The Economics of Information Networks, edited by C. Antonelli 129

Network Consumption Externalities

The Case of Portuguese Telex Service

Luís M.B. Cabral and António P.N. Leite
Faculdade de Economia, Universidade Nova de Lisboa, Travessa Estêvão Pinto, 1000 Lisboa, Portugal

1. Introduction

The issue of externalities in telecommunications networks springs from the widely held notion that each agent joining a telecommunications network thereby confers benefits onto other subscribers. Indeed, this is a classic case of externalities in consumption and has crucial implications for telecommunications pricing. There is a long series of articles dealing with consumption externalities in telecommunications, including Squire (1973), Rohlfs (1974), Littlechild (1975), Artle and Averous (1975), and Oren and Smith (1981).

Without going into the details of these models, their main assumptions and results can easily be stated. To do so, suppose that the demand for calls of a particular subscriber depends on her income, the unit price of a call, and the total number of subscribers. Suppose also that the company supplying the communications service wishes to maximize some appropriate measure of the system's total surplus. In the absence of any binding financial constraints and assuming that the price of each call is set equal to its marginal cost, the optimal policy requires that the number of subscribers be increased to the point where the marginal cost of accommodating a new subscriber equals the marginal value which she receives plus the change in consumer surplus which her entry generates for all already existing subscribers. To attain this optimal number of subscribers, the access fee should be set below marginal customer cost by an amount equal to the external benefit received by other users. This external benefit essentially comprises the increase in surplus to already existing subscribers arising from their calls to the new subscriber.

Despite some significant theoretical developments, very little is known about the actual extent of network externalities. The purpose of this paper is to attempt a measurement of externality effects in the Portuguese telex system. After having motivated our analysis with a simple theoretical model of telecommunications demand, we estimate two reduced-form equations, explaining usage of and access to the telex network. Our results for both equations suggest that there are significant network externalities. For sample average values, a 10% increase in the size of the network implies a 1.6% increase in average consumption, a 0.7% short-run increase in the equilibrium number of subscribers, and a 15.9% long-run increase in the equilibrium number of subscribers.

We also explore the implications of our results in terms of optimal pricing policy. Based on some reasonable assumptions which are discussed below, we find that the optimal access fee should be set between 2.5 and 16 percent below marginal cost in order to account for network externalities in consumption for use.

Regarding network externalities in access demand, we find even stronger results and implications. The relatively high elasticity of demand for access with respect to network size suggests that the fast rate of diffusion of telex terminals in the late seventies/early eighties might have corresponded to a catastrophe point in the equilibrium diffusion process. If this were the case, then it might have been optimal to subsidize early adoption of the new technology such that a critical mass of adopters was reached and convergence to the "good" equilibrium assured. We estimate the critical mass to have been about 20% of the number of adopters by 1987.

2. The Model

The basic model to be used throughout the paper is similar to that of Littlechild (1975). Demand for use by each consumer is given by a function c(θ, U, N), where θ is a taste parameter specific to each consumer, U is the usage price, and N the total number of users connected to the network. Corresponding to this demand function is a consumer surplus function s(θ, U, N). The idea of network externalities is that both s(θ, U, N) and c(θ, U, N) are increasing with N, the number of subscribers.

Suppose that access charges are A, and that the benefit from being connected to the network, regardless of usage, is K(N). This is what Taylor (1980) refers to as the value of "option demand". Notice that we allow for the possibility of this value to depend on the total number of users as well.

The decision of being connected to the network depends on whether s(θ, U, N) + K(N) is greater or smaller than A. An indifferent user is characterized by a taste parameter θ′ such that

$$s(\theta', U, N) + K(N) = A. \tag{1}$$

By convention, s(θ, U, N) is an increasing function of θ. Therefore, the equilibrium number of subscribers is given by

$$N = \bar{N} \int_{\theta'}^{\infty} f(\theta)\, d\theta, \tag{2}$$

where $\bar{N}$, is the potential number of users. Total consumption, in turn, is given by

$$C = \int_{\theta'}^{\infty} c(\theta,\ U,\ N)\ f(\theta)\, d\theta. \tag{3}$$

Our econometric estimates will be based on two single-equation models: the consumption equation, and the access equation. The consumption equation has the general form

$$\frac{C_1}{N_1} = \phi\,(U_t,\ N_t,\ N_{t-1}). \tag{4}$$

Notice that we assume N_{t-1} is an argument in $\phi(.)$ in addition to N_t. We believe this to be a realistic assumption since the publicized number of subscribers at the time access decisions are made is more likely to be N_{t-1} than N_t. A user joining the network during period t will not be listed as such until period t + 1. As a result, network externalities should be explained by N_{t-1} and the effect of N_{t-1} on per-terminal consumption should be positive. The effect of U_t on average consumption should be unambiguously negative. Finally, we should expect the effect of N_t to be negative since marginal users joining the network will typically have below average consumption.

The access equation is based on the following equation for the equilibrium number of subscribers:

$$N_t = \phi(A_t,\ U_t,\ N_{t-1}). \tag{5}$$

In practice, this equilibrium number of subscribers is not attained instantly, due to inertia in demand and/or supply behaviour. One way of capturing this temporary disequilibrium is to model N_t as a partial adjustment process. Suppose that N_t^* is the equilibrium value of N at time t (given by equation (5)). We then assume the actual value of N_t results from the partial adjustment

$$N_t - N_{t-1} = \gamma(N_{t*} \quad N_{t-1}),\ (0 < \gamma < 1) \tag{6}$$

or

$$N_1 = (1 - \gamma)\, N_{t-1} + \gamma\, \phi\,(A_t,\ U_t,\ N_{t-1}). \tag{7}$$

We expect both A_t and U_t to have a negative effect on N_t. On the other hand, N_{t-1} has a two-way positive effect on N_t. The first one results from the partial adjustment term $(1-\gamma)N_{t-1}$, where γ is between zero and one. The second effect is the above mentioned network externality effect.

3. Data and Estimation Procedures

Our estimations are based on a 27-observation sample of annual data ranging from 1962 to 1987. We should mention that more recent data is available. However, we decided not to include it since we believe there were significant structural changes in 1988 due to the introduction of fax machines.

The data consists of the following variables.

A: Access fee. There is a one time access fee and a monthly access fee. We constructed our variable as the annualized sum of these two components: 10% times the one time fee plus twelve times the monthly fee. (This of course is open to criticism since we assumed a particular value for the implicit discount factor. The results turn out not to depend greatly on this assumption.)

U: Usage fee. Cost of one minute of telex use, annual average. Both A and U are in real terms. The GNP deflator (at factor prices) was used as price index.

N: Number of users. Number of installed telex machines by the end of the period.

W: "Waiting list". Number of potential users willing to enter the system but not yet accommodated.

D ≡ N+W. Effective demand for access.

C: Domestic consumption for use. Thousands of minutes of telex use when both ends of the communication link are domestic users.

c = C/N: Average consumption, more specifically, per terminal consumption.

The functional forms of the equations to be estimated are

$$= \alpha_0 + \alpha_1 U_1 + \alpha_2 N_1 + \alpha_3 \ln N_t + \varepsilon_t \tag{8}$$

for the consumption equation, and

$$D_t = \beta_0 + \beta_1 A + \beta_2 D_{t-} + \beta_3 \ln N_{t-} + \mu_t \tag{9}$$

for the access equation.

A few explanatory notes are in order. First, the substitution of D for N in equation (9) is justified by the fact D is a better measure of actual demand than N. Therefore, the partial adjustment in (9) only reflects inertia in demand; supply constraints are taken care of by considering effective demand as a dependent variable. Second, we should note that the variable usage fee, U_t was excluded from the access equation as it had little explanatory value. Finally, we decided to consider domestic consumption for use instead of total consumption for use because we believe the former is the one most likely to be affected by a change in the number of domestic users.

The particular functional forms chosen were motivated by simplicity and our expectations about the nature of network externalities. We expect the externality to die out as the number of users increases (saturation effect). This justifies the use of the transformed variable ln N_{t-1}.

These equations were first estimated using ordinary least squares. We detected the presence of autocorrelated errors in the consumption equation, and corrected for this by using the Cochrane-Orcutt procedure. The results did not change significantly when we tried maximization of the likelihood function instead of minimization of the sum of squares, or when we used grid search methods instead of iterated ones.

We also detected the presence of autocorrelated errors in the access equation (the Durbin t-statistic is significantly different from zero), and corrected for this using the Cochrane-Orcutt procedure. Following Fair (1970), we included all lagged dependent and independent variables as instruments for D_{t-1} in order to obtain consistent estimates of the regression parameters. (GNP at constant 1977 prices was also included as an instrument.)

4. Results and Discussion

The results of the estimation of the average consumption equation are shown in Table 1.

Table 1
Estimation results for the consumption equation

Var	Coef.	St. dev.	t-ratio
Const	-4.1742	0.7172	-5.8203
U_t	-0.0433	0.0628	-0.6899
N_t	-5.7E-05	1.1E-05	-5.0768
$\ln N_{t-1}$	0.8261	0.0794	10.4040

The overall fit of the equation is good: $R^2 = 0.9521$. The estimated value of ρ is 0.3561, with a standard error of 0.1907. The coefficient of the price variable is not statistically significant, but the coefficients of both N_t and $\ln N_{t-1}$ are. Furthermore, the signs of these coefficients do correspond to our expectations: a positive network externality effect and a negative "marginal user" effect.

The value of α_3, the network size coefficient, is also "economically" significant. One way of seeing that, is to determine the value of the elasticity of average consumption with respect to N_{t-1}. Since we do not have a log-log functional form, this will depend on the particular value of c_t. The elasticity values for the minimum, maximum and mean values of c_t are 0.2645, 0.1186, and 0.1568, respectively. That is, a 10% increase in the network size implies a 1.6% increase in average consumption, on average, the value being greater for lower values of c_t.

Another way of interpreting these results is to determine the value for existing users of connecting an additional user to the network. Since we do not know the exact functional form of each consumer's demand function, we will have to make some assumptions about the relation between the values of consumption and consumer's surplus. One of such assumptions is that, for each price, consumer's surplus is a fixed proportion of consumption value. This will be the case if demand has the form

$$c = (a + b\ U)g(N). \tag{10}$$

We present our results contingent on the value of ξ, the ratio of consumer surplus to consumption value. The value of the externality of an additional user is then given by $(\partial c/\partial N)\xi\ U\ N = \beta_3\ \xi\ U$. For example, if ξ equals 0.5, then there is an externality of 1,391 1977 Portuguese escudos. In order to get a better feel for the relative magnitude of these results, Table 2 presents the values of the externality gain as a percentage of the sample average access charge.

Tentative as they may be, these results have important consequences regarding optimal pricing in the presence of network externalities. As Littlechild (1975) has shown, the optimal policy requires the access fee to be set equal to marginal cost minus the increase in surplus to existing subscribers generated by an additional subscriber. Suppose that the actual values of A_t were set approximately equal to marginal cost of access. Then, the results of Table 2 indicate the optimal reduction of access fees, i.e., the one which takes into account the externality effect on existing users.

Finally, we turn to the estimation results of the access equation. These are shown in Table 3. The overall fit is excellent, as the $R^2 = 0.9947$ statistic indicates. All coefficients are statistically significant (5% significance level) and have the expected signs. We should note, however, that the coefficient on D_{t-1} is greater than one (though we cannot reject the hypothesis that it is not). This seems inconsistent with our assumption that the partial adjustment factor, γ, lies between zero and one. We believe this is justified by the fact that β_2 includes some externality effect together with the partial adjustment effect. Independently of that, the value of β_3 suggests that there are important externality effects. Specifically, the partial (short-run) elasticity of D_t with respect to N_{t-1} based on the coefficient β_3 is equal to 1.544, 0.022, and 0.084, respectively for the minimum, maximum, and average values of D_t.

Since the estimated β_2 coefficient is greater than one, we are unable to compute long-run elasticities from these results. In order to incorporate the a priori information that β_2 must be less than one, we performed several regressions assuming different values for β_2. As it turns out, the value of $\beta_3/(1 - \beta_2)$, the one which is relevant for the purpose of computing long-run elasticities, does not change substantially for values of β_2 lower than 0.7, as can be seen from Table 4.

Based on the value of $\beta_3/(1 - \beta_2)$, we can compute the long-run 'network' elasticity ε, which is given by $\varepsilon = \beta_3/(1 - \beta_2)/D$. The elasticity value is decreasing in D, and since D is increasing in time, the elasticity is itself decreasing

Table 2
Consumption externality gain as a function of ξ
($\eta \equiv$ externality gain/A)

ξ	η (%)
0.25	2.63
1.00	10.52
1.50	15.79

Table 3
Estimation results for the access equation

Var	Coef.	St. dev.	t-ratio
Const	-2403.4	1997.4	-1.2032
A_t	-0.0434	0.0112	-3.8639
D_{t-1}	1.0658	0.0486	21.9240
$\ln N_{t-1}$	526.67	292.38	1.8013

in time. Table 5 shows the value of ε for some of the sample years assuming that $\beta_3/(1 - \beta_2) = 10{,}000$ (which seems consistent with values in Table 4).

Table 4
Estimated value of $\beta_3/(1-\beta_2)$ as a function of β_2

β_2	$\beta_3/(1-\beta_2)$
0.9	17,790
0.8	13,184
0.7	11,672
0.6	10,889
0.5	10,256
0.4	9,932
0.3	9,695
0.2	9,517
0.1	9,375

Table 5
Long-run 'network' elasticity (e) for some sample years

Year	e
1962	20.83
1980	1.06
1981	0.85
1987	0.39

5. Multiple Equilibria and Discontinuous Paths

Figure 1 plots the values of D corresponding to our 1962-1987 sample. The data shows a very high rate of diffusion of telex terminals during the late seventies/early eighties. We believe this strongly suggests the possibility of a discontinuous change in the equilibrium network size (a "catastrophe") occurring about 1977. In a recent paper (Cabral, 1990), it has been shown that, in the presence of network externalities, a discontinuous equilibrium path D_t is possible even if we consider the primitives of the model, in particular ϕ (.), to be nicely behaved, smooth functions.

Specifically, suppose the relation between D^* ("desired" network size) and N (actual network size) is as shown in Figure 2. For low values of N (but not too low), the elasticity of D^* with respect to N is greater than one. This implies that there are multiple equilibrium values (where $D^* = N$), in this case three values, two of which are stable.

The reason why a system like this might produce a catastrophe is the following. Suppose that we start from the low-N equilibrium and that, due to changes in some exogenous variables (e.g., per capita GNP), the whole curve $\phi(N)$ shifts upwards.

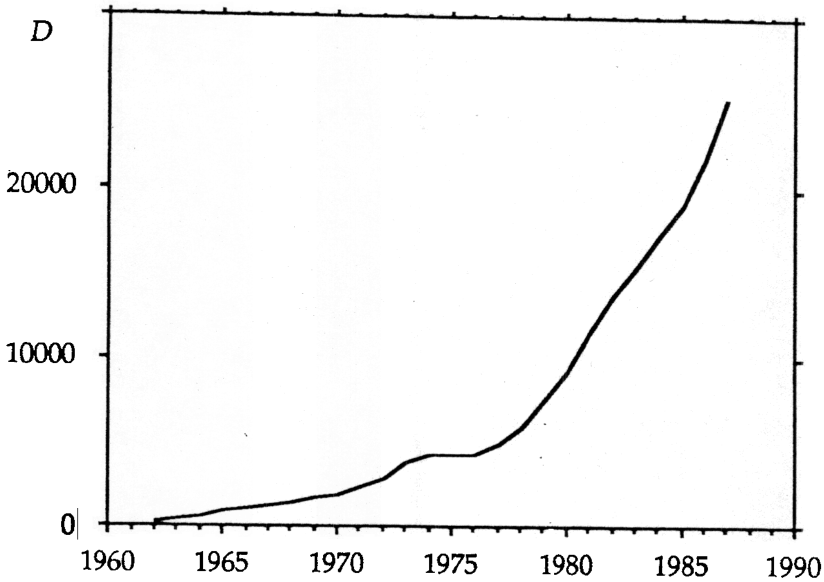

Figure 1. Demand for access to the Portuguese telex network

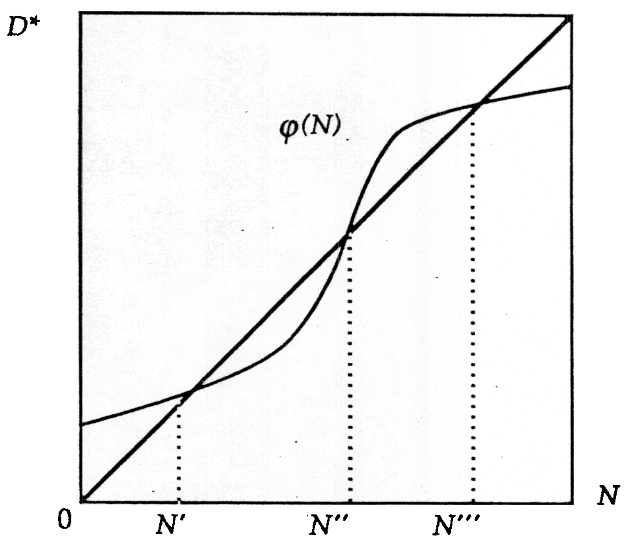

Figure 2. Multiple network size equilibria

It can be seen from Figure 3 that there will be a point beyond which the high-N equilibrium is the only equilibrium, and the system will thus move "catastrophically" towards it. Based on a model similar to this one, Linhart *et al.* (1990) also conclude that "one expects to see a relatively abrupt onset of demand as prices drop" (p. 15).

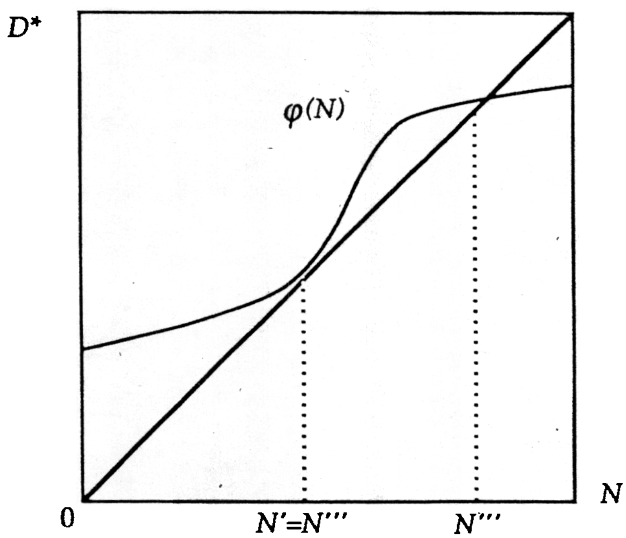

Figure 3. Catastrophe point

In the telecommunications literature, this situation is also known as a critical mass problem (e.g., Rohlfs, 1974; Oren and Smith, 1981). The idea is that if we can get to a sufficiently large value of N, specifically a value which is greater than the critical mass, then the system will converge to the "good" stable equilibrium, with a high number of subscribers. The implications in terms of pricing are that it may be optimal to set access fees lower than the marginal cost of a new product or service in order to attract the critical mass of customers, and then let the system converge to the "good" equilibrium.

Notice that the nature of this pricing policy is very different from that considered in the previous section. In the latter, we considered the possibility of setting access fees lower than marginal cost is order to account for the marginal externality of a new user. That is, we derived the optimal Pigouvian subsidy. In a critical mass situation, however, prices are used as a means of switching from one equilibrium to another one, which is clearly not a marginal calculation.

There are, of course, various competing theories for the sharp increase in network size during the late seventies.

(i) 1974 and 1975 correspond to a period of political and economic instability following the April 1974 revolution. This partly explains the sharp increase in the growth rate of D_t following this period. However, even if we exclude the years 1974 and 1975, there remains a significant shift in the slope of D_t.

(ii) The introduction of new, more sophisticated terminal equipment implies a discontinuous shift in the benefit function, which could account for the sharp increase in demand. However, there are reasons to believe that this occurred mainly in the early eighties, after the beginning of the "bandwagon" process.

(iii) Antonelli (1984) argues that "during the 1970s the growth of international telecommunications caused a worldwide communication infrastructure to be created" (p. 333). In fact, while US exports plus imports increased by a factor six in the period 1970-1981, the number of US outgoing telex messages increased by a factor of nine (cf Antonelli, 1984, Table 1). Based on these results, we can hypothesize that domestic demand for access is mainly derived from the demand for international access. This can happen in two different ways. Benefits for domestic users might be a function of (a) the international network size or (b) the need to communicate with foreign agents. We tested for (a) by adding the explanatory variable "size of international network". This is a weighted average of the network size in the six Countries with highest volume of telex flows from and to Portugal. We found this variable to have no significant impact on the value of D_t. We tested for (b) by using exports plus imports in real terms as a proxy for "need to communicate with foreign agents". This turned out to have a significant effect on the value of D_t.

(iv) There are various theories which explain sharp S-shaped diffusion paths independently of network externalities. See, for example, David (1969) for a theory based on adopters' heterogeneity and Jensen (1982) for a theory based on adopters' uncertainty. In order to compare these theories with ours we would need firm-level data, which we presently have no access to.

We believe the catastrophe hypothesis still holds as a valid one, and that promising further research can be done on this topic. There are three extensions which we plan to follow on our research:

(i) Use more disaggregated data in order to get a better idea of the shape of the benefit function and the distribution of potential adopters.

(ii) Use a two-regime model in order to account for the temporary disequilibrium during the adjustment from the low equilibrium to the high equilibrium.

(iii) Formulate testable hypotheses which compare the catastrophe hypothesis to other competing ones.

6. Conclusion

This paper has been a first attempt at evaluating the extent of network externalities in Portuguese telex service. Our results suggest that network externalities are significant. For average sample values, a 10% increase in network size implies a 1.6% increase in average consumption and an increase in the equilibrium number of subscribers of 0.7% in the short-run and 15.9% in the long-run. These elasticities are greater the lower the values of average consumption or network size are.

Our results have important implications for optimal pricing policy. Assuming that consumer's surplus is between 25 and 150 percent of the value of telex usage, we find that the optimal access fee should be set between 2.5 and 16 percent below marginal cost in order to account for network externalities.

The relatively high elasticity of demand for access with respect to network size suggests that the high rate of diffusion of telex terminals in the late seventies/early eighties might have corresponded to a catastrophe point in the equilibrium adoption process. If this were the case, then it might have been optimal to subsidize early adoption of the new technology such that a critical mass of adopters was reached, and convergence to the "good" equilibrium assured at an early stage.

Acknowledgements

We are grateful to the M. Amélia Melo Foundation for financial support; to Sílvia Luz (CTT and Universidade Nova de Lisboa) and Paulo Melo (Telecom Portugal) for help in gathering data; to Cristiano Antonelli, Paul David, J. António Machado and Max Pinheiro for helpful conversations; and to João Ejarque for able research assistance. Remaining errors and shortcomings are our sole responsibility.

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