WORKING paper

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Who Takes the Land? Quantifying the Use of Built-Up Land by French Economic Sectors to Assess Their Vulnerability to the 'No Net Land Take' Policy

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ABSTRACT

In 2021, the French Parliament passed a law aiming for "No net land take" (NNLT) by 2050, while the rate of land take should be halved by 2031. These objectives are notably justified by the fact that land take, defined as the conversion of agricultural, forest and other semi-natural and natural land into built-up land, causes biodiversity loss and affects soil functions. Because they contribute to land take and use built-up land to produce, economic sectors will likely be affected by this new policy. This paper investigates this exposure. Using cadastral data and geolocated information on French firms, we develop accounts tracing the annual use of built-up land (a stock) and the annual land take (a flow) by economic sectors over 2008-2021. Our results show a strong time-varying sectoral heterogeneity regarding land use and land take, with some sectors (e.g. wholesale and retail trade, manufacturing or accommodation and food services) being significant users of built-up land. Regarding land take, we find that wholesale and retail trade has had the greatest responsibility. Then, we combine these new accounts with additional data and propose a multi-criteria analysis to assess the vulnerability of each sector in a 'severe but plausible' scenario of increasing land prices induced by the NNLT policy. Our results show that the sectors contributing most significantly to land take may not necessarily be the most vulnerable because of their relatively higher adaptive capacity.

Keywords: Land Use Regulations; Real Estate Markets; Land; Environmental Accounts; Production

JEL classification: R52; R33; Q24; Q56; E23

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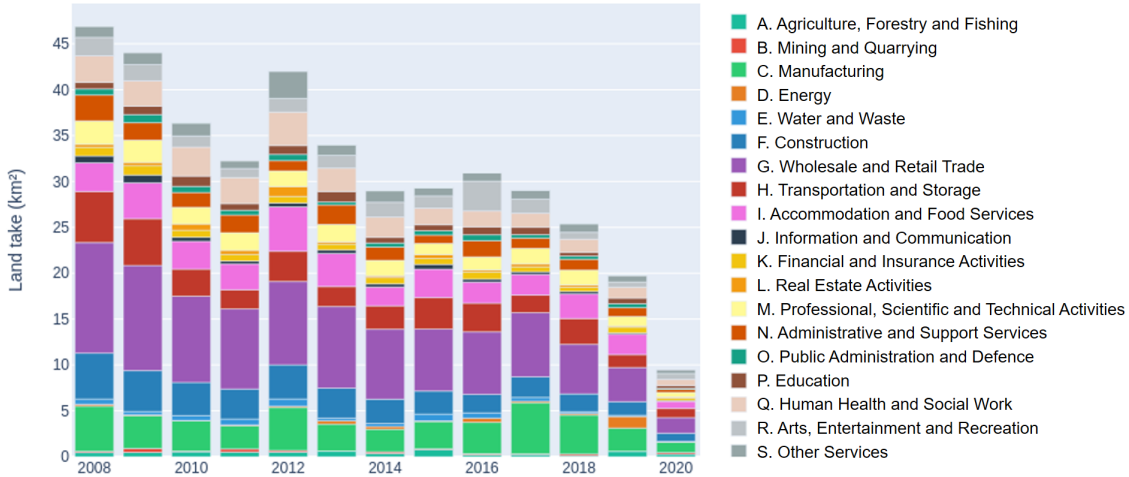
NON-TECHNICAL SUMMARY

How do economic sectors use built-up land in their production process? What sectors contributed most to land take, which is the conversion of agricultural, forest and natural land into built-up land, resulting in biodiversity loss and a degradation of soil functions? How vulnerable are economic sectors to a decrease in the availability of land and a land prices hike? In 2021, the French Parliament passed a law aiming for 'No net land take' (NNLT) by 2050, while the rate of land take should be halved by 2031. This paper investigates the potential impacts of this policy on economic sectors.

We construct annual accounts of the use of built-up land (a stock) and the contribution to land take[3] (a flow) by each economic sector in France between 2008 and 2021. We do so by spatially matching the surface of built-up land at the parcel level (from Fichiers fonciers, CEREMA) with the establishment of French firms (from Sirène, INSEE), based on their location. We then aggregate the surface of built-up land used by establishments at the NAF sector level. The new databases we obtain first enable us to draw stylised facts regarding the use of built-up land and the land take by sectors. Regarding land take, we find that the Wholesale and Retail Trade sector has been the main contributor throughout the period, even though its absolute and relative impact has declined. Sectors like Manufacturing, whose contribution to land take increased over the period, Construction, Transportation and storage, and Accommodation and food services were also significant contributors. The latter sector has contributed to a significant part of the land take occurring in natural areas. Moreover, this work helps understand how economic sectors use the total stock of built-up land. Some sectors require substantial built-up areas per establishment on average, particularly Mining and Quarrying, Energy and Waste and Water, or subsectors like steel and cement manufacturing.

Figure 1. Distribution of annual land take by economic sectors in France



Note: In 2018, the economic sectors contributing most to land take were Wholesale and Retail Trade, Manufacturing, Construction, Accommodation and Food services, and Transportation and Storage. We define a sector as a 'contributor to land take' in year t if it is the first user of the parcel converted in year t from natural/agricultural to built-up. Sectors are those of the NAF Rev. 2 classification of economic activities.

Based on this analysis, we explore the relative vulnerability of economic sectors to the NNTL policy in case the latter contributed to increasing land prices (which, however, is not a necessary outcome of the law). We develop a multi-criteria analysis disentangling various vulnerability components using our database and complementary data sources, such as firms' balance sheets. The sectors that emerge as most vulnerable include Agriculture and Accommodation and food services, while some sectors producing public goods (Waste and water treatment) could face financial difficulties to cope. Finally,

3 Our accounts focus on *gross* land take, but as the conversion of built-up land into natural or agricultural land is still extremely rare, this is very close to *net* land take.

although some sectors seemed more likely to be exposed to increasing land prices because of their important use of built-up land (such as Wholesale and Retail Trade, Transportation and storage, or even Manufacturing), they appear somewhat able to adapt relatively to other sectors, thanks to financial or technical means.

Our work contributes to several strands of the literature. First, our accounts of built-up land use and land take complement the existing environmental accounting tables, enabling the assessment of the built-up land footprint of economic activities. By exploring the type and surface of built-up land used by different economic sectors, it is also inscribed in the literature working towards integrating land as a production factor. It contributes to the emerging field of macroeconomics focusing on the transition to protect nature, in particular via land-use policies. Finally, our paper is a step in analysing economic and financial transition risks beyond those induced by the low-carbon transition.

Investigating the economic vulnerabilities to a policy may help envisage its broad set of consequences. In particular, it aims to anticipate forthcoming changes (e.g., incentivise economic sectors to change the way they use land, including through technical and organisational change), revealing possible trade-offs, and triggering reflections on the possible tools to support a reduction in the demand for built-up land (e.g., through mixed use of existing buildings). As was already emphasised by classical economists, land is finite, and dealing with its scarcity should be of concern for economics today.

Quantifier l'utilisation du foncier bâti par les secteurs économiques français pour évaluer leur vulnérabilité au « Zéro Artificialisation Nette »

RÉSUMÉ

En 2021, le Parlement français a adopté une loi visant à atteindre l'objectif "Zéro artificialisation nette" (ZAN) d'ici 2050, tandis que le taux d'artificialisation devrait être divisé par deux d'ici 2031. Ces objectifs sont notamment justifiés par le fait que l'artificialisation des sols, définie comme la conversion d'espaces naturels, agricoles et forestier en surfaces bâties, entraîne une perte de biodiversité et affecte les fonctions des sols. Parce qu'ils contribuent à l'artificialisation des sols et utilisent des terres bâties pour produire, les secteurs économiques seront probablement affectés par cette nouvelle politique. Le présent document étudie cette exposition. En utilisant des données cadastrales et des informations géolocalisées sur les entreprises françaises, nous développons des comptes annuels sur la période 2008-2021 retraçant (i) l'usage du stock de sols artificialisés, et (ii) la contribution au flux d'artificialisation des sols de chaque secteur économique. Nos résultats montrent une forte hétérogénéité sectorielle en termes d'usage des sols artificialisés et de contribution à l'artificialisation. Certains secteurs, comme le commerce, l'industrie manufacturière ou les services d'hébergement et de restauration, sont d'importants utilisateurs de sols artificialisés. Concernant l'artificialisation des sols, nous montrons que le commerce est le principal secteur contributeur. Puis, nous combinons ces nouveaux comptes avec des données supplémentaires pour proposer une analyse multicritère visant à évaluer les vulnérabilités sectorielles dans un scénario où la politique ZAN ferait augmenter le prix du foncier bâti. Nos résultats montrent que les secteurs qui contribuent le plus à l'artificialisation ne sont pas nécessairement les plus vulnérables en raison d'une capacité d'adaptation qui apparait relativement plus élevée.

Mots-clés : usage des sols et régulations ; marchés immobiliers non résidentiels ; comptabilité environnementale ; production

1 Introduction

Central banks and financial supervisors have been increasingly concerned with the financial risks that could emerge from the ecological transition. The latter will entail ambitious new policies, technologies, and consumption patterns (Vermeulen et al., 2021). If companies face difficulties aligning their business models with this new path, this could eventually affect the financial sector and be a source of 'transition risks'. While they initially focused on the risks associated with the climate transition, central banks and supervisors have started recently to explore risks associated with the transformations required to halt and reverse biodiversity loss (NGFS and INSPIRE, 2022; NGFS, 2023). Indeed, the Kunming-Montreal Agreement adopted in late 2022 states that Governments must halt and reverse biodiversity loss by 2030 and restore it by 2050, implying significant changes in most human and economic activities. In a first attempt to assess the economic and financial consequence of these changes, recent analyses have investigated the 'biodiversity footprint' of economic sectors and developed implicit scenarios assuming that biodiversity policies will target activities with more significant impacts on biodiversity in priority (van Toor et al., 2020; Svartzman et al., 2021; World Bank and Bank Negara Malaysia (BNM), 2022). Other works have explored more explicit policy scenarios, adapted to the context of the country under investigation, such as Calice et al. (2021), who focus on the establishment of new protected areas in Brazil, or van Toor et al. (2020), who investigate the impact of limiting nitrogen runoffs in the Netherlands. To our knowledge, however, analyses with explicit 'biodiversity policy' scenarios adapted to France are still lacking.

In this paper, as a first step towards assessing biodiversity-related transition risks in France, we propose to investigate the economic consequences of a specific biodiversity transition scenario for France, focusing on the ambitious 'no net land take' (NNLT) objective introduced in the law in 2021. The latter states that, by 2050, land take should reach 'net zero', implying that all the new built-up areas will have to be compensated for (by reconverting built-up land into non–built-up land). The law also introduces an intermediary objective to halve land take by 2031 as compared to the rate of the past ten years. In this paper, we define land take as the conversion of agricultural, forest, and other semi-natural and natural land into built-up land.[1] This policy notably aims to protect soils, which are non-renewable and a major global reservoir of biodiversity. Decaëns et al. (2006) estimate, for example, that more than 40% of living organisms in terrestrial ecosystems are directly associated with soils during their life cycle. Soils provide habitats for many species, both above and below ground, and land use change (including the conversion of natural or agricultural land into built-up land) is the most important driver of terrestrial biodiversity loss worldwide (IPBES, 2019) and in Europe (WWF, 2020). Preserving soils is also crucial, for they provide essential services such as carbon storage and flood protection.[2]

While limiting land take is crucial from an ecological standpoint, it will imply significant changes in how society – and, notably, economic sectors, which are the focus of this paper – use land. In the specific case of a 'severe but plausible' scenario (typically used to assess risks), the increasing competition for land induced by the NNLT policy could push land and Commercial Real Estate (CRE) prices up and affect economic sectors using large areas of built-up land in their production process. This increase in prices and the physical boundaries put to expansion could also limit the installation of new activities. We investigate the heterogeneous exposure of economic sectors to the 'no net land take' policy through their use of built-up land (e.g., via their buildings or parking lots) as a production factor. Our approach is thus quite similar to the one typically adopted by analyses of climate-related transition risks, which usually rely on forward-looking scenario analyses (e.g., assuming an increase

[1] The law introduces two definitions of land take. Until 2031, the definition is the same as the one adopted in this paper. After 2031, land take is defined as the lasting alteration of all or part of the ecological functions of the soil. We focus on the former definition because the data to assess the latter –e.g., the OCSGE database, which should be ready at the end of 2024 – is not available yet.

[2] For instance, according to the hydrologist Florence Habets, the conversion of soils into built-up land makes draughts more severe as it limits the ability for water to be stored underground, hence reinforcing the effects of climate change (Habets, 2023)

in carbon prices, see Network for Greening the Financial System (NGFS) (2020)) and subsequently identify the economic activities most exposed to the scenario by relying on their GHG emissions or 'carbon footprint'.

We assess the heterogeneous exposure of French economic sectors to this scenario by constructing annual (i) built-up land use accounts and (ii) land take accounts at the sector level (1- and 2-digit NAF sectors). We distinguish between the total stock of built-up land that each sector uses ('built-up land use') and the additional flow of land that each sector converts into built-up areas ('land take'). We construct our database by spatially matching a dataset produced by CEREMA (Fichiers Fonciers) picturing built-up land at the parcel level and data coming from Insee (Sirène database) providing the location and characteristics (including the NAF sector) of French firms' establishments. To our knowledge, this represents the first attempt to do such a matching at the national level in France.

The exploration of this innovative dataset documents a substantial time-varying heterogeneity regarding the sectors' use of built-up land and land take.[3] First, regarding the stock of built-up land, we find that the Wholesale and Retail Trade sector is the biggest user, followed by Manufacturing, Accommodation and food services, Transportation and storage, and Construction. However, the sector with the most extensive use of built-up land per establishment is the Mining and quarrying sector (14,000m² on average), followed by Energy and Waste and water (both around 4,500m² on average). Within each large sector (i.e., 1-digit NAF sectors), we can also observe significant discrepancies between subsectors (i.e., 2-digit NAF sectors), in particular in the Manufacturing sector where the average built-up land use per establishment is very heterogeneous and can reach areas up to 70,000m² for the Manufacture of steel. Then, regarding the flow of land take over 2008-2020, we find that although it has decreased in absolute terms, the share of land take due to economic activities (as opposed to housing) has increased. Overall, the sectors most responsible for land take are the same as those using the most built-up land –e.g., trade, although the contribution of this sector to land take has tended to decrease slightly over time. We also find that sectors may be taking different types of land: for example, the Accommodation and food services sector appears to be a significant contributor to the land take occurring on forests, semi-natural areas, wetlands, and water bodies.

Based on these accounts of built-up land use and land take, we investigate which sectors could be most vulnerable in a scenario of increasing land prices induced by the NNLT implementation. Defining *vulnerability* as resulting from the combination of (i) a shock, (ii) exposure to this shock, and (iii) an incapacity to adapt, we perform a multi-criteria analysis assessing each of those steps for each economic sector. We first assess exposure based on our accounts, followed by adaptive capacity using additional economic and financial data at the sector level. We find that some sectors are particularly vulnerable to NNLT (i.e., both exposed and possibly unable to adapt), including Agriculture (A) and Accommodation and food services (I). Had the law considered mines and quarries as 'land take', the Mining and Quarrying (B) sector would also have been particularly vulnerable. Some sectors producing public goods (e.g., Waste and water treatment or Residential care) could also face difficulties. Conversely, sectors like Wholesale and Retail Trade (G), Transportation and storage (H), or even Manufacturing (C) are exposed to the policy due to their sizeable use of built-up land but may be relatively more able to adapt. However, a deeper investigation at the sub-sector level shows that there can be considerable heterogeneity within each sector.

Our work contributes to several strands of the literature. First, our sector-level accounts of built-up land use and land take complement the existing environmentally extended input-output tables, which usually focus on agricultural and natural land, enabling the assessment of the built-up land footprint of economic activities. By exploring the type and surface of built-up land used by different economic sectors, our work is also inscribed in the literature working towards integrating land as a factor of production. Our exploration of the consequences of a national land-restriction policy for a comprehensive set of economic sectors also differs from the existing approaches in urban economics

[3] In this paper, we define as 'responsible' for land take the first user of the built parcel. However, we acknowledge that other actors may be deemed responsible, such as those who decided to build the land (e.g., the municipalities, the State, or private owners of the land – who may not use it but lend it to others), or those who built it (e.g., the construction sector).

that investigate the use of built-up land at a city level. This innovative work contributes to developing a field of macroeconomics focusing on the transition to protect nature and biodiversity, particularly through land-use restrictions. Finally, our paper is a step in the analysis of economic vulnerabilities and financial transition risks beyond those induced by the low-carbon transition.

This paper proceeds as follows: Section 2 explores the link between so-called 'biodiversity-related transition risks' and the NNLT policy and explains the paper's rationale. Section 3 presents the data and methods we use to build our accounts. We then split our results into two parts. Section 4 first analyses these new accounts and presents the main sectors using built-up land and the main contributors to land take. Based on these results, Section 5 then provides a multi-criteria analysis investigating the relative vulnerability of sectors to our scenario. Section 6 concludes and presents future avenues of research.

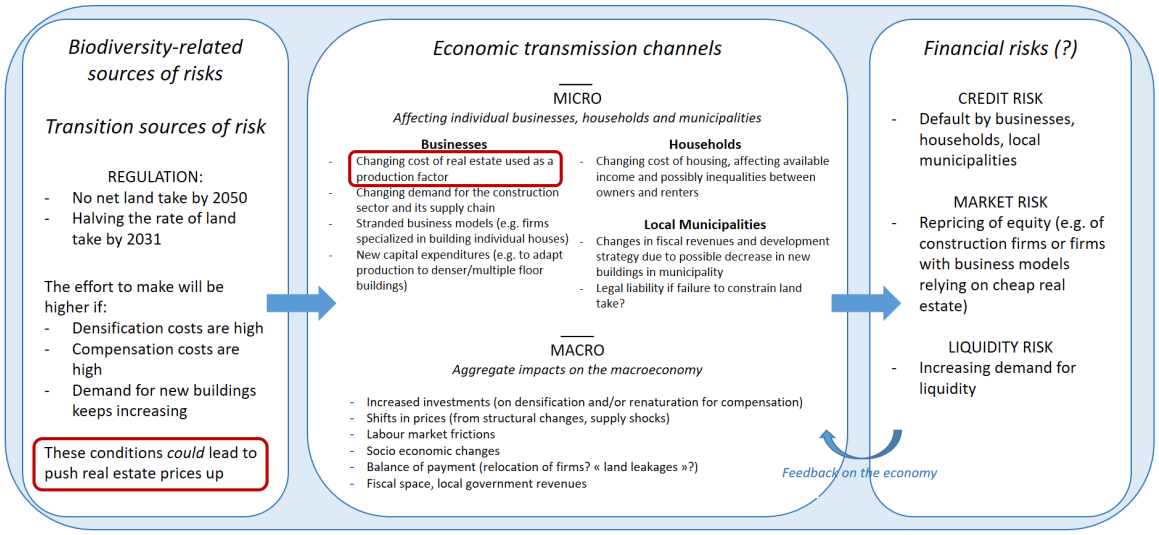
2 Rationale: 'biodiversity-related transition risks' and the no net land take policy

This section presents the context in which central banks are paying increasing attention to so-called 'biodiversity-related risks'. Given the complexity of biodiversity loss drivers and the changes to reverse it, exploring such risks calls for focusing on specific scenarios relevant to the country under investigation. We sketch a scenario around the no net land take policy in France and examine the literature available for analysing the economic consequences of this transition policy. This analysis points to the need for building new data to understand better the use of built-up land by economic sectors and their contribution to land take.

2.1 Context: Biodiversity-related risks

The 'No net land take' policy, which is the focus of this paper, is an example of a *possible* source of 'transition risk' related to biodiversity. Since a landmark speech by the governor of the Bank of England in 2015 (Carney, 2015), central banks have been increasingly paying attention to the financial risks related to environmental change (NGFS, 2019). While the focus was initially on climate-related risks, analyses are now emerging on the risks induced by biodiversity – or, as is often framed, 'nature' – loss (NGFS and INSPIRE, 2022; NGFS, 2023). Those risks are assessed along the distinction between 'physical' and 'transition' risks. 'Physical' sources of risks relate to the degradation of ecosystems that could decrease the many services they provide to economic agents (such as disease regulation or water retention in soils), possibly inducing economic losses. Conversely, the actions taken to halt and reverse biodiversity loss can be 'transition' sources of risks. Indeed, protecting and restoring nature will imply rapid and significant social and political changes (what IPBES (2019) calls 'transformative changes') that can be at odds with current business models and a source of economic losses, at least for some economic actors. The extent to which these losses could reverberate in the financial system and materialize into financial risk is a concern for central banks (Figure 1).

Figure 1: Transmission channels – From NNLT to financial risk



Source: Authors, adapted from Network for Greening the Financial System (NGFS) (2020)

Our analysis focuses on investigating the possible vulnerability of economic sectors to the NNLT policy, through their use of built-up land – and we leave for future research the question of how these impacts could be passed on to financial institutions and be a source of financial risks.

Note that NNLT could affect the economy in several other ways than via the use of land by firms: for example, households could face increasing housing prices, and local municipalities could see their revenues from property taxes decrease. Figure 1 lists some of these possible 'transmission channels' of risk to the economy – importantly, it does not picture the possible opportunities that could emerge from this policy, such as the creation of new economic sectors around ecosystem restoration (BenDor et al., 2015), the ecological gains, or the preservation of agricultural land. The impact on firms may also come from various channels. For example, construction companies whose business model relies on building cheap housing estates in agricultural areas could see their business model become 'stranded' (for a literature review on stranded assets, see Daumas (2023)). However, this paper focuses on another specific transmission channel of risk to firms: because they use built-up land (like buildings or parking lots) as a production factor, all companies may theoretically be affected by the restrictions on land take – CEREMA[4] indicates for example that around one-quarter of land take occurring in France between 2009 and 2021 was dedicated to economic activity, the rest being for residential purposes. However, some sectors of the economy may be more constrained by those restrictions on land take than others, as suggested by an article in the newspaper *Le Monde* entitled "'No net land take' scheme: 'Where will we put the factories tomorrow?'".[5] Our paper therefore investigates this possibly heterogeneous sectoral exposure and subsequent economic vulnerability.

[4] https://cartagene.CEREMA.fr/portal/apps/dashboards/9810991c73dd463191e84e7111a1b639

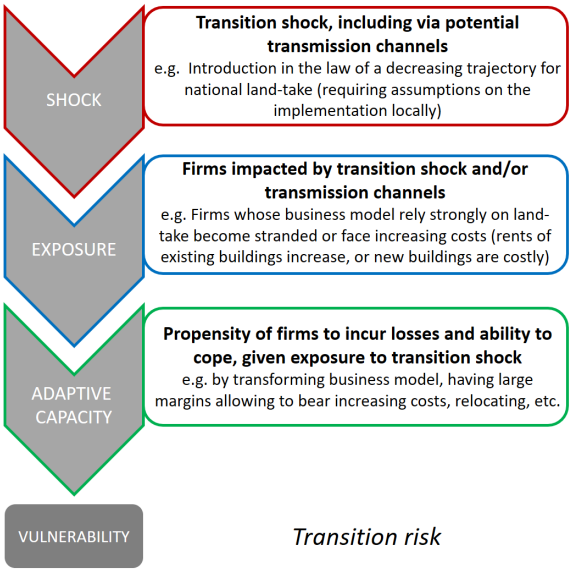
[5] https://www.lemonde.fr/economie/article/2022/07/04/dispositif-zero-artificialisation-nette-on-les-mettra-ou-les-usines-demain_6133225_3234.html

2.2 The 'No net land take' policy: how to explore the vulnerability of economic sectors?

2.2.1 From the NNLT policy to a vulnerability

The Intergovernmental Panel on Climate Change (IPCC, 2014) defines vulnerability as 'the propensity or predisposition to be adversely affected'. Building on both Carley et al. (2018) and Viner et al. (2020), we conceptualise economic vulnerability, in the case of a transition,[6] as resulting from three elements (Figure 2): a hazard, an exposure, and an adaptive capacity.

Figure 2: The construction of vulnerability



Source: Authors

First, the vulnerability of sectors to the transition policy will depend on the shock features (step 1 of Figure 2), i.e., the specific policy taking place, including which local territories will have to make more efforts and at what pace. In addition, the economic impacts of the policy implementation are uncertain: NNLT could, for example, lead to a more or less high increase in the price of real estate (see below). These *uncertainties* call for the elaboration of forward-looking scenarios. Second, the exposure of firms and sectors to the shock (step 2 of Figure 2) will be heterogeneous, depending on their location, use of built-up land, or business models. Finally, if exposed, firms and sectors will have heterogeneous abilities to cope (step 3 of Figure 2), depending on their financial health, their ability to innovate, translate increased costs into increased prices, change business models, or relocate.

This paper explores sequentially these three main components of vulnerability: shock (in the following subsection), exposure (Section 4), adaptive capacity (Section 5).

2.2.2 Sketching scenarios of shock

The scenario we investigate in this paper is one in which the decreasing supply of built-up areas and new buildings implied by possibly high compensation and densification costs eventually pushes real estate prices up, assuming that demand remains constant or keeps increasing. Note that this is a very particular type of scenario, typically described as 'severe but plausible', used to analyse what could go wrong and identify agents with specific vulnerabilities. This approach is in line with the philosophy

[6]Note that in the IPCC reports and Carley et al. (2018), the concepts of 'vulnerability' and 'risk' are defined in a context of natural disaster, or what we called 'physical risks'. Viner et al. (2020) however, investigates vulnerability in a transition context.

of financial stress tests (Borio et al., 2012), which consists in assessing the resistance of individual financial agents or the financial system to severe stress scenarios.

We rely on a forward-looking scenario of shock due to the pervasive uncertainties regarding how the law will be implemented and its consequences.

The first uncertainty regards the precise implementation of the policy. Concerning the timeline, the trajectory described in the law consists of two points in time, one for 2031 and one for 2050, but the precise trajectory they imply remains to be determined. In addition, the distribution of efforts across space, between regions and municipalities, is still ongoing – we assume here that all municipalities face the NNLT constraint and must limit the expansion of buildings.

An additional source of uncertainty relates to NNLT's impacts on the prices of built-up land and the construction and real estate markets. The decreasing supply of built-up land may imply a decrease in the supply of buildings, which, if demand remains constant or increases, may increase the price of built-up land and real estate. In theory, the possibility of compensating for land take could relax this supply constraint, as the law defines zero 'net' land take in 2050 as the fact that all flows of land take should be compensated through a restoration of the ecological functions of another deteriorated land. However, converting built-up land into (semi-) natural land implies numerous and possibly costly operations. To our knowledge, there are few studies on the actual costs of these operations apart from Fosse (2019), which states that they would range between 160 and 425€/m².[7] Soil is a non-renewable resource and an ambitious restoration of sealed soil is challenging, uncertain, and requires time. Therefore, the priority is likely to be on building on already strongly degraded land (like fallow land and parking lots) and on densifying existing urban areas (e.g., adding floors to existing buildings or substituting detached houses with collective housing). However, this may entail additional construction costs per useful m², as suggested by Colsaet (2021). Indeed, collective buildings can imply additional technical and regulation constraints compared to individual housing, such as a need for deeper foundations (Bouteille, 2008). Similarly, construction on fallow land entails additional costs due to decontamination requirements or constraints associated with being in already dense areas (e.g., in terms of accessibility for construction trucks). Refurbishing and re-organising existing buildings is also often more costly than building new ones (Colsaet, 2021).

In our 'severe' scenario, we assume that high compensation costs and high densification costs lead to a reduction of building supply and increasing land and real estate prices, consistent with some, but not all, findings in the economic literature. For example, Dawkins and Nelson (2002)'s meta-analysis of case studies investigating the reaction of housing prices to different containment policies finds that no matter how they are implemented, urban containment programs affect land prices positively (but not necessarily density). However, Glaeser and Ward (2009) find that zoning regulations are no longer associated with higher land prices when density and demographics are added as controls because price changes lead to relocation. Overall, it is, therefore, hard to draw solid conclusions regarding the effect of NNLT on land and real estate prices. Indeed, while the regulations studied in the literature are municipality-specific – leaving the possibility for demand to adjust by relocating –, the NNLT policy will be a national-level regulation. To our knowledge, such a broad regulation on new constructions has never been experienced and, consequently, analysed.

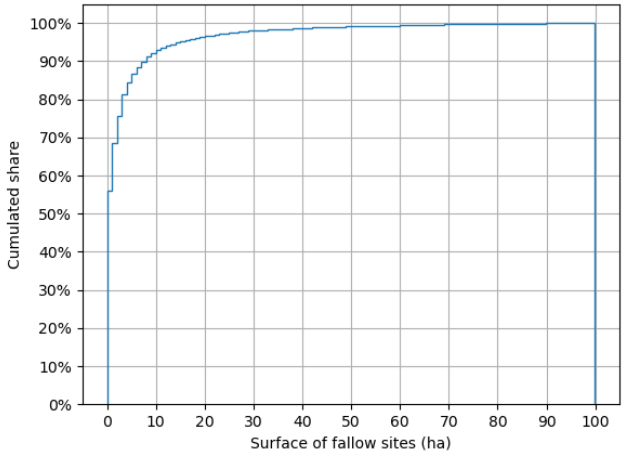
Therefore, this scenario should not be interpreted as an *expected* outcome of the NNLT policy, in particular, because numerous levers, on the demand and supply side, could also affect land and real estate prices simultaneously. On the demand side, for example, the evolution of households' preferences towards smaller housing, working-from-home, the development of buildings with mixed uses (e.g., a school on working days, a place for gym or theatre classes by nights and on weekends) or the taxation of multiple-home ownership could reduce the demand for buildings. The demand for commercial real estate (CRE) is also influenced by financial investors (e.g., real estate trusts and funds), whose demand adds to the one stemming from firms for their own production.[8] Finally, demand for real

[7] These include deconstruction costs (65€/m²), decontamination costs (from 2 to 65€/m²), de-sealing costs (from 60 to 270€/m²), and costs for the reconstruction of soils (33 to 55€/m²).

[8] On the housing market, Daly et al. (2023) show that real estate investment funds amplify the housing price cycle.

estate also depends strongly on macroeconomic and financing conditions (e.g., GDP or interest rates) which could mitigate or exacerbate the effect of NNLT on built-up land prices. On the supply side, government subsidies in favour of the densification of existing buildings or construction on fallow land, joint with new training favouring the development of refurbishment skills in the construction sector, could increase the supply of built-up areas while being compatible with an NNLT objective. In that regard, the supply may be limited by the availability of already built-up land, especially fallow land. The Cartofriches database (Cerema)[9] shows for example that most fallow sites have an area lower than 1 hectare (Figure 3). Large fallow sites (>50ha), which could be necessary to the production of specific sectors, make up a small fraction of registered fallow sites (Figure 3), and are concentrated in specific locations, in particular in départements that have faced deindustrialisation (Figure 4).

Figure 3: Distribution of fallow sites surfaces

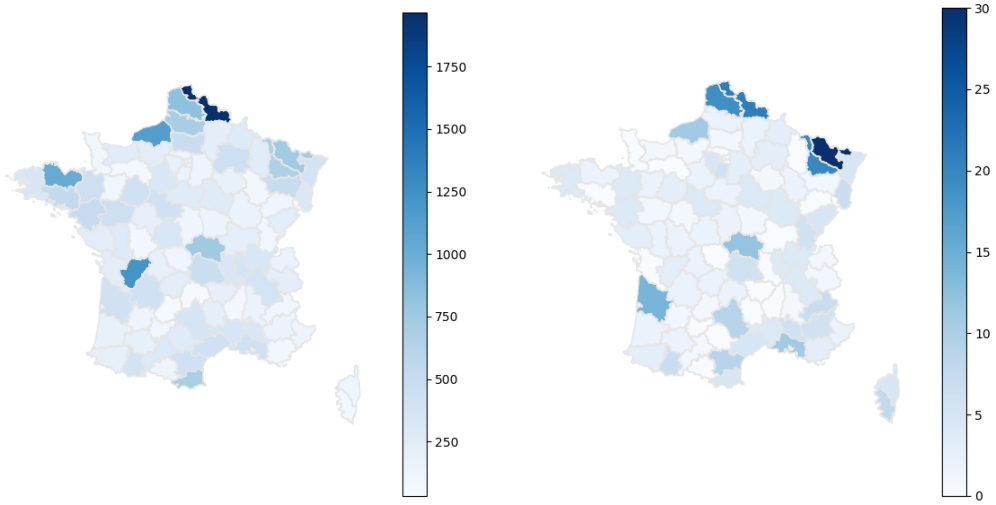


Source: Authors, based on Cartofriches database

Figure 4: Geographical distribution of fallow sites by département

(a) All fallow sites

(b) Large fallow sites (>50ha)



Source: Authors, based on Cartofriches database

On the CRE market, this effect is likely to be even stronger as the role of investors is much larger than on housing markets.

[9] A national inventory of fallow sites gathering 9,561 sites with a total surface of 170 000 ha.

We conclude this 'Rationale' section with a literature review that may help investigate the vulnerability of economic sectors to this NNLT scenario.

2.3 Literature review: Activity-driven land-take, and built-up land as a production factor

Investigating the exposure of sectors to NNLT and the constraint on the supply of built-up land requires understanding (i) the extent to which firms contribute to land take and (ii) how they use built-up land in their production processes – to understand how restrictions could disrupt production. One can draw a parallel with the analyses of climate-related transition risks, where identifying the sectors most exposed to climate policies requires understanding the reliance of their production on energy and computing associated GHG emissions (see, for instance, European Central Bank (ECB) (2022)).

We have found no detailed data analyses examining companies' contribution (or 'responsibility') to land take, nor their use of built-up land: the database we build in this paper aims to fill this gap. Multi-regional input-output tables with environmental extensions (such as EMERGING, Huo et al. (2022)) have mostly focused on the use by economic sectors of agricultural, forest and pasture land, but very seldom include urban land. Those which do so, like EXIOBASE (Stadler et al., 2018), attribute urban land use to households only, in the final demand account. Global models investigating the use of land by economic sectors, such as GTAP-AEZ (Hertel et al., 2009) or MAgPIE (Dietrich et al., 2023), also set aside the use of urban land by economic activities. Similarly, accounting analyses with existing databases for France (like Corine Land Cover, Fichiers Fonciers or Teruti-Lucas) do not fully account for the role of economic activity in land take. They either allocate land take to economic activity without disentangling between sectors (Bocquet, 2020), or allocate land take to economic sectors in a rather coarse way, based on the land cover morphology which does not explicitly identify the real activity of the land user.[10]

Overall, the *role of economic activity in land take* (point (i) above) has been mostly overlooked. However, research on the drivers of land take (see Colsaet et al. (2018) for a systematic literature review) tends to focus on identifying the factors causing urban sprawl – such as the fall in commuting costs, structural changes, or public policies– rather than the actors. In addition, most of this literature focuses on housing as the primary driver of land take. However, Cavailhès (2015) highlights that, while it was the case in the 1980s, in the 2000s, 'it is no longer 'the individual house [that] is eating up natural spaces', it is offices, shopping centres factories, roads and recreational areas that are eating into agricultural land.' Lejoux and Charieau (2019) suggests several explanations for this lack of attention to economic activity as a driver of land take in urban studies, including the significant focus of public research funding on residential peri-urbanisation and the residential-oriented way policy-makers have framed their struggle against urban sprawl. Demazière (2015) also emphasises that the high economic stakes (as firms provide jobs and tax resources) can contribute to overlooking the responsibility of economic activity in land take. However, a marginal strand of the literature investigates urban sprawl by economic activity via analyses of the decentralisation of jobs. These analyses notably explain that jobs migrate to the outskirts of cities due to advances in communication technologies enabling firms to relocate the less productive activities to cheaper locations Rossi-Hansberg et al. (2009).

We also find that little attention has been paid to the *use of built-up land* as a production factor by economic sectors other than agriculture, neither in the micro nor macro literature (point (ii) above). This lack of interest contrasts with the role land played in pre-classical and classical economics (Hubacek and van den Bergh, 2006), with concepts such as the 'urban rent' developed by Henry George. By the second half of the 20th century, it had become the "missing factor" (Ryan-Collins et al., 2017) in standard macroeconomic production functions, abridged to capital and labour alone. Land has, however, remained a central production factor in two specific fields of economics: agriculture and urban economics. In agricultural economics, land is better defined as 'soil', with specific quality and

[10] https://www.eea.europa.eu/data-and-maps/dashboards/landtake-statistics

productivity. In contrast, urban economics sees land as a 'location' in space, chosen by agents based on the relative position of other agents. Applying the monocentric model of Fujita and Ogawa (1982), Duranton and Puga (2015) shows, for example, that manufacturing plants, whose land use is intensive, are likely to spread out, while services, which depend a lot on agglomeration economies, will remain concentrated. We find, however, very few analyses (e.g., Needham et al. (2013)) focusing explicitly on land as 'extent' or 'surfaces' being potentially sealed and used as a production factor by firms. Moreover, urban economics rarely intersect the notion of land use in urban contexts with broader macroeconomic aspects.

Finally, land, and more specifically built-up land, has rarely, if ever, been considered a finite resource that could constraint production in modern macroeconomics (unlike other natural resources or energy, see Couix (2020)). This disappearance relied on the belief of a high degree of substitutability between natural and manufactured inputs and is symptomatic of a broader 'oblivion' of natural (and finite) resources in economic theory. In recent years, research has shown how land returned as a crucial explanatory element of wealth (Trannoy and Wasmer, 2022) and, as a corollary, has stressed the necessity of its re-integration in economic analysis (Ryan-Collins et al., 2017). Indeed, land displays specificities (a fixed supply, not produced nor reproducible, permanent and recyclable, and limitational), implying that it should be analysed as a factor distinct from capital (Gaffney, 2022). While Bergeaud and Ray (2021) investigate the complementarity between labour and land in the production function, Needham et al. (2013) is one of the rare papers investigating the role of land as a limiting factor for production and the possibilities of its substitution. Relying on two extreme cases, offices and industries, the article shows that the limited availability of land, due to its unique characteristics (indispensable to production and immobile), may hamper the growth of firms: land restrictions lead to land-inefficiency and the need for firms to relocate. The paper concludes with regrets for the lack of granular data to test empirically their intuitions.

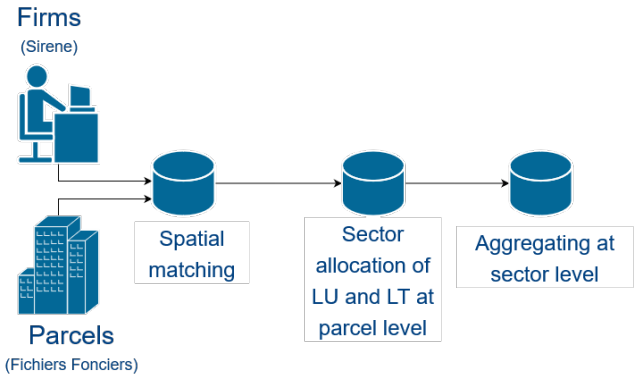
This review suggests the need for a meso-level analysis quantifying the contribution of economic sectors to land take and their use of built-up land in production. The following section presents our methodology to build sectoral accounts of land use and land take by economic sectors.

3 Data and Method

Our method to construct annual sectoral (i) built-up land use and (ii) land take accounts is based on three main steps. Using data on the French cadastral parcels coming from Fichiers Fonciers (CEREMA), providing each parcel's built-up or partially built-up (e.g., gardens) surface, we allocate this surface to housing or activity uses. Then, based on information on the firms' establishments present on the parcel coming from the Sirene database (Insee), we split the surface allocated to activity use equally between each establishment. Finally, as we know each establishment's economic sector, we create sectoral accounts of the use of built-up land by re-aggregating at the sector level. By repeating this process for each year, we create annual accounts of the surface of built-up land used by economic sectors in France for the 2008-2020 period (Figure 5).[11]

[11] A similar analysis matching the Fichiers Fonciers with Sirene has been performed by Martin Bocquet in 2018 (https://datafoncier.cerema.fr/sites/datafoncier/files/fichiers/2019/02/rapport_SIREN_DRIEA_V3_0_0.pdf) but it was restricted to the Ile-de-France region.

Figure 5: Method sketch



Source: Authors

This section presents the data and the treatment we applied to it to obtain annual accounts (i) of the use of built-up land by sector and (ii) the land take by sector.

3.1 Data

3.1.1 Data on built-up land

We use the 2021 vintage of Fichiers fonciers (FF), a dataset on the land and built-up infrastructures in France, constructed by the Ministry of Finance using fiscal data on land and enriched by CEREMA.[12] The FF are made of a collection of datasets, including one focused on the parcels of the *cadastre* ('base parcelle') and one on the facilities located on each parcel ('base local'). Using these datasets, we compute for each parcel the share σ_A of the parcel dedicated to activity (the rest being dedicated to housing) in 2021 and extract the surface of the parcel that is built in 2021 (B) and the year of construction of the first building on the parcel (j). The methodology to obtain these variables is detailed in Annex. Finally, we use the variable called *dcntarti* to obtain the surface of the parcel considered as 'built-up'.[13]

3.1.2 Data on Firms' establishments

Produced by Insee, the Sirene database (Répertoire National d'identification des entreprises et des établissements) provides information on each business establishment located in France. It includes all the companies in activity when the database was created in 1973 and those created since then.[14] We use the dataset called StockEtablissementHistorique, including historical data on the establishments (each with an identifier called SIRET) of each company (each with an identifier called SIREN) in France. The variables of interest for us are the opening and closing dates of the establishment, its economic sector (NAF code or NAP code before 1993) and whether the establishment is hiring workers. We obtain the geolocation of each establishment thanks to a merge of this dataset with the

[12]CEREMA is a French public agency developing expertise in the fields of urban planning and ecological transition. Note that the Fichiers Fonciers will be the official data to monitor land take in France for the next decade, as it is considered the most precise data source.

[13]The *dcntarti* variable, computed based on information coming from tax payments, includes the ground surface, on the parcel, of: quarries, gardens, land 'to-be-built', land for leisure (including e.g., the parks of castles), and land covered with buildings, impervious or semi-impervious surfaces. Therefore, in our analysis, all gardens and areas covered with grass for recreation are considered to be 'built-up' land, in contrast with the last version of the law where some of these areas are now considered 'non–built-up' ('non-artificialisés')

[14]Public administrations were included in 1983, and farms in 1993.

"Géolocalisation des établissements du répertoire Sirene" dataset,[15] based on the SIRET identifier. Further details on the data treatment and final representativity of our data are provided in Annex. Although we had to remove some establishment from our sample due to data limitations (especially regarding geolocation), the distribution of sectors in our final sample remains quite similar to the one of the initial database (see Annex, Figure A3).

3.1.3 Data on Land cover

To get information about the 'type' of land being taken by economic activity, we rely on the CORINE Land Cover (CLC) dataset, coordinated and integrated by the European Environment Agency (EEA). CLC is based on visual interpretation of high-resolution satellite imagery and consists of several vintages (2000, 2006, 2012, 2018). The covered area is split into homogeneous land units with a minimum surface of 25 hectares (ha) for areal phenomena and a minimum width of 100m for linear phenomena. Each unit is associated with a specific cover within 44 classes belonging to five broader categories: artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands, and water bodies. We focus on the 2006 vintage: as our land take accounts span the 2008-2021 period, we can find the kind of land cover present on the parcel in 2006 before the land was taken.

3.2 Method – Spatial Matching

3.2.1 Spatial matching of establishment and parcels

We match each point representing an establishment (SIRENE database) to the nearest polygon representing a built parcel (FF database) through a nearest-neighbour spatial joint. Hence, while one establishment can only be matched with one parcel, we can find multiple establishments on the same parcel. In order to avoid matching an establishment with a parcel where no building is built, we removed the unbuilt parcels from the FF before the matching procedure. For example, we match the establishment represented by the red dot in figure 6 with the nearest built dark grey parcel instead of the unbuilt light grey parcel on which it is located. We then remove from our sample the establishments matched with a parcel that was further than 5 meters away; hence, the establishment represented by the green dot on figure 6 is dropped. We removed the few establishments matched with more than one parcel because we cannot define the parcel they 'truly' belong to.

Figure 6: Spatial joint

Source: Authors

3.2.2 Spatial matching of parcels and land cover

We use the data on land cover to gain insight into the types of land that are taken by economic activity. The land cover units from the CLC database (300m x 300m) are much larger than the parcels. Thus, to attribute a land cover to each parcel, we compute the shares of the different land covers in the parcel

[15] https://www.data.gouv.fr/fr/datasets/geolocalisation-des-etablissements-du-repertoire-sirene-pour-les-etudes-statistiques/

and then keep only the main cover type. Note that due to this difference in spatial scale between FF and CLC, the results obtained regarding where land-take occurred are only indicative and must be taken with a pinch of salt.

3.3 Method – Building the Accounts

The main challenge is now the attribution of the stock of built surfaces and the flow of land take to firms' establishments and, ultimately, to economic sectors.

In both land use and land take accounts, we assume that the surface of the parcel dedicated to activity is split equally between each establishment located on the parcel. If there are four establishments on a parcel, we will attribute one-fourth of the activity on the parcel to each establishment.

3.3.1 Built-up land use account (stock)

Therefore, we define the use of built-up land by a given sector s on a given year y (denoted $B_{s,y}$) in the following way:

$$B_{s,y,i} = \sum_i B_i \times \sigma_{s,y,i} \tag{1}$$

where i is a parcel, B_i is its built surface, and $\sigma_{s,y,i}$ is the share of the parcel dedicated to activity of sector s on year y. As mentioned above, this share is equal to the share of the parcel dedicated to activity in 2021 ($\sigma_{A,i}$), multiplied by the share of establishments on the parcel on the given year y that belonged to sector s. Denoting $n_{s,y,i}$ the number of establishments on the parcel on the given year y that belonged to sector s, we can write:

$$\sigma_{s,y,i} = \sigma_{A,i} \times \frac{n_{s,y,i}}{\sum_{s \in S} n_{s,y,i}} \tag{2}$$

3.3.2 Land take accounts (flow)

We first assume that the entire flow of land take on the parcel happened at once, on the year just before the parcel appears as built in our data (call it year $j-1$, j being the year when the first building on the parcel appears in the FF data – called *jannatmin* in the dataset). Therefore, if we observe in our 2021 data that the built surface on parcel i is B_i, we assume this land take occurred in year $j-1$ only.

We then choose to allocate the responsibility for the flow of land take occurring at year $j-1$ to the first users of the parcel (who can arrive on the parcel any year following $j-1$). Let us take the example of a parcel built during the year 2009 (that therefore appears as 'built' in our data as from 2010), and on which we see a first establishment, belonging to economic sector s_1, arriving only in 2012. In our accounts, the flow of land take will appear for 2009, but we will allocate the responsibility for this flow to s_1. Note that, with this option, an establishment from another sector s_2 arriving on the parcel in 2013 or later will not be deemed responsible for the flow of land take – as we focus on the first users only. We present alternative ways to allocate the responsibility for land take in Annex, but find that this choice has little impact on the results, because establishments tend to remain on their parcels for a substantial amount of time and only change location occasionally.

3.3.3 1-digit NAF Sectors

The accounts presented in this paper follow the 1-digit NAF sector classification. Table A14 provides the list of these sectors with a short description[16] and the share of French GDP they represented in 2018 (Eurostat data).

[16] https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

Table 1: Sectors (NAF 1-digit)

Code	Name	Description	% of 2018 GDP
A	Agriculture, Forestry and Fishing	Includes crop and animal production, hunting and related service activities, forestry and logging, fishing and aquaculture	1.7%
B	Mining and Quarrying	Includes mining of coal and lignite, of metal ores and other, Quarrying, Extraction of crude petroleum and natural gas, mining support activities	0.1%
C	Manufacturing	Includes Manufacture of food, beverages, tobacco textiles, wearing apparel, products of leather, wood, straw, paper, coke and refined petroleum, chemicals, pharmaceuticals, rubber and plastic, other non-metallic mineral products, products of basic and fabricated metal, computer, electronic and optical products, electrical equipment, machinery, motor vehicles, other transport equipment, furniture, printing and reproduction of recorded media, repair and installation of machinery	12.5%
D	Electricity, Gas, Steam and Air Conditioning supply	Includes the production, distribution and trade of electricity, Manufacture and distribution of gas, ans steam and air conditioning supply	1.9%
E	Water Supply; Sewerage, Waste Management And Remediation Activities	Includes water collection, treatment and supply, sewerage, waste collection, treatment and disposal activities; materials recovery, waste management	1.2%
F	Construction	Includes the construction of buildings, civil engineering and specialised construction activities	6.1%
G	Wholesale and Retail Trade; Repair Of Motor Vehicles and Motorcycles	Includes wholesale and retail trade and repair of motor vehicles and motorcycles, and wholesale and retail trade of other products (food, household goods, machinery, etc.)	11.2%
H	Transportation and Storage	Includes transport via land, pipelines, water, air, warehousing and support activities for transportation postal activities	4.9%
I	Accommodation and Food Service Activities	Includes accommodation (hotels, camping grounds, etc.) and food and beverage services activities (restaurants, event catering activities, etc.)	3.1%
J	Information and Communication	Includes publishing activities, production of motion picture, video, television, music, broadcasting, telecommunication, computer programming, consultancy, information services	5.9%
K	Financial and Insurance Activities	Includes financial service activities, Insurance, reinsurance and pension funding (except compulsory social security), auxiliary financial and insurance activities	4.4%
L	Real Estate Activities	Includes buying, selling, renting and operating, managing real estate	5.5%
M	Professional, Scientific and Technical Activities	Includes Legal and accounting activities, head offices, management consultancy, architecture and engineering, scientific R&D, advertising, veterinary activities	9.0%
N	Administrative and Support Service Activities	Includes activities of rental and leasing, of employment, travel agencies, security and investigation, services to buildings and landscape, office administrative and support	6.6%
O	Public Administration and Defense; Compulsory Social Security	Includes Public administration, defence, justice, public public, compulsory social security	7.4%
P	Education	Includes pre-primary, primary, secondary, higher education, driving, sport and cultural education, educational support	5.8%
Q	Human Health and Social Work Activities	Includes human health, residential care, social work activities without accommodation	9.8%
R	Arts, Entertainment and Recreation	Includes creative, arts and entertainment activities, libraries, archives, museums, gambling and betting, sport and amusement and recreation activities	1.5%
S	Other Service Activities	Activities of membership organisations (trade unions, etc.), repair of computers and personal and household goods, other personal service activities (hairdressing, funeral, etc.)	1.4%
T	Activities of Households As Employers	Includes employment of housing personnel and production of goods and services of households for own use	0%
U	Activities of Extraterritorial Organisations and Bodies	Activities of extraterritorial organisations and bodies	0%

3.4 Discussion on the method

Our method differs from the one by Bocquet (2020) (used by the government to monitor land take) in several aspects. First, we use only one vintage of FF (2021), and we define the year when land take occurred as the year of the first construction on the parcel, while Bocquet uses each on the annual vintage of FF and looks at the evolution of parcels from one year to another. This difference comes from data availability issues but has little impact on the results. We also consider a parcel as 'built' only if it has a facility on it, while Bocquet (2020) also includes some parcels with no facilities (e.g., parking lots) in its account of land take. Our method, therefore, does not include these common spaces (for example, common car parks or roads shared by multiple firms) in the accounts due to the difficulty of allocating shared infrastructures to specific sectors. Finally, regarding the definition of the parcels' users, Bocquet (2020) defines only one principal use of each parcel (either activity, housing or mixed). In contrast, in our method, a given parcel can be used partly for activity and housing purposes.

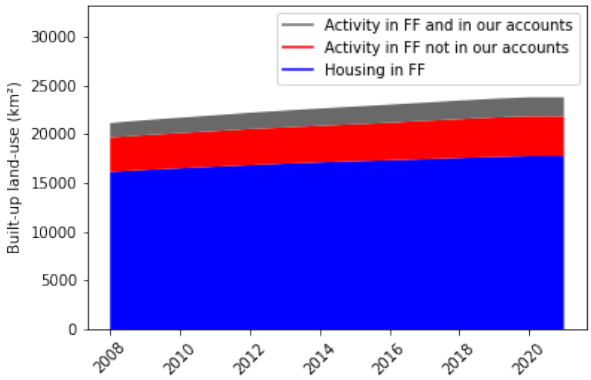
4 Results: how do economic activities use and take land?

This section presents the main results we draw from our accounts. We describe how various economic sectors occupy the *stock* of built-up land, before focusing on the *flow* of annual land take and the sectors using it – and which can be deemed partly 'responsible' for it.

4.1 Built-up land use

Overall, the total area of built-up land went from approximately 21,200 km² in January 2008 – representing approximately 3.8% of the area of metropolitan France –, to 23,800 km² in January 2021, i.e., 4.3% of France's area (Figure 7). Therefore, at least 0.5% of the French territory was converted into built-up land in 13 years.[17] In 2008, 76.4% of this built-up surface were used for housing purposes, and 23.6% were dedicated to economic activity, and this share increased regularly to reach 25.3% in 2021. However, due to the matching procedure (see Annex) and poor geolocation of some establishments, we can only capture in our accounts no more than 32% of this built-up land use by economic activity (a share increasing over the period, starting at 29.7% in 2008). Therefore, our results provide an incomplete picture of the built-up land use by economic activities in absolute terms. However, the relative results between sectors remain accurate (see Figure A3 in Annex) and provide interesting insights into how economic activities are heterogeneously using land.

Figure 7: Evolution of built-up land use by housing and economic activity (2008-2021)



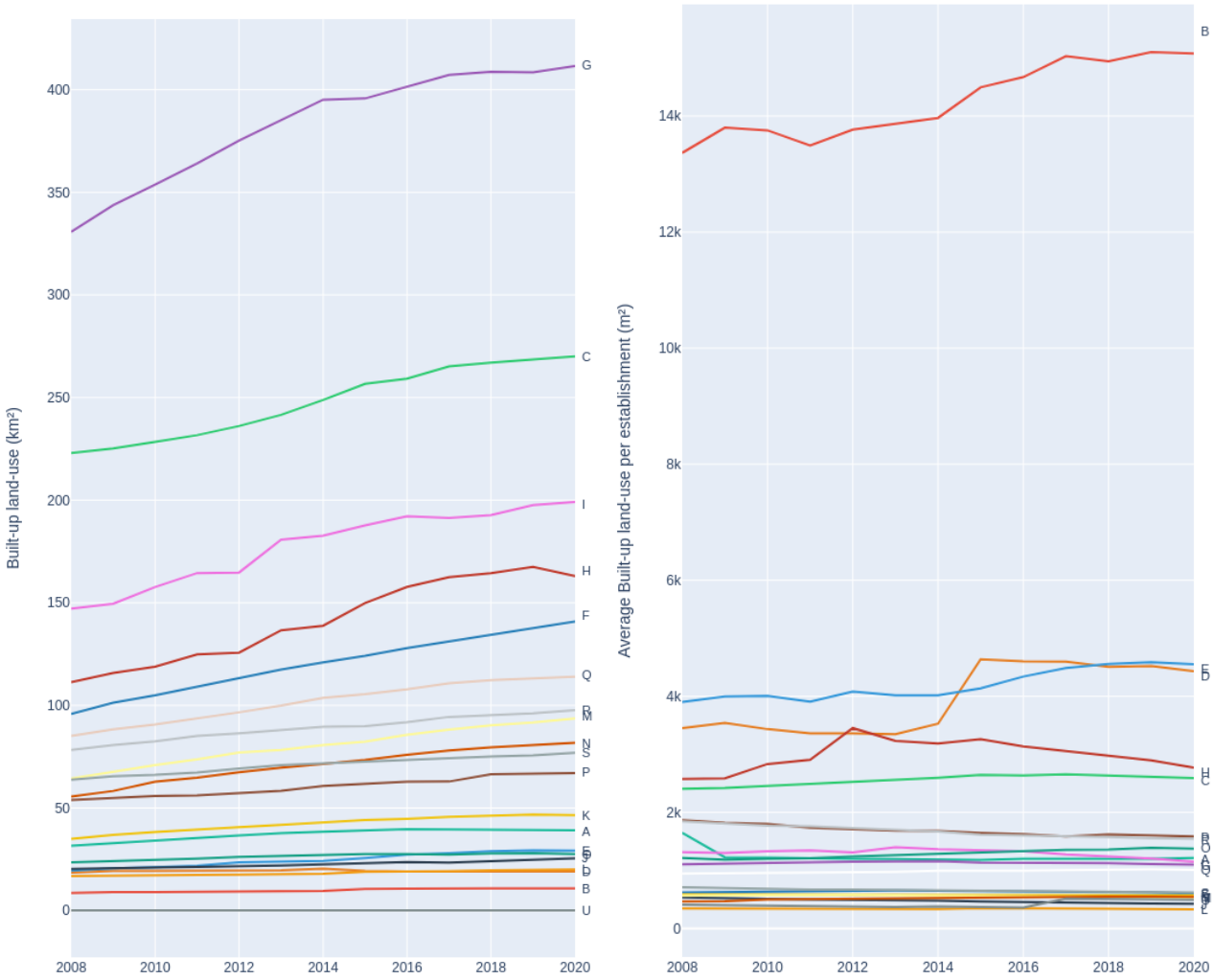
When we investigate which economic activities use this built-up surface (Figure 8a), we find that Wholesale and Retail Trade (sector G) was the biggest user of built-up land over the period, although at a decreasing growth rate since 2014. In 2021, the built-up surface dedicated to trade activities in France was equivalent to approximately four times the area of the city of Paris. In the ranking of the most 'land-using' sectors, Wholesale and Retail Trade is followed by the sectors of Manufacturing (C), Accommodation and Food services (I), Transportation and Storage (H) and Construction (F). Within these large sectors, we observe a substantial variability in the use of built-up land among sub-activities (see Annex).

[17] Note that this surface does not account for the land covered with non-building infrastructures such as roads, streets, pavements, or even some parking lots. Therefore, the agricultural, semi-natural or natural land converted into artificial land over the period represents probably much more than 0.5% of France's area.

Figure 8: Evolution of built-up land use by sector

(a) Total built-up land use (km²)

(b) Average built-up land use by establishment (m²)



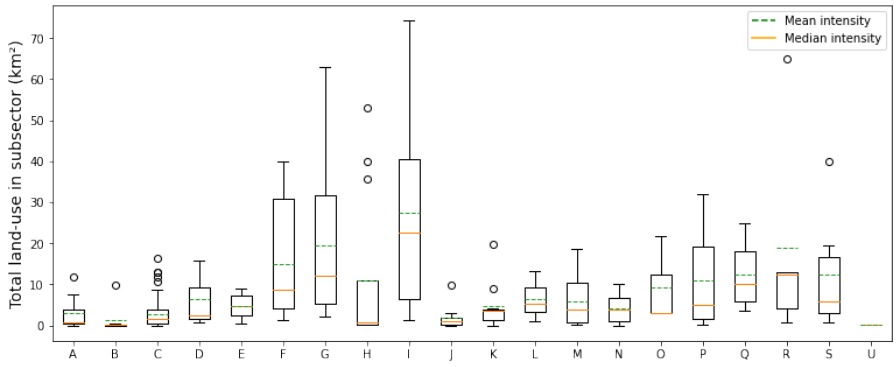
However, this ranking of sectors changes when we divide these total surfaces of built-up land by the number of firms' establishments that use them (Figure 8b). The Mining and Quarrying sector (B) is, by far, the sector where establishments use the most land, with an average built-up land use of 15,000m² per establishment. It is then followed by the sectors of Electricity, Gas, Steam and Air Conditioning Supply (E), Water Supply, Sewerage, Waste Management and Remediation Activities (D), Transport and storage (H) and Manufacturing (C).[18] This average use of built-up land per establishment can vary greatly within a given sector. In Manufacturing (C) in particular (Figure 9b), the establishments in the subsectors of Manufacture of basic iron and steel and of ferro-alloys (24.1), refined petroleum products (19.2), man-made fibres (20.6), and cement, lime and plaster (23.5) use more than 35,000m² of built-up land on average (up to 70,000m² for subsector 24.1). Conversely, some subsectors, such as Repair of fabricated metal products, machinery and equipment (33.1) or Manufacture of plastic products (22.2), use an average built-up surface lower than 10,000m² per establishment, even though they represent a large part of the total built-up land use of the Manufacturing sector (see Annex). One can also observe this significant variation between subsectors in the total built-up land use by sector: for example, sector R (Arts, Entertainment and Recreation) ranks relatively low in its total

[18]The agricultural sector does not stand out because we focus on *built-up* land, so the parcels with crops are not included in the accounts. The construction sector does not stand out because we focus on the *use* of built-up land, not on its production.

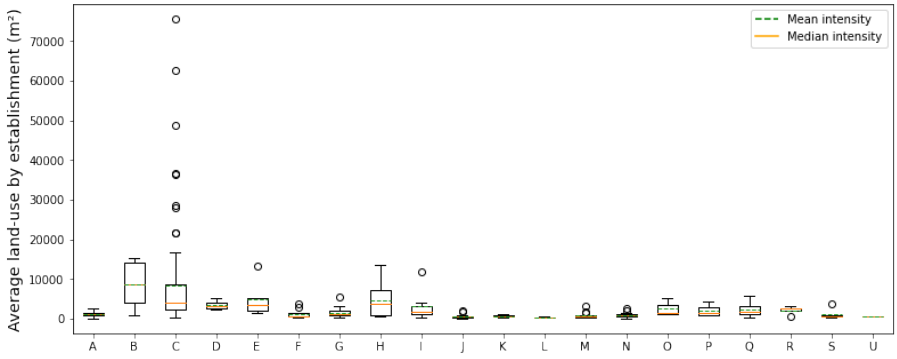
use of built-up land, but its subsector called Sports activities and amusement and recreation activities (93) has one of the highest built-up land use among 2-digit subsectors (see Figure 9a in Annex). This discussion on the needs for built-up land should be related to questionings regarding its availability (see Annex).

Figure 9: Within 1-digit sectors in 2018, distribution of 2-digit sectors by:

(a) Total built-up land use



(b) Average built-up land per establishment



4.2 Land take

We now turn to the *flow* of land take and its main contributors. In the first section, we look at land take in general, while the second section will differentiate between land take occurring on already built and natural areas.

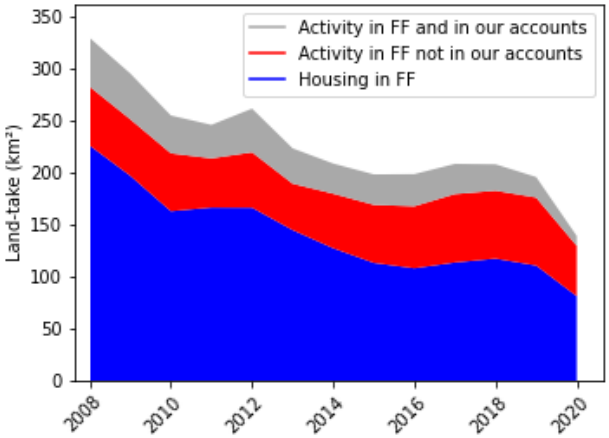
4.2.1 Undifferentiated land covers

When looking at the Fichier fonciers (FF) alone, the total flow of land take has been declining over the 2008-2020 period – these results are consistent with CEREMA.[19] Indeed, the total surface of land take went from around 325km² in 2008 (around 3.25 times the area of Paris) to around 200km² in 2019 and 150km² in 2020 (keeping in mind that the sharp decrease in 2020 is probably explained by Covid more than by "structural" change). Out of this total flow, in 2008, 69% were due to housing, against 31% to economic activity. This share increased until 2016, when it reached 46%, then declined to reach 42% in 2020. Therefore, over the period, the share of land take for economic activity was around 30-45% of total land take. This is larger than the share of built-up land use dedicated to economic activity over the same period (around 23-25%, see previous section). Finally, in our accounts, we can identify 45% of the total land take dedicated to economic activity in the FF database in 2008, a share which

[19] https://cartagene.cerema.fr/portal/apps/dashboards/9810991c73dd463191e84e7111a1b639

declines over the period to reach 16% in 2020 (see Annex for a possible explanation for this missing data, besides the poor geolocation quality of some establishments).

Figure 10: Evolution of land take by housing and economic activity (2008-2020)

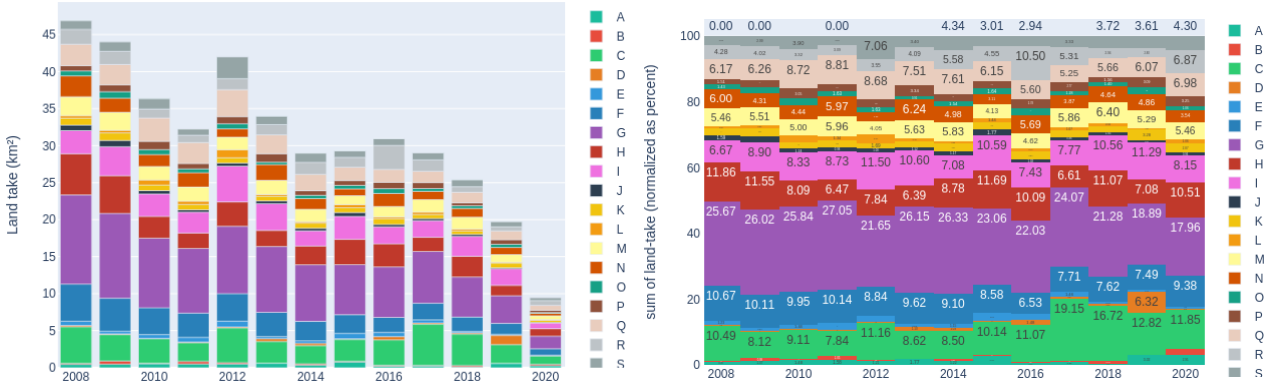


The first sector 'responsible' (see below) for land take is Wholesale and Retail Trade (sector G), although its contribution has been declining over the years (from representing in our accounts 25-30% of land take due to activity in the late 2000s to less than 20% in the late 2010s). Conversely, the Manufacturing sector (C) has seen its contribution to total land take increase over the period and reach up to 15-20% of the land taken by activity in our accounts in 2017-2018. Other significant contributors to land take include the construction sector (F) and the Accommodation and Food services sector (I). Note that in this paper, we define 'responsible' for land take the first users of the parcel after its construction. Therefore, this definition sets aside the fact that other sectors may also arrive on the parcel a few years after the first users. We test the sensitivity of our results in the Annex by defining several allocation options (e.g., by taking into account all the users over the first x years of the built parcel rather than the first users only) and find that our results do not vary much with the allocation mode, because most companies tend to remain a long time on the same parcel. However, note that besides the firms that use the buildings, other actors may be deemed responsible for taking the land, such as the local or central governments who have decided to grant building permits, or the construction sector that built the parcel and that draws revenues from such an activity. Because we focus on built-up land as a factor of production, our methodology does not allocate any responsibility for land take to these actors and focuses on land users. Nonetheless, depending on the research question, one may choose to proceed differently.

Figure 11: Sectors 'responsible' for land take

(a) In absolute terms (km²)

(b) In relative terms (%)

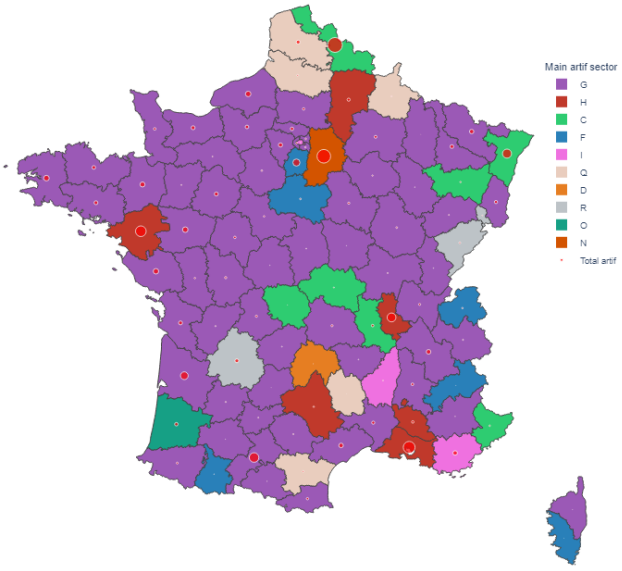


Overall, the sectors that are significant users of built-up land are also important contributors to land take. For some of them (e.g., Transport and Storage, Construction), their flow of land take in 2008 reached up to 4% of their built-up land use stock the same year. This figure tended to decline over the years, and in 2019, most sectors had a flow of land take amounting to around 1% of their built-up land use (see Figure A7 in Annex).

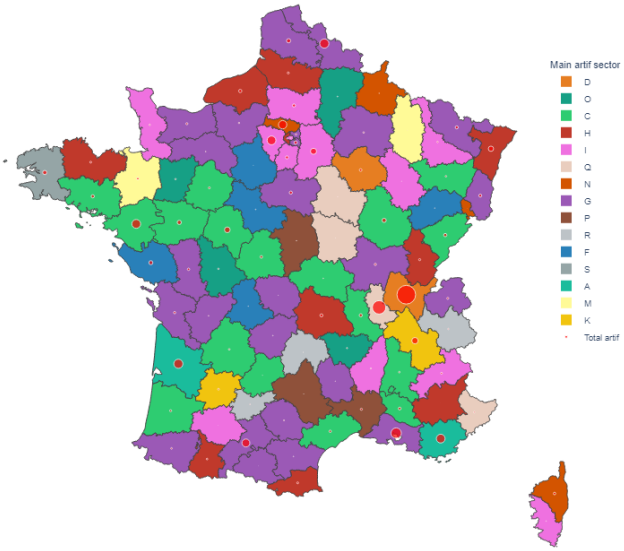
Finally, a spatial representation of the results by département shows that the primary sector responsible for land take can vary greatly depending on the local context and evolve with time. While the Wholesale and Retail Trade sector was the main contributor to land take by economic activity in most départements in 2008, the leading local 'land taker' has increasingly diversified. In 2019, the Trade, Manufacturing, and Accommodation and Food services sectors were more or less equally important contributors to land take. The regions where most of the land take due to economic activity occurred also changed over the period: while in 2008, the départements surrounding Paris were concentrating a large part of the expansion of urban areas, in 2019, the départements around the city of Lyon were the most critical contributors to land take by economic activities.[20]

Figure 12: Main sector taking land by département

(a) In 2008



(b) In 2019

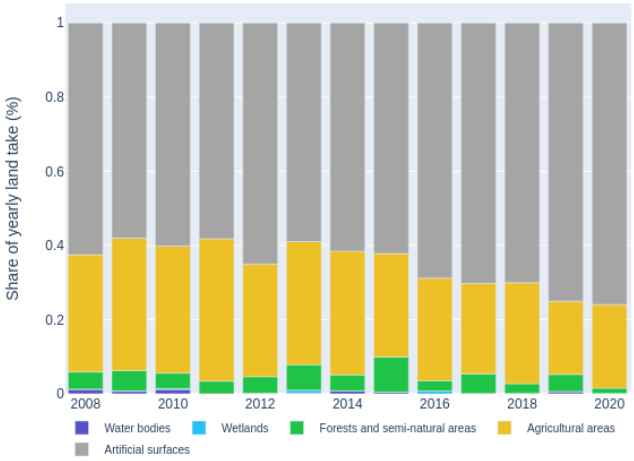


4.2.2 Differentiated land covers

We investigate further the land take by economic activities by looking at the type of land cover (forests, agriculture, urban, wetlands or waterbodies) that characterised the parcels in 2006, before the land take occurred – as our land take accounts start in 2008.

[20]Those results are consistent with the ones of Insee regarding land take for housing (https://www.insee.fr/fr/statistiques/7721436#titre-bloc-9).

Figure 13: Annual land take over 2008-2020, by type of land cover present on the parcel in 2006

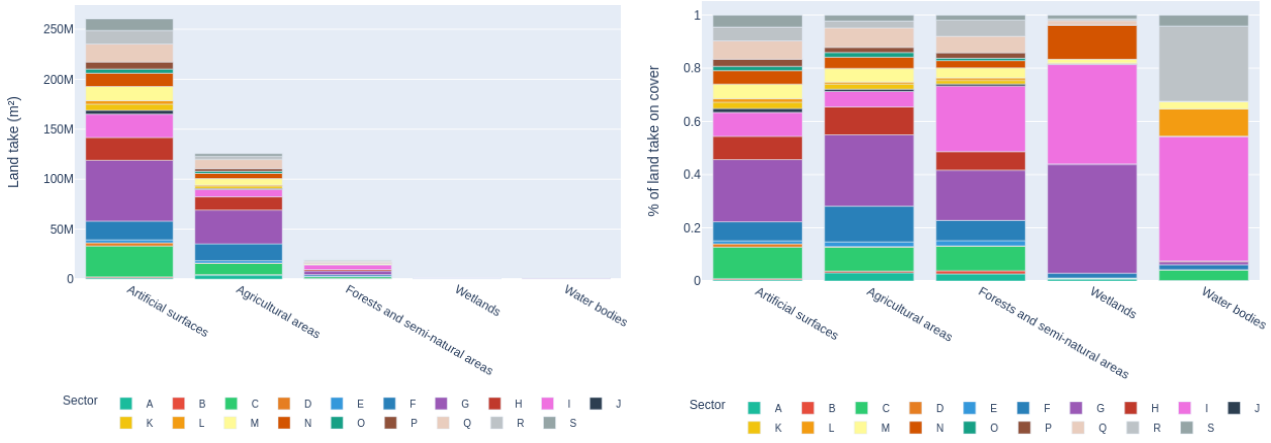


We find that, out of the approximately 200km² of land take due to activity between 2008 and 2020, around 30% consisted in the conversion of agricultural areas into built-up ones, 5% in the conversion of Forest and semi-natural areas, and less than 1% in the conversion of wetlands or water bodies (Figure 13). The results tend to indicate that while in the years 2009-2015, around 40% of the land take consisted in the conversion of agricultural, forest or semi-natural land into built-up land, this share seems to have declined since 2016 to reach around 25-30% in the years 2019-2020. A significant portion (more than 60%) of the land take by economic activity, therefore, appears to have occurred on parcels already 'artificial' in the CLC classification. However, this figure likely overestimates the land take occurring on already 'artificial' land due to the spatial scale mismatch between the FF and CLC datasets (see Method section). Indeed, the areas where land is classified as 'artificial' in CLC include parcels that were indeed 'artificial' (e.g., sealed ones), but also 'natural' parcels (e.g., meadows) surrounded by built parcels.

Figure 14: Sum of land take over the period 2008-2020 split by type of land cover in 2006 and sector

(a) In absolute terms

(b) In relative terms



The distribution of sectors varies greatly between the different types of 2006 land covers (Figure 14). Land take occurring on wetlands and water bodies predominantly comes from activities related to leisure and outdoor activities, such as Accommodation and Food services (sector I) or Arts, Entertainment and Recreation (sector R). However, these results are to be taken with a pinch of salt as land take on water bodies and wetlands represents a very small part of the total (hence, measurement errors would have a notable influence on the results). The land take due to activity that occurs in forest areas appears also caused to a large extent by the Accommodation and food services sector (e.g.,

campsite facilities). The Wholesale and Retail Trade, Construction, and Transportation and storage sectors mainly cause the land take occurring in agricultural areas.

These first results pointed to the heterogeneous responsibility of economic activities in urban expansion. In the next section, we explore how responsibility for land take can be translated (or not) into a vulnerability of economic sectors to policies that restrict land take.

5 Multi-criteria vulnerability assessment at a sector-level

We now use our new database, combined with additional sector-level data, to analyse the heterogeneous economic and financial vulnerability of sectors, possibly emerging from a scenario in which an ambitious implementation of the NNLT policy would increase real estate prices. We base our analysis on our decomposition of vulnerability as a combination of a shock, an exposure and an (in)ability to adapt, introduced in Section 2 (Figure 2).

5.1 Criteria for exposure and adaptive capacity

This section goes through the criteria and associated metrics we selected to assess economic sectors' exposure and adaptive capacity (summarised in Table A13). The Annex of the paper describes how those metrics are built and the detailed results by sector.

Table 2: Criteria and metrics for NNLT vulnerability assessment

. Stage in vulnerability assessment	Criteria	Metric (assessed by sector)
Exposure to price increases	Possibly more exposed to price increase if:	
	0. Sector's land take is considered as land take by the law	No; No for part of sector; Yes
	1. Expansion outside city boundaries	i. Conquistador; Recycler; Declining; over 2008-2019
		ii. Conquistador; Recycler; Declining; over 2016-2019
	2. Average establishment is a big user of land	Average built-up land use per establishment over 2008-2021*
	3. Increase in price of land not shared with other users	Share of low density parcels used*
	4. Land usually taken is more expensive and difficult to compensate	Share of land take on non-urban land over 2008-2020*
	5. Mostly renter of buildings	Share of firms not owning their buildings*
Adaptive capacity	Possibly less able to adapt if:	
	6. High dependency of production to built-up land use	Built-up land use/output*
	7. Densification of buildings is difficult	Share of low density parcels used*
	8. Rental expenses already make a significant portion of costs	Rental Expenses/Total Expenses*
	9. Financially less able to incur losses	i. Share of firms with LR>100%*
		ii. Share of firms with ICR<3*
	10. Relocating abroad is difficult	Belonging to Insee groups G1 or G2 – vs G3 or G4

'Exposure' criteria. We first check that the land take by the sector is indeed considered as land take in the law[21] (*criterion 0*). Second, we specify whether the sector, according to our data, has tended to expand outside cities ('conquistador' behaviour) rather than inside the already built-up area ('recycler' behaviour) – over the whole period covered by our accounts (2008-2019) and over the last year of the period (2016-2019) (*criterion 1*). Indeed, sectors that tend to expand through land-take rather than through locating in existing built-up land may be more exposed to the NNLT law (a small model explaining this intuition can be found in Annex). Third, we assess whether, on average, the establishments of the sector tend to require large built-up surfaces – as those large surfaces may become harder to find (*criterion 2*). Then, we explore whether sectors share their built-up land with other users, i.e. whether they are located in densely built areas (*criterion 3*). Those who do may be less affected by the increase in land prices, as the financial effort will be shared between the various users of the parcel. We also investigate the type of land usually taken by the sector (*criterion 4*), particularly whether the sector tends to expand on natural areas, e.g., for tourism purposes. Finally, the sectors that mostly rent their facilities will be more negatively affected by the possible increase in land prices (*criterion 5*). Conversely, those who own their buildings will see their wealth increase (see

[21]The land take by quarries and Mines is not defined as 'land take' in the law, notably because the sector is already subject to an obligation to restore its sites after operation ('Arrêté du 22 septembre 1994 relatif aux exploitations de carrières'). Under certain conditions, covering land with solar panels is also not considered 'land-take' ('LOI n° 2021-1104 du 22 août 2021' and 'Décret n° 2023-1096 du 27 novembre 2023 relatif à l'évaluation et au suivi de l'artificialisation des sols').

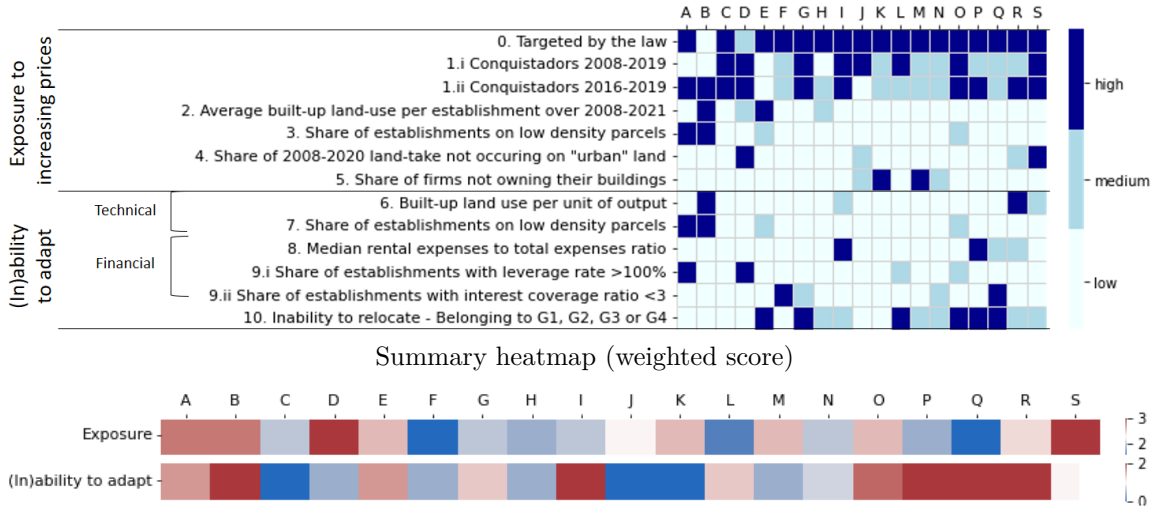
Fougère et al. (2017) who make the distinction between these two channels for French sectors). Note, however, that in sectors tending to own their buildings (e.g., Manufacturing, see Annex), newcomers may face difficulties in buying the land – i.e. they could face barriers to entry, while the 'incumbent' firms of the sector will be advantaged.

'Inability to adapt' criteria. We then explore sectors' technical, financial and locational ability to adapt. On the technical side, we first investigate the (current) dependency of production on built-up land by assessing the surface of built-up land used on average by the sectors to produce one unit of output (*criterion 6*). The idea is that having a land-intensive production may reflect a more substantial reliance of the production process on built-up land, which can make it more challenging to adapt. We then again use the built-up density of the parcels used by each sector to assess whether they can adapt by locating many of their establishments in multiple-floor buildings (*criterion 7*). On the financial side, we first look at the renters more precisely and at the share their rental expenses represent among their total expenses (*criterion 8*) – with the idea that if rents make up a large share of their expenses, they may be less able to absorb an increase in rents. We then look at the sectors' overall 'financial health' (using two metrics described in Annex: the leverage rate and the interest coverage ratio) to see whether they can afford possible cost increases (*criterion 9*). Finally, we explore the ability of sectors to adapt through a relocation abroad, using a typology developed by Insee and differentiating between sectors that can more easily migrate abroad (G3 and G4) and those that cannot (G1, and, to a lesser extent, G2) (*criterion 10*).

5.2 Results: Vulnerability analysis

Figure 15 provides the level of exposure or inability to adapt associated with each criterion, for each sector. Note that the assessment is not based on absolute terms but relative to other sectors.

Figure 15: Vulnerability assessment heatmap – By sector



Methodological/Lecture note: A 'high' (dark blue) level indicates that the criterion is an important contributor to vulnerability for the sector, as compared to other sectors. For a set of variables that appear with a star in Table A13, we choose to define a 'high' level as indicating that the sector is in the top 10% of sectors for the given variable and a 'medium' level as indicating that the sector is in the top 20% of sectors for the given variable. An alternative way to proceed can be found in Annex. The summary heatmap is then built by considering that 'high' = 1 and 'medium' = 2 and summing the scores for each sector (with the following weights for 1.i, 1.ii, 9.i and 9.ii: $\omega_{1.i} = 0.25$, $\omega_{1.ii} = 0.75$, $\omega_{9.i} = 0.5$, $\omega_{9.ii} = 0.5$*)*

Among the sectors most exposed and vulnerable to the NNLT policy, we find Mining and Quarrying (B), Agriculture (A), Food and Accommodation (I), Public Administration (O), Education (P) and Arts and entertainment (R). However, as mentioned above, Mining and Quarrying (B) has been

exempted from the policy by the law and should, therefore, face no direct vulnerability associated with the NNLT policy. Agriculture (A) and Accommodation and food services (I) sectors[22] are also exposed, and may face difficulties to adapt: for sector I, because of a relative inability to relocate abroad and a substantial dependency of output to built-up land use, notably located outside urban areas; for sector A, because of possibly fewer possibilities to locate in multiple-floor buildings. Some sectors producing (at least some) 'public goods', like Public administration (O), Education (P) and Arts and Entertainment (R), are particularly exposed and may find it more challenging to adapt, in particular, due to their local nature.[23] This may raise concerns and trade-offs for local and national governments.

By contrast, despite their sizeable use of built-up land and significant contribution to land take, Wholesale and Retail Trade (G) and Manufacturing (C) appear less vulnerable than expected. The Trade (G) subsectors have a rather good ability to adapt, even though some might have significant exposure to increasing land prices (in particular, Wholesale trade (46) – see subsector analysis in Annex). The explanation is quite similar for most Manufacturing subsectors, which own a large share of their facilities and may be able to relocate abroad – which may have important macroeconomic consequences. Nevertheless, a finer analysis of the sector is required: some subsectors in Manufacturing, like the Manufacture of wood (16), other non-metallic mineral products (23), fabricated metal products (25), or other machinery and equipment (28), seem both exposed and less able to adapt to an increase in real estate prices (see Annex).

6 Conclusion

The forthcoming policies aiming to limit human pressures on ecosystems and biodiversity pose new challenges to our economic systems. In France, reaching a 'No Net Land Take' (NNLT) target in 2050 may bear significant (positive or negative) and heterogeneous economic consequences, which we start investigating in this paper. We do so by constructing annual accounts of the use of built-up land (a stock) and land take (a flow) by each economic sector in France between 2008 and 2021. We then use this data to propose a multi-criteria assessment of vulnerability to the NNLT policy at the sector level.

Our new database first allows us to draw stylised facts regarding the use of built-up land and the land take by economic sectors in France. Attributing the 'responsibility' for land take to the first users of the new buildings, we find that the Wholesale and Retail Trade sector has been the main contributor to land take throughout the period, even though its absolute and relative impact has declined over time. It is followed by sectors like Manufacturing, whose land take increased over the period, Transportation and storage, and Accommodation and food services. The latter sector appears responsible for a significant part of the land take that occurred in semi-natural areas (forests, wetlands and water bodies), while most of the land take occurring in agricultural areas appears due to the Wholesale and Retail Trade, Construction, and Transportation and storage sectors. Second, this statistical work is a novel brick to understand how economic sectors use built-up land. Some sectors require substantial built-up areas, particularly Mining and Quarrying, Energy and Waste and Water, or subsectors like steel and cement manufacturing.

This data helps us analyse possible sectorial vulnerabilities induced by a particular 'severe but plausible' scenario of increasing land prices for firms due to NNLT. In particular, we use our sector-level historic trends of build-up land use to identify the sectors that rely heavily on land for their production and could be more affected if built-up land prices increase. We develop a multi-criteria analysis disentangling various vulnerability components using our database and complementary data

[22] Going more into the details of subsectors (see Annex) shows that, within sector I, for example, the Accommodation (55) subsector is particularly vulnerable (rather than the Food services (56) subsector).

[23] At the subsector level (see Annex, we find that this is more particularly the case for Public administration and defence, public social security (84), Residential care activities (87) and Sport activities and amusement and recreation activities (93).

sources, such as firms' balance sheets. The results suggest that the economic sectors most vulnerable to the 'no net land take' policy are Agriculture, and Accommodation and food services (and more particularly Accommodation), in particular due to the latter's apparent tendency to expand more on natural and semi-natural areas than other sectors. An additional finding is that some sectors producing public goods (like Public administration, Waste and water treatment, residential care, or leisure goods and services – which include some public services) could face limitations to their expansion and financial difficulties to cope with increasing land prices. This heralds the emergence of notable trade-offs in land allocation by public authorities. Finally, although some sectors seem more likely to be exposed to increasing land prices (such as Construction, Transportation and storage, or even Manufacturing), they appear somewhat able to adapt relatively to other sectors, thanks to financial or technical means. Nevertheless, firms may be able to hedge against the risk at the micro level at the cost of negative macroeconomic consequences, for example with the relocation of some activities outside of France, which should be further investigated.

The limitations of our analysis pave the way for future research. First, the other types of exposures to the NNLT policy should be explored – as this paper focuses only on exposure through the *use* of built-up land. In particular, one could explore how the law could also affect actors who currently benefit from the expansion of built-up land without necessarily using it, such as the construction sector (building the land), some municipalities (raising taxes from built-up land), and real-estate actors like funds, insurance companies or developers (possibly owning the land and earning income from it). Work is still needed to get a comprehensive macro-financial picture of the NNTL consequences, and our analysis contributes to this objective. Second, one could also explore the positive economic outcomes (or 'opportunities') that could emerge from the NNLT implementation, including the emergence of new sectors, as suggested by BenDor et al. (2015). Finally, one could further explore the different pressures economic activities apply to ecosystems through land use (e.g., see Albizzati et al. (2017)). For example, we know that some manufacturing activities affect soil functions via the pollutants they release, or that the transport sector uses roads – not accounted for in our analysis – that break ecological continuities. Such research would allow to refine our accounts in which land is either 'built' or 'not built', while the concrete impacts on ecosystems, especially soils, are overlooked.

Investigating the economic vulnerabilities to a policy may help envisage its broad set of consequences. In particular, it aims to anticipate better the forthcoming changes (e.g., incentivise economic sectors to change the way they use land, including through technical and organisational change), revealing possible trade-offs (e.g., for the financing of public goods requiring significant floor space) and triggering reflections on the possible tools and policies to support a reduction in the demand for built-up land (e.g., through mixed use of existing buildings or changes in preferences). As was already emphasised by John Stuart Mill more than 150 years ago (Mill, 1848), land is not infinite, and dealing with its scarcity should be of concern for economics today.

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7 Annexes

7.1 Data and Method – Supplementary material

7.1.1 Data treatment of Fichiers fonciers

The share of the parcel dedicated to activity, denoted σ_A, is obtained with the *dteloc* variable of FF at the facility level. For each parcel, we compute the share $\sigma_{A,2021}$ of the parcel dedicated to activity use in 2021, while $1 - \sigma_{A,2021}$ is the share dedicated to housing. As our method only relies on the last vintage of FF (2021), we can only know the share of the parcel usage that was dedicated to activity that year. Hence, we must assume that this share was fixed through time, i.e. that $\forall y, \sigma_{A,y} = \sigma_{A,2021} = \sigma_A$.

Computation of σ_A We compute σ_A by recovering the information on the type of use – housing or activity – of each facility located on the parcel. Denoting $\mathbb{1}_{A,f}$ a dummy equal to 1 if facility f on the parcel is dedicated to activity (i.e. *dteloc* is not equal to 1, 2 or 3, i.e. the local is not a house, a flat nor an outbuilding), and 0 otherwise, and denoting S_f the surface of facility f, we define the share of the parcel that is dedicated to activity as

$$\sigma_A = \frac{\sum_{l \in L} S_l \times \mathbb{1}_{A,l}}{\sum_{l \in L} S_l} \tag{3}$$

However, some facilities are used for activity purposes but have a surface that is set to zero or that is false, which leads to σ_A being missing or wrong. This is the case in particular for facilities dedicated to activity such as factories, which do not have to declare their surface. We are able to identify such facilities when the variable *ccoeva* is equal to "A". The way we redefine the shares σ_A when the activity surface of some facilities on the parcel is missing is described in table A1.

Table A1: Treatment of σ_A when parcels include an activity facility with null surface

Activity facilities with surface = 0	Activity facilities with surface ≠ 0	Housing facilities with surface ≠ 0	σ_A obtained	σ_A redefined	Share of parcels in this situation
Yes	No	No	NaN	1	
Yes	Yes	No	1	1	
Yes	No	Yes	Not NaN but False	1 if $\sigma_{ccoeva} \neq 0$, 0 otherwise	
Yes	Yes	Yes	Not NaN but False	1 if $\sigma_{ccoeva} \neq 0$, m otherwise	

where

$$m = \frac{\bar{s}_{activity}}{\bar{s}_{activity} + s_{housing}} \tag{4}$$

with

$$\bar{s}_{activity} = \frac{s_{activity}}{n_{activity,s\neq 0}} \times (n_{activity,s\neq 0} + n_{activity,s=0}) \tag{5}$$

Where s stands for the surface of the locals on the parcel, n for the number of locals on the parcel, and $\bar{s}$ is the new (recomputed) surface.

The second variable of interest is B, **the surface of the parcel that is built** (in 2021). We use the *dcntarti* variable of FF. When this variable is missing, we replace it with the surface of the entire parcel.

Finally, the last variable we collect from FF is j, **the year of construction of the first building on the parcel**. We define the (unique) year of land take, j, as the year when the first building of the parcel appears in the FF database (variable *jannatmin*). We therefore assume that the whole

built surface observed in 2021 on the parcel was built at year j, instead of the construction on the parcel being spread through time, from year j up to 2021. When the construction year of the parcel is unknown (*jannatmin* equals 0), we replace it by 2003. Indeed, a 2003 reform made the declaration of construction years compulsory, hence all parcels without a construction year were built before that year.

7.1.2 Data treatment of Sirene

In the database of historical establishments, multiple lines can correspond to the same establishment. Indeed, each change in the establishment information (on its sector of activity, on whether it hires workers of not, etc.) creates a new line. We keep only the establishments during their "active" lifetime, i.e. we remove the lines representing establishments once they are closed (however, we keep the lines representing the same establishment at times when they were open). We then aggregate the information to keep only one line by establishment: for all the establishment variables, we keep the most recent information, except for the opening date for which we keep the oldest one.

From the database of establishment obtained, we remove all the establishments with an activity code "NAP". We also remove those with a bad quality geolocation (i.e. with a quality code different from 11 in the Sirene database, indicating that the street number, the street or the city are unknown). As creating a firm is quite easy to do, especially in France, we restrict our sample to establishment hiring at least one person in order to keep only "productive" firms with a real activity. Finally, as we want to know which firm was active each year, we remove the establishment whose opening date is unknown (with an opening date equal to 01/01/1900).

Table A2: Descriptive statistics after filtering steps

Samples (siret in SIRENE database, open at least one year between 2008 and 2020 included)	Number of siret	Share of Initial sample	Share of previous sample
Initial (SIRENE database)	20 928 917	100,0%	—
Initial – Filtered for employers only	4 562 496	21,8%	21,8%
Initial – All filters*	3 826 585	18,3%	83,9%
Initial – All filters* – After spatial joint	3 440 169	16,4%	89.9%

Table A3: Employer status of establishments in initial sample

Employer status of establishment	Share of siret in sample Initial
No	78,19%
Yes	21,80%

Table A4: Geolocation quality of establishments in initial sample

Quality of geolocation	Share of siret in sample Initial
11.0 – No uncertainty on street, streetnumber found	80,40%
12.0 – No uncertainty on street, streetnumber not found	9,41%
21.0 – Uncertainty on street, streetnumber found	2,05%
22.0 – Uncertainty on street, streetnumber not found	1,50%
33.0 – Unknown street, random position in city	5,41%

Table A5: Sector nomenclature of establishments in initial sample

Nomenclature of establishment's sector	Share of siret in sample Initial
NAFRev2	99,9969%
NAF1993	0,0010%
NAFRev1	0,0006%
NAP	0,0001%

Table A6: Opening dates of establishments in initial sample

Opening date of the establishment	Share of siret in sample Initial
Unknown (1900-01-01)	0,72%
Known (not 1900-01-01)	99,28%

Figure A2: Comparison between samples by years for which establishment are open

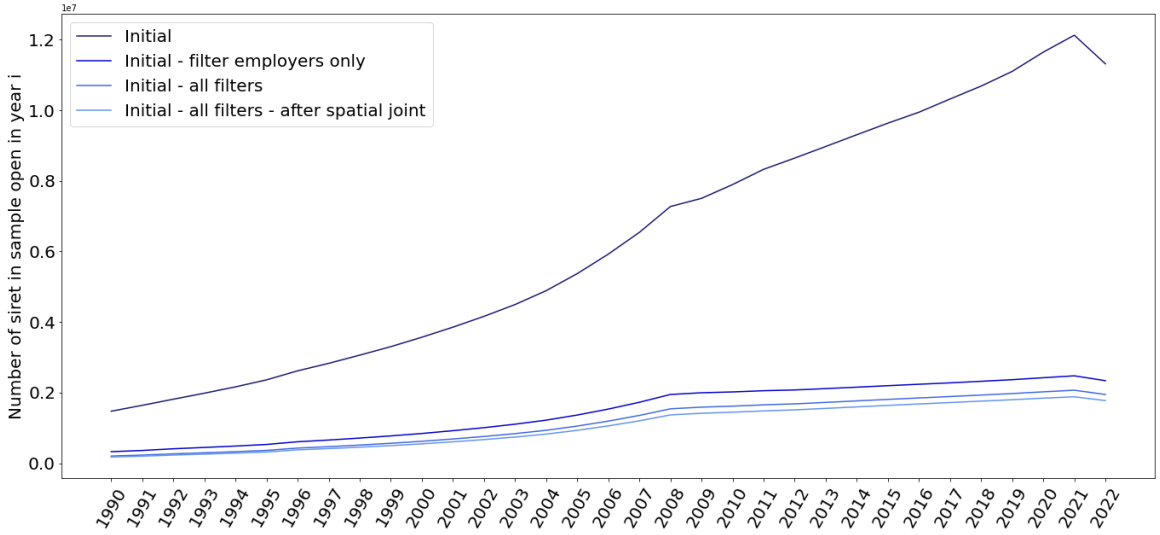
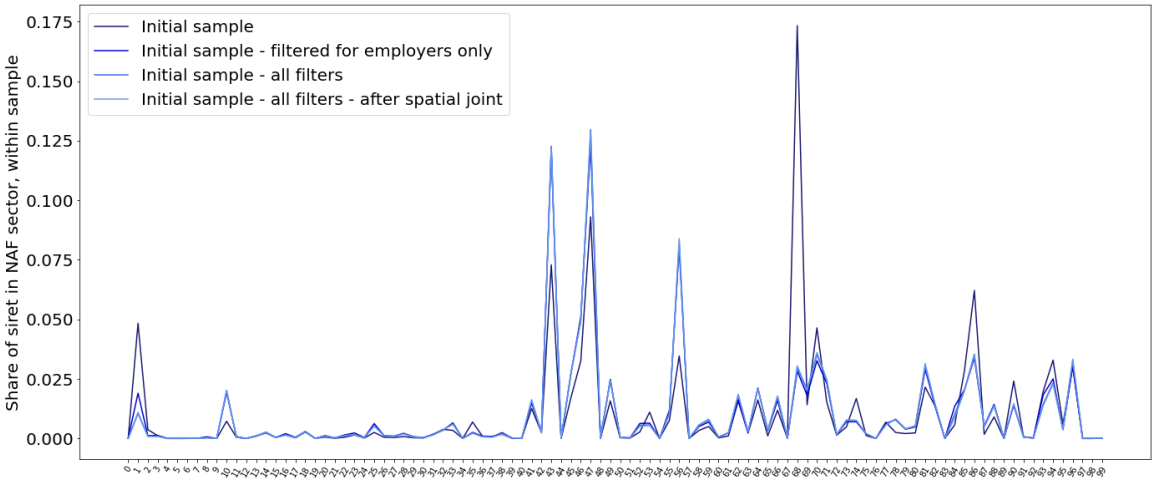


Figure A3: Comparison between samples by sectors



7.1.3 Spatial matching procedure

Spatial matching of FF and Sirene

Spatial matching is done with the geopandas nearest_joint() function in Python. Before the matching procedure, we removed the unbuilt parcels from the FF, I.e. those with *jannatmin*=-1.

One issue we face is that many establishments are matched with a parcel with no activity facilities in 2021 (i.e. $\sigma_A = 0$). Hence, we modify σ_A to avoid "erasing" such establishments from the accounts. For those parcels, we therefore chose to define σ_A the following way:

$$\sigma_A = \frac{1}{f+1} \tag{6}$$

where f is the number of (housing) facilities on the parcel. In addition, we also find that some establishments were open before the date when the parcel they are matched to was built. One reason may be that the establishment is legally created before the activity actually starts. In such situations, we define a new opening date for the establishment, equal to the date when the parcel was built (*jannatmin*).

Spatial matching with Corine Land Cover

To obtain the main land cover on the parcel before it was built, we operate a spatial overlay (using geopandas overlay() function) between CLC (2006 vintage) and the parcels in FF.

7.1.4 Building the land-use accounts

Let j be the year when a building on the parcel is observed for the first time in the Fichier fonciers (*jannatmin* variables), let y be the year observed, and Y the last year of the Fichiers fonciers vintage (2021). Let $\sigma_{s,y}$ be the share of the parcel used by sector s in year y and $\sigma_{A,y}$ be the share of the parcel used for the purpose of economic activity in year y. $n_{s,y}$ is the number of firms from sector s on the parcel in year y. We have that, for a given parcel i:

$$\sigma_{s,y,i} = \sigma_{A,i} \times \frac{n_{s,y,i}}{\sum_{s \in S} n_{s,y,i}} \tag{7}$$

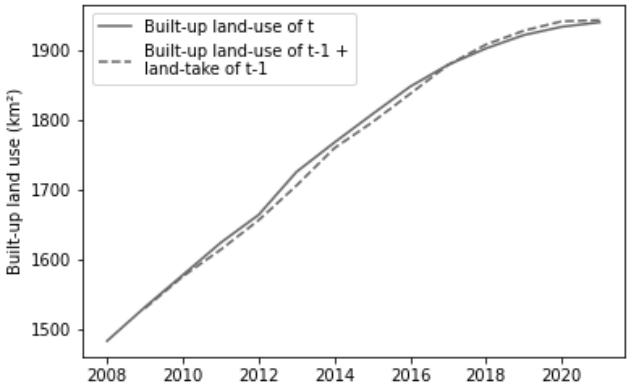
Denoting i a parcel, B_i the built-up surface of the parcel, $\sigma_{A,i}$ the share of the parcel dedicated to activity uses, $n_{s,y,i}$ the number of establishments for sector s on parcel i in year y, the use of built-up land by sector s in year y can be written:

$$B_{y,s} = \sum_i \sigma_{s,y,i} \times B_i \tag{8}$$

7.1.5 A test on the results: comparing land use (stock) and land take (flow)

The flow of land take we find for all economic sectors in aggregate is consistent with the evolution of the stock of built-up land use by economic sectors described in the previous section. Indeed, we do obtain that, at year t, the flow of land take we attribute to economic activities is approximately equal to the difference between the built-up land at year t+1 and the built-up land at year t (Figure A4).

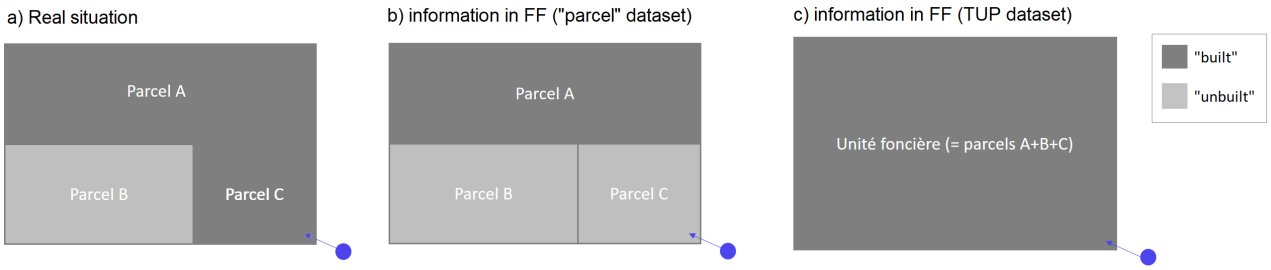
Figure A4: Comparison between built-up land use (stock) and land take (flow) in our accounts



7.1.6 A possible way to increase coverage of the accounts

Our accounts, resulting from the matching of parcels (Fichiers fonciers) with firms' establishments (Sirene), cover only part of the built-up parcels dedicated to activity according to the Fichiers fonciers. One possible explanation for that, which we need to explore further, is the following. When one actor (e.g. a firms or person) owns multiple parcels that are close together, he or she fills a tax receipt at the "unité foncière" level, which groups all the parcels together. Then, in the FF database, this information is allocated to the biggest parcel in the unité foncière.

Figure A5: A possible matching issue to explore



Therefore, if in reality, parcel C is built and used by the blue establishment (Figure A5 a), the FF database will only provide the information at parcel A level, which is the biggest one in the Unité foncière, while we won't have any information for parcels B and C and consider the latter as not built. Therefore, our methodology will match the establishment to parcel A (the closest built-up parcel in the FF data) but will then remove it because the distance between the establishment and parcel A is too large (Figure A5 b). One way of regaining information is to use another FF dataset, at the Unité foncière level (Figure A5 c). This will conversely tend to overestimate the built-up surface used by the establishment, as the latter would be matched with the whole unité foncière. Such sensitivity analysis is ongoing work.

7.2 Results

7.2.1 Sensitivity of land-take accounts to the responsibility allocation rule

- Option 1: the flow of land take occurring at year $j-1$ is split between the users of the parcel at year j, i.e. the year just after the flow of land take occurred. For a given parcel, we would have:

$$A_{(j-1),s} = \sigma_{s,j} \times B \tag{9}$$

- Option 2: the flow of land take is split between the users of the parcel at year j, j+1, ..., j+m, i.e. the (m+1) years after the flow of land take occurred. For a given parcel, we would have:

$$A_{(j-1),s} = \sum_{y=j}^{(j+m)} \frac{\sigma_{s,y}}{(m+1)} \times B \tag{10}$$

- Option 3: the flow of land take is split between the users of the parcel during all the life of the built parcel, i.e. the (Y-j+1) years after the flow of land take occurred. For a given parcel, we would have:

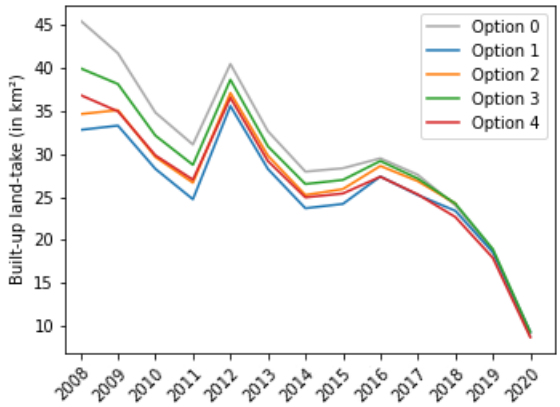
$$A_{(j-1),s} = \sum_{y=j}^{Y} \frac{\sigma_{s,y}}{Y-j+1} \times B \tag{11}$$

- Option 4: same as option 3, but we give more weights to the first users than to the last ones. For a given parcel, we would have:

$$A_{(j-1),s} = \sum_{y=j}^{Y} (\sigma_{s,y} \times \omega_{y,j-1}) \times B \tag{12}$$

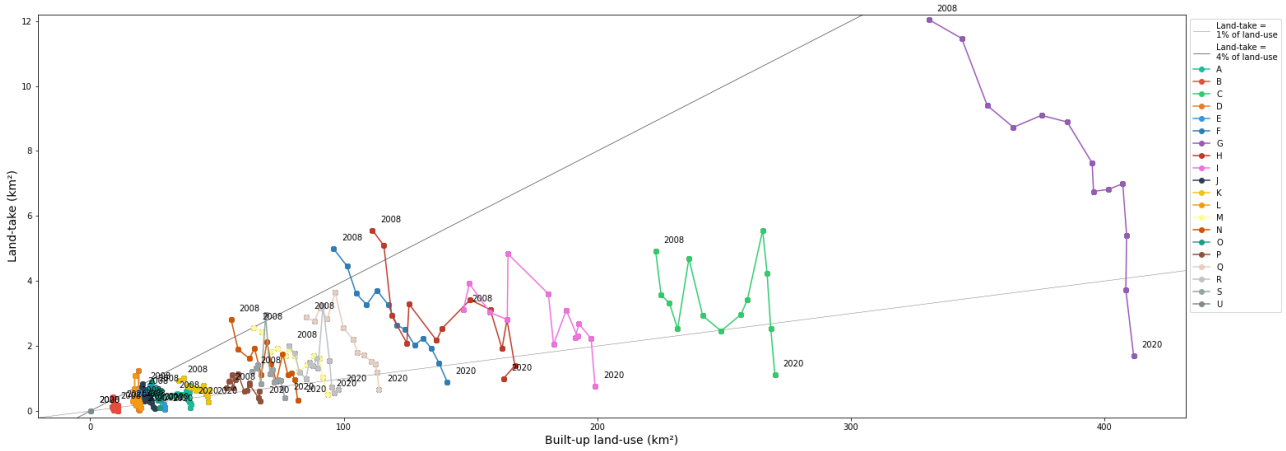
With $\omega_{y,j-1} = \frac{f(y)}{\sum_{k=j-1}^{Y} f(k)}$, where f is a decreasing function of y.

Figure A6: Sensitivity of land take results to allocation rule



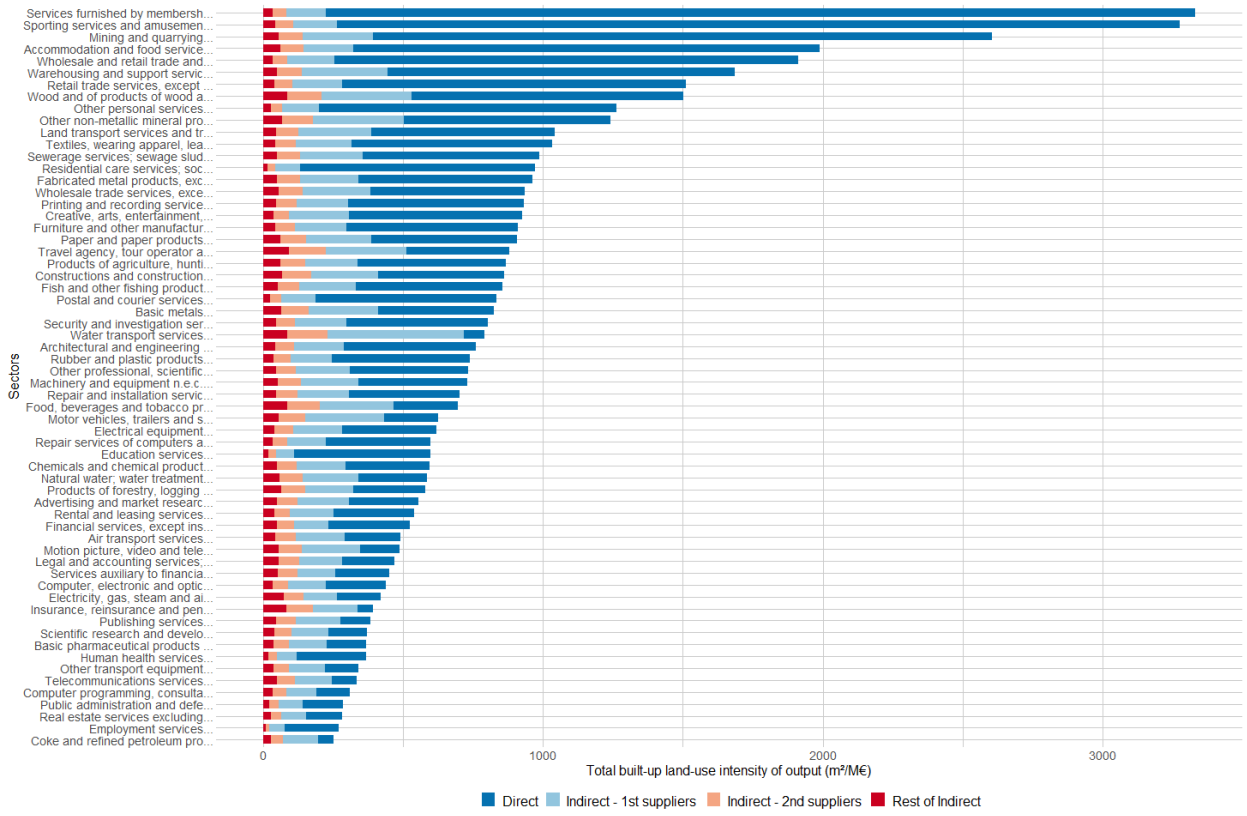
7.2.2 Additional graph: comparing flows and stocks

Figure A7: land take (flow) vs land use (stock)



7.2.3 Footprint analysis

Figure A8: Footprint intensity of value added in 2018



Using a Leontief matrix obtained with a Eurostat Input-output table for France in 2018, we can obtain the total – direct and indirect – use of built-up land per unit of output (Figure A8). We find that some sectors with a relatively low *direct* intensity of value added in terms of built-up land-use have a

large indirect use of built-up land use: this is the case in particular for water transport services, or, to a lesser extent, food, beverages and tobacco products. Note that the sectors used for this graph are those of the Eurostat IO table and are close what we called "subsectors" (i.e., NAF Rev. 2 2-digit sectors).

7.2.4 Some results at the NAF 3-digits level

Figure A9: Built-up land use of Subsectors in sector C

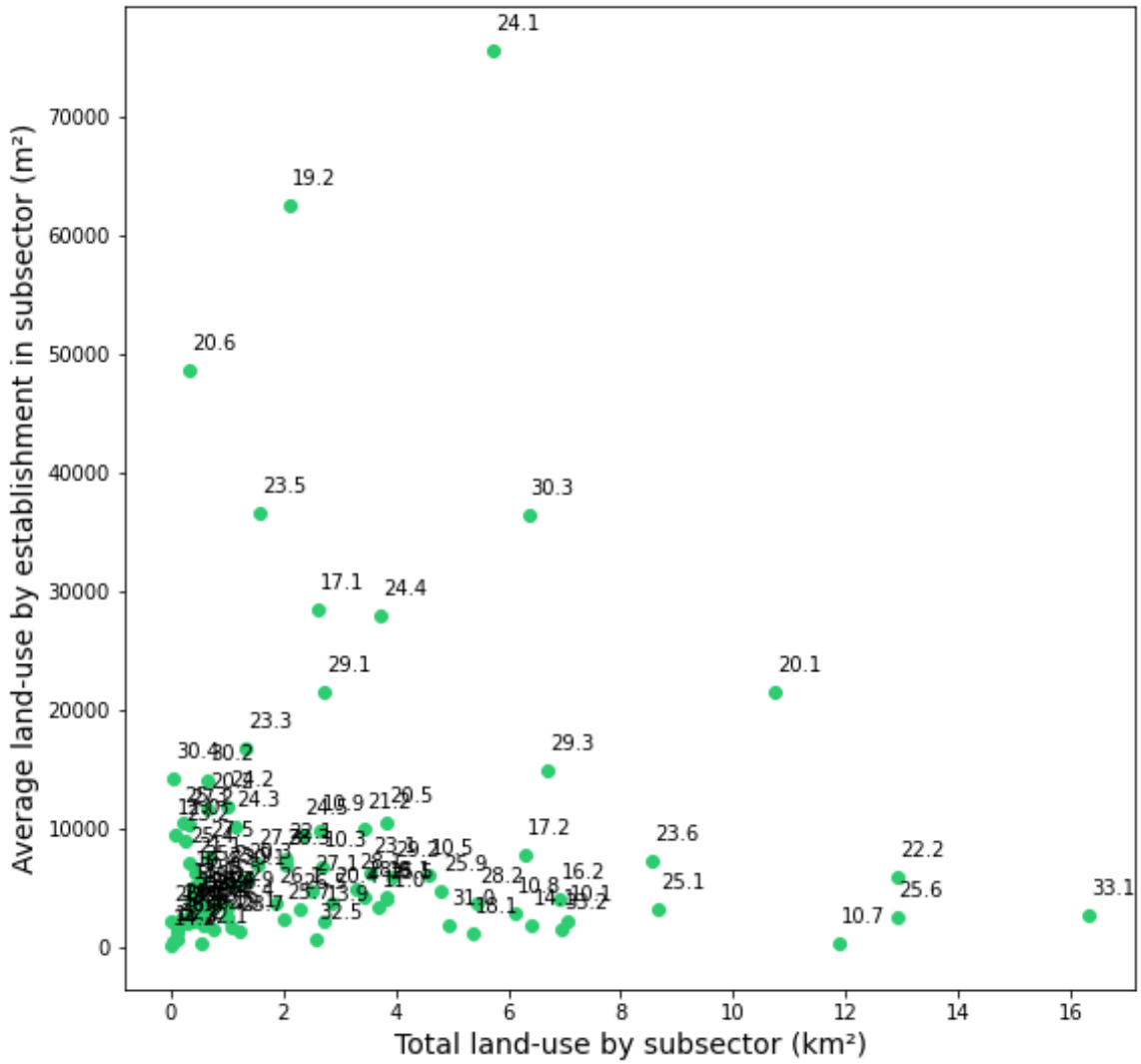


Table A7: Subsectors in sector C

10.1 Processing and preserving of meat and production of meat products
10.2 Processing and preserving of fish, crustaceans and molluscs
10.3 Processing and preserving of fruit and vegetables
10.4 Manufacture of vegetable and animal oils and fats
10.5 Manufacture of dairy products
10.6 Manufacture of grain mill products, starches and starch products
10.7 Manufacture of bakery and fariNAFous products
10.8 Manufacture of other food products
10.9 Manufacture of prepared animal feeds
11.0 Manufacture of beverages
12.0 Manufacture of tobacco products
13.1 Preparation and spinning of textile fibres
13.2 Weaving of textiles
13.3 Finishing of textiles
13.9 Manufacture of other textiles
14.1 Manufacture of wearing apparel, except fur apparel
14.2 Manufacture of articles of fur
14.3 Manufacture of knitted and crocheted apparel
15.1 Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur
15.2 Manufacture of footwear
16.1 Sawmilling and planing of wood
16.2 Manufacture of products of wood, cork, straw and plaiting materials
17.1 Manufacture of pulp, paper and paperboard
17.2 Manufacture of articles of paper and paperboard
18.1 Printing and service activities related to printing
18.2 Reproduction of recorded media
19.1 Manufacture of coke oven products
19.2 Manufacture of refined petroleum products
20.1 Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
20.2 Manufacture of pesticides and other agrochemical products
20.3 Manufacture of paints, varnishes and similar coatings, printing ink and mastics
20.4 Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
20.5 Manufacture of other chemical products
20.6 Manufacture of man-made fibres
21.1 Manufacture of basic pharmaceutical products
21.2 Manufacture of pharmaceutical preparations
22.1 Manufacture of rubber products
22.2 Manufacture of plastic products
23.1 Manufacture of glass and glass products
23.2 Manufacture of refractory products
23.3 Manufacture of clay building materials
23.4 Manufacture of other porcelain and ceramic products
23.5 Manufacture of cement, lime and plaster
23.6 Manufacture of articles of concrete, cement and plaster
23.7 Cutting, shaping and finishing of stone, 23.9 Manufacture of abrasive products and non-metallic mineral products n.e.c.
24.1 Manufacture of basic iron and steel and of ferro-alloys
24.2 Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
24.3 Manufacture of other products of first processing of steel
24.4 Manufacture of basic precious and other non-ferrous metals
24.5 Casting of metals
25.1 Manufacture of structural metal products
25.2 Manufacture of tanks, reservoirs and containers of metal
25.3 Manufacture of steam generators, except central heating hot water boilers
25.4 Manufacture of weapons and ammunition
25.5 Forging, pressing, stamping and roll-forming of metal; powder metallurgy
25.6 Treatment and coating of metals; machining
25.7 Manufacture of cutlery, tools and general hardware
25.9 Manufacture of other fabricated metal products
26.1 Manufacture of electronic components and boards
26.2 Manufacture of computers and peripheral equipment
26.3 Manufacture of communication equipment
26.4 Manufacture of consumer electronics
26.5 Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks
26.6 Manufacture of irradiation, electromedical and electrotherapeutic equipment
26.7 Manufacture of optical instruments and photographic equipment
26.8 Manufacture of magnetic and optical media
27.1 Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
27.2 Manufacture of batteries and accumulators
27.3 Manufacture of wiring and wiring devices
27.4 Manufacture of electric lighting equipment
27.5 Manufacture of domestic appliances
27.9 Manufacture of other electrical equipment
28.1 Manufacture of general-purpose machinery
28.2 Manufacture of other general-purpose machinery
28.3 Manufacture of agricultural and forestry machinery
28.4 Manufacture of metal forming machinery and machine tools
28.9 Manufacture of other special-purpose machinery
29.1 Manufacture of motor vehicles
29.2 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
29.3 Manufacture of parts and accessories for motor vehicles
30.1 Building of ships and boats
30.2 Manufacture of railway locomotives and rolling stock
30.3 Manufacture of air and spacecraft and related machinery
30.4 Manufacture of military fighting vehicles
30.9 Manufacture of transport equipment n.e.c.
31.0 Manufacture of furniture
32.1 Manufacture of jewellery, bijouterie and related articles
32.2 Manufacture of musical instruments
32.3 Manufacture of sports goods
32.4 Manufacture of games and toys
32.5 Manufacture of medical and dental instruments and supplies
32.9 Manufacturing n.e.c.
33.1 Repair of fabricated metal products, machinery and equipment
33.2 Installation of industrial machinery and equipment

Figure A10: Built-up land use of Subsectors in sector G

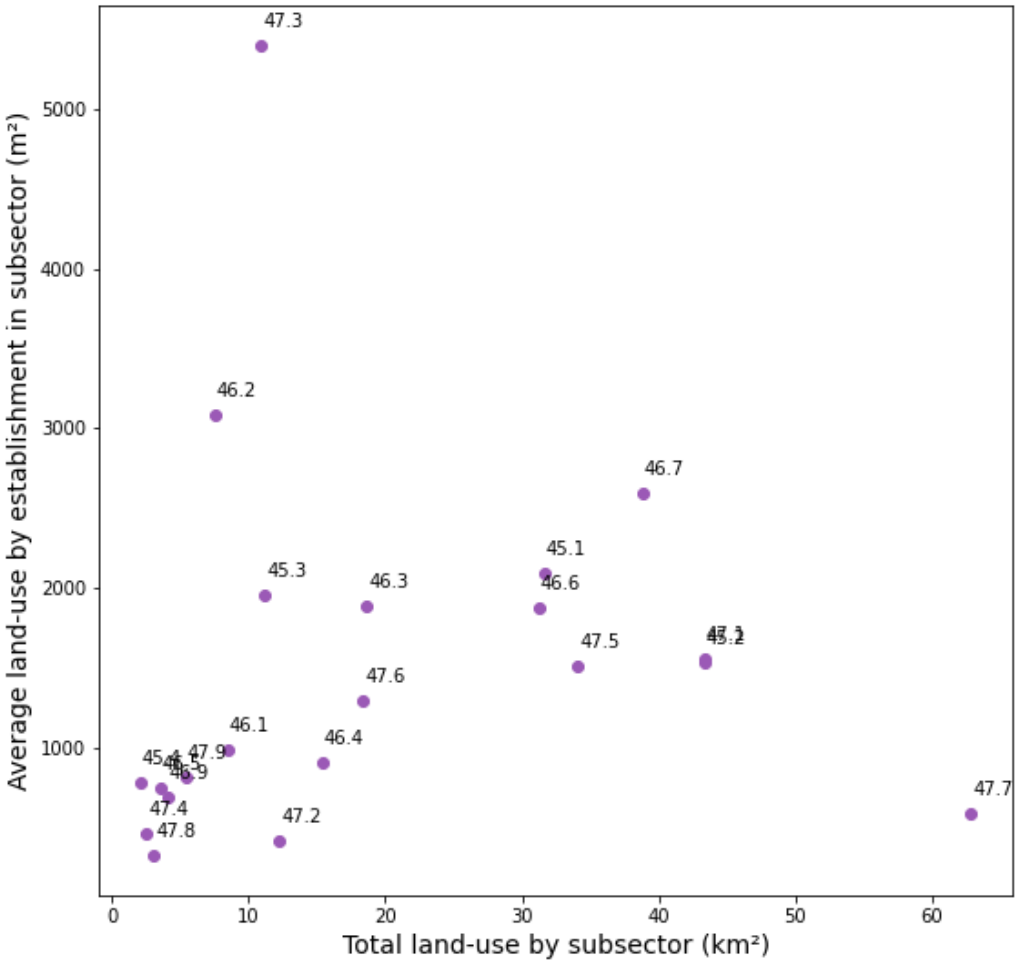


Table A8: Subsectors in sector G

45.1 Sale of motor vehicles
45.2 Maintenance and repair of motor vehicles
45.3 Sale of motor vehicle parts and accessories
45.4 Sale, maintenance and repair of motorcycles and related parts and accessories
46.1 Wholesale on a fee or contract basis
46.2 Wholesale of agricultural raw materials and live animals
46.3 Wholesale of food, beverages and tobacco
46.4 Wholesale of household goods
46.5 Wholesale of information and communication equipment
46.6 Wholesale of other machinery, equipment and supplies
46.7 Other specialised wholesale
46.9 Non-specialised wholesale trade
47.1 Retail sale in non-specialised stores
47.2 Retail sale of food, beverages and tobacco in specialised stores
47.3 Retail sale of automotive fuel in specialised stores
47.4 Retail sale of information and communication equipment in specialised stores
47.5 Retail sale of other household equipment in specialised stores
47.6 Retail sale of cultural and recreation goods in specialised stores
47.7 Retail sale of other goods in specialised stores
47.8 Retail sale via stalls and markets
47.9 Retail trade not in stores, stalls or markets

Figure A11: Built-up land use of Subsectors in sector H

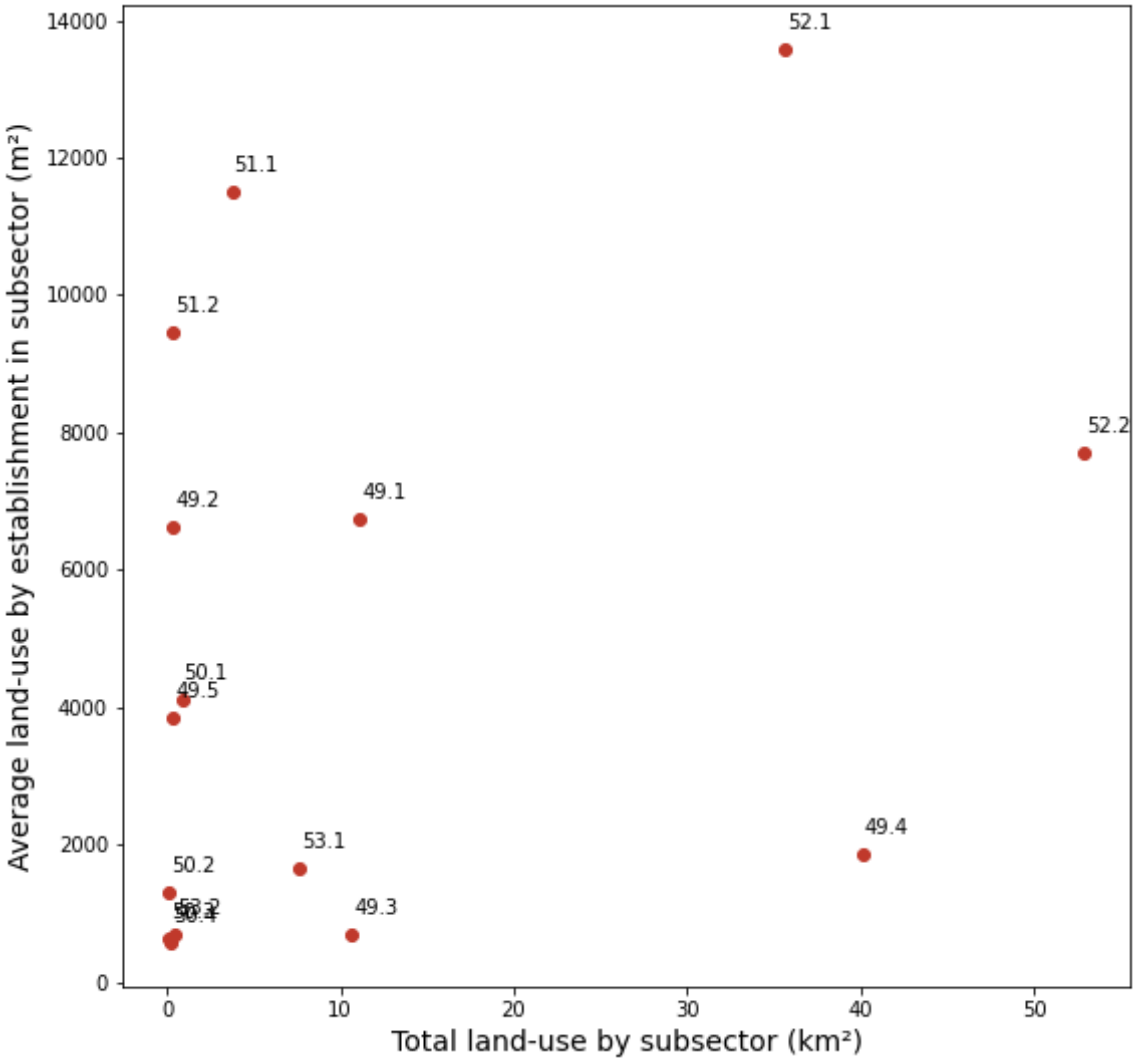


Table A9: Subsectors in sector H

49.1 Passenger rail transport, interurban
49.2 Freight rail transport
49.3 Other passenger land transport
49.4 Freight transport by road and removal services
49.5 Transport via pipeline
50.1 Sea and coastal passenger water transport
50.2 Sea and coastal freight water transport
50.3 Inland passenger water transport
50.4 Inland freight water transport
51.1 Passenger air transport
51.2 Freight air transport and space transport
52.1 Warehousing and storage
52.2 Support activities for transportation
53.1 Postal activities under universal service obligation
53.2 Other postal and courier activities

Figure A12: Built-up land use of Subsectors in sector I

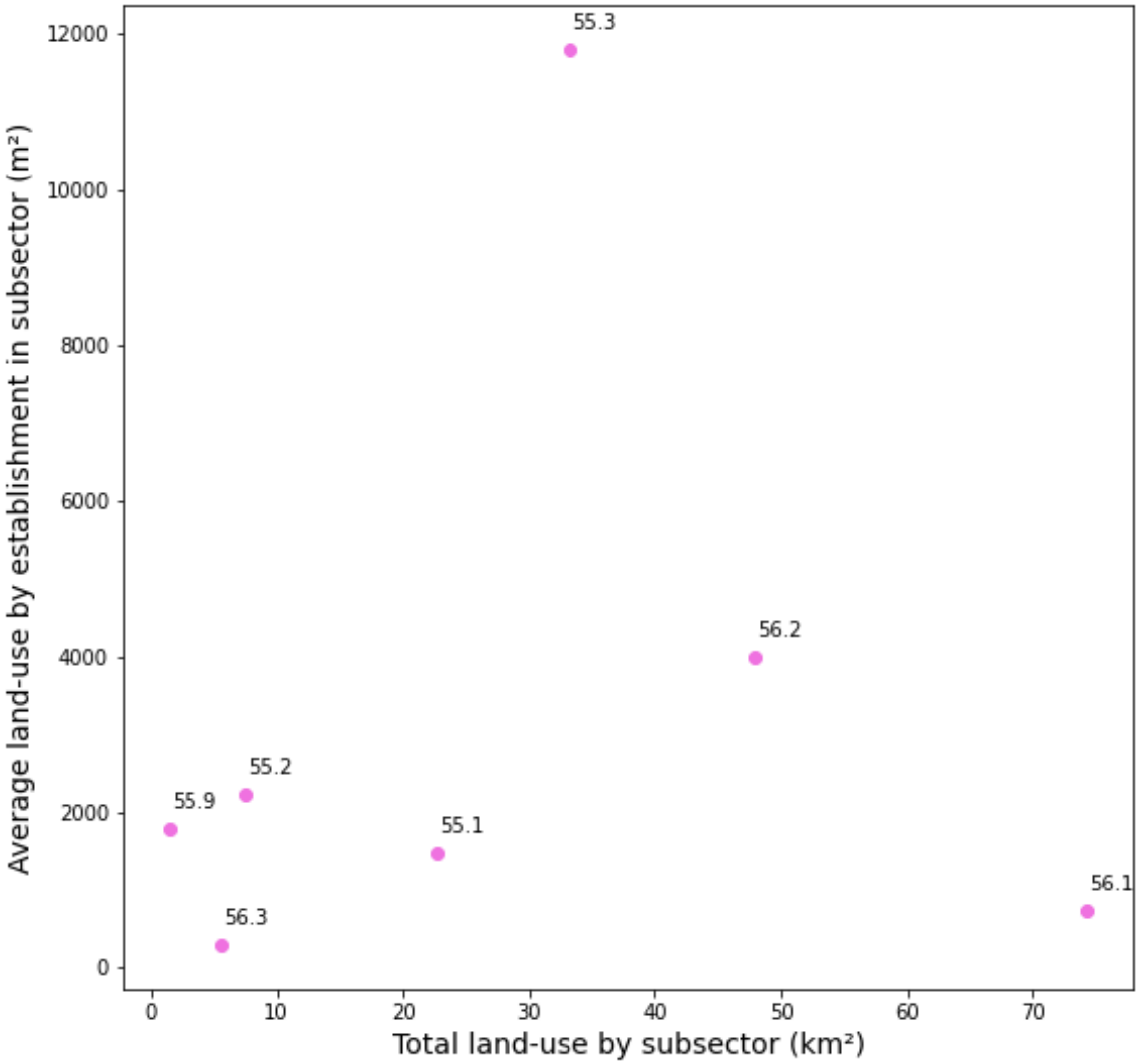


Table A10: Subsectors in sector I

55.1 Hotels and similar accommodation
55.2 Holiday and other short-stay accommodation
55.3 Camping grounds, recreational vehicle parks and trailer parks
55.9 Other accommodation
56.1 Restaurants and mobile food service activities
56.2 Event catering and other food service activities
56.3 Beverage serving activities

Figure A13: Built-up land use of Subsectors in sector R

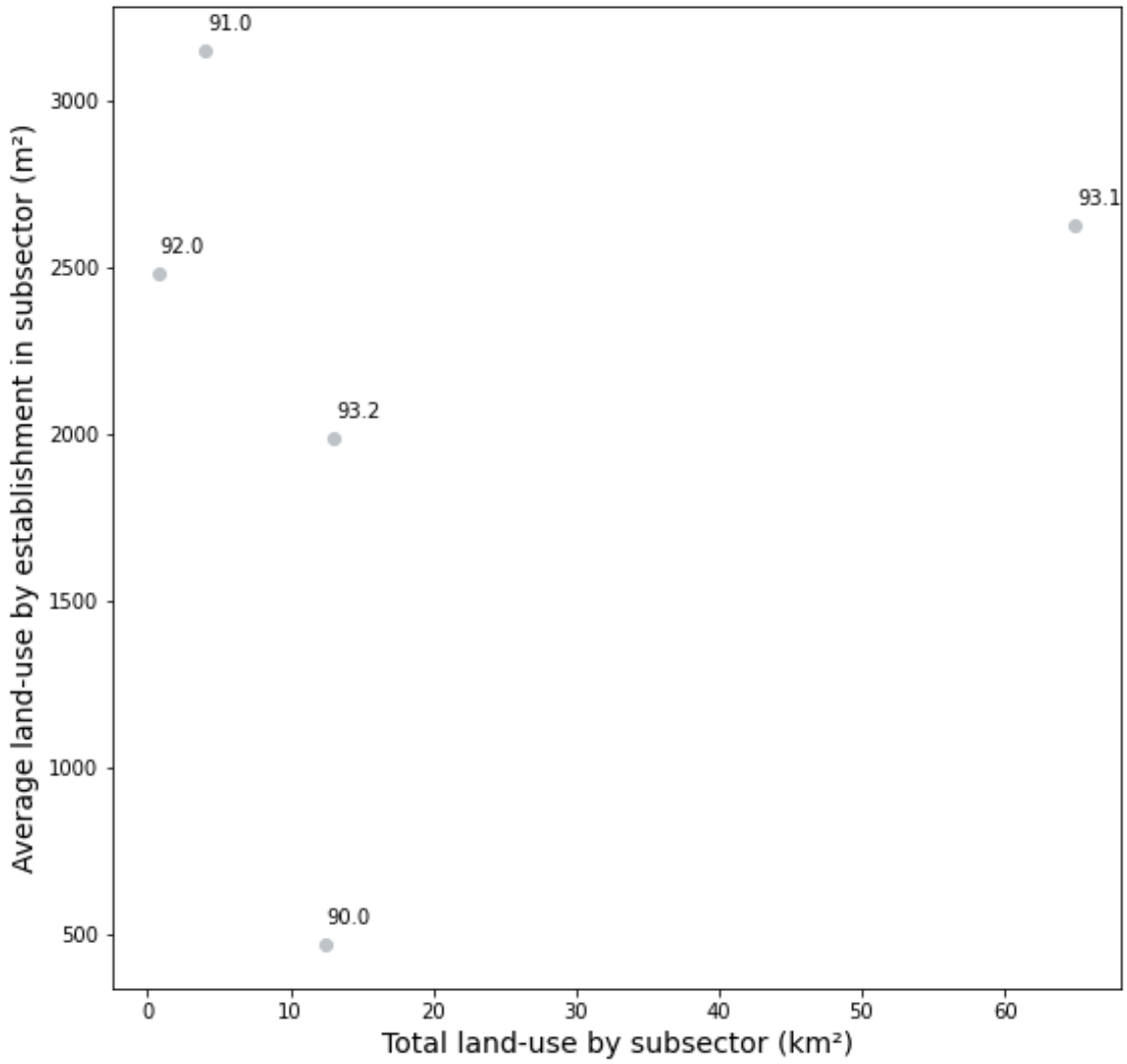


Table A11: Subsectors in sector R

90.0 Creative, arts and entertainment activities
91.0 Libraries, archives, museums and other cultural activities
92.0 Gambling and betting activities
93.1 Sports activities
93.2 Amusement and recreation activities

7.3 Vulnerability analysis

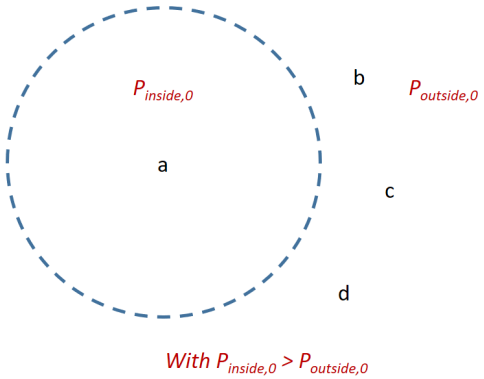
7.3.1 A small model of heterogeneous exposure to price increases

Let us split the urban area in two parts: the “inside” and the “outside” (where land take occurs). The inside is more dense, and more expensive, as most firms want to locate near the center to benefit from agglomeration economies. Conversely, the outside is less expensive ($P_{inside} > P_{outside}$) and less dense, and contributes to land take. Let us assume we have different types of firms. (a) "Well-off office firms", locate inside, because they have the technical ability to do it, and it is worth it financially as they benefit for agglomeration and they have the ability to afford rather expensive buildings. (b) "Low-cost office firms", locate outside: they would have the technical ability to be inside, as offices can locate in multiple floor buildings in dense area, but they financially prefer to locate outside as they usually do not benefit enough from agglomeration economies. Locating inside would therefore only have a cost for them, due to higher real estate prices, but no benefits. (c) "Well-off trade warehouses", locate outside: they would have a rather good financial ability to pay for high rents to locate inside cities but it is more profitable to locate outside to benefit from road network and because they need large surfaces on one-floor buildings to store their products. However, they would have the ability to adapt to multiple-floor buildings if incentivised to, through longer-term technical change. (d) "Poor Factories", locate outside: they don’t have the financial ability to locate inside cities nor the technical capacity, as they need to use large surfaces on one-floor buildings. They are not really able to adopt technical change allowing then to produce on multiple floor buildings. The initial situation before the introduction of the NNLT policy is described in Figure A14.

Table A12: Typology of firms

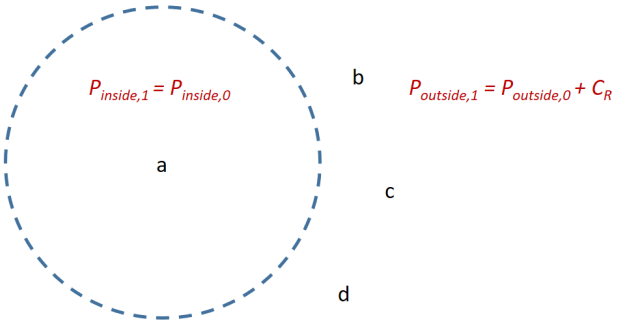
		Financial difficulty to be inside cities	
		–	+
Technical difficulty to be inside cities	–	a – Well-off offices firm	b – Low-cost offices firm
	+	c – Low-cost trade Warehouse firm	d – Poor factory

Figure A14: Step 0: ’equilibrium’ before NNLT policy



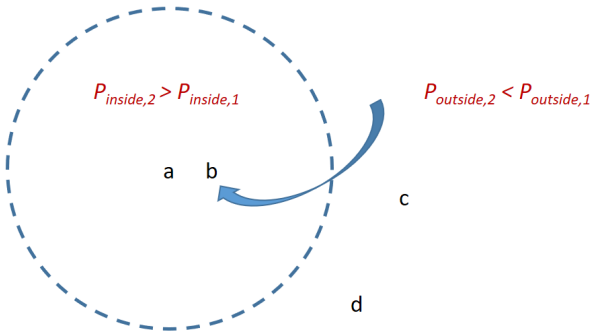
With the introduction of the NNLT policy, the construction of new building outside the city decreases and/or new buildings face compensation costs (C_R), so overall $P_{outside}$ increases (Figure A15.)

Figure A15: Step 1: Introduction of NNLT policy



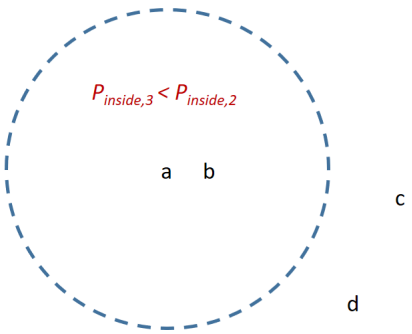
Firms of type b can rather easily move inside the city, as it faces no technical difficulty to do so and as this option becomes more profitable. Consequently, the demand for buildings outside the city decreases, and so does $P_{outside}$, while P_{inside} increases due to higher demand for locating inside the city and no increase in the supply of buildings inside (Figure A16).

Figure A16: Step 2: Migration of b-type firms



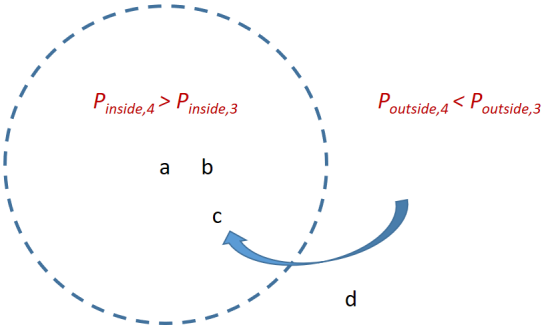
Then, the supply of buildings inside the city can more or less increase (densification process, depending on densification costs), which will decrease P_{inside}. However, as this densification process implies the construction of multiple-floor buildings – or adding floors to existing buildings –, firms of type c and d cannot easily migrate inside due to technical constraints. Eventually, there is therefore a gap that remains between P_{inside} and $P_{outside}$ (no full convergence process). This gap depends on the densification (affecting the supply of buildings inside the city) and restoration costs (affecting the supply of buildings outside the city).

Figure A17: Step 3: no convergence to short-term 'equilibrium'



In the longer run, firm of type c could adopt technical changes that would enable it to produce in multiple-floor buildings and move inside the city. Whether it will do so depends on the costs of technical change, P_{inside} and $P_{outside}$.

Figure A18: Step 4: Longer-term equilibrium



This model shows that sectors tending to locate outside the city boundaries – of type b, c, and d, which we call "conquistadors" – may face higher increases in real estate prices than those locating mostly inside – of type a, called "recyclers". However, type b sector may be able to adapt by relocating within the city frontiers, while it may be more difficult for sectors of type c and d, so ultimately real estate prices increase outside cities may remain higher than inside. This change in prices will notably depend on the relative costs of densification and renaturation. Note also that this model assumes a fixed demand for buildings – reasults may differ if the demand for building decreases.

7.3.2 Balance sheet data on firms (Fiben) – Data and method

In our vulnerability analysis (see Section 5 of the paper, and the next section of this annex), we derive much information about sectors from the FiBEn database on firms' balance sheets. It is built by the Bank of France from fiscal documents and contains detailed information on flow and stock accounting variables, notably real estate assets. One caveat is that FiBEn covers only firms whose turnover is above 750,000€. Although this sampling might lead to some representativity bias, the firms in the database account for a very large share of turnover and employment in France.

Share of non-owners We simply check if firms own land or construction as assets, to build a binary variable stating whether the firm is an owner or not.

Rental expenses For each firm, we compute the share of expenses that are dedicated to the payment of rents.

Leverage Ratio (LR) and Interest Coverage Ratio (ICR)

$$ICR = \frac{EBIT}{Interestexpenditures} LR = \frac{Netdebt}{EquitywithNetDebt} = GrossDebt - -Cash\_st\_assets$$

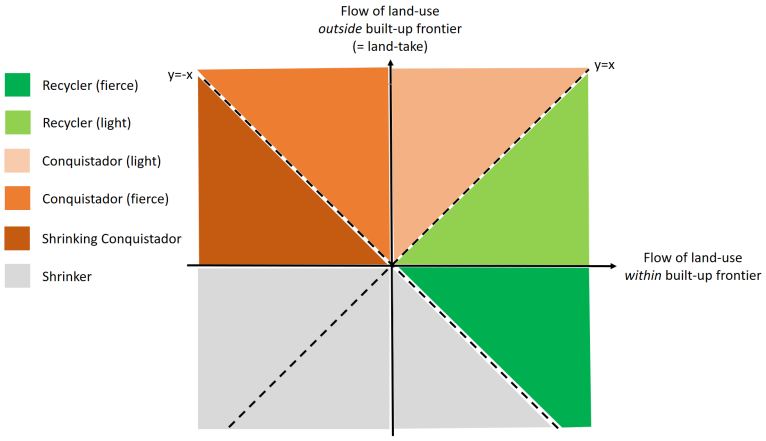
Where Gross Debt is the sum of Loans, Debt securities and Other debt.

7.3.3 Criteria for vulnerability assessment

Criteria for 'Exposure'

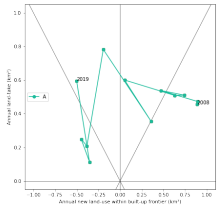
Criterion 1: Type of expansion (inside vs outside). The magnitude of the price increase will be heterogeneous depending on the characteristics of firms' built-up land use, and in particular on whether sectors tend to expand outiside cities ('conquistadors') or within the existing urban fabric ('recyclers'). We explain this with a small model presented in Section 7.3.1 above. With our data, we can identify which sectors are rather 'conquistadors' – potentially facing higher price increases – and which ones are more 'recyclers' – possibly facing lower price increase, at least in the short-run (Figure A19).

Figure A19: Typology of sectors' expansion (within or outside built-up area)

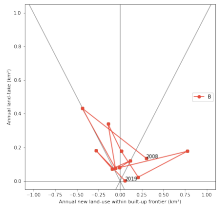


Lecture note: For each year t, we look at the new flow of land use (equal to built-up land use in t minus the built-up land use in t-1). This flow can be split between one part that took place outside of the area of existing built-up land (land take), while another part takes place inside (through moving within previously existing buildings).
- above the x-axis, the sector has a positive expansion happening outside the existing built-up area (through land take).
- to the right of the y-axis, the sector has a positive expansion happening inside the existing built-up area.
=> Sectors in the right quadrant are therefore expanding both inside and outside the built-up frontier. However:
- below the y=x line, the sector is expanding inside existing built-up area more than outside.
=> We call these sectors **"recyclers"**. Conversely, we call the sectors above this line **"conquistadors"**, as they tend to expand outside existing built-up areas more than within.
- below the y=-x line, the sector has a declining total built-up land use (equal to the sum of their land use inside and outside the built-up area)
=> We call this type of sectors **"shrinkers"**.

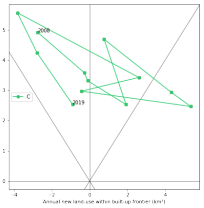
Sector A



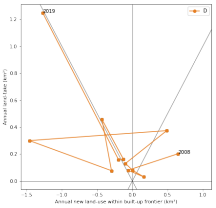
Sector B



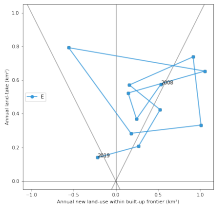
Sector C



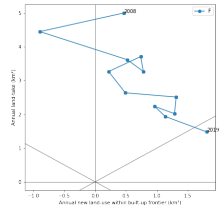
Sector D



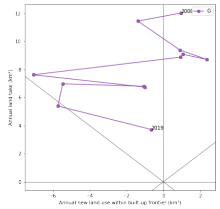
Sector E



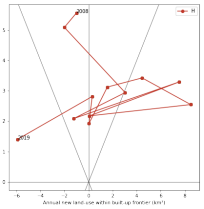
Sector F



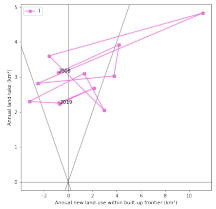
Sector G



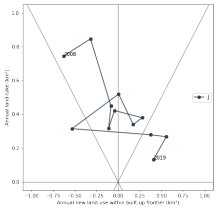
Sector H



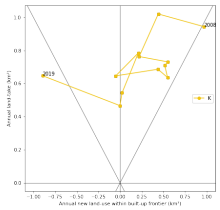
Sector I



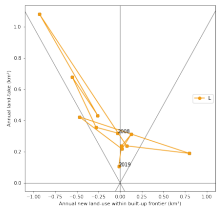
Sector J



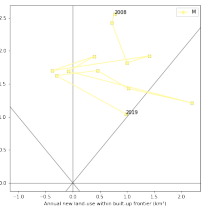
Sector K



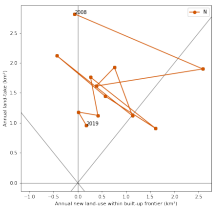
Sector L



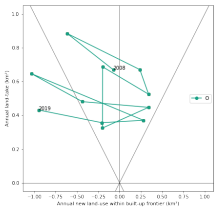
Sector M



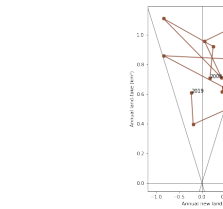
Sector N



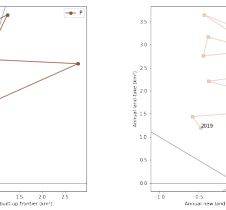
Sector O



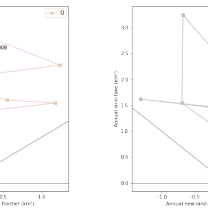
Sector P



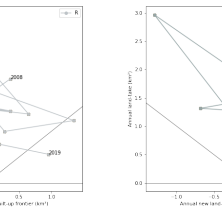
Sector Q



Sector R



Sector S



We find that Trade (G) appears to be a 'fierce conquistador' over the whole period, while Agriculture (A), Insurance and Finance (K) and Manufacturing (C) are turning into fiercer conquistadors over time. Conversely, the Water and waste (E) tends to be a recycler as compared to other sectors – but overall, few sectors remain recyclers during a long period. The Construction (F) and Information and communication (J) sectors also tend to recycle more and more. However, many sectors are hard to classify and display a pattern that varies a lot with time. Finally, we don't find any sector with a negative land take, as our data and methodology does not allow to capture the restoration of land. However, given the negligible flows of land restoration observed at the national level, capturing restoration would probably provide similar results.

Criterion 2: Built-up land use per extablishment. Sectors will be heterogeneously affected by the increase in real estate prices because their establishments differ in the surface of land they use. Sector using larger surfaces of built-up land may be more exposed in case of increasing built-up land prices. As shown in section 4, the sectors with the largest use of built-up land per establishment are Mining and Quarrying (B), Energy (D), Water and waste (E), Transportation and storage (H) and Manufacturing (C).

Criterion 3: Buildings' density (one-floor vs multiple floor). The increase in real estate prices may be lower for sectors able to produce in multiple-floor buildings (type b sectors in the model presented in Annex). In addition, if converting 1m^2 of natural or agricultural land into built-up land becomes more expensive, then denser buildings with numerous floors will allow to distribute the increase in price between the different facilities in the building and their users. Conversely, in facilities such as warehouses made of one or two floors at most, the whole increase in the price will be borne by one or very few users. To assess this heterogeneous exposure, we compute a density index by parcel, equal to the total surface of facilities on the parcel (i.e. dwellings, offices, etc.) divided by the surface of the built-up ground on the parcel. An index higher than 1 implies that there are multiple floors on the parcel. We then define two thresholds for distinguishing between low, medium and high density,[24] and simply count, by sector, the number of yearly built-up parcels that fall in each of these three categories. As could be expected, we find that, on average, the sectors that are users of denser buildings are tertiary (I, J, K, L) and mostly consisting in office work. Then, sectors such as Trade (G), Transportation and storage (H) or Arts and entertainment (R) tend to locate on less dense parcels (e.g., because they require storage), and are followed by more 'industrial' sectors such as Water and waste (E), Energy (D), Construction (F) and Manufacturing (C). Finally, the sectors located on less dense parcels are Agriculture (A) and Mining and quarrying (B).[25][26]

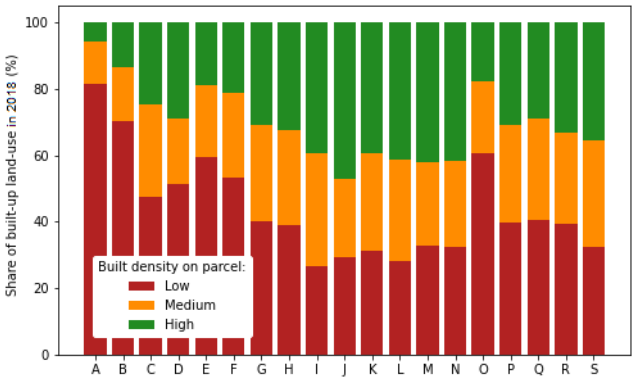
[24] A score below 1 means that the density is low, a score above 3 means that the density is high.

[25] One explanation for that may be 'built-up area' including gardens and part of the crops and quarries on the parcel.

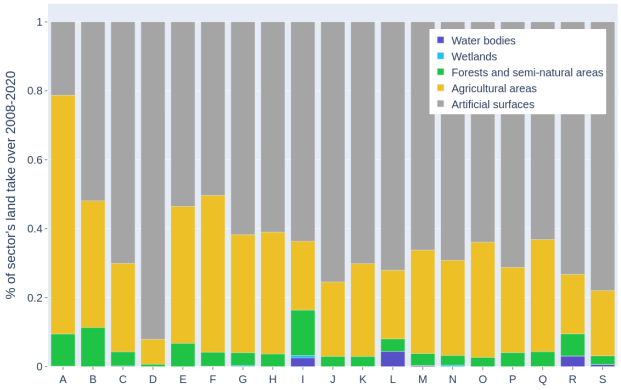
[26] When investing density at the 2 digits level (see Appendix), the heterogeneity between sectors is even more striking, for instance between metallurgy (24), located on parcels with very low density, and insurance (65), located on high-density parcels. It also allows to distinguish subsectors within sectors: for instance, Trade (G) exhibits highly heterogeneous densities, with Wholesale trade (46) being on average located on less dense parcels than Retail trade (47).

Figure A20: Building density and land taken by buildings, by sector:

(a) Built-up density of parcels, by sector



(b) Land cover before land take, by sector



Criterion 4: Type of land taken by buildings. In addition, buildings usually built on non-artificial land could exhibit higher prices because they typically face particularly high compensation costs. Indeed, building on agricultural or semi-natural land may require costly compensating operations. Therefore, firms that need to be located on such land could be more exposed to the increase in prices. This may be the case for dangerous plants that must be located outside of the urban fabric, or warehouses for storage that must be located near the national transport network to decrease transportation costs. According to our results (Figure A20b), sectors with the largest share of land take occurring on land previously dedicated to agriculture are Agriculture (which makes sense), Construction (F), Water and waste (E), Trade (G) and Transportation and storage (H). The sectors with the largest proportion of land take happening on land previously covered with forests are Accommodation and food services (I), Mining and Quarrying (B), Arts and Entertainment (R), Agriculture (A) and Water and waste (E). Finally, those with the largest share of land take occurring on wetlands or water bodies are Real Estate (L) (although the reason for that result is still unclear), Arts and entertainment (R) and Accommodation and food services (I).[27]

Criterion 5: Owning or renting the building facilities. The exposure of firms to the increase in real estate prices will depend on whether they own their buildings or not: while owners will see the price of their assets (and hence their wealth) increase, renters will face increasing rents that may jeopardise their profitability. We assess this differentiated exposure using the FiBEn database on firms' balance sheets.[28] We identify the share of firms owning real estate in each sectors – the non-owning firms being possibly negatively exposed to the increase in real estate prices. We find a large heterogeneity between sectors (Figure A21a): Agriculture (A), Mining and Quarrying (B) have more than 80% or building-owning firms, and Water and waste (E), Manufacturing (C) and Real Estate (L) more than 50%. Conversely, firms in the Finance (K), Insurance (J), Professional, scientific and technical activities (M) and Administrative and support services (N) have much lower owning rates. For K and J, this might be because we look at the firm and not the group level (there may be holdings in the group that own the buildings).

Criteria for 'Adaptive capacity'

Finally, this section proposes some proxies to assess the technical and financial ability of sectors to cope if they are exposed to increasing real estate prices.

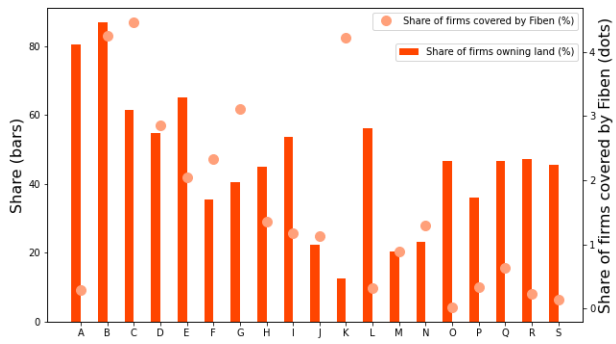
Criterion 6 (Technical): Dependency of production to built-up land use. We use the

[27]These sectors may also be exposed to other biodiversity policies than NNLT, such as the restoration of rivers and water bodies inscribed in the EU Restoration Law (2022).

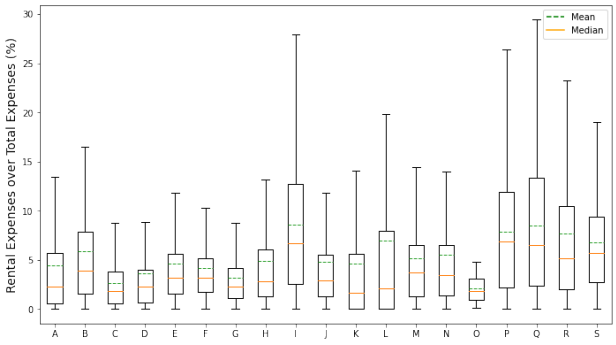
[28]FiBEN is built by the Bank of France from fiscal documents and contains detailed information on flow and stock accounting variables, notably real estate assets. One caveat is that FiBEn covers only firms whose turnover is above 750,000€. This selection sample issue might bias slightly our analysis.

Figure A21: Renting buildings, by sector in 2019:

(a) Share of firms owning real estate



(b) Rental expenses over total expenses



intensity of output in terms of built-up land use (in m² per k€) as a proxy for this dependency. According to Figure A22, the sectors with an output that is particularly intensive in built-up land use are Mining and Quarrying (B), Arts and Entertainment (R), Other service activities (S) and Accommodation and food services (I). The results for value added (instead of total output) provide quite similar results.

Figure A22: Comparison between built-up land use and output by sector, in 2018

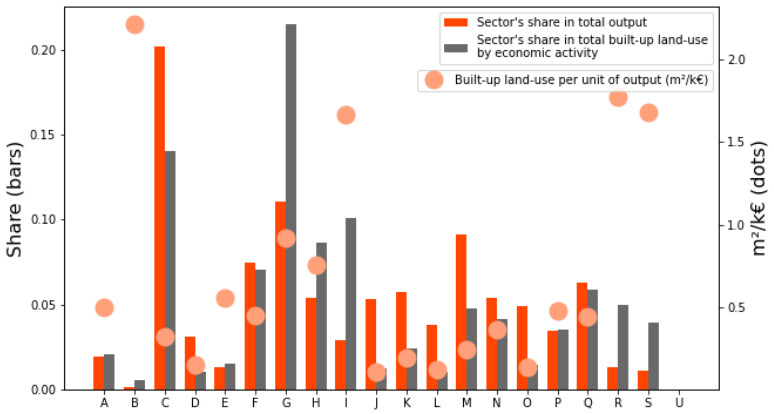
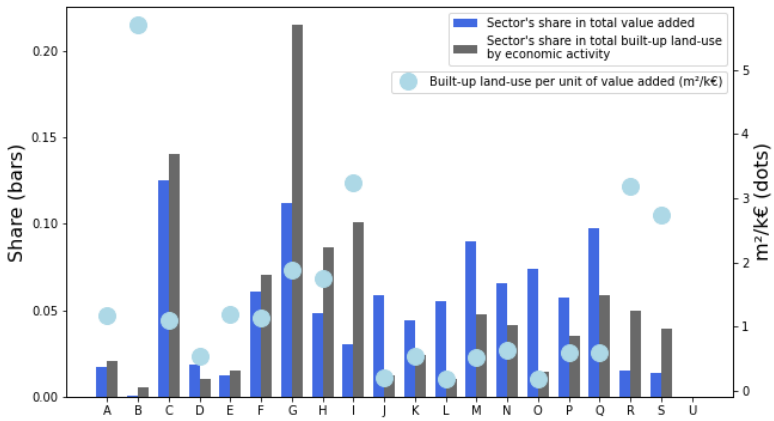


Figure A23: Comparison between built-up land use and value added by sector, in 2018



Criterion 7 (Technical): Ability to densify buildings. A 'technical' way firms can adapt to the increase in land prices is through densification of their buildings. A proxy or such possibility

may be provided by the density of the parcels on which sectors are currently located (see results from Figure A20a in the previous section): location on less dense parcels may indicate a technical difficulty to locate on denser parcels. This would therefore be particularly the case for Water and waste (E), Energy (D), Construction (F) and Manufacturing (C). However, the relevance of this metric as a proxy for 'adaptive capacity' can be questioned: it is possible that, on the contrary, sectors already locating in dense areas could face less leeway to densify their activities than those that are currently less dense.

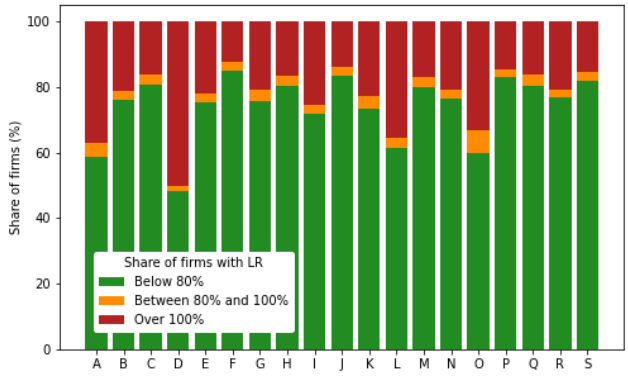
Criterion 8 (Financial): Ability of renters to pay higher rents. For renters, the ability to face an increase in rents may depend on the share rents already represent in their total costs. Using FiBEn, we compute the ratio of rental expenses over total expenses for each firm, a large ratio indicating a more important vulnerability to a large increase in rents. Figure A21b shows that the most exposed sectors are Accommodation and food services (I), Education (P), and Arts and entertainment (R).

Criterion 9 (Financial): Global financial 'health'. We assess the latter at the sector level by looking at the two standard financial ratios used by the High Council for Financial Stability to assess firms' financial health (Couaillier et al. (2020)): (i) the net leverage ratio and (ii) the interest coverage ratio. Figure A24a shows that some sectors display a particularly high proportion of highly indebted firms (with LR over 100% or between 80% and 100%): Energy (D), Agriculture (A), Real estate (L) (K), Public Administration (O). For some sectors (e.g. for Energy), this potential source of weakness is partially offset by the fact that they also have a majority of firms whose revenues can cover interests (i.e. ICR higher than 3, Figure A24b).

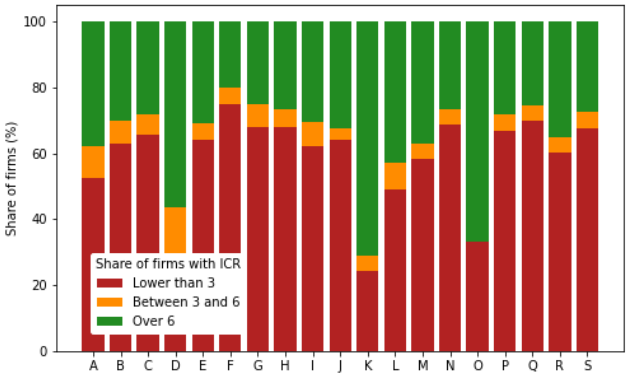
Criterion 10: Relocation of activities abroad. Finally, firms could also cope with the policy by relocating their activity outside of France. We assess this ability to relocate by using the classification developed by Chassard (2020) and Regions de France (2023) based on Frocrain and Giraud (2017), which distinguishes between four groups of sectors depending on their reliance on local demand. Such a reliance will impact the ability for firms to relocate: sectors from G1 and G2 will have a lower ability, while conversely, sectors in G3 and G4, and in particular those whose production require large surfaces of land, could be more likely to migrate abroad. Figure A25 shows that firms that depend the most on local demand are also the most intensive users of land: they need a lot of land surface to produce output. This should be no surprise as they tend to be less capital-intensive and less productive. They could therefore be directly affected by an increase in real-estate prices. Conversely, the sectors that have a particularly high land use inefficiency (superior to the median) in G4 are those which, if threatened by an increase in real estate prices, might end up relocating outside France. Most of them are from the Manufacturing sector: food production (10), textile (13), clothes (14), Printing and reproduction of recorded media (18), and Manufacture of other non-metallic mineral products (23).

Figure A24: Financial ratios by sector, in 2019:

(a) Leverage ratios (LR)

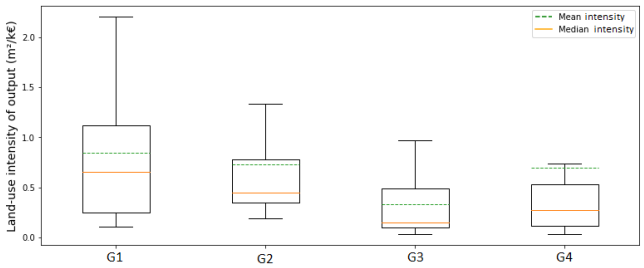


(b) Interest coverage ratios (ICR)



Lecture note: (a) The net leverage ratio is the ratio between a firm's debt net of cash holdings over its equity, and describes the firm's financing structure. A high net leverage ratio (over 100%) means that the value of a firm's assets may be insufficient to cover its debts.The interest coverage ratio or ICR is defined as the ratio between a firm's earnings before interest and tax (EBIT) and the interest payments on its debt. It measures a firm's interest payment burden: an ICR below 1 indicates that a firm does not generate sufficient income to pay its creditors. It is generally considered that an ICR below 3 is risky, meaning that the firm might not be able to withstand a temporary decline in earnings or a rise in its financing costs.

Figure A25: Distribution of land use intensity of output, depending on sector's reliance on local demand



Lecture note: Based on Insee (2020) G1 gathers sectors with a local market area and nearby catchment area; G2, sectors with a local market area but a regional catchment area; G3, sectors with a non-local market area, and having common activities; and G4, sectors with a non-local market area and rare activities. We find that sectors in G4 and G3 have an output that is relatively less intensive in built-up land. However, the high mean in G4 distributions reflects the existence of sectors with a particularly high built-up land use, that may be able to relocate abroad.

Not a proper criterion but a question: Can firms pass through land costs to selling prices? For the picture of potential reactions of firms to the price shock to be complete, the possibility to raise prices should be mentioned. This strand is not fully investigated but this discussion could rely on the parallel between energy and land prices that has been already highlighted. Arquié and Thie (2023) explores the link between market power and pass through of energy prices. They estimate firm-level markups on French manufacturing firms balance sheet data, and aggregate them at the sectoral level. They show that in the least competitive sector, firms pass through up to 115% of the energy shock to the producer price index (PPI). With many precautions, the results of this study can be used to proxy the heterogeneous capacity of firms to adapt to the increase of land prices by raising their selling prices. A sector like Waste collection (38), characterized as fragile in our MCA, has one of the lowest capacity to pass through, while Clothing (14) that is quite exposed to the policy, might be able to increase its prices due to the high firms markups.

7.3.4 Vulnerability analysis – Construction of a heatmap and sensitivity analysis

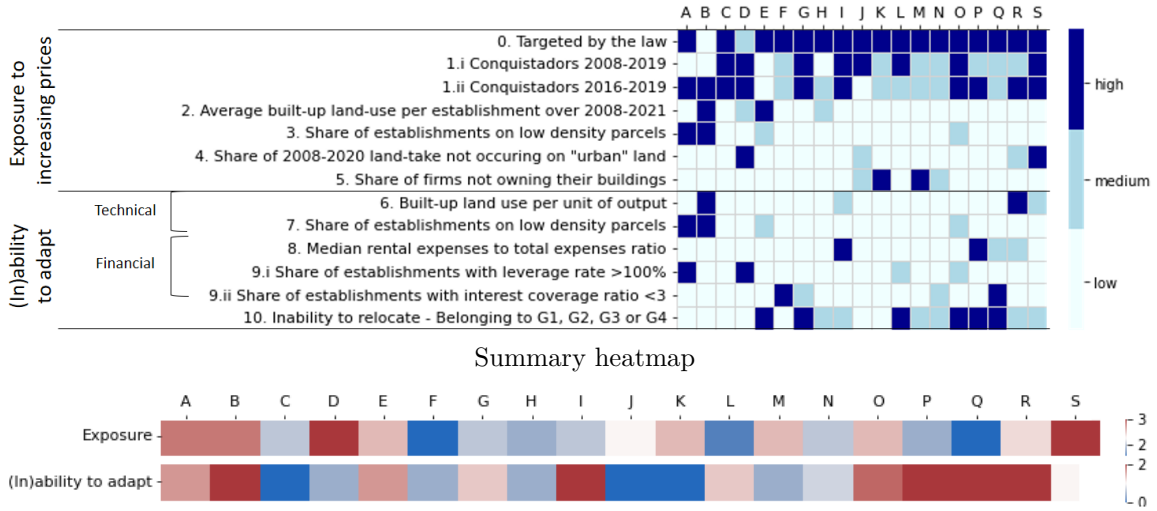
We build the heatmap for the vulnerability analysis as follows. A "high" (dark blue) level indicates that the criterion is an important contributor to vulnerability for the sector, *as compared to other sectors*. For a set of variables that appear with a star in the table below, we either choose to define a "high" level as indicating that the sector is in the top 10% of sectors for the given variable (Figure A26a, also presented in section 5 of the paper), or that it is higher than 80% of the maximum value found among sectors for the variable (Figure A26b). Similarly, we choose to define a "medium" level as indicating that the sector is in the top 20% of sectors for the given variable (Figure A26a), or that it is higher than 50% of the maximum value found among sectors for the variable (Figure A26b). While we acknowledge that these choices are rather arbitrary, we present several criteria and scales for the sake of transparency.

Table A13: Criteria and metrics for NNLT vulnerability assessment

Stage in risk assessment	Criteria	Metric (assessed by sector)
Exposure to price increases	Possibly more exposed to price increase if:	
	0. Sector's land take is considered as land take by the law	No; No for part of sector; Yes
	1. Expansion outside city boundaries	i. Conquistador; Recycler; Declining; over 2008-2019 ii. Conquistador; Recycler; Declining; over 2016-2019
	2. Average establishment is a big user of land	Average built-up land use per establishment over 2008-2021*
	3. Increase in price of land not shared with other users	Share of low density parcels used*
	4. Land usually taken is more expensive and difficult to compensate	Share of land take on non-urban land over 2008-2020*
	5. Mostly renter of buildings	Share of firms not owning their buildings*
Adaptive capacity	Possibly less able to adapt if:	
	6. High dependency of production to built-up land use	Built-up land use/output*
	7. Densification of buildings is difficult	Share of low density parcels used*
	8. Rental expenses already make a significant portion of costs	Rental Expenses/Total Expenses*
	9. Financially less able to incur losses	i. Share of firms with LR>100%* ii. Share of firms with ICR<3*
	10. Relocating abroad is difficult	Belonging to Insee groups G1 or G2 – vs G3 or G4

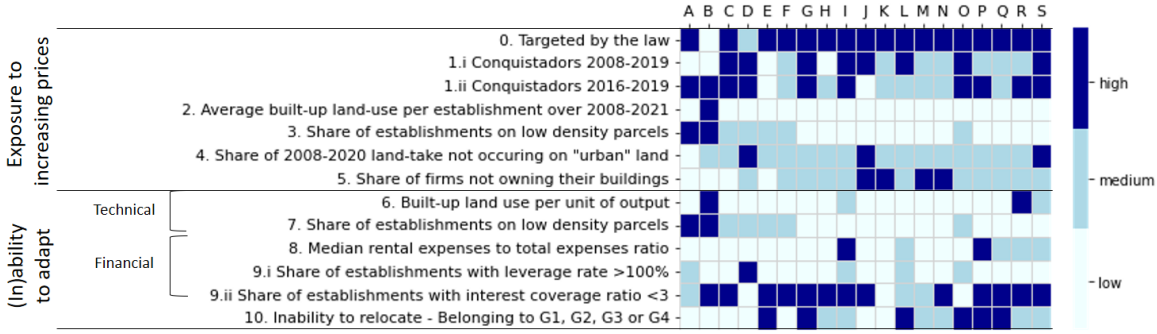
Figure A26: Sensitivity analysis of risk assessment heatmaps

(a) A criterion is "high" if in top deciles

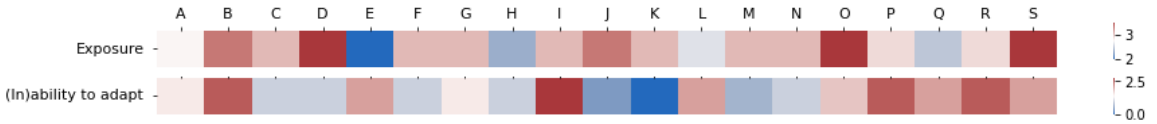


Summary heatmap

(b) A criterion is "high" if close to maximum value



Summary heatmap



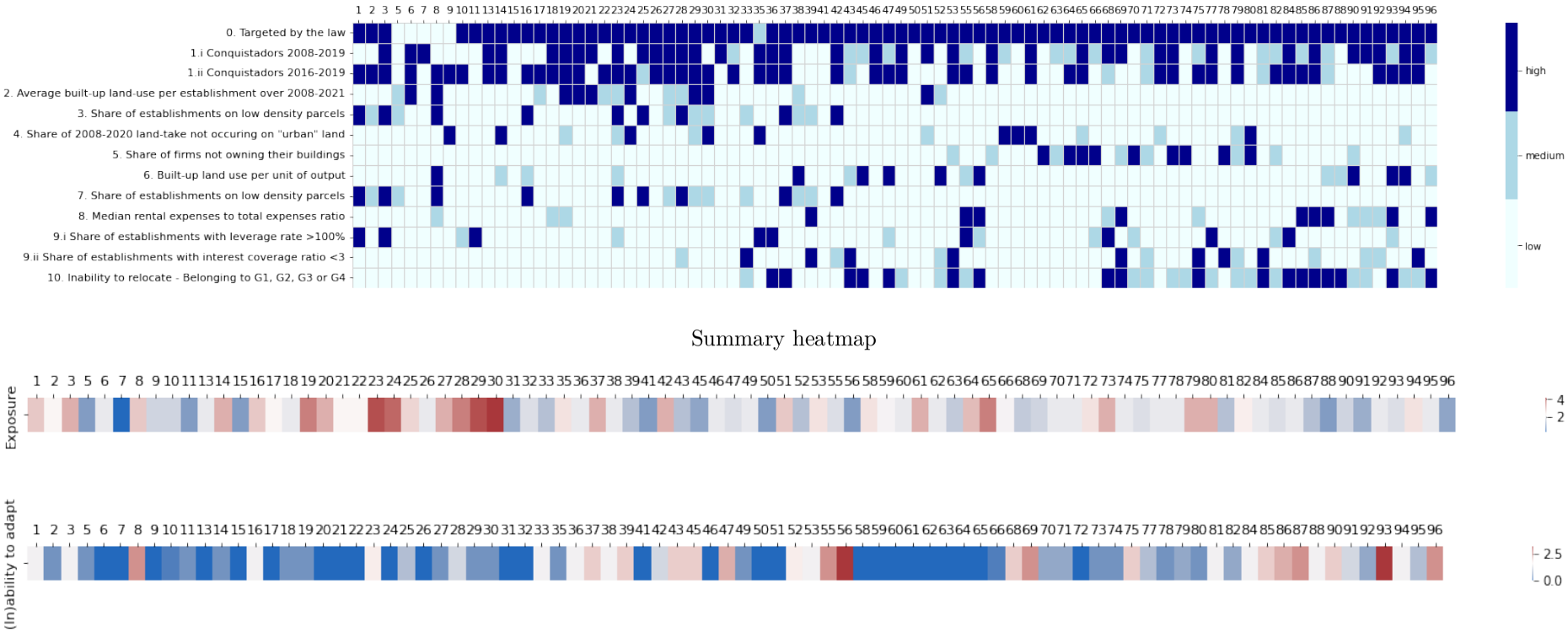
7.3.5 Vulnerability analysis at the NAF 2-digits level

Table A14: Subsectors (NAF 2-digits)

A – 1 Crop and animal production, hunting and related service activities
A – 2 Forestry and logging
A – 3 Fishing and aquaculture
B – 5 Mining of coal and lignite
B – 6 Extraction of crude petroleum and natural gas
B – 7 Mining of metal ores
B – 8 Other mining and quarrying
B – 9 Mining support service activities
C – 10 Manufacture of food products
C – 11 Manufacture of beverages
C – 12 Manufacture of tobacco products
C – 13 Manufacture of textiles
C – 14 Manufacture of wearing apparel
C – 15 Manufacture of leather and related products
C – 16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C – 17 Manufacture of paper and paper products
C – 18 Printing and reproduction of recorded media
C – 19 Manufacture of coke and refined petroleum products
C – 20 Manufacture of chemicals and chemical products
C – 21 Manufacture of basic pharmaceutical products and pharmaceutical preparations
C – 22 Manufacture of rubber and plastic products
C – 23 Manufacture of other non-metallic mineral products
C – 24 Manufacture of basic metals
C – 25 Manufacture of fabricated metal products, except machinery and equipment
C – 26 Manufacture of computer, electronic and optical products
C – 27 Manufacture of electrical equipment
C – 28 Manufacture of machinery and equipment n.e.c.
C – 29 Manufacture of motor vehicles, trailers and semi-trailers
C – 30 Manufacture of other transport equipment
C – 31 Manufacture of furniture
C – 32 Other manufacturing
C – 33 Repair and installation of machinery and equipment
D – 35 Electricity, gas, steam and air conditioning supply
E – 36 Water collection, treatment and supply
E – 37 Sewerage
E – 38 Waste collection, treatment and disposal activities; materials recovery
E – 39 Remediation activities and other waste management services
F – 41 Construction of buildings
F – 42 Civil engineering
F – 43 Specialised construction activities
G – 45 Wholesale and retail trade and repair of motor vehicles and motorcycles
G – 46 Wholesale trade, except of motor vehicles and motorcycles
G – 47 Retail trade, except of motor vehicles and motorcycles
H – 49 Land transport and transport via pipelines
H – 50 Water transport
H – 51 Air transport
H – 52 Warehousing and support activities for transportation
H – 53 Postal and courier activities
I – 55 Accommodation
I – 56 Food and beverage service activities
J – 58 Publishing activities
J – 59 Motion picture, video and television programme production, sound recording and music publishing activities
J – 60 Programming and broadcasting activities
J – 61 Telecommunications
J – 62 Computer programming, consultancy and related activities
J – 63 Information service activities
K – 64 Financial service activities, except insurance and pension funding
K – 65 Insurance, reinsurance and pension funding, except compulsory social security
K – 66 Activities auxiliary to financial services and insurance activities
L – 68 Real estate activities
M – 69 Legal and accounting activities
M – 70 Activities of head offices; management consultancy activities
M – 71 Architectural and engineering activities; technical testing and analysis
M – 72 Scientific research and development
M – 73 Advertising and market research
M – 74 Other professional, scientific and technical activities
M – 75 Veterinary activities
N – 77 Rental and leasing activities
N – 78 Employment activities
N – 79 Travel agency, tour operator and other reservation service and related activities
N – 80 Security and investigation activities
N – 81 Services to buildings and landscape activities
N – 82 Office administrative, office support and other business support activities
O – 84 Public administration and defence; compulsory social security
P – 85 Education
Q – 86 Human health activities
Q – 87 Residential care activities
Q – 88 Social work activities without accommodation
R – 90 Creative, arts and entertainment activities
R – 91 Libraries, archives, museums and other cultural activities
R – 92 Gambling and betting activities
R – 93 Sports activities and amusement and recreation activities
S – 94 Activities of membership organisations
S – 95 Repair of computers and personal and household goods
S – 96 Other personal service activities
T – 97 Activities of households as employers of domestic personnel
T – 98 Undifferentiated goods- and services-producing activities of private households for own use
U – 99 Activities of extraterritorial organisations and bodies

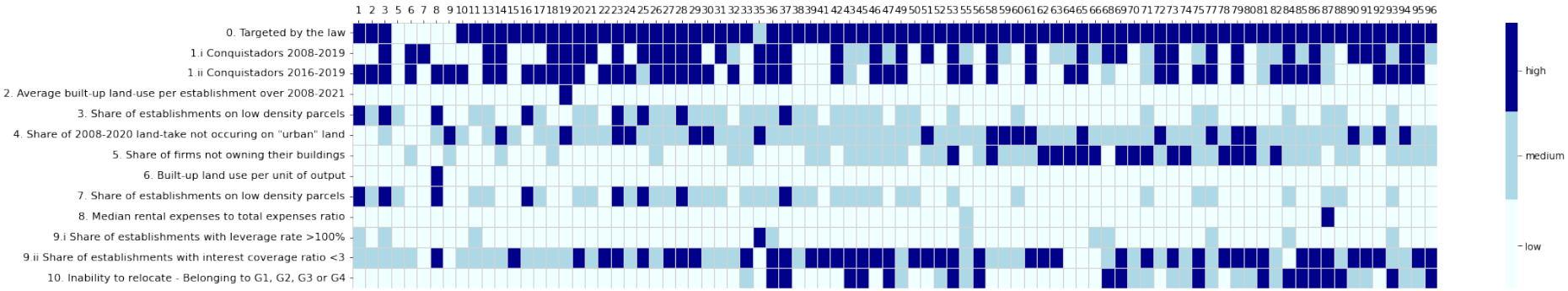
Figure A27: Sensitivity analysis of risk assessment heatmaps – 2-digit subectors

(a) A criterion is "high" if in top deciles

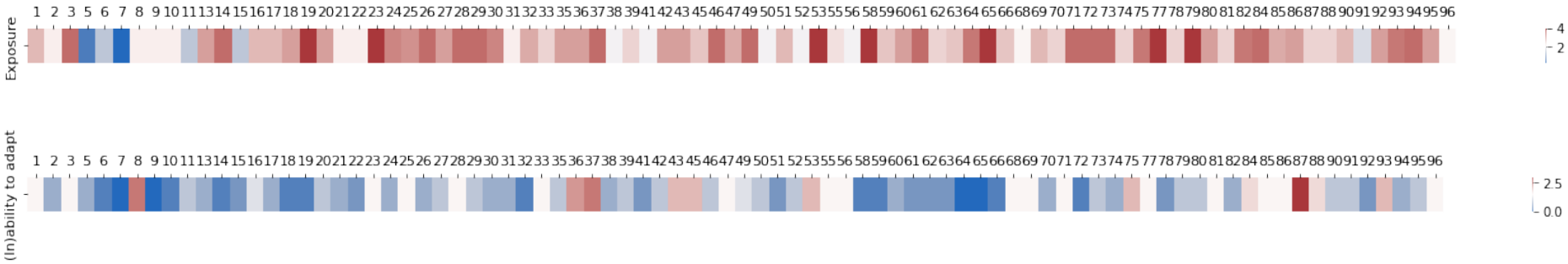


Methodological/Lecture note: A "high" (dark blue) level indicates that the criterion is an important contributor to risk for the sector, as compared to other sectors. For a set of variables that appear with a star in Table A13, we define a "high" level as indicating that the sector is in the top 10% of sectors for the given variable, and a "medium" level as indicating that the sector is in the top 20% of sectors for the given variable.

(b) A criterion is "high" if close to maximum value



Summary heatmap



Methodological/Lecture note: A "high" (dark blue) level indicates that the criterion is an important contributor to risk for the sector, as compared to other sectors. For a set of variables that appear with a star in Table A13, we define a "high" level as indicating that the value for the sector is higher than 80% of the maximum value found among sectors for the given variable, and a "medium" level as indicating that the value for the sector is higher than 50% of the maximum value found among sectors for the variable.

Figure A29: Built-up density of parcels – by 2-digit sector