Centre de Recherche en Economie Publique et de la Population

CREPP WP No 2011/05

Gradual Network Expansion and Universal Service Obligations

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April 2011

CREPP - Centre de recherche en Economie Publique et de la Population
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CREPP Working Paper Series

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March 21, 2011

Abstract

Universal service obligations are usually not competitively neutral as they modify the way firms compete in the market. In this paper, we consider a continuum of local markets in a dynamic setting with a stochastically growing demand. The incumbent must serve all markets (ubiquity) possibly at a uniform price and an entrant decides on its market coverage before firms compete in prices. Connecting a market involves a sunk cost. We show that the imposition of a uniform price constraint modifies the timing of entry: for low connection cost markets, entry occurs earlier while for high connection cost markets, entry occurs later.
Jel Codes: L11, L50
Keywords: Universal service, uniform pricing, entry, network expansion, postal sector.

1 Introduction

Universal service obligations (USO) have long been imposed in industries like telecommunication, energy or postal services. Universal service obligations are usually defined as the obligation for an operator (or a group of operators) to provide a range of basic services of specified quality to *all* consumers at an *affordable* rate (Cremer *et al.*, 2001). In many instances, a uniform price is imposed as an additional requirement to the service provider.

Universal service obligations and, in particular, the imposition of a uniform price constraint are usually not competitively neutral. The USO modify competition in the market in at least three different ways: (i) the entry behavior of competing firms (Armstrong, 2004), (ii) the price game (Valletti *et al.*, 2002; Gautier and Wauthy, 2010), and (iii) the extent of market coverage by incoming firms (Valletti *et al.*, 2002). We briefly sketch these three points.

The uniform price makes the urban (or low cost) sub-markets artificially profitable and this may attract inefficient competitors i.e. firms that would not be able to challenge the incumbent in the absence of the universal service obligations. Conversely, rural (or high cost) sub-markets are artificially unprofitable and this may deter the entry of efficient competitors. Prices that are not cost-reflective may thus generate inefficient entry.

Concerning the point (ii), suppose that the incumbent firm must offer a service nationwide at the same price while the competitors can compete on part of the territory (usually in the most profitable urban regions). There are *de facto* two types of local sub-markets: those covered by the competitors and those still monopolized by the incumbent, for instance because entry is prohibitively costly. The uniform price creates a strategic link between these two types of markets. For the incumbent, challenging the entrants in the contested markets by decreasing its price has an opportunity cost because the same price discount must be offered to consumers in the sub-markets that the incumbent still monopolizes. This strategic link makes the incumbent softer in the price game. As a result, prices in contested markets are higher under uniform pricing.

(iii) stems from the result of (ii). If they face a less aggressive incumbent, competitors are able to realize higher profits and this should, in principle, stimulate market expansion. But, if the competitors extend their market coverage, they reduce the incumbent's opportunity cost of decreasing its price. Thus larger market coverage by the entrants triggers a more aggressive price behavior by the universal service provider. For this reason, the entrants have strategic reasons to limit their market penetration. Combining the two effects, the market coverage by non-USO firms may be higher or smaller when a uniform price is part of the universal service.

This paper focuses on another potential effect of the uniform price: its impact on the timing of entry by a competing firm. Consider a continuum of local markets in a dynamic setting where demand growth is uncertain. To supply goods or services in any local market, the entrant must pay a sunk connection cost. Local markets differ according to their connection cost. The USO impose that the incumbent must serve all the local markets (ubiquity of the service) but the entrant can progressively expand its network as the number of consumers grows. Connection costs are at least partially sunk. With uncertain demand and partially irreversible investment decisions (connection costs cannot be fully recovered), the firm has the opportunity to wait for new information on the evolution of demand before entering the market. The entrant's problem can be formalized as a real option one (Dixit and Pindyck, 1994). In particular, the problem faced by the entrant is to decide if and when it pays the sunk connection cost to enter any given local market. The entrant's investment behavior is summarized in a threshold function that specifies, for each local market, a demand level at which the entrant connects the local market.

We show that, for low connection cost markets, entry occurs earlier in the uniform pricing regime than in an unconstrained pricing regime, while for high connection cost markets, entry occurs later. That is, the path of gradual network expansion is affected by the uniform pricing with entry occurring earlier in low cost markets and later in high cost markets.

Gradual network expansion is often observed in network industries.[1] In the postal sector, alternative end-to-end operators develop their delivery network gradually (see our section 2 for a detailed description). In the broadband internet market, the most common technology is the ADSL, using the existing copper wires network. The main competing technology uses optic fiber to transmit data at a higher speed. Currently, FTTH networks develop gradually, first in and around the city centers and the main business districts. Lower connection costs in the city centers due to a higher concentration of users explain this gradual deployment of the network. In this paper, we want to go further than that and look at factors such as the rate of demand growth, the uncertainty surrounding demand and the pricing behavior of the incumbent firms to explain the rate of network expansion. We show that these factors, together with the distribution of connection costs, influence the path of network deployment.

2 An illustration: Network expansion in the postal sector

In Europe, postal markets are fully liberalized since the 1^{st} of January 2011. With full market opening, alternative postal operators can freely compete with the incumbent operator for all range of products and operations.[2] In Europe, full market opening means

[1] Our analysis is also applicable to infrastructure expansion in developing countries. See Kessides (2004) for the issues concerning the infrastructure expansion in developing countries.

[2] This is in sharp contrast with the US situation where the competitors of USPS are not allowed to perform final delivery to mailboxes, the so-called last mail delivery. Despite that, competition in the US postal market is intense but concentrated in the upstream segments of the market (collection, transport, sorting).

that rival firms have two options to compete with the incumbent postal operator: they can buy access to the incumbent's delivery network[3] or they can install their own and provide end-to-end services to their clients.

Alternative end-to-end operators already started to compete with historical operators on parts of the European postal market. Those competitors adopt the business model of CityMail, a pioneering Swedish alternative postal operator. They target non-urgent bulk mail pre-sorted by the sender. Collection and sorting costs are therefore limited. Unlike the historical operator that must deliver mail nationwide at least five times a week[4], alternative operators choose to deliver mails at a lower frequency (usually two or three times a week). Moreover, they do not necessarily cover the whole territory. These alternative operators reach the break-even point with a limited market share (5-10%). Table 1 reports the market coverage (in percentage of the addresses) and the market share (in percentage of the total addressed mail market) of five sizable alternative end-to-end operators for the year 2006.

	CityMail Sweden	CityMail Denmark	Sandd The Netherlands	SelektMail The Netherlands	Unipost Spain
Market coverage	40%[a]	40%	100%	100%	70%
Market share	8.6%	n.a.[b]	6%	5%	3.8%

[a] increased to 44% in 2007.

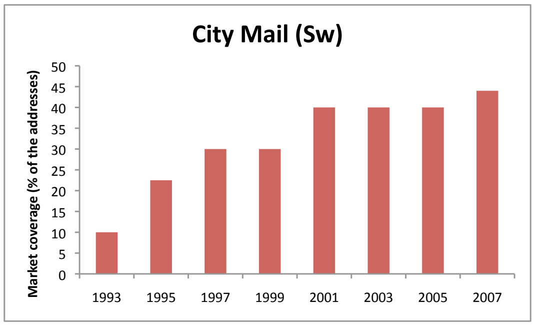
[b] started operations on January, 1^{st}, 2007.

Table 1: Market coverage and market shares, 2006

Interestingly, new postal operators start their operations in the most dense regions and progressively expand their network to less dense areas, eventually ending in nationwide coverage. Gradual network expansion seems to be a striking feature of the development of alternative postal operators. Figure 1 illustrates that. It depicts the evolution of coverage for two major alternative operators, CityMail and Sandd.

[3]As in the US and currently in the UK where competitors do not (yet) deployed a delivery network.

[4]These obligations are part of the universal service obligations. Competitors are not subject to such obligations, though they might be asked to contribute to their financing.



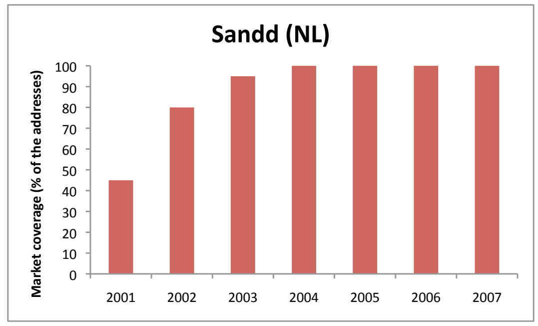


Figure 1: Evolution of market coverage

City Mail started operations in 1993 in the Stockholm metropolitan area. At this time, it covered 10% of the addresses. The firm gradually expanded its network first in and around Stockholm and latter to other densely populated urban centers of Sweden, Gothenburg and Malmö. Its network currently covers 44% of the addresses. In the Netherlands, there are currently two alternative postal firms with nationwide coverage but they operated at lower scale when they entered the market. Sandd for example covered 45% of the addresses when it started to operate in 2001 and it took four years to reach nationwide coverage.

New postal firms target the most profitable customers, the frequent and large senders, and the most profitable products, the (non-urgent) bulk mails that are prepared in numbers and possibly pre-sorted by the sender. This market represents a significant share of the total mailing stream and the mail demand is highly concentrated in the hands of a limited number of large senders.[5] For frequent and large senders, transit time and the operator's reliability are, together with the price, key elements of the mail demand. And, the operator's reliability potentially improves over time with the mail volume handled. Consumers

[5] In a calibration exercise based on French data, Billette de Villemeur *et al.* (2008) consider that roughly one fourth of the total mail demand originates from 500 firms who pre-sort their mail and the largest 5000 firms represent half of the total mail volume.

may therefore switch *progressively* to the new operator once it has proven its reliability.

When an operator faces a growing demand, it has reasons to develop its delivery network gradually.[6] Table 2 illustrates that for Sandd, an alternative Dutch operator who had nationwide coverage since 2004. The number of clients had continuously grown over time (at a double-digit rate). The mailing volume handled has grown too even if the average number of mails per client has decreased. The turnover has followed an evolution parallel to the mailing volume, which means that the growth cannot be fully explained by price rebates. Indeed, the revenue per item remains fairly stable over time. Thus, the increasing number of clients seems to be the main driver of the growth in the mailing volume

	2001	2002	2003	2004	2005	2006	2007	2008
Turnover (million euros)	3	6	14	32	50	68	80	80
Mailing volume (million items)	14	40	68	130	230	320	390	400
Revenue per item (eurocents)	0.21	0.15	0.20	0.24	0.21	0.21	0.20	0.20
Number of clients	25	100	269	400	1000	1500	2000	2200
Coverage (in % of the addresses)	45	80	95	100	100	100	100	100

Table 2: Sandd, key figures 2001-08 (Source: www.sandd.nl)

In the postal sector, competition from alternative postal firms is still at its infancy but the stylized facts we presented suggest that (1) new firms progressively install their delivery network and (2) mail volumes carried by new firms are growing over time. Hence, our model of gradual network expansion with a stochastically growing number of consumers/senders could be applied to competition in the postal sector.

Moreover, we show in our model that the path of network expansion depends, in addition to the cost of the network, on two factors that are currently discussed a lot in the postal sector: the uncertainty surrounding the demand growth and the pricing constraints included in the universal service obligations.

[6] For the entrant, expanding the delivery network involves a substantial amount of sunk cost (network gridding, sorting and storage facilities, ...).

For long time, the mail demand has grown at the same rate as GDP but currently, it is no longer the case. With the development of electronic communications, mail demand has grown at a lower rate and some countries even experience a decrease in the mail volume. Moreover, there are countries where the total mail demand is declining but the direct mail volumes are continuing to rise at a lower rate. E-substitution has modified the drivers of mail demand and its future evolution is currently viewed as highly uncertain, even in the short run. Finally note that a declining global mail volume could be perfectly consistent with an increasing demand faced by the entrant (see table 2).

The universal postal service, as it is defined in the third European postal directive (2008/6/EC), does not include a mandatory uniform tariff. Countries have the freedom to include or not a geographically uniform tariff in their definition of the universal service. Full market opening will put pressures on the financing of the universal service. In particular, the uniform tariff may open the door to *cream-skimming* of the most profitable market segments, treat the viability of the universal service provider and break down the universal service (Crew and Kleindorfer, 2005). Relaxing the universal service constraints and, in particular, allowing the universal service provider to apply non-uniform prices for bulk mails is sometimes advocated as a flanking measure to maintain the universal service in a competitive environment (PricewaterhouseCoopers, 2006; Gautier and Paolini, 2011).

Growing uncertainty on demand and possible changes in the definition of the universal service will have an impact on the development of alternative postal networks and particularly on the rate at which they will be deployed. The model we develop in the next sections illustrates the role of uncertainty and universal service on the gradual extension of alternative postal networks and thereby offers elements to evaluate the future evolution of end-to-end competition in postal markets.

3 The model

We consider a country with a continuum $[0, \bar{x}]$ of independent local markets. Two firms potentially operate at $x \in [0, \bar{x}]$: the incumbent and the entrant, denoted respectively by i and e. Universal service obligations are imposed on firm i. These obligations include the ubiquity of the service meaning that firm i must offer its product or service in all local markets. Eventually, the USO includes a uniform pricing requirement. Universal service constraints are not imposed on firm e who is free to choose the local markets in which it decides to compete in.

To serve market x, firm e must incur a sunk connection cost $g(x)$. Local markets are ordered in such a way that $g'(x) \geq 0$. Except for the connection cost, all the local markets are identical. Thus, firm e enters in priority in the lower cost markets. Let us denote by x_e the last market covered by e. The country divides in two subsets: contested markets $[0, x_e]$ where both firm supply their products and monopolized or insulated markets $[x_e, \bar{x}]$ where firm i is still a monopolist.

Our model is a continuous time model. At each time t, the entrant decides on its market coverage x_e and firms simultaneously name a price. Let us denote by $Y(t)$ the number of consumers in each local market at time t[7]; by $Q_i^d(p_i, p_e)$ and $Q_e^d(p_i, p_e)$ the demand at prices p_i, p_e addressed by each consumer to firm $k = i, e$ in a contested market (superscript 'd') and by $Q^m(p_i^m)$ the demand at price p_i^m addressed to firm i by each consumer in a monopolized market (superscript 'm') . The two firms offer differentiated products and the demand functions have standard properties.

The number of consumers is stochastically increasing over time and we will consider

[7]In our model, the number of consumers $Y(t)$ is treated as an exogenous variable. This treatment is justified by taking the product innovation that would appear in a market in consideration as given, or by the natural rate of population growth.

that $Y(t)$ evolves according to a geometric Brownian motion:

$$dY\,(t) = \alpha Y\,(t)\,dt + \sigma Y\,(t)\,dW \tag{1}$$

where dW is the standard increment of a Wiener process, $\alpha > 0$ is the drift parameter and σ is the variance, our measure of the uncertainty surrounding the demand growth. Since the realization of stochastic variable $Y(t)$ is identical for all local markets in this formulation, it represents a sort of macro shock in this economy.

Firm e can gradually expand its network as the number of consumers increases. Firm e must decide if and when it pays the connection cost $g(x)$ to serve the consumers in the local market x.[8]

The production cost is identical for all local markets and, for analytical simplicity, we assume zero marginal production cost for both firms. To summarize, the profits of the firms at time t are given by:

$$\begin{aligned} \Pi_i(t) &= x_e Y(t)\pi_i(p_i, p_e) + (\bar{x} - x_e)Y(t)\pi_i^m\left(p_i^m\right), &(2)\\ \Pi_e(t) &= x_e Y(t)\pi_e(p_e, p_i), &(3) \end{aligned}$$

where $\pi_i(p_i, p_e) \equiv p_i Q_i^d(p_i, p_e)$, $\pi_i^m\left(p_i^m\right) \equiv p_i^m Q^m(p_i^m)$, and $\pi_e(p_e, p_i) \equiv p_e Q_e^d(p_e, p_i)$, each of which represents firm $k\,(= i, e)$'s profit per consumer in the relevant market.

In addition to the ubiquity requirement, universal service obligations may include constraints on the provider's pricing behavior. In particular, the regulator may regulate the price structure by imposing a uniform pricing constraint.[9] With a uniform pricing constraint (UP), the price charged by the incumbent must be independent of the consumer's

[8] Under the ubiquity requirement, firm i has connected all local markets by incurring a sunk connection cost at the initial period.

[9] If the market is not competitive enough, the regulator may also constraint the price level and requires that the good/service shall be offered at an affordable price to consumers.

location ($p_i = p_i^m$).

There are thus two different pricing regimes for the incumbent: the unconstrained (profit-maximizing) pricing regime and the uniform pricing regime. On the other hand, the entrant is not subject to any price regulation. We analyze the two pricing regimes in turn.

4 Equilibrium in the unconstrained pricing regime

In this section, we derive equilibrium and the threshold function that characterizes the entrant's coverage decision in the unconstrained pricing regime.

4.1 The price game

Firms compete in prices and, at each time t, they name simultaneously a price. Then, the entrant's profit-maximizing price in any covered market $x \in [0, x_e]$ is given by

$$\phi_e(p_i) \equiv \underset{p_e}{\operatorname{argmax}}\; Y(t)\pi_e(p_e, p_i).$$

This best reply function depends on the price p_i charged by firm i on market x but it is independent of both the realization of the stochastic variable $Y(t)$ and the market coverage x_e.

When firm i is not subject to any price regulation, it will apply two prices: the monopoly price p_i^{m*} in the $(\bar{x} - x_e)$ markets that the incumbent still monopolizes and a duopoly price in the x_e contested markets. The monopoly price is the solution of:

$$p_i^{m*} \equiv \underset{p_i^m}{\operatorname{argmax}}\; Y(t)\pi_i^m\left(p_i^m\right).$$

And the incumbent's profit-maximizing price in any covered market $x \in [0, x_e]$ is given by:

$$\phi_i(p_e) \equiv \underset{p_i}{\text{argmax}}\ Y(t)\pi_i(p_i, p_e).$$

Hence, in the contested markets, the equilibrium prices (p_i^*, p_e^*) are represented as the solution of $\{p_i^* = \phi_i(p_e^*), p_e^* = \phi_e(p_i^*)\}$. We should note that all prices are independent of both the realization of the stochastic variable $Y(t)$ and the market coverage x_e.

4.2 Market coverage

Let us examine the entrant's decision on market coverage. To operate in a local market x, firm e must incur a sunk cost $g(x)$. Once it is connected to this market x, it starts to collect a profit $Y(t)\pi_e(p_e^*, p_i^*)$ in this market with a stochastic number of consumers $Y(t)$. The problem of firm e's market coverage can thus be considered as a real option problem (Dixit and Pyndick, 1994). The entrant must choose if and when it incurs the sunk cost and starts offering products at x. The option to delay entry in a given market has a value only if (a) the investment cannot be fully recovered and (b) the firm operates in an uncertain environment. Clearly, these conditions apply in our model.

Furthermore, since local markets are ordered in such a way that $g'(x) \geq 0$ and firm e can gradually expand its network as $Y(t)$ changes, firm e's problem is reduced to determine the last market x_e covered as $Y(t)$ varies. Then, we can define *the equilibrium threshold function* $Y^*(x_e)$ such that once $Y(t)$ reaches $Y^*(x_e)$, firm e enters market x_e at cost $g(x_e)$. In fact, the equilibrium threshold function is firm e's optimal investment rule.[10]

Using the standard procedure of a capacity expansion problem (see Appendix A), the equilibrium threshold function $Y^*(x_e)$ under the unconstrained price regime is defined as

[10] See Pindyck (1988) and Chapter 11 of Dixit and Pindyck (1994) for the definition and derivation of equilibrium threshold function in a gradual or incremental capacity expansion problem.

follows:

$$
\begin{aligned}
Y^*(x_e) &= \frac{\beta}{\beta-1}\frac{r-\alpha}{\pi_e(p_i^*,p_e^*)}g(x_e), &(4)\\
\text{where } \beta &= \frac{1}{2}-\frac{\alpha}{\sigma^2}+\sqrt{\frac{2r}{\sigma^2}+\left(\frac{1}{2}-\frac{\alpha}{\sigma^2}\right)^2}. &(5)
\end{aligned}
$$

The characteristics of the equilibrium in the unconstrained pricing regime are summarized in a proposition.

Proposition 1 *Suppose the incumbent faces only the ubiquity constraint (i.e., it serves all local markets). Under the unconstrained price regime, we have the followings.*

(i) The monopoly price p_i^{m*} *and the duopoly prices* (p_i^*, p_e^*) *are independent of both the realization of the stochastic variable* $Y(t)$ *and the entrant's market coverage* x_e*.*

(ii) As the number of consumers $Y(t)$ *increases, the entrant's market coverage* x_e *increases.*

(iii) As uncertainty increases (i.e., as σ *increases), the entrant's threshold function shifts upward.*

In the above proposition, (i) is obvious. (ii) states that the equilibrium threshold function $Y^*(x_e)$ is monotonically increasing in x_e. This is because the sunk connection cost $g(x)$ is increasing in x. (iii) shows the effect of uncertainty on firm e's market coverage. In a more uncertain environment, firm e waits for a larger number of consumers before entering a local market. Uncertainty thus slows down network expansion by the entrant. The reason is that, in a more uncertain environment, the option value to wait i.e. to delay investment, increases.

5 Equilibrium in the uniform pricing regime

As in the unconstrained pricing regime, we characterize the equilibrium in the price game and the equilibrium threshold function for the uniform price case.

5.1 The price game

In the uniform pricing regime, the same price must prevail in the contested and the monopolized markets. The imposition of a uniform pricing constraint creates a strategic link between otherwise independent markets (Valletti *et al.*, 2002): for the incumbent, decreasing the price to challenge the entrant in the contested markets has an opportunity cost equals to the lost profit (due to the price decrease) in the monopolized markets.[11]

When firm i decides to challenge the entrant in the x_e contested markets, it will do so by charging a price $\phi_i^{UP}(p_e)$ defined as follows:

$$\phi_i^{UP}(p_e) \equiv \underset{p_i}{\operatorname{argmax}}\; x_e Y(t)\pi_i(p_i, p_e) + (\bar{x} - x_e)Y(t)\pi_i^m(p_i).$$

This function is decreasing in x_e meaning that a larger market coverage by the entrant triggers a more aggressive price reaction by the incumbent. On the other hand, firm e's profit-maximizing price in any covered market x is the same as in the unconstrained pricing regime and given by $\phi_e(p_i)$. Thus, the price equilibrium $P^{UP} = (p_i^{UP*}, p_e^{UP*})$ is formally defined as $\{p_i^{UP*} = \phi_i^{UP}(p_e^{UP*}), p_e^{UP*} = \phi_e(p_i^{UP*})\}$.

At this stage, three properties of the 'market sharing' equilibrium worth be mentioned (Valletti *et. al*, 2002). First, for $x_e \in (0, \bar{x})$, we have price bracketing: $p_i^* < p_i^{UP*} < p_i^{m*}$.

[11] Notice that there is an alternative strategy for firm i: It can charge a price close or equal to the monopoly price. In this case, firm i sells little or possibly nothing in the contested markets but it collects the monopoly profit in the insulated markets. However, this cannot be an equilibrium under a uniform pricing regime, as long as the products are sufficiently differentiated (Gautier and Wauthy, 2010). In the remaining of the paper, we will assume that this condition is indeed satisfied and that firm i challenges the entrant in the whole set of contested markets.

That is, as long as the entrant does not cover the whole set of markets, the price charged by firm i lies in between the duopoly price p_i^* and the monopoly price p_i^m that would be applied in the contested and the monopolized markets in the unconstrained pricing regime. Second, firm i's optimal uniform price is decreasing in x_e: $dp_i^{UP*}/dx_e < 0$. When the number of contested markets increases, firm i becomes relatively more aggressive i.e. its best reply correspondence shifts downward when the entrant's market coverage expands. Third, because of strategic complementarity, firm e's price is also decreasing in x_e: $dp_e^{UP*}/dx_e < 0$ but it remains above the price p_e^* as long as the entrant does not have full coverage.

As a final remark in our discussion of the price game, we mention the following properties on firm e's equilibrium profit per consumer under the uniform pricing regime, $\pi_e(p_e^{UP*}, p_i^{UP*})$: (i) The uniform price constraint increases its profit per consumer in each covered market $\pi_e(p_e^*, p_i^*) < \pi_e(p_e^{UP*}, p_i^{UP*})$ but (ii) expanding its network decreases the profit per consumer in the uniform pricing regime: $d\pi_e(p_e^{UP*}, p_i^{UP*})/dx_e < 0$ (Valletti *et. al.*, 2002). For notational simplicity, we hereafter denote firm e's profit per consumer at equilibrium prices by $\pi_e^{UP*}(x_e)$.

5.2 Market coverage

The derivation of firm e's threshold function is similar to the previous case and it is represented by

$$Y^{UP*}(x_e) = \frac{\beta}{\beta - 1} \frac{r - \alpha}{[\pi_e^{UP*}(x_e) + x_e\, d\pi_e^{UP*}/dx_e]} g(x_e), \tag{6}$$

with β given by (5). As in the unconstrained pricing regime, we summarize some of the properties of the equilibrium in a proposition.

Proposition 2 *Suppose the incumbent faces not only the ubiquity constraint but also the uniform price constraint. Then, we have the followings.*

(i) When $x_e \in (0, \bar{x})$, equilibrium prices are higher in the contested markets: $p_k^* < p_k^{UP*}$, $k = i, e$ and lower in the monopolized markets: $p_i^{UP*} < p_i^{m*}$

(ii) Although the prices (p_i^{UP*}, p_e^{UP*}) are independent of the realization of the stochastic variable $Y(t)$, they decrease as the entrant's coverage x_e expands.

(iii) As the number of consumers $Y(t)$ increases, the entrant's market coverage x_e expands.

(iv) As uncertainty increases (i.e., as σ increases), the entrant's threshold function shifts upward.

The properties of (i) and a part of (ii) are already found in Valletti *et. al.* (2002). (iii) and (iv) are the same qualitative characteristics as in the unconstrained pricing regime. Firm e has an incentive to expand its network as the number of consumers increases. However, the degree of network expansion can be different in the two pricing regimes. We examine this point in the next section.

6 Comparisons

As mentioned, the entrant's network expands as the number of consumers increases in the two pricing regimes i.e., the threshold functions $Y^*(x_e)$ and $Y^{UP*}(x_e)$ are both increasing in x_e. The following proposition compares the two threshold functions.

Proposition 3 *Suppose $\Psi(x_e) \equiv \pi_e^{UP*}(x_e) + x_e\, d\pi_e^{UP*}/dx_e$ is a decreasing function of x_e. Then, there exists a critical value $\widehat{Y}$ such that $x_e^{UP*} \geq (<)\, x_e^*$ if and only if $Y(t) \leq (>)\, \widehat{Y}$.*

Proof. See Appendix B ■

In Proposition 3, the presumption that $\Psi(x_e) \equiv \pi_e^{UP*}(x_e) + x_e\, d\pi_e^{UP*}/dx_e$ is decreasing in x_e is satisfied in many cases, including the linear demand model of Singh and Vives

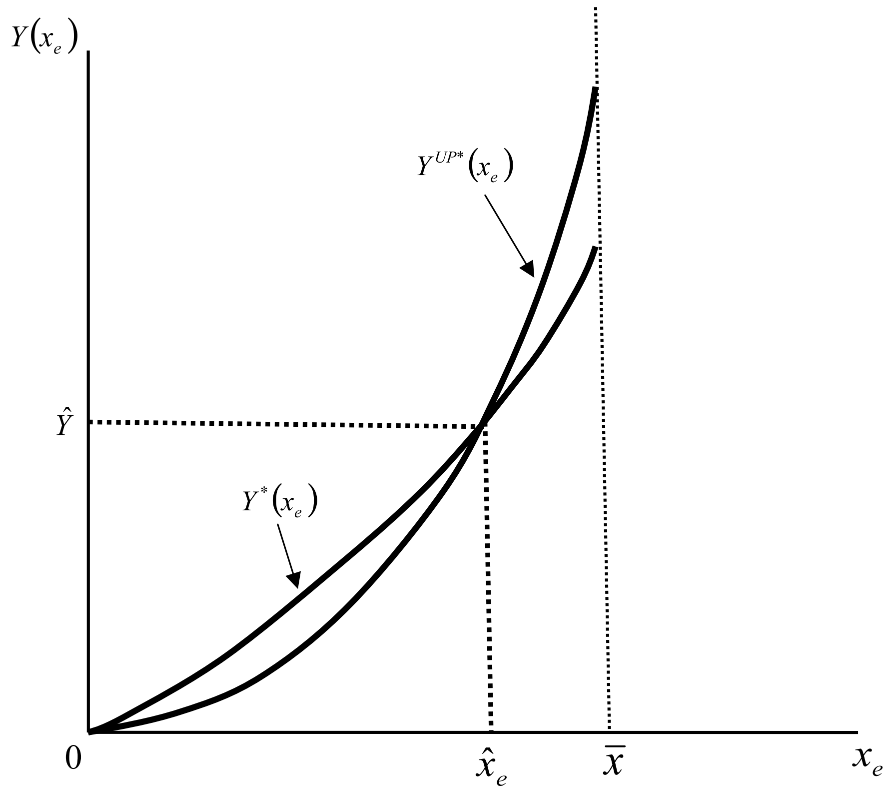


Figure 2: Evolution of market coverage

(1984). According to the proposition, when $Y(t)$ is small (large), the entrant's market coverage under the uniform price regime x_e^{UP*} is larger (smaller) than that under the unconstrained price regime. Or equivalently, for the local markets $x \in [0, \widehat{x}_e]$, entry occurs earlier when a uniform price constraint is imposed while for markets in $[\widehat{x}_e, \bar{x}]$, entry occurs later, with $\widehat{x}_e$ formally defined as $Y^*(\widehat{x}_e) = \widehat{Y} = Y^{UP*}(\widehat{x}_e)$. Figure 2 illustrates that.

We can intuitively explain this result as follows. Uniform pricing leads to higher prices in contested markets and thus higher profits for the entrant. Contemplating the possibility of higher profits, the entrant has incentives to enter local markets earlier. However, as the market coverage increases competition becomes fiercer in the contested markets and the entrant has strategic incentives to delay entry in a new local market.[12]

When market coverage is limited, the higher profit effect dominates the strategic effect and entry occurs earlier under the uniform price regime. But, as the entrant expands its network, the benefit of covering an additional market decreases ($\Psi(x_e)$ is decreasing) and the entrant will slow down its network expansion. At some point ($\widehat{x}_e$), the strategic effect countervails the higher profit effects and the network expansion will be slower under the uniform price regime despite a higher profit in each covered local market. Hence, the uniform price constraint accelerates entry in the local markets with a low connection cost but it slows it down for the high connection cost markets.

Including a geographically uniform tariff in the universal service implies price distortions that reduce overall efficiency. The efficiency cost of the uniform tariff must be balanced against its redistributive benefit and a welfare evaluation must trade-off these two dimensions, efficiency and equity (Cremer *et al.*, 2001). In this paper, we show that, in a dynamic perspective, uniform pricing creates an additional distortion by modifying the timing of entry in local sub-markets, an effect that must be taken into account in any welfare analysis.

In our dynamic framework, each market x will pass through three phases: a *pre-entry period* characterized by the fact that no entry take place at x whatever the price regime, a *transition period* when entry at x occurs under one pricing regime but not under the other and a *post-entry period* when entry occurs whatever the price regime. As in a static context, the imposition of a uniform price leads to higher prices if the market is challenged by the entrant i.e. during the post-entry period and a lower price if it is not i.e. in the pre-entry period. Prices at x during the transition period are either higher or lower depending on

[12] This strategic effect of the uniform price on the coverage decision has been pointed by Valletti *et al.* (2002) in a static context.

the localization of x.

For markets in $[0, \widehat{x}_e]$, the transition period is characterized by entry under the uniform price regime but no entry under the unconstrained regime.[13] For these local markets, prices are lower during the transition period when a uniform price constraint is imposed ($p_k^{UP*} < p_i^{m*}$). The opposite is true for markets in $[\widehat{x}_e, \bar{x}]$. During the transition period, entry occurs only in the unconstrained price regime and prices are thus lower ($p_k^* < p_k^{UP*}$). Table 3 summarizes the impact of the uniform tariff on the prices in the three periods (pre-entry, transition, post-entry). Beyond these qualitative effects, a complete welfare

Market	$(x < \widehat{x}_e)$	$(x > \widehat{x}_e)$
Date of entry	earlier	later
Prices in		
pre-entry	lower	lower
transition	lower	higher
post-entry	higher	higher

Table 3: Impact of the uniform price constraint

comparison should take into account not only the difference in prices and surplus in the three periods but also the (expected) length of these periods. Such an analysis is obviously difficult and beyond the scope of this paper. From our qualitative analysis, it appears that no consumer unambiguously benefits from the imposition of a uniform price constraint.

7 Concluding remarks

In this paper, we have shown that the imposition of a uniform price constraint is not neutral with respect to the timing of entry by a competing firm. In particular, uniform pricing by the incumbent accelerates entry in the urban markets but it delays entry in the rural ones. In this view, whether a uniform price constraint should be maintained in

[13]Formally, this transition period corresponds to realizations of $Y(t) \in [\widehat{Y}^{UP*}, \widehat{Y}^*]$.

the long run in a liberalized market is a debatable question. We show that, when the demand is sufficiently mature, the negative effects of uniform pricing (higher prices in the contested markets, delays in entry) are likely to outweigh the benefits (lower prices in the non-covered markets). Consequently, the uniform price should be only transitory in a liberalized market.

Currently, the development of alternative postal network remains hypothetical in many countries. Postal markets are now fully liberalized in Europe but e-substitution has increased dramatically the uncertainty surrounding the future of the industry. This paper contributes to the debate by highlighting the factors that drive entry and network expansion by alternative postal firms. Importantly, we show that network expansion does not depend only on the local market characteristics[14] but also on the demand uncertainty and the pricing policy adopted by the incumbent universal service provider. Increased uncertainty and greater price flexibility are likely to delay the development of alternative postal networks. If competition develops further, it would be interesting to compare the path of network expansion of alternative postal firms and, in particular, to study the influence of the pricing constraints included in the universal service on the extent and the speed of network deployment.

A Derivation of the threshold functions $Y^{*}(x_e)$ and $Y^{UP*}(x_e)$

Consider first the unconstrained price regime. We follow the procedure of an incremental investment problem (See pp. 357-377 of Dixit and Pindyck, 1994). Let us denote the maximized value function (the Bellman equation) of firm e when its coverage is x_e and the state of demand is Y by $W(x_e, Y)$. Suppose that firm e expands its coverage from x_e to

[14] See d'Alcantara and Gautier (2008) and Gautier and Paolini (2011) for a static analysis of entry in postal markets with different geographical characteristics.

x_e' when the number of consumers changes from Y to $Y+dY$. Then, its expected value is:

$$[Y\int_0^{x_e}\pi_e(p_i^*,p_e^*)dx]dt+e^{-rdt}\left\{E\left[W\left(x_e',Y+dY\right)\right]-\int_{x_e}^{x_e'}g\left(\xi\right)d\xi\right\}. \tag{7}$$

First of all, we need to check whether the Bellman equation is concave in x_e. Consider two (arbitrary) initial coverages x_e^a and x_e^b where $x_e^a<x_e^b$ and suppose the optimal investment policy leads to $\{x_e^a\}$ and $\left\{x_e^b\right\}$ from these initial market coverage, respectively. Then, firm e's net profit flow at $Y\left(t\right)$ (i.e., the profit flow minus the investment cost flow) under the optimal investment path $\{x_e^a\}$ is written by

$$Y\left(t\right)\left[\int_0^{x_e^a}\pi_e(p_i^*,p_e^*)dx\right]dt-\left[\int_0^{x_e^a}g\left(\xi\right)d\xi\right]dt=\left[Y\left(t\right)x_e^a\pi_e(p_i^*,p_e^*)-G\left(x_e^a\right)\right]dt,$$

where $G\left(x_e^a\right)\equiv\int_0^{x_e^a}g\left(\xi\right)d\xi$. Similarly, the net profit flow at $Y\left(t\right)$ under the optimal investment path $\left\{x_e^b\right\}$ is written by

$$Y\left(t\right)\left[\int_0^{x_e^b}\pi_e(p_i^*,p_e^*)dx\right]-\left[\int_0^{x_e^b}g\left(\xi\right)d\xi\right]dt=\left[Y\left(t\right)x_e^b\pi_e(p_i^*,p_e^*)-G\left(x_e^b\right)\right]dt.$$

Define $x_e^\theta\equiv\theta x_e^a+\left(1-\theta\right)x_e^b$ where $\theta\in(0,1)$. Here, we notice that $G\left(x_e\right)\equiv\int_0^{x_e}g\left(\xi\right)d\xi$ is convex in x_e, because $g'(x)>0$. In fact, we have

$$\begin{aligned}G\left(x_e^b\right)-G\left(x_e^a\right)-\left(x_e^b-x_e^a\right)G'\left(x_e^a\right) &= \int_{x_e^a}^{x_e^b}g\left(\xi\right)d\xi-\left(x_e^b-x_e^a\right)g\left(x_e^a\right)\\ &> \int_{x_e^a}^{x_e^b}g\left(x_e^a\right)d\xi-\left(x_e^b-x_e^a\right)g\left(x_e^a\right)=0.\end{aligned}$$

Hence, $\theta G\left(x_e^a\right)+(1-\theta) G\left(x_e^b\right)>G\left(x_e^\theta\right)$. Then, we have the following:

$$\begin{aligned}
& \left[Y(t) x_e^\theta \pi_e(p_i^*, p_e^*)-G\left(x_e^\theta\right)\right] dt \\
> \quad & \theta\left[Y(t) x_e^a \pi_e(p_i^*, p_e^*)-G\left(x_e^a\right)\right] dt+(1-\theta)\left[Y(t) x_e^b \pi_e(p_i^*, p_e^*)-G\left(x_e^b\right)\right] dt .
\end{aligned}$$

Discounting, and taking the expectation, we have

$$W\left(x_e^\theta, Y\right)>\theta W\left(x_e^a, Y\right)+(1-\theta) W\left(x_e^b, Y\right),$$

which states that $W\left(x_e, Y\right)$ is concave in x_e.

Then, the following first-order condition is necessary and sufficient for the maximization with respect to $x_e^{\prime}$ of (7).

$$e^{-r dt}\left\{E\left[W_x\left(x_e^{\prime}, Y+dY\right)\right]-g\left(x_e^{\prime}\right)\right\}=0. \tag{8}$$

As $dt \rightarrow 0$, (8) can be written as

$$W_x\left(x_e^{\prime}, Y\right)=g\left(x_e^{\prime}\right), \tag{9}$$

which is exactly the threshold function. In the following, we characterize it by developing the standard argument.

Consider the region in which firm e does not change its behavior (i.e., no incremental investment). That is, $x_e^{\prime}=x_e$. Substituting $x_e^{\prime}=x_e$ into (7), we have

$$W\left(x_e, Y\right)=[Y \int_0^{x_e} \pi_e(p_i^*, p_e^*) dx] dt+e^{-r dt}\left\{E\left[W\left(x_e, Y+dY\right)\right]\right\} \tag{10}$$

Using Ito's lemma for the expansion of the right-hand side of (10), we have

$$\begin{aligned} W(x_e, Y) &= W(x_e, Y) \\ &+ \left[Y \int_0^{x_e} \pi_e(p_i^*, p_e^*) dx - rW(x_e, Y) + \alpha Y W_Y(x_e, Y) + \frac{1}{2}\sigma^2 Y^2 W_{YY}(x_e, Y) \right] dt. \end{aligned}$$

Hence, we obtain the following differential equation.

$$\frac{1}{2}\sigma^2 Y^2 W_{YY}(x_e, Y) + \alpha Y W_Y(x_e, Y) - rW(x_e, Y) + Y \int_0^{x_e} \pi_e(p_i^*, p_e^*) dx = 0$$

From the boundary condition at $Y = 0$, its general solution is represented by

$$W(x_e, Y) = B(x_e) Y^\beta + \frac{Y \int_0^{x_e} \pi_e(p_i^*, p_e^*) dx}{r - \alpha}, \tag{11}$$

where

$$\beta = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\frac{2r}{\sigma^2} + \left(\frac{1}{2} - \frac{\alpha}{\sigma^2} \right)^2}.$$

Notice that the constant of integration B in (11) depends on x_e: $B(x_e)$. Then $B(x_e)$ and the threshold value Y are simultaneously determined by the following value-matching and smooth-pasting conditions:

$$B'(x_e) Y^\beta + \frac{Y}{r - \alpha} \pi_e(p_i^*, p_e^*) = g(x_e). \tag{12}$$

$$W_{xY}(x_e, Y) = B'(x_e) \beta Y^{\beta - 1} + \frac{1}{r - \alpha} \pi_e(p_i^*, p_e^*) = 0 \tag{13}$$

Hence, from (12) and (13), we obtain the threshold function $Y^*(x_e)$ and the associated constant term $B(x_e)$.

$$Y^*(x_e) = \frac{\beta}{\beta - 1} \frac{r - \alpha}{\pi_e(p_i^*, p_e^*)} g(x_e), \tag{14}$$

$$\begin{aligned} B(x_e) &= \int_{x_e}^{\infty} \left[-B'(y)\right] dy \\ &= \frac{\pi_e(p_i^*, p_e^*)}{\beta - 1} \left(\frac{\beta - 1}{\beta(r-\alpha)}\right)^{\beta} \int_{x_e}^{\infty} \left[\left(\frac{\pi_e(p_i^*, p_e^*)}{g(y)}\right)^{\beta-1}\right] dy \end{aligned} \tag{15}$$

The procedure to derive the threshold function $Y^{UP*}(x_e)$ is exactly the same, except the change in firm e's profit flow from $\pi_e(p_i^*, p_e^*)$ to $\pi_e^{UP*}(x_e)$. The concavity of $x_e\pi_e^{UP*}(x_e)$ in x_e is sufficient for the concavity of the Bellman equation. Notice that the concavity of $x_e\pi_e^{UP*}(x_e)$ in x_e is equivalent to the supposition of Proposition 3 (i.e., $\Psi(x_e) \equiv \pi_e^{UP*}(x_e) + x_e\, d\pi_e^{UP*}/dx_e$ is decreasing in x_e).

B Proof of proposition 3

First of all, we can ensure that $\pi_e^{UP*}(x_e)$ is monotonically decreasing in x_e. In fact, by the envelope theorem, we have

$$\frac{d\pi_e^{UP*}}{dx_e} = \frac{\partial \pi_e^{UP*}}{\partial p_i^{UP*}} \frac{\partial p_i^{UP*}}{\partial x_e} = p_e^{UP*} \frac{\partial Q_e^d(p_i, p_e)}{\partial p_i} \frac{\partial p_i^{UP*}}{\partial x_e} < 0,$$

because goods are demand substitute and the equilibrium prices (p_i^{UP*}, p_e^{UP*}) are decreasing in x_e. Hence we have $\pi_e^{UP*}(x_e) \geq \pi_e(p_i^*, p_e^*)$ for any $x_e \in [0, \overline{x}]$. (The equality holds at $x_e = \overline{x}$.)

Next, consider $\Psi(x_e)$. Evaluating it at $x_e = 0$, we have $\Psi(0) > \pi_e(p_i^*, p_e^*)$. Similarly, evaluating it at $x_e = \overline{x}$, we have $\Psi(\overline{x}) < \pi_e(p_i^*, p_e^*)$ because $\pi_e^{UP*}(\overline{x}) = \pi_e(p_i^*, p_e^*)$. Therefore, as long as $\Psi(x_e)$ is monotonically decreasing in x_e, there exists a threshold $\widehat{x}_e$ such that $\Psi(\widehat{x}_e) = \pi_e(p_i^*, p_e^*)$. Since both $Y^*(x_e)$ and $Y^{UP*}(x_e)$ are monotonically increasing in x_e, we can ensure that there exists a threshold $\widehat{Y}$ such that $Y^*(\widehat{x}_e) = Y^{UP*}(\widehat{x}_e) \equiv \widehat{Y}$.

References

[1] Armstrong, M. (2001). Access Pricing, Bypass and Universal Service, *American Economic Review*, 91(2), 297-301.

[2] Billette de Villemeur, E., Cremer, H., Boldron, F. and B. Roy (2008). Worksharing: A Calibrated Model, *Review of Network Economics*, 7(2), 272-293.

[3] Cremer, H., Gasmi, F., Grimaud, A. and J.-J. Laffont (2001). Universal Service: An Economic Perspective, *Annals of Public and Cooperative Economics*, 72(1), 5-43.

[4] Crew, M. A. and P. R. Kleindorfer (2005). Competition, Universal Service and the Graveyard Spiral, in M. A. Crew and P. R. Kleindorfer (eds.), *Regulatory and Economics Changes in the Postal and Delivery Sector*, Kluwer Academic Press, Boston.

[5] d'Alcantara, G. et A. Gautier (2008). National Postal Strategies after Full Postal Market Opening, in M. A. Crew, and P. R. Kleindorfer (eds.), *Competition and Regulation in the Postal and Delivery Sector*, Edward Elgar, Cheltenham.

[6] Dixit, A. K. and R. S. Pindyck (1994). *Investment under Uncertainty*, Princeton University Press, Princeton, New-Jersey.

[7] Gautier, A. and D. Paolini (2011). Universal Service Financing in Competitive Postal Markets: One Size Does not Fit All, CORE discussion paper 2010/32 and *Review of Network Economics*, forthcoming.

[8] Gautier, A. and X. Wauthy (2010). Price Competition under Universal Service Obligations, *International Journal of Economic Theory*, 6(3), 311-326.

[9] Kessides, I. N. (2004). *Reforming Infrastructure: Privatization, Regulation, and Competition*, World Bank and Oxford University Press, Washington DC.

[10] Pindyck, R. S. (1988). Irreversible Investment, Capacity Choice, and the Value of the Firm, *American Economic Review*, 78(5), 969-985.

[11] PricewaterhouseCoopers (2006). The Impact on the Universal Service of the Full Market Accomplishment of the Postal Internal Market in 2009, Final report to the European Commission.

[12] Singh, N. and X. Vives (1984). Price and Quantity Competition in a Differentiated Duopoly, *RAND Journal of Economics*, 15(4), 546554.

[13] Valletti, T., Hoernig, S. and P. Barros (2002). Universal Service and Entry: The Role of Uniform Pricing and Coverage Constraints, *Journal of Regulatory Economics*, 21(2), 169-190.