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The Role of Demand in Land Re-Development

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Abstract

Several governments throughout the world apply policies aimed to re-mediate and recover vacant or idle land for other uses. This paper provides estimates of the price sensitivity of redevelopment, a crucial parameter for the success of these policies. My cross-sectional estimates measure how prices affect long-run conversion of unused or underused previously developed land in England. In order to solve the classical problem in the estimation of supply elasticities from market outcomes, I exploit school quality information and school admission boundaries to obtain a demand-shifter that is orthogonal to re-development costs. Estimation is conducted using a boundary discontinuity design based on this instrument. Results show that the probability of re-development is effectively sensitive to housing prices. Estimates indicate that a 1% increase in housing prices leads to a 0.07 percentage point reduction in the fraction of hectares containing brownfield land. Back-of-the envelope calculations using these estimates suggest that a large increase of 21% in prices across locations, or an equivalent subsidy, would be required to eliminate most of these vacant or underused land plots.

Key words: re-development, supply elasticity, brownfields
JEL: R14; R31

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1. Introduction

Cities are areas of intense land use. Yet it is common to find vacant, idle or underused land within them. According to Pagano and Bowman (2000), up to 15% of land within US cities was vacant in 2000. In England, idle or underused previously-developed land sites represented 5.45% of the total urban land in 2007 (Adams, De Sousa and Tiesdell, 2010). This prevalence is puzzling. Land demand is high in cities; in urban models this is what usually results in higher densities (Brueckner, 1987). So why are there vacant or severely underused patches of land in urban areas? Is the presence of these plots sensitive to local demand conditions? Knowing this is instrumental to understanding how market mechanisms shape urban density and, through density, the set of associated social, economic and environmental outcomes identified by urban economists. In addition, it is also informative about the potential success of the re-development promotion policies which have become popular over the past decades.

In this paper, I provide the first available estimates of the sensitivity of re-development to local housing prices, a key parameter linking infill site development with market forces. The analysis focuses on English previously-developed land (PdL) or *brownfield* sites, defined as land that was developed but is now vacant, derelict, or has known potential for re-development.[1] The empirical challenge to be addressed here is similar to the classical problem of estimating supply or demand elasticities from observed equilibrium outcomes. To estimate the price elasticity of PdL re-development I need a demand-shifter, a variable that affects demand but is known not to affect re-development costs and other determinants of supply. My empirical strategy will use school quality and school admission district boundaries in a boundary discontinuity design (BDD) to generate variation in housing demand that is credibly exogenous to costs. Implementation follows Gibbons, Machin and Silva (2013) in combining standard BDD methods (as in Black (1999) or Dell (2010)) with matching across boundaries. I start by conducting a cross-sectional analysis to compare the presence of brownfield sites in high price and otherwise identical low price areas across an administrative boundary. Next, I extend this analysis to look at land use changes and estimate the effect of prices on subsequent residential construction activity.

Using a tractable but general theoretical framework, I show that we can think of the elas-

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[1] In the United Kingdom, these are often referred to as brownfield sites. As a result, the terms brownfield and PdL site will be used interchangeably in the paper. It is important to note that, contrary to the definition prevalent in the United States, in the British definition brownfields are not necessarily polluted or affected by a hazardous substance.

ticity of PdL re-development as deriving from a primitive (unobserved) distribution of redevelopment costs. Housing prices determine the cut-off in this distribution to the left of which re-development takes place. From this point of view, I show that my estimates can be seen as local estimates of the re-development cost density function. In addition, my theoretical framework clarifies how cross-sectional differences in brownfield presence across boundaries relate to the elasticity of re-development.

My estimates indicate that a 1% increase in prices reduces the presence of brownfield sites on a hectare by 0.07 percentage points. While this effect appears to be small, only 1.5% of the hectares in my sample contained a PdL site in 2007. Back of the envelope calculations using these estimates suggest that a 21% increase in the house price level across the board would be necessary to prompt the re-development of most brownfield sites. These results are consistent with anecdotal evidence indicating that many brownfield sites in England are currently going through the planning process. Moreover, they are also consistent with estimates of ex-post land use changes in the 2007-2011 period.

My estimates inform the debate on *smart growth* policies and urban compactness in urban planning and economics. A growing consensus among urban planners and policy-makers has emerged on the desirability of achieving *compact cities* (see OECD (2012)), cities with high densities and few undeveloped patches of land within the urban footprint. The increased density is often assumed to reduce commuting time, promote productivity gains and reduce driving as well as environmental damage. While the debate over the supposed welfare enhancing effects of compactness continues (see Ahlfeldt and Pietrostefani (2017), Cheshire (2006)) several cities have embraced the smart growth agenda and its set of recommended policies. In many cases, governments have tackled this by promoting the redevelopment of brownfield or previously-developed land. Examples include the brownfield first policy in the United Kingdom which aims at channelling at least 60% of new developments to brownfield sites. Brownfield initiatives exist in Chicago, New York, Los Angeles and many other US cities, providing either grants or financing options to promote re-development. Re-mediation relief for polluted sites provided by the Environmental Protection Agency in the United States often achieves a similar outcome. Appendix C provides a review of policies tailored to promote re-development and re-mediation in North America and Europe. The potential success of incentive-based re-development policies crucially depends on the price sensitivity of brownfield conversion. With a value of zero or close to zero, re-development is unlikely, even when prices increase substantially or a subsidy is in place. Conversely, positive and large elasticities imply high responsiveness and a potentially large effect of incentive policies such as tax breaks or re-mediation subsidies.

Results suggest that these policies could induce in a substantial amount of brownfield re-development. In addition, I show that the price sensitivity of re-development is substantial in large cities, which are areas exhibiting a disproportionate number of PdL sites and also where local governments are more likely to engage in specific re-development policies. Using data on planning restrictiveness from Hilber and Vermeulen (2016), I show that the elasticity of re-development is lower in areas with tight planning restrictions. Finally, I find that brownfield presence is sensitive to prices even for relatively high cost sites, such as those in which land was previously used in manufacturing, mining or physical infrastructure.

This study contributes to the long literature on the estimation of the elasticity of housing supply. Housing supply elasticities are crucial to understand city-level house price volatilities (Glaeser, Gyourko and Saiz (2008), Paciorek (2013)), city systems' responses to shocks (Hornbeck and Moretti (2015)) and urban growth (Glaeser, Gyourko and Saks, 2006). The methods developed over the last twenty years combine longitudinal data on home-building with city level price indices (Malpezzi and Maclennan (2001), Green, Malpezzi and Mayo (2005)) and incorporate supply shifters such as geographical characteristics and regulation constraints to obtain city level elasticity estimates (as in Saiz (2010)). These city level estimates are important in their own right, but they tell us very little about re-development of idle land, as city level changes in supply may also be affected by sprawl or changes in building heights. The estimates provided below are, to my knowledge, the first in the literature to focus specifically on re-development of idle or vacant land. Given that the data on PdL sites is usually cross sectional, I also depart from this literature in my identification strategy. In this sense, my paper is closer in spirit to the exercise in De Leeuw and Ekanem (1971), although I propose a more ambitious identification strategy by exploiting credibly exogenous variation in demand conditions. The theoretical framework below will illustrate how cross-sectional and longitudinal estimates are related, and clarify under which conditions they identify the same object.

My paper also contributes to the literature studying the effect of site clean-up policies on local housing prices and neighbourhood composition. Greenstone and Gallagher (2008) use discontinuities in the assignment of clean-up funding to identify price effects of clean up policies in the US. Gamper-Rabindran and Timmins (2013) exploit the timing of clean-up and document that price effects are concentrated at the lower end of the price distribution. There is also evidence of household sorting as a response to these clean-up efforts (Gamper-Rabindran and Timmins, 2011) and of persistent negative externalities after clean up took place (Kiel and Williams, 2007). My paper follows the *opposite* direction relative to these studies, by looking at the effect of prices on conversion of PdL sites. In this sense, the estimates below should be an indication of the effectiveness of subsidies to trigger clean-up of polluted sites. The negative effect of polluted brownfields on prices documented in this literature, stresses the need to rely on a credible identification strategy which avoids reverse causality from PdL sites to prices.[2] These studies also highlight the potential welfare impacts of re-development in reducing local negative externalities arising from vacant land sites.

This paper also relates to the literature estimating the effects of new construction on local housing prices. Ooi and Le (2013) uses a hedonic model to study the effect of infill development of vacant or underused sites on local house prices in Singapore, finding positive and robust effects. Zahirovich-Herbert and Gibler (2014) study the effect of new construction and find price effects are especially high for newbuilds well above the local mean floor area. Again, my paper flips the direction of causality by studying how prices shape conversion and new-building at the local level. Finally, this paper relates to studies of urban decline. Both in Glaeser and Gyourko (2005) and in more recent work by Owens, Rossi-Hansberg and Sarte (2017), vacant land is a key feature of a declining city. My contribution relative to this work is to look at the link between demand and re-development in a context in which vacant land is not the result of general urban decline but of fundamental redevelopment cost differences.

The rest of the paper is structured as follows: Section 2 presents a theoretical framework used to guide the analysis and illustrate the nature of the empirical problem at hand. Section 4 describes the empirical strategy and section 5 provides cross-sectional estimates of the effect of prices on conversion, as well as results for *ex-post* land use changes. Section 6 presents a series of robustness checks to validate my analysis and its results. Finally, section 7 presents the main conclusions.

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[2] Given that the definition of PdL or brownfield sites used here also includes non-polluted plots, my estimates correspond to sites with arguably lower conversion costs than those covered in studies of clean-up effects.

2. Theoretical Framework

2.1. Setup and Equilibrium

The following static, open-city framework illustrates how cross sectional data on PdL sites can be used to estimate the house price sensitivity of conversion of into residential use. It also helps clarifying what is the empirical challenge to be tackled and provide structural interpretation to the reduced form estimates presented in section 4. Some of its basic elements are borrowed from Turner (2005) and Glaeser and Gyourko (2005).[3]

There is a unit mass of atomistic PdL sites available for construction in a city, each of which is indexed by i. Sites are heterogeneous along two dimensions. They differ in the costs of re-development c_i and their amenity value a_i which are observable for all agents. They are distributed according to a joint continuous probability distribution function $g(c, a)$ which is defined over a set so that that $c \in [\underline{c}, \overline{c}]$ and $a \in [\underline{a}, \overline{a}]$ with $\underline{c}, \underline{a} > 0$. Note that a and c may be correlated. Profit-maximizing absentee landowners own PdL sites and obtain a reservation return $\underline{r}$ from ownership when the sites are not developed.[4] The landowner of site i can sell PdL to a developer in exchange for a price r_i, the price of land at i. As shown below, if sites are heterogeneous in c and a, r_i will be heterogeneous too. A given site will be re-developed if landowner can sell it for a price $r_i > \underline{r}$, this will determine supply of re-developed land.

Total supply of re-developed PdL is given by $L_S = 1 - F_r(\underline{r})$, where F_r is the cumulative distribution of individual site prices r. Intuitively, if the equilibrium price distribution is fixed, total supply is a decreasing function of $\underline{r}$, so total supply is decreasing in the reservation return of brownfield land. Costs and amenity values do not appear explicitly in the expression of land supply but their distribution will affect site prices in equilibrium as shown below.

The market for residential development or home building is populated by competitive developers and has free entry. Developers buy land site i by paying price r_i, pay re-development costs c_i and sell the built home for price p_i. For simplicity, only one home can be built in every site.

Finally, there is a unit mass of potential residents which may decide to move into the city. Their utility of moving to site i in the city is equal to total consumption inclusive of amenities: $U(c_i) = C_i = a_i + w - p_i$ where w is the city level wage rate, p_i is the priced paid for a home on

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[3] My framework does not feature housing externalities, which are present in Turner (2005) and Rossi-Hansberg, Sarte and Owens III (2010).

[4] The framework is essentially unchanged if costs are made fixed and heterogeneity in supply conditions is included via variation in reservation returns of landowners. Re-development costs, however, are likely to be a more important factor in practice so I keep the heterogeneity there throughout the analysis.

site i and a_i the corresponding amenity level.[5] As stated above, the city is open so that potential residents can freely move into the area as long as they purchase a residence there. Alternatively, they can stay in a different city in the system and obtain reservation utility $\underline{u}$. Assume that a potential resident moves into the city if indifferent. Given that the mass of potential residents is large, any site with a (p_i, a_i) combination which ensures a consumption level such that $u_i > \underline{u}$ will be occupied in equilibrium.

Timing is as follows: land owners simultaneously post land prices for their sites. Developers observe prices and simultaneously decide whether to buy land, build on it paying the associated cost and post prices for the resulting home. Potential residents observe posted home prices and decide whether to move to the city or not. An equilibrium is a set of prices (p_i, r_i) for all sold sites and a set of occupied S^* sites such that residents, developers and land owners are choosing optimally. Given the timing and the absence of strategic interactions within each group, the equilibrium is easily solved backwards.

Proposition

A set of prices for re-developed sites P^*, R^* and a set of re-developed locations S^* is an equilibrium if and only if:

1. All developed locations $i \in S^*$ satisfy $a_i - c_i + w - \underline{u} \geq \underline{r}$.
2. All undeveloped locations $i \notin S^*$ satisfy $a_i - c_i + w - \underline{u} < \underline{r}$.
3. For each location $i \in S^*$, equilibrium transaction prices for land and houses are $r_i = a_i - c_i + w - \underline{u}$ and $p_i = a_i + w - \underline{u}$, respectively.
4. The total mass of re-developed sites is $\int_{\underline{a}}^{\overline{a}} \int_{\underline{c}}^{a+w-\underline{u}} g(c,a)\, dc\, da$

Proof:

Faced with a set of prices $\mathcal{P}$ and amenities $\mathcal{A}$, residents' strategies are a mapping from these sets into a set of locations $\mu(\mathcal{A}, \mathcal{P}) \in \mathcal{S} \cup \mathcal{O}$ where $\mathcal{O}$ represents the set of locations outside the city. A location in the city is occupied as long as $U_i \geq \underline{u}$, which implies $a_i + w - p_i \geq \underline{u}$.

Faced with this demand, the developer who bought site i will set prices $p_i = a_i + w - \underline{u}$. To show this, I proceed by contradiction. If $p_i > a_i + w - \underline{u}$, the house is not sold and the developer makes negative profits equal to $-(c_i + r_i)$, so developers would be better off not building a home.

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[5] This simple characterization of household preferences is similar to that present in Turner (2005). Utility need not be equal to consumption. The equilibrium allocations and prices will be the same if $U(C_i)$ is a strictly increasing function of C_i (as in Saiz (2010)).

If $p_i < a_i + w - \underline{u}$ the home is sold with certainty and the developer's profit would be $p_i - (c_i + r_i)$, which is increasing in p_i. Note that developers could deviate to a price $p'_i \in (p_i, a_i + w - \underline{u}]$, still sell and make larger profits.

Foreseeing demand by developers and potential residents, landowners will post prices $r_i^* = a_i - c_i + w - \underline{u}$, as long as this price is larger than or equal to $\underline{r}$ (otherwise they post land price $\underline{r}$ and the site is not sold). If they post a larger price, developers would not buy land as they would make negative profits. If they set a lower price $r_i < a_i - c_i + w - \underline{u}$ they can deviate by posting land price $r'_i \in (r_i, a_i - c_i + w - \underline{u}]$ still sell and make additional profits. The set of sold homes in equilibrium S^* is defined by the set of locations for which $a_i - c_i + w - \underline{u} \geq \underline{r}$. The mass of sold sites is the corresponding integral over the joint (a, c) distribution. This area is illustrated in Figure 1, which represents the support of $g(c, a)$, the area of developed sites (in yellow) and the area of undeveloped sites (in gray).

Define s_i taking value 1 if a site is re-developed and 0 otherwise The fraction of redeveloped sites, as a function of house prices is $E(s) = Pr(p - c > \underline{r})$, where $p = a + w - \underline{u}$. The effect of prices on the probability of redevelopment can be obtained from deriving this expression, keeping c constant. To simplify notation, define constant $\kappa \equiv w - \underline{u} - \underline{r}$. If $a_i \perp\!\!\!\perp c_i$, then we know that

$$E(s|a) = G_{c|a}(a + \kappa) = G_c(a + \kappa) \tag{1}$$

where $G_{c|a}$ is the conditional cumulative distribution of c given a and G_c is the marginal cdf of c. Note that the second equality follows from the independence assumption. If this is the case, then an estimate of

$$\frac{d\,E(s|a)}{d\,a} = g_c(a + \kappa) \tag{2}$$

measures the price sensitivity of development.[6] To see this clearly, suppose that a and c are uncorrelated, which each having a uniform distribution defined over a compact support.

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[6] Recall that $p_i = a_i + w - \underline{w}$ so that $\dfrac{\partial p}{\partial a} = 1$.

Illustration - Uniform Distribution

If both G_a and G_c are uniform and $c_i \perp\!\!\!\perp a_i$:

$$Pr(s_i = 1|a_i) = \begin{cases} 0 & \text{if } a_i \leq \underline{c} - \kappa \\ \dfrac{a_i + \kappa - \underline{c}}{\overline{c} - \underline{c}} & \text{if } a_i \in (\underline{c} - \kappa, \overline{c} - \kappa) \\ 1 & \text{if } a_i \geq \overline{c} - \kappa \end{cases}$$

If $\underline{a} > \underline{c} - \kappa$ and $\overline{a} > \overline{c} - \kappa$, the $Pr(a \in (\underline{c} - \kappa, \overline{c} - \kappa)) = 1$ and the derivative $\dfrac{d\,Pr(s_i = 1|a_i)}{d\,a_i} = \dfrac{1}{\overline{c} - \underline{c}}$ measures price sensitivity of development. As a consequence, the size of the increase in the mass of developed homes given an increase in a_i identifies the pdf of the cost distribution (in the uniform case). This is illustrated in Figure 2, which represents different increases in development resulting from an equivalent increase in a_i. In the low dispersion case (when $\overline{c} - \underline{c}$ is small, left-panel), the same change in amenities results in a larger increase in the mass of developed land than in the high dispersion case (right-panel). Note that the effect of amenities (or prices) on development depends on the pdf of the cost distribution and not on average costs.

Before turning to how this theoretical framework informs our empirical strategy, it is useful to highlight how the derivative in equation 2 relates to a policy parameter of interest. Suppose a local government engages in a policy to promote re-development, providing a subsidy σ to developers who re-develop PdL sites. In this context, it is straightforward to see that the equilibrium is characterized by the following statements:

1. Developed locations $i \in S^*$ satisfy $a_i + \sigma - c_i + w - \underline{u} \geq \underline{r}$.
2. All undeveloped locations $i \notin S^*$ satisfy $a_i + \sigma - c_i + w - \underline{u} < \underline{r}$.
3. For each location $i \in S^*$, equilibrium transaction prices for land and houses are $r_i = a_i + \sigma - c_i + w - \underline{u}$ and $p_i = a_i + w - \underline{u}$, respectively.
4. The total mass of re-developed sites is $\int_{\underline{a}}^{\overline{a}} \int_{\underline{c}}^{\sigma+a+w-\underline{u}} g(c,a)\, dc\, da$

With the subsidy in place, equation 1 becomes:

$$E(s|a) = G_{c|a}(\sigma + a - \kappa) = G_c(\sigma + a - \kappa)$$

where the second equality follows from the independence assumption $a_i \perp\!\!\!\perp c_i$. In this case, note that:

$$\frac{d\,E(s|a)}{d\,a} = \frac{d\,E(s|a)}{d\,\sigma} = g_c(a+\sigma+\kappa)$$

Hence, we can use the effect of (exogenous) amenities a to estimate the potential effect of subsidies σ on re-development. Note that a similar case can be made for changes in w. Actually, changes in income or employment are often used to trace out housing supply schedules (see for example Saiz (2010)). Longitudinal estimates of housing supply elasticities are easy to rationalize within this framework. Instead of using cross-sectional variation in a, one could use time series variation in w to estimate the response of supply to prices.[7]

2.2. ***Empirical Strategy through the Lens of the Model***

A first empirical challenge emerges because the assumption $a \perp\!\!\!\perp c$ may not be true in general. For example, in a monocentric city, low amenity areas such as areas far from the city centre may be harder to re-develop because of reduced accessibility. Conversely, previously developed land near the center may be more likely to contain larger structures such as derelict buildings, so that high amenity areas could have higher re-development costs. If the independence assumption does not hold, then the second equality in equation 1 does not follow. Different values of a may be associated with different distributions of c. In a regression of s_i on a_i omitted costs may generate bias, so that it is not possible to know whether the resulting derivative measures moves along the cost distribution (as in Figure 2) or shifts in the cost distribution. A second empirical problem is that, in general, a_i is not observed by the econometrician. Moreover, prices p_i are only observed for developed sites. A solution of both of these problems is possible if an amenity q_i which is uncorrelated to c_i can be observed in all locations. By studying the effect of changes in an observed amenity (school quality) on prices we solve the second problem. Assuming that is uncorrelated with c_i within certain locations, we solve the first one.

Formally, suppose there are different sets of locations $b_1, ..., b_B$ in which school quality q_i is observed for the econometrician. In this context, assume a_i can be decomposed into an observable and an unobservable component as in

$$a_i = f(q_i) + \alpha_i$$

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[7] Recall that $\kappa \equiv w - \underline{u} - \underline{r}$.

such that

$$q_i, \alpha_i \perp\!\!\!\perp c_i | b$$

where function $f(.)$ is strictly increasing, q_i is observed and α_i is unobserved. If this is the case, we can use observed variation in q_i to estimate a local effect of prices on s_i, where the cost distribution is fixed, conditional on the site's group b, as a result of the conditional independence assumption.[8] We can then use $f(q_i)$ as a demand shifter to estimate the price sensitivity of development of PdL sites. Function $f(.)$ is generally unknown but can be estimated from observed housing transactions if q_i is known.

We can then proceed as follows: i) Using observed home sales, we estimate the effect of q_i on p_i using variation within groups only. This yields $\widehat{f(q_i)}$. ii) Given q_i is observed for all locations, we can obtain predicted prices by substituting q_i into $\widehat{f(q_i)}$ in all locations. iii) Finally, we can obtain a measure of how prices affect the probability of re-development by estimating the effect of $\widehat{f(q_i)}$ on $Pr(s_i = 1)$ within each group $b_1, ..., b_B$.

This framework has a straightforward mapping to the empirical strategy below. The sets $b_1, ..., b_B$ are the groups of locations within 1 kilometre of school admission boundaries, q_i is the quality of the closest school to each location. Finally, steps i) to iii) are similar to a two stage least square estimation in which school quality is used as an instrument for housing prices (under the assumption that $f(.)$ is linear). Implementation will proceed by using a measure of brownfield presence as a dependent variable (corresponding to $1 - s_i$ in the model) and using a sample which includes currently vacant or idle PdL sites as well as other areas which may or may not have been re-developed in the recent past. This requires to add the assumption that within our location groups (bs) the location of initial PdL sites are uncorrelated to a. The validity of this assumption is discussed in sections 4.3 and 6.

The framework is also helpful to clarify what is the external validity of the estimates below. Consider the set $\Omega = \{b_1 \cup b_2 ... \cup b_B\}$. The resulting estimate of the effect of prices on re-development will be given by the distribution of c_i within Ω, $G_{c|\Omega}$. It is in this sense that the estimates will be local. If the locations in Ω are a random sample of all locations then we will have that $G_{c|\Omega} = G_c$ and the method outlined above estimates the population parameter. In general this may not be the case and I will obtain local estimates. It is worth noting that this issue

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[8] Note that I have not assumed $q_i \perp\!\!\!\perp \alpha_i | b$. This is a standard assumption in studies trying to identify the willingness to pay for school quality. It is unnecessary here as long as the unobserved amenity is uncorrelated with building costs.

is likely to be shared by any empirical strategy relying on local randomization or policy-induced natural experiments that do not encompass the whole set of land sites under consideration.

3. Data

In the baseline empirical analysis I combine data from different sources. Data on previous developed land sites is obtained from the National Land Use Database of Previously Developed Land (NLUD-PDL). This dataset was assembled by the Department for Communities and Local Government from information provided by English Local Authorities. It includes geo-location (latitude and longitude), site area (in hectares), type of previous use and other characteristics for each site. I use the 2007 version of this dataset in this paper.[9] Sites are drawn as circles on a plane, centred in the coordinates of each site with radius recovered from the surface area data. Both the coordinates and the area of each site are obtained from the source. This data covers PdL sites for all of England.

I use two alternative sources of data for housing transaction prices and housing characteristics. On the first place I use a data from Nationwide, the UKs largest mortgage provider, for the years 2002-2006, with a total of 356,369 transactions. The data includes price, date of sale, postcode and a series of physical characteristics including house size (in squared metres), number of bedrooms and bathrooms, building age, and dummies for homes with garage or central heating. These characteristics are filtered out in a hedonic regression to obtain comparable price levels not driven by structural differences. I also use administrative data from the Land Registry including the universe of housing transactions in England for the years 2002-2006, with over 6 million sales in total. The dataset includes the date and price of each transaction as well as the postcode for each property. It also includes a small set of housing characteristics comprising property type, a newbuild dummy and a leasehold dummy.[10] Importantly, the dataset does not include information on floor size or other structural characteristics of the property. The lack of information about the property implies that the dataset does not allow to filter hedonic characteristics. As a result, I only use this source to validate the Nationwide dataset and in a robustness check (see section 6).

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[9] Later versions are available for the years 2010, 2011 and 2012 which are broadly consistent with the 2007 version. I use the 2007 version here because I later use data on land use changes in an ex-post analysis for the years 2007-2011.The 2010 version of the NLUD-PDL is used in a robustness check in section 6.

[10] In the Land Registry Price Paid dataset property type is recorded as a categorical variable with types corresponding to detached, semi-detached, terraced houses and flats.

Data on school performance are obtained from the Department of Education, which is the government department responsible for education in England. The school performance tables include data on standardized test scores for students completing key-stage 2 education level (11 years of age) as well as measures of value added, teacher-to-pupil ratios, school postcodes and others school characteristics. County borders are school admission boundaries, so locations are matched with the closest school within each county.

I combine data on test scores with information on physical land characteristics and other determinants of supply (potential supply-shifters) including elevation, landslide risk, planning refusal rates, agricultural land quality, etc. Most of these variables are obtained from the British Geological Survey. These are used to validate the empirical strategy in section 4. I obtain demographic characteristics at a disaggregated level from the 2001 census. The data is at the level of 2001 output areas (OAs) which are defined for data collection purposes as aggregations of postcodes containing roughly 140 households each. There were 165,665 OAs in England in the 2001 census, for which I have the fraction of black and Asian residents, fraction of unoccupied housing units, fraction of residents employed and unemployed.

In a complementary analysis in section 4.3, I use data from the Land Use Change Statistics (LUCS) which record the changes in land use as measured in the Ordinance Survey (a British geographical database) for the years between 2007 and 2011. The LUCS data includes georeferencing, approximate area, new and previous use of each site and year in which the change occurred. I draw the changing sites in a plane, assuming circular shapes centred at the coordinates and radius inferred from the approximate area measure in the dataset.

Finally, I use maps for English OAs, postcodes, English counties (which define admission boundaries) and Unitary Authorities provided by the Office of National Statistics and Digimap. A thorough discussion of data sources and dataset assembly is present in Appendix B.

4. Empirical Strategy

4.1. Boundary Discontinuity Design

The empirical strategy presented here is devised to estimate price sentsitivity of re-development by addressing the classic endogeneity problem in the estimation of supply elasticities from market outcomes. Observed changes in the re-development of PdL may be driven by demand changes or changes in costs, which we can think about as supply shifters. In terms of the framework above, we want to induce variation in prices induced by observed amenities which is orthogonal to changes in re-development costs. For this purpose I implement a boundary discontinuity design (BDD) using school admission boundaries and measures of school quality based on standardized test scores. This BDD has often been used to obtain estimates of willingness to pay for education quality as in Black (1999) or Gibbons, Machin and Silva (2013). In my case I use a version of the specification used in these studies as a first stage in a regression of PdL presence on log prices.

The objective of the analysis is to study how the presence of PdL sites in space is affected by local housing prices, so the unit of analysis is a spatial unit. I construct a grid of 100m × 100m cells (or hectares) within 1 km of county boundaries. For each grid cell, I construct a dummy taking value 1 if there is any PdL within the cell, and also a continuous variable measuring the fraction of PdL in each cell. These will constitute the main outcome variables in the analysis. I then impute data on hedonic-filtered house prices of the closest transaction, quality of the closest school (as measured by ks2 scores) within the admissions district and census characteristics from LSOAs. I also compute distance between each cell centroid and the corresponding council boundary. The resulting dataset contains roughly 1.6 million hectares, each assigned to a specific school admission boundary and matched with the test scores of the closest primary school within its county. Basic descriptive statistics for this dataset can be found in table A.16, in appendix A and details of dataset assembly presented in Appendix B.

Using this dataset, I proceed to estimate the effect of prices on the probability of having PdL land in a given hectare by two stage least squares, as indicated in section 2. The two equations are:

$$ln(P_i) = b_i + \gamma SchoolScore_i + County_i + \eta' X_i + v_i \tag{3}$$

$$PdL_i^{2007} = b_i + \beta \widehat{ln(P_i)} + County_i + \theta' X_i + u_i \tag{4}$$

where $ln(P_i)$ is the log of prices imputed to grid cell i, b_i represents a set of boundary dummies, included so that the coefficient of interest is estimated exclusively from within-group variation for properties close, and on either side, of the boundary. These are the groups of locations referred to in section 2. Given that counties often have more than one boundary we can also control for county specific effects $County_i$. Controlling for county effects is important because other policies may vary between different counties.[11] $SchoolScore_i$ is a measure of observed school quality which records average point score for each primary school. In all specifications, I add a set of controls X_i including independent terms for distance to the boundary in the good (high school quality) and bad (low school quality) sides of the boundary, as well as latitude and longitude of each hectare centroid. Other controls relating to potential *supply-shifters* are included in some specifications. Census characteristics are potentially an outcome of the treated so my preferred specification does not include these controls. In any case, their inclusion has little impact on the quantitative findings.

The outcome variable in the second stage is PdL_i^{2007} which can be a dummy taking value 1 if a hectare contains brownfield land or the fraction of brownfield land in the grid cell, depending on the specification. The coefficient of interest is β, where $\widehat{ln(P_i)}$ are fitted values obtained from the first-stage regression. The interpretation of β depends on the outcome variable used. When using a dummy outcome, it measures the effect of a 1% change in prices on the probability that a given hectare contains brownfield land. My hypothesis is that prices have a negative influence on the probability of having PdL land in a hectare, and the estimated coefficient provides a measure of the price sensitivity of re-development as discussed in section 2.

The key assumption for identification is that the distribution of re-development costs is the same on either side of the boundary conditional on boundary effects and controls. The credibility of this assumption hinges on selecting grid cells sufficiently close to the boundary and assuming that re-development costs vary continuously at the border. Results are provided for different spatial bandwidths.

4.2. *Matching Across Boundaries*

A problem with the previous estimates is that they rely on comparing hectares which are potentially far away from each other. Boundary fixed effects ensure that estimates are obtained from within variation only and bandwidth restrictions ensure observations are not too far away from the boundaries. However, low school quality cells could still be several kilometres away from high school quality cells they are compared to because I impose no restriction on the distance between cells. In order to avoid this issue, I first implement a one-to-one matching algorithm on cells from either side of the boundary. The algorithm proceeds as follows:

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[11] For example, planning restrictiveness could differ between counties (see Hilber and Vermeulen (2016)). However, I will show below that planning restrictiveness, as measured by the fraction of rejected planning applications, is smooth across boundaries.

Matching Algorithm

1. Select the grid cell closest to boundary b.
2. Select the closest grid cell on the other side of b.
3. Attribute a match identifier, and a distance between grid cell centroids to the pair of cells
4. Remove the pair from the eligible cells.
5. Continue from step 1 until all cells are matched for b on one side of the boundary.

Once all matches are obtained, I can estimate a spatially-differenced version of the equations above, in which all key variables are differenced within each match. Specifications in 2 and 3 then become:

$$\Delta ln(P_i) = b_i + \gamma \Delta SchoolScore_i + \eta \Delta X_i + \Delta v_i \tag{5}$$

$$\Delta PdL_i^{2007} = b_i + \beta \widehat{\Delta ln(P_i)} + \theta \Delta X_i + \Delta u_i \tag{6}$$

Spatial differencing eliminates the boundary fixed effect b_i, as matches are obtained *within* each boundary. The differenced county fixed effects can now be represented with a boundary effect as their spatial difference is equal for all cells on one side. Estimation of spatially differenced equations can then follow the standard 2sls procedure.

4.3. Land Use Changes

One possible concern with the cross-sectional methods discussed above is that the school quality differences across boundaries may be correlated to pre-existing differences in land use (e.g. manufacturing location) which later gave rise to differences in brownfield presence. Suppose school quality differences where persistent over decades and that the associated amenities are only valued by households and not firms. If this was the case, then historical land use patterns could be affected by school quality. The resulting observed cross-sectional differences in PdL site presence could not be interpreted as the result of conversion but rather as the consequence of initial differences in land use.[12] While this may be of some interest, it confounds estimate interpretation and, importantly, implies that the estimates in the previous sections cannot be linked to the elasticity of brownfield conversion which constitutes the interest of this paper.

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[12] One factor that mitigates this concern is that school performance tables were only made available in the late 90s.

In order to address this issue, I first implement a complementary empirical strategy which focuses on the effect of prices on *changes* in land use after 2007. For this purpose I use data on land use changes for the period 2007-2011 coming from the Land Use Change Survey (LUCS). Specifically, I use data on this survey to identify grid cells where at least some of the land changed towards residential use in the specified period. Moreover, I restrict the analysis to 2007 brownfield sites as defined in section 3. I use this sample to re-estimate by baseline model as specified in equations 3 and 4 but substituting the dependent variable in 4 for $LUCS_i^{07-11}$ which is the fraction of land within a grid cell i which experienced a change towards residential use in the 2007-2011 period. The estimating equation now becomes:

$$ln(P_i) = b_i + \gamma^{LUCS} SchoolScore_i + County_i + \eta^{LUCS\prime} X_i + \xi_i \tag{7}$$

$$LUCS_i^{07-11} = b_i + \beta^{LUCS} \widehat{ln(P_i)} + County_i + \sigma^{LUCS\prime} X_i \epsilon_i \tag{8}$$

If high amenities lead to PdL conversion, I should find a positive estimate for β^{LUCS}. This would suggest that our cross-sectional estimates are not driven by differences in initial land use but rather by actual brownfield conversions responding to amenity differences across the boundary. In a complementary analysis in section 6, I try to tackle this issue by focusing on school admission boundaries that were instituted only in the mid-late 1990s.

4.4. Validating the Empirical Strategy

This empirical strategy used here requires that i) re-development costs vary smoothly at the boundary, and ii) school quality has a sufficiently large effect on housing prices to warrant its use as an instrument.

As a sanity check, I first show that latitude and longitude vary smoothly across boundaries, and that school quality jumps when moving from the low quality to the high quality side of the county border. The graphs, displayed in figure A.7 of Appendix A, merely show that the dataset has been adequately constructed. As expected, both latitude and longitude vary smoothly at the boundary and school quality exhibits a sharp discontinuity, with school qualities in the *good* side exhibiting roughly 0.6 of an s.d. higher average quality than in the *bad* side.

I next turn to show that supply-shifters such as physical characteristics of the terrain (elevation and landslide risk), of the soil (aquifer and agricultural land quality), presence of parks or gardens, or regulatory constraints vary continuously at the boundary. Aquifers and landslide risk are cited as important determinants of sprawl and residential density (and presumably development costs) in Burchfield et al. (2006) and Duranton and Turner (2016), respectively. Presence of parks or gardens may limit access or transit to an area. Land parcels with higher agricultural yields may have higher alternative use and therefore be less likely to be developed. Finally, planning constraints can be seen as increasing construction costs substantially and are known to be an important obstacle to development (see Gyourko and Molloy (2015), Glaeser and Gyourko (2018) and the references therein). I measure them using average planning application refusal rates for English local planning authorities obtained from Hilber and Vermeulen (2016).

Figure 3 illustrates changes in supply-shifters at school admission boundaries. The horizontal axis measures distance to the boundary. I identify which side has the highest average school quality and sort homes according to their side. Positive distances correspond to the high average school quality side and negative distances correspond to the low average school quality side of the boundary, respectively. Solid lines represent fourth degree polynomials estimates on either side, dashed lines correspond to 95% confidence intervals and gray circles correspond to distance bin averages. We can observe that in general there are no substantial discontinuities in supply drivers at the boundary. In the case of the planning refusal rates there appears to be a slight discontinuity with refusal rates being roughly 0.5 percentage points higher on the high quality side of the boundary. This difference is however not statistically significant in a reduced-form regression.

Table 1 provides estimates of the partial correlations between school quality and the local supply shifters enumerated above using matching across boundaries as discussed in section 4.2. These estimates are a necessary complement to the descriptive analysis in figure 3 because they incorporate more detailed variation in school quality over space. We observe that in all cases the coefficient of interest is very small and also statistically insignificant in 23 out of the 24 cases. Take the case of planning refusal rates. The point estimate indicates that a 1 standard deviation increase in school quality leads to a minute 0.1 percentage point increase in planning refusal rates (over an average of 26%). These coefficients provide reassuring evidence that supply conditions do not jump with schooling quality at the boundary.

The variation induced on prices by school quality is illustrated in figure 4. The horizontal axis measures distance to the boundary, with cells in the low average score side having negative distances and cells in the high average score side having positive distances. The vertical axis represents mean prices in thousands of pounds (log scale). Solid lines are fitted using fourth degree, dashed lines represent 95% confidence intervals, and gray circles represent local averages. We can observe a clear discontinuity in prices at the boundary, with high school quality areas having higher prices that low school quality areas a few metres away. There is substantial overlap between confidence intervals, largely because I am only using a fraction of the variation in school quality for this graphical illustration. A formal test of relevance of the instrument is conducted by estimating the first-stage using matching across boundaries, with results provided in table 2.[13] I provide estimates for different bandwidths (in columns) and different sets of controls and fixed effects (in rows). Across specifications, we observe that school quality is a significant determinant of house prices. Point estimates indicate that a 1 standard deviation increase in school quality leads to an 5% increase in housing prices. F-statistics for the instrument in question are provided in each row and are all above 20; the instrument is strong.

Note that the effects reported in table 2 can be compared to those provided in the associated literature on willingness-to-pay for education. The closest paper in term of geographic scope and study period is Gibbons, Machin and Silva (2013). They find a 1 s.d. effect in ks1 scores (7 years) increases house prices by roughly 3%, and a similar effect of value added as measured by the increase in scores between ks1 and ks2 levels (between 7 and 11 years of age). As can be seen from table A.17, my estimated effects are in this range, with 3% falling within the associated 95% confidence interval.

5. Results

5.1. Reduced-Form and Baseline Estimates

Reduced-form effects of school quality on brownfield presence are illustrated in figure 5. The vertical axis now measures the average fraction of cells with some brownfield land at each distance. Fourth degree polynomials are independently estimated in both sides of the boundary, and gray circles correspond to local averages. We observe a discontinuity in the fraction of hectares containing PdL sites, with brownfield being less likely on the high price (good school quality) side of the boundary. Confidence bands are large and it is unclear whether this discontinuity is indeed statistically significant. One reason for this is that we are only using a fraction of the variation in the data by grouping hectares on good and bad sides only. These can differ from boundary to boundary, not to mention that there is also variation in school quality *within*

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[13] First-stage estimates without matching across boundaries are provided in table A.17 of Appendix A and lead to the same qualitative conclusions.

each side. In fact, estimates from reduced-form regressions of a brownfield dummy on school quality, reported in table 3 indicates school quality has a negative and significant effect on the presence of brownfields at all conventional levels.

In order to quantify the magnitude of the effect of prices on the conversion of brownfield land, I obtain 2sls estimates, using school quality as an instrument for housing prices. Results for different spatial bandwidths and fixed effects/controls are presented in table 4. Estimates of the effect of prices on the probability of finding a PdL site in a grid cell are consistently negative and significant at all conventional levels. The point estimates are fairly stable, at roughly -0.09. This implies that a 1% increase in prices reduces the probability of a PdL site by 0.09 p.p. While this effect is admittedly small, it economically significant. Recall that the baseline average in the dependent variable is 1.45% so this implies that a significant increase in prices would make a sizeable dent in the presence of brownfield sites. Assuming that the true effect is indeed linear in log prices this would mean that a 16% increase in prices would essentially wipe out all brownfield sites. This linearity assumption is admittedly strong, but provides an easily interpretable back of the envelope figure.

5.2. Spatial Matching Estimates

My baseline estimates are the result of within-boundary regressions. Even when the bandwidth around boundaries is restricted to short distances of 250 metres, grid cells used in estimation could still be quite far away from each other. In order to avoid this, I employ the matching method described in section 4.2 and use spatial differenced data to obtain my preferred estimates of the effect of prices on the incidence of previously developed land sites.

Instrumental variable estimates of the sensitivity of brownfield conversion to prices for out matched specification are provided in table 5. The coefficients are still negative and significant across specifications. In my preferred specification, with a 250 metre bandwidth, county effects and other controls, the effect of interest is -0.069 (last column, final row). This implies that a 1% increase in prices reduces the probability of finding a PdL site in a given grid cell by 0.069 percentage points. Note that the baseline estimate of 0.08 falls within the 95% confidence interval of this estimate given by $-0.069 \pm 1.96 \times 0.029$. Under the assumption of linearity of the effect of log prices on the probability of redevelopment, this result implies that a 21% increase in housing prices across English locations would be necessary to prompt the conversion of most English PdL sites in the long run.

I now turn to the estimates of the sensitivity of brownfield conversion to prices using a continuous outcome measuring the fraction of brownfield land in a grid cell. The estimates are reported in table 6. Estimates lie between 0.03 and 0.04 depending on the bandwidths and sets of controls, with the point estimate in my preferred specification being -0.037 . In all cases, estimates are significant at the 5% level. The average fraction of brownfield land taken over all grid cells within 1 km of a county boundary (including zeroes) is 0.64%. Therefore, our estimate suggests that a 18% increase in prices in all locations would be sufficient to trigger re-development of the vast majority of PdL sites. This number is close to the one obtained using brownfield dummies only, indicating no substantial difference in qualitative results – and only a minor difference in quantitative results – when incorporating finer spatial variation in PdL location.

Taken together, the results of the cross sectional analysis reveal that there is substantial sensitivity of brownfield re-development to prices. Given these are cross-sectional estimates and that school quality is quite persistent we can interpret them as long run estimates of the effect of prices on re-development, with short run estimates likely to be lower. This is encouraging for re-mediation relief and other infill re-development policies such as subsidies or tax breaks which also depend on the price sensitivity of re-development to be successful.

5.3. Land-Use Changes

I now present results for the analysis of the effect on prices on observed land use changes over the 2007-2011 period. The purpose of the analysis is to elucidate whether the differences in brownfield presence documented in the previous sections are simply a static fact or rather whether conversions continue in high residential price areas after 2007. The sample is now restricted to all grid cells containing some brownfield land. First-stage estimates for the restricted sample have been relegated to table A.18 in Appendix A and confirm the instrument is still strong, despite the sample restriction.

The resulting IV estimates of the effect of price levels on land use changes are presented in table 7. The dependent variable is the fraction of the brownfield cell that experience a change to residential land use between 2007 and 2011. We observe positive effects across specifications, with most coefficients being significant at the 5% or 10% level. Qualitatively, this implies that cells with higher amenity-induced demand are more likely to experience a change towards residential land use, consistent with the notion that higher prices lead to brownfield conversion. The coefficients are somewhat unstable across specifications, but this is likely to be a consequence of the lack of precision induced by the small sample, as will be discussed in section

6. My preferred specification corresponds to the estimates using the shortest bandwidth in the equation with county effects and controls, yielding an estimate of 0.098. Over the 2007-2011 period, areas with higher amenity values experienced higher rates of brownfield conversion. A 1% increase in prices increases the fraction of a hectare changing towards residential use by 0.1 percentage points. Two conclusions can be extracted from these results. On the first place, it is unlikely that cross sectional estimates are driven by initial differences in land use. Secondly, it shows that the conversion of these brownfields takes time, as differences in school quality were still leading to conversions after the 2002-2006 period in which I measure school quality differences. The estimated effects are relatively small, suggesting that much of the conversion had already taken place in 2007.

*5.4. **Heterogeneous Effects***

In this section, I discuss factors that could affect the sensitivity of re-development to demand conditions. The potential effects of an incentives-based brownfield remediation policy could differ substantially depending on the location of the site in the city system, the origin and characteristics of different types of sites, or the policy environment itself in the form of planning restrictions. I turn now to test whether the price sensitivity of brownfield presence is shaped by these conditions.

5.4.1. Cities

Previously developed land sites occur in urban and rural environments, but sensitivities to re-development could differ. For example, the cost distribution could be different in these different areas because of lack of access to employment or road transport in remote locations. To explore this I study different subsamples focusing only on urban spatial cells, the 20 largest English cities or the metropolitan area of London. Sample restrictions applied here are based on Travel-to-work Areas, which can be thought of as metropolitan areas for selected cities, defined based on commuting patterns.

Results are provided in table 8, where the first row present baseline estimates and the second presents estimates after spatial matching. In both cases I measure PdL sites with a dummy taking value 1 if there is any brownfield land within the hectare.[14] The first column presents the baseline and matched estimates that have been reported above for comparison purposes. In column 2, the sample is restricted to hectares in urban areas based on the urban/rural classification by the ONS.

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[14] Estimates using the fraction of brownfield land in a grid cell are reported in table A.20 in appendix A.

We see that the point estimates increase relative to those obtained with the full sample. Column 3 reports results excluding London. The point estimates are almost unchanged, indicating results are not driven solely by the English capital, which accounts for roughly 5% of my sample. Results in columns 4 and 5 are obtained focusing exclusively on London and on the 20 largest cities in England, respectively.

Together with the results for all urban hectares, these estimates show that the sensitivity of unused land to prices is higher in cities. This occurs mainly because the baseline probability of having a PdL site in a grid cell is generally larger in urban areas. Differences in amenities will generate very limited changes in brownfield presence in areas which have almost no brownfields to begin with.[15] That being said, it is important that the effect of demand conditions on brownfields is clearly present and large in cities given that it is it is usually city or local governments in urban areas that are more concerned with re-mediation and PdL regeneration policies. An additional message from the estimates reported in table 8 is that the main results in section 5 are not driven by a few geographical areas. In fact, estimates are quite similar when looking at other, smaller, urban areas in England too (not shown).

5.5. Previous Land Use

I next study whether brownfields of different origins respond differently to demand conditions. It is reasonable to think, for example, that the cost of re-development is higher for sites that used to be devoted to manufacturing, mining or physical infrastructure as these may contain pollutants or require specialized machinery. This difference in the cost distribution could lead to a difference in price sensitivity. To study this, I split brownfields between those with a manufacturing origin and those with a different origin (residential, commercial or other).[16] With these I construct variables PdL_i^{Manuf} and PdL_i^{Other} taking value 1 if there is PdL of manufacturing or other origins in a grid cell, respectively. I then obtain separate estimates of the effect of log prices on each type of brownfield.

Results for baseline estimates are provided in table 9. We observe that the estimates are very similar for both types of brownfields across specifications, for baseline and matching estimates and for different bandwidths. For example, baseline estimates of the effect of log price on the probability of development are -0.043 and -0.037 for manufacturing and other brownfields,

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[15] The fraction on hectares containing PdL in my full sample is 1.45%, while the same fraction is as high as 2.8% in the 20 largest English urban areas.

[16] Alongside manufacturing I also consider sites with mining, or infrastructure origin as these are expected to also have high or very high re-development costs.

respectively.[17] No two coefficients are statistically different from each other. This suggests the responsiveness of brownfield redevelopment to prices is similar despite its previous land use and, presumably, the associated cost of redevelopment. The result may seem surprising at first given that the average cost of re-development is likely to be higher in ex-industrial or ex-mining sites. However, as discussed in section 2, it is the density of the cost function and not the expected value that determines the price sensitivity of re-development. So this may rather indicate that the cost distribution is fairly flat. If this is indeed the case, then a subsidy is likely to have a similar effect on conversion for different types of sites, which is relevant given that policies are usually tailored to high cost sites containing or pressumably containing chemicals, pollutants or heavy structures such as those found in ports or large manufacturing plants.[18] Moreover, it is these sites that are likely to generate the largest negative externalities and, therefore, the ones for which redevelopment can have a larger effect on welfare. It is encouraging that these sites are also sensitive to demand conditions.

5.6. Planning Restrictiveness

I now turn to study whether the price sensitivity of brownfield re-development varies with planning restrictiveness. Planning policy is perhaps the single most relevant policy affecting land use. Understandably, its link with land supply, prices, or the allocation of land to different uses has been studied thoroughly. Planning policy can sometimes operate by imposing restrictions to development. Does this have an impact of the sensitivity of re-development to prices? In order to test whether this is the case, I use a measure of planning refusals borrowed from Hilber and Vermeulen (2016). This records the fraction of all applications that were rejected in the planning process between 1979 and 2008 for all English planning authorities. I use this refusal rate as a cross sectional proxy for the different levels of restrictiveness of the planning authorities in different local areas. I split my sample around the median refusal rate and obtain separate estimates for each subsample.[19]

Results are provided in the first two rows of table 10. Panel A displays estimates for low refusal rate areas - areas with low planning restrictiveness - and panel B displays those for high

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[17] Estimates for the spatial matched sample using a 750 metre bandwidth around the boundary. See first and third columns of the lower row in table 9

[18] See Appendix C for a policy review including details on site eligibility conditions and examples of government funded re-development projects.

[19] I obtain average refusal rates for every group of cells - every boundary - and use the median of that boundary average to split the sample into a high refusal and a low refusal area. This ensures that grouped bands of hectares around each boundary are kept together when selecting the sample.

refusal areas. Columns 1 and 2 provide estimates of the effect of prices on the probability of finding a PdL in a grid cell. Columns 3 and 4 focus on the changing fraction of developed land within a cell. We observe that prices affect brownfield presence both for areas with low and high refusal rates. However, point estimates are roughly 25% larger (in absolute value) in high refusal rate areas that in low refusal rate areas across specifications.

To incorporate more of the variation in refusal rates in the analysis I estimate the baseline equation adding an interaction between log prices and the average refusal rate in the boundary to the second stage. I add in as an instrument an interaction between school quality and the refusal rate. This deals with endogeneity of the price variable but the refusal rate may still be endogenous and therefore interpretation should proceed with caution. Panel C provides estimates of both the coefficient of log price and the interaction term. The refusal rate has been normalized to have mean zero and a s.d. of 1 therefore the first coefficient estimates price sensitivity at the mean and the interaction term indicates how that changes for a 1 s.d. increase in restrictiveness. The coefficient on the interaction term is positive in all specifications and statistically significant in three out of four cases. Looking at columns 1 and 2, this suggests that in areas with planning restrictiveness 1 s.d. above the mean, the price responsiveness is about 2/3 of the magnitude in areas with average restrictiveness.

I interpret this as suggesting that planning restrictiveness prevents brownfield re-development. This also indicates that an incentive based policy for re-development (e.g. a subsidy) could have larger effects in places with relatively more lenient planning processes.

6. Robustness Checks and Placebos

In this section, I present a series of robustness checks to show my main results are not driven by i) household sorting in response to brownfield sites contaminating the instrument, ii) original differences in land use before PdL sites became vacant or derelict, ii) details of the specification such as bandwidth choice or functional form assumptions, or iv) measurement error in brownfield location. I also include a series of placebos to validate my results on land use changes between 2007 and 2011.

6.1. Household Sorting and School Value-Added

Perhaps the most serious threat to identification given the empirical strategy employed in this paper is associated to sorting of households in response to brownfield sites. Previous research has documented the presence of negative externalities for at least some of these sites (Greenstone and Gallagher (2008), Kiel and Williams (2007)), as well as sorting in response to these externalities (Gamper-Rabindran and Timmins (2011)).[20] Household sorting could affect school scores, particularly if sorting is income-related and income can affect students' performance (see for example **?**). In that case, there could be reverse causality from the dependent variable to the instrument, thus compromising the credibility of our estimates. Moreover, this would bias our estimates away from zero.

To avoid this potential problem, I propose two potential solutions. On the first place, I substitute school value added for the average school score as my instrument. School-value added measures increases in standardized test scores between school entry and 11 years of age (between *key-stage 1* and the end of *key-stage 2*, in the English Department for Education terminology). Insofar as student household quality effects are already present at school entry, this instrument will not be affected by household sorting. Results from estimation using this instrument and a PdL site dummy outcome are reported in Table 11. Results from estimation using a PdL fraction outcome are reported in Table A.21 in appendix A. In both cases we observe that coefficients continue to be negative, significant and of a similar magnitude, if slightly larger in absolute value. Estimates are generally not significantly different from the point estimates using average school score as an instrument. This is reassuring. Even if value-added adjustments did not fully account for sorting, we would expect the bias mentioned above to be reduced substantially if it was present at all. However, point estimates actually move *away* from zero, and not by much.

In addition, I have estimated equation 4 by using the initial instrument and controlling for census characteristics of households in each grid cell. Results are essentially unaltered, again showing that *contemporaneous* household sorting appears not be affecting my main estimates.[21] The next subsection presents additional checks which address potential concerns about *historical* and persistent sorting effects of land use and school quality.

6.2. New Boundaries: Unitary Authorities

My interpretation of the cross-sectional estimates in section 5 could be compromised if the observed differences in brownfield presence is not driven by differences in re-development of sites but rather by initial differences in land use. For instance, if areas with good school quality

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[20] This literature has largely focused on the United States, where the definition of brownfield requires some degree of existing or perceived contamination. Perhaps these types of externalities are weaker in the context of this paper, were most sites will feature no contamination.

[21] Results not reported but available upon request.

decades ago were less likely to contain manufacturing activities, this could have led to lower brownfield presence today after the structural transformation away from manufacturing that began in the seventies. If school quality is very persistent over time, then this could induce our cross-sectional correlation even if there was no effect of amenities on ex-post conversion.

As mentioned above, the evidence on land use changes between 2007 and 2011 casts doubt on this interpretation. But I can further explore this possibility by exploiting the creation of Unitary Authorities (UAs) by a decentralization reform in the 1990s. UAs are administrative divisions of UK local government similar to counties in their functions, including those related to public education.[22] Most of these were created in the late 1990s following previous local authority boundaries. Because local authorities had no functions or responsibilities with regard to educational services, we would not expect sharp discontinuity in available school quality in these areas prior to the creation of UAs between 1995 and 1998. Hence, when focusing on these boundaries, we know initial differences in land use from decades past are unlikely to be correlated with available educational quality in the early 2000s.

Table 12 provides results for the restricted sample of UA boundaries. Because counties typically have only one boundary with a UA, I cannot use county fixed-effects when imposing this sample selection. I only provide estimates with and without supply-shifter controls and for different bandwidths around the boundary. We observe coefficients oscillate around -0.08, similar to those reported in table 4 for the full sample. This is reassuring as it shows that our results are largely unchanged when focusing on boundaries where persistent school quality differences cannot have generated differences in initial land use.[23] Therefore, I continue to interpret the results in my cross sectional analysis as displaying differences in the probability of re-development.

6.3. Bandwidth Choice & Functional Form

A potential concern regarding the robustness of the results in section 5 relates to the choice of bandwidths. Several methods are available to determine one *optimal* bandwidth, following the bandwidth selection literature that has emerged recently. However, it is also straightforward to reproduce results for different bandwidths close to the threshold and observe whether estimated effects experience substantial changes. I follow the latter approach here. Panel A of figure 6

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[22] The main analysis includes these areas as counties.

[23] Similar estimates with spatial matching are presented in table A.22 in Appendix A. Precision suffers because both the number of clusters and the number of observations within a cluster drop substantially after the sample restrictions associated to UA boundaries and to matching are combined. Point estimates in that table are around -0.055, slightly lower but not very different from those in table 5 which oscillated around -0.069 for short bandwidths.

displays the different coefficients obtained by estimating the baseline specification in section 4.1 under several different bandwidths. We observe the coefficients are stable and slightly above 0.08, as reported in table 4. The coefficient is similar even for small bandwidths of 100 metres. Hence, baseline results are robust to changes in bandwidth selection.

Panel B contains a similar graph for the coefficients obtained when using matching across the boundary. Again, the estimated coefficients are negative and significant as expected. The point estimates appear to be smaller for shorter boundaries, but the difference is generally not significant. Finally, panel C displays the coefficients measuring the effect of log prices on the probability of a Land Use Change in the period 2007-2011, as discussed in section 4.3. The coefficients are quite stable and between 0.05 and 0.1, with point estimates for smaller bandwidths being slightly larger. It is also worth noting that this stability in point estimates is accompanied by noticeable differences in the size of confidence intervals, which grow substantially for smaller bandwidths, especially in panel C. This is in all likelihood a consequence of the relatively smaller sample sizes. Recall that my estimates from section 4.3 are obtained restricting our sample to grid cells containing brownfield land only. Given that most changes in the significance of coefficients in panel C of figure 6 are a consequence of larger confidence intervals and not of smaller point estimates, I conclude that the weakly significant coefficients in table 7 are the result of lower statistical power only.

I next evaluate the robustness of my estimates regarding the choice of functional form restrictions implicit in the baseline analysis. In all specifications in the paper using a dummy outcome, the second-stages can be interpreted as a linear probability model. As has been argued in Horrace and Oaxaca (2006), OLS estimates of linear probability models can exhibit significant bias when the average of the dummy dependent variable is either close to 0 or close to 1. In my case, the probability of having PdL Site $= 1$ is only 1.46%, so I cannot rule out that a significant small sample bias may exist. In order to check the relevance of this possible bias on my results, I re-estimate the baseline specification using the two-step estimator in Newey (1987), which specifies the second stage as a probit model. In this way, I avoid the somewhat problematic linear specification of the conditional distribution of a limited dependent variable. Results are provided in table 13. We observe that the probit specification still leads to a significant and positive house price elasticity of re-development.

6.4. Measurement Error

Throughout the analysis, data for brownfield locations in 2007 is obtained from the NLUD-PDL, as discussed in section 3. This dataset records the geolocation and surface area of each brownfield site as reported by local authorities. It is likely that there is some degree of misreporting by local authorities. That is a first potential source of measurement error which would affect our dependent variable. A second source of measurement error relates to prices. As described in section 3, the housing price data used here is derived from hedonic regressions using data on housing transactions from a mortgage provider and subsequently imputed on our grid cell based on spatial location. The spatial imputation mechanism necessarily induces some measurement error in our price measure. Moreover, the data from the mortgage provider may not be representative of all transactions, which could result in further measurement error in the instrumented variable.

I expect these sources of measurement error to have a limited impact on estimated effects. Regarding the problem with imputing brownfield land to cells, this would lead to measurement error in the dependent variable only. Under classical measurement error this would only affect precision, which appears not to be a problem in our estimates. Moreover, the use of the education instrument to obtain predicted values for prices induces some spatial smoothing which can help with this problem. Education quality will be relatively smooth in space when no boundary is crossed. Regarding measurement error in prices, because I use an IV strategy, I do not expect this to have a substantial effect on my estimates.

That being said, I provide two different robustness checks to ensure measurement error is not a significant problem in this context. On the first place, I validate the PdL site location data by obtaining alternative estimates using the 2010 edition of the NLUD. The 2010 data was part of a three year effort to have a consistent PdL atlas after the last NLUD-PDL edition in 2007. The broad methodology of data collection based on local authorities is similar but significant efforts were made to increase data accuracy.[24] Estimates using the 2010 brownfield measures are provided in panel B of table 14 in Appendix A. Estimates of price sensitivity are similar to those obtained with the 2007 measures, negative and significant across specifications. The point estimates are slightly larger than for the 2007 data but all fall comfortably within the corresponding 95% C.I..

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[24] The metadata for the 2010 NLUD-PDl reads “In 2010, detailed reviews of current site intelligence for brownfield sites took place in several local authorities across England to improve the accuracy, currency and completeness of data. ”

In order to evaluate the potential measurement error in prices, I also obtain baseline estimates using Land Registry prices. These are spatially imputed as above but, because they include all transactions in England and Wales, the distances involved in spatial imputation are significantly lower. On the other hand, the amount of housing characteristics present in the Land Registry data is quite limited so the hedonic adjustment is not as relevant as when using the Nationwide dataset. Panel C of table 14 indicates our estimates are still negative and statistically significant. Again, point estimates are almost exactly the same as those reported in panel A using the 2007 NLUD-PDL, and the Nationwide prices.

I conclude from this discussion and the associated estimates that measurement error is unlikely to have a substantial effect on my results.

6.5. Placebo

Finally, I conduct a placebo exercise to further validate the results obtained when looking into the effect of local house prices on ex-post land use changes. As has been argued above, school quality can be seen as an amenity that affects demand of housing in a specific area. While other amenities such as transport access or clean air may affect demand for different land uses, local access to good schools is likely to have an effect only on households, and hence, should only affect re-development towards residential activities. With this intuition in mind I conduct a simple placebo in which land use changes to commercial, industrial and other non-residential uses are taken as dependent variable in the specification presented in section 4.3. Results for this placebo are provided in table 15. Across specifications we obtain small and often negative effects of house prices on changes towards non-residential use. Coefficients are statistically insignificant in all cases. The zero coefficients are consistent with the notion that school quality is a residential-specific amenity. I interpret these results as validating the proposed method to look at changes towards residential use.

7. Conclusion

This paper provides the first estimates of the price sensitivity of vacant or idle land redevelopment. I find that high demand reduces the prevalence of brownfield land in cities. Under the assumption that costs and other supply-side shifters vary smoothly at the school admission boundary, my results can be interpreted as evidence that brownfield redevelopment is responsive to housing prices. Estimates indicate that a 1% increase in local prices reduce the number of hectares with brownfield land in 0.07 percentage points. Given that only about 1.5% of hectares in the sample contain PdL sites, this figure is economically significant. Back of the envelope calculations indicate that a 21% across-the-board increase in prices could lead to the conversion of most English brownfield sites in the long-run. Furthermore, I find substantial effects of prices on ex-post land use changes in 2007 sites for the period 2007-2011.

The results provided here are relevant to evaluate the potential effect that re-mediation relief, tax breaks and price growth can have on re-development of vacant, derelict or underutilized sites. Results indicate that increased demand-side incentives can have moderate effects on re-development, especially in cities. I also find that this is the case regardless of the previous land use of the sites, with relatively higher cost sites such as those previously used in manufacturing or mining also being sensitive to demand conditions. Finally, I provide suggestive evidence indicating that planning restrictiveness has a negative impact on the price elasticity of re-development.

The notion of decomposing the price elasticity of land supply into its different sources opens up several avenues for further research. Local estimates such as the ones presented here could be provided for changing building heights, or development in greenfield land. It may also be possible to account for externalities across sites and estimate their influence on re-development in future work. Finally, the empirical strategy provided here can be implemented to study shifts in land use between commercial, industrial and residential uses.

Tables

TABLE 1

COVARIATE BALANCE ESTIMATES OF DETERMINANTS OF HOUSING SUPPLY ACROSS BOUNDARIES

	1000m	750m	500m	250m
	Elevation	Elevation	Elevation	Elevation
Δ School Qty.	-0.269	-0.335	-0.481	-0.554
	(0.719)	(0.710)	(0.701)	(0.690)
	Landslide	Landslide	Landslide	Landslide
Δ School Qty.	-0.002	-0.002	-0.001	-0.001*
	(0.002)	(0.002)	(0.001)	(0.001)
	Aquifer	Aquifer	Aquifer	Aquifer
Δ School Qty.	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)	(0.001)
	Ag. Quality	Ag. Quality	Ag. Quality	Ag. Quality
Δ School Qty.	0.001	0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
	Refusal Rate	Refusal Rate	Refusal Rate	Refusal Rate
Δ School Qty.	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
	Parks	Parks	Parks	Parks
Δ School Qty.	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.001)	(0.001)
Observations	789986	610861	420880	219202

Notes: Grid cell level regression using differenced estimates based on matched grid pairs. Dependent variable is the spatial difference in each variable as indicated in the row heading. The variables are elevation above sea level (in metres), landslide risk (dummy taking value 1 if moderate or high), fraction of planning application refused, a dummy taking value 1 if agricultural land quality is high and a dummy taking value 1 if the grid cell contains a park or garden. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. All specifications include boundary fixed effects to account for differenced county effects. S.E. clustered at the boundary level in parentheses.

TABLE 2

FIRST-STAGE MATCHED ESTIMATES

	1000	750	500	250
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
Δ School Score (closest)	0.050***	0.050***	0.050***	0.048***
	(0.01)	(0.01)	(0.01)	(0.01)
F-Stat	67	59	53	47
Boundary Effects	N	N	N	N
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
Δ School Score (closest)	0.041***	0.041***	0.041***	0.040***
	(0.006)	(0.007)	(0.007)	(0.007)
F-Stat	41	36	33	29
Boundary Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
Δ School Score (closest)	0.040***	0.040***	0.039***	0.039***
	(0.007)	(0.007)	(0.008)	(0.008)
F-Stat	33	28	25	23
Observations	600922	464178	318984	165676
Boundary Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Grid-cell level regressions after differencing within matches. Dependent variable is the differenced log of housing prices. School score normalized to have mean 0 and s.d. equal to 1. Linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. Boundary effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level.

TABLE 3
REDUCED-FORM ESTIMATES

	1000m	750m	500m	250m
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
School Score	-0.005***	-0.006***	-0.005***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
County Effects	N	N	N	N
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
School Score	-0.005***	-0.006***	-0.005***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
School Score	-0.004***	-0.005***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	1350047	1044354	720359	375375
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Grid-cell level regressions. Dependent variable is a dummy taking value 1 if there is a PdL site in the grid cell. School quality measured as average test scores of the closest primary school within the county and normalized to have mean 0 and s.d. equal to 1. Boundary fixed effects and linear terms for distance to the boundary on either side, as well as latitude and longitude, included in all specifications. County effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level in parentheses.

TABLE 4

BASELINE IV ESTIMATES

	1000m	750m	500m	250m
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.089***	-0.093***	-0.090***	-0.085***
	(0.014)	(0.015)	(0.015)	(0.016)
County Effects	N	N	N	N
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.089***	-0.095***	-0.091***	-0.087***
	(0.014)	(0.016)	(0.016)	(0.017)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.077***	-0.084***	-0.080***	-0.080***
	(0.013)	(0.015)	(0.015)	(0.017)
Observations	1350047	1044354	720359	375375
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Two-stage least square estimates. Dependent variable is a dummy taking value 1 if there is a previously-developed site in the grid cell. Boundary fixed effects and linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. County effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level in parentheses.

TABLE 5
MATCHED IV ESTIMATES

	1000	750	500	250
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.078***	-0.083***	-0.075***	-0.058***
	(0.019)	(0.021)	(0.020)	(0.017)
Boundary Effects	N	N	N	N
Controls	N	N	N	N
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.086***	-0.100***	-0.094***	-0.075***
	(0.027)	(0.031)	(0.029)	(0.026)
Boundary Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.071***	-0.083***	-0.084***	-0.069***
	(0.022)	(0.026)	(0.027)	(0.026)
N	600922	464178	318984	165676
Boundary Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: S.E. clustered at the boundary level in parentheses. Δ corresponds to a difference taken within matched pairs. Dependent variable is a spatially differenced dummy taking value 1 if there is a previously-developed site in the grid cell (2007).

TABLE 6

MATCHED ESTIMATES (CONTINUOUS OUTCOME)

	1000	750	500	250
	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction
Δ Log(Price)	-0.031**	-0.036***	-0.035***	-0.031**
	(0.012)	(0.014)	(0.013)	(0.012)
Boundary Effects	N	N	N	N
Controls	N	N	N	N
	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction
Δ Log(Price)	-0.039**	-0.050**	-0.049**	-0.045**
	(0.018)	(0.021)	(0.019)	(0.018)
Boundary Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction	Δ PdL Fraction
Δ Log(Price)	-0.027**	-0.034**	-0.037**	-0.037**
	(0.012)	(0.014)	(0.015)	(0.016)
N	600922	464178	318984	165676
Boundary Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Matching Estimates. Dependent variable measures the fraction of 2007 brownfield land in the grid cell, after spatial differencing within a matched pair. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. S.E. clustered at the boundary level in parentheses.

Table 7

Land Use Change & Prices - IV Estimates

	1000m	750m	500m	250m
	LUC Site	LUC Site	LUC Site	LUC Site
Log(Price)	0.047**	0.046*	0.050*	0.070*
	(0.023)	(0.027)	(0.030)	(0.040)
County Effects	N	N	N	N
Controls	N	N	N	N
	LUC Site	LUC Site	LUC Site	LUC Site
Log(Price)	0.061**	0.063*	0.065	0.121*
	(0.028)	(0.036)	(0.041)	(0.070)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	LUC Site	LUC Site	LUC Site	LUC Site
Log(Price)	0.059**	0.061*	0.054	0.098*
	(0.027)	(0.034)	(0.037)	(0.058)
Observations	16729	12985	8861	4508
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: S.E. clustered at the boundary level in parentheses. Dependent variable is the fraction of land experiencing a change towards residential use in the grid cell (2007).

Table 8

Cities

	Full Sample	Urban Only	Excl. London	London	20 Largest
	PdL Site	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.080***	-0.112***	-0.070***	-0.352**	-0.085***
	(0.017)	(0.025)	(0.017)	(0.147)	(0.026)
Matching	N	N	N	N	N
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.069***	-0.132***	-0.061**	-0.354	-0.083**
	(0.026)	(0.049)	(0.026)	(0.298)	(0.032)
Matching	Y	Y	Y	Y	Y

Notes: Results for different cities and groups of cities. First column corresponds to the full sample, second column excludes the London metropolitan area, third column restricts the sample to cells in the London metropolitan area, and fourth column restricts the sample to the 20 largest English metropolitan areas by size of workforce. Dependent variable is the fraction of land in a grid cell that is covered by brownfield. In all specifications, bandwidths correspond to 250 metres around the boundary. First row corresponds to baseline estimates. Second row corresponds to estimates obtained using spatial matching. S.E. clustered at the boundary level in parentheses.

TABLE 9

PREVIOUS LAND USE

	PdL Manufacturing		PdL Other Sites	
Log(Price)	-0.040***	-0.043***	-0.043***	-0.037***
	(0.008)	(0.009)	(0.010)	(0.011)
Observations	1044354	375375	1044354	375375
Bandiwdth	750m	250m	750m	250m
Matching	N	N	N	N
	PdL Manufacturing		PdL Other Sites	
Δ Log(Price)	-0.040**	-0.030*	-0.043***	-0.040**
	(0.017)	(0.017)	(0.015)	(0.017)
Observations	464178	165676	464178	165676
Bandiwdth	750m	250m	750m	250m
Matching	Y	Y	Y	Y

Notes: S.E. clustered at the boundary level in parentheses. Dependent variable is a dummy taking value 1 if there is a previously-developed site of manufacturing origin (columns 1 and 2) or of other origins (columns 3 and 4) in the grid cell. Columns 1 and 3 correspond to estimates using bandwidths of 750 metres and columns 2 and 4 use bandwidths of 250 metres. All specifications include county effects and control for supply-shifters.

Table 10

Planning Restrictiveness

	PdL Site	PdL Site	PdL Fract.	PdL Fract.
A. Low Refusal Rates				
Log(Price)	-0.097***	-0.099***	-0.044***	-0.048***
	(0.020)	(0.021)	(0.013)	(0.013)
Observations	242004	126072	242004	126072
Bandiwdth	500m	250m	500m	250m
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y
	PdL Site	PdL Site	PdL Fract.	PdL Fract.
B. High Refusal Rates				
Log(Price)	-0.068***	-0.064**	-0.037***	-0.031**
	(0.023)	(0.026)	(0.014)	(0.013)
Observations	478355	249303	478355	249303
Bandiwdth	500m	250m	500m	250m
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y
	PdL Site	PdL Site	PdL Fract.	PdL Fract.
C. Interactions				
Log(Price)	-0.072***	-0.070***	-0.035***	-0.033***
	(0.015)	(0.016)	(0.009)	(0.009)
Log(Price) × Refus. Rate	0.020**	0.023**	0.008	0.012**
	(0.010)	(0.010)	(0.006)	(0.006)
Observations	720359	375375	720359	375375
Bandiwdth	500m	250m	500m	250m
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: S.E. clustered at the boundary level in parentheses. Dependent variable is a dummy taking value 1 if there is a previously-developed site in the grid cell (2007) in columns 1 and 2, and the fraction of PdL land in the grid cell in columns 2 and 3. Bandwidths around the boundary are 250 metres in columns 1 and 3 and 500 metres in columns 2 and 4. Panel A displays estimates obtained with the sub-sample of boundaries with below median refusal rates, panel B displays estimates for the sub-sample of boundaries with above median refusal rates, and panel C uses the full sample and adds an interaction term between imputed prices and average refusal rates.

TABLE 11

VALUE-ADDED INSTRUMENT - DUMMY OUTCOME

	1000m	750m	500m	250m
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.090**	-0.102**	-0.101**	-0.111**
	(0.035)	(0.040)	(0.044)	(0.049)
County Effects	N	N	N	N
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.095**	-0.112**	-0.111**	-0.122**
	(0.039)	(0.044)	(0.047)	(0.053)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.100**	-0.118**	-0.118**	-0.139**
	(0.043)	(0.049)	(0.051)	(0.063)
Observations	1350476	1044667	720563	375471
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Two-stage least square estimates using school value-added as an instrument for prices. Dependent variable is a dummy taking value 1 if there is a previously-developed site in the grid cell. Boundary fixed effects and linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. County effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level in parentheses.

Table 12

Baseline Estimates for Unitary Authority Boundaries Only

	1000m	750m	500m	250m
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.083***	-0.087***	-0.074***	-0.079***
	(0.023)	(0.026)	(0.027)	(0.029)
F-Stat	54	53	52	48
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-0.080***	-0.086***	-0.075***	-0.084***
	(0.021)	(0.025)	(0.026)	(0.030)
F-Stat	48	46	44	39
Observations	441596	341965	236265	123505
Controls	Y	Y	Y	Y

Notes: Sample restricted to hectares around county boundaries for Unitary Authorities created before 2000. Dependent variable is a dummy taking value 1 if there is a previously-developed land plot in a grid cell in 2007. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. First-stage F-statistics provided below each estimate. S.E. clustered at the boundary level in parentheses. Baseline Estimates (see matching estimates in Appendix A.

Table 13

Robustness Checks - Probit

	1000	750	500	250
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-1.904***	-1.947***	-1.931***	-1.863***
	(0.219)	(0.226)	(0.245)	(0.257)
Boundary Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Site	PdL Site	PdL Site	PdL Site
Log(Price)	-1.760***	-1.834***	-1.777***	-1.795***
	(0.239)	(0.248)	(0.268)	(0.292)
Boundary Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Coefficients obtained by maximum likelihood using boundary fixed effects. Dependent variable is a dummy taking value 1 if there is a previously-developed site in the grid cell (2007). Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. Second row of coefficients obtained including potential supply-shifters as controls. S.E. clustered at the boundary level in parentheses.

TABLE 14

MEASUREMENT

	PdL Fract.	PdL Fract.	PdL Fract.	PdL Fract.
A. Matched Estimates				
Δ Log(Price)	-0.027**	-0.034**	-0.037**	-0.037**
	(0.012)	(0.014)	(0.015)	(0.016)
Observations	512465	442023	314978	163428
Controls	Y	Y	Y	Y
Boundary Effects	Y	Y	Y	Y
B. Matched Estimates for 2010 PdLs				
Δ Log(Price)	-0.041***	-0.041**	-0.041***	-0.042***
	(0.015)	(0.016)	(0.016)	(0.016)
Observations	512465	442023	314978	163428
Controls	Y	Y	Y	Y
Boundary Effects	Y	Y	Y	Y
C. Matched Estimates using Land Registry Prices				
Δ Log(Price) (LR)	-0.031***	-0.033***	-0.035**	-0.038**
	(0.012)	(0.013)	(0.014)	(0.015)
Observations	512465	442023	314978	163428
Bandwidth	1000m	750m	500m	250m
Controls	Y	Y	Y	Y
Boundary Effects	Y	Y	Y	Y

Notes: Matching Estimates. In panels A and C, the dependent variable is the fraction of previously-developed site in the grid cell according to the 2007 NLUD-PDL database. In panel B, the dependent variable is a dummy taking value 1 if there is previously developed land in a grid cell according to the 2010 NLUD-PDL database. All specifications include boundary effects and control for supply conditions. S.E. clustered at the boundary level in parentheses.

Table 15

Placebo - Non Residential Land Use Changes

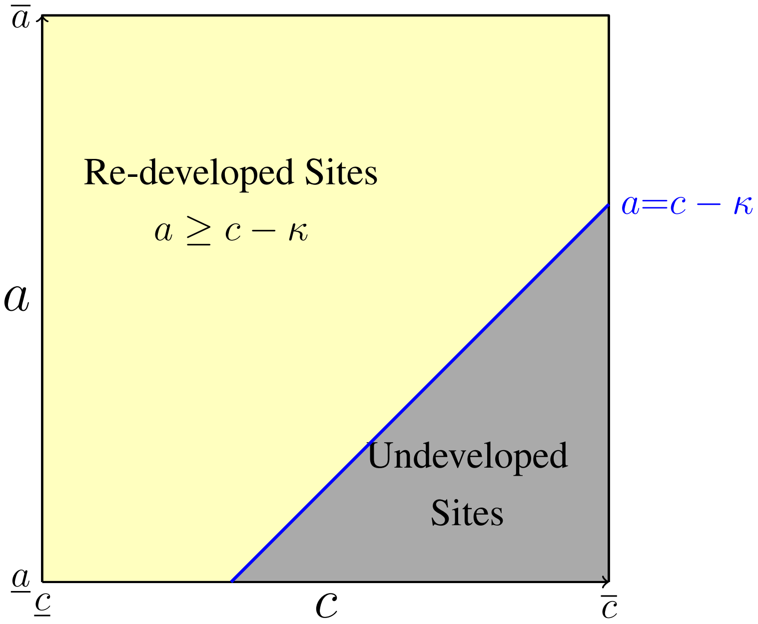
	1000m	750m	500m	250m
	Chng.Use Other	Chng.Use Other	Chng.Use Other	Chng.Use Other
Log(Price)	-0.018	-0.028	-0.014	0.019
	(0.03)	(0.04)	(0.04)	(0.04)
Observations	22774	17795	12174	6175
County Effects	N	N	N	N
Controls	N	N	N	N
	Chng.Use Other	Chng.Use Other	Chng.Use Other	Chng.Use Other
Log(Price)	-0.002	-0.025	-0.019	0.023
	(0.06)	(0.07)	(0.08)	(0.08)
Observations	22774	17795	12174	6175
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Chng.Use Other	Chng.Use Other	Chng.Use Other	Chng.Use Other
Log(Price)	0.022	-0.004	0.005	0.059
	(0.09)	(0.11)	(0.11)	(0.11)
Observations	22774	17795	12174	6175
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Dependent variable is the fraction of the grid cell that experienced a change towards a non-residential use (commercial, industrial, etc.) in the period 2007-2011. Sample restricted to hectares containing PdL in 2007. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. S.E. clustered at the boundary level in parentheses.

Figures

FIGURE 1

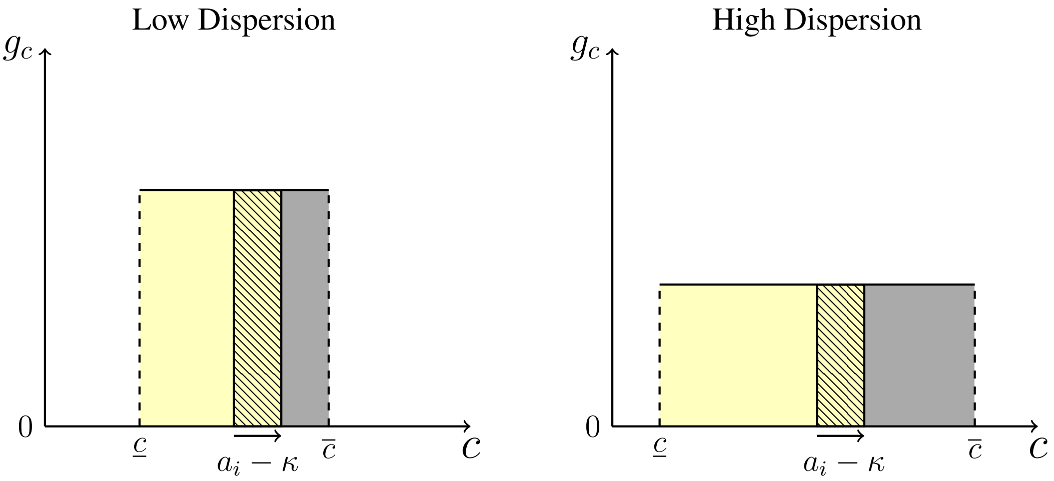
RE-DEVELOPMENT REGION ON THE (a,c) SPACE



Note: Horizontal axis corresponds to re-development costs, drawn within the support $[\underline{c}, \overline{c}]$. Vertical axis corresponds to amenity values within the support $[\underline{a}, \overline{a}]$. Constant κ is defined as $\kappa \equiv w - \underline{u} - \underline{r}$.

FIGURE 2

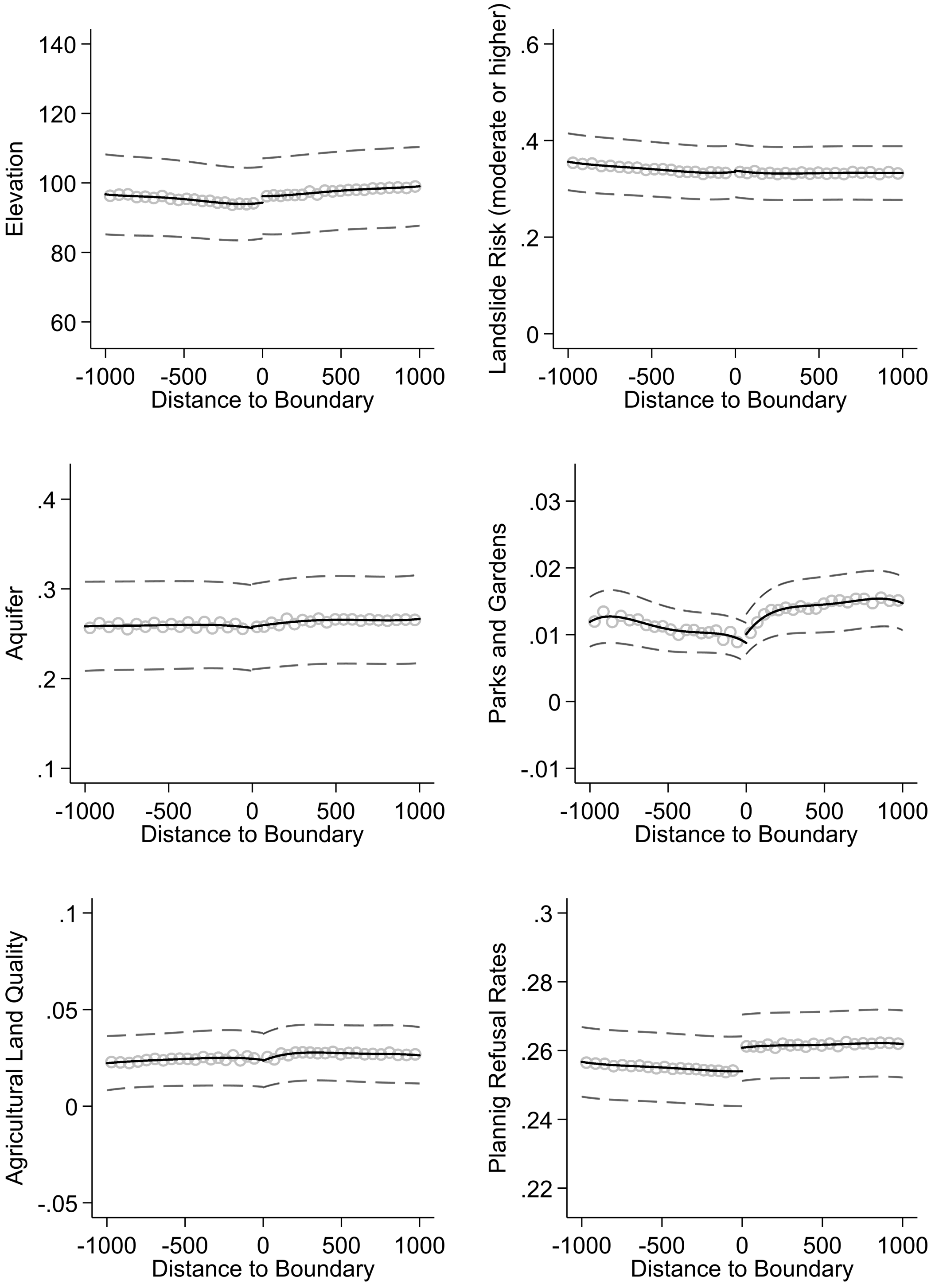
RE-DEVELOPMENT REGION CONDITIONAL ON a (UNIFORM CASE)



Note: Horizontal axis corresponds to re-development costs. Vertical axis corresponds to g_c, the marginal pdf of c. Under the assumption $a_i \perp\!\!\!\perp c_i$, then $g_{c|a}$ is the same for different levels of a. The left panel represents the case in which the variance of c is low, the right-panel represents the high variance case. The black patterned rectangle represent the additional development resulting from an increase in a_i of the same magnitude in both cases.

FIGURE 3

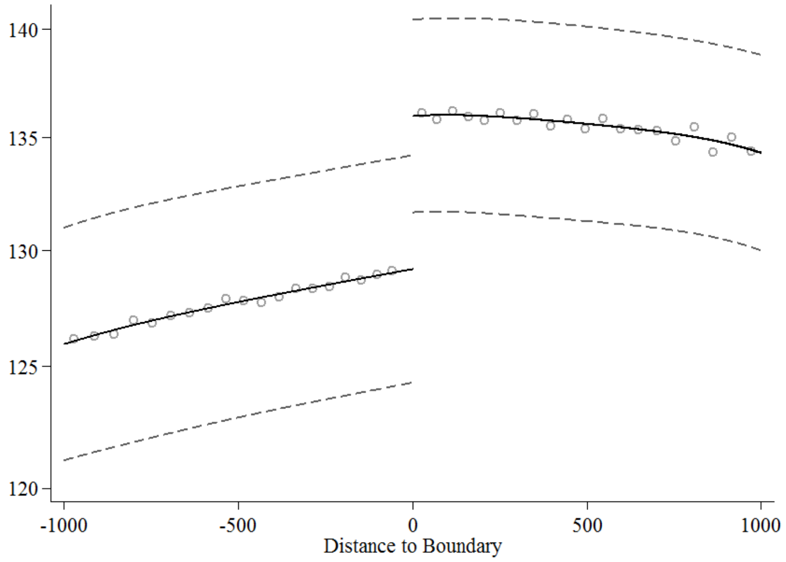
COVARIATE BALANCE FOR DETERMINANTS OF HOUSING SUPPLY



Notes: Negative distances to boundary correspond to grid cells with low average school quality and positive distances to boundary correspond to grid cells with high school quality. Vertical axis corresponds to elevation above sea level (top-left), a landslide risk (top right), probability of aquifer presence (centre left), probability of a park or garden in the cell (centre right), probability of high agricultural land quality (bottom left) and refusal rates (bottom right). Third degree polynomials fitted on the raw data represented in solid lines on either side of the boundary. 95% confidence intervals in dashed lines, with standard errors clustered at the boundary level. Bubbles correspond to averages taken within 40 distance bins.

FIGURE 4

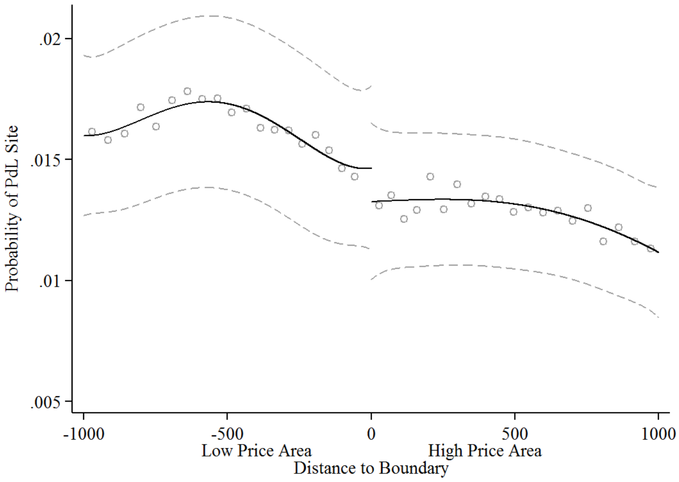
FIRST-STAGE ILLUSTRATION



Notes: Negative distances to boundary correspond to counties with low average school quality and positive distances to boundary correspond to counties with high school quality. Third degree polynomials fitted on the raw data represented in solid lines. 95% confidence intervals in dashed lines, with standard errors clustered at the boundary level.

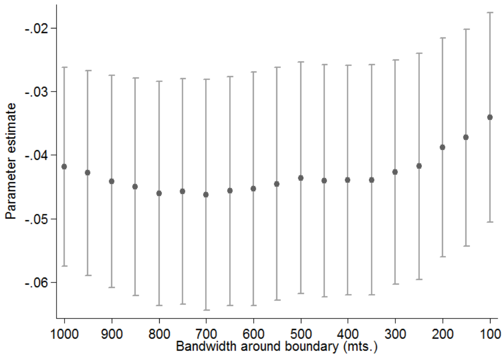
FIGURE 5

REDUCED-FORM GRAPH

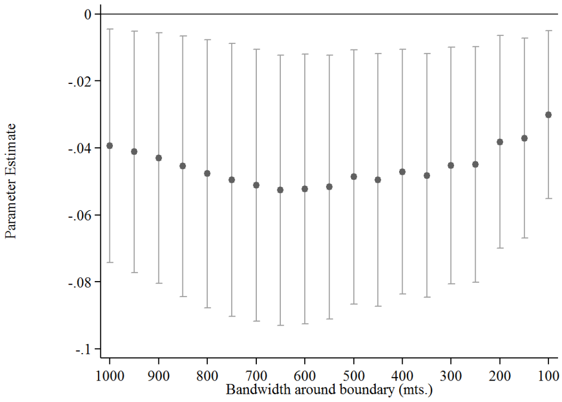


Notes: Horizontal axis represents distance to the boundary with negative distances corresponding to the county with low average school quality and positive distances corresponding to the county with high average school quality. Fourth degree polynomials fitted on the raw data represented in solid lines. Reduced-form estimates when incorporating intensive margin variation in school quality can be found in table 3 in Appendix A.

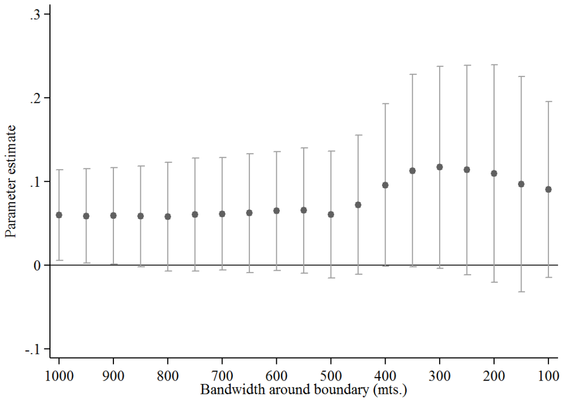
FIGURE 6
COEFFICIENTS BY BANDWIDTH



(A) BASELINE ESTIMATES FOR DIFFERENT BANDWIDTHS



(B) MATCHED ESTIMATES FOR DIFFERENT BANDWIDTHS



(C) LAND USE CHANGE ESTIMATES FOR DIFFERENT BANDWIDTHS

Notes: Panel A: Baseline estimates for different bandwidths using a continuous outcome (see section 4.1). Panel B: Matching estimates for different bandwidths using a continuous outcome (see section 4.2). Panel C: Land use change estimates for different bandwidths using a continuous outcome (see section 4.3). Parameter values indicated in the vertical axis. Bandwidths indicated in the horizontal axis. Baseline and land use change specifications include county fixed effects. Matching specification includes boundary fixed effects. 95% confidence intervals represented in vertical lines.

Appendices

A. Additional Tables and Figures

This Appendix presents a series of tables and figures complementing those in the main text. These includes descriptive tables, matching or baseline estimates and results for alternative outcome variables.

TABLE A.16

DESCRIPTIVES - CENSUS AREA LEVEL DATA

	Mean	Std. dev.	Min	Max
Any Brownfile in this cell (Dummy) 2007	0.015	0.120	0	1
Fraction Brownfiled in this cell (2007)	0.006	0.071	0	1
LUCS Site. To Residential	0.021	0.142	0	1
School Score	27.956	1.448	21.500	31.850
Latitude	52.529	1.127	50.332	55.188
Longitude	-1.377	1.095	-4.549	1.739
Elevation above sea level	96.423	84.406	-10.000	570.000
House Price (Smoothed)	141703	56145	13268	1477636
Population (2001 census)	1588	310	1000	4569
Observations		1,566,798		

Notes: Descriptive statistics for the full sample. Grid cells (hectares) within 1 km of a county (school admission) boundary.

TABLE A.17

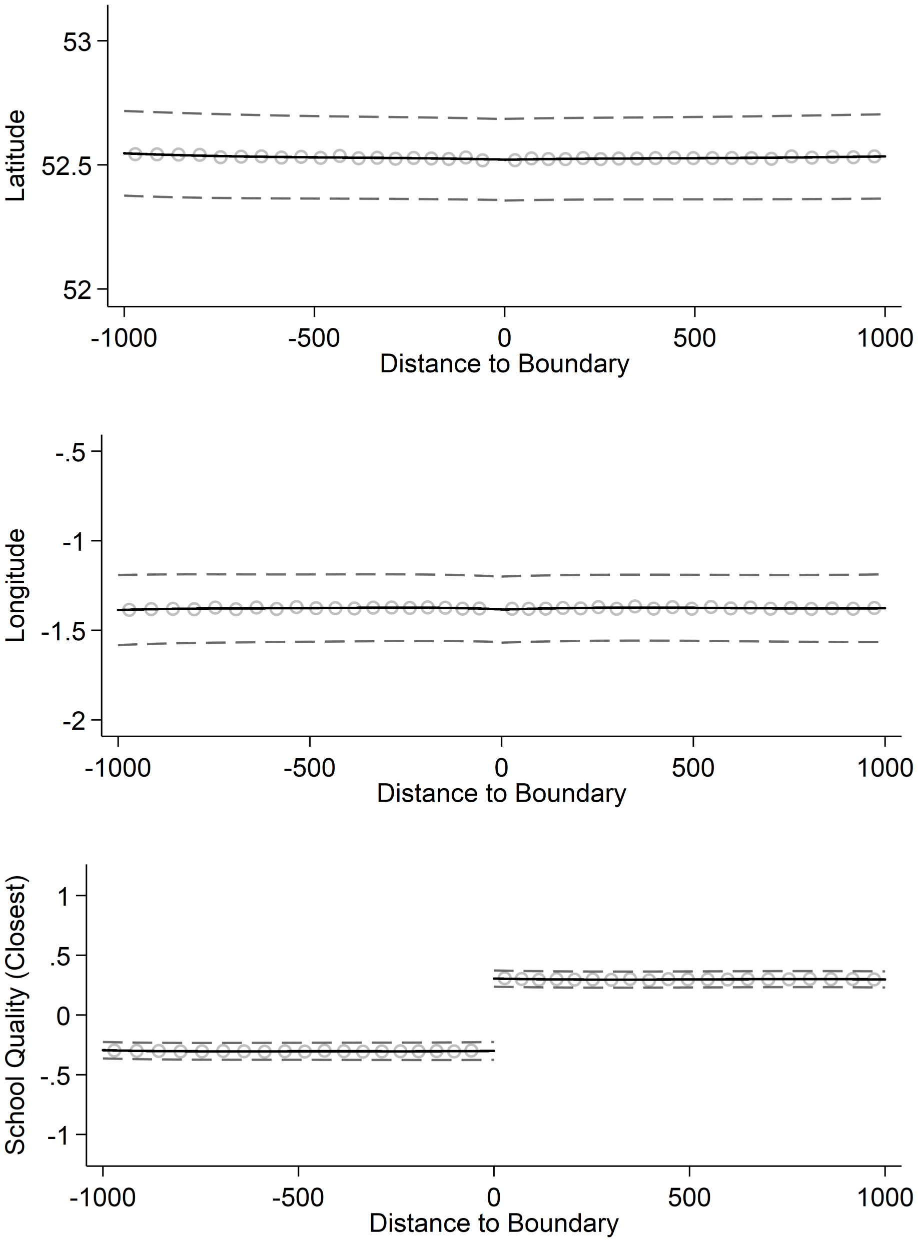
FIRST-STAGE BASELINE ESTIMATES

	1000m	750m	500m	250m
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.061***	0.061***	0.060***	0.059***
	(0.005)	(0.006)	(0.006)	(0.006)
County Effects	N	N	N	N
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.058***	0.058***	0.058***	0.057***
	(0.005)	(0.006)	(0.006)	(0.006)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.055***	0.055***	0.055***	0.055***
	(0.006)	(0.006)	(0.006)	(0.006)
Observations	1350047	1044354	720359	375375
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Grid-cell level regressions. Dependent variable is the log of housing prices imputed to a hectare. School score normalized to have mean 0 and s.d. equal to 1. Boundary fixed effects and separate linear terms for distance to the boundary on either side, latitude and longitude included in all specifications. Other fixed effects and controls as indicated in the table S.E. clustered at the boundary level in parentheses.

FIGURE A.7

COVARIATE BALANCE (SANITY-CHECK)



Notes: Distance to boundary represented in the horizontal axis. Negative distances to boundary correspond to grid cells with low average school quality and positive distances to boundary correspond to grid cells with high school quality. Vertical axis corresponds to latitude (top panel), longitude (middle panel) and closest school quality (bottom panel). Third degree polynomials fitted on the raw data represented in solid lines on either side of the boundary. 95% confidence intervals in dashed lines, with standard errors clustered at the boundary level. Gray circles correspond to averages taken within 40 distance bins.

TABLE A.18

FIRST-STAGE: LUCS SAMPLE

	1000m	750m	500m	250m
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.045***	0.045***	0.047***	0.040***
	(0.009)	(0.009)	(0.010)	(0.012)
County Effects	N	N	N	N
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.038***	0.034***	0.037***	0.032**
	(0.008)	(0.009)	(0.010)	(0.012)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	Log(Price)	Log(Price)	Log(Price)	Log(Price)
School Score	0.042***	0.041***	0.045***	0.042***
	(0.007)	(0.008)	(0.009)	(0.011)
Observations	16729	12985	8861	4508
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Grid-cell level regressions. Sample restricted to cells containing brownfield land in 2007. Dependent variable is the log of housing prices. School score normalized to have mean 0 and s.d. equal to 1. Boundary fixed effects and separate linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. County effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level in parentheses.

Table A.19

Baseline Estimates (Fraction of Brownfield in Grid Cell)

	1000m	750m	500m	250m
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.041***	-0.044***	-0.043***	-0.041***
	(0.008)	(0.009)	(0.009)	(0.009)
County Effects	N	N	N	N
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.043***	-0.047***	-0.045***	-0.044***
	(0.008)	(0.010)	(0.010)	(0.010)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.036***	-0.040***	-0.039***	-0.038***
	(0.008)	(0.009)	(0.009)	(0.009)
Observations	1350047	1044354	720359	375375
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Baseline estimates. Dependent variable measures the fraction of 2007 brownfield land in the grid cell. Boundary fixed effects and separate linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. S.E. clustered at the boundary level in parentheses.

Table A.20

Robustness Checks - Cities (Fraction)

	Full Sample	Urban Only	Excl. London	London	20 Largest
	PdL Fract.	PdL Fract.	PdL Fract.	PdL Fract.	PdL Fract.
Log(Price)	-0.038***	-0.050***	-0.033***	-0.221***	-0.044***
	(0.009)	(0.014)	(0.010)	(0.085)	(0.015)
Matching	N	N	N	N	N
	Δ PdL Fract.	Δ PdL Fract.	Δ PdL Fract.	Δ PdL Fract.	Δ PdL Fract.
Δ Log(Price)	-0.037**	-0.060**	-0.033**	-0.234	-0.043*
	(0.016)	(0.030)	(0.016)	(0.175)	(0.022)
Matching	Y	Y	Y	Y	Y

Notes: First column corresponds to the full sample, second column excludes the London metropolitan area, third column restricts the sample to cells in the London metropolitan area, and fourth column restricts the sample to the 20 largest English metropolitan areas by size of workforce. Dependent variable is the fraction of land in a grid cell that is covered by brownfield. All bandwidths correspond to 250 metres measured as distance to the boundary. First panel corresponds to baseline estimates. Second panel corresponds to estimates obtained using spatial matching. S.E. clustered at the boundary level in parentheses.

TABLE A.21

VALUE-ADDED INSTRUMENT - CONTINUOUS OUTCOME

	1000m	750m	500m	250m
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.038*	-0.047**	-0.050*	-0.065**
	(0.019)	(0.023)	(0.026)	(0.030)
County Effects	N	N	N	N
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.049**	-0.059**	-0.061**	-0.077**
	(0.023)	(0.027)	(0.029)	(0.034)
County Effects	Y	Y	Y	Y
Controls	N	N	N	N
	PdL Fraction	PdL Fraction	PdL Fraction	PdL Fraction
Log(Price)	-0.051**	-0.061**	-0.066**	-0.085**
	(0.025)	(0.029)	(0.032)	(0.039)
Observations	1350476	1044667	720563	375471
County Effects	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Two-stage least square estimates using school value-added as an instrument for prices. Dependent variable measures the fraction of 2007 brownfield land in the grid cell. Boundary fixed effects and linear terms for distance to the boundary on either side as well as latitude and longitude included in all specifications. County effects included for second and third row of estimates. Supply-shifters included as controls in the third row of estimates. S.E. clustered at the boundary level in parentheses.

TABLE A.22

SPATIAL-MATCHING ESTIMATES FOR UNITARY AUTHORITY BOUNDARIES

	1000	750	500	250
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.066**	-0.063*	-0.056*	-0.056*
	(0.033)	(0.034)	(0.033)	(0.031)
F-Stat	22	22	20	17
Controls	N	N	N	N
	Δ PdL Site	Δ PdL Site	Δ PdL Site	Δ PdL Site
Δ Log(Price)	-0.063*	-0.063*	-0.053	-0.052
	(0.035)	(0.037)	(0.037)	(0.034)
F-Stat	20	20	18	15
Observations	191965	167164	119622	62022
Controls	Y	Y	Y	Y

Notes: Grid cell level regression using differenced estimates based on matched grid pairs. Sample restricted to boundaries of Unitary Authorities created between 1995 and 2000. Dependent variable is the spatial difference in dummies taking value 1 if there is previously-developed land in a grid cell. Columns 1 through 4 correspond to bandwidths of 1000, 750, 500 and 250 metres, respectively. S.E. clustered at the boundary level in parentheses.

B. Data Sources and Dataset Assembly

B.1. Data Sources

Data on previously-developed land sites is obtained from the **National Land Use Database of Previously Developed Land** (NLUD-PDL). Most of the analysis uses the 2007 version of the database which was published by the Department of Communities and Local Government in 2008, and is currently held at the UK National Archives. Later versions of the database were released in 2010, 2011 and 2012. I use 2010 in a validation exercise in section 6.4.

Data on housing transactions is obtained from **Nationwide**, a British building society and one of the largest providers of household mortgages in the United Kingdom. The advantage of this dataset lies in that it includes detailed housing characteristics which allow to control for structural attributes of the property in a hedonic regression before spatial imputation of prices to grid cells. Section 6.4 shows that, using alternative data from the Price Paid database made public by the **Land Registry** leads to comparable results.[25]

Data on school quality is obtained from the **school performance tables**, made available by the Department of Education at https://www.gov.uk/school-performance-tables. These includes several measures of school quality for primary schools in England and Wales.

Data on land use changes is obtained from the **Land Use Change Database** (LUCS). This data is available since 1985 and 2011. While land use change statistics exist for the period after 2011, there was a substantial methodological break in the regular surveys that year. That is why I focus on land changes in the period 2007-2011 only in section 4.3. Trends in land use changes for the sample period can be found at "Land Use Change Statistics in England: 2011" published by the Department for Communities and Local Government. [26]

Variables for potential supply shifters, used as controls in most specifications and in the balancing tests displayed in table 1 and figure 3 are obtained from different sources. The data on elevation above sea level is based on a combination of Ordinance Survey Terrain 50 which records elevation data for the British territory in a 50 metre grid, imputed to postcodes based on their centroids. The postcode grid-cell match in my dataset is based on spatial assignment based on postcode centroids. The landslide risk measure and the data on underground aquifers are obtained from the **British Geological Survey**. In the case of the landslide risk, it is specifically

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[25] Data produced by Land Registry © Crown copyright 2015.

[26] See `https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/267551/LUCS_Stats_Release__Dec_2013_FINAL_.pdf`.

obtained from the GeoSure 5km Hexagonal Grid. The data on aquifers is obtained from the Hydrogeogology map (scale 1:625,000) and spatially matched with grid cell centroids. The aquifer variable used here takes value 1 if the grid cell centroid falls in an aquifer identified as "highly productive". Data on agricultural land quality is based on the 1988 Agricultural Land Classification of England and Wales, elaborated by the Ministry of Agriculture, Fisheries and Food and the Welsh Office Agriculture Department at the time. Data on the location of registered parks and gardens is obtained from the Historic England shapefile recording these locations. Historic England is a public body devoted to caring about England's historic environment. Spatial imputation of parks and gardens to grid cells is again based on grid cell centroids. Data on planning application average refusal rates at the local planning authority level for the period 1979-2008 obtained from Hilber and Vermeulen (2016).

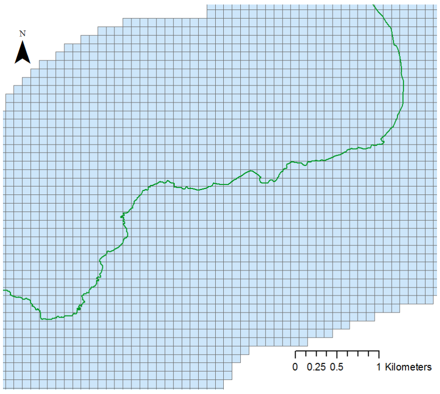
B.2. Dataset Assembly

The dataset assembly in this study relied heavily on combining spatial data using Geographic Information Systems. The basic process involved several steps. On the first place, I use a shapefile of counties (polygons) to obtain county boundaries (lines). I build a buffer area of 1km around those boundaries and create a grid of hectares within those buffer areas. Boundaries with the sea or boundaries against Wales or Scotland are removed from the sample. The resulting grid cell constitutes my sample, with each hectare-cell being one observation (see panel A of Figure B.8).

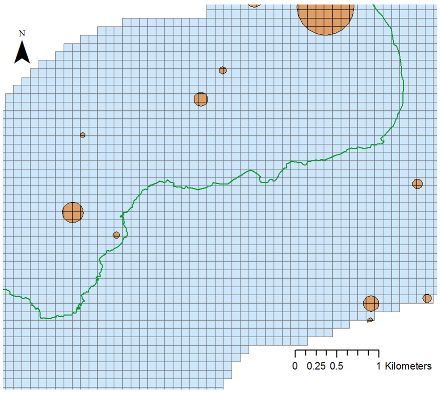
The next step is to impose the location of brownfield sites. As discussed above, these are created as circular polygons around the centroids reported in the NLUD-PDL data. An overlay identifies which grid cells contain brownfield land and which do not (see panel B of Figure B.8). I next impute the hedonic-filtered prices and the school quality to each hectare by imputing these variables based on closeness within the corresponding county, as county boundaries are operate as admission boundaries in this context (see panel C of Figure B.8).

Other variables such as those recording potential supply shifters or census characteristics are imputed using grid cell centroids. I remove from the analysis all grid cells that are crossed by a county boundary.

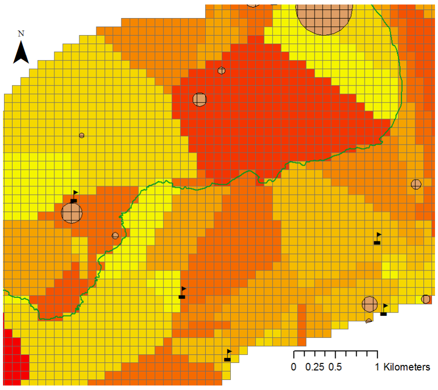
FIGURE B.8
DATASET ASSEMBLY



(A) COUNTY BOUNDARY AND HECTARE GRID



(B) OVERLAY OF BROWNFIELD LOCATIONS



(C) IMPUTING SMOOTHED HOUSING PRICES AND SCHOOLS

C. Re-Development Policies for Brownfield and Previously Developed Sites

Idle or vacant land plots within cities, often containing the remnants of previous developments, are a common feature of cities worldwide. While an internationally harmonized definition for previously developed unused or underused sites is not available, several individual studies bare witness to this fact. In England, Adams, De Sousa and Tiesdell (2010) claim previously developed sites amount to 5.45% of total urban developed land. In the Greater London area alone, there are over 2000 hectares of land identified as brownfield sites with potential for redevelopment.[27] Estimates from the European Commission indicate there are over 3 million brownfield sites across Europe located and well connected to urban boundaries, with 500,000 hectares of brownfield land estimated to be available for development (Comission, 2013).

In the case of the United States, up to 15% of urban land is classified as vacant (Pagano and Bowman, 2000). The US definition of brownfields is restricted only to property where expansion, redevelopment or reuse may be complicated by "the presence or potential presence of a hazardous substance, pollutant or contaminant".[28] The EPA estimates that there are over 450,000 brownfields in the USA according to this definition, though some authors increase the figure to over 1 million, covering 6% of urban areas (Adams, De Sousa and Tiesdell, 2010).

There are several types of policies deployed to promote the development of vacant land, previously developed land and contaminated sites within cities. The policies themselves vary substantially by jurisdiction, because of, among other things, the different administrative frameworks applying to these sites. Policy objectives encompass the urban densification, clean-up of contaminated sites (especially, but not exclusively, in the US) and removing financial barriers to re-development. The policies themselves can be classified into four broad categories:

1. Grants and Subsidies such as clean-up grants
2. Financial Instruments such as low interest loans to developers.
3. Public Ownership schemes in which local governments buy the land, conduct part of the re-development efforts and sell it out to developers.
4. Differential Planning schemes aiming to target new developments to previously developed sites.

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[27] Calculations based on data from the London Brownfields Sites Review, accesible at `https://data.london.gov.uk/dataset/london-brownfield-sites-review`.

[28] EPA's Brownfields and Land revitalization Programs. Properties with New Purpose. `https://www.epa.gov/sites/production/files/2015-09/documents/oblr_brochure_weblayout_508.pdf`

I use this taxonomy to classify the most salient brownfield policies in North America and Europe. This policy review is not meant to be exhaustive. It provides an overview of the policy levers currently in use for this purpose. As I will argue below, many of these policies can be linked, in one form or another, to the sensitivity of re-development to demand conditions.

Grants and Subsidies

Grants and subsidies for clean up of pollutants, as well as for redevelopment of derelict sites are one common mechanism to foster brownfield conversion. Low interest loan can be also seen as a form of subsidy, but will be treated separately. I provide three examples here for the United Kingdom and the United States. Other state and city level programs are available in the USA (e.g. Los Angele's Citywide Brownfields Program, City of Chicago's Brownfield Initiative).

United Kingdom - Department for Environment, Food & Rural Affairs (DEFRA)

DEFRA funding had been available for local authorities from 2000 until 2017. The amount of funding available peaked at GBP 17.5 million in 2009-2010 and was gradually faced out until 2017. The funding was made available via small grants with an average value of GBP 38,000. This was directed to clean up and other remediation activities carried out jointly by local authorities and land owners/occupiers who provided 17% of all funding for remediation efforts in this context. The phase out of the program has led to discussions about the ability of English local governments to meet their statutory obligations in aiding the process of land remediation. [29]

United States - Environmental Protection Agency Grants

The EPA is the primary enforcer of environmental statutes and regulations in the United States. EPA has launched the Brownfields and Land Revitalization Programs to revitalize contaminated land and return properties to productive use.

There are broadly two types of grants, Assessment grants and Clean Up grants. Both can fund up to 200,000 USD for plans lasting up to 3 years. The Assessment grants are meant to fund evaluation of clean up costs, including detection of hazardous substances on site. Clean up grants apply only to sites owned by the grantee and can only cover up to 80% of the total clean up costs. The EPA also runs an area-wide planning grant program directed to local governments, in their role as planning authorities, which is meant to aid in the development of planning processes

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[29] For further reference see https://publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/180/18005.htm.

to assess, clean and reuse brownfield sites.

The 2016 budget of the EPA's Brownfield programs amounted to 110 million USD funding over 151 cooperative programs with municipalities, clean up costs over 142 sites and assessments for over 3000 sites. The EPA also provides technical assistance to lower level government bodies.[30] The assessment and clean-up grants can be seen as subsidies for re-development, and interpreted in the context of the framework laid out in section 2.

New York - Brownfield Opportunity Areas (BOA) Program

The BOA program was launched in 2003 through the New York (NY) State Brownfields Reform Act and is administered by the NY State Department. It is targeted to brownfield redevelopment in poor communities and provides grants of up to 90% of the eligible project costs to finalise revitalization plans and ultimately lead to brownfield re-development. The goal is to reduce re-development costs by removing uncertainty regarding site conditions, ownership structure or future feasible uses. Eligible applicants are not private developers but rather municipal governments and community-based organizations. That being said, the program also includes a 2% tax credit bonus for proposed development projects on sites that are part of the program. Note that, in terms of net present value of a project, a tax credit operates as a subsidy.

The budget allocated to this program has varies substantially over the years, from 32 million USD in 2011 to 45 million in 2016. The program is still operational. A formal evaluation of the effect of this program on nearby housing prices was conducted in Cohen et al. (2016).

Financial Instruments

The supply of appropriate financial instruments to promote brownfield and infill re-development has been a popular policy approach, especially in the European Union. These provide both low-interest conventional loans as well as equity loans and other financial engineering tools.

European Union - Joint European Support for Sustainable Investment in City Areas (JESSICA)

JESSICA is a European Comission initiative developed jointly with the European Investment Bank and the Council of Europe development Bank to support urban development and urban regeneration schemes. The initiative is implemented as part of the European Regional Development Fund. The objective of the policy is to provide financial assistance in the form

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[30] For further referent visit `https://www.epa.gov/brownfields/overview-brownfields-program` and `https://www.epa.gov/sites/production/files/2015-02/documents/fy_2016_bib_combined_v5.pdf`.

of equity, loans or guarantees channelled through public-private partnerships. This is meant to cover insufficient availability of equity from private investors, or to compensate for low returns that need to be leveraged to attract private investors (due to contamination of property or poor local infrastructure). Guarantees are meant to enable developers and other private participants to secure funding from third parties (e.g. banks). Potential proceeds from these financing operations are meant to be re-invested in new urban development projects.

European Union - GINGKO Fund

European Investment Bank and Edmond de Rothschild Group funding dedicated to acquiring a portfolio of brownfield sites, including also other private investors. The goal of the fund is to signal investment appeal to other private equity funds interested in regeneration and redevelopment of brownfield sites in its role as an environmental remediation specialist. It conducts supplementary environmental conditions studies before acquisition and analyses economic feasibility of operations to bolster its signalling effect. The fund's activity has been mostly concentrated in Belgium and France where most redevelopment has been publicly led. The total assets in the fund amounted to 140 million euros in 2016. The actions of GINGKO fund can be seen as reducing actual and perceived costs or re-development for investors.[31]

California Environmental Protection Agency: Brownfields Initiative

California's environmental authority in charge of restoring, protecting and enhancing the environment launched the initiative to remedy brownfields. The policy consists of a fund meant to provide low cost loans to developers, property owners, NGOs and local government agencies which own brownfield sites with potential for redevelopment. The budget consists of 2.7 million USD available for low interest loans which operate both as a financing tool and as an effective subsidy given the low rates. Government and non-for profits can only request loans up to USD 200,000.

An example of a development using these funds is the Third Street Project in the South Market Area in San Francisco. The program provided a 1.6 million USD loan used to clean-up lead contamination of the soil in the site.[32]

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[31] For further information please see http://www.eib.org/infocentre/publications/all/eib-information-1-2011-n141.htm.

[32] For further information, see `http://www.dtsc.ca.gov/SiteCleanup/Brownfields/Loans_Grants.cfm`.

Public Ownership

In some jurisdictions, brownfield remediation is carried out in the context of public ownership of the sites themselves. In its simplest form, a public authority simply acquires a site, pays the cost of remediation, and sells it of to developers or other private agents.

Redevelopment in the Netherlands

Dutch land policy is often characterized by an important role of public ownership and command-and-control tools. The Netherlands has a "public land development strategy, [that] involves public purchase, ownership and servicing of land and active planning for land use before land is released for actual development to the private sector. This guarantees building developments according to public policies, it realizes full cost recovery of all public works via the sale of building plots and it captures at least part of the surplus value of the land after a change in use" (Van der Krabben and Jacobs, 2013). This model is also applied to brownfield projects and requires strategic land acquisitions prior to regeneration. Categorized as a public comprehensive top-down model: a public body (usually the municipality) acquires the land for future development, services that land and re-parcels it into building plots that can be sold of for cost recovery and value capture. For further reference, see Van der Krabben and Jacobs (2013), which also discusses the potential risks associated to this type of top-down approach to land use and re-development policies.

An example of a large scale regeneration project carried out by public authorities acting as leaders in the development process can be found in the recent regeneration of areas within the Rotterdam inner-city harbour. The national government provided a 31 million euros subsidy for this purpose, which adds to other 27 million from a public fund and additional municipal resources. Municipalities, who lead the project, were allowed to modify zoning laws to accommodate this redevelopment. While the endeavour is publicly controlled, private parties are actively incorporated to cover for the additional costs at an early stage. The municipality and Havenbedrijf Rotterdam first acquire the subsidies, permits, property management, and spatial legislation before the project was commissioned to private developers. The regeneration project includes housing development, revitalising economic activity in the harbours, and investment in the local innovation system.

Chicago - Brownfields Initiative

The City of Chicago launched the Brownfields Pilot in 1990 with a 2 million investment from General Obligation Bonds to redevelop brownfield sites. The pilot project was a success, and was leveraged into the Brownfields Initiative in 1993 with additional loan guarantees from the US Department of Housing and Urban Development and funds from the EPA. The city's Departments of Environment, Planning and Development coordinates the program in collaboration with several other organisations. The initiative recycles neglected properties to reuse the land for the creation of green and open areas, affordable housing, office space and economic redevelopment. The City acquires contaminated sites to add to the city's investment portfolio. After the sites have been assessed, enrolled in Illinois EPA's Site Remediation Program and cleaned, the sites are marketed by the City for redevelopment.

Since 1990 funding for brownfields redevelopment has been leveraged from several sources: 2 million USD from the General Obligations Bonds, 74 million from the HUD Section 108 Loan Guarantee, $691.000 from the Brownfields Showcase Community Designation, etc. [33]

Urban Planning Tools

In some cases planners try to use planning guidelines to provide incentives for brownfield redevelopment. This can involve relaxation of planning restrictions (as in the case of the Rotterdam harbour mentioned above), tightening of restrictions on planning development or a combination of both.

United Kingdom - Brownfield First & Green Belts

The Brownfield First policy was launched in 1998 with the goal of ensuring that 60% of new urban development in the United Kingdom happens within the urban footprint. The argument motivating the policy is that developers do not pay the social cost of greenfield development because local governments are the ones in charge of providing transportation, sanitation and other infrastructure. Presumably, the cost of providing this infrastructure is much lower for properties located within the urban footprint. The policy led local authorities to factor these priorities into their planning guidelines (for example in Local Development Frameworks). By 2008, 80% of developments was happening on previously developed land sites.

Another British planning policy that was crucial in directing new development to PdL sites is the widespread use of urban greenbelts. These were introduced in London in 1935 and gen-

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[33] For further reference, see Higgins (2008) and `https://www.cityofchicago.org/city/en.html`.

eralized for other cities in the 1947 Town and Country Planning Act. This sets out an area - the greenbelt - around cities where development is forbidden. Greenbelts cover roughly 12% of England and are usually placed around urban areas. They are meant to contain sprawl, operate as a sort of urban lung and safeguard the countryside among other uses. Its presence is a highly debated issue, as many authors argue that green belts amount to a tight restriction on urban residential construction which results in high housing prices Cheshire (2014). The combined imposition of greenbelts and the brownfield first policy implies most new development in the United Kingdom effectively happens on previously developed land. For further reference, see Dixon and Adams (2008) and Mace et al. (2016).

Netherlands - "Ladder for Sustainable Urbanization"

The Dutch minister of Infrastructure and Environment introduced the "ladder for sustainable urbanization" in 2012. This process requires planning agencies to go through three steps before planning approval. Municipalities or regional government organizations have to first document there is demand for new development in their area. If, even accounting for current and future supply, demand for development is still identified, then the agencies pushing for development should identify appropriate sites, giving priority to sites in existing urban areas. If, for example because of high re-development costs, development cannot take place in existing urban areas, the planning application moves to the third step. Approval for greenfield development can be provided if no financially viable site within the city is available and a good case can be made. Using the ladder to justify actions is obligatory, even though compliance is not monitored or enforced by the central government. The general guidelines are simple but can lead to very different arguments depending on the context.

One of the goals of this policy framework is to ensure that a proper case is made before development happens outside of brownfield land. It also attempts to ensure an efficient use of urban land (were the term efficient is loosely defined) and promote densification of existing urban areas. For further reference, see Salet (2014).

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