Journal of Benefit-Cost Analysis

Volume 3, *Issue* 3 | 2012 | *Article* 6

External Benefits of Brownfield Redevelopment: An Applied Urban General Equilibrium Analysis

Niels Vermeer, *CPB Netherlands Bureau for Economic Policy Analysis*

Wouter Vermeulen, *CPB Netherlands Bureau for Economic Policy Analysis, VU University and Spatial Economics Research Centre (SERC)*

Recommended Citation:

Vermeer, Niels and Vermeulen, Wouter (2012) "External Benefits of Brownfield Redevelopment: An Applied Urban General Equilibrium Analysis," *Journal of Benefit-Cost Analysis*: Vol. 3: Iss. 3, Article 6.
DOI: 10.1515/2152-2812.1092

External Benefits of Brownfield Redevelopment: An Applied Urban General Equilibrium Analysis

Niels Vermeer and Wouter Vermeulen

Abstract

Does brownfield redevelopment warrant government support? We explore several external benefits in an urban general equilibrium framework. Preferences are modelled such that demand for housing units in the city is downward sloping, which yields a more general setup than the extreme open and closed city cases. We shed light on the relative importance of general equilibrium effects of nonmarginal redevelopment projects and we isolate the external benefits of the removal of a local nuisance, the exploitation of agglomeration economies and the preservation of open space at the urban fringe. A numerical application indicates that local nuisance and agglomeration effects may push social returns significantly beyond the value of redeveloped land that accrues to its owner. However, depending on the price elasticity of urban housing demand and the strength of agglomeration economies, the amount of preserved greenfield land may be small and it only generates additional benefits to the extent that direct land use policies fail to internalize its value as open space.

KEYWORDS: brownfield redevelopment, land use externalities, urban general equilibrium, cost-benefit analysis

Author Notes: We gratefully acknowledge helpful comments by two anonymous referees, as well as Paul Cheshire, Janet Kohlhase, Christina Plerhoples and our colleagues at CPB. In particular, we thank Carel Eijgenraam for suggesting the spatial setup of this analysis to us. An earlier version of this paper was presented at 57th Annual North American Meetings of the Regional Science Association International in Denver, Colorado. Address correspondence to: Wouter Vermeulen, CPB Netherlands Bureau for Economic Policy Analysis, P.O. Box 80510, 2508 GM, The Hague, The Netherlands. Phone: +31 70 3383467. Fax: +31 70 3383350. Email: w.vermeulen@cpb.nl.

1 Introduction

Government involvement in the regeneration of outdated or derelict industrial sites in centrally located urban areas is widespread. In the US, for instance, several federal and state level programs support the remediation of hazardous waste sites. Total expenditure on the largest of them, the so-called Superfund program, amounted to approximately $35 billion in 2005.[1] Moreover, land use policies tend to favor densification in existing urban areas over the development of greenfield sites at their fringe, particularly in Europe. The Dutch government aims to realize 40% of new housing supply in existing urban areas and a planning target set by the UK government even states that 60% of new housing should be provided on previously developed land and through the conversion of existing buildings.[2] The US Smart Growth Network similarly advocates densification through the restoration of center cities and older suburbs.[3] The transformation of outdated industrial or brownfield sites is an obvious channel through which such targets can be met.

The presence and magnitude of external benefits is a key issue for the evaluation of government support for brownfield redevelopment. The owner of a brownfield site will weigh the value of real estate after redevelopment against investment costs. However, if this site imposes negative local externalities in its current use, then surrounding residents will also benefit from the project. In addition to the health risks that are associated with soil contamination, one may think of noxious emissions, noise or unpleasant odors from industrial activity, or the vandalism and illegal dumping that derelict sites attract. Because of these externalities, a redevelopment project may be socially desirable even if investment costs outweigh the real estate value, so that government support is warranted.

This paper explores the evaluation of external benefits of brownfield redevelopment in a tractable urban general equilibrium framework. It aims to shed light on various important methodological issues, as identified in a recent handbook on Benefit-Cost Analysis (BCA) of land cleanup and reuse from the US Environmental Protection Agency (EPA, 2011). In the first place, we investigate the relative importance of general equilibrium effects. It is common to evaluate external benefits through capitalization in the value of proximate real estate, as under certain conditions, a hedonic model identifies the marginal willingness to pay for the removal of a local pollutant or nuisance. Greenstone and Gallagher (2008) provide an insightful discussion and a particularly thorough application to

[1] See Greenstone and Gallagher (2008) and EPA (2011).

[2] See VROM *et al*. (2004) and CLG (2010) for policy statements in the Dutch and UK cases, respectively.

[3] See http://www.smartgrowth.org/.

the Superfund cleanups.[4] However, a redevelopment project of nonmarginal size will affect land value throughout an urban area, so that a hedonic partial equilibrium framework overestimates its benefits. Our analysis relates the magnitude of this bias to the size of the project and to housing demand conditions at the level of the urban area.

A considerable body of empirical evidence supports the existence of a positive relationship between urban density and productivity.[5] For instance, Greenstone *et al*. (2010) found that existing plant productivity improves after the entry of a new large plant, so that the redevelopment of urban space adjacent to other firms may further the exploitation of agglomeration benefits. An increase in population density may generate agglomeration economies by sharing fixed costs of infrastructure or other local public goods.[6] Hence, through its impact on density, brownfield redevelopment should be expected to generate additional external benefits. We incorporate agglomeration externalities into our general equilibrium framework and isolate the additional benefits that accrue through this channel.

A third issue is the external benefit of greenfield preservation. The 'brownfield/greenfield offset' is commonly derived on the basis of residential densities, which are higher in centrally located redeveloped brownfields than on greenfield land at the urban fringe[7], yet this overlooks housing demand conditions at the urban level. We show that the offset vanishes if demand is sufficiently elastic and that brownfield redevelopment may even induce the conversion of additional greenfield land in the presence of agglomeration economies. The external benefit of greenfields preservation depends on the extent to which the market price of open space misrepresents its social value.[8] However, this external value may have been internalized by land use constraints at the urban fringe already, so that brownfield redevelopment does not yield additional benefits. This often-overlooked point seems of particular relevance in a European context, where compact urban development is a ubiquitous feature of land use planning. Nevertheless, when the implementation of first-best policies at the urban fringe is

---

[4] See, e.g., Michaels and Smith (1990), Kohlhase (1991), Gayer *et al*. (2000), Kiel and Zabel (2001), McCluskey and Rausser (2003), Ihlanfeldt and Taylor (2004), and Kaufman and Cloutier (2006) for earlier applications of hedonic pricing to the valuation of hazardous waste site or brownfield externalities. A review and in-depth methodological discussion is provided in EPA (2011) and Smith (2011).

[5] See Rosenthal and Strange (2004) for a survey.

[6] Duranton and Puga (2004) provide an overview of micro-economic foundations for agglomeration economies.

[7] See, e.g., Deason *et al*. (2001) or De Sousa (2002).

[8] The notion that greenfields near the urban fringe represent a nonmarket value as open space is supported in several empirical studies; see McConnell and Walls (2005) for a survey.

hindered for institutional or other reasons[9], preserved greenfields may contribute to the external benefits of brownfield redevelopment.

Housing demand conditions at the urban level play a key role in the evaluation of these external benefits. The urban economics literature distinguishes two standard, yet extreme cases: the ‘open’ and the ‘closed’ city. The total number of households in a closed city is fixed, so aggregate demand for housing units is perfectly price inelastic. Furthermore, the density gradient determines the brownfield/greenfield offset in this case, as brownfield redevelopment does not attract any additional residents to the city. Agglomeration economies in the total urban population are irrelevant.[10] In an open city, households can freely migrate to or from perfect substitutes that fix a reservation utility level. Hence, demand for housing units is perfectly elastic: households bid prices up to the level where they enjoy exactly the same utility as outside of the city. In the absence of agglomeration externalities, the general equilibrium effects of brownfield redevelopment will coincide with the partial equilibrium effects that are identified in a hedonic framework. The reason is that even a nonmarginal project becomes marginal if the relevant market also includes the perfect substitute places that fix utility. Brownfield redevelopment does not affect greenfield conversion under these assumptions, because the perfectly elastic demand dictates prices at the urban fringe, irrespective of urban land supply in the city center.

We model household preferences in such a way that demand for housing units in the city becomes downward sloping. Following Hilber and Robert-Nicoud (2010), we introduce heterogeneity in the taste for some unique attribute of the city under consideration.[11] One may think of a specific amenity or of idiosyncratic attachment through personal history or social networks. The city is populated by the households that have the strongest taste for its attribute. As housing supply expands through brownfield redevelopment, new households enter with an ever lower taste. This depresses prices and introduces the negative general equilibrium effect in the welfare analysis. The elasticity of demand for housing units is

---

[9] For instance, impact fees in the US typically must satisfy a ‘rational nexus’ test that ties them to the costs of providing facilities (Ihlanfeldt and Shaughnessy, 2004). Direct regulation of the use of greenfield land may be similarly hindered by protection of the property rights of its owners.

[10] Smith (2011), which collects peer review reports for an earlier draft of EPA (2011), contains a particularly insightful illustration of the welfare effects of brownfield redevelopment in the closed city case by Jan Brueckner. Similarly, Quigley and Swoboda (2007) and Walsh (2007) use a closed city framework to show that local provision of open space may be ineffective because it spurs the conversion of agricultural land at other sites. The new supply that is generated through inner city redevelopment reduces development elsewhere through the same underlying mechanism.

[11] This approach is based on discrete choice theory of product differentiation (Anderson *et al.*, 1992). The relevance of heterogeneous preferences for location has been well acknowledged in the urban economics literature; see Arnott and Stiglitz (1979) for an early reference.

decreasing in the variation in idiosyncratic tastes, encompassing the open and the closed city as limiting cases.

The next section sets out the general equilibrium framework and derives analytical expressions for the internal and external benefits of redeveloping a brownfield site. An empirical application illustrates the key mechanisms in our model and it provides a crude sense of their quantitative significance. We calibrate our model to a redevelopment project in the medium-sized town of Nijmegen in the Netherlands, which proposed moving an industrial site from its center to the outer fringe, partly to get rid of unpleasant odors from a producer of tomato ketchup and a large abattoir, and replacing it with residential real estate. The project proposal was part of a recent series of applications for grants of the Dutch government to support urban redevelopment projects. In several of these applications, the external benefits that this paper considers featured prominently.[12]

2 Analytical framework

We consider a circular city in which a sector ω is available for urban use. All jobs are located in a dimensionless Central Business District (CBD). The industrial site or brownfield surrounds this CBD up to a distance r^a.[13] Households live in the area that ranges from r^a to the urban fringe r^b, which will be endogenized in an extension of the model. The opportunity cost of urban land use is foregone agricultural production and open space. Production in the CBD $\Pi(N)$ exhibits external increasing returns to scale, where N denotes the number of households or jobs in the city, whereas the industrial land yields some constant return P that may equal zero in the case of a derelict brownfield site. Industrial land reduces the environmental quality $E(r)$ in its vicinity through noxious emissions, unpleasant odors or some other type of negative externality.[14] The project involves conversion of the site into a residential area, which eradicates the reduction in environmental quality.[15] Structures and plot sizes in the existing city will not be adjusted because of durability.[16]

[12] CPB and PBL (2010) provides an overview.

[13] Chapter 5 of EPA (2011) considers a setup in which the brownfield is situated in between the center and the urban fringe.

[14] This setup closely follows the 'externality model of residential choice' in Fujita (1989).

[15] To fix ideas, we assume that industrial production on the brownfield is terminated. The setup is easily adapted to the case in which firms are relocated to an industrial site outside of the city.

[16] Whereas this simplifying assumption is realistic in the short run, changes in land prices should affect densities throughout the city in the long run. The implications for welfare are limited in our analysis, because lot sizes are chosen optimally prior to redevelopment of the brownfield. Hence, it follows from the envelope theorem that benefits of subsequently adjusting them are of second-order importance for small projects. Alternatively, we could have assumed that plot sizes are fixed and independent of location, but this seems less realistic than the assumption that they were

2.1 Equilibrium on urban housing and labor markets

The city has some unique feature and households vary in their appreciation for it. Following the setup of Hilber and Robert-Nicoud (2010), we enter the taste for residing in the city as a *random component* into the household utility function. More formally, the city is part of a country inhabited by a continuum I of households indexed by i. Utility is additively separable into a common component v and the random component that is specific to each household i, giving:

$$u(i) = v + \varepsilon(i). \tag{1}$$

Random components are drawn from a common distribution with cumulative density function $F(\varepsilon)$. The ordering of households on I is such that $\varepsilon(i)$ is a monotonously decreasing function. The households with the highest draw sort into our city and as this draw does not depend on their location within the city, they should all receive the same common utility level.[17] We assume the rest of the country to be large, so that the reservation utility u that households can attain elsewhere is exogenous. For the marginal household in the city $\bar{i}$ it must hold that $u(\bar{i}) = u$ and hence $\varepsilon(\bar{i}) = u - v$. We thus obtain the number of households that choose to live in the city as:

$$N^D(v) = I\left[1 - F(u - v)\right]. \tag{2}$$

This equation may be interpreted as a demand equation for housing in the city: more households will be attracted when a higher common utility level is on offer. If the variation in the random or idiosyncratic component is large, then only a small number of additional households will be drawn into the city, so that it behaves much like a closed city. Limited variation in the idiosyncratic component implies that a small increase in the common utility level will attract a large number of new households, as in the open city case.

Apart from their idiosyncratic taste for living in the city, households are homogeneous and they derive utility from the size of the plot of land s on which they live and from the consumption of a composite commodity z. Proximity to the industrial site reduces their wellbeing because it reduces the environmental

chosen optimally, as density generally declines with distance from the city center (see, e.g., Anas *et al.*, 1998).

[17] Suppose, on the contrary, that common utility were higher in one particular location. Irrespective of the random draw they had received, households from the rest of the city would move to this place until higher land prices had undone the common utility differential.

quality. The common utility function is written as $U\left(s,z,E\left(r\right)\right)$ and in a spatial equilibrium, it should equal *v*. This condition may be inverted to obtain $Z\left(s,E\left(r\right),v\right)$, the amount of *z* a household in the city requires to obtain *v* given *s* and *E(r)*.

Households provide one unit of labor for which they receive a wage *w*. Commuting costs are given by *tr*, where *t* is the transport cost per unit of distance. The *bid rent* or maximum rent a household can afford to pay per unit of land is then given by:

$$\psi\left(r,w,v\right)=\max_{s}\frac{w-tr-Z\left(v,s,E\left(r\right)\right)}{s}, \tag{3}$$

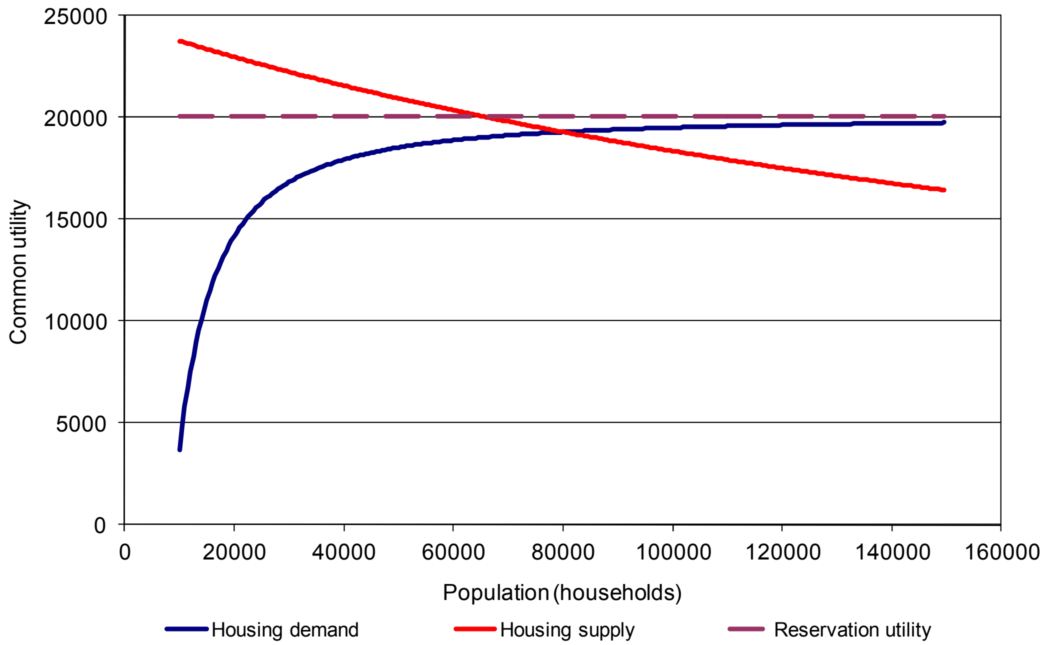
where the price of *z* is normalized to one. In a spatial equilibrium, rents should be equal to bid rents. The first-order condition associated with Eq. (3) reads:

$$-\frac{\partial Z\left(v,s,E\left(r\right)\right)}{\partial s}=\frac{w-tr-Z\left(v,s,E\left(r\right)\right)}{s}. \tag{4}$$

This expression states the usual condition that the marginal rate of substituting the composite commodity for land should equal their rate of exchange at market prices. The lot size function $s\left(r,w,v\right)$ that satisfies this condition solves the consumer problem.[18] We assume that the size of structures and plots in the existing city is not affected by the project, which means that condition (4) is not satisfied after its completion. In that case, bid rents are obtained by substituting an exogenous lot size function into Eq. (3).

[18] Households and small developers throughout the urban area would not take external agglomeration benefits into account in their choice of lot size. Hence, we do not consider densification as a second-best land use planning instrument to enhance the exploitation of agglomeration benefits.

Figure 1: Urban housing market



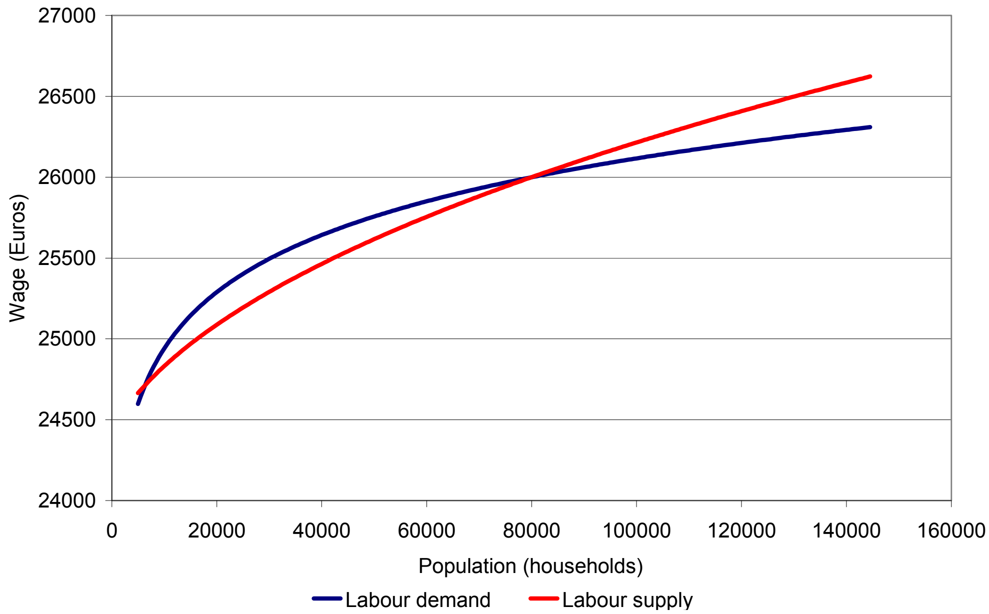
Each plot will be used for the construction of one house that will accommodate one household. Urban housing supply is thus obtained by integrating plot density over the entire residential area, which will be denoted by *L*:

$$N^S(w,v) = \int_L \frac{1}{s(r,w,v)}. \tag{5}$$

At a given wage *w*, a higher common utility level is realized by increasing the size of plots, which results in a lower density and less housing supply. The equilibrium number of households $N^*(w)$ and common utility level $v^*(w)$ are obtained by equating this supply to housing demand from Eq. (2). This market clearing process is illustrated in Figure 1, which plots the demand and supply for housing in the city as a function of the common utility level.[19]

[19] All figures in this paper are based on simulations with the base scenario of our calibrated model.

Figure 2: Urban labour market



As each household provides one unit of labor, the equilibrium number of households $N^*(w)$ may also be interpreted as a labor supply equation. In the CBD, labor is the single input in the production of a good that is traded on international markets for a price normalized to unity, employing a production technology of the shape $\Pi(N) = g(N)N$, where $g(N)$ may be thought of as an increasing concave function of the urban employment level. The marginal product of labor is $g(N) + g'(N)N$, but individual firms ignore the impact of wage setting on N, so that they pay labor its average product $g(N)$. Hence, the labor market is in equilibrium when wages are set at such a level that:

$$w = g\left(N^*(w)\right). \tag{6}$$

In addition, there is a stability condition: the cost of attracting an additional household must exceed its average product. We assume that there is a unique stable equilibrium on the urban labor market and we denote the equilibrium wage and number of households by w^* and N^*, respectively. Figure 2 illustrates labor demand and supply curves in our calibrated model. There are two intersections and only the second one is stable.

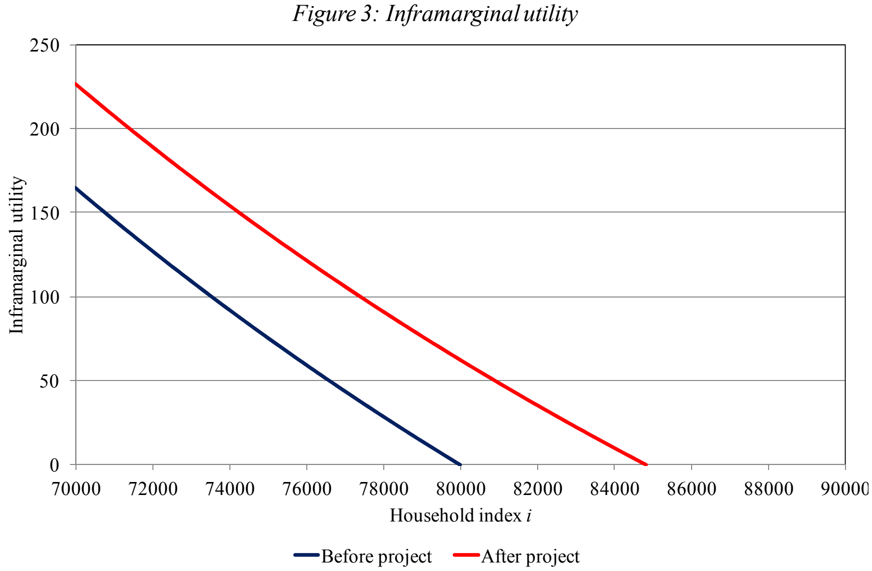
https://doi.org/10.1515/2152-2812.1092 Published online by Cambridge University Press

2.2 Welfare analysis

It is a standard result in urban economic theory that social surplus, defined as the difference between the value of the urban produce and all costs that have to be made to ensure a common utility level, equals the total differential land rent in an open city (see, e.g., Fujita, 1989).[20] Hence, the welfare effects of converting a industrial site into a residential area are given by the *investment costs* Q that are associated with cleaning or decontamination and conversion and the induced change in the total differential land rent. We refer to the total land value in urban use net of its value in agriculture and open space as the *developer surplus*, as it equals the profit of an urban developer who buys land from farmers, compensates society for the loss of open space and then rents it out to households and firms.

In our general equilibrium framework, the heterogeneity of preferences over a unique attribute of the city gives rise to an additional welfare effect, which is the induced change in inframarginal utility. Figure 3 plots $u(i) - u$, the difference between the utility level that is reached by household i and the reservation utility level, against the household index i. Brownfield redevelopment raises housing supply, so the common utility level must rise to attract new households. This implies that all households in the city will be made better off, except the last or marginal household, which cannot attain more than the reservation utility level in equilibrium. The change in the area under $u(i) - u$, thus reflects a change in *consumer surplus*.

Figure 3: Inframarginal utility



[20] It is common to evaluate surplus under the side condition that utility is equalized over space. The allocation that maximizes a Benthamite social welfare function cannot be supported by a competitive equilibrium, as it involves the 'unequal treatment of equals'.

Let v_0, w_0 and N_0 denote the equilibrium common utility level, wage and corresponding number of households prior to the project, respectively. These are obtained by substituting the residential area that ranges from r^a to r^b for L in Eq. (5) and then solving it simultaneously with Eqs. (2) and (6). Furthermore, let C denote the annualized[21] private opportunity costs, consisting of conversion costs and the value of land in agricultural use, and assume that the annualized external value of agricultural land as open space equals V.[22] Prior to the redevelopment project, the developer surplus then reads:

$$S_0 = \Pi(N_0) + \int_0^{r^a} PL(r)\,dr - \int_{r^a}^{r^b} \left(tr + Z\left(v_0, s_0(r), E_0(r)\right)\right) n_0(r)\,dr - \int_0^{r^b} (C+V)\,L(r)\,dr\,, \tag{7}$$

where $s_0(r) \equiv s(r, w_0, v_0)$, $L(r) \equiv 2\pi\omega r$, $n_0(r) \equiv L(r)/s_0(r)$ and $E_0(r)$ reflects hazard or nuisances caused by the brownfield site. The first two terms in this expression represent the value of the produce in the CBD and on the industrial site. The third term reflects commuting costs and the expenditure on the composite commodity that is required to ensure a common utility level of v_0 for all households. Opportunity costs of the urban land are included through the final term. We may rewrite this surplus as:

$$S_0 = \int_0^{r^a} \left[P - (C+V)\right] L(r)\,dr + \int_{r^a}^{r^b} \left[\psi_0(r) - (C+V)\right] L(r)\,dr\,, \tag{8}$$

where $\psi_0(r) \equiv \psi(r, w_0, v_0)$.[23] Hence, it is seen to equal the *total differential land rent*, defined here as the difference between land rents and the sum of opportunity costs.

The project changes L in Eq. (5), the residential area now ranges from the CBD to r^b, and it establishes a new environmental quality $E_1(r)$. Lot sizes in the existing urban area remain equal to $s_0(r)$ because of durability of structures, but

[21] We convert all costs and benefits to annual values to make them comparable. Even if conversion is a one time cost in reality, it may be thought of as being paid through debt that has to be serviced annually. The present value of service payments would then equal the one time conversion costs.

[22] Open space is not included explicitly in the utility function to keep the analysis tractable. The external value of open space V may be justified by a nonuse or existence value that wider society attaches to the stock of open space. McConnell and Walls (2005) survey the literature on use and nonuse values of open space.

[23] This is seen by using the fact that $\Pi(N_0)$ equals w_0 integrated over household density throughout the city, as workers get paid their average product in equilibrium, and by substituting in the definition of $n_0(r)$.

density in the redeveloped area is endogenous. Otherwise, equilibrium on urban housing and labor markets is determined in the same way, yielding v_1, w_1 and N_1. Developer surplus in this new equilibrium is given by:

$$S_1 = \Pi(N_1) - \int_0^{r^a} \left(tr + Z\left(v_1, s_1(r), E_1(r)\right)\right) n_1(r)\, dr$$
$$- \int_{r^a}^{r^b} \left(tr + Z\left(v_1, s_0(r), E_1(r)\right)\right) n_0(r)\, dr - \int_0^{r^b} (C+V) L(r)\, dr. \tag{9}$$

This expression may again be written as a total differential land rent:

$$S_1 = \int_0^{r^b} \left[\psi_1(r) - (C+V)\right] L(r)\, dr, \tag{10}$$

where bid rents in the existing area are obtained by substitution of $s_0(r)$ into Eq. (3). The change in developer surplus thus equals:

$$\Delta S = \int_0^{r^a} \psi_1(r) L(r)\, dr - \int_0^{r^a} PL(r)\, dr + \int_{r^a}^{r^b} \left[\psi_1(r) - \psi_0(r)\right] L(r)\, dr. \tag{11}$$

The first term of Eq. (11) represents the benefits of the project that capitalize into the price of the redeveloped land. These will be taken into account by a profit-maximizing owner, so we will refer to them as the *internal benefits*. The second term represents the opportunity cost of the redeveloped land and, together with the investment costs, it represents the internal costs of the project. The third term represents welfare effects that are not internalized into the price of the redeveloped land. They may be decomposed as:

$$\int_{r^a}^{r^b} \left[\psi_1(r) - \psi_0(r)\right] L(r)\, dr =$$
$$\int_{r^a}^{r^b} \left[Z\left(v_0, s_0(r), E_0(r)\right) - Z\left(v_0, s_0(r), E_1(r)\right)\right] n_0(r)\, dr \tag{12}$$
$$+ N_0 \Delta w - \int_{r^a}^{r^b} \left[Z\left(v_1, s_0(r), E_1(r)\right) - Z\left(v_0, s_0(r), E_1(r)\right)\right] n_0(r)\, dr.$$

The first term in Eq. (12) represents the external benefit of removing a hazard or nuisance for surrounding residents. The new households raise productivity of households who were already in the city, which gives rise to the second term. The third term reflects the increase in expenditure on the composite commodity that is required to assure the rise in the common utility level. To attract new households to the city, the common utility level must rise and given the fixed lot sizes and environmental quality, this can only occur through an increase in consumption of

https://doi.org/10.1515/2152-2812.1092 Published online by Cambridge University Press

other goods, which must be granted through a discount on land prices. Note that this increase may vary with distance to the CBD.

To obtain the total benefits from the project, we have to augment the change in developer surplus as expressed in Eq. (11) with a monetary measure for the rise in consumer surplus. Three groups of households may be distinguished. Households with a taste $\varepsilon < \bar{\varepsilon}_1$, where $\bar{\varepsilon}_1 \equiv u - v_1$, do not enter the city after the project, so they are indifferent. Households with a taste $\varepsilon \geq \bar{\varepsilon}_0$ were already in the city prior to the project, so they all experience the same rise in common utility level. As we have just seen, this rise materializes through increased consumption of the composite commodity. Hence, the third term of Eq. (12) constitutes a *transfer* from landowners to consumers and not an additional benefit.[24] The final group with tastes $\varepsilon \in (\bar{\varepsilon}_0, \bar{\varepsilon}_1]$ consists of new households in the city. The marginal household with taste $\bar{\varepsilon}_1$ is again indifferent, but there are *inframarginal* new households who are made better off by the project. To measure the inframarginal surplus, we compare $Z(v_1, s_0(r), E_1(r))$, the consumption of composite commodities at distance *r* required to sustain the utility distribution in the new equilibrium, to $Z(u-\varepsilon, s_0(r), E_1(r))$, which is the amount that would be required for a household with taste ε to sustain the (lower) reservation utility level. Assuming that all new households would locate at a distance *r* from the CBD, a money metric for the utility gain of this group would be:

$$M(r) = I\int_{\bar{\varepsilon}_0}^{\bar{\varepsilon}_1}\left[Z(v_1, s_0(r), E_1(r)) - Z(u-\varepsilon, s_0(r), E_1(r))\right] f(\varepsilon)\, d\varepsilon, \qquad (13)$$

where $f(\varepsilon)$ is the density function that corresponds to the distribution of tastes and *I* is the number of households in the country. An unattractive but unavoidable trait of this metric is that it depends on location, which is a consequence of the fundamental property that the marginal utility of income varies with distance to the CBD (Wildasin, 1986). In our calibration, we arbitrarily evaluate Eq. (13) at the average commuting distance $\hat{r}$ within the newly developed area. It has been verified using our calibrated model that this choice is of little consequence.

Table 1 summarizes the benefits and costs of the redevelopment project. In Table 1, the benefits of removing a hazard or nuisance and increased scale have been classified as external, together with the inframarginal surplus. The owner of the redeveloped land would not take these benefits into account, so they may

[24] For an owner-occupier, this gain in consumer surplus would be exactly offset by the loss in asset value.

justify government intervention. Hence, the magnitude of these benefits relative to the value of the redeveloped land is an important outcome in the policy debate on brownfield redevelopment. The fact that this project depresses land rents in the rest of the city along the housing demand curve is inconsequential for the BCA.

Table 1 Benefits and costs of the redevelopment project

Internal effects	
$\int_0^{r^a} \psi_1(r, w_1, v_1) L(r)\, dr$	benefits that capitalize into land prices in the project area
$\int_0^{r^a} PL(r)\, dr$	value of the land in industrial use
Q	costs of demolishment, decontamination, conversion
External benefits	
$\int_{r^a}^{r^b} \left[\begin{array}{c} Z(v_0, s_0(r), E_0(r)) \\ -Z(v_0, s_0(r), E_1(r)) \end{array} \right] n_0(r)\, dr$	effect of removing nuissance
$(w_1 - w_0) N_0$	agglomeration benefit
$M(\hat{r})$	inframarginal consumer surplus
Transfers	
$\int_{r^a}^{r^b} \left[\begin{array}{c} Z(v_1, s_0(r), E_1(r)) \\ -Z(v_0, s_0(r), E_1(r)) \end{array} \right] n_0(r)\, dr$	transfer of surplus from landowners to households in the existing part of the city

2.3 Preservation of open space at the urban fringe

Suppose that the redevelopment project will be finalized in some future year in which demand for housing in the city will be higher than it is now. The increase in demand is likely to bring forth new development at the urban fringe, some of which may be prevented by the project. In this sense, the project preserves a certain amount of open space, which may yield additional welfare. The effect is incorporated into the model by endogenizing the urban fringe. We assume that to internalize the value of open space, the local government levies a tax on development τ, which is independent of whether or not the project takes place. Hence, r^b is determined by the condition that:

$$\psi\left(r^b, w, v\right) = C + \tau\,. \tag{14}$$

We denote r_0^b the urban fringe in the situation in which the industrial site is not converted and r_1^b the urban fringe if the project is executed. For the project to preserve open space, we must have $r_1^b < r_0^b$, although the reverse may also occur if housing demand is sufficiently elastic and if scale economies are sufficiently strong.

The change in developer surplus is now given by:

$$\Delta S = \int_0^{r^a} \psi_1(r) L(r) dr - \int_0^{r^a} PL(r) dr + \int_{r^a}^{r_0^b} \left[\psi_1(r) - \psi_0(r)\right] L(r) dr + \int_{r_1^b}^{r_0^b} \left[C + V - \psi_1(r)\right] L(r) dr. \quad (15)$$

The final term in this equation is additional to the welfare effects in Eq. (11) and it represents the value of the preserved open space. If the project is executed, then $\psi_1(r)$ must be smaller than $C+\tau$ beyond r_1^b, so we have:

$$\int_{r_1^b}^{r_0^b} \left[C + V - \psi_1(r)\right] L(r) dr > (V - \tau) \int_{r_1^b}^{r_0^b} L(r) dr . \quad (16)$$

The right-hand side of this equation is the gap between the value of open space and the development tax, multiplied by the surface of the preserved area. It should approximate the left-hand side well if $\psi_1(r)$ is not too steep. Hence, if the government is able to internalize the value of open space through direct planning policies, there is little additional benefit in supporting brownfield conversion. However, legal constraints that are based on the protection of property rights may render it difficult to effectively internalize the value of open space at the urban fringe. In that case, the additional benefit of open space preservation may be more substantial.

Equations for the other welfare effects, as summarized in Table 1, remain unchanged, provided that the appropriate v_1 and w_1 are substituted. If $r_1^b < r_0^b$, then the number of new households will be smaller than in the case of an exogenous urban fringe. Hence, the agglomeration benefit, the transfer and the inframarginal surplus will also be smaller, but the internal benefits will be larger. Costs of the project and the external benefit of removing the nuisance are unaffected.

3 Numerical application

3.1 Calibration of the model

The analysis is applied to the conversion of a brownfield of approximately 100 hectares, which corresponds to 5% of the total amount of residential land available in the Dutch town of Nijmegen.[25] This hypothetical project is chosen to be significantly larger than the industrial site that was considered in the 'Nijmegen Waalfront' project, so that we get a clearer view on the implications of transforming a nonmarginally large site when demand is downward sloping. Other urban parameters, such as the share of land developed, the surface of the residential area and the number of households, generally correspond to statistics for Nijmegen. Table 2 provides a comprehensive overview of the parameters used in subsequent simulations.

Common utility is assumed to be a product of environmental quality and a Constant Elasticity of Substitution (CES) component in land and the composite commodity. This yields the indirect utility function:

$$v\left(R(r), Y-tr, E(r)\right) = E(r)\left[Y-tr\right] \Big/ \left(\alpha^{\sigma} + \beta^{\sigma} R(r)^{1-\sigma}\right)^{1/(1-\sigma)}, \qquad (17)$$

where $\alpha + \beta = 1$, $R(r)$ denotes the land rent at distance r from the CBD and the price of the composite good has been normalized to one. The elasticity of substitution σ is chosen at 0.5, so households are less willing to substitute away from land than in the Cobb-Douglas case and land rents have a stronger impact on wellbeing.[26]

[25] EPA (2011) reports an average size for brownfield sites of 3.5 hectares, whereas the average superfund site has a size of 890.8 hectares, so the brownfield area in our application is approximately in the middle. Table 3 also shows results for projects that are either smaller or larger by a factor four.

[26] This parameter is taken from Vermeulen (2011), where a comparison of predicted to actual residential land use across cities provided a crude check on the calibration. Table 6 contains a sensitivity check with regard to the elasticity of substitution.

Table 2 Parameters

	Description of parameter	Value
Utility		
α	preference parameter composite good	0.998515
β	preference parameter land	0.001485
σ	elasticity of substitution	0.5
v_0^*	equilibrium common utility level	19287.3
u	reservation utility level	20039.6
N	total number of households in the city prior to the project	80,000
I	number of households in the Netherlands	7 million
γ	parameter of the Pareto distribution	0.675156
Environmental externality		
η_1	parameters of logistic decay function for proximity to	9.168764
η_2	industrial sites from De Vor and De Groot (2011)	-1.717655
η_3		0.012687
η_4		-1.49752
δ	semi-elasticity of house prices with respect to (minus) the share of surrounding land within 500 meters in industrial use from Rouwendal and Van der Straaten (2008)	0.006
Urban form		
r_a	boundary of brownfield area	1 km
r_b	outer city boundary	4.50461 km
ω	share of land in development	0.33
L	total surface of residential area prior to project	2000 ha
t	annual commuting costs per meter	0.45 €/m
ρ	share of house price spent on land	25%
C	annualized price of agricultural land plus conversion costs	4 €/m^2
V	external value of agricultural land as open space	5 €/m^2
Production		
w	annual wage	26,000
κ	scale elasticity	0.02
K	constant in production function	20744.9

Note: Information on the number of households and residential land use in Nijmegen is obtained from Statistics Netherlands and information on the average household income in Nijmegen is obtained from its municipal government. Commuting costs and the conversion and opportunity costs of agricultural land are based on Vermeulen (2011), the external value corresponds to the smaller cities in the sample of that paper.

We assume that the tax on conversion of agricultural land is equal to an external value of 5 euros and that conversion costs an additional 4 euros annually, which is generally in line with the numbers reported in Vermeulen (2011). Hence, if we evaluate Eq. (17) at the urban fringe, we can substitute $R(r)$ from the boundary condition, Eq. (14). The average household income Y is observed and we make empirically founded assumptions on t (also based on Vermeulen, 2011) and the shape of $E(r)$, on which more details are provided below. By substitution, we obtain an equilibrium common utility level v for each assumption on the taste parameters. The condition that this v must be the same throughout the city implicitly defines land rents, whereas lot sizes follow from the corresponding compensated demand equation. Substitution into the urban housing supply, Eq. (5), prior to the execution of the project, yields the number of households in the city and α and β are chosen such that this corresponds to the number we observe. This condition simultaneously determines the equilibrium common utility level v_0.

Tastes are Pareto distributed according to the cumulative density function:

$$F(\varepsilon) = 1 - 1/\varepsilon^{\gamma} , \tag{18}$$

which yields the demand equation:

$$N^D(v) = I/(u-v)^{\gamma} . \tag{19}$$

The parameter u is set such that $N^D(v_0) = 80,000$ with I = 7 million – the number of households in the Netherlands. The parameter γ is calibrated on the price elasticity of urban housing demand, which is defined as:

$$\varepsilon_D \equiv \frac{R(\bar{r})}{N^D(v_0)} \frac{\partial N^D\left(v\left(R(\bar{r}), Y - t\bar{r}, E(\bar{r})\right)\right)}{\partial R(\bar{r})} , \tag{20}$$

where $\bar{r}$ is the distance of the average household to the CBD. In the baseline, we choose γ such that this elasticity equals –2.[27]

We consider two specifications of $E(r)$ that are based on alternative empirical studies of the impact of proximity to industrial sites on house prices in the Netherlands. First, following De Vor and De Groot (2011), we model the impact of an industrial site at distance d as:

$$\log(R_1(r)) - \log(R_0(r)) = 1_{d<750} \frac{1}{\rho}\left(\eta_1 \frac{e^{\eta_2+\eta_3 \log(r-r_a)}}{1+e^{\eta_2+\eta_3 \log(r-r_a)}} + \eta_4\right), \tag{21}$$

[27] This elasticity refers to the price responsiveness of the number of units demanded in a specific city. We are not aware of any estimates in the literature, which usually considers the elasticity of housing services demanded with respect to prices (see, e.g., Ermisch *et al*., 1996). A sensitivity analysis is reported in Table 4.

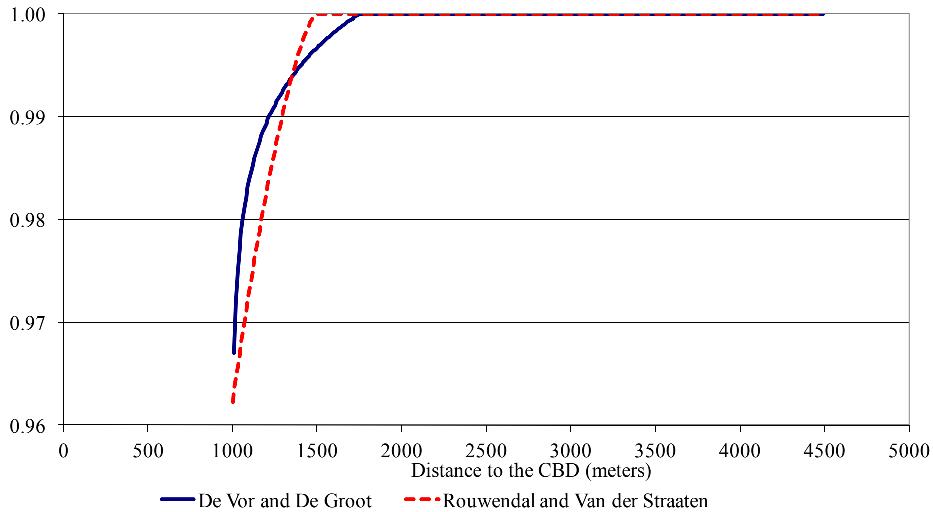
where R_0 and R_1 denote land rents with and without the presence of the site, respectively. We use their estimates for the province of Brabant nearby Nijmegen for η_1 to η_3, whereas η_4 and the dummy $1_{d<750}$ ensure that the effect levels off continuously after 750 meters. These estimates of the nuisance effect are conservative compared with other results in their paper. Setting $E_1(r)=1$, the function $E_0(r)$ can be solved analytically by substituting land rents into Eq. (21). Finally, De Vor and De Groot estimate a house price equation and we model the impact on land rents. The share of house prices that is spent on land ρ is approximately equal to 25% in the center of Nijmegen. The factor $1/\rho$ on the right-hand side of Eq. (21) reflects the assumption that the entire effect of the nuisance on house prices operates through land rents.

Our second specification of $E(r)$ is based on Rouwendal and Van der Straaten (2008), who estimate the impact of proximity to industrial sites as:

$$\log\left(R_1(r)\right)-\log\left(R_0(r)\right)=\delta\theta/\rho, \tag{22}$$

where θ is the percentage of land in industrial use in a circle with a radius of 500 meters surrounding the house. We use $\delta=0.006$, which corresponds to the estimate for Rotterdam, where Rouwendal and Van der Straaten found the strongest effect. Eq. (22) assumes that houses are surrounded by either residential or industrial land, i.e., the nonurban land (of which there is a share 1 – ω) is located further away than the 500-meter radius. This leads to an overestimation of the impact of the nuisance. The function $E_0(r)$ is obtained from Eq. (22) in a similar way as before. Both variants are plotted in Figure 4.

Figure 4: Environmental quality functions



The urban production function is given by:

$$\Pi(N) = KN^{\kappa}N\,, \qquad (23)$$

where κ is the elasticity of average labor productivity with respect to urban scale – the number of households or jobs in the city. Rosenthal and Strange (2004) survey the early literature on this elasticity as indicating that doubling city size raises productivity by an amount that ranges from approximately 3% to 8%. However, these studies did not control for unobserved factors, such as the composition of the local workforce, that recent work has shown to result in downward bias (see, in particular, Combes *et al*., 2008). Therefore, we somewhat conservatively choose κ = 0.02.[28] The constant K is chosen such that in the baseline equilibrium, the predicted wage in Nijmegen equals the observed average disposable household income.

3.2 Simulation results

Figure 5 shows land rents in the residential sector prior to and after the redevelopment project for the baseline scenario, where the urban fringe is held

[28] In an applied general equilibrium analysis of US county-level employment, Chatterjee (2006) also chooses a scale elasticity of 0.02, following essentially the same line of reasoning. This study illustrates that such a seemingly small elasticity can still have a substantial impact on the spatial distribution of jobs. Table 5 contains a sensitivity analysis with regard to this elasticity.

constant. The change in these land rents reflects the change in developer surplus. In the project area itself, extending to 1 kilometer from the CBD, any rents of land in alternative use should be subtracted. Rents of residential land close to the industrial site rise substantially, because of removal of the nuisance. However, land rents further away fall because of downward sloping demand, which turns out to dominate the agglomeration effect. Finally, note the slight dip in land rents near the boundary between the residential and the redeveloped industrial land, which is a consequence of fixing lot sizes in the existing city: these lot sizes would have been optimal in the presence of nuisance but after its removal they are too large. Lot sizes and consumption of the composite commodity that corresponds to this figure are documented in Appendix Figures A1 and A2, respectively.

Figure 5: Land rents

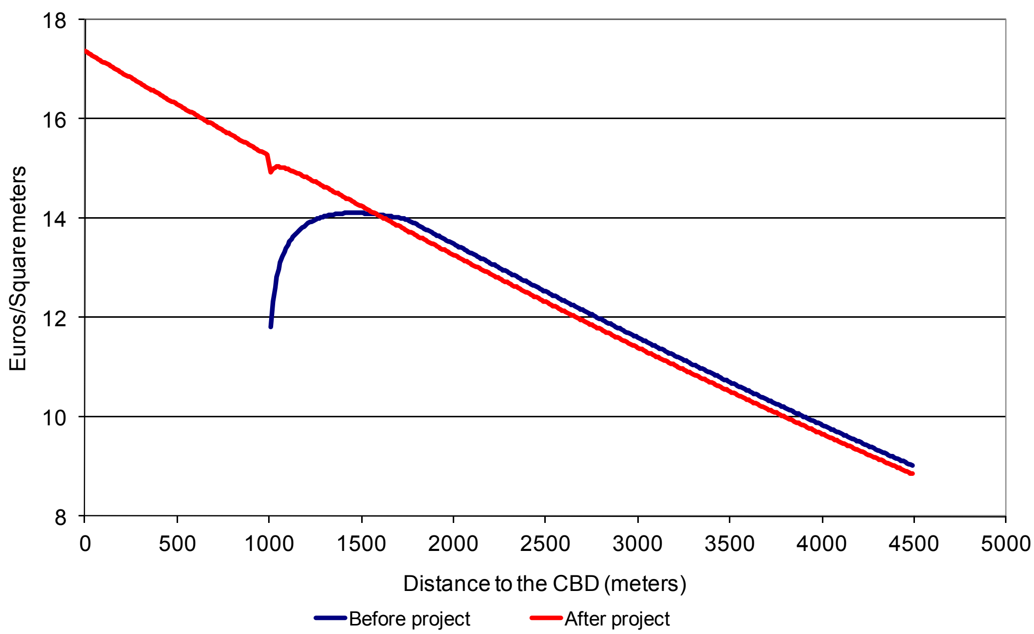


Table 3 shows the benefits and costs of the project as obtained in Table 1 for the baseline project, as well as for two projects that are smaller and larger by a factor four. The number of additional households in the city equals 4814 in the baseline project and internal benefits amount to almost 17 million euros annually, corresponding to a present value of 330 million euros at a discount rate of 5%. The external benefit of removing a nuisance to surrounding residents, based on the estimates from De Vor and De Groot (2011), constitutes 10% of these internal benefits and external agglomeration benefits are worth another 15%. Hence, total benefits are substantially larger than what an owner of the site would consider in her investment decision. The benefit to new consumers is negligible compared with the internal benefits, yet there is a substantial transfer from landowners to consumers who lived in the city already prior to the project.

Table 3 BCA for baseline, small and large project

	small project r_a = 0.5 km	baseline project r_a = 1 km	large project r_a = 2 km
Internal effects			
Benefits	4.30	16.54	61.73
Costs	0.26 $P + Q$	1.04 $P + Q$	4.15 $P + Q$
External benefits			
Removal of nuisance	0.98	1.59	2.67
Agglomeration benefit	0.63	2.43	8.80
Inframarginal surplus	0.01	0.19	2.23
Transfers			
To old households	1.72	6.37	20.06

Note: Amounts are measured in millions of euros per year. The environmental externality is based on De Vor and De Groot (2011). The urban fringe is exogenous.

The internal benefits, the agglomeration benefits and the transfer rise more or less proportionally with the size of the redeveloped site. However, the relative importance of removing the nuisance declines. The reason is that this effect is only external to the extent that it crosses the boundary of the industrial site, whereas within this boundary it is fully internalized in land rents. For a larger (circular) site, the area within is larger compared with the area at the fringe, so the owner will take a larger share of the nuisance into account. The inframarginal surplus rises more than proportionally with the size of the project, as new households have an ever lower taste for living in the city. For the largest project in Table 3, this benefit is almost as large as the benefit of removing the nuisance.

Table 4 investigates the impact of the demand elasticity on costs and benefits and it is based on the alternative estimate of the nuisance effect from Rouwendal and Van der Straaten (2008). Comparison of the second column of this table with the second column of Table 3, which has the same demand elasticity, shows that the external effect due to removal of the nuisance is almost equally large for both specifications. It should be borne in mind, however, that the magnitude of this benefit critically depends on the nature and magnitude of the environmental externality, which may vary considerably across brownfield sites.

Table 4 BCA for alternative environmental externality and demand elasticities

	demand elasticity ε_D = -1	demand elasticity ε_D = -2 (baseline)	demand elasticity $\varepsilon_D = -\infty$
Internal effects			
Benefits	16.16	16.54	16.95
Costs	1.04 $P + Q$	1.04 $P + Q$	1.04 $P + Q$
External benefits			
Removal of nuisance	1.86	1.86	1.86
Agglomeration benefit	2.40	2.43	2.47
Inframarginal surplus	0.38	0.19	0
Transfers			
To old households	12.53	6.36	0

Note: Amounts are measured in millions of euros per year. The environmental externality is based on Rouwendal and Van der Straaten (2008). The urban fringe is exogenous.

A comparison of results across columns in Table 4 sheds light on the relative importance of general equilibrium effects. Recall that the case of perfectly elastic housing demand in the third column corresponds to the open city case, in which brownfield conversion does not induce a general equilibrium effect through reduced housing demand in the rest of the urban area. Direct benefits decrease when housing demand is more inelastic. The rise in inframarginal surplus, which will not be internalized by the owner of a brownfield site, offsets generally half of this loss. Furthermore, the transfer from landowners to households may become fairly substantial. Agglomeration benefits rise slightly with the demand elasticity, whereas the nuisance effect does not depend on it at all.

The impact of the strength of agglomeration economies is illustrated in Table 5. This table indicates that agglomeration benefits rise proportionally with the scale elasticity and it also identifies a minor positive impact on internal benefits. Table 6 contains a sensitivity analysis with respect to the elasticity of substitution. A higher willingness to substitute the composite commodity, which may include the services from housing capital, for land implies a steeper urban density gradient. Hence, the density of housing on the centrally located redeveloped site is larger if the substitution elasticity is higher. This explains the higher direct benefits, agglomeration benefits, inframarginal surplus and transfer.

Table 5 BCA for baseline and alternative scale elasticities

	scale elasticity $\kappa = 0$	scale elasticity $\kappa = 0.01$	scale elasticity $\kappa = 0.03$
Internal effects			
Benefits	16.39	16.46	16.61
Costs	1.04 $P + Q$	1.04 $P + Q$	1.04 $P + Q$
External benefits			
Removal of nuisance	1.59	1.59	1.59
Agglomeration benefit	0	1.21	3.66
Inframarginal surplus	0.19	0.19	0.20
Transfers			
To old households	6.34	6.35	6.38

Note: Amounts are measured in millions of euros per year. The environmental externality is based on De Vor and De Groot (2011). The urban fringe is exogenous.

Table 6 BCA for baseline and alternative elasticities of substitution

	elasticity of substitution $\sigma = 0.25$	elasticity of substitution $\sigma = 0.5$	elasticity of substitution $\sigma = 0.75$
Internal effects			
Benefits	16.42	16.54	16.66
Costs	1.04 $P + Q$	1.04 $P + Q$	1.04 $P + Q$
External benefits			
Removal of nuisance	1.60	1.59	1.58
Agglomeration benefit	2.26	2.43	2.63
Inframarginal surplus	0.17	0.19	0.23
Transfers			
To old households	5.94	6.37	6.85

Note: Amounts are measured in millions of euros per year. The environmental externality is based on De Vor and De Groot (2011). The urban fringe is exogenous.

Table 7 shows how the value of preserved open space, the final term in Eq. (15), depends on key model parameters. The demand elasticity varies over columns in a similar way as in Table 4. Agglomeration externalities are assumed to be absent in the upper panel while the scale elasticity equals 0.02 in the lower panel, just as in the baseline model. Within each panel, we vary the value of open space V while holding the development tax τ constant. Consider the upper panel first. With a demand elasticity of –2, redevelopment of a brownfield site of approximately 100 hectares preserves an area of open space at the urban fringe of approximately 50 hectares. The resulting benefit is negligible if its value is fully internalized through land use policy at the urban fringe. If the value of open space is twice as high as the development tax ($V - \tau = 5$), then the additional benefit rises to approximately 15% of the internal benefits. The amount of open space that is preserved and the benefit this generates fall with the demand elasticity. In the limiting case of infinitely elastic demand, the redevelopment project does not reduce development at the urban fringe at all.

Table 7 Value of preserved open space

	demand elasticity $\varepsilon_D = -1$	demand elasticity $\varepsilon_D = -2$ (baseline)	demand elasticity $\varepsilon_D = -\infty$
$\kappa = 0$			
$V - \tau = 0$	0.15	0.07	0
$V - \tau = 1$	0.85	0.54	0
$V - \tau = 2$	1.55	1.02	0
$V - \tau = 5$	3.64	2.44	0
$\kappa = 0.02$			
$V - \tau = 0$	0.12	0.03	0.12
$V - \tau = 1$	0.73	0.33	-1.08
$V - \tau = 2$	1.34	0.63	-2.28
$V - \tau = 5$	3.16	1.52	-5.88

Note: Amounts are measured in millions of euros per year. The environmental externality is based on De Vor and De Groot (2011).

The presence of agglomeration externalities renders development at the urban fringe more attractive, which is partly reflected in the price of land at newly developed sites. Hence, with a demand elasticity of –2 and a scale elasticity of 0.02, redevelopment of the same brownfield site of approximately 100 hectares now preserves an area of open space of only approximately 30 hectares. If demand is sufficiently elastic, then the project may even *increase* development at the urban fringe – approximately 120 hectares in the case of an infinite elasticity. This yields additional costs rather than benefits if planning policies at the fringe are not capable of internalizing the value of open space. As documented in Appendix Table A1, which provides a complete overview of the costs and benefits that correspond to the lower panel of Table 6, agglomeration benefits are also affected by adjustment of the urban fringe. Preservation of open space means that fewer households enter the city so that the rise in productivity is lower than in a scenario in which it is held exogenous. By contrast, the extension of the urban fringe that occurs if demand is sufficiently elastic leads to higher agglomeration benefits. Hence, it may even be desirable to impose a development tax below the value of open space, as its loss is compensated by a productivity gain.

4 Conclusions and discussion

This paper proposes a tractable urban general equilibrium framework for the evaluation of direct and indirect benefits of brownfield redevelopment. A numerical application explores the order of magnitude of effects under alternative parameter assumptions. We found that brownfield redevelopment may yield substantial external benefits through the exploitation of urban agglomeration economies and the removal of a nuisance. Hence, owners of brownfield sites would underinvest in such projects and government intervention may be warranted. The preservation of open space does not appear to be a relevant consideration from a welfare economic point of view, unless governments are unable to internalize the value of open space directly through planning policies at the urban fringe and the demand for housing in the city is sufficiently inelastic.[29] With elastic demand, development pressure at the urban fringe may even increase because of agglomeration economies. Downward sloping demand for housing units in the city leads to several other general equilibrium effects. In the first place, brownfield redevelopment induces a transfer from landowners to households, which may be fairly substantial. In the second place, there is a modest loss in direct benefits that is partly offset by a gain in inframarginal consumer surplus.

A caveat on the additionality of external agglomeration benefits is that we focus exclusively on welfare in the city in which brownfield redevelopment occurs. There may be an offsetting loss in external agglomeration economies in the cities from which the incoming households originate. In that case, the enhanced exploitation of agglomeration economies should not be counted in a BCA at the national level. However, this offsetting effect does not necessarily occur, as incoming households may also originate from the countryside, where agglomeration economies are largely absent, or come at the expense of fewer rather than smaller cities. The underlying mechanisms are the same as in Vermeulen (2011), which studies the external agglomeration benefits of relaxing urban growth controls in a system of cities.

Our analytical framework is suitable for a range of applications. Instead of the redevelopment of an industrial site that is still in use, it may be applied to the cleanup and redevelopment of contaminated land, such as the US Superfund sites. In that case, the environmental quality function should reflect pollution or health risk, rather than nuisance. Alternatively, this function could be made to reflect the urban blight that is often associated with vacant land (Wright, 1997). Of course, the magnitude of the external benefit that will be generated by the model will be

[29] It is remarkable that EPA (2011) does not discuss the possibility that direct land use controls at the urban fringe internalize part of the external value of open space already. This may be due to the fact that such policies are less common in the US than in Europe.

driven by the empirical estimates of the environmental externality on which it is calibrated.[30] Furthermore, it should be borne in mind that the benefits in our analytical framework are not comprehensive and may need to be augmented depending on the specific application.[31]

Finally, our results should not be interpreted as unqualified support for current government involvement in brownfield redevelopment and densification of land use in existing urban areas. Even if the value of redeveloped land underestimates social returns, these returns may still be surpassed by the costs of transformation projects. Moreover, the supply of redevelopable land is probably upward sloping, so a strong commitment to densification will lead planners to consider increasingly more expensive sites. Well-informed policymaking will require a careful and empirically founded analysis of the costs and benefits of each particular redevelopment project.

[30] Notably, Greenstone and Gallagher (2008) found that the external health and environmental benefits from cleaning up Superfund sites are rather small. Our analytical framework could simply be adapted to reflect the absence of local externalities by setting $E_0(r) = E_1(r) = 1$.

[31] In particular, we ignore the stigma effects resulting from imperfect information that appear to play an important role in the cleanup of hazardous waste sites. The environmental externality as identified in a hedonic analysis reflects the perception of risks or other externalities, so the benefits will be underestimated if brownfield redevelopment improves health more thoroughly than perceived. See Table 6.1 in EPA (2011) for a more general overview of the benefits of land cleanup and reuse. Section 4 of this document provides a discussion of stigma effects.

Appendix Table A1 and Figures A1 and A2

Table A1 Extended BCA for Table 6, lower panel (κ = 0.02)

	demand elasticity ε_D = -1	demand elasticity ε_D = -2 (baseline)	demand elasticity $\varepsilon_D = -\infty$
Internal effects			
Benefits	16.43	16.59	17.07
Costs	1.04 $P + Q$	1.04 $P + Q$	1.04 $P + Q$
External benefits			
Removal of nuisance	1.59	1.59	1.59
Agglomeration benefit	1.33	1.91	4.56
Inframarginal surplus	0.12	0.12	0
Preserved open space			
$V - \tau = 0$	0.12	0.03	0.12
$V - \tau = 1$	0.73	0.33	-1.08
$V - \tau = 2$	1.34	0.63	-2.28
$V - \tau = 5$	3.16	1.52	-5.88
Transfers			
To old households	7.07	5.03	0

Note: Amounts are measured in millions of euros per year. The environmental externality is based on De Vor and De Groot (2011). The urban fringe is endogenous.

Figure A1: Lot sizes

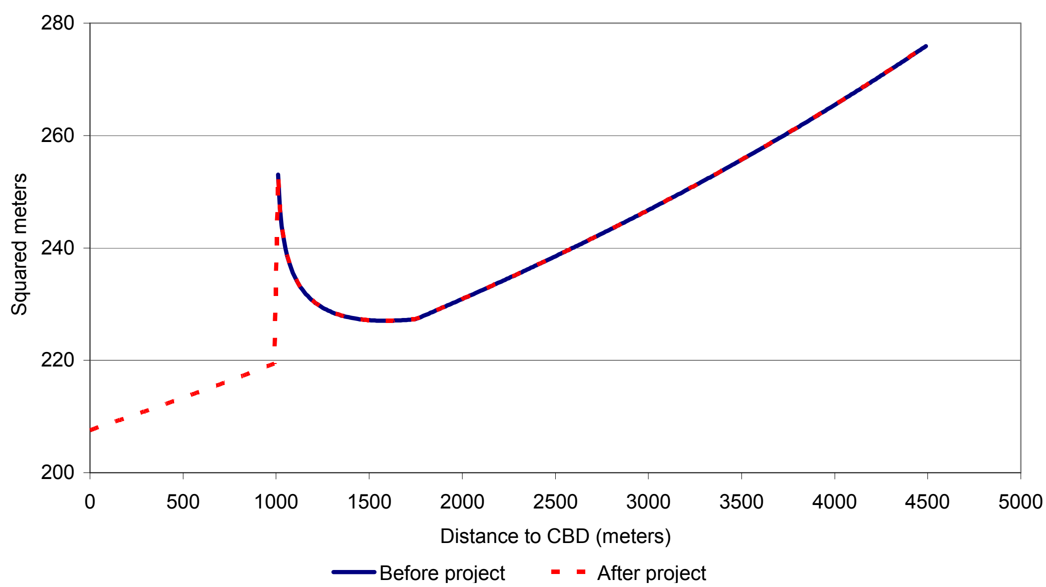
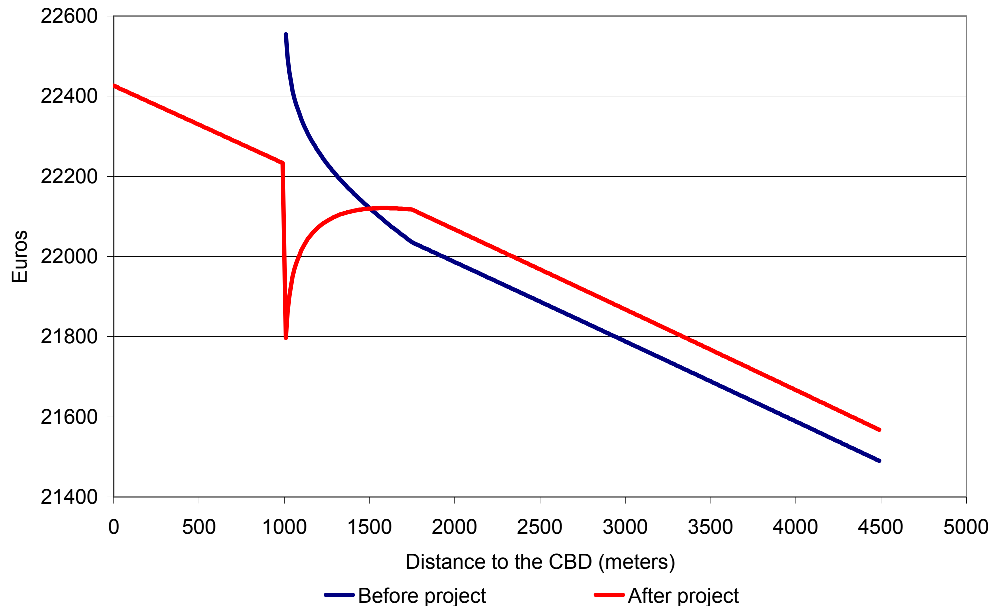


Figure A2: Consumption of composite commodity



References

Anderson, S. P., De Palma, A., and Thisse, J. F. (1992). *Discrete Choice Theory of Product Differentiation*. Cambridge, MA: MIT Press.

Anas, A., Arnott, R. and Small, K. A. (1998). Urban spatial structure. *Journal of Economic Literature*, **36**, 1426–64.

Arnott, R. and Stiglitz, J. (1979). Aggregate land rents, expenditure on public goods, and optimal city size. *Quarterly Journal of Economics*, **93**, 471–500.

Chatterjee, S. (2006). *A Quantitative Assessment of the Role of Agglomeration Economies in the Spatial Concentration of U.S. Employment*. Federal Reserve Bank of Philadelphia Working Paper no. 06-20.

CLG (2010). *Planning Policy Statement 3: Housing*. London: Department of Communities and Local Government.

Combes, P.-P., Duranton, G., and Gobillon, L. (2008). Spatial wage disparities: sorting matters! *Journal of Urban Economics*, **63**, 723–42.

CPB and PBL (2010). *Evaluatie beoordelingen Nota Ruimteprojecten.*[*Evaluation of assessments of spatial investment proposals.*] Den Haag: Centraal Planbureau en Planbureau voor de Leefomgeving.

Deason, J. P., Sherk, G. W., and Carroll, G. A. (2001). *Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights and Areal Differentials*. Submitted to U.S. EPA, Office of Solid Waste and Emergency Response, George Washington University, Washington, DC.

De Sousa, C. (2002). Measuring the public costs and benefits of brownfield versus greenfield development in the greater Toronto area. *Environment and Planning B: Planning and Design*, **29**, 251–80.

De Vor, F. and De Groot, H. L. F. (2011). The impact of industrial sites on residential property values: a hedonic pricing analysis from the Netherlands. *Regional Studies*, **45**, 609–23.

Duranton, G. and Puga, D. (2004). Micro-foundations of urban agglomeration economies. In Henderson V. J. and Thisse, J. F. (eds.), *Handbook of Regional and Urban Economics*, Volume 4. Amsterdam: North-Holland/Elsevier.

EPA (2011). *Handbook on the Benefits, Costs and Impacts of Land Cleanup and Reuse*. Washington, DC: Environmental Protection Agency (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/homepage).

Ermisch, J. F., Findlay, J., and Gibb, K. (1996). The price elasticity of housing demand in Britain: issues of sample selection. *Journal of Housing Economics*, **5**, 64–86.

Fujita, M. (1989). *Urban Economic Theory: Land Use and City Size*. Cambridge, UK: Cambridge University Press.

Gayer, T., Hamilton, J. T., and Viscusi, W. K. (2000). Private values of risk tradeoffs at superfund sites: housing market evidence on learning about risk. *Review of Economics and Statistics*, **82**, 439–51.

Greenstone, M. and Gallagher, J. (2008). Does hazardous waste matter? Evidence from the Housing Market and the Superfund Program. *The Quarterly Journal of Economics*, **123**, 951–1003.

Greenstone, M., Hornbeck R., and Moretti, E. (2010). Identifying agglomeration spillovers: evidence from winners and losers of large plants openings. *Journal of Political Economy*, **18**, 536–98.

Hilber, C. A. L. and Robert-Nicoud, F. (2010). *On the Origins of Land Use Regulations: Theory and Evidence from US Metro Areas*. LSE Working Paper, July.

Ihlanfeldt, K. R. and Shaughnessy, T. (2004). An empirical investigation of the effect of impact fees on housing and land markets. *Regional Science and Urban Economics*, **34**, 639–61.

Ihlanfeldt, K. R. and Taylor, L. O. (2004). Externality effects of small-scale hazardous waste sites: evidence from urban commercial property markets. *Journal of Environmental Economics and Management*, **47**, 117–39.

Kaufman, D. A. and Cloutier, N. R. (2006). The impact of small brownfields and greenspaces on residential property values. *Journal of Real Estate Finance and Economics*, **33**, 19–30.

Kiel, K. and Zabel, J. (2001). Estimating the economic benefits of cleaning-up superfund sites: the case of Woburn, Massachusetts. *Journal of Real Estate Finance and Economics*, **22**, 163–84.

Kohlhase, J. E. (1991). The impact of toxic waste sites on housing values. *Journal of Urban Economics*, **30**, 1–26.

McCluskey, J. J. and Rausser, G. C. (2003). Hazardous waste sites and housing appreciation rates. *Journal of Environmental Economics and Management*, **45**, 166–76.

McConnell, V. and Walls, M. (2005). *The Value of Open Space: Evidence from Studies of Nonmarket Behavior*. Washington, DC: Resources for the Future.

Michaels, R. G. and Smith, V. K. (1990). Market segmentation and valuing amenities with hedonic models: the case of hazardous waste sites. *Journal of Urban Economics*, **28**, 223–42.

Quigley, J. M. and Swoboda, A. M. (2007). The urban impacts of the Endangered Species Act: a general equilibrium analysis. *Journal of Urban Economics*, **61**, 299–318.

Rosenthal, S. S. and Strange, W. C. (2004). Evidence on the nature and sources of agglomeration economies. In Henderson V. J. and Thisse, J. F. (eds.), *Handbook of Regional and Urban Economics*, Volume 4. Amsterdam: North-Holland/Elsevier.

Rouwendal, J. and Van der Straaten, J. W. (2008). *The Costs and Benefits of Providing Open Space in Cities*. Tinbergen Discussion Paper no. 2008-001/3.

Smith, V. K. (2011). *Peer Review Report for the Draft Handbook on the Benefits, Costs, and Impacts of Land Cleanup and Reuse*. Washington, DC: Environmental Protection Agency (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/homepage).

Vermeulen, W. (2011). *Agglomeration Externalities and Urban Growth Controls*. SERC Discussion Paper no. 93.

VROM LNV, V&W, EZ (2004). *Nota ruimte. Ruimte voor ontwikkeling.* [*Whitebook on planning. Space for development.*] Ministerie van Ministerie van Volkshuisvesting, Ruimtelijke ordening en Milieu, Ministerie van Landbouw, Natuurbeheer en Visserij, Ministerie van Verkeer en Waterstaat and Ministerie van Economische Zaken, SdU, Den Haag.

Walsh, R. (2007). Endogenous open space amenities in a locational equilibrium. *Journal of Urban Economics*, **61**, 319–44.
Wildasin, D. E. (1986). Spatial variation of the marginal utility of income and unequal treatment of equals. *Journal of Urban Economics*, **19**, 125–29.
Wright, J. G. (1997). *Risks and Rewards of Brownfield Development*. Cambridge, MA: Lincoln Institute of Land Policy.