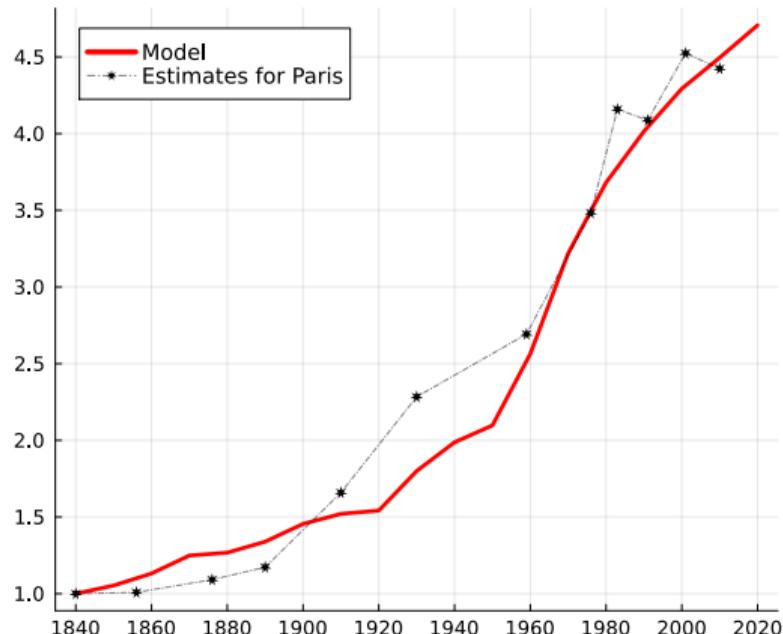
(a) Urban density (1840=1).



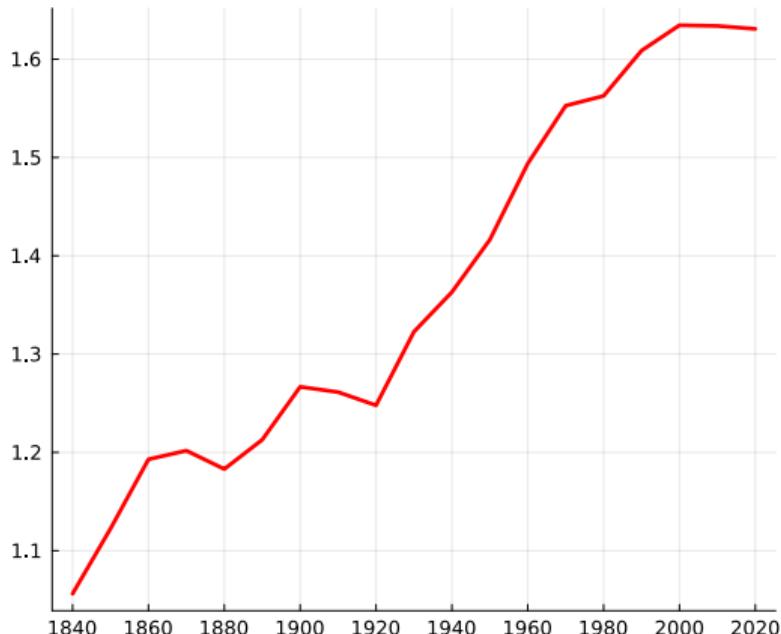
(b) Density gradient (2020).

Figure: Density across space.

Aggregate Results: Commuting Speed and APG



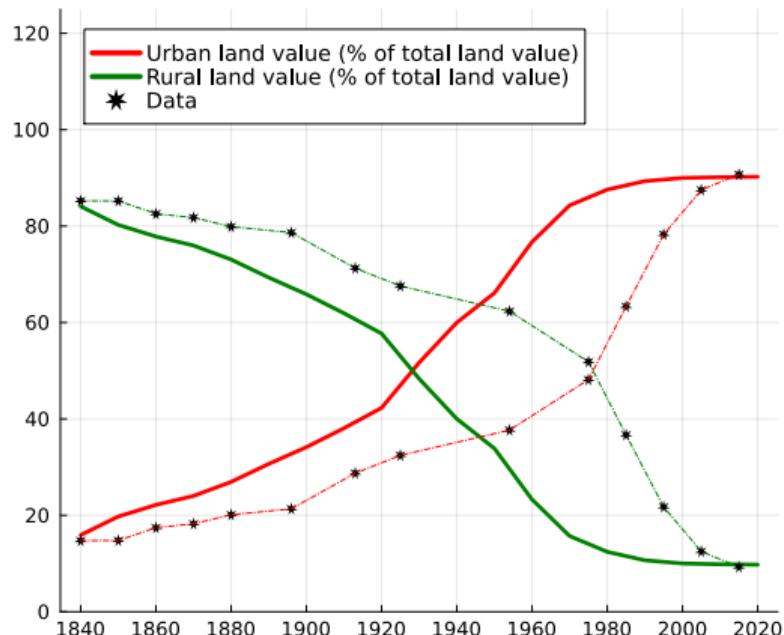
(a) Average urban commuting speed (1840=1).



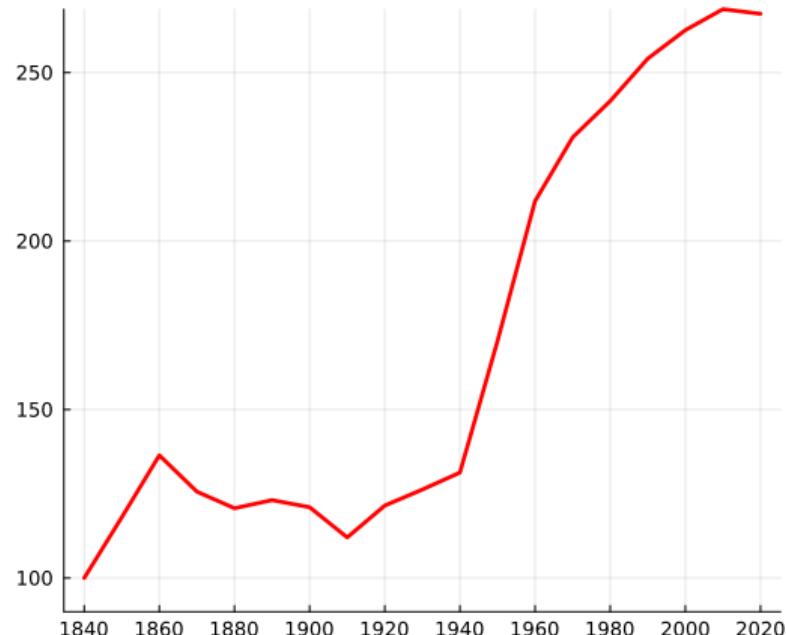
(b) Agricultural productivity gap.

Figure: Commuting speed and the 'agricultural productivity gap'

Aggregate Results: Wealth Distribution and House Price



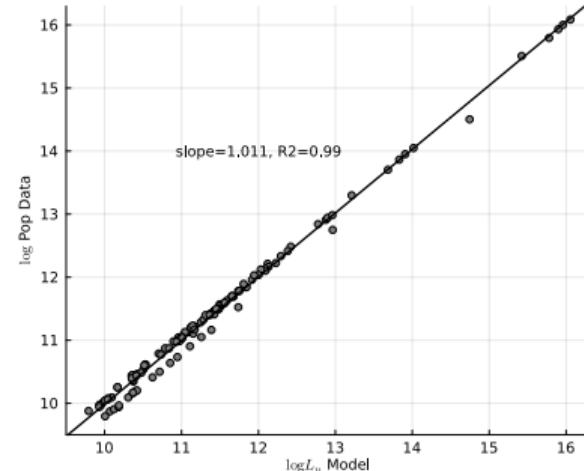
(a) Urban versus rural land wealth.



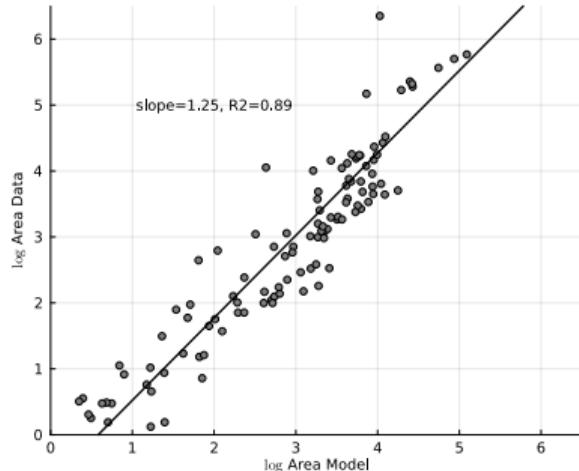
(b) Real Housing Price Index (1840=100).

Figure: Land values and housing price

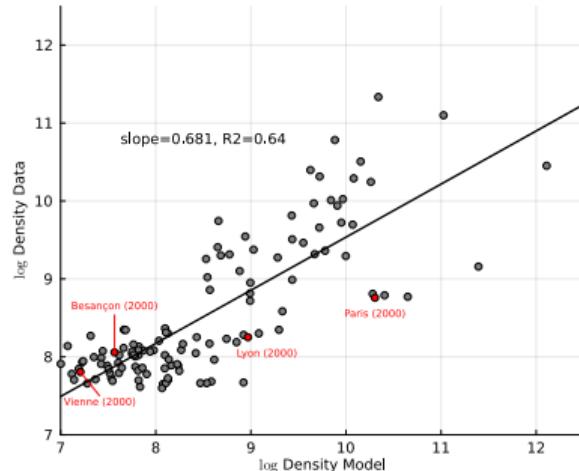
Regional Results



(a) Urban Population.



(b) Urban Area.



(c) Urban Density.

Figure: Regional Urban Moments

Regional Results: Urban Density and Land Values

	log Urban Density		
	Model	Data (OLS)	Data (IV)
$\log \bar{\rho}_{r,k,t}$	0.370*** (0.020)	0.126*** (0.026)	0.346*** (0.084)
Num.Obs.	80	766	314
R2	0.994	0.253	0.336
Controls	$w_{u,k,t}$	$w_{u,k,t}$	$w_{u,k,t}$
FE: year	X	X	X

Table: Urban density and rural land values in model and data.

Sensitivity Analysis

Counterfactuals enlightening the mechanisms

- ▶ The role of rural productivity growth. ▶ lower rural growth
- ▶ The role of faster commuting modes. ▶ $\xi_w = 1$
- ▶ The elasticity of substitution between land and labor in the rural sector. (Section B.3.1. in [Appendix B](#))
- ▶ Constant housing elasticity $\epsilon = 3$. ((Section B.3.2. in [Appendix B](#)))

Extensions

1. Agglomeration. (Section B.3.3. in Appendix B)
2. Relaxing Monocentricity. (Section B.3.4. in Appendix B)

Conclusion

We introduced a spatial general equilibrium model of land use to explain

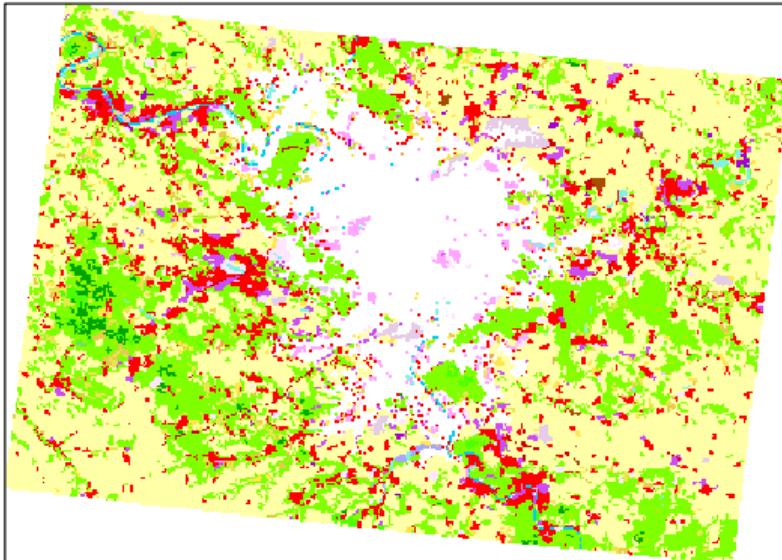
1. Evolution of sectoral allocation across space.
2. Evolution of Urban Density.
3. Evolution of the land value distribution.

We found:

- ▶ Rural Productivity growth is crucial to understand urban expansion.
- ▶ Quantitatively, both rural and urban productivity growth as well as falling commuting costs are needed to explain data.

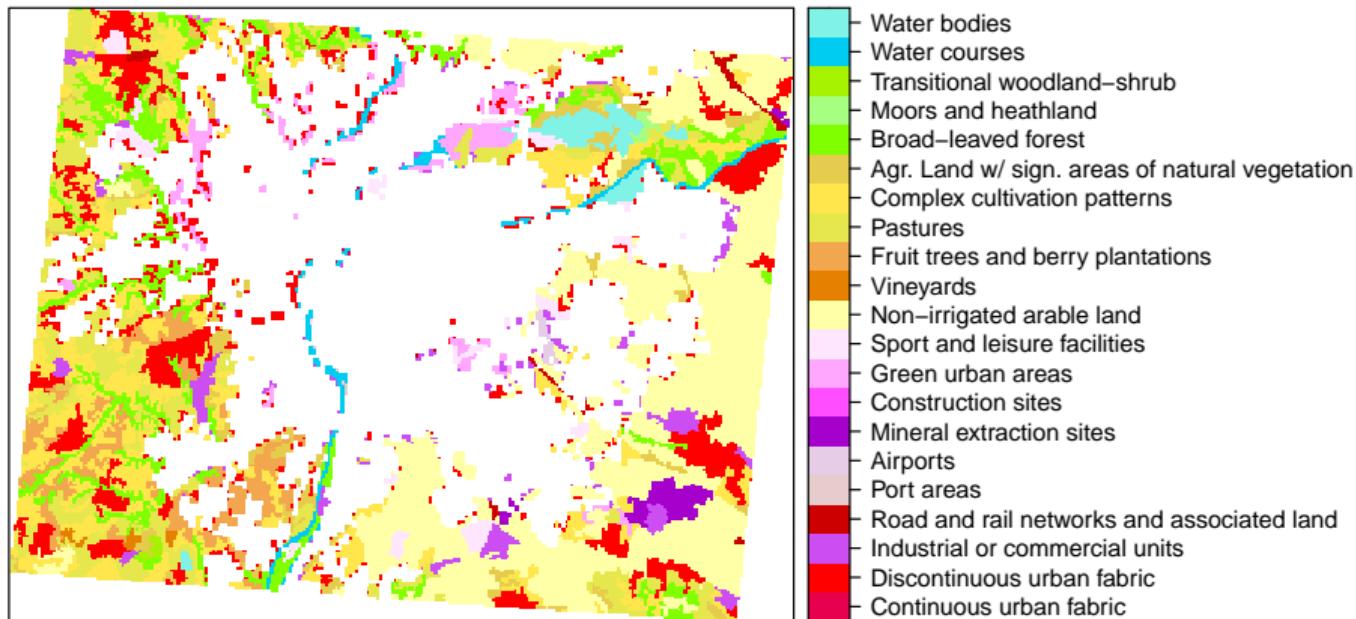
THANK YOU!

Land Use outside Paris 2020

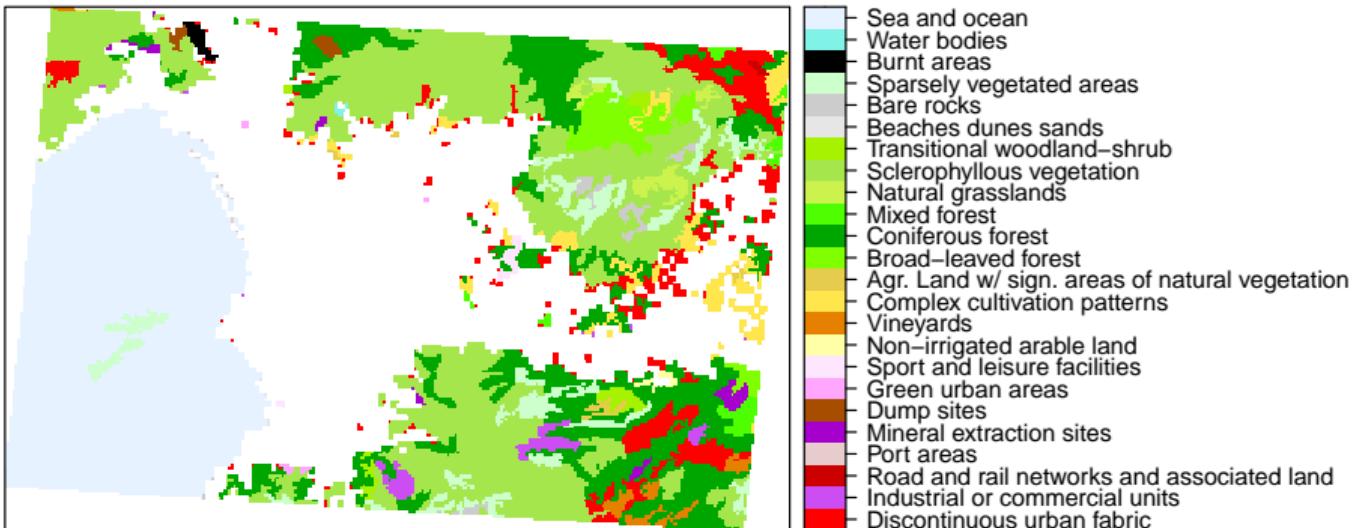


- Water bodies
 - Water courses
 - Inland marshes
 - Transitional woodland-shrub
 - Moors and heathland
 - Mixed forest
 - Coniferous forest
 - Broad-leaved forest
 - Agr. Land w/ sign. areas of natural vegetation
 - Complex cultivation patterns
 - Pastures
 - Fruit trees and berry plantations
 - Non-irrigated arable land
 - Sport and leisure facilities
 - Green urban areas
 - Construction sites
 - Dump sites
 - Mineral extraction sites
 - Airports
 - Port areas
 - Road and rail networks and associated land
 - Industrial or commercial units
 - Discontinuous urban fabric
 - Continuous urban fabric

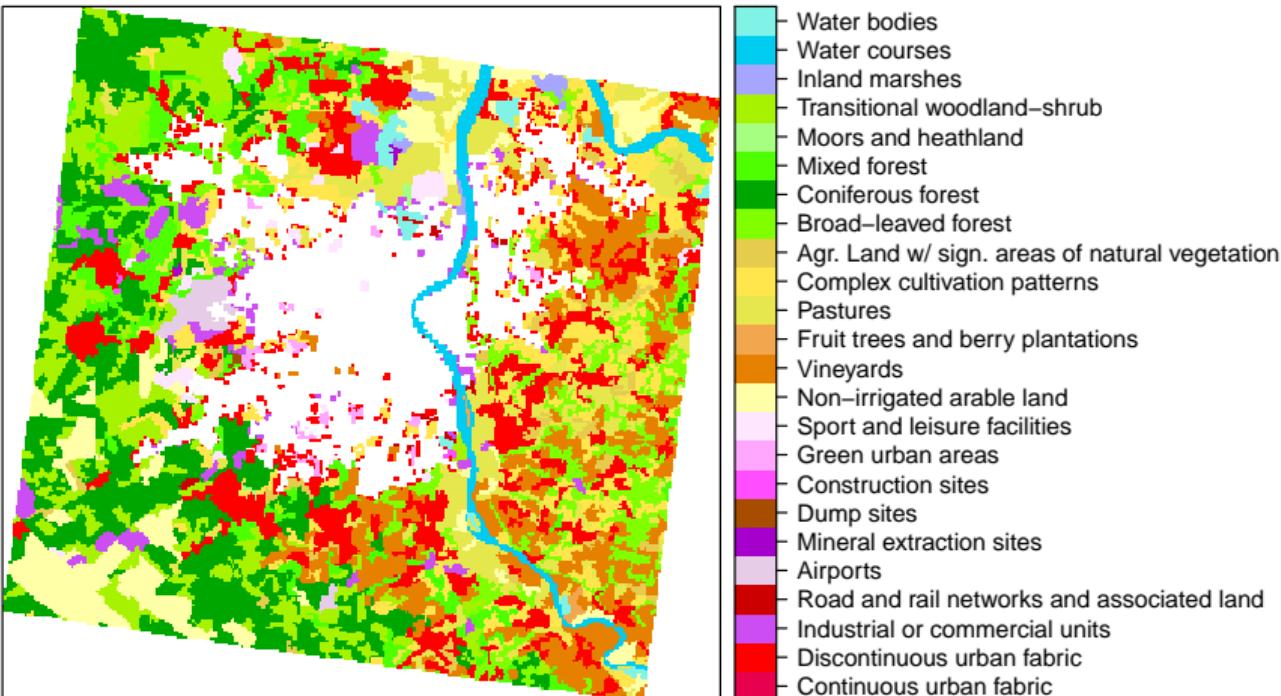
Land Use outside Lyon 2020



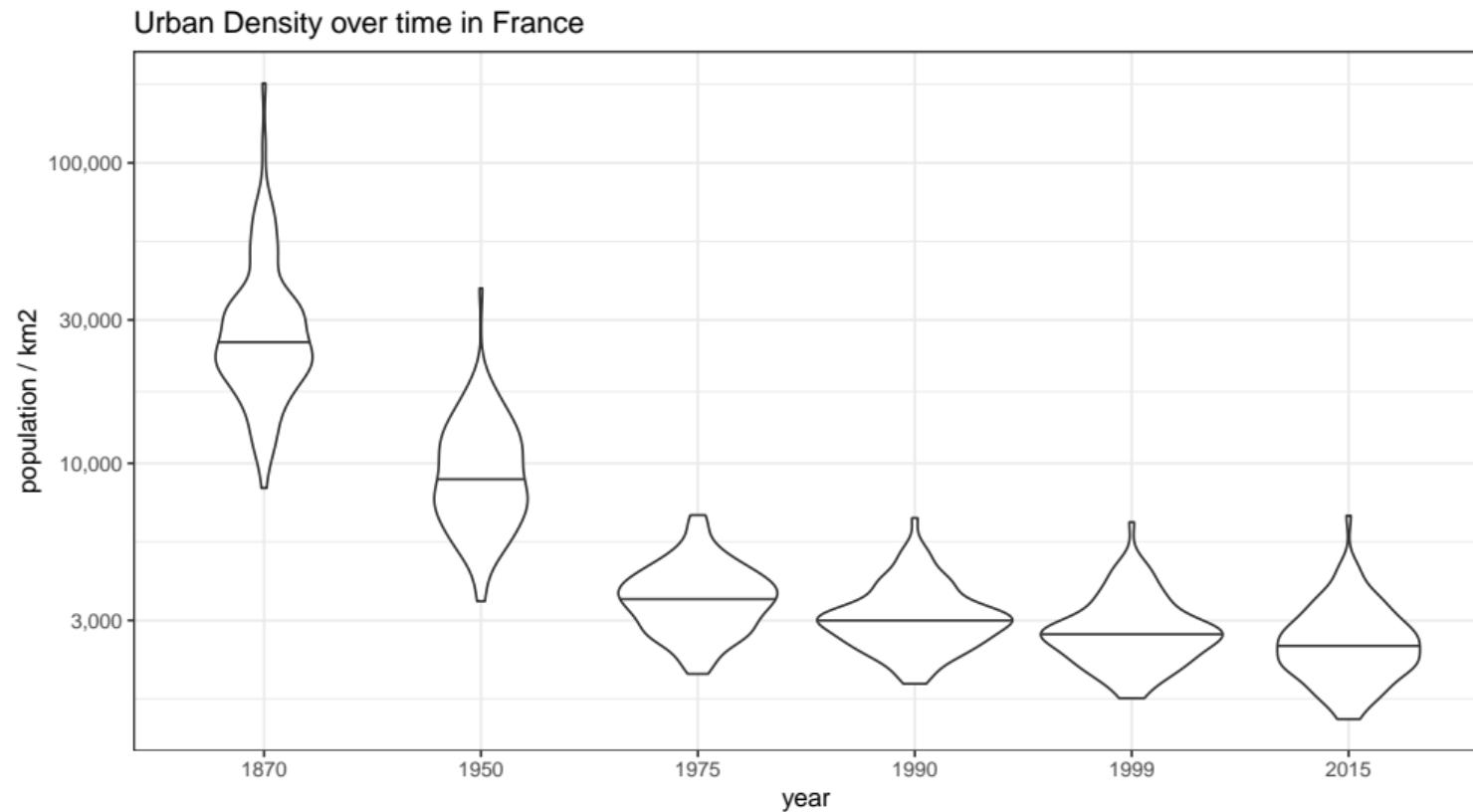
Land Use outside Marseille 2020



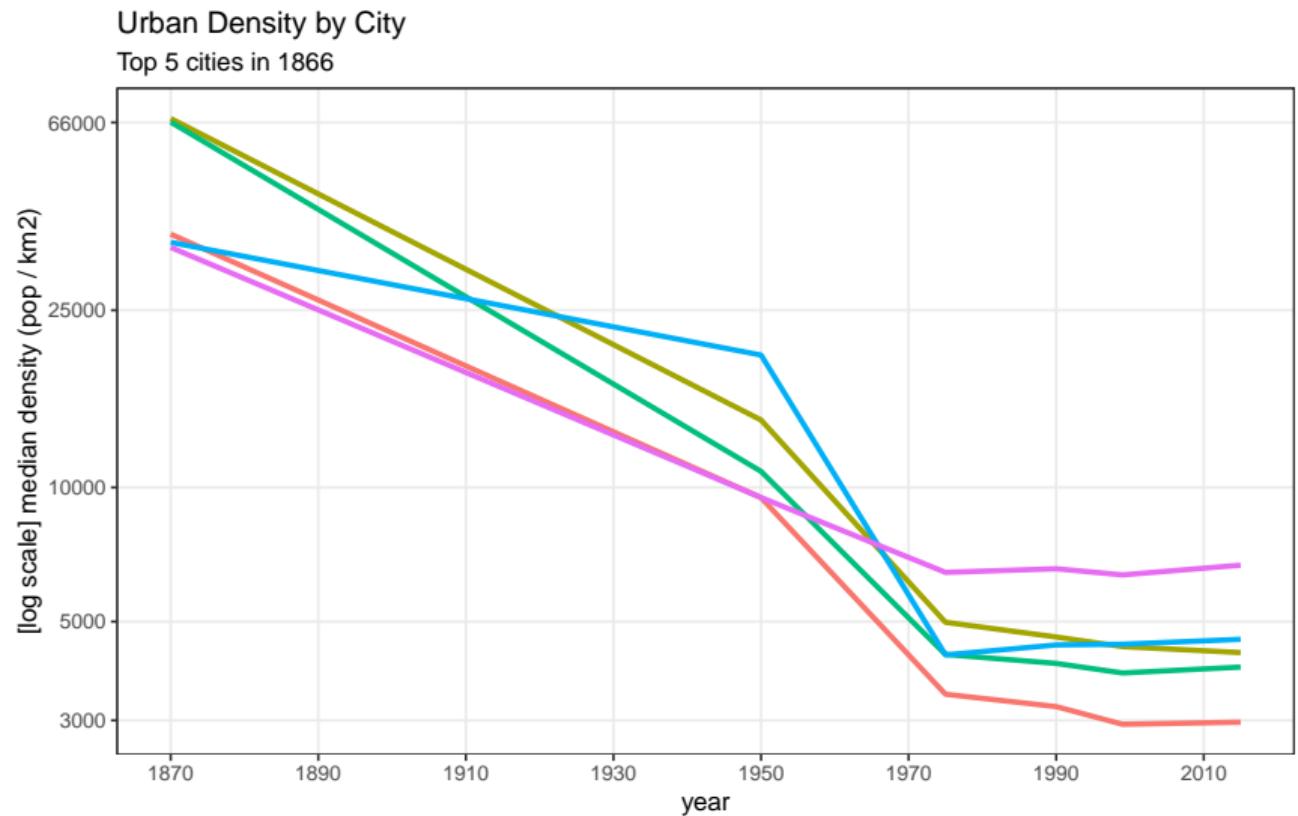
Land Use outside Bordeaux 2020



The historical fall in urban density

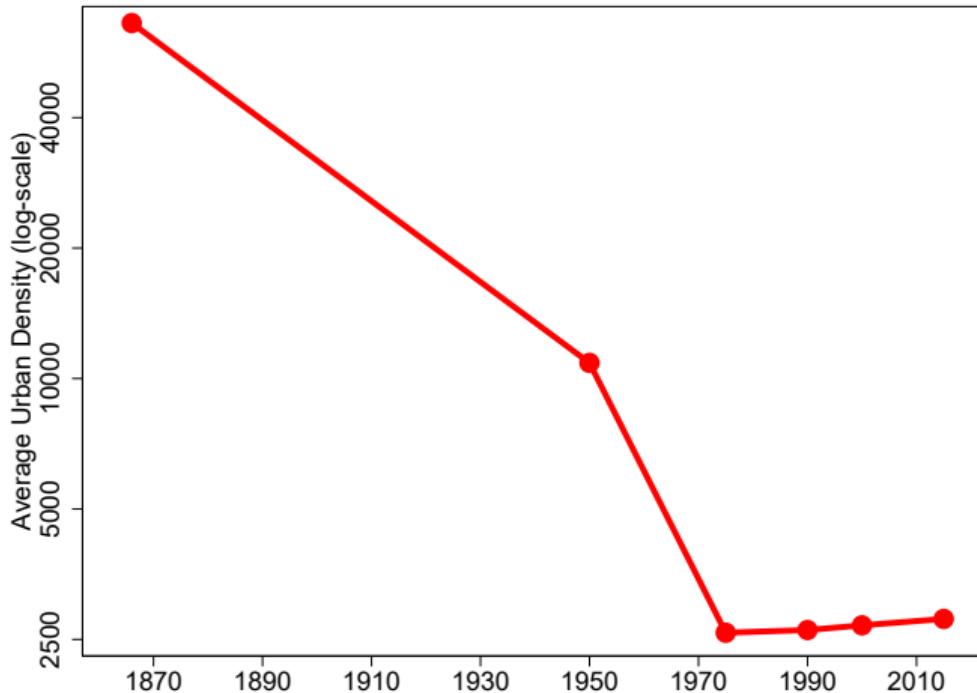


The historical fall in urban density



The historical fall in urban density

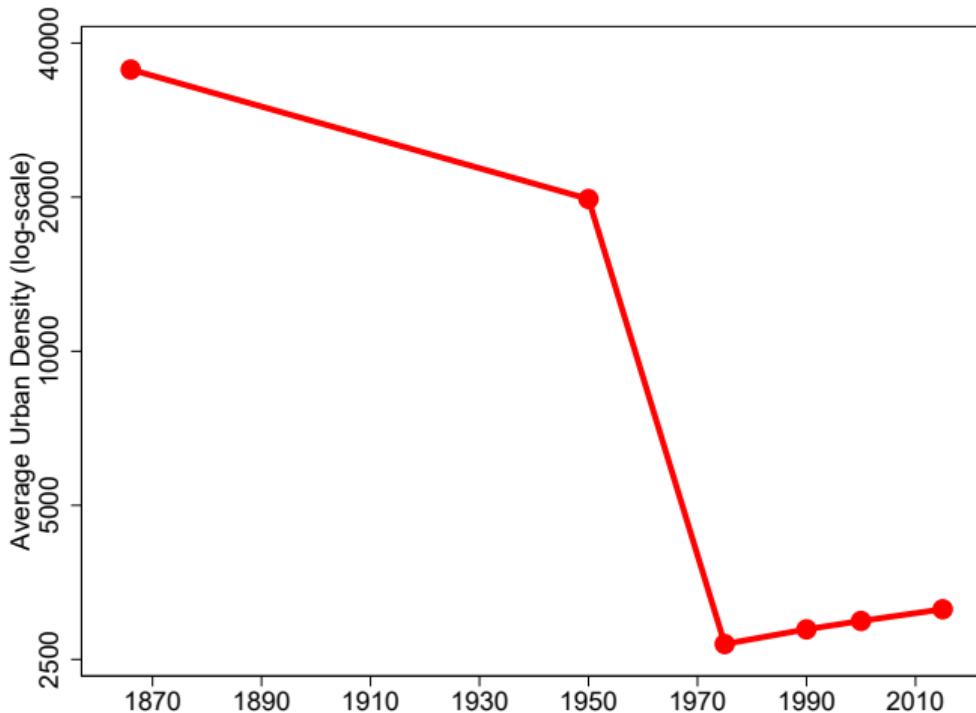
Lyon



▶ back

The historical fall in urban density

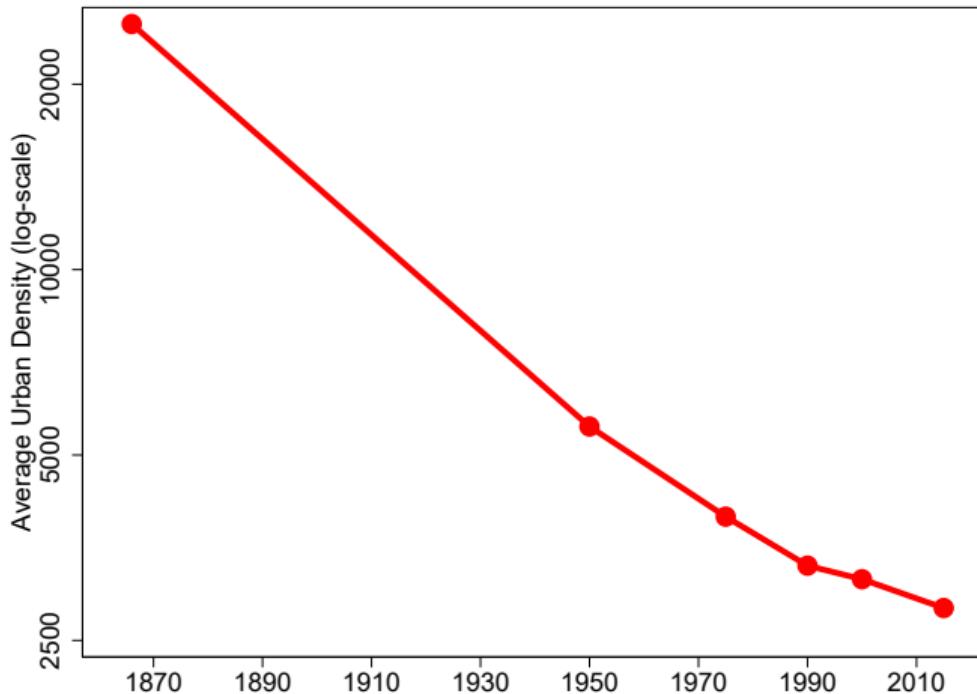
Marseille



▶ back

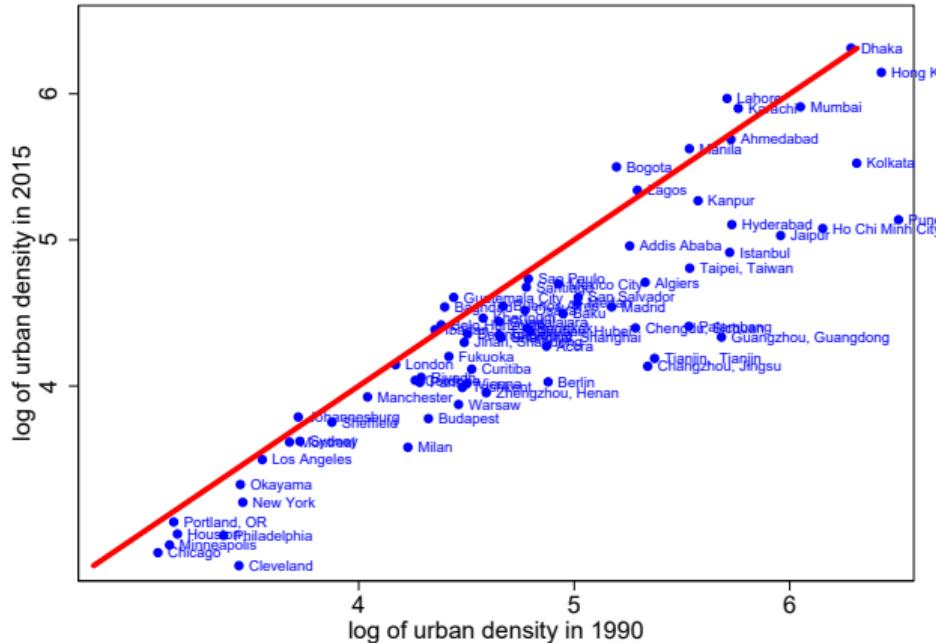
The historical fall in urban density

Reims



The fall in urban density across the globe, 1990-2015

World sample of large cities

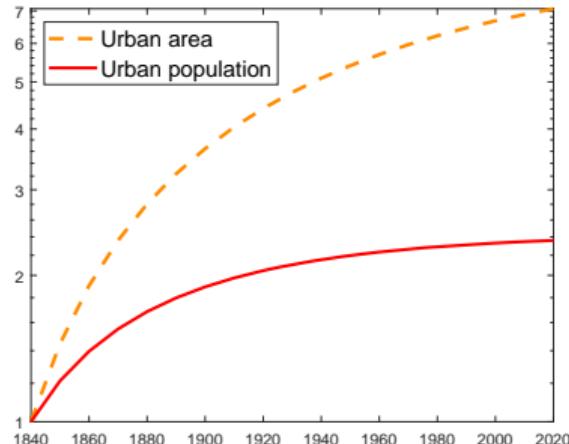


Source: Atlas of Urban Expansion. Sample of 73 cities above 1 000 000 people. Details in Angel et al. (2010).

back

Toy Models

Rural Productivity Growth Only

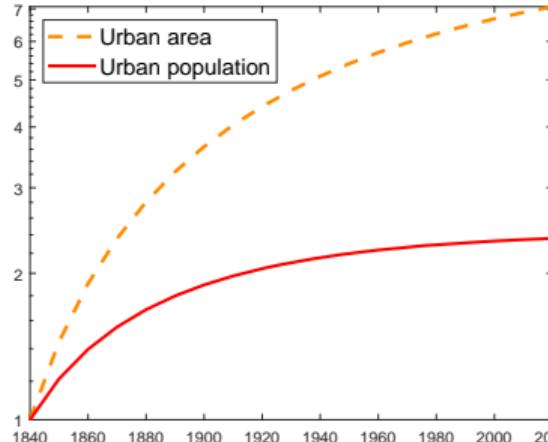


(a) City Size

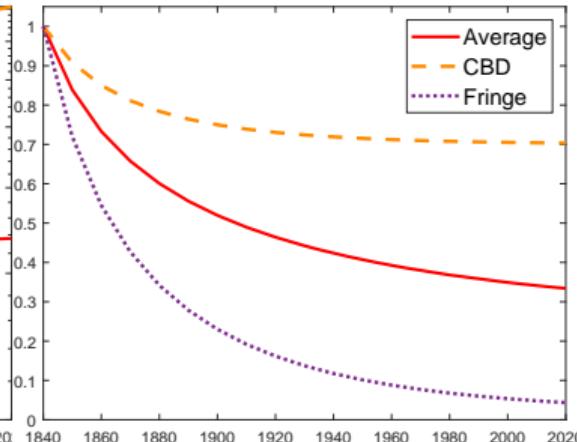
▶ back

Toy Models

Rural Productivity Growth Only



(a) City Size

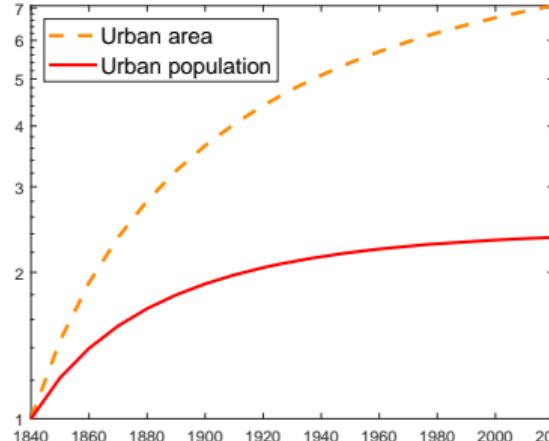


(b) Urban Densities

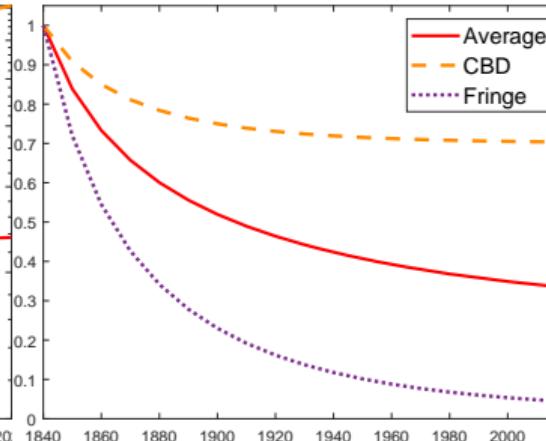
▶ back

Toy Models

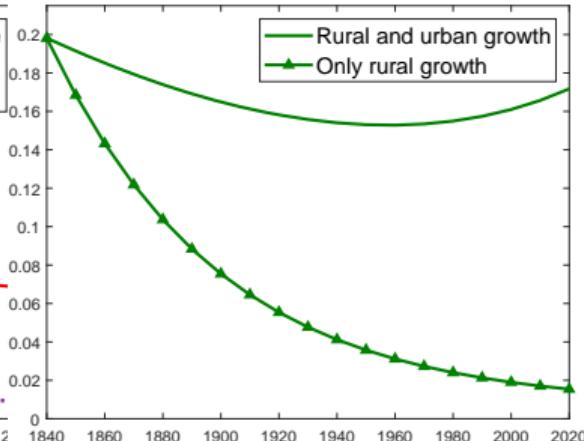
Rural Productivity Growth Only



(a) City Size



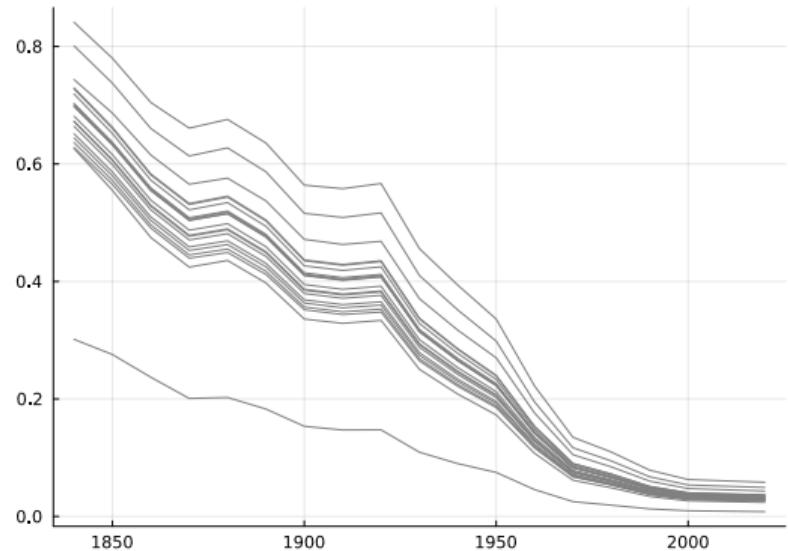
(b) Urban Densities



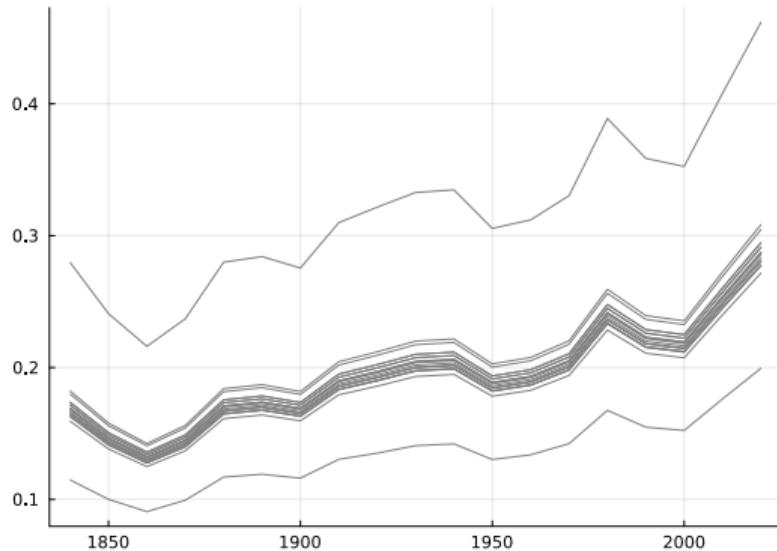
(c) Farmland Price

▶ back

Identification of $\{\theta_{s,t}^k\}$

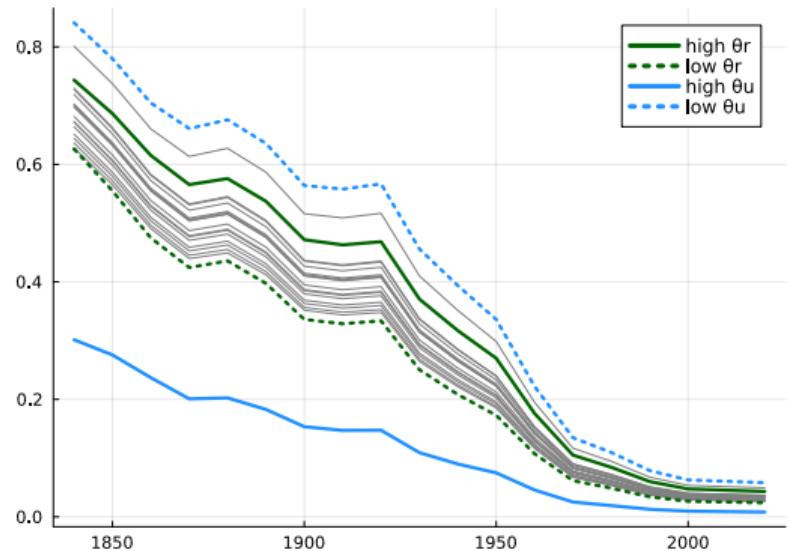


(a) Rural Labor Share $L_r/(L_r + L_u)$.

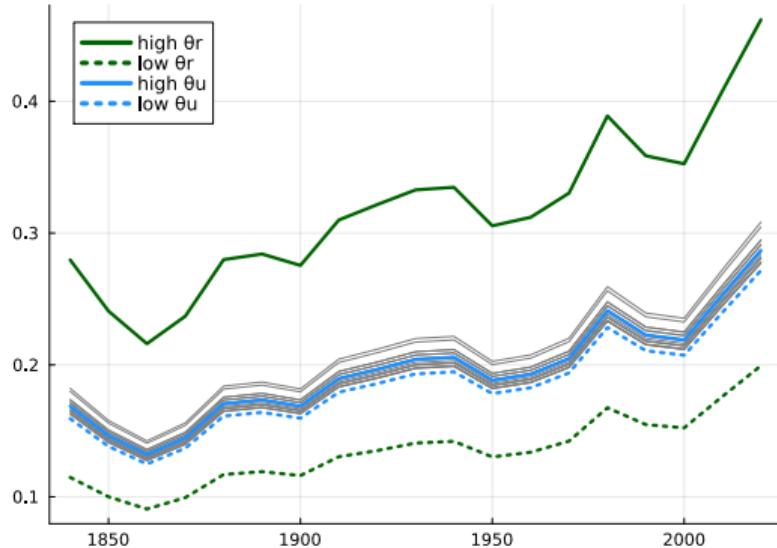


(b) Rural land rents ρ_r .

Identification of $\{\theta_{s,t}^k\}$



(a) Rural Labor Share $L_r/(L_r + L_u)$.



(b) Rural land rents ρ_r .

▶ back

Housing Market Equilibrium

Land developers

- ▶ Housing supply provided by land developers.
- ▶ Use more or less intensively the land for residential purposes.
- ▶ Technology

In each location, developers supply housing space $H(\ell)$ per unit of land with a convex cost,

$$\frac{H(\ell)^{1+1/\epsilon}}{1 + 1/\epsilon},$$

in units of the numeraire.

ϵ = cost parameter, possibly dependent on the location.

Housing Market Equilibrium

Housing supply

- ▶ Profits per unit of land at ℓ ,

$$\pi(\ell) = q(\ell)H(\ell) - \frac{H(\ell)^{1+1/\epsilon_\ell}}{1 + 1/\epsilon_\ell} - \rho(\ell),$$

$\rho(\ell)$ the price of a unit of **land** in ℓ .

- ▶ Housing supply from profit maximization,

$$H(\ell) = q(\ell)^{\epsilon_\ell},$$

with housing supply elasticity $\epsilon_\ell \geq 0$, $\partial\epsilon_\ell/\partial\ell \geq 0$.
see Baum-Snow and Huan (2019).

Housing Market Equilibrium: Supply

Land Prices and Land Use

- ▶ Profit maximization and free entry of developers pins down land prices in ℓ ,

$$\rho(\ell) = \frac{q(\ell)^{1+\epsilon_\ell}}{1 + \epsilon_\ell},$$

- ▶ Land use with the highest rental value (**Rivalry**)
- ▶ Indifference conditions across uses at the fringe,

$$\rho_r = \frac{(q_r)^{1+\epsilon_r}}{1 + \epsilon_r} = (1 - \alpha)p\theta_r \left(\frac{L_r}{S_r}\right)^\alpha.$$

◀ back

Agricultural Productivity Gap

- ▶ Gollin et al (2013) show that sizeable productivity gap between agricultural and other sectors: Value added is higher in non-agricultural sectors, particularly in developing countries.
- ▶ Proposed mechanisms in literature: migration costs, selection of migrants.
- ▶ Here spatial frictions together with ℓ -specific housing:

$$w(\phi) = w_u - \tau(\phi) = w_r$$

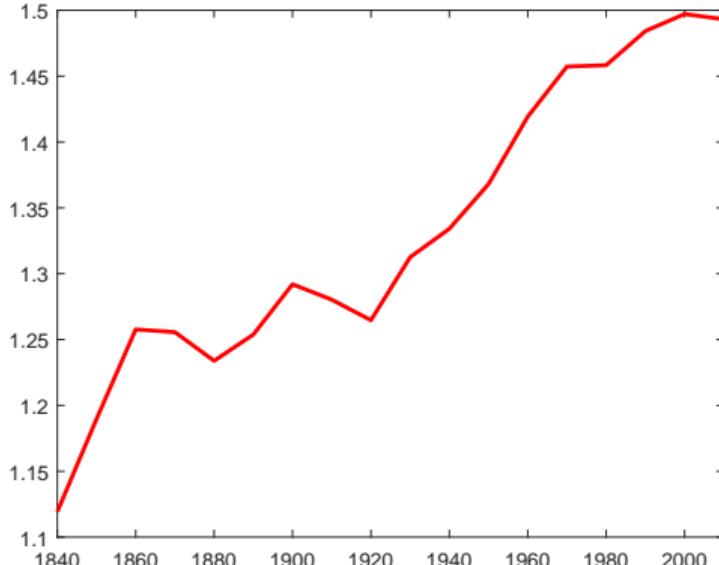
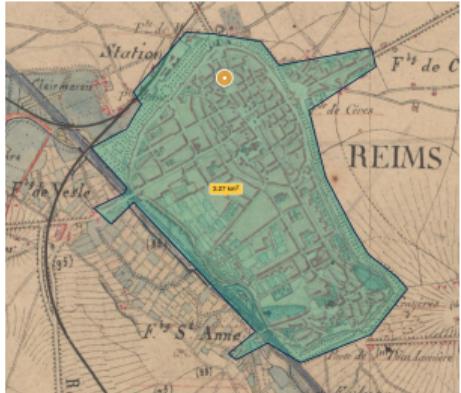


Figure: Agricultural Productivity Gap

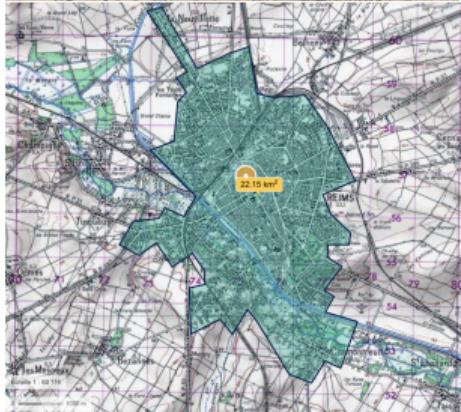
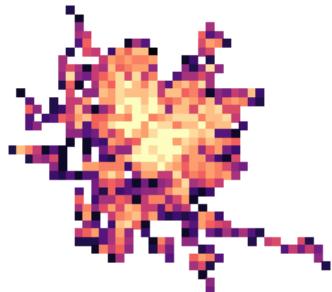
▶ back

GHSI Measurement - Reims

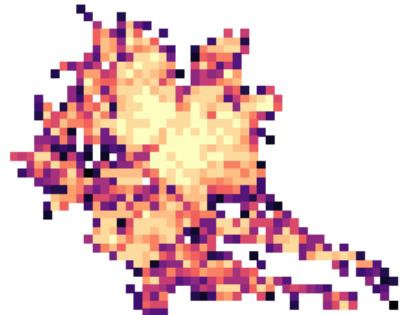
[back](#)



Reims 1975: 31.4 km²



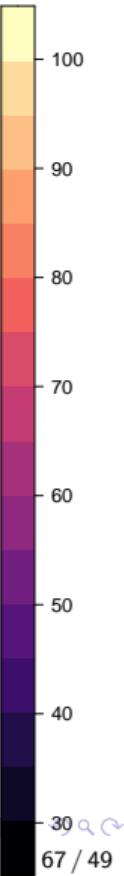
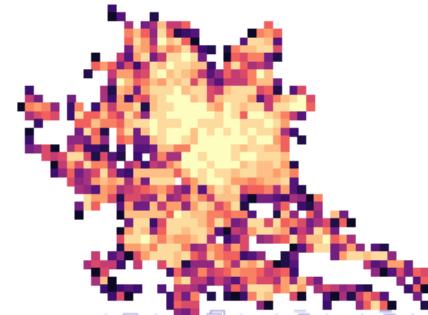
Reims 2000: 49.1 km²



Reims 1990: 43.2 km²

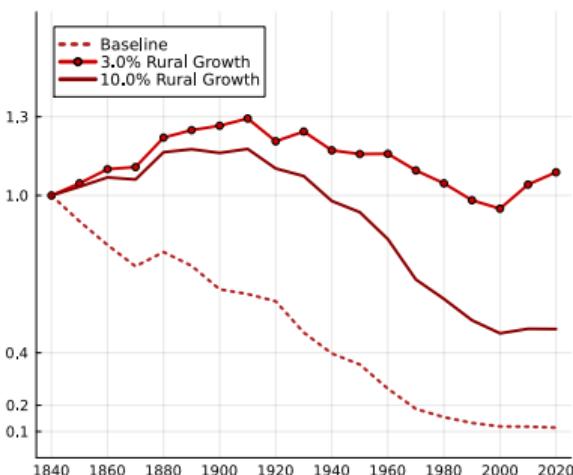


Reims 2015: 55 km²

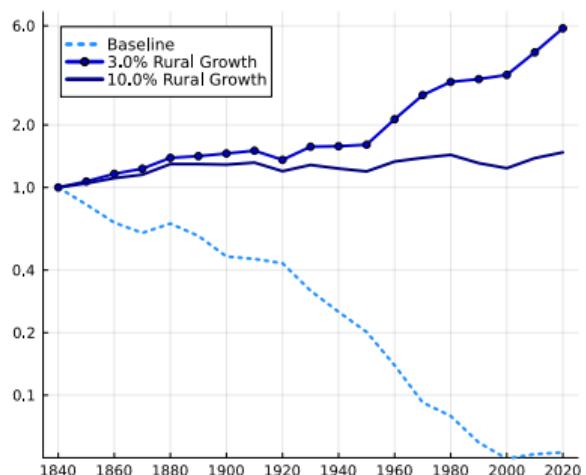


Sensitivity Analysis

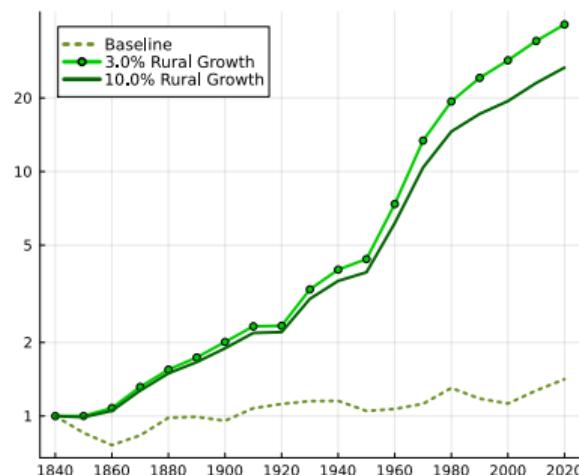
The role of rural productivity growth



(a) Average urban density (1840=1).



(b) Density at the fringe ($1840=1$).



(c) Rental price of farmland.

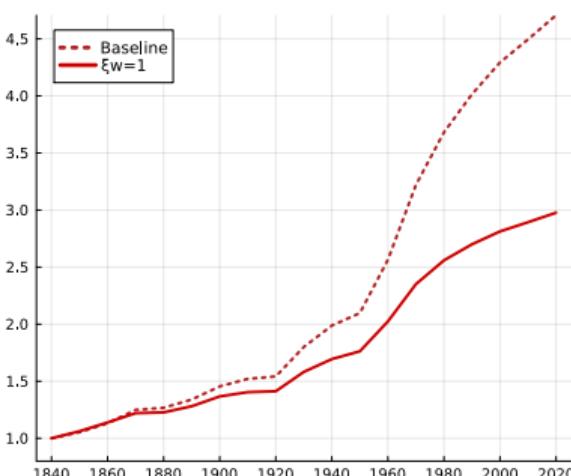
Figure: Sensitivity to rural productivity growth.

Sensitivity Analysis

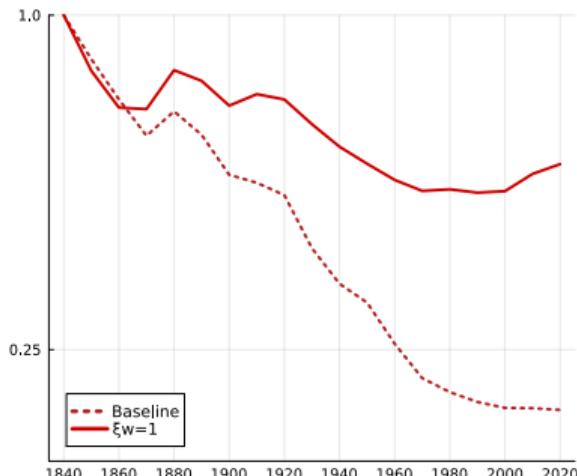
The role of increasing commuting speed

Commuting costs: $\xi_w = 1$

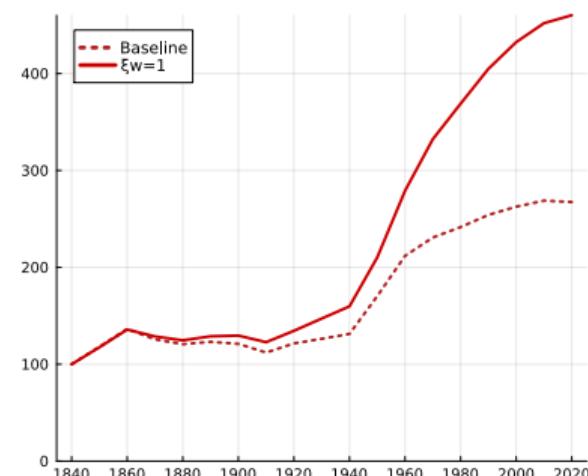
$$\tau(\ell) = a \cdot w_u^{\xi_w} \cdot \ell^{\xi_\ell}$$



(a) Average commuting speed.



(b) Average urban density.



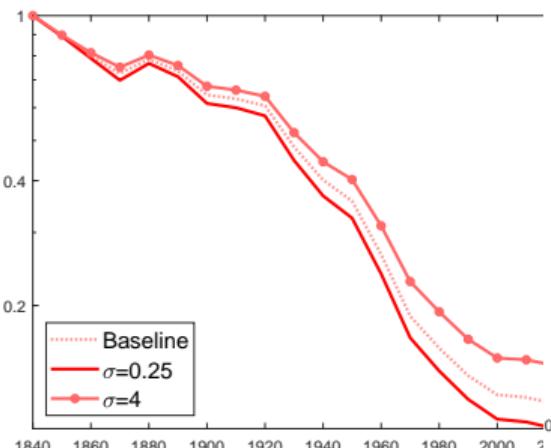
(c) Real Housing Price Index.

Sensitivity Analysis

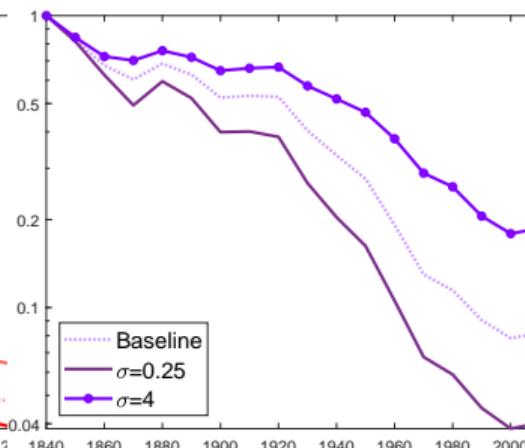
The elasticity of substitution between land and labor in the rural sector

Rural good production function:

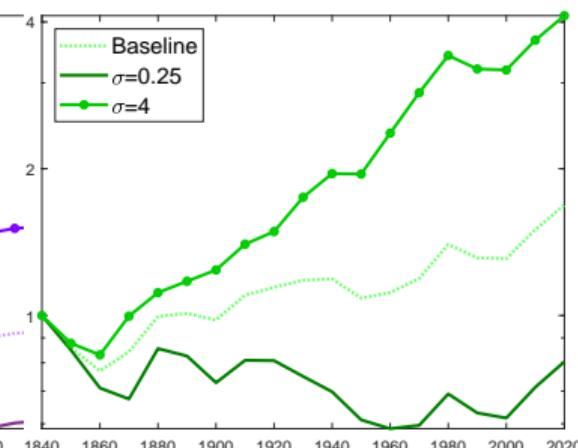
$$Y_r = \theta_r \left(\alpha(L_r)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)(S_r)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$



(a) Urban Density



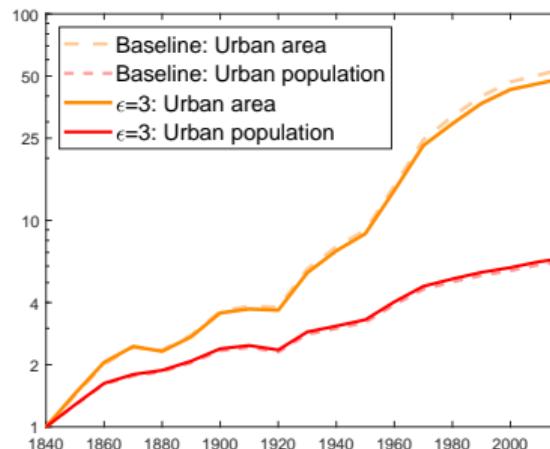
(b) Fringe Density



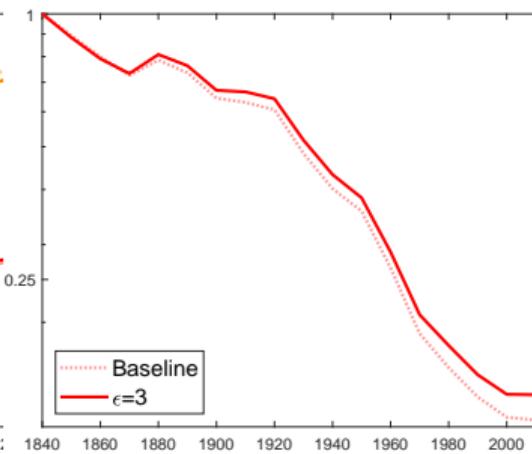
(c) Farmland rental price

Sensitivity Analysis

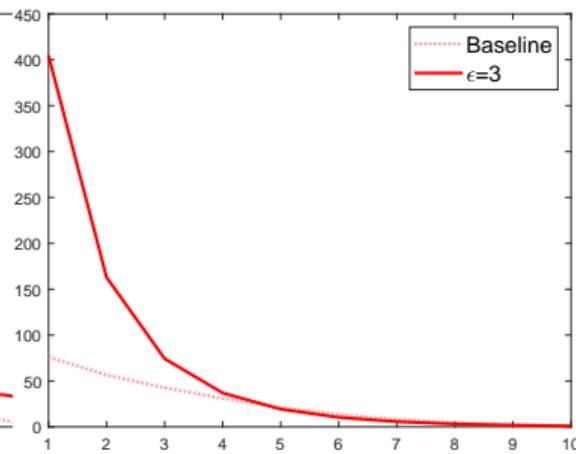
Constant housing elasticity $\epsilon = 3$



(a) City Size



(b) Urban Density



(c) Density by decile (2010)

▶ back

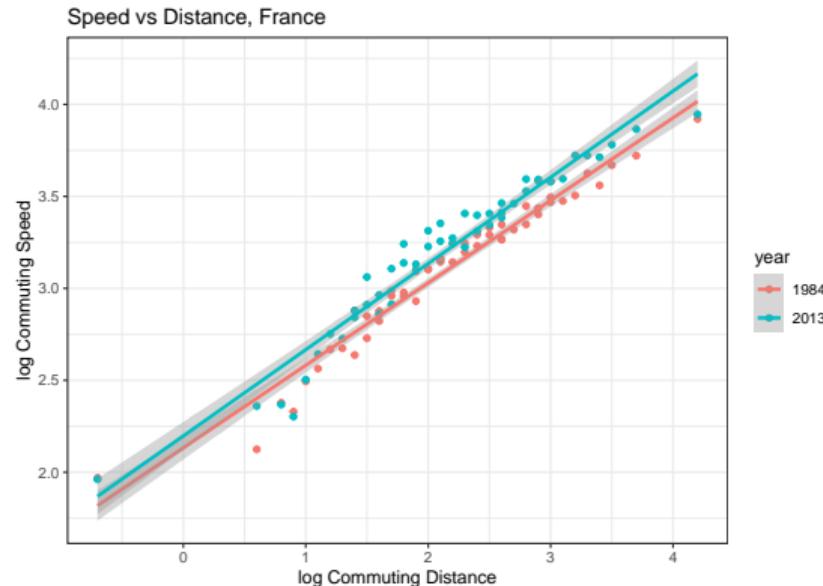
Calibration of τ

- ▶ Micro foundation yields:

$$\tau(\ell) = a \cdot w_u^{\xi_w} \cdot \ell^{\xi_\ell}$$

- ▶ The elasticities of commuting speed m with respect to income and speed are defined and measured in individual commuting data as:

1. Income: $1 - \xi_w$. Given distance, increase in speed over increase in income (across years (see plot)).
2. Distance: $1 - \xi_\ell$. Given income, elasticity of speed to distance (in a given year - see table III in appendix).



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