Environmental cost and universal service obligations in the postal sector

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1 Introduction

During the last two decades, the postal sectors in the EU member states have faced two major trends. On the one hand, markets have been liberalized to an increasing degree, and full liberalization is now just around the corner. On the other hand, traditional postal products have been subject to an increasing degree of competition from electronic substitutes. The first trend has been extensively studied in the literature and its implications are by now well understood. The electronic substitutes have also received a lot of attention but the jury is still out when it comes to assessing their precise impact on the demand for postal products in the coming years and decades.

A third major trend which is likely to have a significant effect on the future of the postal sector has hitherto largely been ignored by the literature: the increasing importance of sustainable growth considerations and of environmental policy. The postal sector affects the environment through at least two channels: the consumption of paper on the one hand, and CO_2 emissions due to transportation and buildings' energy consumption on the other hand. Consequently the environmental debate will bring postal operators to rethink their pricing strategies, their product design and their investment decisions. A step in that direction has already been taken by 20 postal operators members of the International Post Corporation (IPC), including La Poste, that represent 80% of global mail volumes. They have pledged to collectively reduce their carbon emissions by 20% by 2020, based on 2008 levels.[1]

In addition, considerations of sustainable growth and environmental policies will challenge the other postal stakeholders too, as they will also have a substantial impact on regulatory policies, in particular Universal Service Obligations (USO). Indeed, postal operators could reduce their emissions by transforming and modernizing their process like for instance the use of electric vehicles or the thermal insulation of facilities. But, regulatory policies may also be adapted to take into account environmental considerations (constraints on daily letter box collection and mail delivery amongst others).

In this paper, we study the impact of environmental considerations on USO. The

[1] These operators are responsible for the emission of 8.36 million tonnes of CO_2.

cost and benefits of USOs have been extensively studied over the last decade.[2] It is by now well known that USO has social benefits but implies costs at various levels: private costs for the operator and efficiency costs for customers. An optimally designed USO ought to strike a balance between benefits and costs. The point we make is that environmental considerations add yet another dimension to this trade-off.

It is rather difficult to determine which constraints and which processes have the most important impact in terms of emissions. Moreover, it is not the absolute level which is relevant to guide decisions, but *marginal* levels.[3] Without any form of green accounting, determining the least costly way (socially or financially) to reduce CO_2 emissions is a non trivial question. Nevertheless, one can reach some intuitive insight by focusing on sources of emissions and costs. In the case of *La Poste*, the two main sources of emissions are the facilities and the transport. However, facilities are responsible for less than 20% of total emissions, so that focusing on the reduction of transportation emission may be seen as a relevant first step. This is the approach we adopt in this paper.

Emissions due to transportation originate from different parts of the mail process: delivery, collection, employee transport or transportation of mail between delivery centers. Recall that the classical way of analyzing the mail process distinguishes four activities: collection, sorting, transportation and delivery. In France most of the transport process is operated by subcontractors. In 2007, subcontractors of the mail division were emitting more than one third of the total emissions of La Poste (including the parcel division). As far as the USO is concerned, the transportation process is mainly affected by the requirement of a national *D+1* service. Because of the French geography it is necessary to resort to air transport to provide such a service. And air transportation represents 15% of the total transportation cost. Furthermore, the national $D+1$ service also increases (private and social) costs associated with other means of transportation. For instance, it often implies that trucks are not fully loaded; this is costly and this increases the carbon footprint of a *D+1* letter.

[2] See Boldron *et al.* (2008) and the references given there.
[3] See Boldron *et al.* (2009).

To illustrate this argument in the simplest possible way, we concentrate on a specific aspect, namely the speed of processing and delivery. USO often requires that (domestic first-class) mail be processed on a *D+1* basis, irrespective of the distance between sender and addressee (and typically at a uniform rate). Now, transportation costs incurred to ensure next day delivery, both the private ones borne by the operator and the external costs associated with emissions tend to increase quite significantly with distance. For instance, with the *D+1* constraint, long distance mail may have to be carried by plane, while more environmentally friendly means of transportation could be used for less urgent mail. We show that, when environmental considerations are ignored, regulators may impose a larger than otherwise optimal USO. We also study how the USO should be designed to properly account for the environmental cost in a variety of situations ranging from a first-best world to a (Ramsey-type) second-best world with uniform prices.

2 Model

Consider a representative sender who sends mail to addressees located at a distance $\delta \in [0,1]$. The variable δ is uniformly distributed and there is a total mass one of addressees. There are two mail products: x_1 which is processed and delivered at $D+1$ in area $A_1 \subset [0,1]$, and x_2 which is delivered at $D+2$ in area $A_2 \subset [0,1]$. Areas A_1 and A_2 form a partition of $[0,1]$. More specifically we assume that product 1 is available when the addressee is located at a distance $\delta \leq \mu$, while product 2 is available when $\mu < \delta \leq 1$ so that $A_1 = [0,\mu]$ and $A_2 =]\mu, 1]$; see Figure 1.[4]

The utility of the representative sender is given by

$$U = \int_{A_1} [u_1(x_1) - p_1 x_1] d\delta + \int_{A_2} [u_2(x_2) - p_2 x_2] d\delta,$$

where p_1 is the price of x_1 and p_2 is the price of x_2 and where $u_1(x) > u_2(x)$.

The operator's cost of processing mail includes a constant (marginal) delivery cost of k which is the same for the two types of mail. In addition there are transportations

[4] Alternatively we could assume that both products are available in A_1, while only product 2 is available in A_2. This would lead to a more complicated model where the customer (sender) chooses between the two products for addressees in A_1.

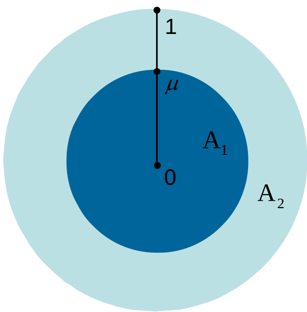

Figure 1: The partition of the market according to the location of the addressee.

costs given by $T_1(x_1, \delta)$ for $D+1$ mail of volume x_1 at distance δ and $T_2(x_2, \delta)$ for $D+2$ mail at volume x_2. We have of course

$$T_1(x, \delta) > T_2(x, \delta) \tag{1}$$

for any x and δ: transportation costs are the higher the faster the speed of delivery. Furthermore, both $T_1(x, \delta)$ and $T_2(x, \delta)$ increase with distance, and T_1 increases faster

$$\frac{\partial T_1(x, \delta)}{\partial \delta} > \frac{\partial T_2(x, \delta)}{\partial \delta} > 0. \tag{2}$$

Both transportation costs are convex in distance

$$\frac{\partial T_i^2(x, \delta)}{\partial \delta^2} > 0, \qquad i = 1, 2. \tag{3}$$

We also assume

$$T_2(x, \delta) < 2T_1\left(\frac{x}{2}, \delta\right). \tag{4}$$

In words, total shipping costs are reduced if we “group” the mail. Rather than shipping say 50 units everyday $(D+1)$ it is cheaper (per unit) to ship 100 every two days $(D+2)$.

Transportation cost T_1 and T_2 are "private" costs, *i.e.,* costs borne by the operator. In addition, transportation also has an environmental impact, in particular in terms of CO_2 emissions. Environmental cost associated with transportation are given by $\varphi_1(x_1, \delta)$ and $\varphi_2(x_2, \delta)$. These external costs have the same properties as the private costs T_i; formally, $\varphi_1(x_1, \delta)$ and $\varphi_2(x_2, \delta)$ satisfy conditions (1)–(4).

Last but not least, the operators production technology involves a fixed cost $F(\mu)$ which may or may not depend on μ. More precisely, we shall assume $F'(\mu) \geq 0$ and $F''(\mu) \geq 0$

Social welfare (total surplus) is given by

$$\begin{aligned} W &= \mu u_1(x_1) + (1-\mu)u_2(x_2) + S(\mu) - F(\mu) - k[\mu x_1 + (1-\mu)x_2] \\ &\quad - \int_0^{\mu} [T_1(x_1,\delta) + \varphi_1(x_1,\delta)]d\delta - \int_{\mu}^{1} [T_2(x_2,\delta) + \varphi_2(x_2,\delta)]d\delta, \end{aligned} \tag{5}$$

where $S(\mu)$ are the social benefits of USO which depend on μ, the proportion of addressees that can be reached on $D+1$. We have $S'(\mu)$ and $S''(\mu) < 0$ so that social benefits are an increasing and concave function of μ. Total delivery cost is given by $k[\mu x_1 + (1-\mu)x_2]$. Observe that this formulation assumes that x_i is constant over A_i. This is a necessary condition if the allocation is to be decentralized with two (linear) prices p_1 and p_2.

3 First-best solution

To determine the first-best allocation, we maximize W defined by (5) with respect to x_1, x_2 and μ. The FOCs are given by

$$\frac{\partial W}{\partial x_1} = \mu\left[u_1'(x_1) - k\right] - \int_0^{\mu} \left[\frac{\partial T_1(x_1,\delta)}{\partial x_1} + \frac{\partial \varphi_1(x_1,\delta)}{\partial x_1}\right] d\delta = 0 \tag{6}$$

$$\frac{\partial W}{\partial x_2} = (1-\mu)\left[u_2'(x_2) - k\right] - \int_{\mu}^{1} \left[\frac{\partial T_2(x_2,\delta)}{\partial x_2} + \frac{\partial \varphi_2(x_2,\delta)}{\partial x_2}\right] d\delta = 0 \tag{7}$$

$$\begin{aligned} \frac{\partial W}{\partial \mu} &= \{u_1(x_1) - kx_1 - T_1(x_1,\mu) - \varphi_1(x_1,\mu)\} \\ &\quad - \{u_2(x_2) - kx_2 - T_2(x_2,\mu) - \varphi_2(x_2,\mu)\} + \{S'(\mu) - F'(\mu)\} \end{aligned} \tag{8}$$

Conditions (6) and (7) state that the marginal benefit for each of the products must equal its marginal cost. Marginal costs consist of three elements: delivery cost (k), private transportation cost ($\partial T_i/\partial x_i$) and environmental cost ($\partial\varphi/\partial x_i$). Recall that x_i concerns *all* addressees in A_i. Consequently, the relevant benefits and costs are determined for the entire set of addressees.[5] Since marginal transportation costs are not constant within a given delivery area, it is convenient to define these costs on a per addressee basis:

$$\begin{aligned}
\overline{T}'_1 &= \frac{\int_0^\mu \frac{\partial T_1(x_1,\delta)}{\partial x_1} d\delta}{\mu}, \qquad & \overline{\varphi}'_1 = \frac{\int_0^\mu \frac{\partial \varphi_1(x_1,\delta)}{\partial x_1} d\delta}{\mu}, \\
\overline{T}'_2 &= \frac{\int_\mu^1 \frac{\partial T_2(x_2,\delta)}{\partial x_2} d\delta}{1-\mu}, \qquad & \overline{\varphi}'_2 = \frac{\int_\mu^1 \frac{\partial \varphi_2(x_2,\delta)}{\partial x_2} d\delta}{1-\mu}.
\end{aligned}$$

The first-best solution can be decentralized by the following prices

$$p_1 = k + \overline{T}'_1 + \overline{\varphi}'_1, \tag{9}$$

$$p_2 = k + \overline{T}'_2 + \overline{\varphi}'_2. \tag{10}$$

In words, prices reflect marginal cost which includes a "Pigouvian" tax (*i.e.*, a tax which is equal to the marginal social damage). To give the right signals to the consumer the price of the goods have to reflect their social marginal costs. The social marginal cost includes the marginal cost of the externality. We can expect prices to differe ($p_1 \neq p_2$) but we cannot presume on their ranking. On the one hand, the $D+1$ good generates larger transportation and environmental costs for any given distance δ, but, on the other hand, good $D+2$ is sent to customers that are more distant from the sender than good $D+1$. We come back to this comparison in section 6.

The third condition may or may not yield interior solution. When social benefits of universal service, $S(\mu)$, are sufficiently large we may have $\mu = 1$. For the sake of interpretation we can rewrite (8) as

$$\begin{aligned}
\frac{\partial W}{\partial \mu} =& [u_1(x_1) - kx_1 - T_1(x_1,\mu)] - [u_2(x_2) - kx_2 - T_2(x_2,\mu)] \\
& - [\varphi_1(x_1,\mu) - \varphi_2(x_2,\mu)] + [S'(\mu) - F'(\mu)].
\end{aligned} \tag{11}$$

[5] This explains the integral in the transportation cost terms and the multiplication by μ or $(1-\mu)$ of benefits and delivery costs.

This expression shows the impact on social welfare of an increase in the size of the $D+1$ area. The first and second terms represent the (private) surplus of sender per addressee (net of delivery and transportation cost) in $D+1$ and $D+2$ area, respectively. As we increase the size of the $D+1$ zone, we gain the difference between $D+1$ and $D+2$ surplus for the marginal addressee that is shifted from zone $D+2$ to zone $D+1$. The third term represents the marginal environmental cost of an increase in μ. The fourth term $[S'(\mu) - F'(\mu)]$ corresponds to the marginal social benefit of USO net of any extra fixed cost that may be incurred. An interior solution for μ (*i.e.*, $0 < \mu^{FB} < 1$) requires $\partial W/\partial\mu = 0$ and thus strikes a balance between the benefits and costs of the increase in μ.[6] When $\partial W/\partial\mu = 0$ for $\mu = 1$, we have a corner solution given by $\mu^{FB} = 1$.

Observe that when the environmental cost is neglected and when the first-best solution is interior, the regulator will choose a level of μ that is too large. When $\mu^{FB} = 1$, the neglect of environmental cost has no (direct) impact on the optimal μ. However, both prices will then be set a too low a level.

4 Uniform pricing

The solution described in the previous section requires (in general) different prices for the delivery areas. Except by coincidence, (9) and (10) imply $p_1 \neq p_2$. When the price is restricted to be uniform ($p_1 = p_2 = p$) this solution can no longer be achieved. We now study the best solution that is feasible under uniform pricing. At this point, no break-even constraint is imposed.

Social welfare continues to be given by (5), except that x_1 and x_2 are now functions of p, determined by the sender's utility maximizing problem. It is convenient to rewrite welfare as $W = U + \pi + E$, where U is (sender's) utility, π_i is profit, while E represents

[6] The second order condition is satisfied per our assumptions on the functions T_i , φ, and S.

social costs and benefits:

$$
\begin{aligned}
W =& \mu[u_1(x_1) - px_1] + (1-\mu)[u_2(x_2) - px_2] \\
&+ p[\mu x_1 + (1-\mu)x_2] - k[\mu x_1 + (1-\mu)x_2] - \int_0^\mu T_1(x_1,\delta)d\delta - \int_\mu^1 T_2(x_2,\delta)d\delta \\
&+ S(\mu) - F(\mu) - \int_0^\mu \varphi_1(x_1,\delta)d\delta - \int_\mu^1 \varphi_2(x_2,\delta)d\delta. \qquad (12)
\end{aligned}
$$

Differentiating and using the envelope theorem yields

$$
\frac{\partial W}{\partial p} = \mu\frac{\partial x_1}{\partial p}\left[p - k - \overline{T}_1' - \overline{\varphi}_1'\right] + (1-\mu)\frac{\partial x_2}{\partial p}\left[p - k - \overline{T}_2' - \overline{\varphi}_2'\right] = 0,
$$

which implies

$$
p = \frac{\mu\frac{\partial x_1}{\partial p}\left[k + \overline{T}_1' + \overline{\varphi}_1'\right] + (1-\mu)\frac{\partial x_2}{\partial p}\left[k + \overline{T}_2' + \overline{\varphi}_2'\right]}{\mu\frac{\partial x_1}{\partial p} + (1-\mu)\frac{\partial x_2}{\partial p}},
$$

so that the price is a weighted sum of marginal costs (including environmental costs).

The *expression* with respect to μ is the same as before, so that[7]

$$
\begin{aligned}
\frac{\partial W}{\partial \mu} =& [u_1(x_1) - kx_1 - T_1(x_1,\mu)] - [u_2(x_2) - kx_2 - T_2(x_2,\mu)] \\
&- [\varphi_1(x_1,\mu) - \varphi_2(x_2,\mu)] + [S'(\mu) - F'(\mu)].
\end{aligned}
$$

However, the actual *level* of μ will differ from the first-best solution because quantities (demand levels) differ. At this level of generality, it is not possible to assess analytically the impact of uniform pricing on the optimal level of μ. This is one of the issues that will be examined in more detail in the numerical examples in Section 6.

5 Second-best

So far, we have not required the operator to break even. In other words, we have not required that revenues be sufficient to cover all the costs, including the fixed cost. When $F'(\mu) = 0$ the fixed cost then had no impact at all on the solution, while it did affect the optimal level of μ when $F'(\mu) > 0$. Observe that when no break even constraint is imposed, the use that is made of environmental tax revenues does not

[7] The *expression* is the same because quantities do not (directly) depend on μ.

matter. Specifically it does not matter, in our quasi-linear setting, whether the revenue is refunded to consumers (on a lump-sum basis) or to the operator.[8]

We now turn to the cases where the operator faces a break-even constraint (requiring $\pi \geq 0$). In these circumstances the allocation of environmental tax proceeds does matter. We shall first consider the case where tax revenues are refunded to the operator and then assume that they are not refunded to the operator but to the representative sender.

5.1 No uniform pricing constraint

5.1.1 Environmental taxes are refunded to operator

Let λ denote the multiplier associated with the break-even constraints. The Lagrangian expression associated with the second-best problem is given by $\mathcal{L} = U + (1+\lambda)\pi + E$ which yields

$$\begin{aligned}
\mathcal{L} =& \mu[u_1(x_1) - p_1 x_1] + (1-\mu)[u_2(x_2) - p_2 x_2] \\
&+ (1+\lambda)\left\{\mu p_1 x_1 + (1-\mu)p_2 x_2 - k[\mu x_1 + (1-\mu)x_2] - \int_0^\mu T_1(x_1,\delta)d\delta \right. \\
&\left. - \int_\mu^1 T_2(x_2,\delta)d\delta - F(\mu)\right\} \\
&+ S(\mu) - \int_0^\mu \varphi_1(x_1,\delta)d\delta - \int_\mu^1 \varphi_2(x_2,\delta)d\delta. \qquad (13)
\end{aligned}$$

The decision variables are the same as in the first-best problem, namely p_1, p_2 and μ. Observe that environmental taxes do not explicitly appear in this problem. They are included in consumer prices p_1 and p_2.[9]

There are two possible types of solution, respectively with $\lambda = 0$ or $\lambda > 0$. The case $\lambda = 0$ occurs if the first-best solution remains feasible, *i.e.*, yields a revenue high enough to cover fixed cost. When the first-best does not yield budget balance, we are in a Ramsey type second-best with $\lambda > 0$, and optimal prices are given by

$$\begin{aligned}
\frac{p_1 - k - \overline{T}'_1}{p_1} &= \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_1} + \frac{1}{1+\lambda}\frac{\overline{\varphi}'_1}{p_1}, \\
\frac{p_2 - k - \overline{T}'_2}{p_2} &= \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_2} + \frac{1}{1+\lambda}\frac{\overline{\varphi}'_2}{p_2},
\end{aligned}$$

[8] As long of course as it is somehow refunded.

[9] Explicitly introducing taxes t_1 and t_2 would not change the analysis. Per unit revenue of the firm is then equal to the producer price $p_i - t_i$ plus the tax refund t_i which adds up to p_i.

where ε_i is the absolute value of the price elasticity of good i. These expressions can be rewritten as

$$\frac{p_1 - k - \overline{T}_1'}{p_1} = \alpha \frac{1}{\varepsilon_1} + (1-\alpha)\frac{\overline{\varphi}_1'}{p_1}, \qquad (14)$$

$$\frac{p_2 - k - \overline{T}_2'}{p_2} = \alpha \frac{1}{\varepsilon_2} + (1-\alpha)\frac{\overline{\varphi}_2'}{p_2} \qquad (15)$$

where $\alpha = \lambda/(1+\lambda)$. These expressions are similar to those derived by Sandmo (1974) who has studied Ramsey taxation in the presence of externalities; see also Cremer *et al.* (1998). They state that the implicit tax on good i is a weighted average of the inverse elasticity (Ramsey) term and the Pigouvian term (marginal social damage). Note that when $\lambda = 0$ these equations reduce to the first-best expressions (9), (10).

Differentiating with respect to μ yields

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \mu} =& [u_1(x_1) - kx_1 - T_1(x_1,\mu)] - [u_2(x_2) - kx_2 - T_2(x_2,\mu)] \\ & - [\varphi_1(x_1,\mu) - \varphi_2(x_2,\mu)] + S'(\mu) \\ & + \lambda[(p_1x_1 - kx_1 - T_1(x_1,\mu)) - (p_2x_2 - kx_2 - T_2(x_2,\mu))] - (1+\lambda)F'(\mu), \qquad (16)\end{aligned}$$

which can be rearranged as

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \mu} =& [u_1(x_1) - (1+\lambda)kx_1 - (1+\lambda)T_1(x_1,\mu)] - [u_2(x_2) - (1+\lambda)kx_2 - (1+\lambda)T_2(x_2,\mu)] \\ & + \lambda(p_1x_1 - p_2x_2) - [\varphi_1(x_1,\mu) - \varphi_2(x_2,\mu)] + S'(\mu) \\ & - (1+\lambda)F'(\mu). \qquad (17)\end{aligned}$$

When $\lambda = 0$, this equation reduces (not surprisingly) to the first-best expression (11). For the case $\lambda > 0$ its interpretation is also quite straightforward. Equation (17) shows that private costs now have to be multiplied by $(1+\lambda)$ and that we have to account for the extra revenue: $\lambda(p_1x_1 - p_2x_2)$ which is positive or negative. Equation (16), on the other hand, isolates the extra terms (compared to (8)); they can be positive or negative. When the fixed cost does not depend on μ, the last term vanishes.

While expressions (16) and (17) are rather intuitive, they are too complex to yield precise results. In particular, the impact of λ on μ does not appear to be unambiguous and this is where the simulations presented in Section 6 provide additional insight.

5.1.2 Environmental taxes are not refunded to the operator

So far, we have not introduced a specific notation for the environmental tax. We can think of $p_i - k - \overline{T}_i'$ as the total (per unit) tax levied on product i. This includes the contribution to fixed costs and the environmental component. We can introduce a specific environmental tax t_i in this problem. One can readily verify that when it is refunded to the operator, its level does not matter. The important variable is p_i. We can set the tax t_i at the Pigouvian level (or any other level). When t_i is not refunded to the operator (but to the representative sender) this variable is no longer redundant. The Lagrangian expression is now given by

$$\begin{aligned}\mathcal{L} =& \mu[u_1(x_1) - p_1x_1] + (1-\mu)[u_2(x_2) - p_2x_2] \\ &+ (1+\lambda)\left\{\mu(p_1 - t_1)x_1 + (1-\mu)(p_2 - t_2)x_2 - k[\mu x_1 + (1-\mu)x_2] - \int_0^\mu T_1(x_1,\delta)d\delta \right. \\ &\left. - \int_\mu^1 T_2(x_2,\delta)d\delta - F(\mu)\right\} + \mu t_1 x_1 + (1-\mu)t_2x_2 \\ &+ S(\mu) - \int_0^\mu \varphi_1(x_1,\delta)d\delta - \int_\mu^1 \varphi_2(x_2,\delta)d\delta. \end{aligned} \tag{18}$$

This expression shows that environmental tax revenue is deducted in the break-even constraint (and has a weight of $(1+\lambda)$) and added as tax revenue (redistributed lump sum to the representative sender, with a weight of 1). It is then plain that the optimal policy implies $t_1 = t_2 = 0$. For the rest we have the same solution as if tax proceeds were refunded (and as above we have the two cases, $\lambda = 0$ and $\lambda > 0$). This result crucially depends on the fact that the regulator has independent control of p_i; if the consumer price is not controlled, the result would be different.

5.2 Uniform pricing

The issue of tax revenue refunds arises in the same way as under non-uniform pricing. Consequently, we shall concentrate on the case where tax proceeds are refunded to the operator.[10] The Lagrangian expression associated with the maximization of welfare is

[10] Keeping in mind that the alternative assumption yields the same result with the statutory environmental tax, t_i set equal to zero.

given by

$$\begin{aligned}\mathcal{L} =&\mu[u_1(x_1) - px_1] + (1-\mu)[u_2(x_2) - px_2] \\ &+ (1+\lambda)\left\{p[\mu x_1 + (1-\mu)x_2] - k[\mu x_1 + (1-\mu)x_2] - \int_0^\mu T_1(x_1,\delta)d\delta \right. \\ &\left. - \int_\mu^1 T_2(x_2,\delta)d\delta - F(\mu)\right\} \\ &+ S(\mu) - \int_0^\mu \varphi_1(x_1,\delta)d\delta - \int_\mu^1 \varphi_2(x_2,\delta)d\delta. \end{aligned} \tag{19}$$

Once again, when the first-best solution satisfies the break-even constraint it prevails in the second-best and we have $\lambda = 0$. When $\lambda > 0$, on the other hand, the optimal price satisfies

$$\frac{\mu\frac{\partial x_1}{\partial p}\left(p - k - \overline{T}_1' - \frac{\overline{\varphi}_1'}{1+\lambda}\right) + (1-\mu)\frac{\partial x_2}{\partial p}\left(p - k - \overline{T}_2' - \frac{\overline{\varphi}_2'}{1+\lambda}\right)}{p\frac{\partial X}{\partial p}} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon}, \tag{20}$$

where ε is the absolute value of the demand elasticity of total volume $X = \mu x_1 + (1-\mu)x_2$.

Under a uniform pricing constraint, the traditional Ramsey problem is degenerate and amounts to solving the budget constraint with respect to the sole decision variable (the price). This is because there is no degree of freedom left once all the constraints are satisfied. In the problem considered here, we do have two decision variables p and μ, so the problem is not degenerate. Still, it is true that for a given level of μ the price will be set at the lowest level which yields budget balancing. Consequently, equation (20) will essentially determine λ (which is needed in the other FOC). This second expression is obtained by differentiating $\mathcal{L}$ with respect to μ, which yields

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \mu} =&[u_1(x_1) - (1+\lambda)kx_1 - (1+\lambda)T_1(x_1,\mu)] - [u_2(x_2) - (1+\lambda)kx_2 - (1+\lambda)T_2(x_2,\mu)] \\ &+ \lambda p(x_1 - x_2) - [\varphi_1(x_1,\mu) - \varphi_2(x_2,\mu)] + S'(\mu) \\ &- (1+\lambda)F'(\mu). \end{aligned} \tag{21}$$

This is essentially the same condition as (17). However, while the *rule* remains the same under uniform pricing, actual levels will differ. To study the impact of uniform pricing on the levels of p and μ we have to resort to simulations to which we now turn.

6 Numerical simulations

This section provides illustrative numerical simulations. The functional forms and the values of the parameters have *not* been calibrated to reflect any specific situation. The exercise is nevertheless very useful because it enhances the intuitive understanding of the solution. In addition it allows us to compare the *levels* of the different variables (prices and μ) accross scenarios.

We use the following functional forms: $T_1(x_1, \delta) = cx_1\delta^2$ and $T_2(x_2, \delta) = \alpha c x_2 \delta^2$, with $0 < \alpha < 1$ and $c > 0$. Observe that the conditions (1) to (4) are all satisfied with this formulation. Similarly, assume that $\varphi_1(x_1, \delta) = ex_1\delta^2$ and $\varphi_2(x_2, \delta) = \beta e x_2 \delta^2$, with $0 < \beta < 1$ and $e > 0$. We consider quadratic utility functions $u_1(x_1) = a_1x_1 - (b/2)x_1^2$ and $u_2(x_2) = a_2x_2 - (b/2)x_2^2$ with $a_1, a_2, b > 0$ and $a_1 > a_2$ so that $u_1(x) > u_2(x)$ for all x. These functions give rise to linear demand functions $x_1(p_1)$ and $x_2(p_2)$ differing in their intercept and such that $x_1(p) > x_2(p)$ for all p.

We further assume that $S(\mu) - F(\mu) = (\text{Log}(\mu))/s$ with $s > 0$. In the first-best analysis, there is no need to separate $S(\mu)$ from $F(\mu)$: the only thing that matters is the net (of fixed costs) social benefit of the USO. It is only in the second-best analysis (when the postal firm has to break even) that we need to distinguish the two.

Finally, the numerical results that we now report are based on the following values of the parameters: $c = 0.2$, $\alpha = 3/4$, $e = 0.2$, $\beta = 1/4$, $a_1 = 5$, $a_2 = 4.9$, $b = 1$, $s = 5$ and $k = 0.2$.

The first-best allocation is given by $x_1 = 4.702$, $x_2 = 4.527$ and $\mu = 0.858$. Observe that we obtain an interior value of μ at the first-best, so that the $D + 1$ good is sent to all recipients located at a distance at most equal to 0.858, while the recipients located further away from the representative sender are sent $D + 2$ mail. Because of our assumption of a uniform distribution of recipients, we also obtain that 85.8% of recipients receive $D + 1$ mail while the remaining 14.2% receive $D + 2$ mail. The quantity of mail sent per addressee is slightly larger for $D + 1$ than for $D + 2$ mail. As a consequence, the share of $D + 1$ mail in the total mail market is, at 86.3%, larger than the share of people who receive $D + 1$ mail in the population.

We can contrast this allocation with the optimal allocation when the planner does not take the environmental costs into account: $x_1 = 4.667$, $\mu = 1$ and thus $x_2 = 0$. In that case, we have a corner solution where the entire country is served with the $D+1$ mail. Observe that the quantity of (D+1) mail sent is lower than in the first-best allocation where the environmental concerns are taken into account.

The first-best allocation ($x_1 = 4.702$, $x_2 = 4.527$, $\mu = 0.858$) can be decentralized with the following prices (given by equations (9) and (10)):

$$\begin{aligned} p_1 &= k + \overline{T}'_1 + \overline{\varphi}'_1 = 0.2 + 0.049 + 0.049 = 0.298, \\ p_2 &= k + \overline{T}'_2 + \overline{\varphi}'_2 = 0.2 + 0.13 + 0.043 = 0.373. \end{aligned}$$

Interestingly, we have that $p_2 > p_1$ because the transport costs are much larger for good 2, which is sent to the customers who reside far away from the representative sender. The marginal environmental cost of good 1 is larger than for good 2, but the difference is smaller than the difference in marginal transport costs.

We now impose a uniform pricing constraint, so that $p_1 = p_2 = p$. In that case, the optimal allocation is $\mu = 0.859$, $x_1 = 4.691$, $x_2 = 4.591$ which is obtained with the uniform price $p = 0.309$. As explained above, the optimal uniform price is a linear combination of the optimal differentiated prices identified above. As a consequence, there is more $D+2$ mail sent *per addressee* than with the optimal differentiated prices (since $D+2$ mail was more expensive with these prices), and less $D+1$ mail per addressee. As in the optimal differentiated prices case, there is more $D+1$ mail per addressee in zone A_1 than $D+2$ mail per addressee in zone A_2. Interestingly, the $D+1$ area is very slightly larger at 0.859 than with optimal differentiated prices. The total mail market volume increases slightly compared to the optimal differentiated prices case, while the share of $D+1$ mail decreases at 86.1%.

We now move to the second-best approach. The differentiated prices that decentralize the first-best allocation ($p_1 = 0.298, p_2 = 0.373$) give a profit before fixed cost $F(\mu)$ of 0.226. If the fixed cost at the optimal value of μ, $F(0.858)$, is smaller than 0.226, these prices are also the second-best (Ramsey) optimal prices. To determine whether first-best prices are also second-best prices, we then need to disentangle $S(\mu)$ from $F(\mu)$.

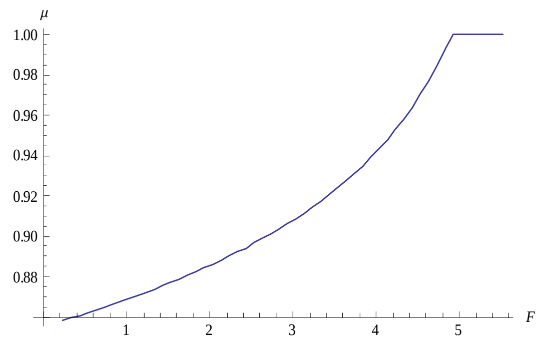

Figure 2: Second-best optimal value of μ as a function F with differentiated prices.

We now assume that $S(\mu) = (\text{Log}(\mu))/s$ but that $F(\mu) = F$ —i.e., that it is a constant. This constant F does not change the results reported above. As long as $F < 0.226$, the first-best prices are also second-best optimal. We now study what happens when F is increased above this threshold. Figure 2 reports the second-best optimal value of μ as a function of F, while Figure 3 reports the second-best optimal value of p_1 and p_2, and Figure 4 that of x_1 and x_2, as a function of F. As F increases, the operator has to increase both its prices in order to recoup its fixed cost. We also have that the welfare-maximizing operator increases the size of the $D+1$ market as F increases. We obtain that $p_2 > p_1$ and that $x_1 > x_2$ as long as $\mu < 1$. As F increases above 4.9, all the market is devoted to $D+1$ mail ($\mu = 1$). The maximum level of F that can be covered is equal to 5.601 and corresponds to the (profit-maximizing) price $p_1 = 2.63$ and to $\mu = 1$: profit is maximized when all the market is devoted to $D+1$ mail.

We have done the same exercise for the second-best uniform optimal price. The uniform price that decentralizes the first-best allocation ($p = 0.309$) gives a profit before fixed cost of 0.227. If the fixed cost F is smaller than 0.227, these prices are also the second-best (Ramsey) optimal prices. If $F > 0.227$, the break-even constraint is binding and the second-best uniform price is larger than 0.309. The results we obtain with the optimal uniform price are similar to those reported in Figures 2 to 4: as F increases, the uniform price p increases together with the size of the $D+1$ market, μ. For a large

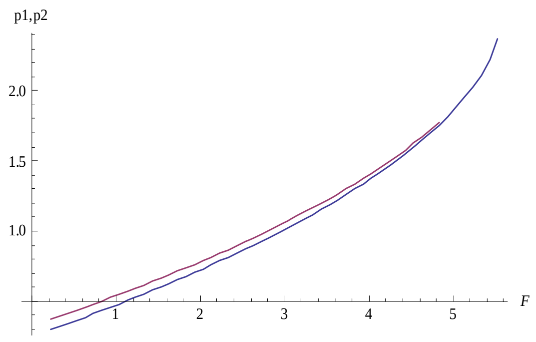

Figure 3: Second-best optimal value of p_1 and p_2 as a function F

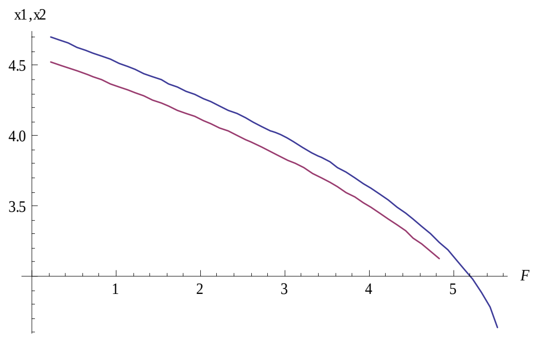

Figure 4: Second-best optimal value of x_1 and x_2 as a function F.

enough value of F, $\mu = 1$ and we are back to the results presented in Figures 2 to 4, since the $D+1$ mail is the only good available in the economy. The profit-maximizing outcome is then the same whether or not a uniform pricing constraint is imposed.

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