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URBAN GREENERY MANAGEMENT PROBLEMS

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ABSTRACT: In this paper, we look at the urban greenery management as a principal-agent (PA) problem. PA problems arise whenever the management of activity requires cooperation of at least two hierarchical levels. In the case analysed in this paper, the city mayor (the higher level) wants to maximise the pollution-mitigation capacity of trees planted; the greenery manager (the lower level) wants to maximise the municipal budget devoted to planting trees subject to some constraints on the outcome of this activity. While the higher level wants certain services to be delivered in the future actually, the lower level is interested in the potential benefits provided by the most attractive tree species, even though they will be delivered only partially and probably in the short run only. As a result, the species composition of trees planted is different from what it would have been if the PA model implemented was incentive compatible.

KEYWORDS: principal-agent models, urban trees

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Introduction

Economic studies of urban greenery are carried out based on at least two approaches. First of all, they can apply cost-benefit analyses to assess whether total expenditures on maintaining green areas are justified by their effects in terms of better public health, improved tourist attractiveness, environmental protection, and so on (e.g. Tempesta, 2015); they start with a list of benefits (e.g. Braubach et al., 2017), monetise them, and compare with the cost of establishing and maintaining such areas. Alternatively, studies can assume that certain objectives with respect to urban greenery are set, and a question emerges whether they are likely to be achieved. The paper adopts this second approach. In particular, we do not check whether planting trees is economically justified; its economic efficiency has been demonstrated both with respect to urban forests (e.g., Dwyer et al., 1992), and street trees (e.g., Mullaney et al., 2015) many times. Instead, we check whether tree planting activities are organised as effectively as possible.

The aim of the paper is to analyse incentives urban greenery managers have to plant tree species that can provide the city with services expected by its inhabitants. Expectations of city inhabitants are reflected by priorities of the top management (mayor of the city or its district). They include (but they are not confined to) pollution remediation. Various tree species reveal very different characteristics with respect to the absorption of air pollutants, and – at the same time – they differ in terms of survival rates. The problem studied here is that the top management is interested (in principle) in services provided actually, that is, taking into account tree survival rates, but they have less information than greenery managers do to check whether trees planted are most suited for this purpose. As a result, greenery managers may prefer to plant trees that do not provide these services at the level expected.

Managing large cities is a complicated problem. A typical city is managed hierarchically with the top management interested in enhancing the welfare of their constituency. At the same time, lower-level officers do not have to be preoccupied with the same concerns; they are interested in maximising their utility subject to some constraints imposed by their bosses. This is a standard hierarchical agency theory model studied by economists under the heading of "principal-agent" (PA) problems. It originated in the 1970s (perhaps even in the 18th century). Many economists link it to the papers of Wilson (1968), Ross (1973), Heckerman (1975), Jensen and Meckling (1976), and – most often – Laffont and Tirole (1988), who made it a part of the standard microeconomics. The model can be kept simple by assuming that there is a two-tier structure with the top management unit – let us call it the mayor (the "principal") – supervising one of its executive branches – let us call it the greenery manager (the "agent"). This paper aims at illustrating how this theoretical approach can be applied to improve the effectiveness of urban greenery management if the top management delegates some of its tasks to lower-level units.

Urban trees provide an example of public goods. Hence, their management is a *raison d'être* of administrative entities such as cities and states. While theoretical analyses of how public goods can be provided by them are numerous (Vahabi, 2020), there were almost no public choice studies of how urban green areas are managed.

A mismatch between the objectives of various units in urban greenery management has been identified in earlier research (e.g., Lindholst, 2008). It was also observed while talking to officers responsible for urban greenery in the city of Warsaw. The mayor is interested in having enjoyable and productive green areas, while the greenery manager is interested in being adequately rewarded by the city budget. Moreover, the information is asymmetric. The manager knows what specific steps need to be taken to improve the performance of greenery, but the mayor does not have this knowledge.

Using the notation typical for PA models (Mas-Colell et al., 1995), one can write that the mayor (principal) wants to maximize

$$B(x) - s(x), \qquad (1)$$

where:
B(x) – stands for net benefits provided by greenery,
s(x) – stands for the salary of the greenery manager, and
x – is the level of effort put into the greenery enhancement/maintenance activities,

while the greenery manager (agent) wants to maximize

$$s(x) - c(x), \qquad (2)$$

where:
c(x) – stands for the cost of the effort,

subject to the usual participation constraints:

$$s(x) - c(x) \geq u^0, \qquad (3)$$

where:
u^0 – is an (unknown to the principal) aspiration level.

Under the standard convexity assumptions adopted in economic modelling (concavity of functions to be maximised and constraints), an incentive compatible contract requires that the greenery manager (agent) is the "residual claimant" (Varian, 2010, 731), i.e.:

$$\partial B/\partial x = \partial c/\partial x. \qquad (4)$$

In this paper, we discuss whether the residual claimant condition can be considered realistic in the management process of green areas in Warsaw. Up to the best of our knowledge, there are no studies of urban greenery using PA approach. There are a number of papers which use this analytical framework, but they aim at general land-use problems rather than planting trees in a city (e.g., Hotte et al., 2016). Kronenberg (2015) identifies institutional barriers to improving urban greenery other than the PA problems. Lindholst (2008) analyses the possibilities to improve greenery managers' performance by designing better contracts, but – again – without referring to the PA framework. Cortinovis and Geneletti (2019) look at ways to improve integration of biological and political considerations in urban planning decisions. They take into account the air purification carried out by green areas, but without analysing whether different management levels may have different incentives. Likewise, Robinson et al. (2019) admit that many different skills and backgrounds interact in taking natural resource decisions, but they do not make a distinction between various hierarchical levels.

The rest of the paper is organised as follows. In the next section, we introduce the basic conceptual model of urban greenery hierarchical management. A review of analyses of the benefits provided by urban trees follows. In section 4, we look at specific measures taken by urban greenery managers. This middle part of the paper is based on our studies of how green areas have been managed in Warsaw. The statistical quality of the data does not allow for a more comprehensive econometric analysis. Section 5 discusses what incentive incompatibility problems are faced by urban greenery management. The last one concludes and identifies directions for future research.

The problem of urban greenery management in Warsaw

The management structure can be more complicated than applied here. Analysing typical urban greenery management structures in a more detailed way is beyond the scope of this paper. A case study referring to the data collected in Warsaw serves as an illustration of problems that may affect the efficiency of management structures elsewhere too.

In Warsaw, the administrative unit which is responsible for the urban greenery, does not manage the resources directly. It hires dozens of firms who take care of designated areas and supervises district authorities who are responsible for their smaller jurisdictions. This complicated reporting structure is expected to change, and a more detailed description of the management mechanism could take into account several tiers and perhaps further additions. Here we take a preliminary approach by assuming a simple two-tier structure.

Our model is based on several stylised facts which are derived from analyses of the urban green management in Warsaw. Most importantly, we confirm that there is a discrepancy between what the city mayor declares and what the lower-level officials care for. We observe that different tree species provide city inhabitants with different benefits. In particular, we contrast two popular species with very different pollution-absorption capacities: large Common oak (*Quercus rrobur spp.*) and Red oak (*Quercus rubra spp.*), and small Callery pear (*Pyrus calleryana*). At the same time, these species vary in terms of survival rates (with oak characterised by much lower rates). We also observe that the lower level prefers to be involved in planting trees which provide large theoretical benefits, irrespective of their survival statistics; failures are seen as a result of someone's neglect rather than natural phenomena. Finally, we assume that the lower level expects a financial premium for planting more attractive species that are characterised by poor survival rates.

One of the most controversial aspects of the PA analysis is how to measure the level of effort x. It cannot be the total area of the municipal green, since this is not under the control of the manager. The area is rather to be decided by the city mayor, and it is easy to measure. Therefore, given the exogenous area, we assume that the manager can use his/her professional knowledge to boost the potential net benefits from a specific composition of trees planted and specific processes applied to provide high ecosystem services. The actual level of services obtained can be lower than declared (expected), but it can be assessed much later – when it is too late to change planting decisions.

Benefits from urban greenery

There are many alternative approaches to analyse benefits from biological resources. Costanza et al. (1997) compiled an early classification of services provided by natural resources. They made a distinction between their "provision", "regulation" and "societal" functions. Subsequent lists retain these three major types, and they differ in the level of details. In our work, we refer to the *Common International Classification of Ecosystem Services* (CICES 2015) –widely used in the European Union (the most recent version was published in 2018) – which lists 47 such services. Sixteen of them refer to the provision of materials (and energy), twenty – to the regulation of natural processes, and eleven – to societal functions (including recreation). To keep the analysis as simple as possible, we take into account only three "regulatory services". In the original list, they were identified as:

- bio-remediation by micro-organisms, plants, algae, and animals,
- bio-chemical detoxification / decomposition / mineralisation, etc.,
- filtration / sequestration / storage / accumulation by ecosystems.

While some crops can be harvested for the benefit of the city dwellers, the most typical gains from urban greenery include regulation of natural processes and recreation. These gains are not necessarily very large in economic terms. A recent study of a major park in southern Warsaw (Zawojska et al., 2016) demonstrated that ecosystem services could be lower (in economic terms) than other benefits provided by the urban infrastructure. Besides, one needs to stress that street trees have different roles than parks and other contiguous green areas – such as urban forests – and hence each category may require different measurement methods (Giergiczny and Kronenberg, 2014).

In this paper, we emphasise the benefits of bio-remediation. Specifically, various tree species turn out to absorb air contaminants to a different degree. In addition, they can provide other ecosystem-regulatory benefits, including mitigation of surface runoff, but – again for simplicity – we do not analyse them here. Neither do we look at other diverse benefits – such as, e.g., mitigating heat island effect – analysed in urban tree planting scenarios (Bodnaruk et al., 2017) – or amenities that might be relevant for greenery management decisions too.

There are numerous empirical analyses on how much a given tree can absorb (or otherwise "avoid") of NO_2, SO_2, PM_{10}, $PM_{2.5}$, VOC, and O_3. The results suggest that – up to 100 years – the remediation benefit is roughly proportional to the age of the tree (McPherson et al., 2007). Apart from what can be found in some parks or forests, a typical urban tree is less than 100 years old, and consequently, it remediates a fraction of the maximum expected of the oldest conceivable one. Therefore, the remediation benefit is simply a percent of what can be absorbed by a 100 years old tree, and various trees of the same age provide – proportionally – the same benefits as the mature ones that belong to the same species. Table 1 lists these maximum absorption benefits for four categories – coniferous trees (1) and three types of deciduous trees (based on the diameter of the canopy): small (2), medium (3), and large (4).

As seen from the table, the physical remediation capacity of trees can vary quite a lot. The capacity depends mainly on the surface of leaves, and the numbers are based on empirical research carried out in the northern United States mainly. Of course, American species composition is not the same as in Warsaw, but the table informs about the order of magnitude of what can be expected of certain tree types.

Table 1. Annual absorption for a 100-year-old tree [in g]

	Coniferous	Deciduous		
		Small	Medium	Large
NO_2	177	93	239	544
SO_2	23	11	28	65
$PM_{2.5}$	14	8	22	48
O_3	307	160	410	933

Source: author's work based on McPherson et al., 2007, and Szkop, 2019.

Removal of toxic substances implies health and other environmental benefits. Ideally, site-specific empirical studies would be needed to estimate these benefits. Lacking the opportunity to rely on such studies, we had to apply a benefit transfer approach. To this end, the results of a number of European research programmes were used. They are summarised in standard coefficients adopted by the ExternE project. They are differentiated for various pollutants. It is also acknowledged that economic impacts depend on whether pollution affects densely or sparsely populated areas. Estimates adequate for urban environments were applied in table 2. Specifically, we used the rates 10.65€ per kg of NO_2 absorbed, 9.47 for SO_2, and 2.07 for $PM_{2.5}$. The ExternE database does not include O_3; hence table 2 omits this pollutant.

Table 2. Annual benefits provided by a 100-year-old tree [in €]

	Coniferous	Deciduous		
		Small	Medium	Large
NOx	1.89	0.99	2.55	5.79
SO_2	0.22	0.10	0.27	0.62
$PM_{2.5}$	0.03	0.02	0.05	0.99

Source: author's work based on table 1 and results of the ExternE project, http://www.externe.info/externe_d7/?q=node/2]; please note that the project calculates monetary benefits for NO_x rather than NO_2; thus numbers in the table should be regarded as rough estimates.

Table 2 demonstrates that annual monetised benefits from the absorption of acidifying substances – such as nitrogen and sulphur oxides – dominate the total. They can be more than 6€ per old large deciduous tree. For coniferous species, they are a fraction of that. Let us emphasise once again, that these numbers have to be treated with great caution. The absorption capacity depends on a number of circumstances (Jin et al., 2014), it is subject to empirical research, and it cannot be easily transferred. Besides, as the sulphur pollution is largely under control, nitrogen contamination – linked to the growing car traffic – emerges as one of the most important air pollution problems in cities. Table 2 suggests that small trees provide roughly four times lower benefits linked to nitrogen abatement than large ones.

Planting trees as an air protection instrument in Warsaw

The mayor of Warsaw has a detailed list of urban trees with information on their age, size, and sanitary condition. The list is too much detailed to be of practical significance for this level of management. Nevertheless, it is a valuable source of information on urban greenery. In addition, the mayor has information on which tree species provide maximum air quality benefits.

Top species recommended for remediation of acidifying substances (Nowak, 2000 and Nowak, and Heisler, 2010):

Red maple (*Acer rubrum*)
Horse chestnut (*Aesculus hippocastanum*)
Yellow birch (*Betula alleghaniensis*)
Deodar cedar (*Cedrus deodara*)
Northern hackberry (*Celtis occidentalis*)
American beech (*Fagus grandifolia*)
White ash (*Fraxinus americana*)
Ginkgo (*Ginkgo biloba*)
Kentucky coffeetree (*Gymnocladus dioicus*)
Black walnut (*Juglans nigra*)
Tulip tree (*Liriodendron tulipifera*)
Cucumber tree (*Magnolia acuminata*)
Norway spruce (*Picea abies*)
Eastern white pine (*Pinus strobus*)
London planetree (*Platanus hybrida*)
Eastern cottonwood (*Populus deltoides*)
American basswood (*Tilia americana*)
Eastern hemlock (*Tsuga canadensis*)
American elm (*Ulmus americana*)
Japanese zelkova (*Zelkova serrata*)

All these species can be found in Warsaw, but only a few of them are planted routinely. The local administration of urban greenery is expected to plant trees that are well adapted to local climatic conditions and – more recently – that were found to be allergic-friendly. Their list includes (ZOM, 2017):

Sycamore maple (*Acer pseudoplatanus*)
Common lime (*Tilia* × *europaea*)
Japanese cherry (*Prunus serrulata*)
Callery pear (*Pyrus calleryana*)
London plane (*Platanus* × *acerifolia*)
Black locust (*Robinia pseudoacacia*)
European ash (*Fraxinus excelsior*)
Common hornbeam (*Carpinus betulus*)
Common oak (*Quercus robur*)

Tree planting strategies in Warsaw

The benefits provided by living trees cannot be questioned. The problem, however, is that not every tree planted survives. The Warsaw experience is quite vast, as thousands of trees are planted every year. Many of them survive, but some do not. There are several reasons why a tree does not survive. First, it is not a native species, and unless an unprecedented (and costly) care is applied, the tree is doomed to die soon as a result of harsh climatic conditions, pest infestation or other causes. Second, it could have been planted in an inappropriate way, e.g., without a reasonable space left for the canopy or root system. Third, it could have been inappropriately maintained, e.g., insufficiently watered. Fourth, it could have been exposed to environmental contaminants such as chlorides (often used as de-icing agents by some real estate owners) (Nowocin, 2017).

Urban greenery managers tend to perceive urban trees as real capital rather than living objects thus expecting that once planted, they will provide a steady flow of benefits. Natural survival rates are perceived as close to 100%. Whereas in fact, they can be much lower. Low survival rates of urban trees have been studied widely (e.g., Nowak et al., 2004; Roman and Scatena, 2011) and linked to a number of threats the trees are exposed to. Climate change has added a new important stressing factor (Fontaine and Larson, 2016).

Specifically for Warsaw, several econometric models were estimated to check the relationship between the number of trees (of a given species) planted and their mortality rates, as well as benefits provided by absorbing air pollutants (Szkop and Żylicz, 2018). Despite numerous attempts, it proved impossible to find statistically significant relationships linking these numbers with mortality rates. The latter was estimated based on a large inventory of 162,500 trees registered in Warsaw. Planting trees seemed to be totally unrelated to their average annual mortality rates which range from almost zero (0.77% for *Pyrus calleryana spp.*), to over 4% (4.13% for *Quercus rubra spp.*). In contrast, potential benefits – as represented by pollutants absorbed by a living tree – did prove correlated with numbers of trees planted (Szkop, 2019). Based on a smaller inventory of 2,111 street trees of 36 species planted between 2014 and 2016, this correlation turned out to be 58%. This allowed to claim that urban greenery managers ignore average annual mortality rates and prefer to plant species known for their large potential to absorb air pollutants.

Let us assume that there are two tree species which provide benefits of b_1 and b_2 per tree, respectively, with $b_1 < b_2$. Therefore, total benefits read $\beta = b_1n_1 + b_2n_2$, where n_1 and n_2, are the number of trees of the first and the second species, respectively. If x is the fraction of trees of the second (i.e. more "valuable") species ($x=n_2/N$), and N is the total number of trees, then the formula reads:

$$\beta = b_1(1\text{-}x)N + b_2xN, \qquad (5)$$

and

$$\partial\beta/\partial x = N(b_2 - b_1) > 0. \qquad (6)$$

From the social welfare point of view, however, as only living trees provide benefits, a more appropriate formula for the total benefits reads:

$$B = b_1(1\text{-}x)N\theta_1 + b_2xN\theta_2, \qquad (7)$$

Where θ_1, θ_2 are survival rates of the first and second species, respectively. If one assumes that the survival rate of the first species is 1 (the first species always survives), then the formula reduces to:

$$B = b_1(1\text{-}x)N + b_2xN\theta_2. \qquad (8)$$

It is then easy to calculate that

$$\partial B/\partial x = N(\theta_2 b_2 - b_1). \qquad (9)$$

If one lifts the assumption that $\theta_1=1$, then the notation becomes more complicated, and θ_2 has to be expressed as a fraction of θ_1 (we assume that the species considered more valuable has a lower survival rate).

The cost of planting a tree is likely to be higher in the case of the more "valuable" species: $c_1 < c_2$. Thus, the raw cost of tree planting activity is $c_1(1\text{-}x)N + c_2xN$, where x and N denote the same variables as before. However, tree planting agents know that the second species is more risky to be planted and hence they request a mark-up proportional to the share of the more risky trees, say, 1+x. Consequently, the cost formula reads:

$$c = c_1(1\text{-}x)N + c_2xN(1+x). \quad (10)$$

The derivative reads:

$$\partial c/\partial x = N(2c_2x + c_2 - c_1). \quad (11)$$

In other words, $\partial c/\partial x$ increases when the share of the more valuable species increases.

One needs now to check these findings against the data observed in Warsaw. $\theta_2 b_2 - b_1$ is certainly lower than $b_2 - b_1$, but its sign is not obvious immediately. Trying to estimate these expressions, we can take two typical species: Red oak (a large tree) and Callery pear (a small tree). The annual survival rate for the more "valuable" species, Red oak, is 96%, while the survival rate for the less "valuable", Callery pear, is virtually 100%. These numbers indicate that for these two typical species, over 10 years (perhaps an upper limit of what greenery managers can realistically contemplate), $\theta_2 b_2 - b_1 > 0$, since θ_2, can be assumed to be 0.66 (0.96^{10} is approximately 0.66) and as long as $b_2 > b_1/0.66$ which is obviously satisfied for the case of Red oak and Callery pear (see table 2 for large and small species, respectively).

The results are based on benefits, survival rates and cost functions collected by relevant authorities. The data inform about the knowledge these authorities rely on, which is not necessarily based on the entire statistical material characterising urban trees properly. The attempt of these analyses is not to discover an optimum composition of urban greenery, but rather to explain why certain tree species can be found in the city more frequently than others.

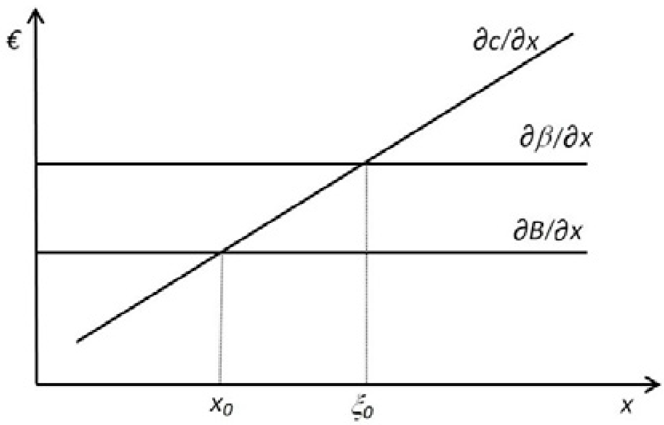

Figure 1. Preferences with respect to tree species composition

Source: author's work.

The main conclusion from these observations (figure 1) is that species composition likely to be chosen by greenery managers (ξ_0) is different from what would be preferred by the mayor (x_0). If urban greenery managers do not take into account low survival rates of the most (theoretically) valuable tree species, then these species are likely to be overrepresented in urban tree planting schedules.

Alternative quantifications of B and β require additional analyses. In our calculations, we assumed that managers look at annual absorption benefits. Actually, the decision-making process can be more complex. For instance, they can look at cumulative benefits over some time horizon, say, 10 years. Additionally, they can discount the future with a positive discount rate. It is easy to see; however, that the proportion of benefits provided by two species to be compared is exactly the same irrespective of whether the annual outcome is taken into account or the cumulative effect, and irrespective of the discount rate applied. It simply depends on the proportion of b_1 and b_2.

Survival rates are a different story. If annual survival rates are different but constant over time, they make expected annual benefits lower than the theoretical ones. Yet it may turn out that they vary over time and, say, are different for the first three years than for the next three years. In this case, the proportion of benefits obtained by planting alternative species may depend on the time horizon adopted.

Conclusions and directions for future research

The main conclusion derived from the model is – to some extent – predictable. The fact that species composition preferred by the lower level is not necessarily what the higher level would like to see is intuitively obvious. What the model can shed more light on are specific management solutions which – when implemented – can reduce the exposure to air contaminants more effectively.

PA models studied in economics suggest that the lower level should be the "residual claimant" of benefits. This is not practical in the context of urban greenery, as it is inconceivable that managers can be reimbursed with any additional benefits their extra effort implies. The model only suggests that greenery managers should be better rewarded when they choose a species composition likely to deliver actual rather than theoretical benefits. A mismatch between preferences with respect to tree species known of very high potential absorption capacity and species that are perhaps not that attractive, but less sensitive to harsh urban conditions, can be addressed by establishing more detailed guidelines for the lower level. For the time being, these guidelines reflect potential benefits and seem to ignore survival rates. However, to arrive at more robust conclusions, more empirical research is called for.

First and foremost, more site-specific research on the absorption of air contaminants is necessary. Our conclusions largely based on the benefit transfer method, with policy-site relationships extrapolated from observations collected elsewhere. While the original data are fairly detailed and probably accurate, local climatic, economic, and environmental conditions somewhere else can be different. Second, we need much broader data on the survival of trees. It would be necessary to know to what extent poor survival rates are caused by planting species that are not fit to local conditions, and to what extent they can be controlled (either through regulations on economic activities in the neighbourhood of trees or through an incentive structure). Likewise, it would be illuminating to see how survival rates depend on the time horizon. Third, it would be interesting to deepen the study of preferences of the higher level and preferences of the lower management level. We assumed that the higher level aims at maximising the absorption capacity of the (living) trees planted. Yet other benefits provided by the urban green may play a role as well. Reviews of important policy documents and adequate in-depth surveys of city officials may help to identify more closely incentives relevant for the urban greenery management.

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