CPB Netherlands Bureau for Economic Policy Analysis

CPB Discussion Paper | 178

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

Niels Vermeer
Wouter Vermeulen

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

by

Niels Vermeer

CPB Netherlands Bureau for Economic Policy Analysis

Wouter Vermeulen

CPB Netherlands Bureau for Economic Policy Analysis

VU University

Spatial Economics Research Centre (SERC)

This version: 18 May 2011

We gratefully acknowledge helpful comments by 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.

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

Abstract

Does brownfield redevelopment warrant government support? We model external benefits of the transformation of an inner city industrial site into a residential area in an urban general equilibrium framework, focussing on the removal of a local nuisance, the exploitation of agglomeration economies and preservation of open space at the urban fringe. These benefits are compared to the value of transformed land, which accrues to the developer. A numerical application indicates that local nuisance and agglomeration effects may push social returns significantly beyond these private returns. However, depending on the price elasticity of local housing demand, 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.

JEL classification: R13, R21, R52

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

1 Introduction

Government involvement in the regeneration of outdated or derelict industrial sites in centrally located urban areas is widespread. Not only is the remediation of contaminated brownfield sites subsidized in the US and in various European countries, but spatial planning policies also tend to favour densification of land use in existing urban areas over the development of greenfield sites at their fringe. The Dutch government, for instance, 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.[1] The transformation of outdated industrial or brownfield sites to residential areas is an obvious channel for meeting such targets.

Can government support for inner city redevelopment be justified on the basis of its external effects? We deploy an urban general equilibrium model to analyse the welfare effects of transforming an inner city industrial site into a residential area. The returns to the developer consist of the value of the transformed land. External benefits result from the removal of a local nuisance, the exploitation of agglomeration economies and preservation of open space at the urban fringe. The contrast between these benefits and the value of the transformed land indicates how badly private returns underestimate social returns to the project.

Our analytical setup may be equally applied to centrally located sites where industrial firms are still active or to deserted brownfield sites. In the former case, surrounding residents benefit from the removal of noxious emissions, noise or unpleasant smells. Derelict sites may pose a health hazard in case of soil contamination and they sometimes attract vandalism and illegal dumping (see e.g., Wright, 1997, for a comprehensive discussion). The presence of this type of environmental effects has been borne out in various hedonic studies of urban housing markets. For instance, Kaufman and Cloutier (2006) find a substantial negative impact of small brownfields on surrounding property values. Kiel and Zabel (2001) similarly report a considerable willingness to pay for the cleanup of a closed and abandoned hazardous waste site, while Kohlhase (1991) shows that house prices rebound when such a cleanup has been completed.[2]

[1] See Kaufman and Cloutier (2006) for a discussion of US government support for brownfield regeneration. See VROM *et al*. (2004) and CLG (2010) for policy statements in the Dutch and UK cases respectively.
[2] See also Smith and Desvousges (1986) for an early estimate of the impact of proximity of hazardous waste sites on land values.

Brownfield redevelopment and the exploitation of agglomeration benefits have not been linked explicitly in the economics literature. However, Rosenthal and Strange (2004) survey a large body of evidence on positive returns to urban scale and density, both of which are enhanced by the transformation of inner city (former) industrial sites into residential and commercial real estate. Furthermore, although this distinction is not explicit in our analysis, the advantages of scale and density matter not only for production but also for consumption (Glaeser *et al*., 2001), which may be particularly relevant for inner city areas where consumer amenities are mostly concentrated.

The notion that greenfields near the urban fringe represent a nonmarket value as open space is also supported in several empirical studies, see McConnell and Walls (2005) for an overview. In a first-best world, this nonmarket value would be internalized through a pigouvian tax on development. However, institutional barriers to development taxation may exist in reality. 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. Hence, in a second-best world, there is a possible scope for subsidization of brownfield redevelopment as a means to preserve open space.

The amount of land that will be preserved depends on demand for housing in the city. Quigley and Swoboda (2007) and Walsh (2007) consider the extreme case of a closed city, in which this substitution effect is largest.[3] At the other extreme, brownfield redevelopment will not directly affect the demand for land at the urban fringe, if households regard alternative cities as sufficiently close substitutes, as in the open city model. We consider the intermediate case of downward sloping demand for housing in the city, by assuming that households differ in their taste for some unique amenity or attribute on offer. Hence, demand for housing in the transformed area is downward sloping as well. The implications of this realistic extension of the standard urban model for welfare analysis have scarcely been investigated in the literature.[4]

Our research was motivated by a recent series of applications for grants of the Dutch government to support urban redevelopment projects, which all had to be founded on a cost-benefit analysis (CPB and PBL, 2010, provides an overview). External effects featured

[3] These studies show that local provision of open space may be ineffective because it spurs the conversion of agricultural land at other sites, yet the underlying mechanism is the same: if restrictions on housing supply in one place raise development elsewhere, then the new supply that is generated through inner city redevelopment should reduce development elsewhere.

[4] Standard urban economic theory assumes that cities are either open or closed, see e.g. Fujita (1989). Our extension with heterogeneity in tastes and places follows Hilber and Robert-Nicoud (2010).

prominently in most of these applications. The analysis in this paper provides a theoretical basis for their assessment, as well as a quantitative intuition for the order of magnitude and its key determinants. We calibrate our model to a representative project in the medium-sized town of Nijmegen, which proposed moving an industrial site from its centre to the outer fringe, partly to get rid of unpleasant smells from a producer of tomato ketchup and a large abattoir, and redeveloping it with residential real estate.

2 Derivation of CBA from the monocentric model

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. 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 exhibits external increasing returns to scale $F(N)$, where N denotes the number of households or jobs in the city, while 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 noise, stench or other externalities. The project involves conversion of the site into a residential area, which eradicates the reduction in environmental quality. Structures and plot sizes in the existing city will not be adjusted because of durability.

2.1 Equilibrium on urban housing and labour markets

The city has some unique feature and households vary in their appreciation for it. This unique feature may either reflect some nonreproducible amenity or personal history – people who grew up in an area are more strongly attached to 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:

$$u(i) = v + \varepsilon(i) . \qquad (1)$$

Random components are drawn from a common distribution with cumulative density function $F(\varepsilon)$. The households with the highest draw sort into our city and since this draw does not depend on their location within the city, they should all receive the same common utility level.[5] 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 into 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. It is downward sloping in prices, since the common utility level depends negatively on land rents.

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

Households provide one unit of labour 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:

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

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 (3) reads

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

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 $s(r, w, v)$ that satisfies this condition solves the consumer problem. We assume that the size of structures and plots in the existing city is not affected by the project, which means that

[5] 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.

condition (4) is not satisfied. In that case, bid rents are obtained by substituting an exogenous lot size function into (3).

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*:

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

For each wage level, the equilibrium number of households $N^*(w)$ and common utility level $v^*(w)$ are obtained by equating this supply to housing demand from expression (2). Figure 1 illustrates the urban housing market using our calibrated model. Note that urban housing supply is downward sloping in the common utility level, since households will demand larger plots in order to attain a higher common utility level.

Since each household provides one unit of labour, the equilibrium number of households $N^*(w)$ may also be interpreted as a labour supply equation. In the CBD, labour 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 $F(N) = g(N)N$, where $g(N)$ may be thought of as an increasing concave function of the urban employment level. The marginal product of labour is $g(N) + g'(N)N$, but individual firms ignore the impact of wage setting on *N*, so that they pay labour its average product $g(N)$. Hence, the labour 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 labour market and we denote the equilibrium wage and number of households by w^* and N^* respectively. Figure 2 illustrates labour demand and supply curves in our calibrated model. There are two intersections and only the second one is stable.

2.2 Welfare analysis

The welfare effects of converting the industrial site into a residential area may be decomposed into three constituents: the cleaning or decontamination and conversion of the site require an investment cost Q and the project induces changes in producer and consumer surplus. Producer surplus is defined as the difference between the value of the urban produce and all costs that have to be made in order to ensure the equilibrium common utility level. This surplus is measured relative to the value of land in agriculture and open space, so 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. Consumer surplus changes through adjustment of the common utility level – note that it would be absent in the limiting (open city) case in which household tastes are homogeneous.

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 equation (5) and then solving it simultaneously with equations (2) and (6). Conversion of land to urban use costs C per unit per year plus annual opportunity costs that consist of value in agricultural production p_A and open space V. Prior to the redevelopment project, the producer surplus reads:

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

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 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 in order to ensure a common utility level of v_0 for all households. Opportunity and conversion costs of the urban land are included through the final term. We may rewrite this surplus as:

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

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

The project changes L in equation (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 density in the redeveloped area is endogenous. Otherwise, equilibrium on urban housing and labour markets is determined in the same way, yielding v_1, w_1 and N_1 . Producer surplus in this new equilibrium is given by:

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

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

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

where bid rents in the existing area are obtained by substitution of $s_0\left(r\right)$ into expression (3). The change in producer surplus thus equals:

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

The first term of expression (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:

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

The first term in expression (12) represents the external benefit of removing a source of 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. In order 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 other goods, which must be granted through a discount on land prices. Note that this increase may vary with distance to the CBD.

In order to obtain the total benefits from the project, we have to augment the change in producer surplus as expressed in (11) with a monetary measure for the rise in utility. Three groups may be distinguished. Households with a taste $\varepsilon < \overline{\varepsilon}_1$, where $\overline{\varepsilon}_1 \equiv u - v_1$, 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 expression (12) constitutes a *transfer* from producers or landowners to consumers and not an additional benefit.[6] 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. In order 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

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

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 treat 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 (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 costs and benefits of the redevelopment project. In this table, the benefits of removing 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 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 CBA.

---

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

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 in order 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:

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

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 producer surplus is now given by:

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

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

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

The right-hand side of this expression 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.

Expressions 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 be smaller as well, but the internal benefits will be larger. Costs of the project and the external benefit of removing the nuisance are unaffected.

3 Calibration

The analyses is applied to the conversion of a brownfield of about 100 hectares, which corresponds to 5% of the total amount of residential land available in the Dutch town of Nijmegen. This hypothetical project is chosen 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, roughly 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 CES component in land and the composite commodity. This yields the indirect utility function:

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

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-Douglass case and land rents have a stronger impact on wellbeing.

We assume that the tax on conversion of agricultural land is equal to an external value of 5 euro and that conversion costs an additional 4 euro annually, which is roughly in line with the numbers reported in Vermeulen (2010). Hence, if we evaluate expression (17) at the urban fringe, we can substitute $R(r)$ from the boundary condition (14). The average household income Y is observed and we make empirically founded assumptions on t (also based on Vermeulen, 2010) and the shape of $E(r)$, on which more 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, while lot sizes follow from the corresponding compensated demand equation. Substitution into the urban housing supply equation (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.[7]

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 (2010), we model the impact of an industrial site at distance d as:

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

where P_0 and P_1 denote house prices with and without presence of the site respectively. We use their estimates for the province of Brabant nearby Nijmegen for η_1 to η_3, while 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 to other results in their paper. Setting

[7] 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).

$E_1(r)=1$, the function $E_0(r)$ can be solved analytically by substituting land rents into expression (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 roughly equal to 25% in the centre of Nijmegen. The factor $1/\rho$ on the right-hand side of expression (21) reflects the assumption that the entire effect of 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:

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

where θ is the percentage of land in industrial use in a circle with a radius of 500 meter 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. Expression (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 (22) in a similar way as before. Both variants are plotted in Figure 3.

The urban production function is given by:

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

where κ is the elasticity of average labour 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 roughly 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 $\kappa = 0.02$.[8] The constant K is chosen such that in the baseline equilibrium, the predicted wage in Nijmegen equals the observed average disposable household income.

[8] 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.

4 Results

Figure 4 shows land rents in the residential sector prior to and after the redevelopment project for the baseline scenario, where the urban fringe is held constant. The change in these land rents reflects the change in producer surplus. In the project area itself, extending to one kilometre 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 nuisance. However, land rents further away fall because of downward sloping demand, which appears 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.

Table 3 shows costs and benefits 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 (2010), 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 to the internal benefits, yet there is a substantial transfer from landowners to consumers who lived in the city already prior to the project.

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 internalised in land rents. For a larger (circular) site, the area within is larger compared to 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, since 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 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. The less elastic demand, the lower the direct benefits, but roughly half of this loss is offset by a rise in inframarginal surplus. The transfer falls with demand elasticity. In the case of infinitely elastic demand, in which tastes for living in the city do not vary across households, inframarginal surplus and transfer are absent. Agglomeration benefits rise slightly with demand elasticity and 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 shows how the value of preserved open space, the final term in equation (15), depends on key model parameters. 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 about 100 hectares preserves an area of open space at the urban fringe of about 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 about 15% of the internal benefits. The amount of open space that is preserved and the benefit this generates fall with demand elasticity. In the limiting case of infinitely elastic demand, the redevelopment project does not reduce development at the urban fringe at all.

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 about 100 hectares now preserves an area of open space of only about 30 hectares. If demand is sufficiently elastic, then the project may even *increase* development at the urban fringe – about 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. In 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, since its loss is compensated by a productivity gain.

5 Conclusions and discussion

Government intervention in the land market is the traditional domain of planners and until recently, cost-benefit analysis was rarely used to evaluate it.[9] This paper has analysed costs and benefits of brownfield redevelopment, which may be regarded as an important aspect of planning in several European countries that pursue densification of land use in existing urban areas. External benefits of redeveloping brownfield land have been formally modelled in an urban general equilibrium framework, which provides a solid theoretical basis for applied cost-benefit analysis. A carefully calibrated numerical application has shed light on the order of magnitude of effects under alternative parameter assumptions.

We have found that brownfield redevelopment may yield substantial external benefits through the exploitation of urban agglomeration economies and the removal of nuisances. Hence, local landowners would underinvest in such projects and government intervention may be warranted. However, 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. With elastic demand, development pressure at the urban fringe may even increase because of agglomeration economies. This insight is of relevance, since planners and policymakers often advocate brownfield redevelopment as a strategy to preserve greenfield land.

[9] Cheshire and Sheppard (2002) pioneered the welfare economics of land use regulation, see Cheshire and Vermeulen (2009) for a recent overview.

Redevelopment projects induce a transfer from landowners to consumers in the rest of the city that may be substantial, depending on the housing demand elasticity. This effect may lead to opposition from landowners, as in Hilber and Robert-Nicoud (2010). On the other hand, the nuisance is likely capitalized into the price of plots surrounding the industrial site, so their owners stand to gain from the project. A property tax will mitigate these effects and a confiscatory 'Henry George tax' on differential land rents would fully eliminate them, but this type of tax is rarely observed in practice. Policymakers may want to take such distributional concerns into consideration.

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 likely 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.

Literature

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.

Cheshire, P. C. and Sheppard, S. (2002). Welfare Economics of Land Use Regulation. *Journal of Urban Economics*, **52**, 242–69.

Cheshire, P. C. and Vermeulen, W. (2009). Land markets and their regulation: the economic impacts of planning. In Geyer, H. S. (ed.), *International Handbook of Urban Policy, vol. 2*, Cheltenham: Edward Elgar.

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.* Den Haag: Centraal Planbureau en Planbureau voor de Leefomgeving.

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.

Glaeser, E. L., Kolko, J. and Saiz, A. (2001). Consumer city. *Journal of Economic Geography*, **1**, 27–50.

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.

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.

McConnell, V. and Walls, M. (2005). *The value of open space: Evidence from studies of nonmarket behavior*. Washington, D.C.: Resources for the Future.

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. and Desvousges, W. H. (1986). The Value of Avoiding a Lulu: Hazardous Waste Disposal Sites. *Review of Economics and Statistics*, **68**, 293–299.

Vermeulen, W. (2010). External scale economies and the cost of urban growth controls in a system of heterogeneous cities. Paper presented at the 5th Meeting of the Urban Economics Association, November 10-13, 2010, Denver, Colorado.

De Vor, F. and De Groot, H. L. F.(2010). The Impact of Industrial Sites on Residential Property Values: A Hedonic Pricing Analysis from the Netherlands. *Regional Studies*, forthcoming.

VROM, LNV, V&W, EZ (2004). Nota ruimte. Ruimte voor ontwikkeling. 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.

Wright, J. G. (1997). *Risks and Rewards of Brownfield Development*. Cambridge, MA: Lincoln Institute of Land Policy.

TABLES

Table 1: Costs and benefits 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	
$\int_{r^a}^{r^b} \begin{bmatrix} Z(v_0, s_0(r), E_0(r)) \\ -Z(v_0, s_0(r), E_1(r)) \end{bmatrix} n_0(r)\, dr$	effect of removing nuissance
$(w_1 - w_0) N_0$	agglomeration benefit
$M(\hat{r})$	inframarginal consumer surplus
Transfers	
$\int_{r^a}^{r^b} \begin{bmatrix} Z(v_1, s_0(r), E_1(r)) \\ -Z(v_0, s_0(r), E_1(r)) \end{bmatrix} n_0(r)\, dr$	transfer of surplus from landowners to households in the existing part of the city

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 (2010)	-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 meter 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	4504.61 m
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%
$p_A + C$	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 (2010), the external value corresponds to the smaller cities in the sample of that paper.

Table 3: CBA 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 (2010). The urban fringe is exogenous.

Table 4: CBA 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.

Table 5: CBA 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 (2010). The urban fringe is exogenous.

Table 6: Value of preserved open space

	demand elasticity ε_D = -1	demand elasticity ε_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 (2010).

FIGURES

Figure 1: Urban housing market

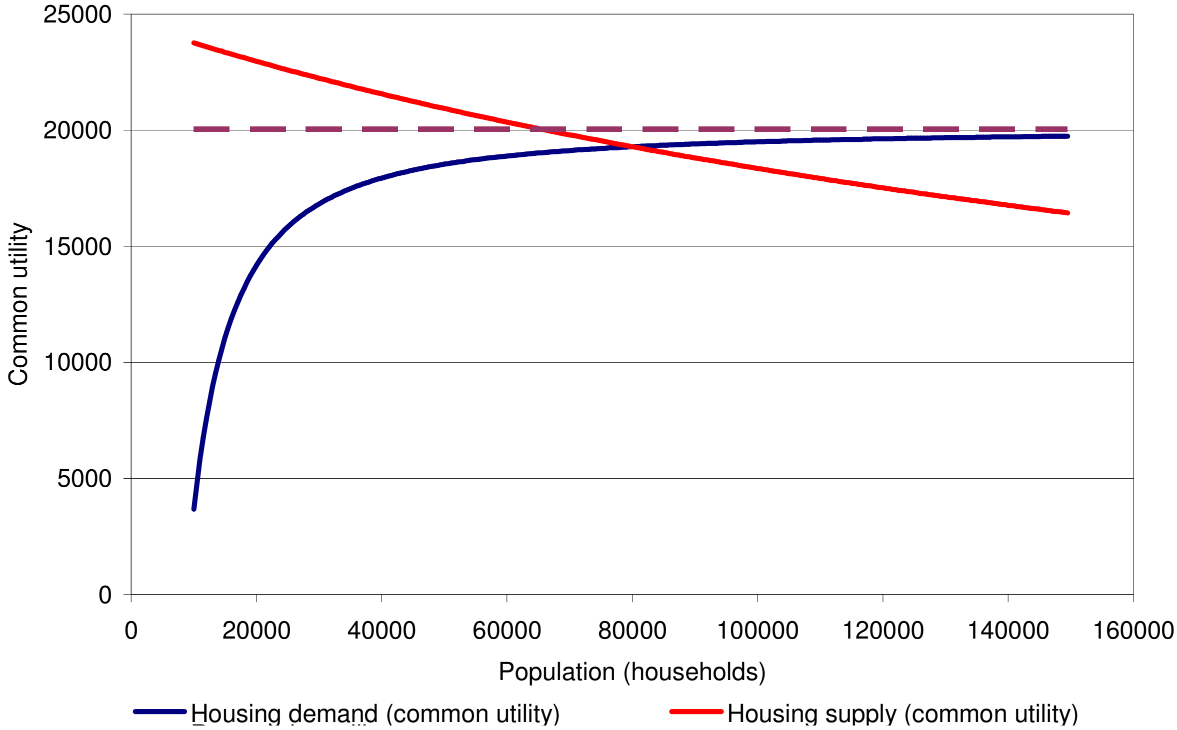


Figure 2: Urban labour market

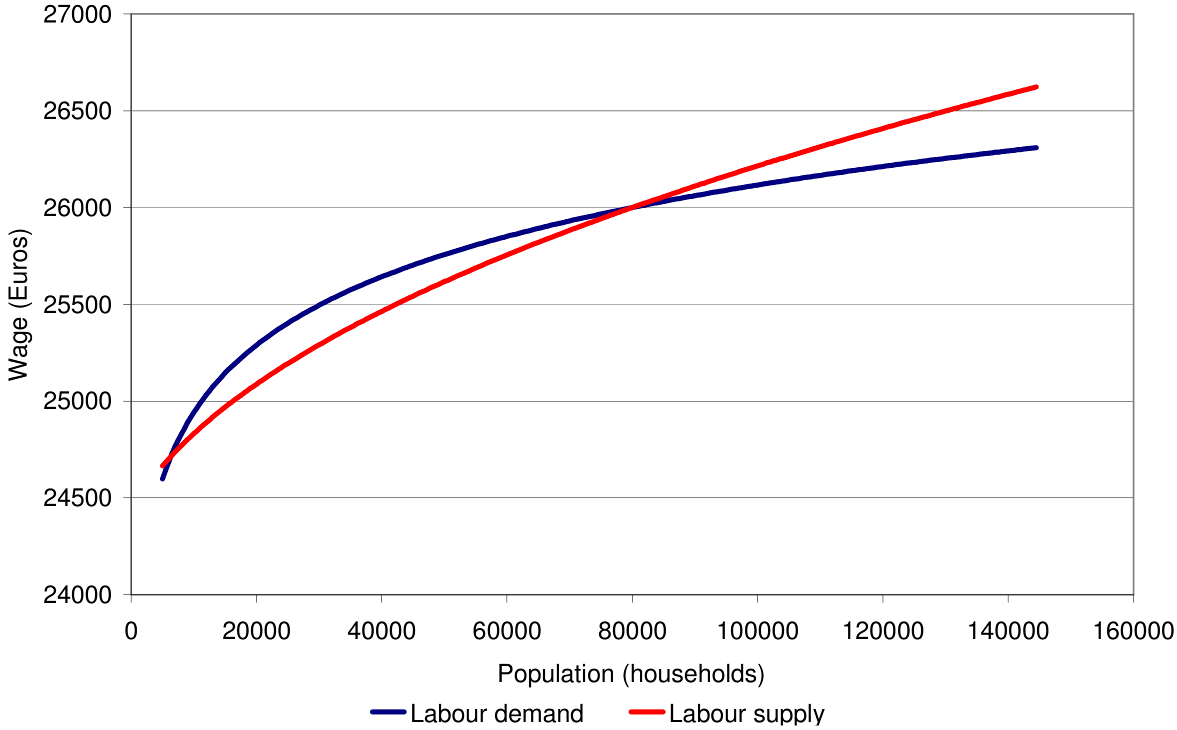


Figure 3: Environmental quality functions

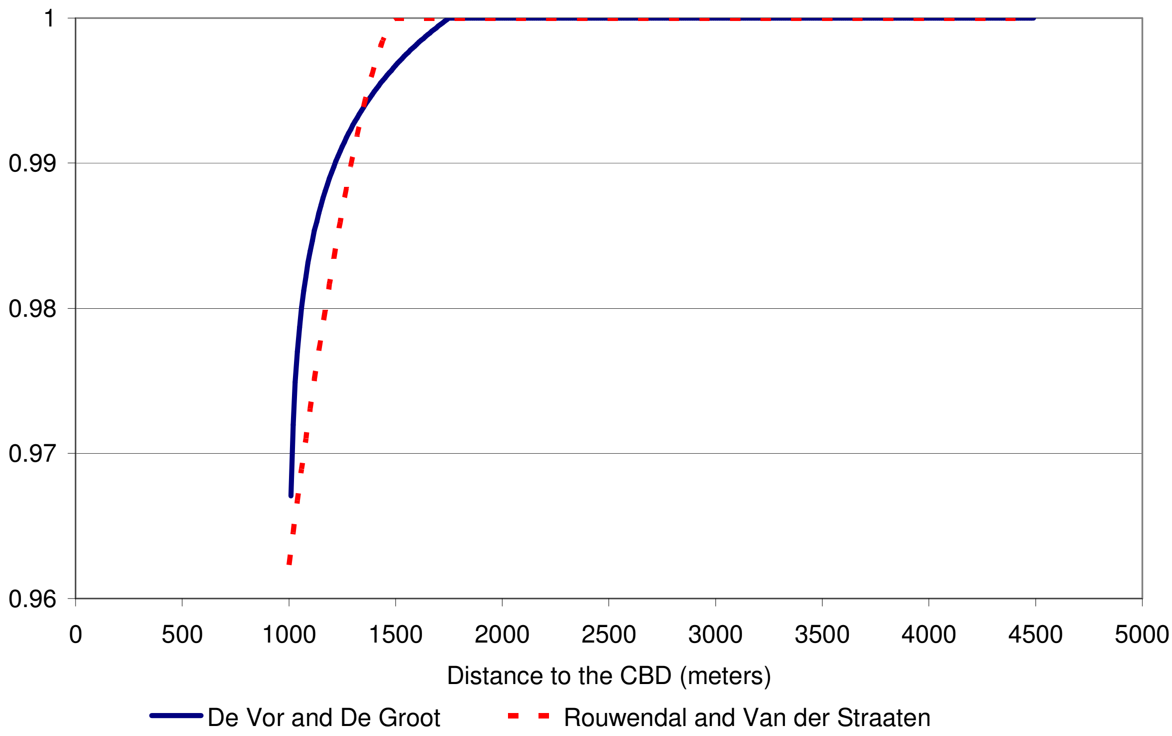
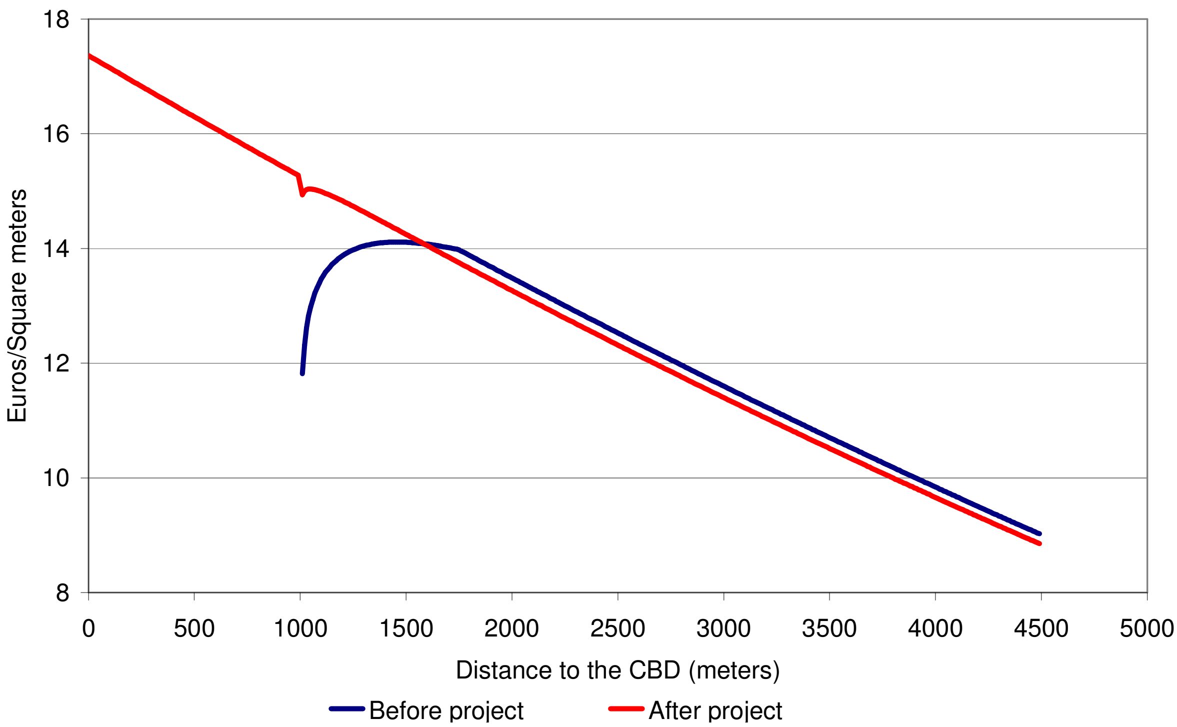


Figure 4: Land rents



APPENDIX TABLES

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

	demand elasticity ε_D = -1	demand elasticity ε_D = -2 (baseline)	demand elasticity ε_D = -∞
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 (2010). The urban fringe is endogenous.

APPENDIX FIGURES

Figure A1: Lot sizes

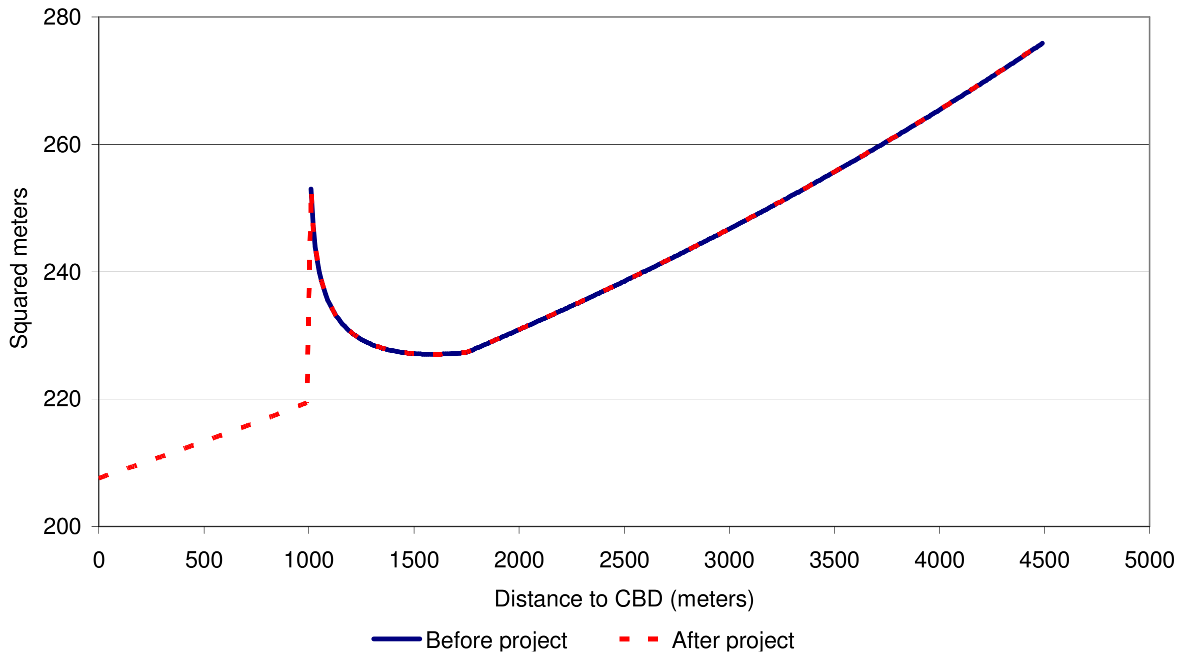
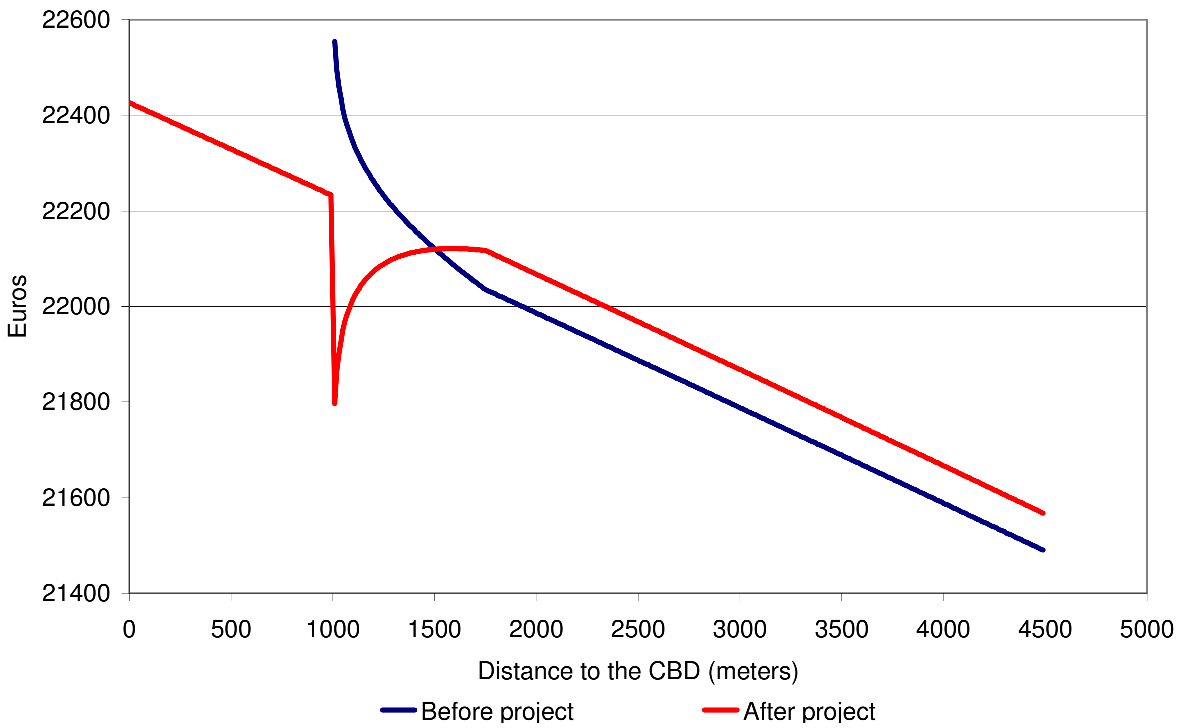


Figure A2: Consumption of composite commodity



Publisher:

CPB Netherlands Bureau for Economic Policy Analysis
P.O. Box 80510 | 2508 GM The Hague
T (070) 3383 380

May 2011 | ISBN 978-90-5833-508-1