Modelization of urban sustainability

I. Urban sustainability or sustainable development at the local level

Urban sustainability can be seen as an adaptation of sustainable development to the local scale. The size and characteristics of urban forms may have implications on environmental degradation, thus protecting or compromising future development possibilities. Urban sustainability policies are often understood as local policies -mainly dealing with transport issues or within the Agenda 21 framework -seeking some kind of environmental goal. The relations between environment and urban form are explored in this section, where an alternative economic definition of urban sustainability is provided.

It is very difficult to consensuate the definition of the concept of sustainable development and, especially, to provide a practical definition. Such complexity partially explains the increasing interest to study, from an urban perspective, the implementation of local policies which take into account environmental goals. At the urban level, the majority of studies identify sustainable development with a more efficient use of resources, tipically fuel consumption

The high level of urban sprawl characteristic of the US cities, especially when compared to the Europeans, in relation with their transport patterns, has been pointed out as one of the reasons causing major environmental problems, although this is a controversial point (Mogridge, 1985). To a lesser extent, the debate applies to other Western cities with large urban sprawl. In the European context, the publication of the *Green Book in Urban Environment* (CEC, 1990) contributed to the increasing importance of urban sustainability. This has been a very criticised document -for example, see Breheny (1991)- because of the way urban environmental problems were treated and the practical recommendations that followed, namely the compact city proposal as the ideal urban model to seek. Furthermore, there is a belief that the Economic and Monetary Union process would be pushing towards a kind of convergence in environmental and local policy, with planning policies resulting also affected. Local assets acquire greater relevance in the context of an open and integrated supranational economy. In this sense, the concern about the consequences and spatial impacts associated to economic integration processes also deals with urban sustainability, and the management of environmental resources appears as a crucial factor since it affects the features and quality standards of local economies. Some authors have even asserted that future competitiveness of cities is going to be closely related to their capabilities to become more sustainable (Allende, 1995). Similarly, outstanding differences in urban planning systems may contribute to promote or limit the possibilities for development of certain economies.

The degree of attention that the issue of urban sustainability receives in different countries depends on their historical urban paths. Among Western countries one can find quite different town planning traditions, and the historical conditions for urban development differ a great deal, too. The current outstanding difference, though, and the one which directly affects the sustainability debate, is how residential and job decentralization varies in intensity among countries. Suburbanization is a consolidated process in the USA or in Northern European countries. In most Southern countries, though, decentralization occurs with considerable delay. This fact could help to explain the existing different approaches about the most convenient urban forms.

One of the main links between urban planning and sustainable development, as it stands in the literature, is the design and planning of transport infraestructure. The relationship between transport and urban form has emerged as one of the main points around which the debate on urban sustainability is focused. Transport design affects urban structure and the ratio of conversion of land from rural to urban. Transport partially determines the way cities develop, and hence the way the environment is affected through energy consumption, pollutants emission and the use of land itself. As for energy, transport networks strongly affect the modal composition of transport demand, by influencing the rate of utilization of private vehicles and fuel consumption. At the same time, the more dispersed a city is, the more difficult it is to satisfy transport demand with public transportation. In empirical studies, though, the relationship between urban form and energy consumption or pollution has not conclusively been proved.

The previously mentioned variables -namely total energy consumption, pollution and conversion of landscape- make reference to the environmental consequences both for the environment as a whole and for the city and its surroundings. These effects are not necessarily suffered or enjoyed by its inhabitants, and therefore the derived costs or benefits would have a non-use component. These environmental consequences, being conditioned by the model of urban development, strengthen or lessen the possibilities for a less environmentally harmful development.

There is also the internal component of urban sustainability, related to the degradation or improvement of the urban environment *within* cities. This internal component of sustainability considers the characteristics of the urban environment which affect the quality of life of citizens, and therefore their welfare levels.

From the global perspective, and since urban form affects resources consumption, pollution or land use, it will affect the welfare levels of present generations, but also the possibilities of consumption and production of future ones. Therefore urban form conditions the possibilities of contributing to sustainable development. From the local perspective, urban form affects the urban environment and the conditions in which people live, clearly affecting their welfare levels. As a consequence, an analysis that seeks to provide rules about optimal urban sprawl levels or the optimal sizes of cities, from the sustainability perspective, should consider environmental assets from this double perspective, global and local, as both of them are going to affect people welfare level.

All the arguments stated above should not betray economic legitimation of the matter. Until now, there has been much economic discussion about the advantages and disadvantages of urban regulation and about the convenience of adopting either model of intervention. Attention has been focused on the analysis of the effects on the efficiency and the functioning of the land market itself, focusing on the search of the best instruments in order to correct land market externalities. The economic justification for zoning instruments, for instance, is the prevention of externalities. Similarly, the strategic planning of development in cities seeks to avoid the negative and external consequences of wrong decisions of private agents, in a market in which reversibility costs are extremely high.

With the new debate on sustainability, there is a new and wide scope of analysis that assigns additional functions to economics. The new role would consist in the correction of part of the externalities we can not assess through existing markets, and that would comprise the non-use value of certain goods, like environmental assets and amenities. The inclusion of these externalities into the economic analysis is therefore an alternative way of viewing the debate on urban sustainability. The consequences in economic terms should then be viewed as an important element to consider when introducing reforms in different land laws and regulations.

II. The indicators of sustainability

The definition of urban sustainability or the characterization of a sustainable city is not easily achieved. Cities are the units which consume more energy and, by definition, they need the resources of a wider environment to be able to survive. That is why Owens (1992) asserts that the concept of the sustainable city is contradictory in itself, as cities are incapable of functioning and organising inside their own boundaries. This strong condition of dependency would be the main cause of the existing malfunction (Naredo, 1996). According to this author, cities growth would have been organised and solved in accordance with the environmental disorders caused by their own development, and urban problems would be tackled in the short run.

In theoretical terms, the objective is to maximize the welfare level of the present generations subject to the restriction of keeping at least the same welfare level for future generations. However, in most studies the underlying definition of a sustainable city is that the use of energy resources are minimised. It is in this sense that Naredo (1996) is sceptical on the convenience of using certain criteria to measure urban sustainability. For every city, urban sustainability can be understood in terms of its need of resources and the possibilities of satisfying those needs with the resources available in the immediate surroundings of cities. Thus Naredo questions whether universal solutions exist. Local authorities should be concerned not only on improving the efficiency of processes using natural resources, but also on their origin and destination. For example, a process based on the utilization of renewable resources would be more sustainable than an alternative one making use of fossil fuel, even though it may appear more expensive. The same argument could be made with respect to the generated waste.

If the concept of sustainable development is controversial, so is the urban sustainability one. The progress in economic research has so far been based on the use of certain variables. The use of energy consumption or pollution levels as agents of sustainability levels in cities is a very common feature. Empirical research has been devoted to estimate the relationship between those variables and others describing the urban morphology. The different urban forms suggested partially respond to the results of several econometric studies[1].

The indicators used refer to the following items: energy demand and supply, pollutants emissions or fallouts generation, the ratio of consumption of land for urban purposes and other variables describing environmental conditions inside cities. Among all these, the variables most often used are those related to energy, in particular the fuel consumption derived from the use of private transport. One could even say that the study of urban sustainability has been confined to the study of a much more constricted topic. Many studies focus on how urban forms, decentralization degrees and transport systems available affect the intensity of use of private vehicles and therefore the effects of this use on energy demand, congestion and pollution. The high dependence on cars and its consequences are central issues in the debate. In a study using data from 1988 for the UK, Banister (1992) finds out that although the private vehicle is the means of only a 48 per cent of the total trips, its use absorbs more than 90 per cent of the energy consumption. Later on, a great deal of authors identified sustainable cities as those generating less number of travels.

It is in this context where the compact city proposal is fully understood. Two features stand out. Firstly, the defense of

1 Note that a great deal of the quoted studies were developed apart from the urban sustainability debate, although their results fit into the current debate.

diversification and mixtures of land uses. And secondly, the containment of growth inside the existing boundaries of the city, increasing density levels. In a very simplified way, the urderlying reasoning is the following. Urban sprawl would cause an increase in commuting. On the other hand, the compact city diminishes distances and facilitates the use of public transport. One of the pioneering studies supporting this view was Kenworthy and Newman (1989). With data from several American cities, they focus their attention on the correlation between fuel consumption and urban density, after testing other non-significant relationships. The main result is that higher densities imply lower fuel consumption, especially in inner areas. But according to the numerous methodological and content criticisms the study received, it would seem that the reasoning is not supported by empirical evidende. Gordon and Richardson (1990) questioned several aspects of the analysis. First of all, there are several factors causing that the relationship between density and fuel consumption is not so immediate. For example, an important proportion of travels is not explained by commuting. Banister (1992) points out that the relative importance of commuting trips is decreasing and, for the Great Britain in 1992, these travels accounted for 20 per cent of the total number of trips.

It must also be considered that housing decentralization occurred parallel to job decentralization, with the emergence of policentric urban structures. Urban decentralization, especially job decentralization, diminished average distances from home to work, trips which would be now between subcentres, and not between the core and the perifery (Gordon et al., 1988). Alternatively, some studies even question that the separation of houses and jobs resulting from zoning strategies may determine the number of trips. In a study for the area of Los Angeles, Giuliano and Small (1993) conclude that there is no statistically significant relationship between commuting and a variable describing imbalanced location on jobs and houses. This result seems to support the critics against the compact model.

A more discouraging result, not only for the compact city proposal but also for urban planning as a means to achieve sustainable development, is the suspicion that the factors determining the use of private vehicle and consequently the high fuel consumption, are others than urban structure itself (Mogridge, 1985). Variables such as vehicle property ratios and cultural patterns appear to be more important in determining the number of trips than others like the availability of public transport and the lenght of the trips.

Congestion is a problem with the compact city proposal that could counterbalance the advantages derived from the reduction in number and length of trips associated with city concentration. Congestion is a key factor when assessing benefits and drawbacks of the compact city, and the analysis of its consequences is a common topic in urban sustainability literature (Owens, 1992; Banister, 1992; Naredo, 1996). One of the main shortcomings comes from the difficulty of implementing local policies capable of relieving congestion in urban centers, thus avoiding its undesired effects.

Finally, a last criticism to the compact city would be the empirical studies based on the use of indicators of urban sustainability focus on transport only. They leave aside many other conditionants of energy demand and composition, for example the technnical possibilities to introduce greener refrigeration and heating systems, based on renewable resources. Similarly, the study of the consequences of different urban forms on pollution and waste generation has hardly received any attention. In summary, there is no conclusive evidence in favor of any of the urban forms considered.

III. Proposal of a theoretical framework for the analysis of urban sustainability

It has already been mentioned that most economic papers concerned on the topic of urban sustainability have focused rather on the institutional aspects of the problem than in the study of the existing statistic relationships between cities morphology and agents of sustainability. But there is little concern, if any, about the theoretical analysis of sustainability. What follows is an attempt to provide an analysis with an analytical tool, rather simple in content, but with a first approximation to the problem of urban sustainability. The original model used as reference is the *bid rent model,* one of the most known models about urban location theory, developed by Alonso (1964a, 1964b).

The bid rent model is based on the assumption of the monocentric city. Alonso's model, as for the urban residential land use, can be viewed as a problem in which the consumer is faced with the task of determining the location and quantity of land that will maximise his utility given a budget constraint. All goods other than housing remain fixed, and the utility function represents essentially a trade-off between quantity of land (lot size) and distance from the center. Other common assumptions deal with the reaching of competitive equilibriums and the optimal allocation of resources. All house--holds and firms are supposed to be identical. The bid rent curve would then describe the maximum rent which a household can pay at a particular distance from the center if it is to receive the given utility level. If the utility level and income are known, the bid rent function provides the equilibrium level rent.

In this paper, and for the sake of simplicity, a more intuitive version of the bid rent model has been used. Thus, the focus is put on two fundamental principles. Firstly, that land rent is determined as a residue *(Leftover principle),* because there exists competition among landowners. That means that in equilibrium, and for every possible use, land rent equals the excess of gross revenue (I) when compared to all non-land costs (C_T). It is important to regard these costs. They include some fix costs per unit of land (C_F), which vary with each economic activity, plus the transport costs (C_{TR}). The latter, which can be understood in a wider sense as accessibility costs, that are also specific to each activity, are assumed to be an increasing function of distance (d) from the center, or

$$\frac{\partial C_{TR}}{\partial d} \geq 0$$

The curve defining land rent (Rent) results from the difference between revenues and costs, and it will be convex when firms have the possibility of substituting factors -namely, proximity to the center and lot size. This is shown in Figure 1. The function shows a negative slope, which results from the assumption that accessibility costs are increasing:

$$Rent = I - C_T = I - C_F - C_{TR}$$

Consequently,

$$\frac{\partial Rent}{\partial d} = \frac{\partial I}{\partial d} - \frac{\partial C_F}{\partial d} - \frac{\partial C_{TR}}{\partial d} \leq 0$$

The previous result is only valid for offices and manufacture activities; for the residential ones the analysis is slightly different. In this last case, total costs, including transport costs, are assumed to be identical and independent of distance, from the perspective of the firm, and so, they are considered as some fixed costs, C_F. It is the revenue achievable with the selling of houses what changes with location, and it decreases with distance to the center. Thus,

$$Rent_{(RES)} = I - C_{RES} = I(d) - C_F,$$

with $\frac{\partial I(d)}{\partial d} \leq 0$,

and it results again that

$$\frac{\partial Rent}{\partial d} \leq 0$$

The second important principle in Alonso's model implies that land is allocated to that activity showing the higher present value of the expected rent land flow. The access to the market, which is supposed to be in the center of the city, is more costly for certain activities and so, one can expect they pay a higher rent for land and consequently they locate closer to the center. According to the importance of accessibility costs, offices, manufacture and residential sectors would occupy the center of the city in this order. The office sector would be in the central circle, and the following rings would correspond to the manufacture and the residential activity. For the rest of the land, the higher rent paid is the one corresponding to rural land.

For the purpose of this analysis, the distribution of activities inside the city is a minor question as for urban sustainability. It can even be assumed that offices and manufacture sectors are located in a dimensionless point in the center of the city, and focus the attention in the residential sector. Then it is possible to understand the residential bid-rent curve as the *urban* one. From its intersection with the *rural* bid-rent curve, the size of the city can be obtained, for the intersection of the two curves delimits the urban size, at d_m (Figure 2). At the edge of the residential zone, the residential rent for land must be equal to the rural rent. The radius of the city determines its size in the model, and so it is one of the outstanding variables from the sustainability point of view.

In mathematical terms, and defining K as the agricultural land rent (assumed to be constant), it is obtained

$$Rent_{(RES)} = Rent_{(AGR)}$$
$$I(d) - C_F = K$$

with Cres and K being constants. It follows that

$$d_m = I^{-1}(K - C_{RES})$$

provides the optimum city size value, with the function I^{-1} being the inverse.

Going back to the debate on sustainability, every city proposal poses costs and benefits. With respect to costs, they can be understood rather as welfare losses associated with the hardening of urban life conditions, than as the decrease in the possibilities of use of resources in the future, for example. The former are costs totally or partially internalised by markets, and they would correspond to the internal urban sustainability. When economic agents take into account these costs in calculating the price they are willing to pay for land, this should bring about a reduction in land rent. Imagine that pollution increases the closer we are to the city center. In this case, the bid rent curve incorporating pollution would be like the one shown in Figure 3.

As it can observed, when introducing the cost of local pollution -caused either by congestion costs or by the worsening of the urban environment as an increase in density levels, for example-, the radius of the city would be bigger, and the city would be wider.

Apart from this impact, we should also take into account the effects of an environmental externality that the market is not able to incorporate, corresponding to the second type of costs or, in other words, the external component of urban sustainability. To analyse the consequences of such costs it is necessary to go back to the urban forms proposals regarded in the previous section. There was no clear and definite solution about the more sustainable urban form. While some authors supported the compact city proposal, others disagree about its convenience and defend the concentrated deconcentration structure. In any case, the model is modified when the external effects of the sprawl or content of cities are introduced.

In Figure 4.a the original urban bid rent curve corresponds to the market solution, including local pollution costs. Then, the intergenerational costs are introduced into the analysis, both are the external costs associated with an excessive level of dispersion or concen-tration. It can be first assumed that the compact city is the one which contributes most to global sustainability - Case A. In this first stage, the curve that represents the externality is increasing with distance[2]. Urban sprawl implies an external cost in terms of reduction of the possibilities of consumption and welfare losses for future generations, a cost for which current economic agents do not pay for and therefore it is not incorporated in the market bid rent curve. If we introduce this additional cost, one can observe that land rent in every point of the city is supposed to be smaller than the one determined by the market (Figure 4.b). Therefore, the equality between agricultural and urban land rent takes place at a smaller distance from the center, $d1_{(A)}<dm$.

2 In this case, the externality has been represented as a linear function setting off the origin. The outstanding feature in the analysis is its positive slope, and inversely when externality is decreasing with distance. It would probably be more logical a function of external cost equal to zero up to a certain distance dc , and that would be positive from that distance on, with positive or negative slope depending on the case.

When introducing the external environmental cost, C_{EXTa} derived from urban sprawl -case A- the new socially optimum city size is $d1_{(A)}$, instead of the d_m value reached by markets. Now, considering all internal and external costs the land rent value would be,

$$\begin{aligned} Rent_{RES} &= I(d) - C_{RES} \\ &= I(d) - C_F - C_{EXTa} \end{aligned}$$

To find the new socially optimum city size, urban land rent has to be equalled to the agricultural land rent

$$\begin{aligned} I(d) - C_F - C_{EXTa}(d) &= K \\ I(d) &= K + C_F + C_{EXTa}(d) \end{aligned}$$

As far as the externality cost is positive for distances below dm, and as the revenue function is decreasing, it follows that for the equality to be kept, the solution $d1_{(A)}$ has to be smaller than d_m.

However, urban sprawl can be considered to be not detrimental but beneficial for sustainability, for instance, if we measure sustainability according to the proportion of renewable resources and greener energies used, and if we assume that the use of these resources is going to be more easily standardised with lesser densities. Then, there would have a similar inwards shift of the bid rent curve, and again the radius describing the socially optimum city size -$d1_{(B)}$ - would be smaller than the one determined by the market but greater than $d1_{(A)}$. As a consequence, it happens that in both cases, independently of the spatial model adopted, there would be certain external costs that the market does not internalise.

Up to this moment, only the market and the socially optimum solutions have been characterised. However, these two solutions are not observable in practice. The former, because the land market is intervened with planning restrictions, for example. And the latter one because it is only an analytical tool which responds only to a theoretical construction. As for urban planning restrictions, they can also be analysed within the proposed theoretical framework (Figure 5). The effects of the introduction of growth containing local policies are a common studied topic in urban economics literature[3].

If the fixed restriction happens to be to the right of market city edges, then the regulation has no effect, and the market solution prevails. In a second case, if the restriction is fixed at distance R from the center, with R<dm, then some changes occur. The outstanding result here is that the bid rent curve shifts upwards: the city limit will be necessarily determined at distance R, density levels will increase and land prices will also be somehow higher. The increase in prices will depend upon how effective the restriction is.

The interesting link comes from integrating both the effects of the introduction of urban restrictions and the external environmental cost associated with urban sustainability. The results can be observed in Figure 6, where the optimum city size is denoted by d*. In some sense, it would seem that urban restrictions would have collaborated in getting a more sustainable city, in the sense described above. In practice, however, the result may not be that ideal. We can differentiate three different cases:

1) dR coincides with d*. In this first case market intervention accomplishes its purpose, at the expense of higher land price levels. In this sense, it is convenient to remember that in the urban sustainability debate, the starting point is in many cases the new role that urban planning can play and that it is the most appropriate instrument to help in the sustainability matter. In general there are no alternative references to the possibility of using other economic tools (namely taxes) to reach environmental sustainability goals at lesser costs.

2) dR is somewhere between dm and d*. Now the economic intervention does not lead to the social optimum, but at least it partially corrects the externality. Again an increase in land prices arises, but since the restriction is less effective the increase in prices is now smaller.

3 See for example Evans (1985).

3) The third and last possibility occurs when the restriction excessively contains urban growth, and dR is located to the left of d*. In this situation, prices raise too much compared to what it would be justifiable from the urban sustainability point of view.

IV. Conclusions

In this paper, urban sustainability has been understood as that sort of spatial development and functional distribution of activities inside cities that minimises the transfer of costs to future generations. The market is not able to internalize certain types of external effects, namely those associated with the non-use value of some environmental goods, values which, despite its importance to determine economic welfare levels of people, are not easily estimated.

In a broader sense, one can say that the sustainable city corresponds to that spatial model causing less consequences in terms of intergenerational costs, but taking also into account the welfare of present generations. As these costs are not known, the environmental economics literature replaces them with agents related to energy, ratios of land conversion from rural to urban use and pollution variables, above all. Other papers focus on the origin and destination of energy and fallouts.

Leaving aside all the controversy existing about the different spatial models under discussion, the aim of this paper is to propose a simple theoretical framework that helps in the understanding of the urban sustainability concept. A very simple framework has been used, the bid-rent model, just as an attempt to formalize the concept. And despite all the assumptions and shortcomings implicit to the model, it provides a very intuitive approach and it paves the way for future and more comprehensive developments.

One of the main results is that when introducing the environmental externality into the analysis, either when urban sprawl is desirable or when the content of cities would be better, it follows that the optimal social city size should be smaller than the one determined by markets. It shoud be outlined, though, that this apparently surprising result lies on the assumption that intergenerational costs are positive for any distance d. Finally, it has been pointed out that the land market is not a competitive one anymore, since a lot of regulations and restrictions are used in western countries. The analitical tool suggested combines both market intervention and environmental externalities, thus suggesting that absolute solutions are not justifiable, and that every single reality has to be analysed if we want to be capable of determining the most desirable urban form from the sustainability point of view.

Figure 1

Revenue, costs and bid-rent function with and without input substitution

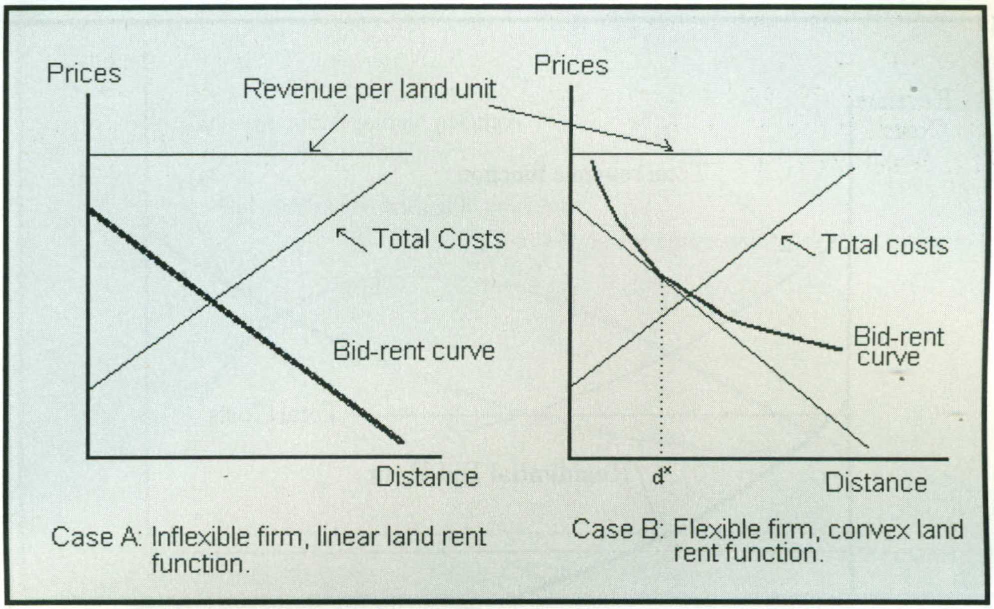


Figure 2

Residential bid-rent curve

(with substitution between lot size and distance to the center)

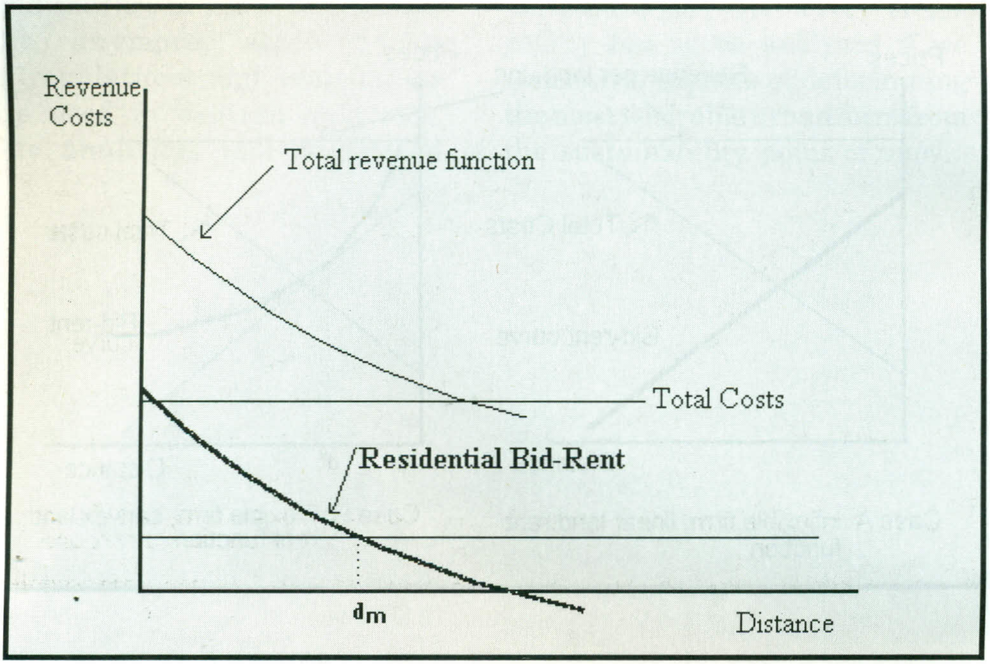


Figure 3

Effects of pollution on land prices in the center of the city

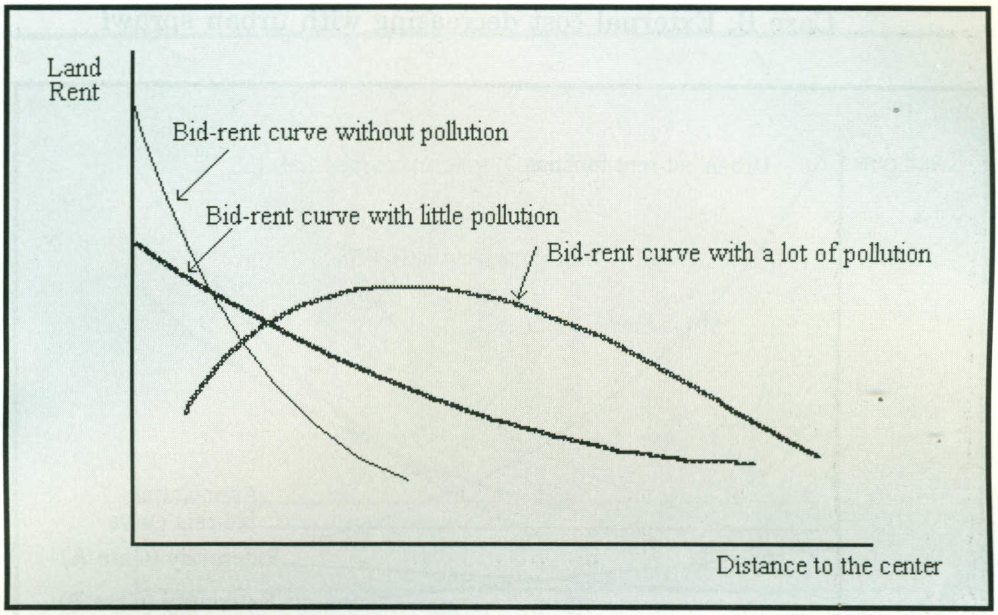


Figure 4.a

Land rent and the environmental

Case A: External cost increasing with urban sprawl

Case B: External cost decreasing with urban sprawl

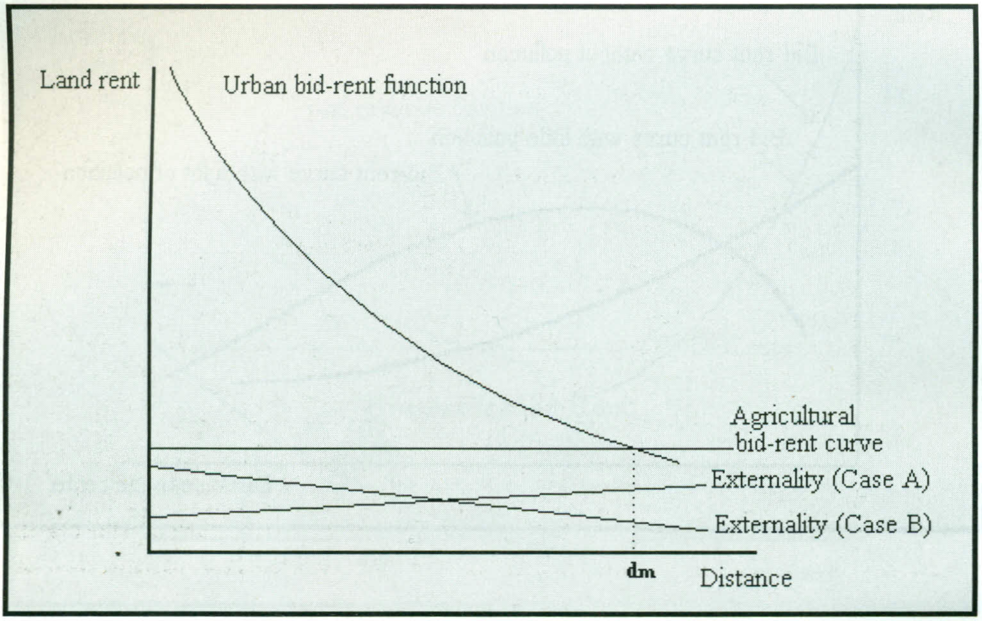


Figure 4.b

Shift of the bid-rent curve with the external cost of urban sprawl/ urban concentration

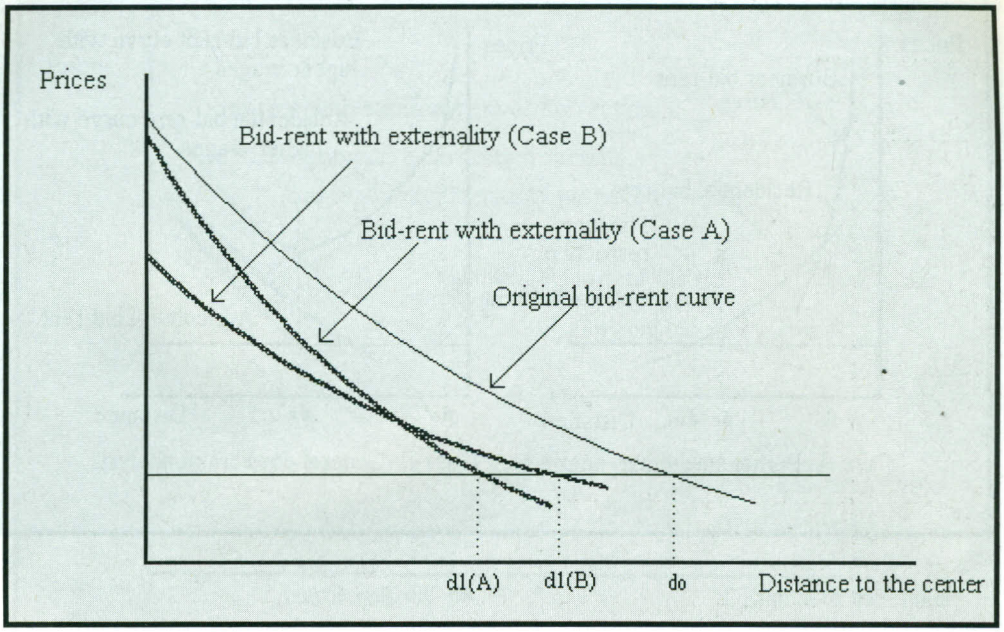


Figure 5

Effects of planning restrictions on land rent and city size

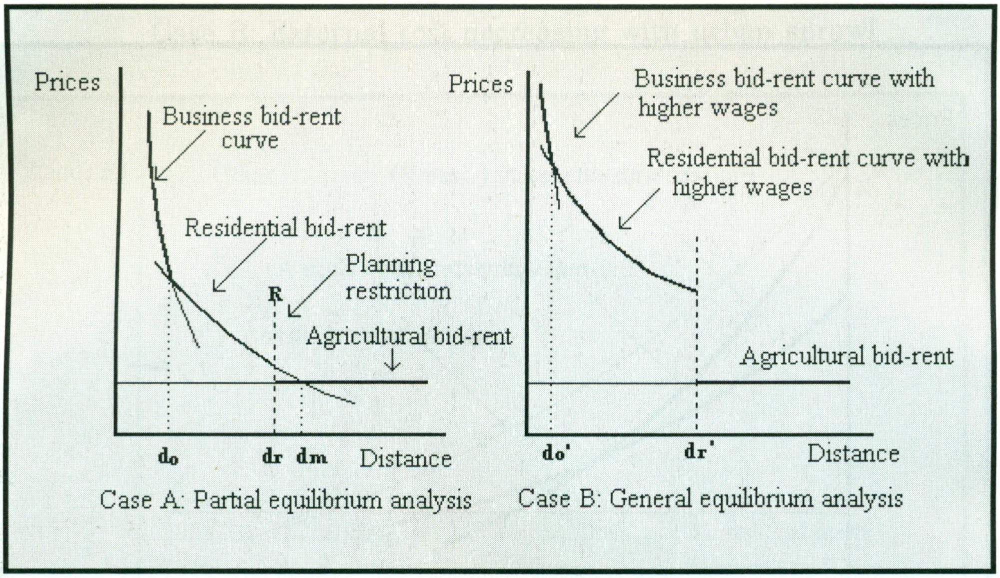
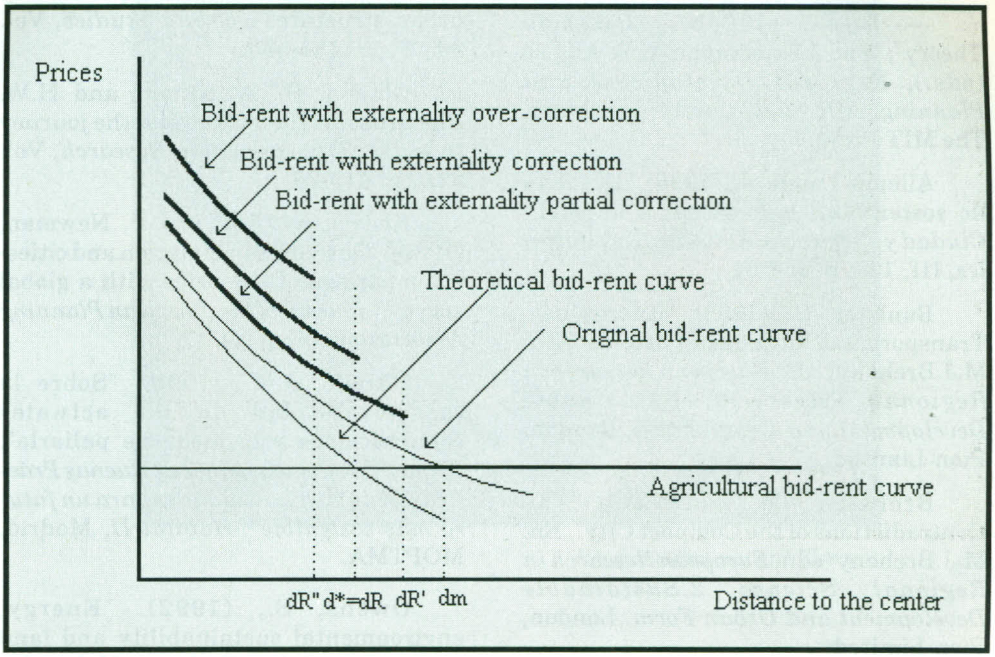


Figure 6

Urban planning restrictions and the correction of the environmental externality (Three cases)



References

Alonso, W., (1964a). *Location and land use*, Cambridge, Mass, Harvard University Press.

------------, (1964b). "Location Theory", En: J.Friedmann y W.Alonso (eds.), *Regional Development and Planning: A Reader*, Cambridge, Mass, The MIT Press.

Allende Landa, J., (1995). "Desarrollo sostenible. De lo global a lo local", *Ciudad y Territorio. Estudios Territoriales*, III, 104, p. 267-81.

Banister, D., (1992). "Energy use, Transport and Settlement Patterns", En: M.J.Breheny (ed.), *European Research in Regional Science 2. Sustainable Development and Urban Form*, London, Pion Limited.

Breheny, M., (1992). "The Contradictions of the Compact City", En: M.J.Breheny (ed.), *European Research in Regional Science 2.Sustainable Development and Urban Form*. London, Pion Limited.

CEC (Comission of the European Community) (1990). *Libro Verde sobre el Medio Ambiente Urbano*, Com(90).

Evans, A.W., (1985). *Urban Economics: an introduction*, Southampton, The Camelot Press.

Giuliano, G. and K.A. Small, (1993). "Is the journey to work explained by urban structure?", *Urban Studies*, Vol. 30, 9, p. 1485-500.

Gordon, P., A. Kumar and H.W. Richardson, (1988). "Beyond the journey to work", *Transportation Research*, Vol. 22A, p. 419-26.

Kenworthy, J.R. and P. Newman, (1989). "Gasoline consumption and cities- a comparison of US cities with a global survey", *Journal of the American Planning Association*, 55, p. 24-37.

Naredo, J.M., (1996). "Sobre la insostenibilidad de las actuales conurbaciones y el modo de paliarla". *Primer Catálogo Español de Buenas Prácticas. Volumen I. "Ciudades para un futuro más sostenible". Habitat II,* Madrid, MOPTMA.

Owens, S., (1992). "Energy, environmental sustainability and land use planning" En: Breheny, M.J. (ed.), *European Research in Regional Science 2. Sustainable Development and Urban Form*, London, Pion Limited.