Structural Change, Land Use and Urban Expansion

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Abstract

We develop a multi-sector spatial equilibrium model with endogenous land use: land is used either for agriculture or housing. Urban land, densely populated due to commuting frictions, expands out of agricultural land. With rising productivity, the reallocation of workers away from agriculture frees up land for cities to expand, limiting the increase in land values despite higher income and increasing urban population. Due to the reallocation of land use, the area of cities expands at a fast rate and urban density persistently declines, as in the data over a long period. As structural change slows down, cities sprawl less and land values start increasing at a fast rate, as in the last decades. Our theory can thus match the joint evolution of population density and land values across time and space, matching historical data assembled for France over 150 years.

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1 Introduction

Since the early years of the industrial revolution, the population massively migrated from rural areas towards cities. This widespread phenomenon of urbanization went together with the reallocation of workers away from the agricultural sector towards manufacturing and service sectors—a phenomenon of structural change. How do cities grow when these well-known phenomena occur? Cities can become denser for a given area—growth at the intensive margin. They can also become larger in surface to accommodate more workers—via growth at the extensive margin. Over a long period, perhaps surprisingly, cities have been growing essentially in area, at such a fast speed that their average density has been falling. In other words, over time, cities expand faster in area than in population. We precisely document this stylized fact for France since 1860 but it is also documented on a global scale in Angel et al. (2010). In France, the population of cities has been multiplied by about 5 since 1860, while their area increased by a factor 50: the average density has thus been divided by about 10. This paper shows that this persistent decline in urban density, despite the process of urbanization and structural change, is well explained by the most conventional theories of structural change augmented with endogenous land use—whereby land can be used for agriculture or urban housing.

The crucial insight of our theory is to consider that the value of agricultural land at the urban fringe determines the opportunity cost of expanding the area of cities for housing purposes. With structural change driven by rising productivity, workers move away from rural areas towards cities, freeing up agricultural land. As the value of land at the urban fringe falls, cities expand in area at a fast rate. Together with the reallocation of workers across sectors, reallocation of land use occurs—from agricultural use to urban use. We document that for France, since 1860, about 15% of French land formerly used for agriculture is no longer used for this purpose. As long as the transitory process of reallocation away from agriculture continues, average urban density keeps falling with urban expansion. Importantly, despite rising housing demand, the fast expansion of cities at the extensive margin limits the increase in urban land rents and housing prices. When the reallocation of workers slows down, the expansion of urban areas slowly ends and urban density does not fall further. If workers' productivity increases further, the value of land must adjust to prevent further expansion of cities with rising housing demand. Land values start to increase at a much faster rate. Our theory thus predicts flat land and housing values for decades before shooting up as the process of structural change ends. This prediction resembles very much the data for France and most advanced economies as best illustrated in Knoll et al. (2017): real housing prices being flat for decades since the nineteenth century before increasing at a fast rate in the recent decades—a *hockey-stick* pattern of housing prices and land values. Our theory thus provides novel insights on the joint evolution of the density of cities and land values along the process of economic development. It also helps understanding how the structure of cities, e.g. their urban extent and density, matters for the process of structural transformation and aggregate productivity. Finally, it sheds new light on the origins of urban sprawl in the process of economic development—a central matter in the artificialization of soils and their environmental impact (IPCC (2018)).

The contribution of our paper is threefold. First, we document new stylized facts on land use and urban expansion for France since 1860. In particular, using historical maps and satellite data for the more recent period, we document the historical decline of the density of French cities. Between 1860 and 1950, the average density was divided by more than 3 and again by more than 3 until 1975—the thirty years post-World War II being characterized in France by a faster structural change and *rural exodus* (Mendras (1970), Bairoch (1985), Toutain (1993)). Together with the slowdown of structural change in the more recent decades, average urban density did not fall much since. These facts, together with the historical evolution of urban and agricultural land values in France, motivate our theory.

The second contribution is to develop a spatial general equilibrium model of structural change with endogenous land use—agricultural or residential land use. The production side features three sectors: rural, urban and housing. The rural (resp. urban) sector produces agricultural (resp. non-agricultural) tradable goods, the production of the rural good being more land intensive. The housing sector produces location-specific housing units using the urban good and land in the process. Land is in fixed supply and land use rivalrous: land is either used for agriculture or for housing. Following the traditional monocentric model after Alonso et al. (1964), Muth (1969), and Mills (1967), urban land use (cities) emerges endogenously due to commuting costs for workers to produce urban goods: urban land is thus more densely populated than rural land and the urban fringe corresponds to the longest commute of a worker producing urban goods. Importantly, the rental value of land at the fringe of the city must be equalized across potential usages—the marginal productivity of land in the rural sector (agriculture) determining the opportunity cost of expanding further urban land. The last important components of our theory are the drivers of structural change. Although not essential for our story—as long as the reallocation of workers away from agriculture frees up some land—, structural change is driven by the combination of non-homothetic preferences on the demand side, a subsistence consumption for the rural good, and increasing (agricultural) productivity on the supply side. This generates transitory dynamics with rising productivity that are at the heart of our story: in the old pre-industrial times, due to low productivity, land is scarce with high values of farmland with respect to income—a resurgence of the 'food problem' (Schultz (1953)). Few urban workers are concentrated on a very small area and urban land is very densely populated. Later on, as economic development continues and productivity increases, farmland is getting less valuable. This frees up rural land for cities to expand, accommodating rising demand for housing of more numerous urban workers. The city sprawls and average urban density falls through two channels: the fall in the rental value of farmland at the urban fringe and the increasing share of spending towards housing, the latter force being more specific to the use of non-homothetic preferences as a driver of structural change. Note that the decline in urban density occurs even without improvements in the commuting technology—the usual source of sprawling in urban economics. At the latest stages of the transition, in more recent times, the reallocation of workers and land use slows down. Urban expansion slows, urban density declines less and land prices increase more with rising productivity.

Land becomes also particularly scarce in some preferential locations of very spread out cities. We also emphasize how the supply side characteristics of the housing sector are essential quantitatively for our mechanisms: with persistently high housing supply elasticities across locations, urban land sprawls less despite more workers leaving the rural sector, urban density declines significantly less and housing prices increase much less in the later stages of the transition. As a side-product, we also show how commuting frictions together with location-specific land values generate a wedge between the workers marginal productivities in the rural and urban sector, an 'agricultural productivity gap' (Gollin et al. (2014)).

While we start with a framework featuring only one city, a quantitative exploration of our theory is later extended to multiple cities. This is the third contribution of the paper. We develop a quantitative version of our spatial equilibrium model applied to the French context since 1860. Using data from various historical sources, we measure sectoral factors of production and productivities over long period and across French regions. We show that the quantitative predictions model match relatively well the joint evolution of population density and land values over time and across space. More specifically, we disentangle the importance of falling commuting costs relative to our novel mechanisms in explaining the persistent decline in urban density. Building upon LeRoy and Sonstelie (1983), we develop a commuting mode choice model, which allows for an endogenous decision of individuals of how to commute, based on their opportunity cost of time and location, in order to account for the large declines in transport cost over the last 150 years.

Related literature. The paper relates to several strands of literature in macroeconomics and spatial economics. From a macro perspective, it relates to the literature linking productivity changes and land values, starting with Ricardo (1817). This traditional view would imply that a fixed factor such as land should continuously rise in value with economic development (see, among others, Nichols (1970) and Grossman and Steger (2017) for a recent contribution). However, such a prediction would not fit well the measurement of housing prices and land values over a long period as in Knoll et al. (2017) (see also Davis and Heathcote (2007) and Piketty and Zucman (2014) for related evidence). An alternative view, in the tradition of the theory of structural change, would argue that land used to be scarce and valuable with low productivity in agriculture but rising productivity alleviates pressure on land—putting downward pressure on its value. In a sense, our approach reconciles both views in a unified framework. From a theoretical perspective, we contribute to the literature on structural change, surveyed in Herrendorf et al. (2014), by considering a spatial dimension—adding an endogenous use of land and a housing sector—in the most conventional multi-sector model with non-homothetic preferences (Kongsamut et al. (2001), Gollin et al. (2007), Boppart (2014), Comin et al. (2015)). Structural change and urbanization are known to be tightly linked (Lewis (1954)). Gollin et al. (2016) shows that not only industrial development but also natural resources rents lead to urbanization. However, the literature has rarely investigated the spatial dimension of structural change, largely abstracting from spatial frictions. Michaels et al. (2012) is a notable exception and the closest paper to ours. Michaels et al. (2012) shows that there is a positive correlation between population density in 1880 and subsequent population growth in the United States regions due to differences in the structural change intensity. The crucial difference is the ability of our framework to replicate the evolution of population density within locations—putting emphasis on the internal structure and density of cities—, while their focus is more on the distribution of population and the sectoral specialization across locations. We also emphasize the implications for land values across time and space, largely absent in their study. Adding a spatial dimension to a multi-sector model of structural change also generates endogenously an 'agricultural productivity gap' (Gollin et al. (2014)) due to the mere presence of commuting frictions and location-specific housing. This provides a complementary explanation to urban-rural wage gaps, different from migration costs or selection of migrants towards cities (Restuccia et al. (2008), Lagakos and Waugh (2013), Young (2013)).

Our paper also contributes to the literature in spatial economics on urban expansion surveyed in Duranton and Puga (2014, 2015). An important feature of our framework is the existence of preferential residential locations within cities, shaping the population density across space, due to the presence of commuting frictions (Alonso et al. (1964); Muth (1969); Mills (1967)). We expand this literature by bringing the endogenous sectoral allocation of factors and the general equilibrium structure at the heart of the macro literature. Importantly, contrary to the bare bone urban monocentric model, land is in fixed supply and the price of land at the boundary of the city becomes an endogenous object itself affected by the process of structural change. The most related work to our approach developed in Brueckner (1990) shows how location-specific land values pin down rural-urban migrations and the extent of urbanization in a spatial equilibrium (see also Brueckner and Lall (2015) for a survey). However, without the drivers of structural change and endogenous land values at the urban fringe as in our framework, this approach stays relatively silent regarding the long-run dynamics of urbanization and land values. In this latter dimension, our work relates to the literature measuring and explaining land values across space (see Glaeser et al. (2005), Albouy (2016), Albouy and Ehrlich (2018) and Combes et al. (2018) for recent contributions). In particular, we show that the dispersion of land values across space and the scarcity of land in some locations depend very much on the extent of economic development and structural change. Our approach also provides an alternative mechanism generating a large sprawling of cities together with economic development. More specifically, it explains, why, over time, most cities expand faster in area than in population as documented on a global scale by Angel et al. (2010). Our story is complementary to the usual explanations based on the improvement of commuting technologies and/or the relocation of economic activity within cities (see references in Glaeser and Kahn (2004) and Heblich et al. (2018) for a recent contribution). We refer to LeRoy and Sonstelie (1983); Glaesera et al. (2008); DeSalvo and Huq (1996) when developing our endogenous transport mode model. Lastly, our paper contributes to the literature on quantitative spatial economics surveyed in Redding and Rossi-Hansberg (2017) (see also Ahlfeldt et al. (2015) for related work on the economics of density).

The paper is organized as follows. Section 2 provides motivating empirical evidence on land use, land values, urban expansion and population density across space over long period in France. Section 3 provides a baseline spatial general equilibrium model of land use and structural change which enlightens the main mechanisms. Section 4 develops a quantitative version with multiple regions/cities calibrated to French historical data. Section 5 concludes.

2 Historical Evidence from France

2.1 Land use and Employment in Agriculture.

Data. Using various sources described in the Appendix, we assemble aggregate and regional data (21 regions)[1] on employment shares in agriculture and agricultural land use since 1860. Data are available roughly every 30 years (or less) until the 1980s and then at higher frequency. Historical data are largely extracted from Toutain (1993) based on Recensement Agricole (and cross-checked with various alternative historical sources). Post-1950, data are from the Ministry of Agriculture.

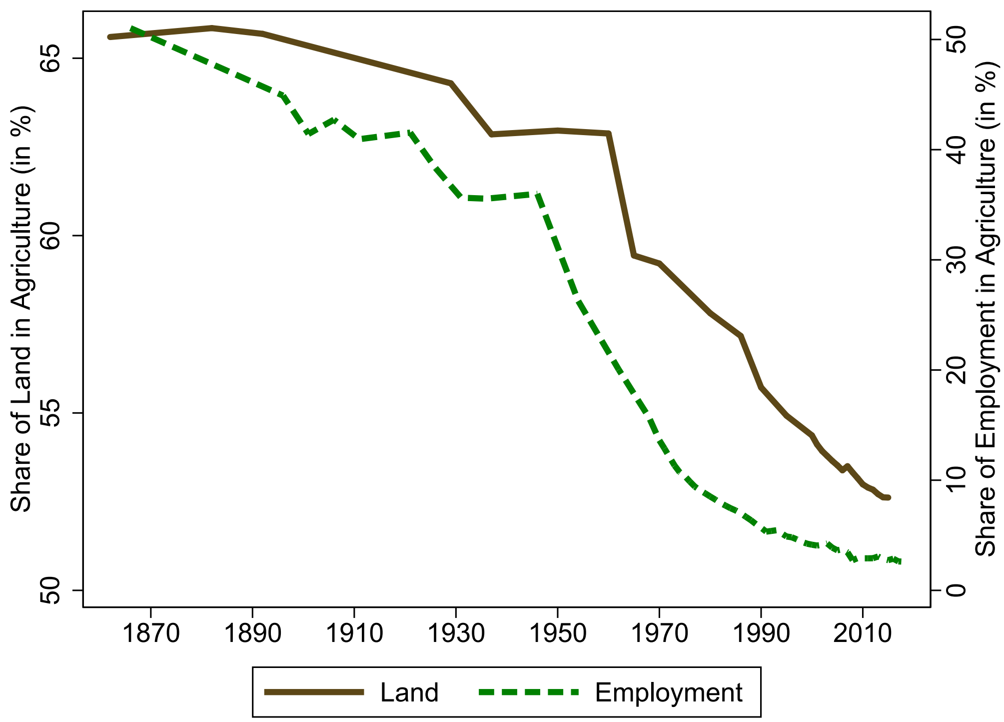


Figure 1: Land use and labor reallocation in France (1860-2015).

Notes: The solid line shows the share of French land used for agriculture (left-axis). The dotted line shows the share of workers in the agricultural sector (right-axis). *Source*: Ministry of Agriculture, Recensement Agricole and Toutain (1993).

Employment. As all countries going through structural transformation, France exhibits a large reallocation of labor away from agriculture over the period, from more than 50% employed in

[1] All metropolitan French regions but Corsica.

agriculture in 1860 to about 2.5% today (Figure 1, dotted line).[2] The process of structural change accelerated significantly over the period 1945-1975: in 1945, 36% of the working population are still in agriculture and this number falls below 10% in 1975. In this sense, France is a bit peculiar relative to the other advanced economies: it is still a very agrarian economy right after World War II—much more than the U.K. or the U.S..

We also observe some significant cross-regional variations even though all regions exhibit structural transformation over time. At each date, some regions have larger shares of employment in agriculture, than others (e.g. in 1860 (resp. 1975), only 12% (resp. 1%) of people work in agriculture in the Parisian region, while at the same dates, 67% (resp. 21%) work in agriculture in Brittany). While the speed and timing of structural transformation is largely common across regions, the data exhibit some relevant variations. For instance, traditional manufacturing regions like Nord-Pas de-Calais saw a massive reduction of the share of agriculture in the early twentieth century, while most regions saw the drastic fall in the thirty years following World War II.

Land use. Although measurement is sometimes difficult for the very early periods, one can confidently argue that, in the aggregate, the share of French land used for agriculture significantly fell since 1860 (Figure 1, solid line).[3] Our preferred estimates are that slightly less than 70% of French land was used for agriculture in 1860 (and at least 65%). In 2015, this number is down to 52%. In other words, about 15% of French land use has been reallocated away from agriculture. While this might not seem like a very large number, this is very large from the perspective of urban expansion. 15% of the French territory is actually more than the total amount of land with artificial use in France nowadays (about 9% of total land today).[4] While this is difficult to assess over such a long period, the novel usage of the land formerly used in agriculture, it is quite likley that a significant fraction of this land has been artificialized—allowing cities to expand. More precise data on land use over the period 1982-2015 show that the surface of artificialized soils increased by about 2 millions of hectares (3.7% of the French territory), about 70% of the quantity of the land no longer used for agriculture over the same period.[5] The measurement of cities area (presented below) provides further compelling evidence that a significant fraction of agricultural land was reallocated towards urban land use.

As for labor, significant differences exist across regions. Not surprisingly, in the Parisian region, more than 30% of the land used for agriculture in 1860 is gone—significantly more than for France as a whole. To the opposite, in some regions, it barely changed (e.g. Normandy) and it even slightly

[2] Estimates of rural population are also available for the same time-period (see Appendix). Rural population follows a similar path with, as expected, higher levels as many people in rural areas do not work directly in agriculture. One needs to be cautious though when using data on rural vs. urban population due as the ad-hoc definition by official statistics varies over the period.

[3] The main issue is the allocation of grazing fields which is not entirely consistent across years. This gives a slight disagreement among historians among the total among of use agricultural land in the pre-WWII period.

[4] Since 1982, data on land use beyond agricultural land use are available on a regular basis from the Enquetes Teruti and Teruti-Lucas.

[5] The rest of agricultural land is to a large extent converted into forests and woods (Enquetes Teruti and Teruti-Lucas). Their surface, inluding groves and hedges, increased by almost 1 million of hectares between 1982 and 2015.

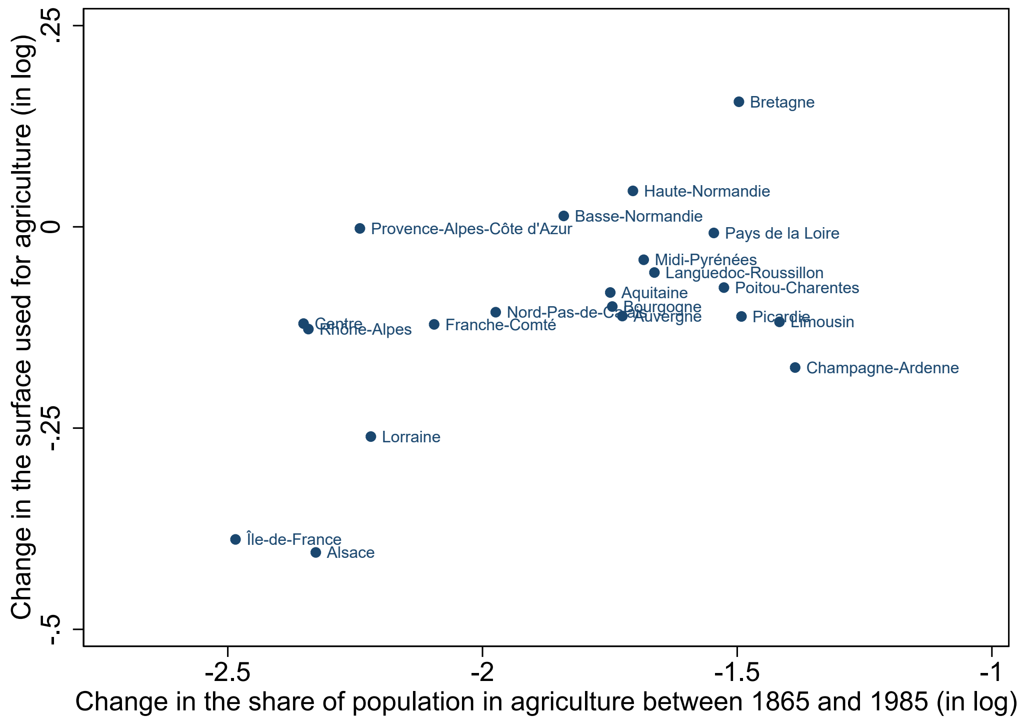


Figure 2: Land use and employment reallocation across regions (change between 1865 and 1985). *Notes*: The scatter plot shows the log-change in the share of land used in agriculture in a given region as a function of the log-change in the share of employment in agriculture in the same region. The log-change is taken over the 120 years period, 1865-1985. *Source*: Ministry of Agriculture, Recensement Agricole and Toutain (1993).

increased in Brittany. Overall, looking at the regional dimension of our data over long period, we find supportive evidence that reallocation of labor away from agriculture across regions is linked to the reallocation of land use across regions. Over the period 1865-1985, regions with a larger fall of the employment share in agriculture did see a larger fall in the use of land for farming (Figure 2).

Spending Shares. We compute expenditure shares on three broad categories: food/drinks, housing and the remaining goods. The expenditure share on food/drinks proxy for the rural goods. The expenditure share outside food, drinks and housing includes manufacturing goods and services. It proxies for the spending share on urban goods. The model's counterparts of the three category are thus respectively expenditure shares on rural goods, housing and urban goods. With some abuse of language, we now refer to these three categories as rural, housing and urban. For details on those data we refer to appendix A.6. Comparing the initial periods in the late nineteenth century to today gives the following broad facts: the food (rural) share went down from almost 50% of expenditures to 17%; the housing share increased slightly to 23% to 31%; the share of expenditure on other goods increased as a consequence from 27% to more than 50%. This reallocation of expenditures way from rural goods towards housing and urban goods fits well with the process of strucutral transformation.

2.2 Urban Expansion

Data. We use maps, areal photograhs and satellite data to measure the area of the main French cities at different dates: 1866 (military maps, e.g. carte d'Etat Major), 1950 (maps and/or photographs), and every five years after 1975 using satellite data from GHLS.[6] One caveat of our area measurement is that we cannot have any measurement between 1860 and 1950. Data on the measurement of the urban extent across French cities are detailed in the Appendix. Measurement of the urban extent using maps in 1866 and 1950 is performed for the 100 largest cities in population in the initial period. For a given city, the urban extent ends when the land is not continuously built. For the satellite data, it is delimited by grid cells where the fraction built is below 25%.[7] As an example, Figures 17 and 18 in the Appendix show the area measurement for a medium-size French city, Reims, in 1866 and 1950 using maps. Figure 19 shows the same city of Reims in 2015 viewed from the sky, with an area of about 50 km^2—more 15 times larger than its 1866 counterpart. This last Figure also clearly shows how the city is surrounded by agricultural land—a crucial element for our story where urban land expands out of farmland.[8] Figures 20 in the same Appendix shows how GHLS satellite data are used to delineate the urban boundaries of Paris.

Using French Census data, we relate the measured land area used by cities to the corresponding population. Census data for 1860 are used for the initial period of study. Census data defines population at the municipality level ('commune') and an urban area can incorporate more than one municipality. In 1860, this is not much of an issue as the main 'commune' of the city is the whole city population. In the later periods, one needs to group municipalities ('communes') into an urban area. Post 1975, GHLS data combines satellite images with the Census data on population. This directly provides the population of every grid cells of our measured urban area, circumventing the issue. However, for the 1950 period, the different municipalities that are part of our measured areas must be selected. This is done municipalities by municipalities looking at the map of each of the 100 largest urban areas. This way, we make sure that the overall population of the area incorporates all the corresponding municipalities' population. Note however that, for most cities in 1950, only very few 'communes' are agglomerated into one city. Only the largest cities, and particularly Paris, are the results of the agglomeration of many different 'communes'.

The area and population of French cities. Not surprisingly, more populated cities are larger in area. In a cross-section, at a given date, an 10% increase in the population of a city corresponds to a 8.5% increase in its area and this elasticity varies little across the different time periods.[9] More surprisingly, over time, cities have been increasing much faster in area than in population. Let us give some order of magnitude and describe the average evolution over time for the largest French

[6] We also double-check the quality of photo/map measurement in the most recent period relative to satellite data measurement. The cross-sectional correlation between measurement using photos and satellite data measurement is very high.

[7] Measurement is not very sensitive to alternative higher thresholds. See Appendix for sensitivity analysis.

[8] This feature is not specific to Reims. Observation of all the main French cities show that they are largely surrounded by agricultural land, apart from their coastal part.

[9] See Appendix for scatter plots of log area on log population at various dates.

cities (say the top 30). Since 1860, the area of cities has been multiplied by a factor 50 to 60 on average. This is very large. Between 1860 and 1950, the area of cities was roughly multiply by a factor 7 to 8. Between 1950 and today, the area of cities was multiplied again by a factor 8 on average—the fastest rate of increase being observed over the period 1950-1975. For comparison, the population of these largest cities has been multiplied by a factor 5 since 1860.[10]

The density of French cities. Using the population and the area of cities at the different dates, one can measure the evolution of urban densities across the different cities over the period 1860-2015. While in the cross-section larger cities are denser, the density of French cities declined over time—area expanding at a faster rate than population. This is shown in Figure 3 for the population-weighted average of density across the 30 largest French cities (and in the Appendix for the 3 largest French cities: Paris, Lyon and Marseille). The average urban density fell massively over the period: density has been divided by a factor of the order of magnitude of 10. Urban density fell at the fastest rate over the period 1950-1975 and barely falls thereafter. Thus, urban density fell the most over the period when people massively left rural areas and the employment share in agriculture also fell the most. The later slowdown of the decline in density coincides with the slowdown in the rate of structural transformation.

The historical decline in urban density is observed across all cities although the magnitude differs across cities: for instance, in Lille, urban density fell from 67,300 to less than 2,500 people/km^2—divided by a factor 27 between 1866 and 2015; over the same period, urban density was divided by about 5 in Nancy, from 13,400 to 2,500 people/km^2.

Ideally, one would like to explore how density evolved in different locations of city (within-city variations). Unfortunately, for most cities we are not able to differentiate the central density to the suburban one as most cities expand the area of their main historical 'commune', particularly so over the period 1860-1950. Thus, we cannot measure the historical population in different parts of a city. However, this can be done for few very large cities divided into districts (Paris, Lyon and Marseille). This is shown in the Appendix for Paris (Figure 21): the central density of Paris did fall over time (by a factor of about 2.5) but significantly less than the average density of the city.

2.3 Housing and Land values

Data. Historical data for the real housing price index for France are from Knoll et al. (2017). Data on land and housing values (over income) for France over a long period can also be found in Piketty and Zucman (2014).

Historical evolution. Figure 4 shows the evolution of the real housing price index in France since 1870. Like other advanced economies, housing prices have been quite stable until the late 1950s

[10]French population was multiplied by a bit less than 2 over the entire period. Due to the reallocation of people way from rural areas towards cities, we get roughly a factor 5 over the period.

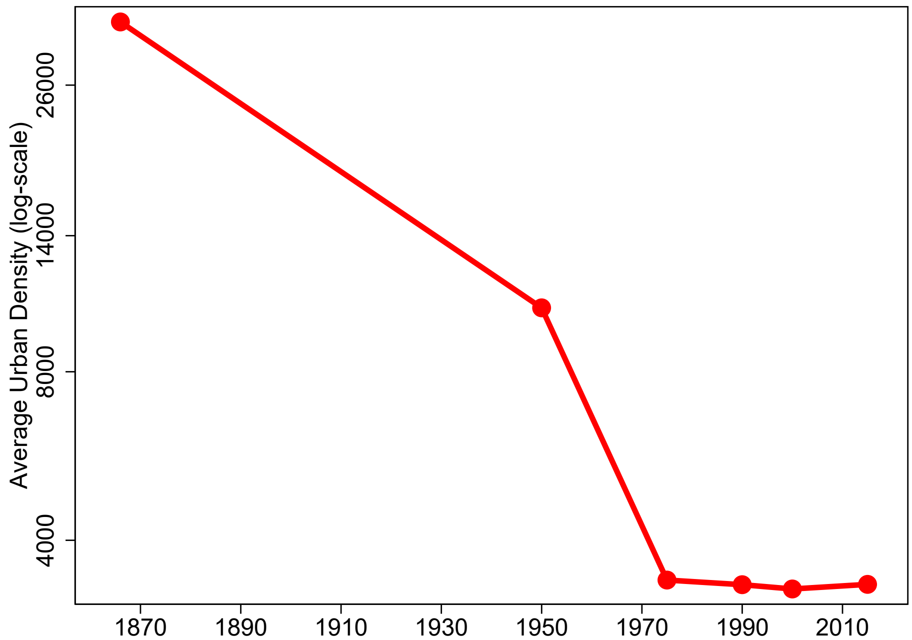


Figure 3: The historical decline in urban density.

Notes: The solid line shows the urban density averaged across the top 30 French cities (weighted average with 1975 population weights). *Source*: Etat major, IGN, GHLS and Census.

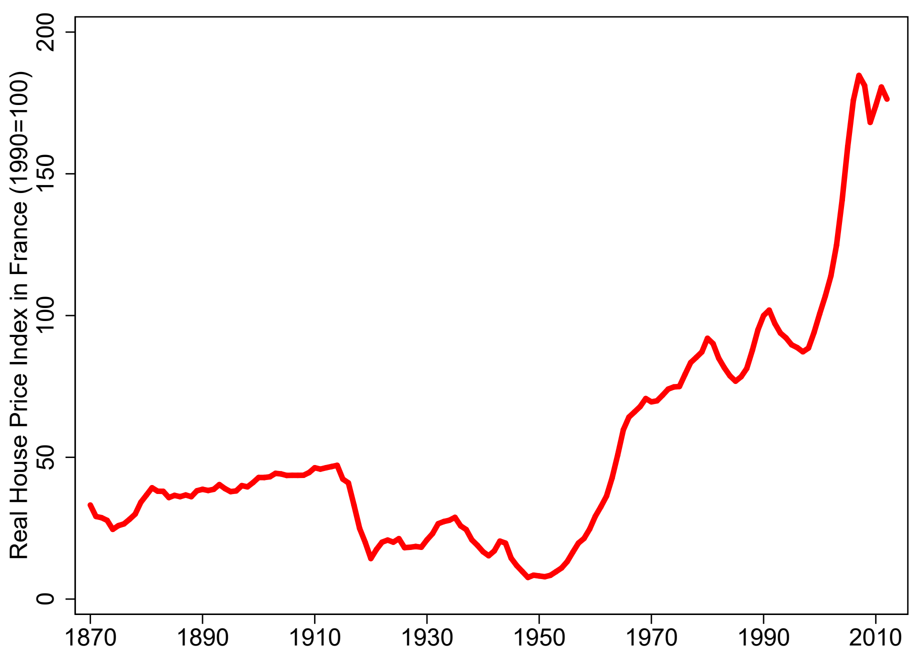


Figure 4: Real Housing Price Index in France (1870-2010). *Source:* Knoll et al. (2017)

before rising at an increasing pace—the *hockey-stick* shape of housing prices identified in Knoll et al. (2017).

Figure 24 in the Appendix provides additional evidence by showing that the fall in the value of housing and land wealth (as a share of income) in the pre-WWII period was essentially driven by a declining value of farmland. While the value of agricultural land accounted for about 2/3 of housing and land wealth in 1830, it accounts for only 3% in 2010. However, despite the falling value of farmland as share of income, the value of land wealth (as share of income) grows at an increasing rate after 1950, in line with the evidence in Knoll et al. (2017).[11] Importantly, this increase is largely driven by the increasing value of urban land—land wealth being reallocated away from agricultural land towards urban land.

This set of stylized facts regarding structural change, urban expansion and the evolution of land values motivate our subsequent theoretical analysis.

3 A Baseline Model

3.1 Production and Spatial Structure

We consider an economy producing a urban good (u) and a rural good (r). The urban good can be thought as a composite of manufacturing good and services, while the rural good can be thought as an agricultural good. Goods and factor markets are perfectly competitive. Both goods are perfectly tradable.

Factor Endowments. The economy is endowed with land and a continuum of workers, both in fixed supply. Land can be used to produce the rural good or for residential purposes. Land area is normalized to unity. Each worker is endowed with one unit of labour and we denote by L the total population of workers.

Production and Factor Payments. The production of the urban good only uses labour as input. One unit of labour produces θ_u units of the urban good. Perfect competition insures that the urban wage is

$$w_u = \theta_u, \tag{1}$$

in terms of units of the urban good, which is used a numeraire. For now, we consider the urban productivity θ_u (and thus the urban wage) as exogenous. We consider agglomeration forces in Section 4. Aggregate production of the urban good is

$$Y_u = \theta_u L_u,$$

where L_u denotes the number of workers working in the urban sector.

[11] Bonnet et al. (2019) show that this increase in the price of housing is largely driven by the price of land and not by the capital and structure component.

The production of the rural good uses labor and land according to the following constant returns to scale technology

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

where L_r denotes the number of workers working in the rural (agricultural) sector, S_r the amount of land used for production and θ_r a Hicks-neutral productivity parameter. $0 < \alpha < 1$ is the intensity of labor use in production, $1-\alpha > 0$ ensures that land is used more intensively to produce the rural good. $\sigma \geq 0$ is the elasticity of substitution between labor and land, $\sigma = 1$ corresponding to the usual Cobb-Douglas case.

Define p the relative price of the rural good in terms of the numeraire urban good. Rural workers and land are paid their marginal productivities,

$$w_r = \alpha p \theta_r \left(\alpha + (1-\alpha) \left(\frac{S_r}{L_r} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}} , \tag{2}$$

$$\rho_r = (1-\alpha) p \theta_r \left(\alpha \left(\frac{L_r}{S_r} \right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha) \right)^{\frac{1}{\sigma-1}} , \tag{3}$$

where w_r is the rural wage and ρ_r the rental price of land anywhere in the rural sector. Note that it will be useful to express the price of land relative to wages,

$$\rho_r = \left(\frac{1-\alpha}{\alpha} \right) w_r \left(\frac{L_r}{S_r} \right)^{\frac{1}{\sigma}} . \tag{4}$$

Note that due to the CES technology, the rental price of land increase with (rural) wages with a unitary elasticity and with population working in the rural sector L_r with an elasticity $1/\sigma$—stronger complementarities between land and labor implying a larger fall of land prices if workers are reallocated to urban production.

Remarks. The important technology assumption is that the rural sector uses a fixed factor, land, for production, which implies (stronger) decreasing return to scale to labor in this sector compared to the urban sector. The fact that the urban sector does not use land is not crucial as long as this sector is less land intensive than the rural one.

Spatial structure. The production of the urban good takes place in the city, while the production of the rural good, being more land intensive, takes place in the rural area. For now, we assume that production of the urban good takes place in only one location $l = 0$. Extension with multiple locations (multiple cities) is provided in Section 4.

One can think of $l = 0$ as the Central Business District (CBD) in a standard urban model. Workers' locations of residence l are ordered from zero to unity depending on the magnitude of the spatial frictions $\tau(l)$, as a fraction of the urban wage, that workers have to pay to work in the urban sector. A worker residing in location l and working in the urban sector earns wage *net of spatial frictions* equal to $w_u - \tau(l)$, with $\tau(0) = 0$ and $\partial\tau(l)/\partial l \geq 0$. The fraction of wage lost $\tau(l)$ incorporates all spatial frictions which lowers disposable income available for consumption when living further away from the location of production. It includes time-costs of commuting (or productivity losses due to long commutes) and the effective spending on transportation. It could also incorporate an income reduction if it is harder to find a job when living further away from the location of production.

Since spatial frictions increase with l, urban workers locate as close as possible to $l = 0$. If one denotes $l = \phi < 1$ the further away location of a urban worker, ϕ is endogenous in our framework and represents the fringe of the city. Workers residing in locations above ϕ produce the rural good, which does not involve spatial frictions.

Remarks. The spatial structure calls for a number of important remarks. First, if it were possible for all workers to locate at $l = 0$, it would save the spatial frictions. Second, one should note that for $l \leq \phi$, land will be used for residential purposes to host urban workers. As a consequence, land available for rural production would also be maximized if all workers could locate at $l = 0$. This case could correspond to an entirely 'vertical' city, where land use and spatial frictions are irrelevant. We view this extreme case as a standard two-sector model of structural transformation. Last, the spatial frictions $\tau(l)$ do not involve traffic congestion—the reason why a more compact city (lower ϕ) always saves on commuting costs in our baseline economy. The case of traffic congestion is explored in Section 4.

3.2 Endogenous Transport Mode Choice

Commuting costs in location l, $\tau(l)$, are the sum of a fixed cost of commuting f in terms of urban goods and an opportunity cost of time proportional to $w_u \cdot t(l)$, where $t(l)$ denotes the time spent on daily commutes of an individual located in l, such that

$$\tau(l) = f + \zeta w_u \cdot t(l) \tag{5}$$

whereby $0 < \zeta \leq 1$ represents the valuation of commuting time in terms of foregone wages. The commuting time (both ways) is equal to $\frac{2l}{m}$, where m is the commuting speed of the transportation mode. Transportation modes available are continuously ordered by their speed m, as in DeSalvo and Huq (1996). The fixed cost $f = f(l, m)$ depends on the tranportation mode/speed and the location l. Faster and longer commutes are more expensive and the fixed cost $f(l, m)$ is increasing in both arguments, with $\frac{\partial^2 f}{\partial^2 l} \leq 0$. The latter technical assumption makes sure that the importance of fixed costs (relative to the opportunity cost of time) decreases as the commuting distance increases. This yields the following expression for the commuting costs,

$$\tau(l) = f(l, m) + 2\zeta w_u \left(\frac{l}{m}\right). \tag{6}$$

For tractability, we will use the following functional form for f,

$$f(l, m) = \frac{c_\tau}{\eta_m} m^{\eta_m} l^{\eta_l}, \tag{7}$$

with $\eta_m > 0$, $0 \leq \eta_l < 1$ and c_τ a cost parameter measuring the efficiency of the commuting technology. This reduced-form parametrization of the fixed cost allows us to preserve some tractability while elucidating the main mechanisms. The fixed-cost has several possible interpretations. At a more macro level, it can represent the fixed-cost of installing public transportation, where a faster mode is more expensive (a train line versus the horse drawn omnibus).[12] At a more individual level, it represents the cost of buying an individual means of transportation—a bike being cheaper than an automobile. However, this reduced-form approach sets aside the possibility that the implemented commuting technologies and the effective speed of commuting depends in a more sophisticated way of the equilibrium allocation in the city (traffic congestion, the construction of a transportation infrastructure, e.g. a subway network, being dependent on the whole spatial allocation of urban residents,...). We now turn to the optimal choice of transportation mode.

Optimal mode of transportation. At any given moment in time, prevailing technology offers different transportation modes to individuals ordered by their respective speed m. An individual in location l chooses the mode of transportation corresponding to speed m in order to minimize the commuting costs $\tau(l)$. This equalizes the marginal cost of a higher speed m to its marginal benefits in terms foregone wage,

$$\frac{\partial f}{\partial m} = 2\zeta w_u \left(\frac{l}{m^2}\right).$$

Using Eq. 7, the optimal chosen mode/speed satisfies

$$m = \left(\frac{2\zeta w_u}{c_\tau}\right)^{\frac{1}{1+\eta_m}} l^{\frac{1-\eta_l}{1+\eta_m}}. \tag{8}$$

Individuals living further away choose faster commuting modes. The speed of commuting also increases with the wage rate as a higher wage increases the opportunity cost of time. Using Eqs. 6-8, we get that equilibrium commuting costs satisfy,

$$\tau(l) = a w_u^{\frac{\eta_m}{1+\eta_m}} l^{\frac{\eta_m+\eta_l}{1+\eta_m}}, \tag{9}$$

where $a = \left(\frac{1+\eta_m}{\eta_m}\right) c_\tau^{\frac{1}{1+\eta_m}} (2\zeta)^{\frac{\eta_m}{1+\eta_m}} > 0$. Commuting costs are falling with faster improvements in the commuting technology (a lower c_τ).[13] They are increasing with the wage rate (the opportunity cost of time) and the distance of commuting trips with constant elasticities. Since individuals optimally choose the commuting speed, the elasticity $\left(\frac{\eta_m}{1+\eta_m}\right)$ of commuting cost to the wage rate is strictly smaller than unity. This is crucial as it implies that, for a given residential location, the share of resources devoted to commuting falls with rising productivity and wages. In equilibrium, this will tend to make individuals willing to live further away when labor productivity increases.

[12] The installation cost is also higher as the transportation mode reaches further away location. However the fixed-cost per unit of distance, $f(l, m)/l$ is decreasing with the distance reached.

[13] a is alike a relative price of commuting: if technology improves relatively faster in the commuting sector, the relative price a of commuting (in terms of urban goods) falls.

3.3 Preferences and Consumption

Preferences. Consider a worker living in a location l. Denote $c_r(l)$ the consumption of rural (agricultural) goods, $c_u(l)$ the consumption of urban goods (used a a numeraire) and $h(l)$ the consumption of housing. The composite consumption good is

$$C(l) = (c_r(l) - \underline{c})^{\nu(1-\gamma)} \left(c_u(l) + \underline{s}\right)^{(1-\nu)(1-\gamma)} h(l)^{\gamma} \tag{10}$$

where $\underline{c}$ denotes the minimum consumption level for the agricultural good, and where $\underline{s}$ stands for the initial endowment of the urban good. Preference parameters ν and γ belong to $(0, 1)$. Workers derive utility only from consumption. The utility of a household in location l is thus equivalent to $C(l)$.

Budget contraint. The household earns a wage income net of spatial frictions $w(l)$ in location l. Given the spatial structure, $w(l) = w_u - \tau(l)$ for $l \leq \phi$ and $w(l) = w_r$ for $l > \phi$. The households also earns land rents, r. Land rents are redistributed lump-sum equally across workers and are thus assumed to independent on the location. The budget constraint of the worker in location l satisfies

$$pc_r(l) + c_u(l) + q(l)h(l) = w(l) + r, \tag{11}$$

with $q(l)$ the rental price per unit of housing in location l.

Expenditures. Maximizing Eq. (10) subject to the budget constraint Eq. (11), expenditures on each good satisfy

$$pc_r(l) = (1-\gamma)\nu(w(l) + r + \underline{s} - p\underline{c}) + p\underline{c} \tag{12}$$

$$c_u(l) = (1-\gamma)\,(1-\nu)\,(w(l) + r + \underline{s} - p\underline{c}) - \underline{s} \tag{13}$$

$$q(l)h(l) = \gamma(w(l) + r + \underline{s} - p\underline{c}). \tag{14}$$

Due to the presence of non-homotheticities, higher income, wages or land rents, individuals reallocate consumption away from the rural good, increasing the consumption share of the urban good and as well as housing.

3.4 Equilibrium Sorting

Mobility equations. We consider an equilibrium, where ex-ante identical workers sort across locations. Since the rural and the urban good are perfectly tradable, workers, which would all prefer locations closer to $l = 0$, compete for these locations. Adjustment of housing prices through the price of land, make sure that households remain indifferent across different locations. This implies the following mobility equation, where consumption is equalized to $\overline{C}$ across locations l,

$$\overline{C} = C(l) = \kappa \frac{w(l) + r + \underline{s} - p\underline{c}}{q(l)^{\gamma}}, \tag{15}$$

with κ constant across locations, equal to $((1-\gamma)\nu)^{(1-\gamma)\nu}\left((1-\gamma)(1-\nu)\right)^{(1-\gamma)(1-\nu)}\gamma^{\gamma}/p^{\nu(1-\gamma)}$.

The mobility Eq. (15) implies that $\left(\frac{w(l)+r+\underline{s}-p\underline{c}}{q(l)^{\gamma}}\right)$ is constant across locations. This holds within urban locations ($l \leq \phi$), within (identical) rural locations as well as when comparing a urban and rural worker. Since workers in the rural sector do not face spatial frictions and live in ex-post identical locations, $l \geq \phi$, the price of housing must be the same across these locations. We denote by q_r the price of housing in the rural sector, where $q_r = q(l \geq \phi)$. A worker in the rural sector is paid his marginal productivity w_r, receives land rents r and faces the same housing rental price $q_r = q(\phi)$ than a urban worker at the fringe. Therefore we have

$$w(\phi) = w_r = w_u - \tau(\phi). \tag{16}$$

In other words, the urban worker at the fringe of the city must have the same wage net of frictions than a rural worker. Eq. (16) shows how the spatial structure matters to understand the urban-rural wage gap. Higher spatial frictions at the fringe ϕ reduce incentives of rural households to move to the urban sector.

Housing Rental Price Gradient. Within city locations ($l \leq \phi$), the rental price of one unit of housing adjusts such that workers are indifferent across locations. Using Eqs. (15) and (16), we get

$$q(l) = q_r\left(\frac{w(l)+r+\underline{s}-p\underline{c}}{w(\phi)+r+\underline{s}-p\underline{c}}\right)^{1/\gamma} = q_r\left(\frac{w(l)+r+\underline{s}-p\underline{c}}{w_r+r+\underline{s}-p\underline{c}}\right)^{1/\gamma}. \tag{17}$$

Within the city, $q(l)$ is falling with l to compensate workers who live in worse locations. For l above ϕ, the housing price is constant across locations and equal to q_r. The crucial difference compared to the standard urban model is that the price at the fringe q_r is endogenously determined in our general equilibrium model.

3.5 Housing Market Equilibrium

Housing Demand. Using Eq. (17), the demand for housing space per worker in each location $h(l)$ is increasing with l for $l \leq \phi$,

$$h(l) = \gamma\left(\frac{w(l)+r+\underline{s}-p\underline{c}}{q(l)}\right) = \left(\frac{\gamma}{q_r}\right)(w(\phi)+r+\underline{s}-p\underline{c})^{1/\gamma}(w(l)+r+\underline{s}-p\underline{c})^{1-1/\gamma}. \tag{18}$$

Facing higher housing prices, household closer to the CBD demand less housing space. For locations in the rural area, housing demand per rural worker is constant equal to $h(l \geq \phi) = \gamma\left(\frac{w_r+r+\underline{s}-p\underline{c}}{q_r}\right)$.

Housing Supply. The supply of housing (floorspace) is provided by land developers, which can use more or less intensively the land for residential purposes. In each location l, developers supply housing space $H(l)$ per unit of land with a convex cost

$$c(l)\frac{H(l)^{1+1/\epsilon(l)}}{1+1/\epsilon(l)}$$

paid in units of the numeraire,[14] where $c(l)$ and $1/\epsilon(l)$ are costs parameters. $c(l)$ and $\epsilon(l)$ can depend on the location, which is meant to capture that it might be more costly for developers to build closer to the city center than in the suburbs or the rural part of the economy. Profits per unit of land of the developers are

$$\pi(l) = q(l)H(l) - c(l)\frac{H(l)^{1+1/\epsilon(l)}}{1+1/\epsilon(l)} - \rho(l),$$

where $\rho(l)$ is the rental price of a unit of land in location l. Similarly to the housing price $q(l)$ above, for locations beyond the fringe ϕ, the land rent is constant, hence $\rho_r = \rho(l \geq \phi)$.

Maximizing profits gives the following supply of housing $H(l)$ in a given location l,

$$H(l) = \chi(l)q(l)^{\epsilon(l)}, \tag{19}$$

where the two parameters $\chi(l) = (1/c(l))^{\epsilon(l)} \geq 0$ and $\epsilon(l)$ summarize the housing supply conditions. The parameter $\chi(l)$ is a supply shifter—higher construction costs reduce the supply of housing in a given location. Note that $\chi(l)$ could have other interpretations linked to the regulatory environment of housing policy (imposed floor-to-area ratios, developable land constraints, building heights limits...).[15] The parameter $\epsilon(l)$ is the price elasticity of housing supply in location l. More convex costs to build intensively on a given plot of land reduces the supply response of housing to prices.[16] In the rural area, housing supply shifters are assumed to be the same across locations, equal to χ_r—$\chi(l) = \chi_r$ for $l \geq \phi$. We also assume that supply conditions are more favourable in the rural area such that, $\chi_r \geq \chi(l)$ for $l \leq \phi$. Similarly, the housing supply elasticity is assumed constant in the rural sector, $\epsilon_r = \epsilon(l \geq \phi)$.

Lastly, free entry imply zero profits of land developers. This pins down land prices in a given location,

$$\rho(l) = \frac{q(l)H(l)}{1+\epsilon(l)} = \chi(l)\frac{q(l)^{1+\epsilon(l)}}{1+\epsilon(l)}, \tag{20}$$

Eq. (20), together with Eq. (17), implies that land prices are higher in locations closer to the city center and in locations where land developers can build more intensively (higher $\chi(l)$ and higher $\epsilon(l)$).

Arbitrage across land uses imply that the latter land price must be in equilibrium above the marginal productivity of land for production of the rural good (Eq. (3)), where the condition holds with

[14]The urban good is used as an intermediary input for the production of housing space.

[15]If each unit of land provides only a fraction that can be developed due to regulations, the supply of housing per unit of land is homogenous to our supply fonction through a lower supply shifter χ—χ incorporating the fraction of developable land per unit of land. χ could be also interpreted as regulatory limits to expand $H(l)$ per unit of land using intermediary input (e.g. limits to build higher). With a 'wedge' $\zeta(l) < 1$ in the FOC of the maximization for $H(l)$, we get: $H(l) = \zeta(l)(q(l)/c(l))^{\epsilon}(l)$, implying $\chi(l) = \zeta(l)\,(1/c(l))^{\epsilon(l)}$.

[16]Some equivalent formulation holds for a Cobb-Douglas production function of housing used for example in Combes et al. (2018).

equality in the rural part of the economy, for $l \geq \phi$,

$$\rho_r = \chi_r \frac{(q_r)^{1+\epsilon_r}}{1+\epsilon_r} = (1-\alpha)p\theta_r \left(\alpha \left(\frac{L_r}{S_r} \right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha) \right)^{\frac{1}{\sigma-1}}. \tag{21}$$

Housing Market Clearing. Consider first locations within the city, $l \leq \phi$. Market clearing for housing in each location implies $H(l) = D(l)h(l)$, where $D(l)$ denotes the density (number of urban workers) in location l. Within the city, the density $D(l)$ follows immediately from Eqs. (18) and (19),

$$D(l) = \frac{H(l)}{h(l)} = \frac{\chi(l)q(l)^{1+\epsilon(l)}}{\gamma(w(l) + r - p\underline{c})}. \tag{22}$$

Density for $l \leq \phi$ can be rewritten using Eq. (17) and Eq. (20) as,

$$D(l) = \rho_r \left(\frac{\chi(l)}{\chi_r} \right) \frac{1}{\gamma_l} (w(\phi) + r + \underline{s} - p\underline{c})^{-1/\gamma_l} (w(l) + r + \underline{s} - p\underline{c})^{1/\gamma_l - 1}, \tag{23}$$

where $\gamma_l = \frac{\gamma}{1+\epsilon(l)}$ represents the spending share on housing adjusted for the supply elasticity in location l. Integrating the density across urban locations gives the total urban population,

$$L_u = \int_0^\phi D(l)dl = \rho_r \int_0^\phi \left(\frac{\chi(l)}{\chi_r} \right) \frac{1}{\gamma_l} (w(\phi) + r + \underline{s} - p\underline{c})^{-1/\gamma_l} (w(l) + r + \underline{s} - p\underline{c})^{1/\gamma_l - 1} dl \tag{24}$$

Eq. (24) pins down the city size ϕ. It says that if more workers are willing to move in the urban sector, the city will have to be bigger in area to host them—ϕ is increasing with L_u. One should also notice that the city's area increases if the price of land ρ_r at the fringe is lower, if housing supply conditions in the city are tighter (low $\chi(l)$ and/or low $\epsilon(l)$), and if spatial frictions $\tau(l)$ are lower.

In the rural area, $l \geq \phi$, market clearing for residential housing imposes

$$L_r \gamma \left(w_r + r - p\underline{c} \right) = S_{hr} \chi_r \left(q_r \right)^{1+\epsilon_r} = S_{hr}(1+\epsilon_r)\rho_r,$$

where S_{hr} is the amount of land demanded in the rural area for residential purposes. This leads to the following demand of land for residential purposes in the rural area,

$$S_{hr} = \frac{L_r \gamma_r \left(w_r + r + \underline{s} - p\underline{c} \right)}{\rho_r}, \tag{25}$$

where $\gamma_r = \frac{\gamma}{1+\epsilon_r}$.

Land and labor market clearing. Land is used for residential or productive purposes. With total land available in fixed supply, the land market clearing condition is

$$S_r + S_{hr} + \phi = 1.$$

Using Eq. (25), this is equivalent to

$$S_r = 1 - \phi - \frac{L_r \gamma_r \left(w_r + r + \underline{s} - p\underline{c}\right)}{\rho_r}. \tag{26}$$

The labor market clearing is such that the total population L is located either in the city or in the rural area,

$$L_u + L_r = L. \tag{27}$$

Land rents. Aggregate land rents, rL, include the land rents generated both in the city and in the rural area,

$$rL = \int_0^\phi \rho(l)dl + \rho_r \times (1 - \phi), \tag{28}$$

where it is useful to notice that the rental value of land in the city exceed the rental value a farmland for the same area due to spatial frictions.

3.6 Goods markets equilibrium

A last step consists in clearing the goods market for rural and urban goods to pin down the allocation of labor across sectors for a given equilibrium city size ϕ.

Aggregate per capita income. Let us introduce y as the aggregate per capita income in the economy net of spatial frictions that is spent on both goods,

$$y = r + \frac{L_r}{L} w_r + \frac{1}{L} \int_0^\phi w(l)D(l)dl.$$

Goods market clearing conditions. Aggregating Eqs. (12)-(13) across locations, we get that aggregate per capita consumption of rural good and urban good satisfy

$$\begin{aligned} pc_r &= \nu(1-\gamma)(y + \underline{s} - p\underline{c}) + p\underline{c} \\ c_u &= (1-\nu)(1-\gamma)(y + \underline{s} - p\underline{c}) - \underline{s} \end{aligned}$$

The rural good is only used for consumption. This gives the following market clearing condition for the rural good,

$$\nu(1-\gamma)y + \nu(1-\gamma)(\underline{s} - p\underline{c}) + p\underline{c} = py_r, \tag{29}$$

where $y_r = \frac{Y_r}{L}$ denotes the production per worker of the rural good.

The urban good market clearing is more involved as urban goods are either consumed, used as intermediary inputs to build residential housing (in all locations) or lost due to spatial frictions. The sum of these three uses equals the supply of the urban good, expressed per capita,

$$c_u + \frac{1}{L} \int_0^\phi \tau(l)D(l)dl + \frac{1}{L} \int_0^1 \frac{\epsilon(l)}{1 + \epsilon(l)} q(l)H(l)dl = y_u, \tag{30}$$

where $y_u = \frac{Y_u}{L}$ denotes the production per worker of the urban good.

3.7 Equilibrium allocation

For a given set of exogenous parameters, technological parameters $(\theta_u, \theta_r, \alpha, \sigma, m)$, commuting cost parameters (η_m, η_l, c_τ) and resulting spatial frictions $\tau(l)$ at each location $l \in \mathcal{L}$, housing supply conditions $(\epsilon(l), \{\chi(l)\}_{l\in\mathcal{L}})$, and preference parameters, $(\nu, \gamma, \underline{c}, \underline{s})$, the equilibrium is defined as follows.

Definition 1. *An equilibrium is a sectoral labor allocation* (L_u, L_r)*, a city fringe* (ϕ) *and rural land used for production* (S_r)*, sectoral wages* (w_u, w_r)*, a rental price of farmland* (ρ_r)*, a relative price of rural goods* (p) *and land rents* (r)*, such that:*

- *Factors are paid the marginal productivity, Eqs.* (1)-(3)*.*
- *Workers are indifferent in their location decisions, Eq.* (16)*.*
- *The demand for urban residential land (or the city fringe* ϕ*) satisfies Eq.* (24)*.*
- *Land and labor markets clear, Eqs.* (26) *and* (27)*.*
- *Land rents satisfy Eq.* (28)*.*
- *Rural and urban goods markets clear, Eqs.* (29) *and* (30)*.*

4 Quantitative Model

In this section we introduce a quantitative version of the model. Our objective is the estimation of both a single and a multiple-city quantitative model on French historical data since 1860. At this stage, we implement a single city economy without agglomeration economies or traffic congestion. One can interpret the following illustrative simulations as aggregate outcomes for the 'average' French city.

Our simulations are repeated static equilibra of the model in fifteen-year steps from 1855 until 2040. We feed the model a sequence of estimated productivity shocks $\{\theta_{u,t}\}, \{\theta_{r,t}\}$ which are shown in figure 5. We describe the proceedure for obtaining those values in appendix A. We will illustrate through counterfactuals the important role played the increase in agricultural productivity, which reduces the rural employment and solves the 'food problem'. Eventually, the economy converges to an equilibrium with constant and positive employment in the rural sector $L_r > 0$, the size of which is governed by the utility function parameter ν.[17] The parameterization is summarized in table 1, and we briefly explain the main features here:

- **Technology**. $\alpha = 0.75$, $\sigma = 1$.

[17]Different productivities across sector yield qualitatively similar results, yet different rates of convergence.

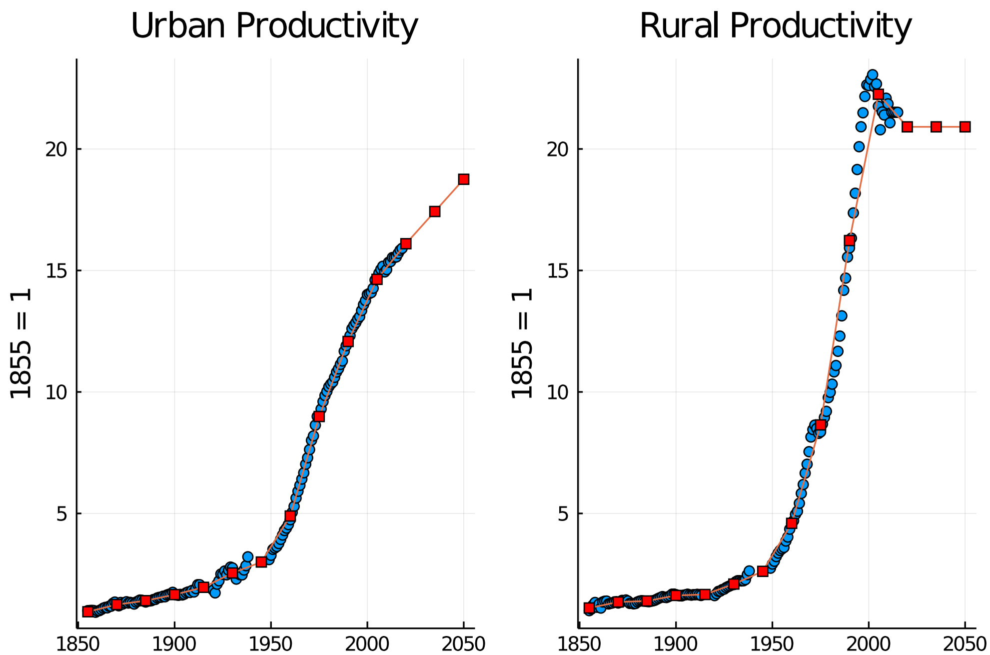


Figure 5: Estimated time series $\{\theta_{u,t}\}, \{\theta_{r,t}\}$ data (blue dots) and smoothed series (red squares), used in the model.

- **Preferences**. Housing weight, $\gamma = 25\%$. Rural weight, $\nu = 5\%$.
  Subsistence level $\underline{c} = 0.7$ such that given initial θ_r, slightly more than 50% of workers in (r), $\underline{s} = 0.2$.

- **Commuting cost parameters**. We set $\zeta = 0.5$ as in Small et al. (2007) who estimate that the opportunity cost of a one-hour commute is worth half an hour's wage. We set $\eta_l = 0, \eta_m = 1$ for now, as we want to estimate those values from individual commuting time data. Notice that this parameterization still implies that distance will enter non-linearly into the commuting cost function $\tau(l)$ defined in 7. Furthermore, we can nest the standard linear-in-distance commuting cost formulation if we let η_m tend towards zero, while setting $\eta_l = 1$. Alternatively, we can suppress any dependence of commuting costs on income under $\eta_m \to \infty$.

- **Housing supply elasticity.** We assume constant elasticity of housing supply $\epsilon = 4$, but we can allow for location-specific supply conditions $\epsilon(l)$.

- **Population.** We fix total population to unity in the simulations. Allowing realistic population growth would amplify our results.

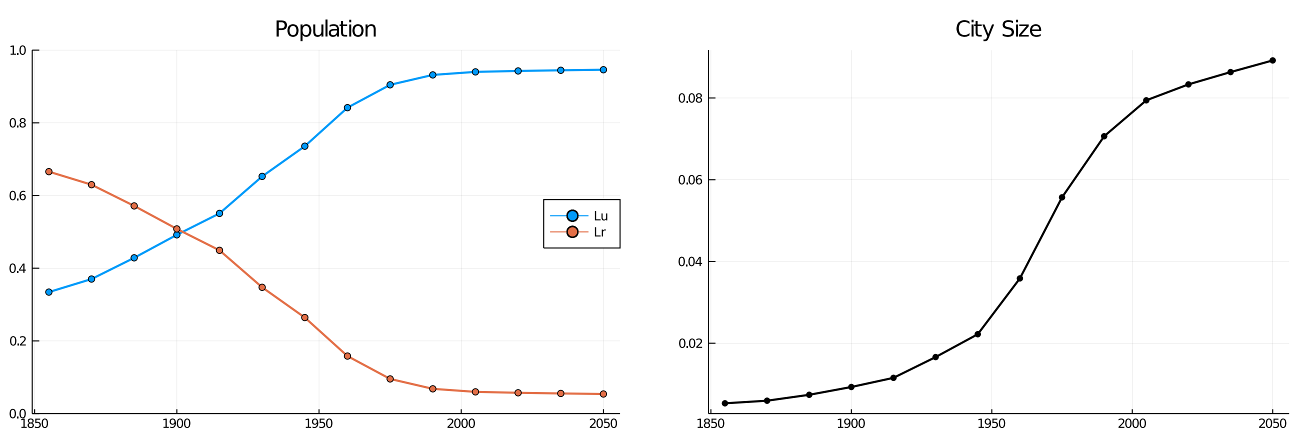
We will first present the baseline version of the model, before performing several counterfactual experiments designed to shed light on our proposed mechanism. All following figures plot an outcome of interest against the time line from 1855 until 2040.

Parameter	Description	value
S	Total Space	1.0
L	Total Population	1.0
γ	Utility Weight of Housing	0.25
σ	Land-Labor Elasticity of Substitution	0.99
α	Labor Weight in Rural Production	0.75
ν	Preference Weight for Rural Consumption Good	0.05
$\underline{c}$	Rural Consumption Good Subsistence Level	0.7
$\underline{s}$	Initial Urban Good Endowment	0.2
η_l	elasticity of F commuting cost wrt location	0.0
η_m	elasticity of F commuting cost wrt mode	4.8
c_τ	Commuting Costs Base Parameter	10.0
ζ	Valuation of commuting time in terms of wages	0.5

Table 1: Parameter values used in baseline simulation

We start in figure 6 with population allocation and city size. In figure 6a we see how rural population starts at a value slightly above 60% and then gradually declines along the transition period until roughly 1970, when structural transformation is complete. The blue line plots urban population, which is just the mirror image of rural population.

In figure 6b we see the novel implication of structural change in terms of land use, that is, we see how the size of the city expands. Given that total land is fixed at $S = 1$, this implies land used in the rural sector has declined accordingly.

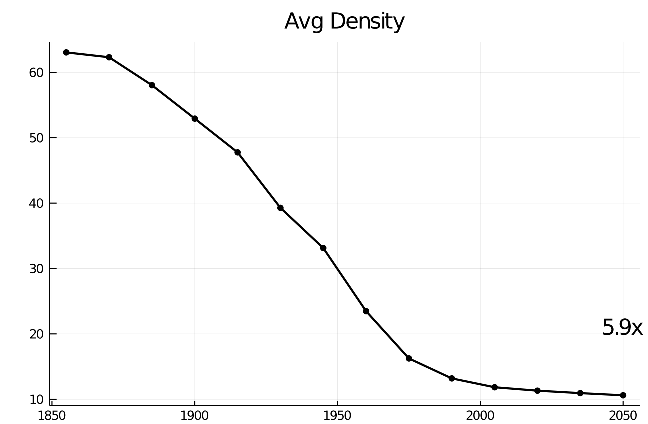


(a) Rural and Urban Population.

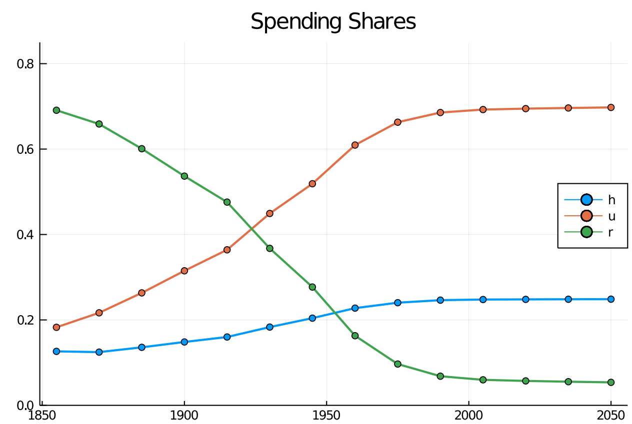
(b) City Size.

Figure 6: Model simulations illustrating land use patterns and city size.

Figure 7a shows that the model generates a dramatic fall in average urban density (in this parameterization, density falls by a factor of around 6). In figure 7b we illustrate the implied spending shares in the economy, which correspond largely to what we observe in the data: the spending share on the rural good starts very high and then gradually falls to a low level, the share spent on the urban good continuously increases, and the spending share on the housing good is slighty increasing over time in a range around 20%. Overall, the spending share pattern is reminiscent of what we observed in the data in figure 16.



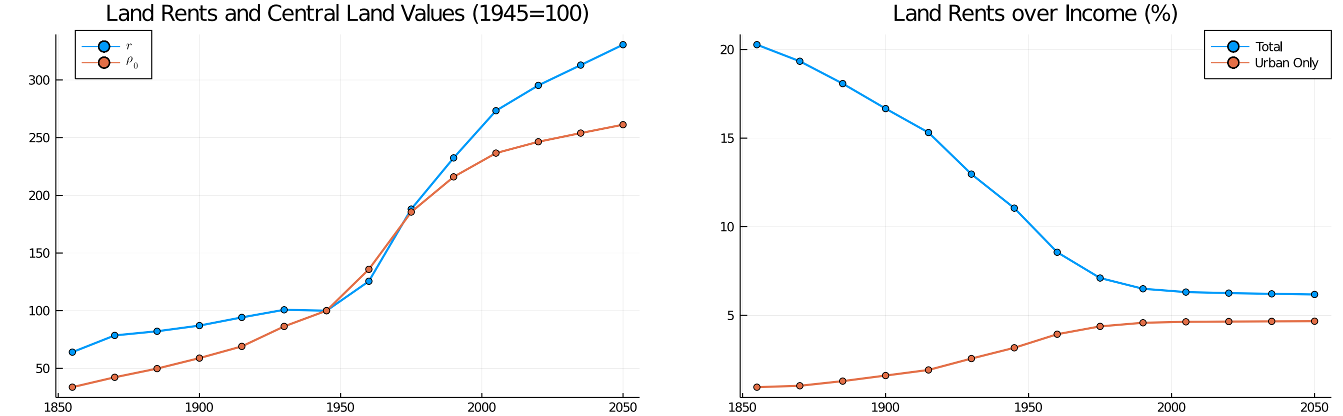
(a) Average urban density falls by a factor of 5.9 in this parameterization.



(b) Spending Shares.

Figure 7: Urban density and spending share patterns.

The model's predictions about land rents are shown in figure 8. The first figure 8a shows how per capita land rents (r) and land values in the central location (ρ_0) evolve over time. While central city land values are continuously increasing, we see that rents r are increasing much less until the 1950's, when they start to strongly increase. The shape reminds of the hockey-stick we have seen in figure 4. Through the lens of our model, this means that as the city's expansion at the fringe is slowed down, increases in productivity and thus household income translate into higher land values and hence land rent. It is interesting to investigate *where* rents are collected and how this evolves over time. We show this in figure 8b, which plots land rents as a percentage of disposable income. It is evident that the fraction of income devoted to agricultural land fell dramatically whereas the share devoted to urban land has increased, which is in line with data from Piketty and Zucman (2014) as shown in figure 24.

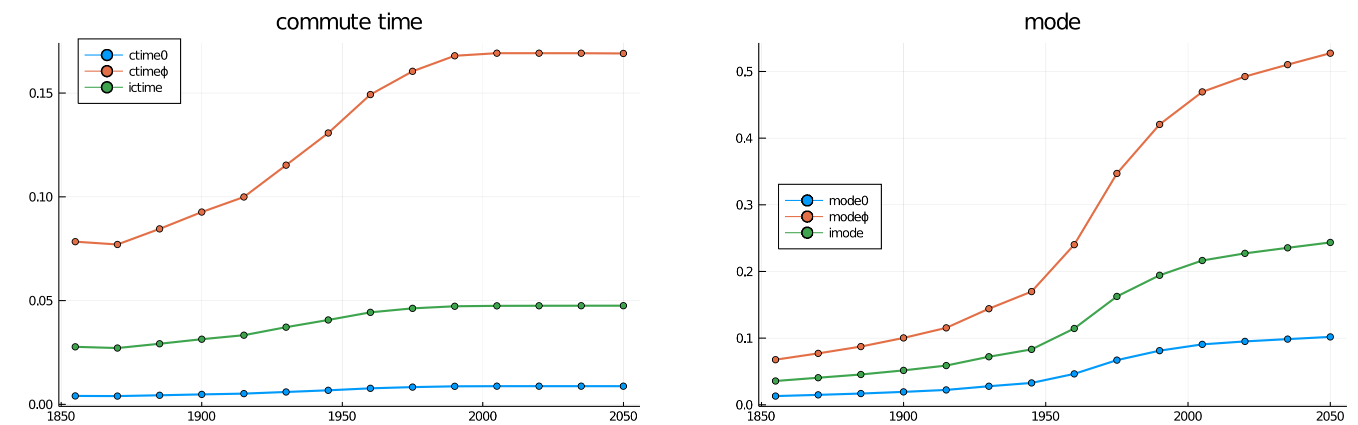


(a) Per capita land rents (r) and the value of land in the city center (ρ_0).

(b) Land Rents as a percentage of disposable income, which we define as GDP per capita net of commuting costs.

Figure 8: Land Rents, Central Land Values, and rents relative to disposable income

In figure 9 we present the model's implications for commuting behaviour. In figure 9a it is evident that the time spent commuting increases at all locations in almost all time periods. Clearly, the commuter residing at the fringe ϕ has the longest commute in each period, and also experiences the greatest increases in commuting time. At the same time, and as ilustrated in figure 9b, the mode (or the speed) of commuting also increases strongly for the fringe resident. As the fringe of the city pushes outward in figure 6b, the increases in commute time are a combination of longer commutes (the city is getting much bigger), but also a change in commuting behaviour.



(a) Commuting times at fringe (ctimeϕ), center (ctime0) and on average (ictime).

(b) Optimal commuting mode choices at fringe (modeϕ), center (mode0) and on average (imode)

Figure 9: Commuting times and mode choices.

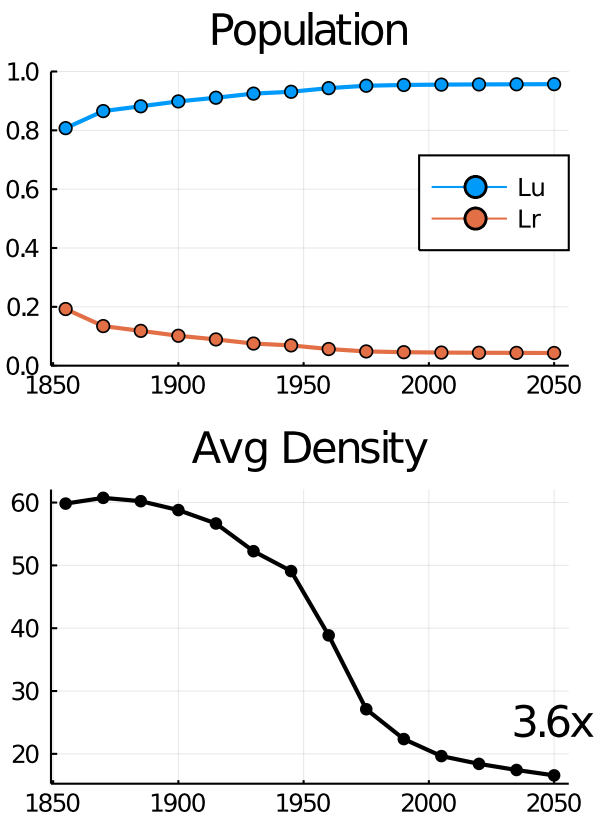


Figure 10: Model with no subsistence needs for the rural good, but substantial subsistence needs for the urban good: $\underline{c} = 0, \underline{s} = 1$

4.1 Counterfactuals

In this section we perform several counteractual experiments to shed light on our proposed mechanism. We start with the role of preferences and the initial endowment of urban good $\underline{s}$. A competing explanation to our theory could be that cities grew because of a very high $\underline{s}$, and a corresponding low $\underline{c}$. This could be labeled a demand-driven explanation of the facts.

We see the results of the calibration with $\underline{c} = 0, \underline{s} = 1$ in figure 10. Notice that this model is able to generate some population reallocation, but clearly not enough. What is more, the implications for spending shares are not what we expect from the data, with spending on rural good very low (as indeed dictated by the low subsistence parameter $\underline{c}$).

A different concern is the importance of growth in either sector. The combination of very strong growth in the urban sector relative to the rural sector, for example, together with some initial urban good endowment $\underline{s} > 0$ could lead reallocation away from the rural economy. We investigate this in figure 11, where we use an aritificial process for sector productivities. The qualitative features of the shown graphs point into right direction, which substantial reallocation of population and spending shares which behave correctly. The problem is that the movements are not pronounced enough – food spending needs to fall faster and the realloaction of people needs to be stronger.

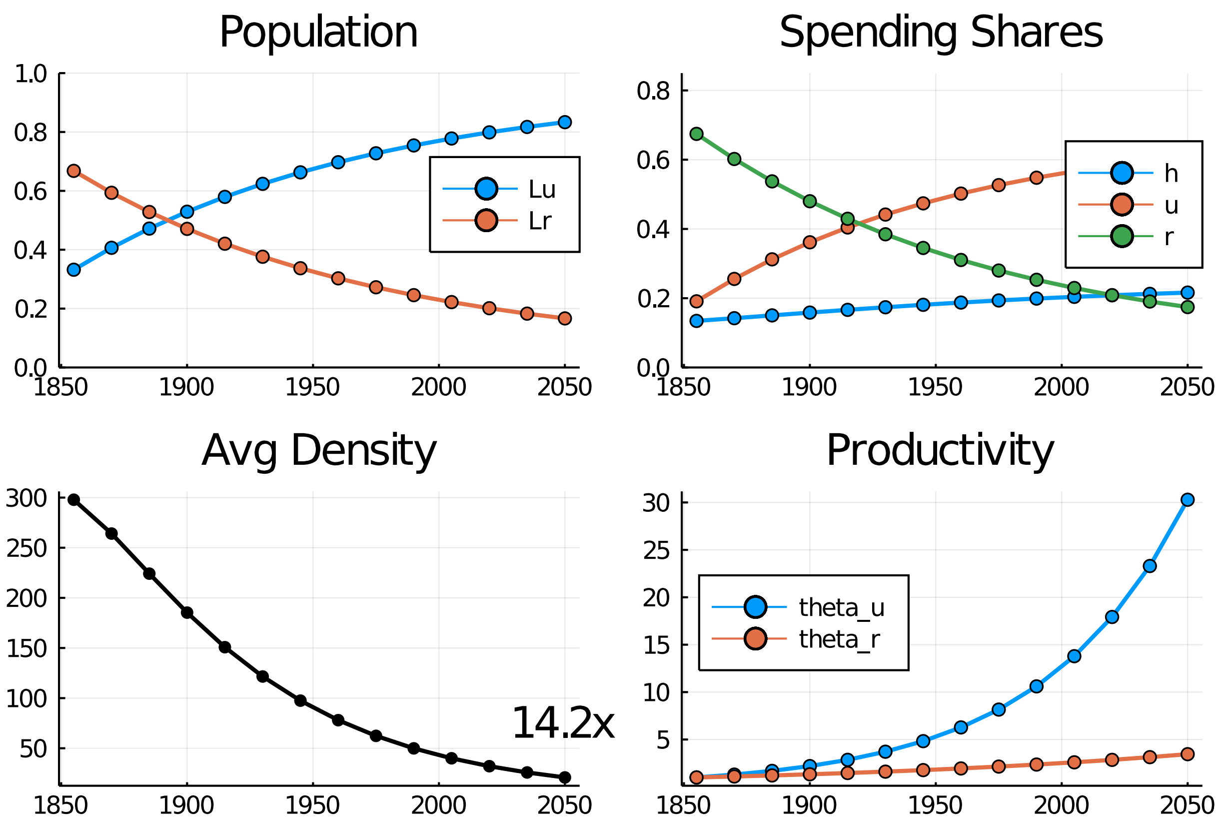


Figure 11: Model with high growth in the urban sector relative to the rural sector. Here, θ_r grows by 10% every 15 years, while θ_u grows by 30%.

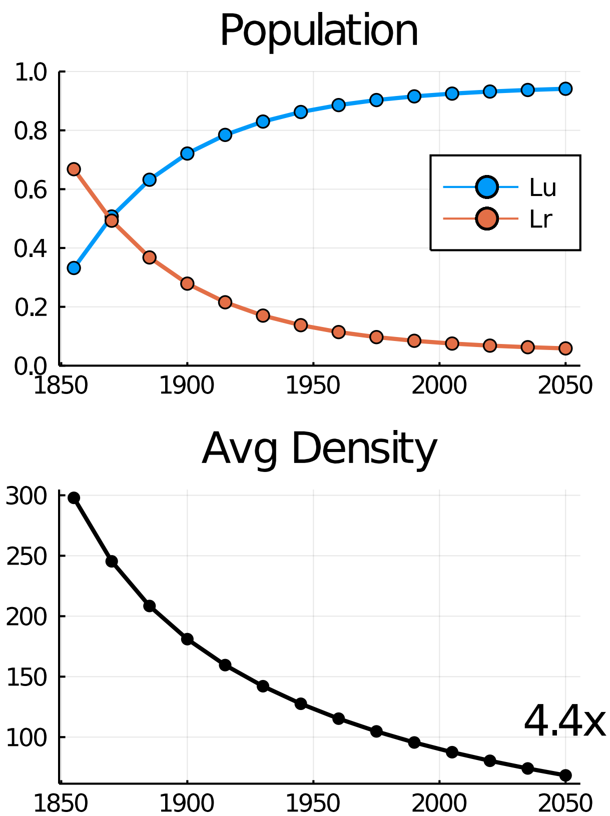


Figure 12: Model with high growth in the rural sector. Here, θ_u grows by 10% every 15 years, while θ_r grows by 30%

The opposite experiment is performed in figure 12. Here we let θ_r grow stronger than θ_u over time. We see that the structural change dimensions are very well replicated by this artificial process, hinting at the importance of this *labor push* factor that is increasing rural productivity. The city does not experience the right amount of fall in average density, however, since incomes of city dwellers are lower and the forces that push the fringe outwards, reducing density, are dampened.

5 Conclusion

t.b.d.

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A Data Appendix

A.1 Agricultural land use

Data sources and definitions. Data for the land used in agriculture are available in various secondary sources based on the French Agricultural Statistics (Statistique Agricole). We checked the consistency of the measures across the different sources.

The variable of interest is the area of land used for agriculture (SAU, for 'Surface Agricole Utilisée'). It is important to note that it includes land that is cultivated but excludes all land that is not (woods and forests, rocky land unfit for agriculture, mountains, swamps. . .).

Post World War 2 (WW2), data for the SAU are provided by the Ministry of Agriculture (data available in Desriers (2007) until 2000 by decade and available on annual basis since 2000 on the website of the Ministry (Agreste)).

Before WW2, agricultural statistics on land use are also available but on a very irregular basis.[18] Through a search across various sources, we compute a measure for the SAU from the first Agricultural Census in 1840 until today. It is worth noting that one must be cautious with such a measure before WW2 in the earlier periods. While it is quite clear that the share of land used in agriculture fell over the whole period, the variations throughout the 19th century (before the 1882 Census) must be taken with caution.

The main difficulty is to make the data presented in various sources comparable across years. First, woods and forest, accounting for 15-20% of French land in the 19th century (and more than 25% today) were initially included in the cultivated agricultural land. We made sure to exclude them from the SAU consistently over the whole time period considered. A second difficulty arises because the French territory varied since 1790: some variations being due to measurement, some due to the loss (or addition) of some parts of France — loss of Alsace and Moselle after the war of 1870 until 1918 and addition of Savoye and Comté de Nice in 1860 (see discussion in Augé-Laribé (1945)). This makes comparison difficult across time, even though we show our measure of the SAU as a share of the French territory at the time. A third difficulty for the early periods (before 1882), detailed below, regards the treatment of pasture and grazing fields in a consistent way across years.

Period 1945-2015. Let us start with the most recent period where the data are arguably of better quality and coherent across time and then present our measures going further back in time. Since 1945, the land used in agriculture has clearly been clearly falling over the period 1950-2015 (see Figure 13).

Interwar Period. In between the world wars, we could find measures for the years 1929 and 1937. Two slightly different measures are available for 1929: one in Toutain (1993) and one in Mauco (1937). We take the average between the two, a SAU of 34 483 thousands of ha in 1929. A measure,

[18] In the 19th century, starting 1840, France aimed at organizing every decade a detailed data collection of agricultural statistics (Agricultural Census, 'Statistique Agricole'). See for instance description in Flechey (1898) and Augé-Laribé (1945). A comparison across years during the 19th century is available in the report of the 1892 Census. Before 1840, Lavoisier provides the first measure of land use in France, in 1790, as described in Mauguin (1890).

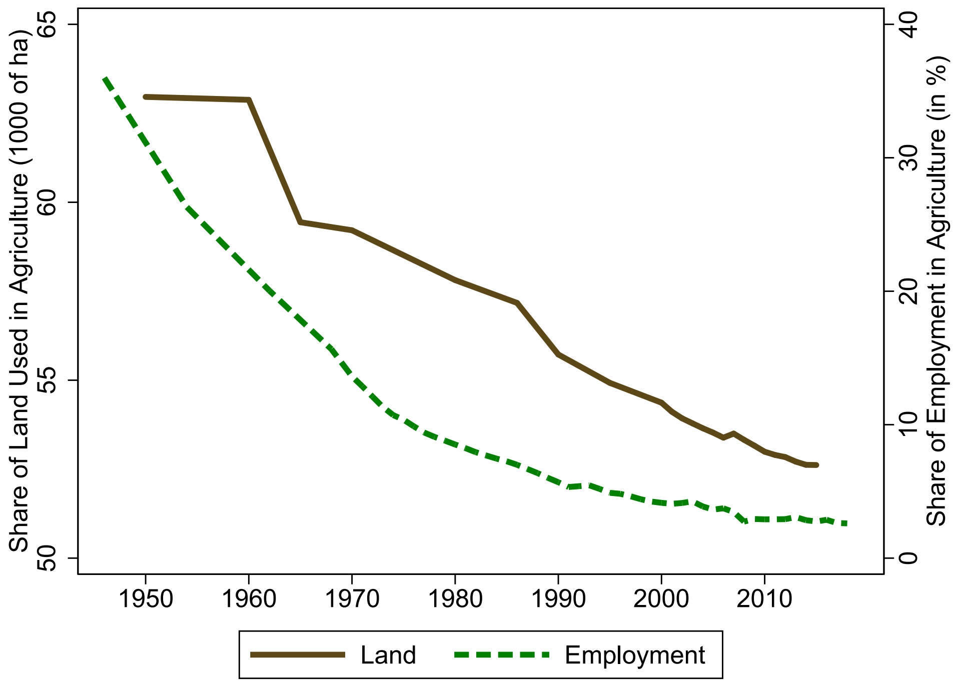


Figure 13: Shares of Land and Labor employed in Agriculture post WW2.

very similar to 1929, is available in Augé-Laribé (1945) for 1937: 34 207 thousands of ha and 33 285 if one excludes Alsace-Moselle for comparison with earlier periods. This corresponds to about 62% of the French territory.[19]

Nineteenth century. Before World War 1, we have measures in 1882 and 1892 (see Mauguin (1890), Flechey (1898), Hitier (1899) and Toutain (1993) for further details). Both measures are consistent across sources, including the main results of the 1892 Agricultural Census as a more primary source.[20] This gives an SAU of 34 882 thousands of ha in 1882 and 34720 in 1892—slightly higher than the values in between the wars despite a smaller French territory. Figure xxx provides the details of the measurement for the 1892 Agricultural Census.[21]

The first measurement in 1840 constitutes our first observation. However, in the 1840 data, an important difficulty is the treatment of meadows, pasture and grazing fields (prés, herbages, pâturages,…). These should be included in the SAU to the extent that the land is used for agricultural purposes (feeding cattle). As grazing fields and meadows account for a large share of French

[19]Mauco (1937) compares to the 1892 value and find very similar numbers than ours once woods are excluded from his measurement. Augé-Laribé (1945) compares to the 1882 value and the measure given for 1882 is also consistent with our data.

[20]Statistique Agricole de la France: Résultats généraux de l'Enquête Décennale de 1892. The online archives are available at: https://gallica.bnf.fr/ark:/12148/bpt6k855121k/f1.item

[21]Comparison of land use as a share of total French land across the 19th century is also available in the report of the 1892 Census.

RÉSUMÉ DES CULTURES.

A. — SITUATION EN 1892.

1. TERRITOIRE.

Nous donnons ci-après, par grandes catégories, la répartition du territoire de la France, telle qu'elle résulte des relevés opérés en 1892 :

CATÉGORIES DU TERRITOIRE.			SUPERFICIES.	RÉPARTITION et PROPORTION.
			hectares.	p. 100.
1° TERRITOIRE AGRICOLE.				
Superficie cultivée.	Terres labourables.	Céréales	14,827,085	28.06
		Grains autres que les céréales	319,705	0.60
		Pommes de terre	1,474,144	2.68
		Autres tubercules et racines pour l'alimentation humaine	128,238	0.24
		Cultures industrielles	531,508	1.00
		Cultures fourragères [1]	4,736,394	9.08
		Jardins potagers et maraîchers	386,827	0.73
		Jachères	3,367,518	6.37
		Ter.es labourables	25,771,419	48.76
	Vignes		1,800,489	3.40
	Prés naturels		4,402,836	8.33
	Herbages paturés [2]		1,810,608	3.42
	Bois et forêts		9,521,568	18.03
	Cultures arborescentes, etc.		934,800	1.76
	Cultures permanentes non assolées.		18,470,301	34.94
	Totaux de la superficie cultivée		44,241,720	83.70
Superficie non cultivée.	Landes, pâtis, bruyères		3,898,530	7.37
	Terrains rocheux et montagneux, incultes		1,972,994	3.73
	Terrains marécageux		316,373	0.60
	Tourbières		38,292	0.07
	Totaux de la superficie non cultivée.		6,226,189	11.77
Totaux du territoire agricole			50,467,909	95.47
2° TERRITOIRE NON AGRICOLE			2,389,290	4.53
Totaux généraux du Territoire			52,857,199	100.00

[1] Non compris les cultures dérobées.
[2] Y compris les herbages alpestres.

Figure 14: Recensement Agricole 1982.

agricultural land (up to 11% in 1892), their inclusion (or not) in the cultivated part of agricultural land (SAU) matters. However, in 1840, a significant share of grazing fields ('pâturages', 'pâtis communaux/vaines pâtures') is excluded from the SAU. The non-cultivated part of agricultural land thus appears to be a much larger measured area than in all subsequent years.[22] As discussed in the results of the 1892 Agricultural Census, comparison across years is difficult due to the reallocation of grazing fields into the cultivated part of French land over the period 1840-1880. This reallocation is quite artificial—mostly a statistical artefact coming from the earlier exclusion of common pasture. Excluding entirely the measured non-cultivated part from the SAU in 1840 gives thus a lower bound, while including it entirely to account for all grazing fields gives an upper bound. To solve this issue, Toutain (1993) provides an estimate of agricultural land in 1840, in between these two values, of 35 500 thousands of ha. While this is just a matter of definition and any solution is somehow arbitrary, we proceed in a similar fashion as Toutain (1993) and assume that the grazing fields later reallocated in the cultivated part are part of the SAU in 1840. This gives a land use in agriculture of 35 497 thousands of ha in 1840—a very similar number to Toutain (1993). Proceeding exactly in the same way for the year 1862 gives an SAU of 36 088 ha—a higher value but for a larger territory. Both values correspond to about two thirds of French land used in agriculture.

We find that about 1.5% of French land was reallocated away from agriculture between 1840 and 1892 and one can use the data provided in the report of the 1892 Census to investigate how this land was reallocated. The majority was used for larger forests but the land built (non agricultural land) also increased by about 0.5% of the French territory (corresponding to 233 thousands of ha).

The measured cultivated agricultural land (as a share of French territory) over the period 1840-2015 is summarized in Figure 15.

Pre-1800. Lastly, Lavoisier provided in 1790 the very first measure of French agricultural land before the creation of the Agricultural Census. Comparison of Lavoisier's measurement with the later 'Statistiques Agricoles' is however difficult. Like for the later measurements, a large fraction of land ('vaines patûres') includes grazing fields as well as rocky land and moor unfit for agriculture (see Mauguin (1890) for an attempt to compare with the 1882 Census). Excluding woods but including the 'vaines patûres' (common pasture) in 1790 gives a surface of almost 40 000 thousands of ha. Excluding all the 'vaines patûres' provides a lower bound of about 31 000 thousands of ha. This gives a reasonable but fairly wide bracket for the total land used for agriculture. Assuming that the non-cultivated part due to rocky land is comparable to the later measures gives a SAU in 1790 around 34 000 thousands of ha—comparable to the later years (on a smaller territory)—about 65% of French land measured at the time. While this measure should be taken with great caution, it nevertheless comforts us in using a value close to the 1840 measurement to start our time series in the quantitative analysis. We will thus assume a constant area used for agriculture from 1815 to 1840 to avoid missing data (national accounts and employment data described below being available

[22]As shown in Figure 14, in 1892, the non-cultivated part includes moor and rocky land arguably unfit for agriculture, accounting for about 11% of French land. The corresponding non-cultivated part in 1840 accounts for 17% of French land as it includes a significant share of grazing fields.

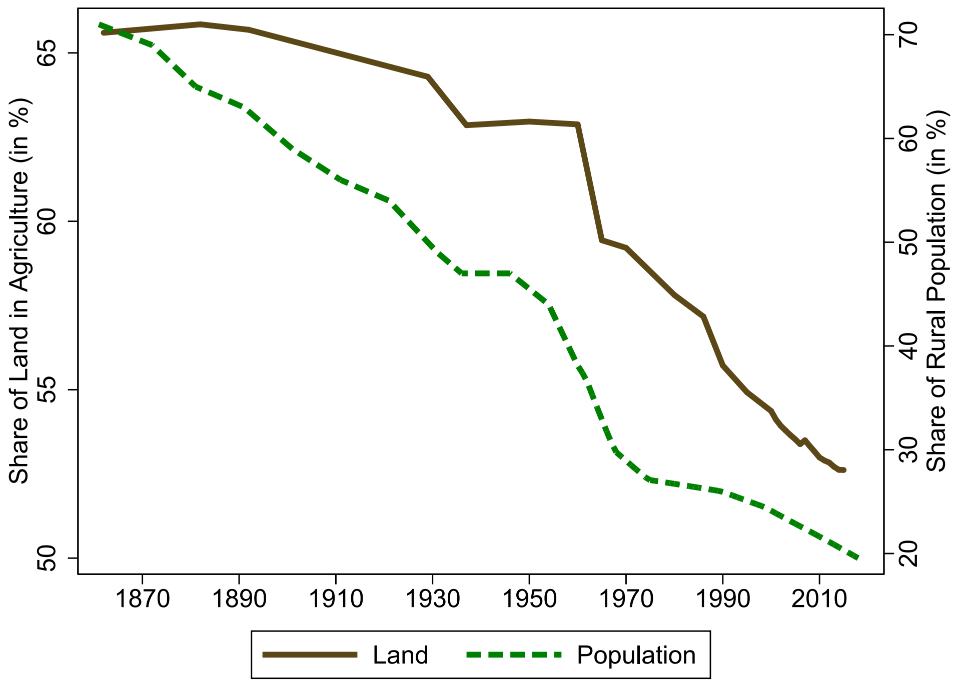


Figure 15: Shares of Land and Population employed in Agriculture since 1840.

over this early period).

A.2 Sectoral employment

Sources. Data on employment are available in three different sources covering different time periods: Marchand and Thélot (1991) ('Deux siècles de travail en France') for the period 1806-1990; Herrendorf et al. (2014) for the period 1856-2006; OECD for the period 1950-2018. When overlapping, the different sources are largely consistent with each other.[23] We use the three sources allowing to span the entire 1806-2018 period. For the pre-WW2 period, data available in Marchand and Thélot (1991) and Herrendorf et al. (2014) are on an irregular basis—typically one or two observations per decade (corresponding to Census years). Annual data are available from 1950 onwards.

Over the nineteenth century (until 1901), we use the data from Marchand and Thélot (1991) as the serie goes further back in time. Over the period 1901-1950, we use the data from Herrendorf et al. (2014). Over the period 1950-2018, we use data provided by the OECD on an annual basis, where the measure of employment is expressed in full-time equivalent.

Share of employment in agriculture. This gives the share of employment in agriculture over the entire period (1806-2018) in Figure xxx. It starts with about 2/3 of the employment in agriculture

[23] Marchand and Thélot (1991) gives a slightly lower share of employment in agriculture in the first half of the 20th century relative to Herrendorf et al. (2014). Our results do not depend on the use of one serie or the other.

in 1806 and falls progressively to 3% in 2018. One can notice the acceleration in the process of reallocation post WW2. In the matter of three decades, the employment share in agriculture went from 36% in 1946 to 10% in 1976.

[insert Figure around here]

Data are linearly interporlated in between two values when data are not available on an annual basis (pre-1950). In the paper, we focus on the period 1815-2018 as the national accounts data starts in 1815. For the starting year 1815, we use a linearly interpolated value between the two first observations (1806 and 1821) from Marchand and Thélot (1991).

A.3 Sectoral national accounts

Sources. Data on value added at the sectoral level together with aggregate value added (GDP) at current prices are available in two different sources covering different time periods. Historical national accounts from Toutain (1987) are used to cover the period 1815-1938. They are directly available at the Groningen Growth and Development Centre (Historical National Accounts Database, http://www.ggdc.net/).

Post WW2, INSEE provides sectoral value added at current prices for the period 1949-2019. For both series, we use agricultural value added and aggregate GDP at current prices. Using both sources gives covers the entire period 1815-2019. The series are interrupted at war times: observations are missing for the periods 1914-1919 and 1939-1948.

Toutain (1987) also provides volume indices for GDP in agriculture and for aggregate GDP over the period 1815-1982 (also available Groningen Growth and Development Centre). The serie for agricultural volumes is extended in Toutain (1993) until 1990. Together with the value added at current prices, these series will be used to compute an agricultural price deflator and a GDP deflator.

A.4 Prices

Sources. Data on agricultural producer prices are available over the period 1815-2019 using two different data sources: one derived from the national accounts in value added and volume from Toutain (1987, 1993) and one from INSEE post-1949.

Using Toutain (1993), we compute a price index of agricultural goods using the value added in agriculture divided by the production volume index in agriculture (period 1815-1990). Post WW2, INSEE directly provides a producer price index for agricultural goods (Indice des prix agricoles à la production, IPPAP)—the serie can be retropolated back to 1949.[24]

These two series will be used to construct a price index for agriculture goods over the period 1815-2019 (with interruptions at war times).

[24] The IPPAP serie is the 'Base 2000 rétropolée' available in Insee Méthodes 114 (INSEE (2006)). Until 1970, the retropolated serie from INSEE excludes fruits and vegetables. The serie including fruits and vegetables and the one excluding them are almost identical when both are available.

Similarly, a GDP deflator over the period 1815-1960 can be computed using GDP at current prices and a GDP volume index from Toutain (1987). Post-1960, we use the GDP deflator from the World Bank.[25]

The price index for agricultural products and the GDP-deflator are both normalized to 100 in 1949.

Relative price for agricultural goods. Using the computed historical time-series for the agricultural producer price index and the GDP-deflator, one can take the ratio of the two series to shed some lights on the evolution of the relative prices of agricultural goods. The serie for the relative price based on Toutain production data (solid green) over the period 1815-1990 and the INSEE producer price (solid black) starting 1949 are shown in Figure xxx. While the relative price of agricultural appears fairly stable until 1910, it exhibits later a clear downward trend over the twentieth century. Both series show a similar trend post WW2.

[insert Figure around here]

Our baseline price index of agricultural goods (denoted P_{agri}) uses the serie computed using the national accounts of Toutain prior to WW2 (1815-1938) and the agricultural producer prices by INSEE post WW2 (1949-2019). The two series are linked by the same normalization to 100 in 1949. The final serie for P_{agri} is only interrupted during the wars.

The model counterpart of our data is the relative price of rural/agricultural goods over the price of urban/non-agricultural goods. The latter is not observed but can be backed out using the GDP-deflator under some assumptions. Let us denote $P_{agri,t}$ the price index for agricultural goods at date t, $P_{non-agri,t}$ the price index for non-agricultural goods and $P_{GDP,t}$ the GDP-deflator. We assume the following relationship at each date t,

$$P_{GDP,t} = P_{agri,t}^{\omega_t} P_{non-agri,t}^{1-\omega_t}, \tag{31}$$

where ω_t is the share in value-added of agricultural goods computed using historical national accounts. Since we observe in the data all the variables but $P_{non-agri,t}$, we can invert Eq. 31 to back out a price index for non-agricultural goods (urban goods including manufacturing and services),

$$P_{non-agri,t} = P_{agri,t}^{-\frac{\omega_t}{1-\omega_t}} P_{GDP,t}^{\frac{1}{1-\omega_t}}.$$

We are now equipped with a price index for agricultural goods, non-agricultural goods and a GDP deflator over the period 1815-2019.

Sensitivity analysis for the price of agricultural goods. Before WW2, the Statistique Generale de France (former INSEE), in particular thanks to the work of Alfred Sauvy, provides an alternative serie for the price of agricultural goods: 'indice des prix de gros agricoles' which is con-

[25]We checked consistency with the consumer price index available over the period 1820-2015 (INSEE). Inflation is very similar in both series.

stituted by a basket of 19 raw agricultural commodities (food related).[26] The serie is retropolated back to 1810 by A. Sauvy (see Sauvy (1952)). This data includes some foreign commodities (e.g. English and US corn prices) and is in part computed using customs price data. For this reason, we use the price of agricultural goods computed using production data of Toutain pre WW2 as baseline. This said, the 'indice des prix de gros agricoles' still contains useful information regarding the price of agricultural goods in France before WW2. Comparison with the price computed using production data from Toutain indicates that the two series exhibit very similar patterns starting 1850. Prior to this date, the 'indice des prix de gros agricoles' from Sauvy (1952) exhibits a significant downward trend, while our baseline from Toutain stays roughly stable (see Figure xxx).[27] We use the serie from Sauvy (1952) as sensitivity analysis—our baseline price serie for agricultural goods uses the serie based on Toutain for the period pre WW2.

A.5 Sectoral Productivities

Equipped with sectoral value added at current prices, sectoral price indices, sectoral employment and land use data, one can back out the sectoral productivities (in the agricultural and non-agricultural sector) that are the counterpart of the model (the θs) up to a constant of normalization.

Urban Productivity. Let us start with the urban/non-agricultural sector. According to the model production function, $\theta_u = \frac{Y_u}{L_u}$. We observe the value added in the non-agricultural sector at current prices. Deflating this serie by the constructed price index for non-agricultural goods gives Y_u. Dividing the latter variable by employment in the non-agricultural sector, $L_{non-agri,t}$, allows us to back out the empirical counterpart of $\theta_{u,t}$,

$$\theta_{u,t} = \frac{VA_{non-agri,t}}{P_{non-agri,t} L_{non-agri,t}}.$$

Due to the mere presence of a price index, this serie is defined up to a multiplicative constant. We normalize $\theta_{u,t}$ to unity in the first period (1815). This gives the time-series for $\theta_{u,t}$ plotted in Figure xxx. This will be our baseline exogenous urban/non-agricultural productivity. It is important to note that the measured urban labour productivity includes technological advances in the non-agricultural sector but also factor accumulation rising labour productivity (physical and human capital accumulation).

[insert Figure around here]

Rural Productivity. We proceed in a similar fashion to compute the model's counterpart of the rural productivity, $\theta_{r,t}$, with one important difference: the agricultural output per worker in the

[26] Details about the index can be found in the 'Etudes spéciales' of the 'Bulletin de la Statistique générale de la France' in 1911. Available online at: https://gallica.bnf.fr/ark:/12148/bpt6k96205098/f73.image

[27] We also compare those series with the relative price of corn. While significantly more volatile, the latter is also fairly consistent with the other series. A period of volatile relative corn price but fairly constant on average until the early 20th century, followed by a downward trend. The downward trend is however more pronounced.

rural sector depends also on the land per worker available for agriculture,

$$\frac{Y_r}{L_r} = \theta_r \left(\alpha + (1-\alpha)(\frac{S_r}{L_r})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} = \theta_r F(\frac{S_r}{L_r}). \tag{32}$$

. Thanks to the data on land use in agriculture, one can back out from the data the land per worker in agriculture at each date: it is simply the cultivated area (SAU) divided by employment in agriculture, $\frac{S_r}{L_r} = \frac{SAU}{L_{agri}}$. Using Eq. 32, one can compute the rural productivity parameter, $\theta_{r,t}$, at each date,

$$\theta_{r,t} = \frac{VA_{non-agri,t}}{P_{non-agri,t} L_{non-agri,t}} \frac{1}{F(\frac{SAU_t}{L_{agri,t}})}.$$

With a unitary elasticity of substitution betweeen land and labor ($\sigma = 1$), this gives,

$$\theta_{r,t} = \frac{VA_{agri,t}}{P_{agri,t} L_{agri,t}} (\frac{SAU_t}{L_{agri,t}})^{\alpha-1}.$$

Due to the mere presence of a price index, this serie is defined up to a multiplicative constant. Like $\theta_{u,t}$, we normalize $\theta_{r,t}$ to unity in the first period (1815). This gives the time-series for $\theta_{r,t}$ plotted in Figure xxx. This will be our baseline exogenous rural/agricultural productivity shifter.

Comments. Comparing urban and rural productivity, one notices the important common component: this can be due to technological advances benefiting both sectors but also to physical and human capital accumulation, which increase labour productivity across the board. Focusing on the more sectoral specific component, it is visible that non-agricultural productivity grew faster from the late 19th century until WW2. Post WW2, agricultural productivity starts growing at a faster speed, catching-up with the non-agricultural one and eventually outpacing it. This is consistent with Bairoch's view that starting the agricultural crisis in late ninetheeth century, technological progress in the French agriculture is slow and delayed relative to other countries, before a catching up post WW2. The period 1945-1985 period is more broadly characterized by a very fast technological progress in agriculture across developed countries (see Bairoch (1989)). A productivity slowdown is later observed in both sectors.

A.6 Consumption expenditures

Sources. Data on consumption expenditures are available using two different data sources. Pierre Villa provided data on consumption expenditures across 24 different categories of goods for the period 1896-1939.[28] INSEE provides data over the period 1959-2017 on personal consumption expenditures ('Consommation effective des ménages par fonction aux prix courants') across 12 broad categories (food, drinks, clothing, housing, transportation,...) and about 100 narrower categories.

[28] Data are publicly available thanks to the CEPII. For details and documentation, see http://gesd.free.fr/villadoc.pdf. See also Villa (1993).

INSEE Data are from the Comptes nationaux (Base 2014).[29]

Expenditure shares. We compute expenditure shares on three broad categories: food/drinks, housing and the remaining goods. The expenditure share on food/drinks proxy for the rural goods. The expenditure share outside food, drinks and housing includes manufacturing goods and services. It proxies for the spending share on urban goods. The model's counterparts of the three category are thus respectively expenditure shares on rural goods, housing and urban goods. With some abuse of language, we now refer to these three categories as rural, housing and urban.

The expenditure share on food/drinks is computed by adding all the good categories corresponding to food and drinks consumption divided by aggregate household expenditures (for the pre and post WW2 data). However, it excludes consumption in restaurants that will enter the remaining category (urban goods). The housing expenditure shares include housing related expenses: rents (effective and imputed), energy expenditures, some housing services (garbage, cleaning, repair, ...) but also housing equipments (furniture, tableware, household appliances...).[30]

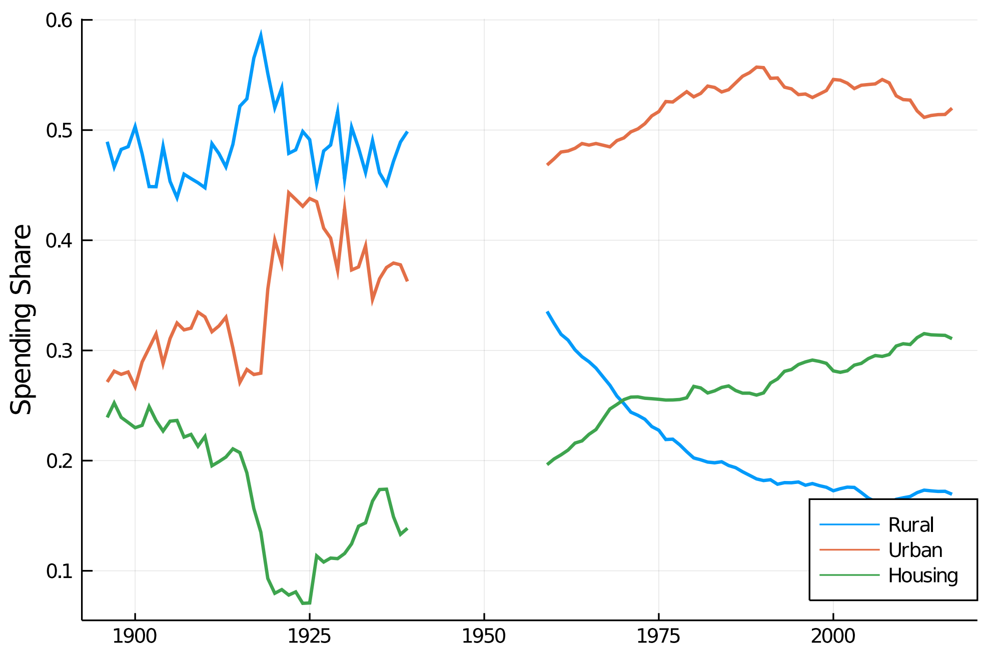


Figure 16: Spending Shares for France. The observations around 1950 are missing because the second world war and associated difficulties in data collection.

Data on expenditure share across these three broad categories are shown in Figure 16. Comparing

[29]Over the period 1950-1958, the CREDOC was providing data on consumption expenditures across broad categories for French households. These data have not been made compatible with the INSEE data post-1959, when INSEE revised the methodology. Investigating data in reports by CREDOC provides some additional insights on consumption expenditure shares in the 1950s across broad categories. As expected, these shares are in between the ones computed using the data from Villa right before WW2 and the later national accounts data of INSEE.

[30]We include housing equiements as (partly) furnished/equipped houses/flats are quite common—even in the early 20th century. Small furnished flats/bedrooms were very common in large cities in the interwar period ('garnis'). However, excluding the latter categorie from housing expenses does not affect our results.

the initial periods in the late nineteenth century to today gives the following broad facts: the food (rural) share went down from almost 50% of expenditures to 17%; the housing share increased slightly to 23% to 31%; the share of expenditure on other goods increased as a consequence from 27% to more than 50%. This reallocation of expenditures way from rural goods towards housing and urban goods fits well with the process of strucutral transformation.

[insert Figure around here]

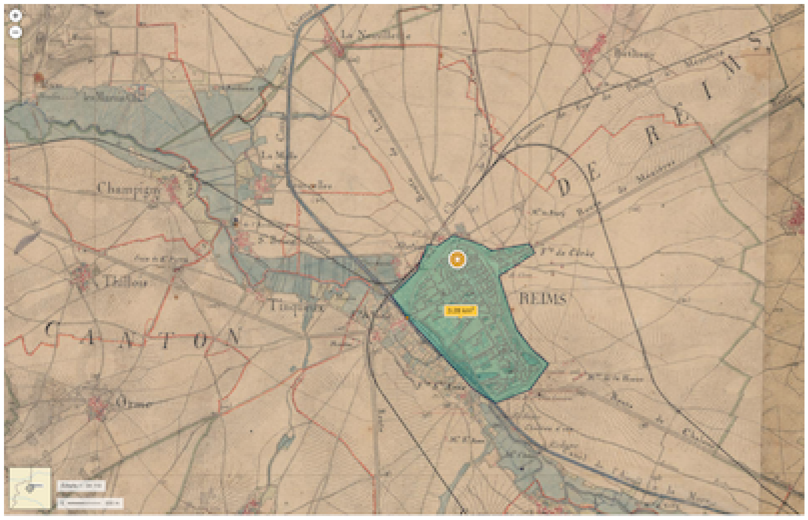
Rent control and the housing expenditure share. An important issue is the significant and persistent dip of the housing expenditure share starting at WW1. This evolution is largely due to the presence of rent controls that were put in place at the beginning of WW1 in France. As the French government wanted families to be able to afford their home during the war, it decreeed that rents would be blocked (in nominal terms). As inflation picked up, this generated a large fall in real housing rents. As rents were very cheap, it freed up resources for households that could be spent on other goods (rural and urban). This is immediately visible on Figure xxx, where the share of expenditures on housing went down from 21% in 1914 to less than 10% at the end of the war in 1919—other expenditure shares increasing simultaneously. While the measure want meant to be temporary, rent control lasted effectively during the whole interwar period despite various modification in the laws. It was eventually profoundly reformed post WW2 in 1948.[31] The reform of 1948 led to a sluggish adjustment of rents and it took some further years before one can reasonably argue that the rent control put in place in 1914 starts playing a more minor role.[32] Given this, our aim is to match the long-run evolution of spending shares while abstracting from the fluctuations in between 1914 and 1959 (first year of observation in the serie provided by INSEE), as illustrated by the dotted lines on Figure xxx.

Area Measurement of cities. to be written.

[31]Rents did increase in real terms during the interwar period. However, regulations still significantly limited the rent increases. The reform of 1948 still kept some housing with regulated cheap rents. Rents could be changed for new renters. Few housing with very cheap rents under the special regime of 1948 still subsists.

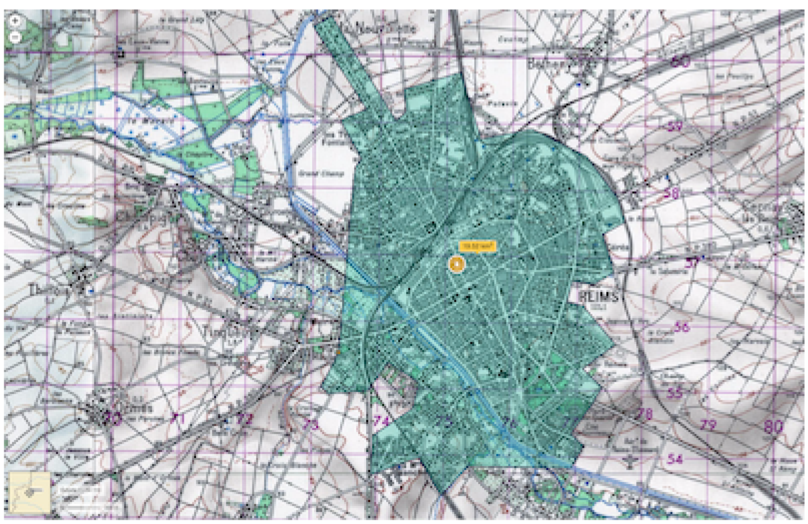
[32]Data from CREDOC in the early 1950s suggests a fairly housing spending share at that time–around 15%.

Figure 17: Reims from above in 1866.



Source: Carte d'Etat Major and IGN.

Figure 18: Reims from above in 1950.

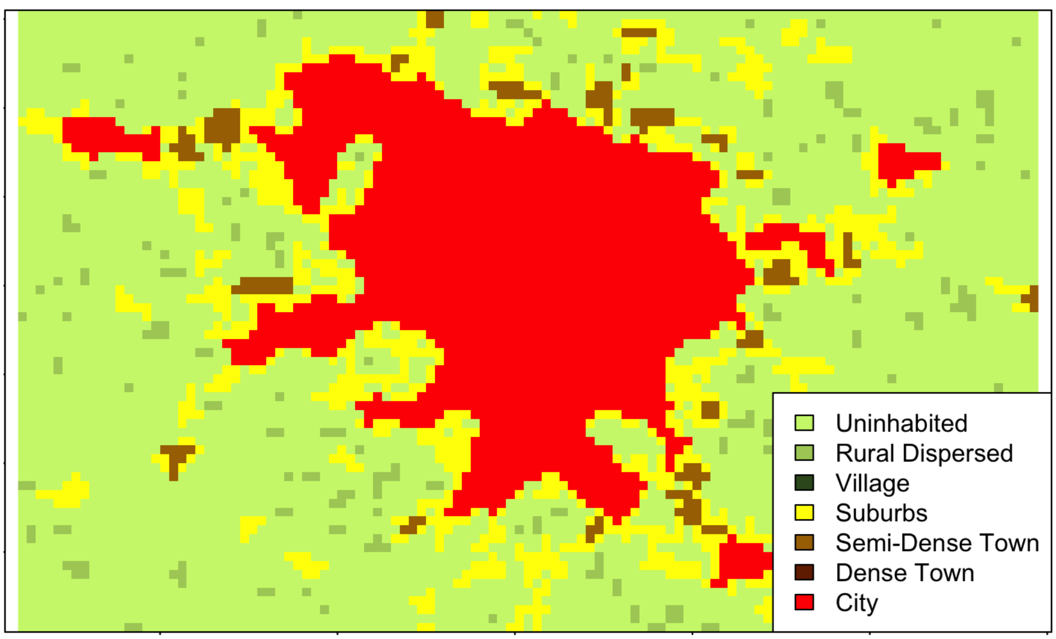


Source: IGN.

Figure 19: Reims from above in 2015.

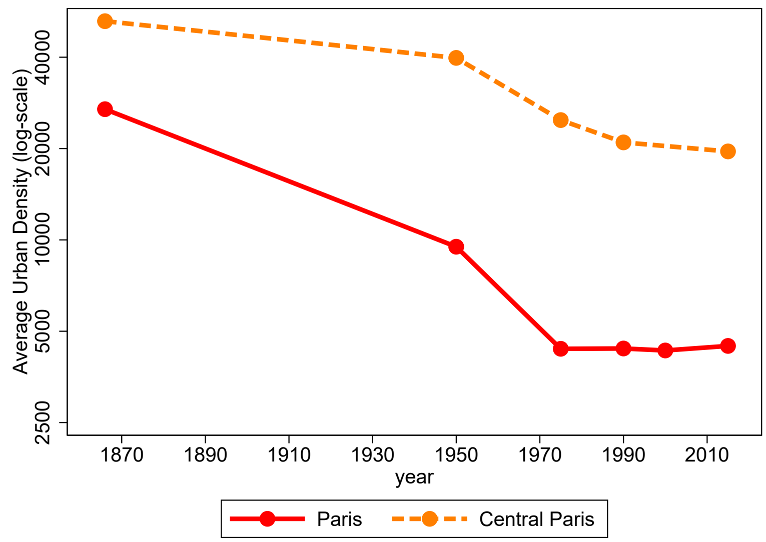
Source: IGN.

Figure 20: Satellite data: Paris from above in 2015.



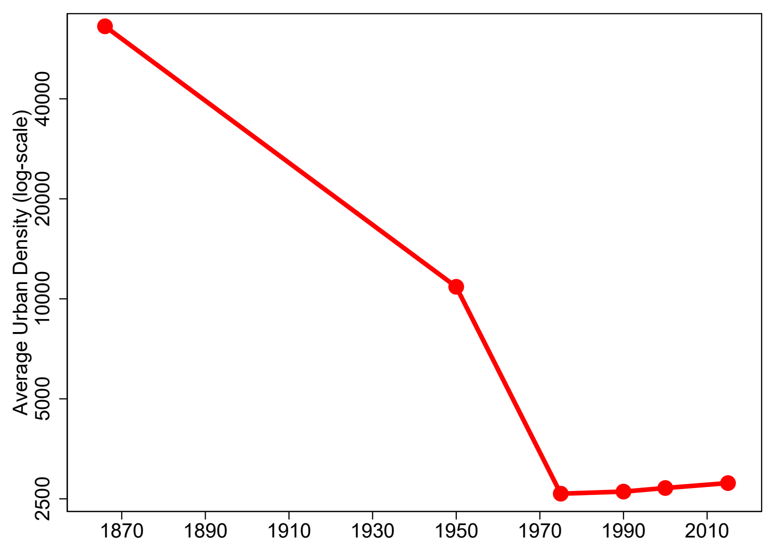
Source: GHLS.

Figure 21: The historical decline in urban density, Paris.



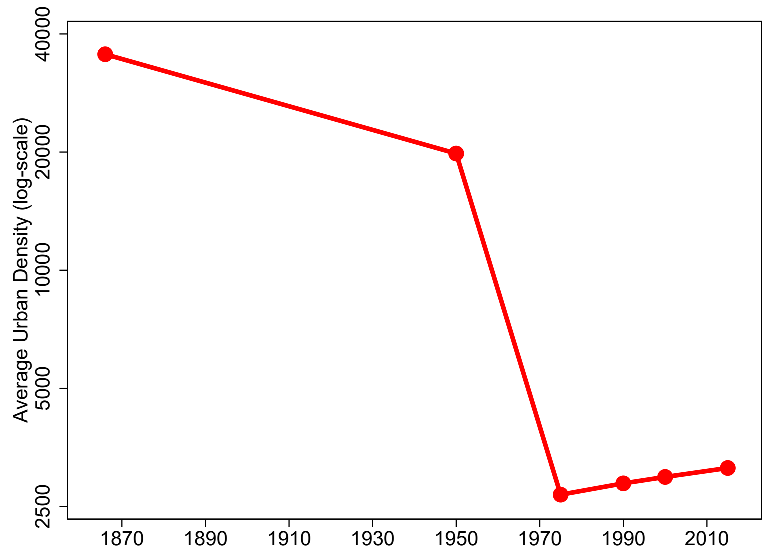
Notes: The solid line shows the urban density in Paris; the dotted line shows the density in Central Paris (districts 1 to 6). *Source*: Etat major, IGN, GHLS and Census.

Figure 22: The historical decline in urban density, Lyon.



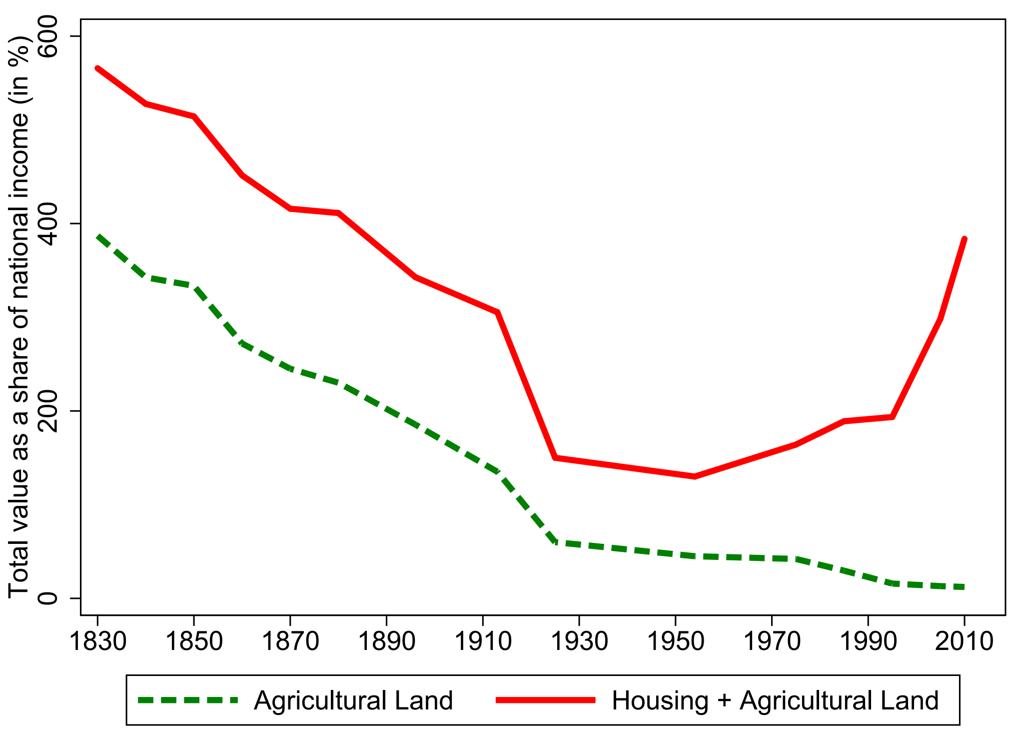
Notes: The solid line shows the urban density in Lyon. *Source*: Etat major, IGN, GHLS and Census.

Figure 23: The historical decline in urban density, Marseille.



Notes: The solid line shows the urban density in Marseille. *Source*: Etat major, IGN, GHLS and Census.

Figure 24: Agricultural Land and Housing Wealth (1830-2010)



Source: Piketty and Zucman (2014).