The Optimal Degree of Decentralisation in the Disposal of Waste: a Welfare Approach

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Abstract

We study the problem of a central government that is to choose the optimal degree of decentralisation across regions for the decision mechanism concerning the final treatment of municipal solid waste. We analyze incentives, equilibria and implications of the governance framework for the disposal of waste. The key decisions revolve around the mobility of waste and the externalities (pollution) associated with its disposal, be it via incineration or landfill. Moreover, if the regions are characterized by different levels of efficiency in the processes they apply to the final treatment of waste, a certain degree of mobility across regions should allow to reap the benefits of higher efficiency. On the other hand, as transportation and other environmental costs implied by mobility and concentration become significant, a trade-off emerges. Our model evaluates the implications of that trade-off for the optimal degree of decentralization and mobility in waste management.

Keywords: waste disposal, decentralisation, welfare

JEL Classification: H70, D02, Q20

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1 Introduction

Since the seminal work of Oates (1972) on fiscal federalism, a central question of public finance has been which level of a federation should be assigned the provision of public goods. Local jurisdictions, municipalities or regions, are likely to account for local conditions, but ignore inter-jurisdictional spillovers; central governments may internalize those spillovers but are likely to neglect local conditions. Both factors appear to be empirically relevant in environmental applications, where the literature seems to agree that centralised decision-making is more efficient in reducing the level of pollution. Waste generation and disposal are key areas of interest in this debate. Waste prevention is the top aim of European policy's 'waste hierarchy', which lists municipal waste management (MWM) objectives in order of descending priority. If waste cannot be prevented, it should be reused (or prepared for reuse), recycled, incinerated with energy recovery, or disposed of in landfill, if no other option is available. By 2020 waste generation should be in absolute decline, according to the EU's Roadmap to a Resource Efficient Europe (COM (2011)). However, the European Environmental Agency acknowledges that waste volumes in the European Union are growing (EEA (2009)), driven by changing production and consumption patterns (Andersen et al. (2007)), whereas environmental costs associated with waste disposal essentially depend on regulation. In order to reduce those costs, policy effectiveness is very important, especially in the system of decentralised waste management that characterizes some western countries.

From an empirical point of view, there is some evidence of a Kuznets curve for the GDP-waste volumes relationship (Mazzanti et al. (2008, 2012); Mazzanti and Zoboli (2008, 2009)), and little evidence of a permanent decoupling. With reference to the so-called “NIMBY” behaviour for the location of hazardous waste disposal sites (Fredriksson (2000)), the theoretical literature is underdeveloped. The few existing contributions employ the standard assumptions of the theory of fiscal federalism to explain the prevalence of decentralised decisions in waste management, but there is almost no agreement on which level of centralisation is more efficient. For instance Ogawa and Wildasin (2009) argue that decentralisation might reach a more efficient allocation than centralisation, while other studies claim that such a context might spur undesirable and distorting effects such as fiscal competition and “race to the bottom” (Oates and Schwab. (1988); Oates (1999)).

The aim of this paper is to offer a simple theoretical model capable of answering some key policy questions. Our theoretical interest into the key governance features of MWM stems from the fact that across countries MWM is operated through a variety of decentralisation solutions. We study the problem of a central government that is to choose the optimal degree of decentralisation across regions for the decision mechanism concerning the final treatment of municipal solid waste. We analyze incentives, equilibria and implications of the governance framework for the final treatment. The key decisions revolve around

\footnote{For reviews see Banzhaf and Chupp (2011); Buchholz et al. (2011)}
the cross-regional mobility of waste and the externalities (pollution) associated with its disposal, be it via incineration or landfill. Moreover, if the regions are characterized by different levels of efficiency in the processes they apply to the final treatment of waste, a certain degree of mobility across regions should allow to reap the benefits of higher efficiency. On the other hand, as transportation and other environmental costs implied by waste mobility and concentration of disposal become significant, a trade-off emerges. Our model evaluates the implications of that trade-off for the optimal degree of decentralization in waste management.

Our model builds a simple framework where, due to spillovers across regions, a centralized solution is best for the maximization of total welfare. However, our model shows that the distribution of welfare gains among the different regions may be unequal and a centralized solution may not always be preferred by each region. The model's first-best shows that the waste flow between the regions depends on the combined effects of efficiency in damage-reduction activities and their cost. The expenditure on investment to mitigate pollution is also unambiguously correlated to the presence of spillovers: the stronger the spillover, the larger the investment. We demonstrate that with spillovers and fiscal illusion this first-best optimal solution cannot be reached. This depends on the decision mechanism on how to allocate the beneficial effects of centralization among the two regions. This means that, although at the national level the sum of regional welfare is always maximized, other second-best solutions may be preferred by the regions themselves. For instance, in equilibrium the price that makes the more efficient region indifferent between trading waste or accepting the no mobility solution (each region disposes of its waste) is higher than the marginal cost of disposal. On the contrary, in a decentralized environment, the regions do not take into account the spillovers created by their own activities and total investment in environmental protection is thus set at a sub-optimal level: the decentralized solution with mobility is always preferred to the solution without mobility.

The paper is organized as follows. In section 2 we describe the most common models of governance for municipal waste management across Europe. In the following section we present our model, while in section 4 we discuss our results and the main policy implications of our analysis. Section 5 concludes.

2 Municipal Waste Management Practises across Europe

In the European Union, the governance system typically involves three institutional layers, sometimes with conflicting targets:

- national level, framed by the EU, mainly focuses on material balance and economic, technical and environmental regulation;
- regional level, focuses on planning of disposal capacity, enforcement of the
self-sufficiency principle, authorization of facilities and overview of MWM practices;

• local level, focuses on the organization of MWM services, within general rules concerning management and finance of local services, competition laws, etc.

In Germany, responsibility for waste management is shared between the national government, the federal states and local authorities. The national Ministry of Environment sets priorities, participates in the enactment of laws, oversees strategic planning, information and public relations and defines requirements for waste facilities. Each federal state adopts its own waste management act containing supplementary regulations to the national law, e.g., concerning regional waste management concepts and rules on requirements for disposal. There is no national waste management plan in Germany. Instead, each Federal State develops a waste management plan for its area.

Since 2007, in France a new waste management policy and strategy have been developed with a detailed stakeholder engagement process, known as the ‘Grenelle Environnement’ process. A new legislative framework has been set with specific targets for waste management at the national level, although the implementation of waste prevention plans is fixed at the municipality level. Italy until recently broadly followed the German model, but with subregional authorities (provinces) responsible for planning, regulation of access to facilities and overview of MWM services. Access to landfill sites and incinerators was limited to provincial waste. Recently, new national laws introduced the provision of final treatment sites receiving municipal waste from any region in the country, subject to certain emergency conditions. Moreover, regional laws have fostered mobility of waste across provinces within the same region. Finally, waste policy is a devolved matter in the UK: the devolved administrations of Scotland, Wales and Northern Ireland are fully responsible for their strategy and policy-related MWM.

3 The model

In our model the final treatment of waste is harmful to the environment. The country is divided into two equally-sized local jurisdictions or regions, 1 and 2, and it is managed by a Central Government (CG). Each region is endowed with fixed income $Y$ and an environmental good (clean air) amounting to $z$. Income generates an amount of waste equal to $q_i$, which can be disposed of in the same region $i$ or it can be exported to the other. We denote by $w_i$ the quantity of waste disposed of in region $i$. Waste treatment has several costs that depend on the technology used and the policy actions each region undertakes to reduce the related environmental damage. We assume that the cost of treating one unit of waste is region-specific and is equal to $p_i$. Each unit of waste to be treated reduces the quantity available of the environmental good by an amount $v$. Pollution in turn can be reduced by investing in a technology that lowers
emissions by a quantity $r_i$. Therefore, the environmental damage is proportional to the quantity of waste treated and to the investment each region undertakes. Analytically,

$$v\left(w_i^2 - \alpha_i r_i w_i\right); \quad i = 1, 2$$

(1)

where $\alpha_i$ measures the productivity of the region-specific investment. The marginal damage is increasing in $w_i$ and it is always positive, i.e. $w_i > \alpha_i r_i$.

Pollution from waste spills over regions’ boundaries: waste treatment in region $i$ causes pollution in region $j$ at a rate $k$. When $k = 1$, there is full spillover. In each region, the stock of the environmental good, net of the damage produced by waste disposal activities, can be written as:

$$z - v\left[(w_i^2 - \alpha_i r_i w_i) + k (w_j^2 - \alpha_j r_j w_j)\right]$$

For $k = 0$ there is no spillover: the damage produced by waste disposal activities does not spread to the neighbouring region, therefore those activities can be considered a local public bad. On the other hand, if $k = 1$, waste disposal becomes a national public bad.

We assume that the cost of disposing one unit of waste is region-specific and is equal to $p_i$. Furthermore, the investment to protect the environment has a cost equal to $\theta_i r_i^2 w_i$, i.e., its cost is proportional to the waste that should be disposed of and is increasing in the level of investment $r$. Such cost is also technology-specific.

We will assume that there is a correlation between the marginal cost of waste disposal, its impact on environment and the technology used to reduce the damage. In particular, we will assume that $\alpha$ and $p_i$ are positively correlated, which means that technologies that are more efficient in reducing the damage to the environment are also more costly. The unit cost of the investment in green technology $\theta_i$ is instead assumed to be a productivity parameter, and will be used to capture efficiency in waste disposal activities.

The welfare function is a linear combination of disposable income and the utility that can be derived from the environmental good. Welfare can therefore be written as:

$$W_i = Y_i + \beta \left( z - v\left[(w_i^2 - \alpha_i r_i w_i) + k (w_j^2 - \alpha_j r_j w_j)\right] \right) - \theta_i r_i^2 w_i - p_i w_i - m c(q_i - w_i)$$

(2)

where $m$ is the price paid by each local authority for waste to be disposed of in the other region. It also represents the unit compensation each region receives to treat waste that has not been produced within its boundaries. In the centralised model this price is set by the government, in the decentralised model it will be decided through a bargaining between the two regions.

This framework allows to study the effects of decentralisation in waste management, i.e., the decision to allow each region to separately determine its level of waste-reducing activities and the effects of allowing for waste disposal outside the region in which waste has been produced. In environments similar to
the present one, where information is symmetric, the centralised solution is always to be preferred to any decentralised one. However, while this is true for total welfare, the distribution of the latter among the two regions may vary significantly and it may have important impacts on the overall outcome.

3.1 First-Best Solution

In the presence of spillovers across regions and no other advantages in terms of productivity differentials nor asymmetry of information about local preferences, welfare is maximised by a central planner that jointly maximises the utility of both regions (Oates (2008); Tresch (2002)). Let us first assume the total amount of waste to be fixed at $2q$. The problem for the central planner is to find the quantity of $w$ to be disposed of in each region and its transfer price, such that the following utility is maximised:

$$W^{FB} = \sum_{i=1}^{2} Y_i + z - v \left( (w_i^2 - \alpha_i r_i w_i) + k \left( w_j^2 - \alpha_j r_j w_j \right) \right) - \frac{\theta_i r_i^2 w_i}{2} - p_i w_i - m^{FB} (q_i - w_i)$$

The main results in terms of the optimal disposal of waste and the investment needed to reduce its environmental impact are the following (maximisation is detailed in Appendix A):

$$w_i = q + \frac{\beta v (1 + k)}{8} \left( \frac{\alpha_i}{\theta_i} - \frac{\alpha_j}{\theta_j} \right) - \frac{1}{4} \frac{p_i - p_j}{\beta v (1 + k)}$$

$$r_i = \frac{\beta \alpha_i v (1 + k)}{\theta_i}$$

The waste flow between the two regions depends on their (cost-adjusted) efficiency differential: the combined effects of efficiency in damage-reduction activities and their cost determines the quantity of waste to be treated in each region. The higher the efficiency of the technology that reduces the negative effects of waste disposal ($\alpha$), the higher both the quantity to be treated and the expenditure on investment. Productivity has of course the same effect: the lower $\theta$, the higher the investment. It is important to note that the expenditure on investment to mitigate pollution is also unambiguously correlated to the presence of spillovers: the stronger the spillover, the larger the investment.

However, this maximisation process does not allow to determine the price at which the waste transferred from one region to the other should be paid. The level of this price might drive the country to choose one solution instead of another, as we will show in the next section.

From an efficiency point of view, the price should be set through a pseudo market process in which the demand for waste is matched by its supply. The process is described in Appendix A and the price should be set equal to:
Table 1: Optimal solution for the Centralised case

<table>
<thead>
<tr>
<th></th>
<th>No mobility</th>
<th>Mobility</th>
</tr>
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<tbody>
<tr>
<td>( w_i )</td>
<td>( q )</td>
<td>( q + \frac{\beta v(1+k)}{8} \left( \frac{\alpha_i}{\theta_i} - \frac{\alpha_j}{\theta_j} \right) - \frac{1}{4} \frac{p_i - p_j}{\beta v(1+k)} )</td>
</tr>
<tr>
<td>( w_j )</td>
<td>( q )</td>
<td>( 2q - w_i )</td>
</tr>
<tr>
<td>( r_i )</td>
<td>( \frac{2\alpha_i(1+k)}{\theta_i} )</td>
<td>( \frac{2\alpha_i(1+k)}{\theta_i} )</td>
</tr>
<tr>
<td>( r_j )</td>
<td>( \frac{2\alpha_j(1+k)}{\theta_j} )</td>
<td>( \frac{2\alpha_j(1+k)}{\theta_j} )</td>
</tr>
</tbody>
</table>

\[ m^{FB} = 2q\beta v(1-k) + \frac{\beta^2 v^2 (3k^2 + 2k - 1)}{4} \left( \frac{\alpha_i^2}{\theta_i} + \frac{\alpha_j^2}{\theta_j} \right) + \frac{p_i + p_j}{2} \quad (4) \]

However, since a market does not really exist in this setting, such solution cannot be attained. This opens up the possibility of reaching second best solutions that may imply a suboptimal level of environmental protection and a higher cost in terms of waste disposal.

### 3.2 Centralisation

Let us assume that the waste management decisions on flows and investment on environmental protection are now taken by the Central Government. The problem is to find the quantity of \( w \) to be treated in each region and to determine the transfer price if the mobility solution is to be preferred to the “no mobility” one. The problem that the Central Government must solve is equivalent to the one in the previous section and the results are summarised in Table 1.

From a welfare point of view, given that in the unconstrained equilibrium there is a flow between the two regions, the solution with waste mobility dominates the one without mobility. However, this does not necessarily mean that both regions are better off with such solution, as the transfer price determines the cross-regional allocation of welfare gains. To show this, let us consider the case where \( \frac{\alpha_i}{w_i} > \frac{\alpha_j}{w_j} \) and \( 0 < p_1 - p_2 < \frac{\beta^2 v^2 (1+k)^2}{2 \left( \frac{\alpha_i}{w_i} - \frac{\alpha_j}{w_j} \right)} \). In this case, it is efficient to transfer waste between regions and the flow should go from region 2 to region 1. The latter holds because, although the marginal cost to dispose waste is higher in region 1 (\( p_1 > p_2 \)), the higher level of productivity in damage-reducing activities in region 1 makes it more efficient to move waste towards this region. Let us now consider the impact on welfare. The welfare for region 1 in the two cases can be written as:

\[
W_1^{c} = Y + \beta \left( z - v \left( (w_1^2 - \alpha_1 r_1^2 w_1^2) + k (w_2^2 - \alpha_2 r_2^2 w_2^2) \right) \right) - \frac{\theta_i r_1^2 w_1}{2} - p_1 w_1 - m^c (q - w_1^c)
\]

\[
W_1^{nm} = Y + \beta \left( z - v \left( (q^2 - \alpha_1 r_1^2 q) + k (q^2 - \alpha_2 r_2^2 q) \right) \right) - \frac{\theta_i r_1^2 q}{2} - p_1 q
\]
Using these equations, we can determine $m^c$, the transfer price which would make indifferent region 1 to choose between the two regimes:

$$m^c = \frac{3}{4}p_1 + \frac{1}{4}p_2 + \beta\nu 2q(1-k) + \left(\frac{\alpha_2 2k - 1 + 7k^2}{\theta_2} + \frac{\alpha_1 5k^2 + 2k - 3}{\theta_1}\right)\frac{\nu^2\beta^2}{8} > p_1$$

The price that makes the more efficient region indifferent between trading waste or accepting the no mobility solution (each region disposes of its waste) is higher than the marginal cost of disposal $p_1$. The economic intuition behind this result is quite clear. Importing waste increases waste management costs and demands damage-reducing activities. It therefore increases the depletion of the local environmental good. The only benefit is associated with a reduction in the spillovers. Even though the productivity gap is quite big and the spillovers are important, such reduction cannot compensate for the higher costs, unless the transfer price is higher than the marginal cost of disposal. It interesting to note that in this case the worse-off region is the one that is more efficient. In our model the productivity parameters are fixed, but in the long run this may not be the case. A transfer price equal to the marginal cost may lead to a race to the bottom effect, as suggested by the traditional literature (Oates and Schwab. (1988)). This is something that should be kept in mind by the regulator in setting the transfer price.

### 3.3 Decentralisation

Let us now assume that each region sets its own level of investment and waste disposal according only to its preferences and resources. To do so, it maximises its welfare function, which can be written as:

$$W_i = Y_i + z\left(\left(\alpha_i r_i w_i\right) + k \left(\alpha_j r_j w_j\right)\right) - \frac{\theta_i r_i^2 w_i}{2} - p_i (w_i) - m(q_i - w_i) \quad i = 1, 2$$

As for centralisation, we can consider two different cases:

- mobility is not allowed, i.e., $w_i = q$
- mobility is allowed, i.e., $w_i \geq q$.

In the first case, the region takes $w$ as a constraint and simply determines the amount of investment in damage-reducing activities. The solution is presented in Appendix B and the results are summarised in 2. The optimal level of $r$ is lower than in the centralised system, as one might expect. In a decentralised environment in fact the region does not take into account the spillovers created by its own activities and total investment is thus set at a sub-optimal level. Welfare is lower than in the centralised solution, because the reduction in welfare due to a suboptimal investment in environmental protection offsets the increase
<table>
<thead>
<tr>
<th>No mobility</th>
<th>Mobility</th>
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<tbody>
<tr>
<td>$w_1$</td>
<td>$q$</td>
</tr>
<tr>
<td>$w_2$</td>
<td>$q$</td>
</tr>
<tr>
<td>$r_1$</td>
<td>$\frac{\beta w_1}{\theta_1}$</td>
</tr>
<tr>
<td>$r_2$</td>
<td>$\frac{\beta w_2}{\theta_2}$</td>
</tr>
<tr>
<td>$m^d$</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Table 2: Optimal solution for the decentralised case

in welfare due to reduction in the investment cost, as shown by traditional literature (Oates (2008); Tresch (2002)).

When mobility is allowed, each region chooses its preferred level of $w$ and $r$, but without taking into account that $w_1 + w_2 = 2q$, as shown in Appendix B. This condition must however be satisfied. To reconcile decentralization with market-clearing conditions, it is necessary to find a value for $m^d$, the transfer price, that satisfies the optimal choice of each region and market-clearing conditions. The problem can be solved using a Nash game:

$$w_1 = \frac{\alpha_2^2\beta v}{4\theta_1} + \frac{m^d - p_1}{2\beta v}$$

$$w_2 = \frac{\alpha_2^2\beta v}{4\theta_2} + \frac{m^d - p_2}{2\beta v}$$

$$2q = w_1 + w_2$$

and the results are presented in 2. The investment in $r$ is sub-optimal as in the previous case, while the quantity of waste that is traded is lower than with centralisation. From a welfare point of view, since no mobility ($w_i = q$) is a possible outcome of the bargaining solution, the decentralised solution with mobility is always preferred to the solution without mobility. In fact, it represents a Pareto improvement, since both regions are better off.

4 Discussion

The model presented in the previous sections shows that decentralisation in waste management activities does not yield a straightforward solution. From the point of view of total welfare, the choice of a centralised system with waste trading is preferable, but obviously the transfer price plays a fundamental role. This means that there are conditions under which it might be difficult to attain an efficient and equitable equilibrium. The distortions are even more important if we consider the choice of which level - if Central Government or the regions - should be responsible for waste management. There does not seem to be a unique solution and much depends on the starting point. In a centralised
Let us now examine the the choice between a centralised system where mobility is allowed and a decentralised one. From the point of view of maximising total welfare, the centralised system is the optimal choice, but this does not necessarily mean that both regions are better off. As before, let us consider

<table>
<thead>
<tr>
<th>Mobility with bargaining</th>
<th>$m^m$ regulated</th>
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<tbody>
<tr>
<td>$w_1$</td>
<td>$w_2$</td>
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<tr>
<td>$q + \frac{1}{8} \alpha \frac{\alpha_1}{\alpha_2} (1 - k^2) e^\beta - \frac{3r_1 - p_2}{4e^\beta}$</td>
<td>$q - \frac{\beta (1 + k)}{8} \alpha \frac{\alpha_1}{\alpha_2} (1 - k^2) e^\beta + \frac{p_1 - p_2}{4e^\beta}$</td>
</tr>
<tr>
<td>$\frac{\beta (1 + k)}{8} \frac{\alpha_1}{\alpha_2} (1 - k^2) e^\beta - \frac{3r_1 - p_2}{4e^\beta}$</td>
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<tr>
<td>$m^m$</td>
<td>$m^m$</td>
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<tr>
<td>$2 \beta v q - \left( \frac{\alpha_1}{\alpha_2} + \frac{\alpha_2}{\alpha_1} \right) (1 - k^2) e^\beta + \frac{p_2 + p_1}{2}$</td>
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</tr>
<tr>
<td>$2 \beta v q - \frac{\beta^2 (1 + k)}{4} \frac{\alpha_1}{\alpha_2} (1 - k^2) e^\beta + \frac{p_2 + p_1}{2}$</td>
<td>$2 \beta v q - \frac{\beta^2 (1 + k)}{4} \frac{\alpha_1}{\alpha_2} (1 - k^2) e^\beta + \frac{p_2 + p_1}{2}$</td>
</tr>
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Table 3: Optimal solution for the two level case

system, waste exchange maximises total welfare, but the more efficient regions may oppose this mechanism unless the price for disposal across the border is “sufficiently high”. It should also be noted that the quantity of waste to be moved across the border should be decided by Central Government in order to mimic the first best solution. This is because each region does not take into account the positive or negative spillovers of its decisions. To show this let us consider a system where Central Government sets the investment in damage reduction at its optimal level ($r_1 = \frac{2\gamma \alpha_1 (1 + k)}{\beta v}$), while the flow of waste across the border is decided at the regional level. The optimal quantity of waste to be disposed of in each region can be found by maximising 6 under the further assumption that $r_i = \frac{2\gamma \alpha_i (1 + k)}{\beta v}$. A process similar to the one described in 3.3 and presented in C leads to the solution proposed in the first column of table 3, which does not coincide with the first best. In fact, in this case the transfer price is higher and, consequently, the waste flow is suboptimal. The problem here arises because each region in maximising 6 takes the level of waste disposed of in the other region as fixed, i.e., they fail to perceive that if more waste is treated within their boundaries the spillovers from the other region will decrease. This produces a welfare loss for both regions in terms of environmental protection. In fact, although investment in the pollution-reducing technology is set at its optimal level, the allocation of waste is not optimal and the region where waste disposal produces more environmental damage is overproducing. A different solution would be for Central Government to set a price that makes the regions choose the optimal flow of waste. However, this solution implies that the price paid by the exporting region is lower than the price received by the importing one as shown in Table 3.
the case where $\frac{d_1}{d_2} > \frac{d_2}{d_1}$ and $0 < p_1 - p_2 < \frac{d_1^2c^2(1+k)^2}{2(d_1 - d_2)}$. In this case, the flow of waste is directed towards region 1, but under decentralisation the flow is reduced. From 1 and 2 we can indeed note that $w_1^c > w_1^d$. This is the result of the fiscal illusion that makes the local authority not perceive the effects their choices have on the environment good of the other region. In this case two effects works in the same direction: the lower investment in pollution-reducing activities means that the marginal cost of importing waste is higher than in the centralised model. Furthermore, since we assume that the region neglects the reduction in pollution arising from a reduction in the level of waste disposed of in the other region, the price for mobility is higher than in the first best.

This positive effect on welfare is offset by the increase in pollution deriving from a reduction in the investment in pollution-reducing technology.

As in the previous case, we need to compare the welfare under the two hypotheses:

$W_1^c = Y + (\beta (z - v ((w_1^c - \alpha_1 r_1 w_1^c) + k (w_2^c - \alpha_2 r_2 w_2^c))) - \frac{d_1}{d_2} r_1 w_1^c - p_1 w_1^c - m^c(q - w_1^c)$

$W_1^d = Y + (\beta (z - v ((w_1^d - \alpha_1 r_1 w_1^d) + k (w_2^d - \alpha_2 r_2 w_2^d))) - \frac{d_1}{d_2} r_1 w_1^d - p_1 w_1^d - m^d(q - w_1^d)$

The algebra becomes quite cumbersome in this case, but in general it can be shown that region 1 may be better off with decentralisation. This is certainly true if $m^c = p_1^2$ and $k = 0$. For $k \neq 0$ we can write:

$W_1^d - W_1^c = \left(\frac{\alpha_2}{\theta_1} + \frac{\alpha_2^2}{\theta_2}\right) \left(5k^3 + \frac{7}{8} k^2 - \frac{1}{4} k - \frac{1}{4}\right) + \frac{\alpha_2^2}{\theta_2} \left(\frac{1}{4} k^3 + \frac{3}{4} k^2\right) \left(\frac{\alpha_1}{\theta_1} - \frac{\alpha_2}{\theta_2}\right) \frac{v^3 \beta^3}{8}

+ \frac{k^2 + k + 1}{4} \left(\frac{\alpha_1^2}{\theta_1} - \frac{\alpha_2^2}{\theta_2}\right) - \frac{k^2 \alpha_2^2}{2 \theta_2} \left(q^2 \beta^3 + \left(\frac{\alpha_2^2}{\theta_2} - \frac{\alpha_1^2}{\theta_1}\right) (p_1 - p_2) \frac{v \beta}{8} \right.

\left.+ \frac{1}{2} (p_1 - p_2) \frac{1 + k}{1 + k} + \frac{1}{16} v (1 + k) \beta (p_1 - p_2)^2\right)

The sign of this expression depends on the relative size of the productivity parameters, as well as on the price and the attitudes of regions towards the environment. In general, the higher the productivity gap, the likelier that region 1 will gain from decentralisation. For $k = 0$, we can write:

$W_1^d - W_1^c = \left(\frac{\beta v}{8} \left(\frac{\alpha_2^2}{\theta_1} - \frac{\alpha_2^2}{\theta_2}\right) - \frac{1}{4} p_1 - p_2\right) \left(2q \beta v - \frac{1}{4} \beta^2 v^2 \left(\frac{\alpha_1^2}{\theta_1} + \frac{\alpha_2^2}{\theta_2}\right) - \frac{p_1 - p_2}{2}\right) > 0$

This expression is certainly positive, since it is the product of a positive quantity $(w_1^d - q)$ times a positive price difference.

However, even when region 1 is better off through decentralisation, the decision to decentralise waste management is not a Pareto improvement from

\[2\text{See D}\]
centralisation. In this case indeed, the less efficient region will suffer a substantial loss. Environmental protection will be lower, hence this solution may not be implemented if protecting the environment is a priority.

Other scenarios could be evaluated, namely: 1) the shift from a centralised system where mobility is not allowed to decentralisation without mobility and 2) the change from a centralised system with mobility to a decentralised system without it. In both cases the more efficient region may be better off under decentralisation, but a higher productivity gap is necessary for region 1 to prefer decentralisation. The intuition behind this result is as follows. The starting solution in the first scenario (centralisation without mobility) is preferred by region 1 to the case of centralisation with mobility. The welfare that can be attained with decentralisation is the same, hence other things being equal a higher productivity gap is necessary to make region 1 better off. In the second case, the only gain for region 1 is represented by the reduction in the loss suffered from setting a cross-border waste disposal price lower than its actual cost.

5 Conclusions

Environmental problems are inter-regional by their own nature. The level of pollution in a local jurisdiction depends on several factors: the level of economic activity, the investments made to reduce emissions, the decisions taken by neighbouring regions concerning the same conditions. For this reason, the assignment of functions for environmental protection is a matter that has received a great attention in the literature. The allocation of this function at the central level may be more efficient because it allows to take into account the spillovers, but this may not be the right level to take into account distributional considerations. Ogawa and Wildasin (2009) study this trade-off and show that it may be possible that decentralised solutions are more efficient, even in the presence of spillovers Oates (1972); Koethenbuerger (2008). In this article we take a different point of view and show that the presence of externalities and fiscal illusion might prevent the implementation of the first best solution. While a centralised control is more efficient in reducing the negative impact that waste disposal has on the quality of the environment, each region may prefer a suboptimal solution depending on the price set by Central Government for across-the-border disposal. Second-best solutions usually imply that the impact on the environment is heavier than optimal, either because the investment in the technology that mitigates the impact on the environment is suboptimal or because the allocation among the two regions does not minimise the environmental cost. This result is quite interesting for its policy implications, since it shows that in this case the interest of each region may not coincide with the interest of the entire community. These findings are also in line with empirical results that show that environmental protection is higher under centralisation. Our model adds possible theoretical explanations as to why decentralisation may prevail in actual municipal waste management even when centralisation should be preferred from a total welfare point of view. From a policy point of view the most
important problem that the regulator faces is that to replicate a FB solution it should decide both the level of environmental protection and the price of waste disposal across regions. Our model in fact shows that a bargaining between the two region does not allow to reach the optimal price due to fiscal illusion.

Our model can be extended in several ways. The first and more interesting is certainly to consider the quantity of waste \( q \) as a variable that partly depends on the income level, as well as on the price that the community pays for waste disposal. This extension could add new elements to our basic framework. Indeed, if the community had to pay waste disposal on its full marginal price rather than a tax, in a context where cross border waste disposal is allowed further trade-offs may be studied. A centralised model with a transfer price equal to marginal cost maximises the level of protection in terms of investment in pollution-reducing technologies, but might incentivize the production of waste since it is priced below its cost. On the other hand, in decentralisation the investment in pollution reducing technologies is very low, but the cross border price is very high and this might sensibly reduce the quantity of waste produced, thus helping to achieve decoupling.

* References


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A Optimal conditions for the First Best model

Let us start with the case where mobility is allowed. The maximisation problem can be written as:

\[
\begin{align*}
\text{Max}_{w_1, w_2, r_1, r_2} \quad W^c &= Y_1 + \beta (z - v (w_2^2 - \alpha_1 r_1 w_1)) - kv (w_2^2 - \alpha_2 r_2 w_2) - \theta r_1^2 w_1 - p_1 (w_1) \\
&+ Y_2 + \beta (z - v (w_2^2 - \alpha_2 r_2 w_2)) - kv (w_1^2 - \alpha_1 r_1 w_1) - \theta r_2^2 w_2 - p_2 (w_2)
\end{align*}
\]

s.t.

\[
w_1 + w_2 = 2q
\]

The F.O.C. for the problem can be written as:
the following utility function:

\[ \text{Max}_{w_i} : W_i^{FB} = Y_i + z - v \left( \left( w_i^2 - \alpha_i r_i w_i \right) + k \left( w_j^2 - \alpha_j r_j w_j \right) \right) \]

\[ -\frac{\theta_i}{2} \left( \frac{\beta v \alpha_i (1 + k)}{\theta_i} \right)^2 w_i - p_i(w_i) - m^{FB}(q_i - w_i) \]

The FOC for the problem can be written as:

\[ \frac{\partial W_i}{\partial w_i} = -2\beta v w_i + \beta v \alpha_i \frac{\beta v \alpha_i (1 + k)}{\theta_i} \frac{\theta_i}{2} \left( \frac{\beta v \alpha_i (1 + k)}{\theta_i} \right)^2 w_i - p_i + m^{FB} = 0 \]

from which we can obtain the following net demand function:

\[ w_i = 2q \frac{k}{1 + k} + \left( \frac{\alpha_i^2 (1 - k)}{4\theta_i (1 - k)} - 2k \frac{\alpha_j^2}{\theta_j} \right) - \frac{1}{2} \frac{p_i - m^{FB}}{\beta v (1 + k)} \]

The two net demands are matched when the price clear the market, i.e. when the following conditions are met:

fully

\[ w_1 = 2q \frac{k}{1 + k} + \left( \frac{1}{4} \alpha_i^2 \frac{1 - k}{\theta_i} - \frac{1}{2} \frac{\alpha_j^2}{\theta_j} \right) v \beta - \frac{1}{2} \frac{p_i - m^{FB}}{\beta v \alpha_i (1 + k)} \]

\[ w_2 = 2q \frac{k}{1 + k} + \left( \frac{1}{4} \alpha_i^2 \frac{1 - k}{\theta_i} - \frac{1}{2} \frac{\alpha_j^2}{\theta_j} \right) v \beta - \frac{1}{2} \frac{p_i - m^{FB}}{\beta v \alpha_j (1 + k)} \]

\[ w_1 + w_2 = 2q \]

which when solved gives the optimal conditions for \( w_i \) and \( m^{FB} \) reported in the text.

For the no mobility case, since the FOCs for \( r_1 \) and \( r_2 \) are independent from \( w_i \), their optimal level is still represented by the no mobility solution while for \( w_i = q \).
B Optimal conditions for the decentralised model

In the decentralised case, when mobility is allowed, each region maximises its welfare which depends on their own choices and what is chosen by the other region.

The problem can be written as:

\[ W^d_i = Y_i + z - v \left( (w_i^2 - \alpha_i r_i w_i) + k \left( w_j^2 - \alpha_j r_j w_j \right) \right) - \frac{\theta_i}{2} r_i^2 w_i - p_i(w_i) - m^d(q_i - w_i) \]  

(8)

The FOC for the problem can be written as:

\[ \frac{\partial W^d_i}{\partial w_i} : -2\beta v w_i + \beta v \alpha_i r_i - \frac{1}{2} \theta_i r_i^2 - p_i + m^d = 0 \]

\[ \frac{\partial W^d_i}{\partial r_i} : \beta v \alpha_i w_i - \theta_i r_i w_i = 0 \]

and the solution is:

From the second FOC we obtain:

\[ r_i = \frac{\beta v \alpha_i}{\theta_i} \]

which can be combined with the first FOC to obtain:

\[ w_i = \frac{1}{4} \beta v \frac{\alpha_i^2 \theta_i}{\theta_i} + m^d - p_i \]

which depends on \( m^d \), the price for the exchange of waste among the two regions. The two functions for optimal waste can be considered a sort of demand/supply model whose market clearing conditions is found for the point where total demand of waste to be disposed is equal to the supply. To find the price that clear the market we can write the following equation system:

\[ w_1 = \frac{1}{2} \beta v \frac{\alpha_1^2 \theta_1}{\theta_1} + \frac{m^d - p_1}{2 \beta v} \]

\[ w_2 = \frac{1}{2} \beta v \frac{\alpha_2^2 \theta_2}{\theta_2} + \frac{m^d - p_2}{2 \beta v} \]

\[ w_1 + w_2 = 2q \]

which gives the solution presented in the text.

C Mixed model

In this case, regions decides \( w \) after that Central Government has set \( r_i = \frac{\beta v \alpha_i (1 + k)}{\theta_i} \).

Each Region maximises the following utility function:

\[ W^m_i = Y_i + z - v \left( (w_i^2 - \alpha_i r_i w_i) + k \left( w_j^2 - \alpha_j r_j w_j \right) \right) - \frac{\theta_i}{2} \left( \frac{\beta v \alpha_i (1 + k)}{\theta_i} \right)^2 w_i - p_i(w_i) - m^d(q_i - w_i) \]  

(9)
The FOC for the problem can be written as:
\[
\frac{\partial W_m}{\partial w_i} = -2\beta vw_i + \beta \alpha \frac{v^2(vw_i + \theta_i)}{\theta_i} - \frac{\theta_i}{2} \left( \frac{2\beta vw_i}{\theta_i} \right) - p_i + m^d = 0
\]
from which we can obtain the following demand function:
\[
w_i = \frac{\alpha_i^2 (1 - k^2)}{4\theta_i} - \frac{1}{2} \frac{p_i - m^m}{\beta v} - \frac{1}{2} \frac{p_i - m^m}{\beta v}
\]
If Central Government wants to replicate the optimal solution in terms of quantity of waste transported from one Region to the other, it will have to set \(m^d: w_i^c = w_i^m\), i.e. the following equation will have be solve for \(m^m\)
\[
\frac{\alpha_i^2 (1 - k^2)}{4\theta_i} - \frac{p_i - m^m}{\beta v} = q + \frac{\beta v (1 + k)}{8} \left( \frac{\alpha_i^2}{\theta_i} - \frac{\alpha_j^2}{\theta_j} \right) - \frac{p_1 - p_2}{4(1 + k) \beta v}
\]
which gives the solution presented in the text.
On the other hand if Central Government leaves Regions free to set the price for mobility the price will be determined by the solution of the following problem:
\[
w_1 = \frac{1}{2} \frac{\alpha_i^2 (1 - k^2)}{\theta_i} - \frac{1}{2} \frac{p_i - m^m}{\beta v} = q + \frac{\beta v (1 + k)}{8} \left( \frac{\alpha_i^2}{\theta_i} - \frac{\alpha_j^2}{\theta_j} \right) - \frac{p_1 - p_2}{4(1 + k) \beta v}
\]
whose solution is presented in the text.

D Welfare comparison

The welfare difference can be written as:
\[
W_m^c = Y + \beta \left( z - v \left( (w_1^c)^2 - \alpha_1 r_1^c w_1^c + k \left( (w_2^c)^2 - \alpha_2 r_2^c w_2^c \right) \right) \right) - \frac{\theta_i}{2} (r_i^c)^2 w_i^c - p_i w_i^c - m^c(q - w_i^c)
\]
\[
W_m^d = Y + \beta \left( z - v \left( (w_1^d)^2 - \alpha_1 r_1^d w_1^d \right) + k \left( (w_2^d)^2 - \alpha_2 r_2^d w_2^d \right) \right) - \frac{\theta_i}{2} (r_i^d)^2 w_i^d - p_i w_i^d - m^d(q - w_i^d)
\]
which can be written as:
\[
W_m^d - W_m^c = \left( (w_1^d)^2 - (w_1^c)^2 + \alpha_1 \left( r_1^d w_1^d - r_1^c w_1^c \right) - k \left( (w_2^d)^2 - (w_2^c)^2 - \alpha_2 \left( r_2^d w_2^d - r_2^c w_2^c \right) \right) \right) v \beta
\]
\[
- \frac{\theta_i}{2} \left( (r_i^d)^2 - (r_i^c)^2 \right) w_i^c + p_i (w_i^c - w_i^d) + m^c (w_i^d - q) - m^d (w_i^c - q)
\]
For \(m^c = p_1\) we can write:
\[
W_m^d - W_m^c = \left( (w_1^c)^2 - (w_1^d)^2 + \alpha_1 (r_1^d w_1^d - r_1^c w_1^c) - k \left((w_2^c)^2 - (w_2^d)^2 - \alpha_2 (r_2^d w_2^d - r_2^c w_2^c)\right) \right) \\
- \frac{\theta_1}{2} \left((r_1^d)^2 w_1^d - (r_1^c)^2 w_1^c\right) + \left(w_1^d - q\right) \left(m^d - p_1\right)
\]

Using tables 1 and 2 we can substitute \( w, r \) and \( m^d \) in equation 10 to obtain the expression in the text.