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Chapter 10

UNIVERSAL RESIDENTIAL TELEPHONE SERVICE

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1. INTRODUCTION

Universal service is a chameleon-like phrase. It refers generally to widespread access to and affordability of telecommunications services, but it takes on different meanings depending on the time and the place, and the particular policy debate. AT&T president Theodore Vail coined the phrase in 1907 to refer to the company's goal of achieving an integrated centrally-controlled telephone network, but today in the United States and other developed countries the phrase essentially means high household telephone penetration (Mueller 1997). In less developed countries, where telephone penetration is low, the phrase more likely means good access to pay telephones (Hudson 1995). Recent universal service initiatives in the United States subsidize high-speed Internet access for schools, libraries, and health centers (Hausman 1998). And in the blue sky of the future, universal service may come to mean high residential penetration of broadband Internet access.

Since this landscape is too big to cover succinctly, this chapter focuses on the "paradigm problem" of advancing and maintaining universal service for basic residential telephone services in the United States in the late 20th century. The focus seems appropriate, if for no other reason than because this is where academic economic research has concentrated its attention. Moreover, some of the issues addressed by the chapter have wider applicability. For example, there is a "deadweight loss" of economic efficiency from taxing regular telephone service in order to subsidize advanced services (Hausman 1998). The chapter makes some international comparisons, and mentions a few emerging issues, but the reader is forewarned not to expect too much on these fronts.

Universal residential telephone service is an important and complex policy issue because large amounts of consumer welfare and corporate profits are at stake in the design of regulatory policies in the pursuit of universal service (Hausman 1998), and because important noneconomic values, like political democracy and social cohesion, are prominent in the policy debates. This volatile mix of elements makes for highly charged political debates on universal service policies, often with the Federal Communications Commission (FCC) at the center.[2] Economic arguments matter in these debates, even when noneconomic values have great salience, making universal service a worthy policy problem for applied economic analysis. What are the economic determinants of telephone penetration? What are the economic arguments for and against universal service policies? What is the most efficient way to achieve universal service goals? How successful are actual universal policies at increasing telephone penetration? The purpose of this chapter is to assess the current state of economic knowledge about universal service, and to point out needs for further research. The chapter mainly restricts its attention to published economic research which presumably has been vetted by some form of peer review.

Section 254 of the 1996 Telecommunication Act directs the FCC and the states to adopt policies "for the preservation and advancement of universal service..." and defines universal service as "an evolving level of telecommunications services that the Commission shall establish periodically..." So far, the FCC has defined universal service essentially to encompass basic residential telephone services (Federal Communications Commission 2000). The language of the Act suggests that universal basic telephone service has been substantially but perhaps incompletely achieved in the United States. Figure 1 confirms this idea by showing that house-

[2]The FCC has various policies designed to promote universal service: subsidies for schools, libraries and rural health centers; support to carriers serving high cost areas; subsidies for low income consumers. See *http://www.fcc.gov/ccb/universal_service/* .

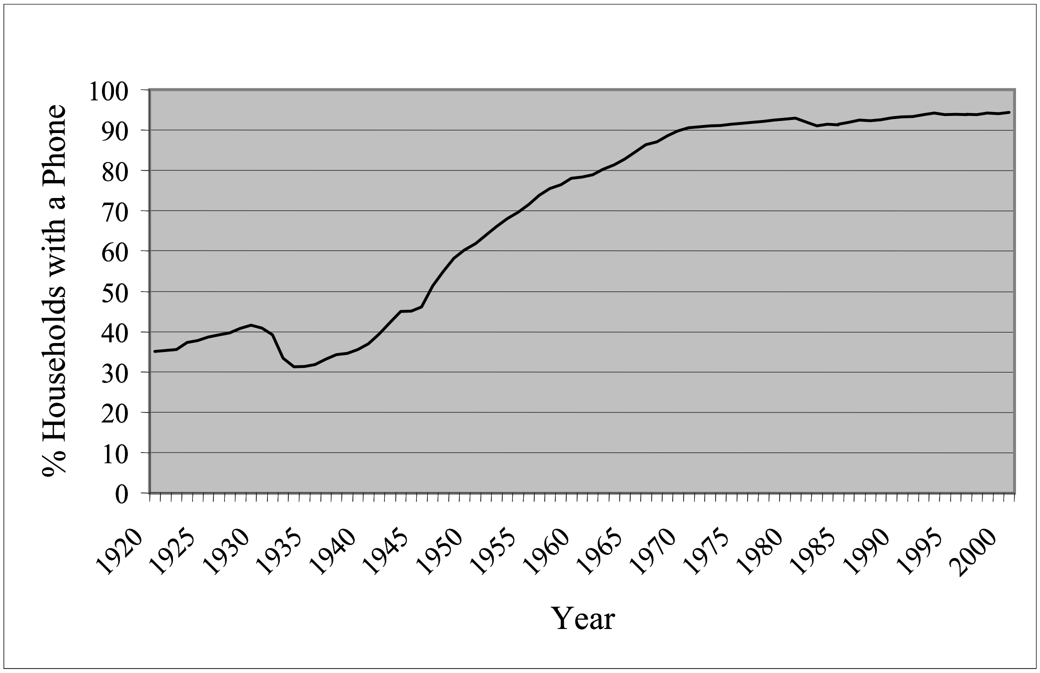

Figure 1: Telephone penetration in the United States, 1920-2000

hold telephone penetration has remained over 90% for more than a quarter century, and today approaches 95%.[3]

Behind this rosy aggregate picture, however, there is considerable regional and local variation. The map in Figure 2 shows that penetration rates varied significantly across the states in 1990, ranging from 87.4% in Mississippi to 97.9% in Maine.[4] The variance is even greater at the county level, where penetration ranges from 40.3% in Apache County, Arizona to 99.5% in Waukesha County, Wisconsin. Mueller and Schement (1996) find large variations in penetration rates among neighborhoods of a single city. At the census block level, penetration varies between zero and one hundred percent.

The United States has one of the highest household telephone penetration rates in the world. Still, some other developed countries enjoy a higher aggregate household penetration rate, e.g. Canada has maintained penetration over 98% through the 1990's. Moreover, while household telephone penetration has remained relatively flat in the U.S. in the 1990s, it has increased significantly elsewhere, e.g. in France, from 94% in 1990 to 98% in 1997 (International Telecommunications Union 1999). Thus, it appears that more could be done to advance universal residential telephone service in the United States. Questions for economists are "How

[3]This chart is constructed from various Census Bureau and FCC data sources, and contains linear approximations for some years to deal with missing and inconsistent data. Details of the construction are available from author upon request. See FCC, "Trends in Telephone Service," March 2000, Wash D.C. for a discussion of subscriber data.

[4]This is based on 1990 census data. See Dyer (1997) on regional variation in penetration rates in the United Kingdom.

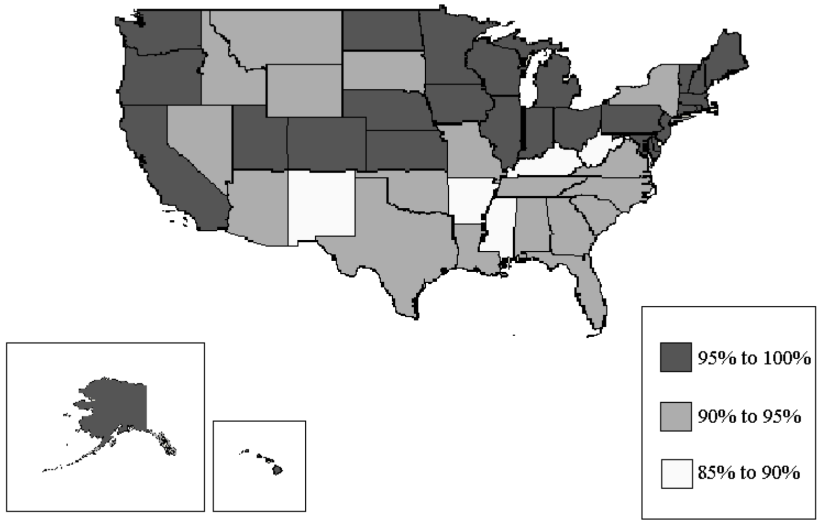

Figure 2: Telephone penetration by state, 1990

and at what cost?" and "Do the benefits outweigh the costs?"

The universal service problem for basic residential services has several dimensions, and the balance of the chapter is organized accordingly. Section II presents empirical evidence on the determinants of telephone penetration rates in the U.S. in 1990. The analysis shows that most of the variation in telephone penetration in the United States is explained by demography and climate. Cost proxies explain a statistically significant but quantitatively small fraction of the variation in penetration, and there is some slight evidence of local network externalities boosting penetration. While there remain significant differences between the states even after controlling for these factors, it appears that superior state regulatory policies can explain at most only a few percentage points of universal service performance. Section 3 reviews the normative economic theory of telecommunications pricing and its implications for universal service. Scale economies and especially network externalities provide theoretical rationales for departures from strict cost-based pricing, even though such departures sacrifice economic efficiency on some margins. Economic theory also demonstrates that optional service plans and low-income and high-cost universal service support potentially are valid methods of price discrimination in the pursuit of universal service goals. Section 4 reviews published empirical evidence on the performance of actual universal service policies. This limited evidence shows that low-income and high-cost subsidy policies are at best only marginally effective at advancing universal service. Section 5 summarizes and draws conclusions.

2. TELEPHONE PENETRATION IN THE UNITED STATES

Although approximately 95% of American households have a telephone, penetration varies significantly from place to place. Figure 2 illustrates different penetration rates in different states. Is this variation due to differences in population characteristics and other factors affecting the demand for telephone service, or differences in costs and regulatory policies affecting the price and availability of service? This section explores this question with a reduced form regression analysis. The purpose of the analysis is to identify and interpret some stylized facts, and to motivate the possibility that differences in state regulatory policies matter for the achievement of universal service goals.

Schement (1995) uses FCC and census data to describe the characteristics of households lacking telephones. The data show that the achievement of universal service varies across population groups. For example, the poor are less likely to have a telephone, as are blacks and Hispanics.[5] This kind of descriptive analysis is suggestive, but could be misleading, and leaves open important questions. For example: Are black households less likely to have a telephone because of different tastes, or because blacks tend to have lower incomes and telephone service is a normal good, or because blacks are discriminated against in the provision of telephone service? Or do blacks tend to live in states with less aggressive policies for promoting universal telephone service? Regression analysis is the appropriate tool for disentangling these effects.

A priori it seems plausible that demography might explain much of the geographic variations in penetration rates. Column (I) in Table 1 reports a regression equation explaining the telephone penetration rates of 1990 census block groups (CBGs) as a function of selected population demographics.[6] The definitions of variables and summary statistics are in an appendix. The numbers in parentheses are t-statistics, with the usual interpretation that a t-statistic above approximately 2.0 indicates statistical significance above a 95% confidence level. At given prices, shifts in the demographic composition of a group of consumers can be expected to shift the community demand for telephone service and change the penetration of service within the community. Nevertheless, the regression must be interpreted cautiously because it does not control for prices. The regression equation can be interpreted as capturing the pure effect of demand shifts on telephone penetration only if demand is price inelastic or if price differences are uncorrelated with population demographics. The results are broadly consistent with demand studies of penetration that do control directly for prices (Crandall and Waverman 2000; Taylor 1994; 2000).

Two things about the regression are striking. First, as expected from Schement's descriptive analysis, poverty is a major predictor of low CBG penetration. An income redistribution that would lower the poverty rate of a CBG by one percentage point, while holding its median income constant, would add $1/4$ percentage point to telephone penetration. FCC Lifeline and LinkUp policies, discussed later in more detail, are designed to make telephone service more affordable to low income households. Second, Native American populations have much lower telephone penetration than other population groups, even after controlling for poverty, median income, education, and other demographics. It is not clear why this is the case. Do Native Americans place less value on telephone service, are they victims of discrimination, or is service

[5] Schement, Belinfante and Povich (1997) provide a more detailed analysis showing among other things that households receiving various forms of public assistance have lower penetration rates.

[6] All of the data for this regression equation are from the 1990 census. This is a weighted least squares regression which adjusts for the varying population sizes of CBGs. For a description of this procedure see Greene (1993).

more expensive or less available in areas occupied by Native Americans? Recently, the FCC targeted increased subsidies at federally-recognized Indian tribes, on grounds that the 47% average telephone penetration for this consumer group is partly due to expensive and unavailable service.[7] [8]

Other demographic characteristics of CBG populations influence penetration noticeably but less dramatically. The estimated effects are generally consistent with published descriptive analyses (Schement 1995; Schement, Belinfante, and Povich 1997) and demand studies (Crandall and Waverman 2000; Taylor 1994). People living in wealthier and more educated communities are much more likely to have a phone in the house. Asian populations are more likely, and black and Hispanic populations less likely than white households to have a phone. Elderly populations are marginally more likely to have telephones, as are households headed by women.

Column (II) adds variables designed to capture aspects of network externalities at the local level, i.e. the idea that the household demand for telephone service depends on who else has telephone service locally. As discussed in Section 3, network externalities are a potentially important theoretical rationale for universal service policies. Controlling for population density, telephone service increases with the size of the wire center population to which the CBG belongs, suggesting that demand shifts out with the reach of local service. This stylized fact supports the hypothesis of local network externalities associated with the number of people that can be reached by a local telephone call.[9] Adding an additional 10,000 people to the wire center increases penetration by about $1/5$ percentage point.[10] Controlling for population size, CBG population density reduces penetration in this regression, suggesting that face-to-face communication is to some extent a substitute for telephone usage. In contrast, Crandall and Waverman (2000), discussed in Section 4,[11] find a small positive significant coefficient on population density, which they interpret as confirming a positive local network externality. Their demand analysis controlled for prices but did not include a variable for population size. Since population size and density are positively correlated, it is possible that their density variable is picking up two contrary effects, the local network externality effect, and a face-to-face communication effect (Taylor 1994 p. 236). Finally, it is noteworthy that including these variables increases the coefficient on Native American population share by several percentage points, suggesting that Native Americans tend to live in relatively unpopulated areas where the ability to make free local calls is not very valuable. Alternatively, the less negative coefficient could be an artifact of a restricted sample, which arises from the fact that wire center data are available only for

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[7] See paragraph 20 of FCC (2000), *Twelfth Report and Order, Memorandum Report and Order, and Further Notice of Proposed Rule Making*, CC Docket No. 96-45, June.

[8] The policy appears to have had an earlier impact in Oklahoma, where $1 a month Lifeline service added 6,000 new subscribers in October 2000. See Kade L. Twist, "The Digital Divide in Oklahoma Indian Country," Benton Foundation (kade@benton.org).

[9] The estimated local network externality could be biased downward, because statet tariffs typically set lower prices where the number of lines is fewer. See National Association of Regulatory Commissioners (NARUC), *Bell Operating Companies Exchange Service Telephone Rates,* various years.

[10] Moreover, doubling population size and density has a significant positive effect on penetration, which is generally consistent with Perl's 1983 study, discussed in Section 3.3. Perl allowed for a non-linear effect of phone density, and found a significant positive effect for areas with between 1,000-2,500 phones per square mile, and a negative effect elsewhere (Taylor 1994).

[11] The other studies discussed in Section 4 also include density variables ("urban" and "rural") with consistent signs.

large local exchange carriers.

Table 1: Determinants of CBG telephone penetration[12]

	(I)	(II)	(III)	(IV)	(V)
% Poor	-0.267	-0.259	-0.258	-0.248	-0.246
	(179.4)	(129.4)	(117.5)	(114.2)	(113.0)
Median income	0.035	0.032	0.034	0.033	0.028
	(31.1)	(22.9)	(21.6)	(21.3)	(17.6)
% Female h.o.h.	0.023	0.025	.007	-0.028	-0.033
	(12.4)	(9.8)	(2.5)	(9.9)	(11.7)
% Senior	0.004	0.003	0.006	0.002	-0.002
	(2.8)	(1.7)	(2.8)	(1.2)	(1.2)
% Children	-0.017	-0.009	-0.018	-0.012	-0.011
	(10.6)	(4.7)	(7.7)	(5.2)	(5.2)
% High school	0.117	0.103	0.111	0.102	0.098
	(63.8)	(42.7)	(41.1)	(38.5)	(36.7)
% College	0.111	0.104	0.105	0.083	0.088
	(77.8)	(57.3)	(52.0)	(40.9)	(43.1)
% Black	-0.013	-0.021	-0.009	-0.009	-0.008
	(19.8)	(22.5)	(8.8)	(9.1)	(8.1)
% Hispanic	-0.010	-0.016	-0.018	0.026	0.022
	(12.7)	(15.3)	(12.4)	(18.3)	(14.9)
% Native	-0.333	-0.247	-0.230	-0.212	-0.212
	(119.1)	(55.2)	(43.8)	(40.9)	(39.0)
% Asian	0.075	0.056	0.077	0.065	0.055
	(47.0)	(28.9)	(25.5)	21.8)	(18.1)
% Other nonwhite	0.115	0.063	0.021	0.002	0.0010
	(5.5)	(2.11)	(0.6)	(0.5)	(2.6)
Pop. density		-0.026	-0.041	-0.40	-0.037
		(11.8)	(17.7)	(17.3)	(15.4)
W.c. population		0.020	0.019	0.012	0.013
		(37.9)	(29.6)	(18.2)	(20.2)
Loop length				-0.020	-0.016
				(19.7)	(15.5)
Average f.l. cost				-0.036	-0.033
				(41.8)	(38.0)
Controls for climate	No	No	Yes	Yes	Yes
State effects	No	No	No	No	Yes
R^2	0.537	0.531	0.551	0.564	0.580
ΔR^2					0.015
$S^2 = \frac{Var(\text{estimated state effects})}{Var(\text{telephone penetration})}$					0.017
# Observations	222,264	116,715	95,171	95,171	95,171

[12]The coefficients in this table represent the percentage point change in telephone penetration in response to a unit change in the independent variable. For example, in column (I) a 1 percentage point increase in *% Poor* is

Column (III) controls for climate (precipitation and temperature) to capture the possibility that people living in inhospitable climates may spend more time indoors and therefore may have a greater demand for telephone service as a means of communication. This is superficially plausible, as the map in Figure 2 shows that penetration rates tend to be higher in the colder northern states. Indeed, Crandall and Waverman (2000) find a significant positive coefficient on a "cold northern state" dummy in their demand analysis. It turns out that penetration is higher where weather is more extreme.[13]

Column (IV) adds FCC estimates of the monthly forward-looking cost of local service and average loop length into the mix. The argument for including these variables is that local service prices, and especially installation charges, are partly cost-based.[14] As predicted by a cost-based pricing hypothesis, higher average costs and longer loop lengths have negative effects on penetration. However, these effects are small quantitatively, as would be expected from the low price elasticities estimated by demand studies (Crandall and Waverman 2000; Taylor 1994). An extra \$1 cost per month (about 3% of the mean CBG monthly cost) reduces penetration by three or four one hundreths of one percent. This implies an elasticity of about -0.01, which is roughly consistent with the demand studies under a cost-based pricing hypothesis.[15] The introduction of these supply side variables does not influence the other estimated coefficients in the regression model remarkably.

Finally, column (V) includes dummy variables for the state in which the CBG is located ("state effects"). The regression indicates significant differences between states even after controlling for demography and costs. An F-test of the joint significance of the state effects easily passes, indicating that these unexplained differences between states cannot be ignored. However, the state effects adds only 0.0153 to the R^2, and the variance share of the estimated state effects (S^2) is only 0.0174.[16] Thus the state effects appear to explain somewhere between

associated with a .267 percentage point decrease in penetration, while a \$1,000 increase in *Median income* (which is defined in thousands of dollars) is associated with a 0.035 percentage point increase in penetration.

[13] The estimated quadratic specifications for climate effects in this and subsequent regressions are:

	(III)	(IV)	(V)
Temperature	-0.5	-0.5	-0.3
	(20.2)	(21.1)	(8.0)
Temperature^2	0.004	0.004	0.003
	(17.9)	(18.6)	(8.6)
Precipitation	-0.006	-0.02	-0.03
	(-0.678)	(2.7)	(2.3)
Precipitation^2	2.56E-04	3.48E-04	4.16E-04
	(5.6)	(7.7)	(6.4)
Temp.*Precip.	-6.77E-04	-4.74E-04	-3.15E-04
	(5.1)	(3.6)	(1.6)

[14] As mentioned before, state tariffs typically set lower residential service prices in wirecenters with fewer lines, suggesting that prices are inversely related to costs within individual states. The regression, however, already captures this by controlling for the number of households served by a wirecenter. The cost-variables possibly could be picking up cost-related price variation across the states. For data on across- and within-state variation in prices see the *Bell Operating Companies Exchange Service Telephone Rates*, published annually by NARUC until 1997.

[15] Admittedly, cost-based pricing of local service is a tenuous hypothesis. Rosston and Wimmer (2000b) estimate that a 10% increase in average costs is associated with only a 0.65% percent increase in average local revenues. Such a small degree of pass-through would imply a much higher price elasticity.

[16] S^2 is equal to the variance of the estimated state effects divided by the variance of telephone penetration. ΔR^2 is the increase in R^2 that results from adding the state effects. These two numbers can be interpreted as upper and

1 and 2 percent of the variance in CBG penetration rates. These differences could be due to other population characteristics that are correlated with state of residence, or could be due to differences in state policies. Inasmuch as the total variation of penetration rates explained by the regression is not much more than 50%, the former explanation seems reasonable. However, it is unclear *a priori* what appropriate demographic or locational variables might soak up the state effects. For example, including more detailed income data into the regressions reduces the explanatory contribution of the state effects only slightly. Although it is worth entertaining the possibility that differences in state regulatory policies matter, the most optimistic interpretation of the evidence is that differences in state policies can explain no more than a small fraction of the variance in penetration rates.[17]

The final regression reported in Table 1 can be interpreted as a reduced form of a structural model in which both penetration and prices are endogenous. The first equation of the structural model is a community demand curve explaining CBG penetration as a function of prices, population demographics (including proxies for network externalities), and climate, as in demand studies (Crandall and Waverman 2000; Taylor 1994). The other equations explain relevant prices as a function of access costs (proxied by loop length and forward-looking cost) and state dummies. The state dummies capture differences in state policies, e.g. different approaches to price regulation or universal service subsidies.[18] It is an open question whether price variation alone is sufficient to explain the state effects on penetration rates. Published research generally finds the price elasticity of demand for local service to be very low - on the order of -0.01 or -0.02 (Crandall and Waverman forthcoming; Taylor 1994). The price elasticity for low income households is significantly higher (Cain and MacDonald 1991), and the elasticity with respect to installation charges is significantly higher than for monthly service charges (Hausman, Tardiff, and Belinfante 1993; Crandall and Waverman 2000). Thus published economics research finds some weak support for universal service policies that target low income households and focus on lowering installation charges. These are the aims of the FCC's Lifeline and LinkUp programs, which are evaluated in Section 4.

An intriguing possibility is that some of the substantial unexplained geographic variation in penetration rates is due to "coordination failures" associated with network externalities.[19] The basic economics of the telephone network externality is that an individual subscriber benefits when other consumers connect to the network. This interdependence of decision-making creates a coordination problem for consumers: "If enough consumers connect, then so will I, but if others don't connect then neither will I." Thus, under the network externality hypothesis, consumer decision-making depends on consumers' expectations about other consumers' decision-making. The circular reasoning inherent in consumer coordination problems allows multiple equilibria, e.g. low level equilibria in which few people connect to the network, and high level equilibria in which many connect. Depending on nonlinearities in demand, there can be many equilibria for a given community, yielding a variety of different possible stable penetration levels. Thus, in theory, part of the geographic variation in penetration levels could be

lower bounds on the percentage of penetration variance explained by state effects. ΔR^2 is a lower bound because it implicitly attributes the explanatory power of the correlated components of the state effects to other variables. S^2 implicitly attributes the correlated components to the state effects.

[17] Sappington (2001) discusses the possibility that certain forms of incentive regulation may increase penetration rates.

[18] Differences in state universal service policies, which establish low-income subsidies, are discussed later.

[19] See Katz and Shapiro (1994) and Liebowitz and Margolis (2001) for discussions of network effects.

due to similar communities arriving at different equilibrium levels of penetration for historical reasons. The significance of network externalities for optimal telecommunications pricing is discussed further in Section 3 below.

The questions “Could the United States do more to promote universal service?” and “Do state policies matter for the achievement of universal service goals?” are important questions in the realm of positive economics. The corresponding normative questions are “What are optimal levels of telephone penetration and how do they vary with the characteristics of consumer groups?” and “What are the best ways to achieve universal service goals?” The next section surveys what economic theory has to say about these and related normative questions.

3. NORMATIVE ECONOMICS OF UNIVERSAL SERVICE

3.1 Price distortions

Perhaps the most fundamental advice of economists is that marginal cost pricing maximizes economic efficiency. As discussed in detail in following subsections, the standard marginal cost pricing prescription must be qualified in the presence of scale economies and network externalities. Nevertheless, economists generally agree that universal service policies that distort usage prices above incremental costs sacrifice economic efficiency.

In the United States, access regulation and universal service policies have helped keep the prices of long distance usage above marginal cost. For example, the price of an interLATA long distance call carried by AT&T reflects federally-mandated access charges paid to the local telephone companies who originate and terminate the call. Almost everyone recognizes that usage-based components of these access charges have been maintained above the marginal cost of access.[20] Hausman (1998) and Prieger (1998) interpret the resulting price distortion as a usage tax,[21] and use approximations from public finance theory to measure the resulting loss of economic efficiency.[22] The analysis below follows Hausman’s logic closely, but measures efficiency losses exactly by assuming a constant elasticity of demand over the relevant range.

The basic issue is illustrated in Figure 3, adapted from Hausman (1998). The price per minute of long distance is p, the marginal cost is c, and usage is q. The usage tax is t. In the absence of the tax, consumers would pay $p - t$ per unit of long distance usage. The revenue raised from the tax is

$$R = tq \tag{3.1.1}$$

For an otherwise fixed market structure, the efficiency loss from the tax (called “deadweight loss” by economists) is measured by the sum of areas A and B. Area A represents the reduction in profits (“producer surplus”) caused by the tax, assuming the tax is fully passed on to consumers.[23] Area B is the loss of consumer welfare (“consumer surplus”) from the tax.

[20] The FCC is phasing out significantly above-cost usage-based access prices, replacing them with higher fixed charges and with revenue-based universal service “contributions” (i.e. revenue taxes).

[21] The FCC is moving from a system of usage taxes, implicit in access taxes, to a system of revenue taxes, implicit in the calculation of universal service contributions. Depending on market structure, revenue taxes may be more efficient than usage taxes.

[22] Hausman (2001) applies the methodology to the market for mobile telephony. See additional references therein.

[23] The assumption of full pass through is hard to defend theoretically in an oligopoly context, and exaggerates the

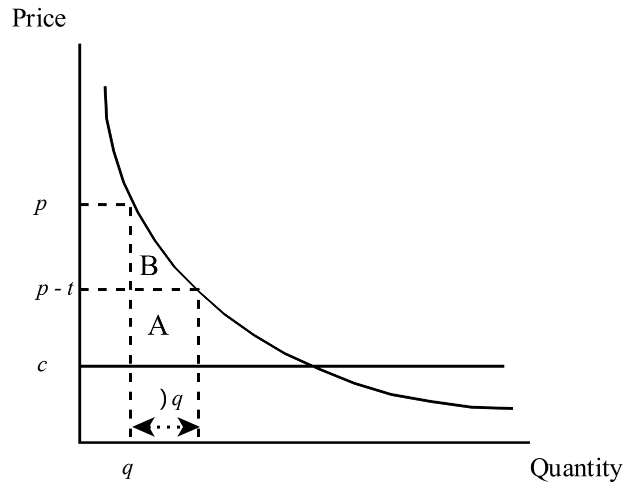

Figure 3: Consequences of an access tax

The deadweight loss per unit of tax revenue raised can be calculated as follows. Assume that the demand for long distance usage has a constant elasticity ε over the range of prices between $p - t$ and p. Then the reduction in quantity resulting from the usage tax is

$$\Delta q = \left[\left(1 - \frac{t}{p} \right)^{-\varepsilon} - 1 \right] q \tag{3.1.2}$$

and loss of producer surplus (Area A) is

$$(p - t - c)\, \Delta q = (p - t - c) \left[\left(1 - \frac{t}{p} \right)^{-\varepsilon} - 1 \right] q \tag{3.1.3}$$

The corresponding loss of consumer surplus (Area B) is calculated by integrating the demand curve between $p - t$ and p and subtracting tax revenue. This gives the formula

$$\left\{ \frac{1}{1 - \varepsilon} \left[p - (p - t) \left(1 - \frac{t}{p} \right)^{-\varepsilon} \right] - t \right\} q \tag{3.1.4}$$

The incremental loss of economic efficiency ("incremental deadweight loss") is equal to the sum of lost producer surplus and consumer surplus. Simple calculations yield an expression

efficiency loss if the tax partially extracts rents from oligopoly market power. Further analsysis of tax incidence and welfare consequences in the oligopoly case would clarify the debate on efficiency losses from usage price distortions.

for the incremental deadweight loss per unit of tax revenue: adding the expressions for lost producer and consumer surplus in equations (3.1.3) and (3.1.4), and dividing by the definition of tax revenue in equation (3.1.1), yields lost consumer and producer surplus per unit revenue raised by the tax; adding these up reveals that the average incremental deadweight loss equals

$$\left(\frac{p}{t} - 1 - \frac{c}{p}\frac{p}{t}\right)\left[\left(1 - \frac{t}{p}\right)^{-\varepsilon} - 1\right] + \left\{\frac{1}{1-\varepsilon}\left[\frac{p}{t} - \left(\frac{p}{t} - 1\right)\left(1 - \frac{t}{p}\right)^{-\varepsilon}\right] - 1\right\}.$$

The significance of this complicated-looking formula is that a calculation of the average incremental deadweight loss from the price distortion caused by the access tax requires three numbers: the demand elasticity ε, the tax rate $\frac{t}{p}$, and the cost share $\frac{c}{p}$. Some representative calculations are presented in Table 2. Each entry in the table has two numbers. The first (larger) number is the incremental deadweight loss per unit of tax revenue; the second number is the corresponding loss of consumer surplus alone. A consensus estimate of the price elasticity of long distance usage is about $\varepsilon = 0.7$ (Taylor 1994). For this elasticity, if the tax rate and cost shares are $\frac{t}{p} = 0.25$ and $\frac{c}{p} = 0.25$, the incremental deadweight loss is $\$0.55$ per unit of revenue,[24] of which $\$0.10$ is lost consumer surplus, the rest being lost profit. In other words, every dollar of revenue raised by the tax costs the economy an additional fifty-five cents and reduces consumer surplus by ten cents.[25]

A debatable aspect of this analysis is the calculation of lost producer surplus. Hausman's calculations make sense if there are prohibitive barriers to entry into the long distance market, enabling incumbent firms to sustain supracompetitive profits. In this case, elimination of the tax does not cause a change in market structure, and area A represents an increase in industry profits that results from the expansion of incumbent firms. However, as Hausman (1998) notes, it is possible "that the industry is imperfectly competitive and price exceeds marginal cost to cover fixed costs." In this case, the elimination of the tax could prompt additional entry, and at least part of area A represent the additional fixed costs incurred by the new entrants. Increased industry fixed costs do not add to economic welfare, suggesting that Hausman's calculation of the efficiency loss from an access tax is biased upward. Indeed, if equally efficient firms drive equilibrium profits to zero both before and after the elimination of the tax, then the efficiency loss from the access tax is only the loss in consumer surplus measured by area B, which is the second, smaller number in each entry of Table 2.[26] Thus one's perspective on the efficiency loss

[24] Perhaps surprisingly, the average efficiency loss is not monotonic in $\frac{t}{p}$. This is because an increase in $\frac{t}{p}$ increases both numerator (total efficiency) and the denominator (tax revenue) of the expression for average efficiency loss.

[25] Hausman (1998) apparently estimated the deadweight loss using a second-order Taylor series approximation, although his precise calculations are difficult to unravel. He also assumed a higher tax rate of $\frac{t}{p} = .403$, which was plausible a few years ago before price caps lowered access rates. He arrived at an estimated deadweight loss of $\$0.654$ for each dollar of revenue raised. Substituting $\frac{t}{p} = .403$ into the above exact formula yields a smaller $\$0.56$. Prieger (1998) applies a similar public finance methodology (and explains it better) to estimate the deadweight loss from prospective universal service taxes. The point is the same. Price distortions to support universal service potentially entail substantial efficiency losses. The authors agree that a more efficient way to fund explicit universal service subsidies would be to tax local access. See also Hausman (1999).

[26] More generally, if entry is "lumpy", then abnormal long run profits can persist in a free entry equilibrium. However, it is unclear *a priori* whether industry profits will rise or fall if the elimination of a tax prompts additional entry. If industry profits were to fall then the efficiency loss from the tax would be even less than area B, and conversely. Lacking finely detailed information on market structure, it appears reasonable to assume a zero effect of entry on long run industry profits and to measure the efficiency loss by area B alone. However, if firms differ

from universal service taxes depends on assumptions about the industrial organization of the long distance market.[27]

Table 2: Efficiency and consumer surplus losses per $ tax revenue

	$\frac{c}{p}=0$		$=0.25$		$=0.50$		$=0.75$	
$\varepsilon=0.6$								
$\frac{t}{p}=0.25$	0.65	0.09	0.46	0.09	0.28	0.09	0.09	0.09
$=0.50$	0.73	0.21	0.47	0.21	0.21	0.21		
$=0.75$	0.85	0.42	0.42	0.42				
$\varepsilon=0.7$								
$\frac{t}{p}=0.25$	0.77	0.10	0.55	0.10	0.33	0.10	0.10	0.10
$=0.50$	0.88	0.25	0.56	0.25	0.25	0.25		
$=0.75$	1.06	0.51	0.51	0.51				
$\varepsilon=0.8$								
$\frac{t}{p}=0.25$	0.90	0.12	0.64	0.12	0.38	0.12	0.12	0.12
$=0.50$	1.04	0.29	0.67	0.29	0.29	0.29		
$=0.75$	1.29	0.61	0.61	0.61				

Hausman (1998 p. 14) argues that a more relevant calculation is the marginal effect of reducing usage taxes. Hausman assumed that any increase in the usage tax is fully passed on to consumers. Under this assumption, the marginal deadweight loss with respect to t is

$$(1-\frac{c}{p})\varepsilon q \tag{3.1.5}$$

of which

$$\varepsilon\frac{t}{p}q \tag{3.1.6}$$

is the marginal loss in consumer surplus. The marginal tax revenue for an increase in t is

$$(1-\varepsilon\frac{t}{p})q. \tag{3.1.7}$$

in efficiency, then part of area A could represent the rents of the more efficient firms, in which case the efficiency loss per unit of tax revenue is somewhere between the two numbers reported in Table 2.

[27]Prieger (1998 p. 66) recognizes that the efficiency loss depends on industry structure, but downplays it by suggesting that short run entry barriers might allow above-normal profits to persist temporarily. His calculations (1998 Table 2) confirm that the welfare loss from an access tax is much lower in the long run once new entry erodes the temporary market power of the incumbents. See Kaserman and Mayo (2001) for a detailed discussion of the industrial organization of the long distance market.

Dividing (3.1.5) and (3.1.6) by (3.1.7) gives the marginal efficiency loss and the marginal consumer surplus loss for an extra dollar of tax revenue raised by an increase in the usage tax. Table 3 presents some representative calculations. Following Hausman, these calculations assume that an increase in the usage tax is fully passed on to consumers in the final price. For example, if $\varepsilon = 0.7$, $\frac{t}{p} = 0.25$ and $\frac{c}{p} = 0.25$, then a $\$1$ increase in the amount of revenue raised by the access tax costs society an additional $\$0.64$, of which $\$0.21$ is a direct loss to consumers. A comparison of Tables 2 and 3 shows that marginal losses exceed average losses.

Table 3: Marginal efficiency and consumer surplus losses

	$\frac{c}{p} = 0$		$= 0.25$		$= 0.50$		$= 0.75$	
$\varepsilon = 0.6$								
$\frac{t}{p} = 0.25$	0.71	0.18	0.53	0.18	0.35	0.18	0.18	0.18
$= 0.50$	0.86	0.43	0.64	0.43	0.43	0.43		
$= 0.75$	1.10	0.82	0.82	0.82				
$\varepsilon = 0.7$								
$\frac{t}{p} = 0.25$	0.85	0.21	0.64	0.21	0.42	0.21	0.21	0.21
$= 0.50$	1.08	0.54	0.81	0.54	0.54	0.54		
$= 0.75$	1.47	1.11	1.11	1.11				
$\varepsilon = 0.8$								
$\frac{t}{p} = 0.25$	1.00	0.25	0.75	0.25	0.50	0.25	0.25	0.25
$= 0.50$	1.34	0.67	1.00	0.67	0.67	0.67		
$= 0.75$	2.00	1.50	1.50	1.50				

Hausman argues that it would be more efficient to finance universal service subsidies from general tax revenues. He bases this recommendation on published estimates of the marginal efficiency losses of general taxes ranging between 0.260 and 0.395 (Hausman 1998 p. 15). Table 3 shows that the marginal welfare effects of the asset tax exceed this range (for $\varepsilon = 0.70$) if lost producer surplus (area A of Figure 3) is part of incremental deadweight loss. However, if producer surplus is dissipated by entry costs, as in a symmetric free entry oligopoly equilibrium, then the marginal welfare effect of the usage tax, which is equal to the marginal consumer surplus loss, is less and may be below the marginal social cost of public funds. Thus, depending on the industrial organization of the long distance market, the access tax may or may not be an economically attractive method to finance universal service compared to financing out of general revenues.[28]

Hausman's main policy recommendation is that universal service is best achieved by targeted subsidies financed by a fixed universal service tax on access. The FCC is moving in

[28]The industrial organization literature recognizes that oligopoly entry may be excessive from a social perspective (Mankiw and Whinston 1986). In this case, an access tax can improve social efficiency by reducing excessive entry.

this direction by reducing per minute long distance access charges and by raising the monthly subscriber line charge (SLC). The wisdom of "going all the way" and completely eliminating per minute access charges depends on scale economies and network externalities, discussed in the next two subsections.

3.2 Scale economies

Local economies of scale provide a rationale for universal service policies, although this economic argument does not feature prominently in today's policy debates on the subject. Certainly, local scale economies cannot be dismissed out of hand. Maher (1999) reports modest estimated scale economies in access, based on central office cost data provided anonymously by two local telephone companies. If there are economies of scale of connecting people, then adding people to the network lowers the average cost of connections, potentially to the benefit of all.

The *a priori* plausibility of local scale economies depends on the nature of the universal service problem. One flavor of scale economy is an economy of density. An increase in telephone penetration at a wire center service area that is already built out amounts to an increase in the number of lines served in a given geographic area. For example, if 95 out of 100 households on a street already are getting telephone service, then the incremental cost of serving an additional household must be less than the average incremental cost of serving the street. The reason is that the necessary poles and conduits, and perhaps even spare copper wire pairs, are already in place. Thus scale economies are very plausible if the universal service problem is to increase penetration in a given service area.

Another flavor of local scale economy is an economy of geographic scope. If greater penetration requires extending the perimeter of the wire center, then it is plausible that the incremental cost of service is either greater or less than the average cost. On the one hand, average cost may decline because the geographic extension relies on existing remote terminals, transport and switching infrastructure. On the other hand, the greater costs of installing and maintaining longer copper wire loops could cause the incremental costs of service to rise above the average cost. For this reason, economies of geographic scope seem less plausible than economies of density as a source of local scale economies.

The economies of scale rationale for universal service poses a well known dilemma. Average cost pricing results in an inefficiently low level of penetration, but marginal cost pricing leaves a deficit to be funded somehow. What's a regulator to do? The famous Ramsey rule for second-best pricing resolves the dilemma optimally by marking-up prices above marginal cost in inverse proportion to the price elasticity of demand.

Most U.S. households pay a fixed monthly price for access (and local service) and usage sensitive prices for long distance calling. The long distance prices may depend on whether the call is intrastate or interstate, and on the distance of the call. However, a simple two-part service arrangement featuring a fixed usage price provides a good basis for an analysis of optimal pricing with economies of scale. The standard Ramsey rule requires some modification if there are separate prices for access and usage. The modification is required because access is a necessary ingredient of residential access to the telephone network. This section outlines the relevant theory of optimal two-part tariffs, along the lines developed by Brown and Sibley (1986), Vogelsang and Mitchell (1991), and Schmalensee (1981). It is appropriate to interpret the economy of scale in the theoretical model as an economy of density.

Ramsey pricing rules are based on demand as well as costs. Thus, the derivation of the optimal pricing rule requires a model of both. To keep matters simple, assume that there are just two services, usage and access, and a separate price for each, p and r.[29] Consumer heterogeneity is represented by a parameter θ. A type θ individual has a utility (consumer surplus) of

$$V = U(p, \theta) - r$$

from connecting to the telephone network. A service plan that is more favorable to the consumer yields a higher consumer surplus.

Different types of consumers have different preferences over service plans. To simplify further, assume a multiplicatively-separable functional form

$$U(p, \theta) = \theta u(p),$$

Thus the consumer surplus of a type θ consumer with service plan (p, r) is

$$V = \theta u(p) - r$$

where $u(p)$ is assumed to be a smooth, convex, and decreasing function of p. A consumer with a higher value of θ is more willing to accept a higher access price for a lower usage price. However, all consumers have the same price elasticity of demand for usage. By a standard economic argument,[30] a type θ individual has a demand curve for usage,

$$\begin{aligned} X(p, \theta) &= -\theta u'(p) \\ &\equiv \theta x(p), \end{aligned}$$

that is derived from the utility function. The corresponding price elasticity of demand for usage is

$$\epsilon = -\frac{p x'(p)}{x(p)}$$

The price elasticity might depend on p, but it does not depend on θ.

Only consumers with a positive consumer surplus will opt to connect to the network. The marginal type is θ_o satisfying

$$r = \theta_o u(p), \tag{3.2.1}$$

meaning that this consumer is just indifferent between connecting or not. By substituting this expression for r into the utility function expressed by equation (3.2.1), the consumer surplus of a type θ is written as

$$V = (\theta - \theta_o) u(p),$$

[29] This is an oversimplification: usage can be interpreted as long distance usage, with local usage bundled into access. More generally, economic efficiency requires separate usage-sensitive prices for local and long distance usage, because these have different price elasticities.

[30] The argument is known in the consumer theory literature as Roy's identity. The partial equilibrium framework adopted here assumes a constant marginal utility of income, implicitly interpreting a decrease in r as an increase in income.

which is a function of the consumer's type, the marginal consumer type, and the usage price.

If M is the total number of consumers, and N are connected, then the penetration rate is $n = \frac{N}{M}$. The penetration rate is related to the identity of the marginal consumer by the formula

$$n = \int_{\theta_o}^{\infty} f(\theta)d\theta \equiv [1 - F(\theta_o)]$$

Here $f(\theta)$ is the frequency (density) of type θ consumers in the population, and $F(\theta)$ is the fraction of consumers who make fewer calls than does a type θ. In this model, the elasticity of the penetration rate with respect to the access price r is

$$\eta = \frac{\theta_o f(\theta_o)}{n}$$

This "access elasticity" measures the sensitivity of the marginal consumer to a change in the access price. The average consumer is type

$$\bar{\theta} = \frac{\int_{\theta_o}^{\infty} \theta f(\theta)d\theta}{n},$$

makes $\bar{\theta}x(p)$ calls, and enjoys a consumer surplus of $\bar{\theta}u(p) - r$. The average consumer surplus over the entire population is therefore

$$\bar{V} = n\left[\bar{\theta}u(p) - r\right]. \tag{3.2.2}$$

Substituting equation (3.2.1) for the marginal consumer into (3.2.2) yields an expression for average population consumer surplus,

$$\bar{V} = n(\bar{\theta} - \theta_o)u(p)$$

as a function of the usage price, the marginal consumer, and the average consumer.

Now turn to costs and profits. Assume for simplicity that the marginal cost of usage is a constant at c. The average cost of a connection is $\bar{h}(\theta_o)$ when all types $\theta \geq \theta_o$ are connected to the network. The marginal cost is related to the average cost according to the formula

$$h(\theta_o) = \bar{h}(\theta_o) - \frac{\bar{h}'(\theta_o)\theta_o}{\eta}.$$

An economy of scale in providing access exists if $\bar{h}'(\theta_o) > 0$. In this case the marginal cost of a connection is lower than the average cost. This means that, as more subscribers are added to the network, the average cost declines. The profits earned on an average consumer are $r + (p - c)\,\bar{\theta}x(p) - \bar{h}(\theta_o)$. Using equation (3.2.1) to substitute for r and averaging over the entire population yields an expression for the average population profit,

$$\bar{\Pi} = n\left[\theta_o u(p) + (p - c)\,\bar{\theta}x(p) - \bar{h}(\theta_o)\right].$$

The problem of maximizing total welfare subject to a break-even constraint on profits amounts to maximizing a weighted sum of consumer surplus and profits according to the Lagrangian function

$$L = \bar{V} + (1 + \lambda)\,\bar{\Pi}$$

where $\lambda \geq 0$ is the shadow price of the break-even constraint. In other words, the optimal service plan maximizes an appropriately weighted sum of consumer surplus and profits (producer surplus). The greater weight on profits reflects the cost to society of solving the Ramsey dilemma of how best to recover access costs. As shown below, the shadow price is strictly positive if there are economies of scale.

Maximizing L with respect to p yields the modified Ramsey formula for pricing usage [**?**, p. 95]:

$$\frac{p - c}{p} = \frac{\lambda}{1 + \lambda}\,[1 - \varpi]\,\frac{1}{\epsilon}$$

where ϵ is the price elasticity of usage defined earlier, and the variable

$$\varpi = \frac{\theta_0}{\bar{\theta}}$$

is equal to the ratio of usage of the marginal consumer to average usage. Thus, assuming that the Ramsey dilemma is real and $\lambda > 0$, the usage markup is higher the greater is the difference in usage between the marginal and average subscriber. Brown and Sibley (1986 p. 96) interpret $1 - \varpi$ as "an adjustment term accounting for the cross-elasticity between consumption and participation." More specifically, the adjustment accounts for the facts that an increase in p requires a decrease in r in order to maintain penetration, and that this rebalancing impacts both average utility and profits.

The usage formula makes clear that marginal cost pricing can solve the welfare maximization problem only if $\lambda = 0$. This case obtains for a particular value of θ_0. In this singular case $p = c$, requiring $r = \bar{h}(\theta_o)$ if the firm is to break even. This consumer type is just willing to accept a strictly cost-based service plan with access price $r = \bar{h}(\theta_o)$ and a usage price $p = c$. Can this be optimal? The answer is no if there is a an economy of scale in connecting people to the network, i.e. if

$$\bar{h}'(\theta_o) > 0$$

To reach this conclusion, consider how social welfare changes with the identity of the marginal consumer. Evaluating the derivative of L with respect to θ_0 at the point of strict cost-based pricing yields

$$\frac{dL}{d\theta_o} = -\bar{h}'(\theta_o)n$$

which is unambiguously negative if $\bar{h}'(\theta_o) > 0$, meaning that welfare would be increased by lowering θ_o. But then the profit constraint becomes binding, i.e. $\lambda > 0$, and $p > c$ according to the usage formula. Thus, economies of scale provide a clear rationale for "price distortions."

The average consumer benefits from the resulting network expansion because economies of scale enable a lowering of the access price relative to the increase in the usage price.

The optimal access price satisfies a modified Ramsey formula that appropriately accounts for opportunity costs. The first-order condition for optimal θ_o yields (Brown and Sibley 1986 p. 95).

$$\frac{r-m}{r} = \frac{\lambda}{1+\lambda}\frac{1}{\eta}$$

where

$$m = h(\theta_o) - (p-c)\,\theta_o x(p)$$

is the marginal opportunity cost of a connection. The formula modifies the standard Ramsey inverse elasticity rule by treating marginal usage revenues as a component of marginal opportunity cost. A key observation from the formula is that, for purposes of optimal access pricing, the theoretically correct definition of marginal cost is marginal opportunity cost, which subtracts the usage profits earned on the marginal consumer from the marginal cost of a connection.

Economists' advice that usage should be priced close to its marginal cost is based on empirical evidence that the access elasticity is small, and on an implicit assumption that the revenue contribution of the marginal consumer is not likely to be large relative to marginal cost.[31] For example, suppose that the usage profits on the marginal consumer just cover the marginal cost of a connection. Then $m = 0$, $\frac{\lambda}{1+\lambda} = \eta$, and $\frac{p-c}{p} = (1-\varpi)\,\frac{\eta}{\epsilon}$. If the access elasticity (η) is small relative to the usage elasticity, then the usage markup is small. Empirical estimates of the price elasticities of access and (long distance) usage are in the neighborhood of $\eta = 0.02$ and $\varepsilon = 0.70$, i.e. the usage elasticity is an order of magnitude greater than the access elasticity, which implies that the usage markup is small. Thus, unless the profit contribution of marginal consumers exceeds the marginal connection cost significantly, scale economies do not appear to be an important justification for large price distortions to achieve universal service.[32]

3.3 Network externalities

Network externalities are inherent in the idea of a telephone network. The larger the network, the more people there are to call, and therefore the greater is the value of being connected to the network. Although network externalities provide a clear rationale for universal service policies, it is a rationale that has lost center stage in the policy debate. Laffont and Tirole (2000 p. 230) offer the following explanation for its neglect:

[31] The fact that penetration is lower for lower income households suggests that marginal consumers are predominantly lower income households. Crandall and Waverman (2000) document that lower income households do spend less on long distance usage, although the difference is not a dramatic one.

[32] This conclusion needs some qualification. If the average demand is great, then even a small usage markup (i.e. small λ) can justify a significant access discount. Moreover, it is possible to construct realistic examples of optimal two-part tariffs featuring both small usage markups and moderate access discounts. Using a model calibrated to 1970 data Mitchell (1978 p. 531) calculated that the optimal two-part tariff for local service has moderately-sized access discounts and usage markups, while achieving a high penetration rate. However, it is noteworthy that price elasticity for local usage implicit in Mitchell's model is significantly less than the consensus 0.7 elasticity for long distance usage (Mitchell 1978 p. 528). Building on Mitchell's example, Brown and Sibley (1986 p. 96) calculated that the optimal two-part tariff raised average consumer welfare by 5 cents a month compared to pricing usage at average cost, although at the cost of significantly reduced penetration.

> Network or club externalities are no longer at the forefront of the universal service debate (except perhaps for new services such as the Internet), partly because networks are largely developed in OECD countries and partly because it is recognized that network externalities are to a large extent internalized by operators.

This dismissal of the network externality rationale for universal service is not fully convincing. The argument that network externalities are unimportant in developed economies rests on an assumption that the average subscriber to the network does not have much interest in calling the marginal subscriber.[33] Crandall and Waverman (2000 p. 25) put the argument this way:

> (T)he network externality argument has little relevance for telephony in developed economies today for several reasons. If my telephone in Manhattan reaches 2 million people, another connection will probably have little value to me. Of course, if that connection is my mother, then the connection is of real value to me, and ... I can subsidize her telephone directly! Otherwise, there is no reason why I - in Manhattan - should subsidize someone in Kalamazoo.

The rhetoric does not quite hit its mark. Even if the average telephone subscriber in Manhattan places a small value on being able to call the marginal subscriber, multiplication of that small value by 2,000,000 can be a large number. Moreover, there surely are people in Manhattan who value calling people in Kalamazoo; that is, a network externality can be long distance as well as local. The magnitude of the network externality remains an empirical issue on which evidence is scant.

How do regulated firms internalize network externalities? To a large extent, this is up to the regulators. Raising the price of usage above its marginal cost, and reducing the price of access below its incremental cost, encourages the subscription of consumers who most likely do not originate a lot of calls.[34] Nevertheless, these subscribers may receive calls from other consumers who benefit from making these calls. Moreover, the increased call volume from this externality generates additional revenue which limits the need to raise the usage price to cover the access deficit. The economic efficiency of such price distortions is the focus of the network externality debate.

It is not hard to construct a theoretical model that illustrates the potential importance of network externalities. Consider a telephone network serving N consumers. Suppose that each consumer is potentially interested in calling a fraction θ of the others, and places an average of $x(p)$ calls to each at a price of p. Therefore, the number of calls the consumer makes is

$$X(p, \theta, N) = \theta(N-1)x(p)$$

and the consumer's value of calling is

$$U(p, \theta, N) = \theta(N-1)u(p).$$

[33] There are other less obvious network externalities. A large subscriber base creates a "market" for various network-based transactions. e.g. bank by phone. Such indirect network externalities most likely less important for mature networks, but arguably of crucial importance for emerging networks such as the Internet. See Katz and Shapiro (1994).

[34] On the other hand, Hausman *et. al*. (1993) report estimates suggesting that rebalancing rates in the opposite direction could increase penetration.

where the relationship between $u(p)$ and $x(p)$ is as in the previous section. Each consumer's usage and value of being connected increases linearly with the number of other consumers connected to the network. This is a mathematical statement of a particularly strong network externality.[35] More generally though, the network externality hypothesis only requires that value increases monotonically with subscribers.

The consequences of network externalities for usage prices can be derived by building on the previous model of optimal two-part pricing; see Vogelsang and Mitchell (1991) for a literature survey and a related model. With a network externality, the utility of an average subscriber is

$$\bar{\theta}\,(N-1)\,u(p)-r$$

and the marginal consumer (type θ_o) is defined by

$$r=\theta_o\,(N-1)\,u(p).$$

Substitution and multiplication by the penetration rate gives the population average utility,

$$\bar{V}=n\left(\bar{\theta}-\theta_o\right)(N-1)\,u(p).$$

Similarly, if the average network cost is fixed at $\bar{h}$ (ignoring scale economies), then the population average profit is

$$\bar{\Pi}=n\left\{(N-1)\left[\theta_o u(p)+(p-c)\,\bar{\theta}x(p)\right]-\bar{h}(\theta_o)\right\}$$

The Lagrangian is defined as before, and the "Ramsey formula" for the optimal usage price is exactly the same:

$$\frac{p-c}{p}=\frac{\lambda}{1+\lambda}\left[1-\varpi\right]\frac{1}{\epsilon}$$

where ϖ is the ratio of marginal to average usage. The optimal access price generalizes the previous formula:

$$\frac{[r-m]}{r}=\frac{\lambda}{1+\lambda}\frac{1}{\eta}-\chi;$$

with opportunity cost similar to as before:

$$m=\bar{h}-(p-c)\,(N-1)\theta_o x(p);$$

and a new term reflecting the network externality:

$$\chi=\frac{N-1}{N}\left[\frac{\bar{h}}{r}+\frac{1}{1+\lambda}\left(\frac{1}{\varpi}-1\right)\right].$$

As in the case of scale economies, marginal cost pricing is not optimal, i.e. $\lambda>0$, which requires an access deficit ($r<\bar{h}$) from the break-even constraint.

[35] This is a statement of "Metcalfe's Law" that the value of a network increases with the number of users squared. Robert Metcalfe was the founder of 3Com Corporation.

The network externality clearly justifies pricing access below the average cost of a connection, perhaps substantially depending on the values of λ and ϖ. Using the approximation $\frac{N-1}{N} \approx 1$, and assuming constant returns to scale, we obtain

$$\frac{r-\bar{h}}{r} \approx \frac{1}{1+\lambda}\left(\frac{1}{\varpi}\right)^2 - \frac{\lambda}{1+\lambda}\left(\frac{1}{\eta}-1\right)\left(\frac{1}{\varpi}\right)$$

The following is an example demonstrating that the network externality can justify a significant discount on the price of access. Suppose that the elasticities of access and usage are $\eta = 0.02$ and $\varepsilon = 0.70$, respectively, and that costs are $c = 0.015$ and $\bar{h} = 20$ with no scale economies. In dollars and cents, this means that the marginal cost of usage is a penny and a half, and the cost of access is \$20. Suppose further that $\varpi = 0.11$ and $\lambda = 0.186$.[36] The solution to the model for this example is: $p = 0.019$; $r = 16.90$. The optimal usage price is just under two cents and the optimal access price is just under \$17.

The example demonstrates that the network externality hypothesis potentially provides a sound theoretical rationale for subsidizing access to achieve universal service. Of course the model is too simple for practical purposes and probably overstates the case for an access subsidy. One blemish is the unrealistic assumption that doubling the size of the network also doubles the amount of usage at a given price. Telephone calls take time and consumers have other things to do. An increasing opportunity cost of time will curtail telephone usage even as network size grows. Nevertheless, with more calling opportunities, consumers can substitute from lower to higher value calls. The increased substitution opportunities of a larger network still validates the network externality hypothesis even if consumers do not make more calls. However, the rising opportunity cost of calls does lessen the quantitative significance of the network externality.

A second blemish is that the model assumes that all consumer types receive the same number of calls, even though they differ in their originating usage. It is possible and perhaps likely that people who make few calls when connected to the network also tend to receive few calls. The external benefits of connecting such people to the network are small. If this were true for marginal users as a class, then the case for an access subsidy is weakened significantly. This apparently is what Crandall and Waverman mean in the quotation above. However, the empirical validity of this intuitively plausible hypothesis remains unclear.

A final blemish is that the analysis ignores call externalities. A call externality occurs when some of the benefits of a telephone call accrue to the recipient, and are not internalized by the caller. In the United States and elsewhere the calling party pays for the telephone call,[37] and may decline to place a call if the price is too high, even though the joint benefits of the call are worth the cost. For example, I may wait for you to call me, and vice versa, and the call gets put off. The model can be modified to account for call externalities by supposing that the

[36] These values can be justified by a suitable choice of distribution function for θ, and by a suitable multiplicative scaling of the value of usage. The usage ratio $\varpi = 0.11$ determines the penetration rate from the distribution of types; for example, if θ has a standard uniform distribution, then the implied penetration rate is about 94%. The Lagrange multiplier $\lambda = 0.186$ means that it costs the economy an additional \$0.18 for every \$1.00 raised this way via the usage markup.

[37] An exception is a call to a wirelesss phone. In the United States the wireless receiver pays airtime charges. Elsewhere in the world, "calling party pays" is the norm even for wireless calls, and there is a move afoot for the FCC to require a "calling party pays" option in the U.S. as well.

value of receiving a call is (on average) equal to ν. Then the Ramsey formula for optimal usage pricing becomes

$$\frac{p-c}{p} = \frac{\lambda}{1+\lambda}\left[(1-\varpi)\frac{1}{\epsilon} - \frac{\nu}{p}\right].$$

Clearly, if ν is sufficiently large relative to p, then the optimal markup is negative, i.e. it is optimal to encourage more calls by setting the usage price below marginal cost.[38] Clearly, if usage is priced below cost, then access must be priced above cost if the firm is to break even. Thus, the call externality could completely undermine the case for access subsidies based on scale economies and network externalities.

Despite the conflict between call externalities and network externalities, the former has not received as much attention in the academic literature. Brown and Sibley (1986 p. 197) put the case against call externalities this way:

> The call externality is probably not too important. It only involves two people and can probably be easily "internalized." For example, two frequent callers could arrange to share the cost of calling. Furthermore, not all call externalities are positive externalities; there are certain phone calls that one is annoyed to receive. Since the telephone company cannot be expected to distinguish between positive and negative call externalities, it is probably not useful to incorporate them into price formulas. For this reason, and because call externalities can be internalized fairly well, they do not provide a strong case for call price reductions.

Vogelsang and Mitchell (1991) give more credence to the call externality by observing that successful bargaining over how to divide the cost of calling may itself require a costly telephone call. They also argue that call externalities are relatively more important in developed economies; their reason is that call externalities involve interactions among all consumers, while network externalities only involve interactions with marginal consumers. In the context of the above theoretical model, this means that, while network externalities increase with network size at rate N, call externalities increase at rate N^2. This is an interesting theoretical argument. However, empirical evidence on the relative significance of call and network externalities is lacking.

There are scraps of evidence on network externalities in telecommunications networks. As discussed in Section 2, Crandall and Waverman (2000) find a positive effect of population density on the demand for residential access, and interpret this as supporting the network externality hypothesis. Another scrap of evidence comes from Louis Perl's 1983 unpublished study of access demand, summarized by Taylor (1994 p. 86-96). Perl included in his discrete choice model measures of the size and density of the local network. His estimates imply that doubling size and density of a local network of 25,000 increases the average value of a subscription by \$4.36, while doubling the network again creates another \$1.17 of value for each subscriber (Taylor 1994 pp. 236-8). Thus, only modest network externalities appear at the local level, and the magnitude of the local network externality declines with size.

[38] Note that $\frac{\lambda}{1+\lambda}\upsilon$ can be interpreted as an additional component of opportunity cost in the Ramsey formula for usage prices. The reason for the $\frac{\lambda}{1+\lambda}$ adjustment is that the call externality enables the firm to charge a higher access price to the marginal consumer.

Network externalities can be either local or long distance. It is valuable to reach more people with a long distance call, as well as to be able to place more calls within a local service territory. It is unclear *a priori* which kind of network externality is the more important. The value of being able to call someone on the telephone depends both on the price of the call and on the availability of alternative means of communication. On the one hand, even though a local call typically is free, face-to-face communication is often an excellent alternative. On the other hand, a long distance call, while costly, often lacks a good substitute. The fact that long distance prices have been dropping sharply suggest that long distance network externalities are becoming more important.[39]

The network externality hypothesis allows that usage increases with the number of connected consumers. Taylor (1994 Appendix 3) estimated a log linear equation relating the average number of calls from city A to city B to relevant prices, the average household income in A, and the number of addressable telephones in B (market size) using quarterly data on off-peak long-haul traffic between Canadian cities between 1974 and 1983. The estimated elasticity of usage with respect to market size was 1.482 with a t-value of 8.5! It is not clear what to conclude from this estimate. Taylor speculates that the high elasticity reflects a usage externality, whereby one call leads to another.[40]

Barnett and Kaserman (1998) caution about the limits of the network externality hypothesis as a justification for subscriber subsidies. They make three important points. First, network externalities are mostly inframarginal at high penetration levels, and it is unnecessary to subsidize the bulk of subscribers who would join the network anyway. Second, economic efficiency is increased by targeting subscriber subsidies at marginal consumers who are most likely to generate network externalities. For example, these might be individuals who receive more calls than they make, and do not value communication sufficiently to subscribe without a subsidy. Third, subscriber subsidies only improve welfare if the external benefits of subscription from the network externality exceed the efficiency losses from financing the subsidies. These arguments lead the authors to the bottom-line conclusion that uniform subsidies are unlikely to improve average consumer welfare.

Although this conclusion is probably overdrawn, Barnett and Kaserman's three cautions are well taken. In particular, it is clearly desirable to target universal service support more efficiently. Third degree price discrimination, which offers discounts to selected consumer groups, or second degree price discrimination based on optional calling plans, are ways to do this.

3.4. Third degree price discrimination

Notwithstanding the attractive properties of Ramsey rules, a simple two-part tariff is not the best way to achieve universal service goals. The efficiency burden of maintaining universal service can be lessened by allowing price discrimination. Economists distinguish various kinds of price discrimination. First-degree price discrimination is charging different prices to different people based on their identity. Leaving aside the question of its legality, an effective first degree

[39] Implicit in this discussion is the idea that it may be possible to draw inferences about network externalities from changes in usage prices. The economic consequences of disconnecting someone from a network is not much different from charging an exceedingly high price for telephone calls. It may be possible to draw an inference about network externalities by extrapolating the consequences of small price change.

[40] This usage externality is discussed also by Taylor (2001).

price discrimination scheme is infeasible for mortal regulators because it requires an omniscient knowledge of consumers' preferences. Second-degree price discrimination is something of a misnomer, because all consumers are offered the same menu of choices and elect different items on the menu according to their preferences. Thus consumers end up paying different prices under second degree price discrimination because they choose to do so. Third-degree price discrimination charges different prices to groups of consumers based on observable characteristics of the group. Different prices based on income or location are examples.

Third degree price discrimination is a recognized tool for promoting universal service. The FCC's low-income and high-cost support policies, discussed in more detail in the next section, fall into this category. Low-income support policies provide discounts to individuals meeting certain means tests. High-cost support policies seek to narrow price differences based on the average cost of service in different locations.

The analytics of optimal third degree price discrimination are a straightforward generalization of the normative theories presented earlier. Suppose consumers are divided into two classes, Class I and Class II, and consider the theory of optimal two-part tariffs with access scale economies but no network externalities (a further generalization to allow for network externalities is pretty straightforward). In general, the two classes may have different demand characteristics and different costs of service. The Ramsey formulas for optimal usage and access prices generalize readily, with notation analogous to before. For Class I, the prices are

$$\frac{p_I - c_I}{p_I} = \frac{\lambda}{1+\lambda}\left[1 - \varpi_I\right]\frac{1}{\epsilon_I}$$
$$\frac{r_I - m_I}{r_I} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I}$$

and for Class II

$$\frac{p_{II} - c_{II}}{p_{II}} = \frac{\lambda}{1+\lambda}\left[1 - \varpi_{II}\right]\frac{1}{\epsilon_{II}}$$
$$\frac{r_{II} - m_{II}}{r_{II}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_{II}}$$

The optimal pricing policies for the two classes are linked by a common value of the Lagrange multiplier λ, which captures the social cost of meeting the expected profit constraint. The linkage arises because profits are aggregated across the two consumer classes. Thus, it is possible for profits on one class of consumers to compensate losses on the other.

This theory provides a rationale for low-income support policies. For simplicity, assume that both classes are served jointly and have the same cost of service, or equivalently that costs are "averaged". Assume also that both classes have the same price elasticity of usage, i.e. the two classes have different demand characteristics based only on different distributions of θ. For concreteness, suppose that Class II consumers are more likely to have a greater demand for usage, i.e. a lower value θ (in the sense of first-order stochastic dominance). Given the empirical evidence that usage increases with income (Crandall and Waverman 2000), it is natural to think of Class I as a low income group.

How should universal service support be targeted at low income (Class I) consumers? Applying the simplifying assumptions, the Ramsey formulas imply

$$\frac{p_I - c}{p_I} = \frac{\left[1 - \varpi_I\right]}{\left[1 - \varpi_{II}\right]}\frac{p_{II} - c}{p_{II}}$$

$$\frac{r_I - m_I}{r_I} = \frac{\eta_{II}}{\eta_I}\frac{r_{II} - m_{II}}{r_{II}}$$

That is, the price-cost markups for the two groups are proportional, although the proportionality factors differ for usage and access. For usage prices, the factor of proportionality depends on the ratios of usage demand for the marginal and average subscribers (ϖ) for each class. If both populations were to face the same prices, then the marginal type would be the same for the two classes, but $\varpi_I > \varpi_{II}$ because of differing mean values of θ. Thus the proportionality factor for usage prices is less than one, i.e.

$$\frac{[1 - \varpi_I]}{[1 - \varpi_{II}]} < 1,$$

indicating that Class I consumers should face a lower usage price. For access prices, the proportionality factor is the ratio of access elasticities. Although a common marginal type implies $m_I = m_{II}$, Class I would have a lower penetration rate because of the less favorable distribution θ, implying $\eta_I > \eta_{II}$, and indicating that Class I consumers should also get a lower access price. Since, at the point of no price discrimination, optimality conditions for usage and access prices fail in the same direction, it would be desirable both to lower p_I (relative to p_{II}) and to lower the price of r_I (relative to r_{II}), to bring the proportionality conditions into balance. This heuristic analysis suggests that optimal low income policies should involve both usage subsidies and access subsidies.[41]

The theory of third degree price discrimination also provides a logical basis for high-cost support policies, although the logic is rather different than for low-income support. Suppose that Class I and Class II consumers are identical, except that Class I consumers have a higher cost of access. At the optimum:

$$\frac{p_I - c}{p_I} = \frac{\lambda}{1+\lambda}[1 - \varpi_I]\frac{1}{\epsilon}$$

$$\frac{r_I - m_I}{r_I} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I};$$

and:

$$\frac{p_{II} - c}{p_{II}} = \frac{\lambda}{1+\lambda}[1 - \varpi_{II}]\frac{1}{\epsilon}$$

$$\frac{r_{II} - m_{II}}{r_{II}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_{II}}.$$

There are two interesting possibilities. On the one hand, if the marginal cost of access were the same for both consumer classes, and the difference were entirely in the fixed cost of access, then $m_I = m_{II}$ implies that both consumer classes should face the same prices. This is the economic logic for "geographic averaging". On the other hand, if the marginal cost of access were greater for Class I, then $m_I > m_{II}$ implies higher access prices for Class I. The resulting lower penetration rate means that $\eta_I > \eta_{II}$ and $\varpi_I > \varpi_{II}$; hence access and usage markups

[41] This theoretical analysis has not been developed much in the literature on optimal pricing. It is worth much more attention.

should be lower for Class I. Thus, some degree of geographic price discrimination is efficient when marginal access costs vary locationally. The price differences between the two classes for access and usage should move in opposite directions, even though the markup differences move in the same direction.

The fact that geographic price discrimination sometimes is efficient does not imply that the two geographic regions should be priced separately based on their respective costs. If the two classes were treated independently, then Class I would necessarily have higher markups to cover its higher access cost. Consequently, the structure of prices would be the same for both classes, except $\lambda_I > \lambda_{II}$. This means that it would be economically efficient to relax the profit constraint on Class I customers, and to tighten the constraint on Class II customers to make up the difference. This could be accomplished by balanced subsidies and taxes on the firms serving Class I and Class II consumers. These transfers should proceed until $\lambda_I = \lambda_{II}$ resulting in the optimal structure. Service to Class I consumers should operate at a deficit, recovered from profits (or taxes) on service to Class II consumers. This is almost a stylized description of federal high-cost policies in the United States. The difference is that in practice high income areas do not receive a usage subsidy, and perhaps receive an excessive access subsidy.

3.5 Second degree price discrimination

Optional tariffs are an example of second-degree price discrimination. Consumers are offered a choice of service plans, and allowed to self-select the plan that is best. In particular, consumers could be offered a range of service plans that trade off the access price against the usage price. Low volume consumers would prefer a plan with a lower access price and a higher usage price, and conversely for higher volume consumers. The optimal menu of service plans can be constructed using what are now well accepted methods from the mechanism design literature in economics.

The following analysis sketches the mechanism design approach to constructing an optimal menu of service plans, and characterizes the price distortions embedded in those plans. Let $[p(\theta), r(\theta)]$ denote the service plan chosen by a type θ consumer. Ignoring network externalities, the consumer enjoys a consumer surplus of

$$V(\theta) = \theta u(p(\theta)) - r(\theta)$$

Using standard analytical tools (i.e. the envelope theorem and integration), it can be shown that consumers maximize utility by choosing from the menu so that

$$V(\theta) = \int_{\theta_o}^{\theta} u(p(s))ds,$$

and that average consumer surplus over the entire population is

$$\bar{V} = \int_{\theta_o}^{\infty} u(p(\theta)) \left[1 - F(\theta)\right] d\theta.$$

Now consider profits. Sales to a type θ consumer are

$$X(\theta) = \theta x(p(\theta)) \equiv -\theta u'(p(\theta))$$

and access revenues are related to usage prices according to

$$r(\theta) = \theta u(p(\theta)) - V(\theta).$$

Allowing for scale economies, the profit earned on the type θ consumer is

$$\pi(\theta) = [\theta u(p(\theta)) - V(\theta)] + [p(\theta) - c]\, \theta x(p(\theta)) - \bar{h}(\theta_o),$$

and average population profit is

$$\bar{\Pi} = \int_{\theta_o}^{\infty} \left\{\theta u(p(\theta)) - [p(\theta) - c]\, \theta x(p(\theta)) - \bar{h}(\theta_o)\right\} f(\theta) d\theta - \bar{V}.$$

Maximizing the Lagrangian $L = \bar{V} + (1 + \lambda)\bar{\Pi}$ with respect to this price function yields the modified Ramsey formula

$$\frac{p(\theta) - c}{p(\theta)} = \frac{\lambda}{1 + \lambda} \frac{1}{\varepsilon} \left[\frac{1 - F(\theta)}{f(\theta)\theta}\right].$$

This formula depends on the hazard rate $\frac{f(\theta)}{1-F(\theta)}$, which is the probability of being a type θ consumer conditional on not being a lower type. If the hazard rate is increasing in θ, as it is for many common distributions, and the average profit constraint is binding ($\lambda > 0$), as it is in the presence of scale economies, then the usage mark-up is smaller for higher volume users.[42] For higher volume users, the usage price is closer to marginal cost. The access price is correspondingly higher for higher volume users, i.e. $r'(\theta) = -\theta x(p(\theta))p'(\theta) > 0$. Moreover, since usage is priced above marginal cost, it is immediate from the break-even constraint that $r(\theta) < \bar{h}(\theta_o)$ for at least some users. An optimal menu of service plans results in higher volume users selecting a plan with a lower usage price and higher access price. The usage price optimally is set above marginal cost for all but the highest volume users, and the access price is below the average cost of access for lower volume users.[43]

Cain and MacDonald (1991) provide some econometric evidence supporting the desirability of optional tariffs for local service. Their demand estimates show that, if a measured service option is available for local service, then telephone penetration is insensitive to the monthly charge for flat rate service. This result is consistent with the idea that marginal consumers opt for measured service when given the choice. Cain and MacDonald interpret their results in the following way (1991 p. 303):

> These estimates suggest that universal service can be maintained and expanded, even while more of the NTS financial burden is shifted to local charges. In particular, since telephone subscribership is sensitive to measured access charges, universal service goals can be met, at relatively low cost, by introducing and expanding budget measured service options.

[42] This generalizes the formula for an unregulated monopolist. See Tirole (1988 p. 156).

[43] Faulhaber and Panzar (1977) is an early analysis of the issue. Riordan (2000) considers the $c = 0$ case and shows that a choice of two extreme service plans is optimal. High volume users would choose a flat rate plan with unlimited long distance usage. Low volume users would choose a cheaper plan with prohibitively expensive long distance usage. By continuity, an extreme two-option menu is approximately optimal for c positive but sufficiently small. As a practical matter, the marginal cost of usage is dropping with technological advance and rapidly approaching zero.

Riordan (2000) points out that similar principles can be applied to long distance usage. In particular, consumers (or long distance companies acting as their agents) can be offered optional access arrangements, or, equivalently, optional arrangements for contributing to a universal service fund. Offered the choice, higher volume users would select a higher fixed monthly payment and lower usage-sensitive payment. Such an arrangement would better target universal service subsidies to marginal consumers.

4. POSITIVE ECONOMICS OF UNIVERSAL SERVICE

4.1 Cross-subsidies in the price structure?

Commentators frequently decry cross-subsidies in the structure of telecommunications prices. The AT&T divestiture was based partly on a claim of cross-subsidies running from local to long distance services (Temin 1990). In contrast, the frequent claims today are that business cross-subsidizes residential, long distance subsidizes local, and urban subsidizes residential services. While the term "cross-subsidy" often is used loosely even in the academic literature, economists typically are complaining that some set of services (residential, local, or rural) is priced below its long run incremental cost (LRIC). This appears to have become the "popular" meaning of cross-subsidy.

Twenty-five years ago, Faulhaber (1975) sought to discipline the discussion of cross-subsidies by advancing a formal definition and corresponding tests. He defined a subsidy-free price structure as one whose revenues do not exceed the stand-alone cost for any subset of services.[44] Moreover, assuming weak economies of scope, subsidy-free prices must also cover the incremental cost of any subset of services.[45] The stand-alone and incremental cost tests are equivalent for a zero-profit firm. If the firm makes positive economic profits, then cross-subsidies are indicated by a failure of the stand-alone test applied to whole product set, even though no product need fail the incremental cost test. Thus, the popular meaning of a cross-subsidy in a regulated price structure is justified in Faulhaber's (1975) framework if the firm is held to zero economic profits.

Temin (1990) recognizes Faulhaber (1975) by defining a "cross-subsidizing service" as one priced above stand-alone cost, but still accepts popular usage by defining a "cross-subsidized service" as one priced below LRIC. If the firm were to earn positive economic profits, then, by this terminology, it would be possible in the presence of joint costs to have a service receiving a cross-subsidy, but no other service doing the cross-subsidization. Temin meant these definitions to apply only to environments in which rate of return regulation held total profits to zero, e.g. the old Bell system.[46] In this case, a failure of incremental cost test for some group of services, necessarily implies a failure of the stand-alone test for other services.

A possible tension between the popular meaning and Faulhaber's definition of a cross-subsidy is revealed in the following quotation from Kaserman and Mayo (1994 pp. 135-6):

> To some extent, the argument over whether a subsidy exists is semantic. The answer hinges upon one's definition of a subsidy and how one would measure the

[44] The stand-alone cost is the cost of producing the relevant services in isolation.

[45] The incremental cost is the cost-saving from not producing these services. The necessary and sufficient condition for the equivalence result is that the services are produced subject to weak economies of scope.

[46] Personal communication with the author.

> costs of the services involved. Regardless of the position one adopts, however, there is no economic justification for a system that places the burden of fixed network costs on usage-sensitive prices. Such a system is inefficient whether or not a subsidy results. Consequently, one need not become mired in the subsidy debate to make definite statements about efficient pricing policies. We will continue to use the cross-subsidization terminology throughout the remainder of this article because it is convenient to characterize the overpricing of one service along with the underpricing of another as a cross-subsidy, whether or not these prices fall outside the range that the Faulhaber criteria define. What is more, we are convinced that such cross-subsidization exists, is substantial, and is an accurate description of the existing price structure in this industry.

Kaserman and Mayo's blanket condemnation of price distortions implicitly denies the importance of scale economies and network externalities. As discussed earlier, normative theory provides a rationale for recovering fixed network costs from usage sensitive prices under these conditions. However, more importantly for the discussion at hand is Kaserman and Mayo's insistence on evaluating the merits of price structures in terms of economic efficiency. This is undoubtedly the principal perspective of economists when discussing cross-subsidy issues. Economists' complaints about cross-subsidies typically are on normative grounds: prices below LRIC encourage an overexpansion of telecommunications networks and are a barrier to more efficient entrants.

In contrast, Faulhaber (1975) had a more practical preoccupation. He was concerned that prices above stand-alone cost were not sustainable in a competitive market. The reason is that an equally efficient entrant could successfully undercut a price above stand-alone cost. This is an important issue for universal service, especially in the wake of the 1996 Telecommunications Act. The Act intends to open all telecommunications markets to competition. To the extent that universal service implicitly is supported by Faulhaber cross-subsidies, these subsidies are likely to be undermined by new competition. Recognizing this, the Act requires that implicit subsidies be made explicit and portable.[47] State regulators have been concerned about too much competition until new universal service mechanisms are in place. So far, there has been substantial new entry into business markets and not much entry into residential markets, suggesting cross-subsidies flowing from business to residential services. The existence of such a business-to-residential cross-subsidy has been established empirically by Palmer (1992). Rosston and Wimmer (2000b) estimate that nationally the average revenue per line for local service is \$39.14 for business lines compared to \$18.29 for residential.

A problem with the stand-alone test is that the stand-alone cost of a group of services typically is not observed and therefore is difficult to estimate (Curien 1991). Palmer (1992) addressed this issue for the case of two services by deriving an upper bound on the stand-alone cost under a non-decreasing returns to scale assumption. Using this bound Palmer derived a pair of sufficient conditions for prices to satisfy the stand-alone and incremental cost tests

[47] A portable subsidy is paid to whichever firm provides services. The flip side of the sustainability argument is that services priced below their stand-alone costs are immune to new competition from equally efficient entrants. This appears to be the case for residential local access services in rural areas. Thus, these areas should not expect much local competition unless there is a portable explicit subsidy that makes up the difference. The FCC has recently established limited portable subsidies for the highest cost wire centers in the highest cost states, but largely has left to the states the problem of creating local competition in high-cost rural areas. See Rosston and Wimmer (2000).

for subsidy-free prices. Palmer estimated costs and revenues for 32 suburban central offices operated by New England Telephone in the mid-to-late 1980s. Almost all of these central offices failed the stand-alone test and a majority failed the incremental cost test. On average, residential revenue fell short of the lower bound on incremental cost by $0.39 per line per month, implying a business-to-residential subsidy of at least $3.45 per business line. These results suggest a substantial business-to-residential subsidy. However, Palmer does not provide confidence intervals or otherwise address estimation errors.

There is some controversy and confusion in the literature about whether long distance services cross-subsidize local services. The stylized fact is that the revenues from local services do not recover their stand-alone costs while the revenues from toll services exceed their incremental costs. The following statement by Curien (1991 p. 91) is typical:

> In telecommunications industries all over the world, the local networks run a deficit, i.e. the connection and subscription charges which are paid by users for their access fail to recover the cost of building and maintaining the connection line and other non-traffic sensitive equipment. As a result, the non-traffic-sensitive costs are subsidized by the revenues derived from traffic and especially from trunk traffic.

Such an assertion apparently flies in the face of Faulhaber's (1975) definition of a cross-subsidy. Indeed, the conditions identified by Curien satisfy Faulhaber's conditions for subsidy-free prices:[48] the price of access is below its stand-alone cost, and the price of usage is above its incremental cost. Gabel (1995) builds on this point, arguing that the access services provided by the local loop should be interpreted as a shared input into local exchange and toll services. The published literature does not contain any rigorous showing of a cross-subsidy from toll services to local exchange services.[49]

It is also widely held that geographic averaging results in a cross-subsidy from urban to rural services. This follows almost immediately for a zero profit firm under the reasonable assumptions that the stand-alone cost of urban service is substantially less than the stand-alone cost of rural services, and that joint costs are small. However, if the firm is making significant positive profits, then the validity of the claim is less clear. In the United States, regulated local exchange carriers are allowed to earn positive profits on unregulated vertical services, e.g. voice mail and call forwarding. The published literature lacks a rigorous demonstration of an urban-to-rural cross-subsidy that takes account of the profits from vertical services.

4.2 Low income subsidies

In the United States, universal service subsidies are targeted at low-income households via the Lifeline (LL) and LinkUp (LU) programs established by the FCC at the end of 1984. The LL program reduces the monthly cost of telephone service of eligible low income households by an amount equal to $7.00 currently.[50] States provide additional support resulting in total

[48] Curien's (1991 p. 91) characterization of a "cross-subsidy from traffic to access" is based on an *ad hoc* approach of using "revenue trade-offs" to measure cross-subsidies. The revenue trade-off approach arbitrarily allocates profits and costs to services, including joint and common costs, and asks whether service revenues recover allocated costs plus profits.

[49] See L. Taylor (1993), W. Taylor (1993), Kahn (1993), Gabel and Kennet (1993), and Gabel (1995) for debate on whether access should be regarded to be an input or a separate service.

[50] This is twice the federal subcriber line charge (SLC). The SLC is scheduled to increase to $5.00 under a recent FCC access reform order. Presumably, the LL subsidy will increase commensurately.

monthly subsidies typically ranging between \$5.25 and \$10.50; the Virgin Islands is an anomaly with total support of \$14.05. The LU program subsidizes the installation charges of a new subscription for eligible households up to \$30 plus up to \$200 in interest on deferred payments. Eligibility criteria for both programs are established by the individual states subject to FCC approval and vary widely (Federal Communications Commission 1999). Together, the federal components of these programs are projected to cost \$480 million in 1999 (Eisner 2000).

Schement, Belinfante and Povich (1997 pp. 193-6) identify twelve states who experienced large increases in telephone penetration for low income households between 1984 and 1994: Connecticut, Georgia, Hawaii, Michigan, Nevada, New Mexico, North Carolina, South Carolina, Tennessee, Vermont, Washington, and Wyoming. Two-thirds of these states were among the early adopters of the federal low-income support programs. This casual evidence suggests that LL and LU programs have been effective at promoting universal service.

There is also some more rigorous empirical evidence showing that low-income subsidies have increased telephone penetration rates, although the quantitative impact appears to be small relative to the cost of these programs.[51] Table 4 reports selected regressions from three different studies: Garbacz and Thompson (1997; hereafter G&T); Eriksson, Kaserman and Mayo (1990; hereafter EKM); and Crandall and Waverman (2000; hereafter C&W). The three studies employ different data; G&T examines state-level data from the 1990 census; EKM examines annual state-level data from the Current Population Survey; and C&W examines 1990 census data at the level of town. The three studies also employ different specifications, and report the significance of estimates differently.[52]

G&T estimate a logit model of state-level penetration, and conclude that the LL and LU programs have a statistically significant but small marginal effect on penetration for the average state. Their explanatory variables include the monthly price of (flat rate) local service, and the installation charge for new accounts. Demographic variables include the percent of households living below the poverty line, and the percent of households living in urban areas. The key variable for testing the effectiveness of low income subsidies is the amount of LL and LU funds paid out per poor household in the state. Although G&T interpret their regression equation as a demand equation, the price variables are not significant.[53]

EKM report a related analysis based on pooled state-level cross section and time series data for the period from 1985 through 1993 and draw similar conclusions. The annual penetration data is drawn from the Current Population Survey, which Garbacz and Thompson (1997; 2000) criticize as being more subject to measurement error than the decennial census data, resulting in unreliable estimates. Also worrisome is that EKM apparently ignore serial correlation in the error terms for each state, which could bias their statistical tests. EKM find a positive significant effect of LL and LU subsidies only in states that have a large poor population.[54]

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[51] Park and Mitchell (1989) show in a calibrated simulation model that Lifeline rates are unlikely to significantly increase penetration.

[52] See also Albery (1995) for a related study.

[53] This could be due to endogeneity bias. Prices of local service and installation are regulated by the states. The coefficients on these variables would be biased toward zero if states with low penetration rates tended to choose lower prices for residential service. (The LL and LU estimates could suffer similar endogeneity bias; see the discussion of C&W below.) G&T do find significant price coefficients in other specifications.

[54] EKM include 1984 penetration in all of their specifications as an explanatory variable "in order to standardize for the cross-sectional variation in the observed penetrations rates prior to the sample time period." It is unlikely that the relationship is stable over time; why should penetration levels in 1993 and 1998 bear the same relation

Both G&T and EKM interpret the estimated quantitative significance of the low income subsidies with the aid of "policy experiments". G&T estimate from their regression analysis that an across the board 10% increase in subsidies would increase average penetration by "substantially less than one tenth of one percent." EKM conclude that an additional $10,000 in subsidies would add only 18 new subscribers for a state whose poverty level is average, and 75 new subscribers for the poorest states. While these calculations are provocative, the policy interpretations are not really valid, because the parameter estimates on which they are based do not have clear structural interpretations. In particular, the models do not distinguish whether the increased subsidy levels of the policy experiment come from more generous support levels or more generous eligibility criteria.

To illustrate how eligibility criteria might matter consider the following simple model. Suppose that a subsidy of s dollars is targeted at households below the poverty line, but that the prevailing eligibility criterion results in only a fraction λ of poor households being able to receive the subsidy. Suppose further that households above the poverty rate choose to have a telephone with probability β_1, subsidized poor households with probability β_2, and unsubsidized poor households with probability β_3, with $\beta_1 > \beta_2 > \beta_3$. If POV is the poverty rate, then the observed penetration rate would be

$$PEN = \beta_1(1 - POV) + \beta_2 \lambda POV + \beta_3(1 - \lambda)POV$$

and the subsidy per household would be

$$SUB = s\lambda POV.$$

Thus, looser eligibility criteria (i.e. higher λ) increases both the penetration rate and the amount of subsidy. Solving these two equations to eliminate λ gives

$$PEN = \beta_1 - (\beta_1 - \beta_3)\, POV + \left(\frac{\beta_2 - \beta_3}{s}\right) SUB.$$

Therefore, holding constant the amount of the subsidy (s), the penetration rate is decreasing in the poverty rate and increasing in the subsidy per household (SUB). In this specification, the subsidy per household is serving as a proxy for eligibility criteria. This simple model provides some justification for including per household subsidies directly into a penetration equation, but also suggests that functional form may be important and that the parameter estimates need to be interpreted carefully. In this example, a doubling of subsidy payments corresponds to the policy experiment of doubling the size of the eligible population. The effect of this experiment on measured penetration would be $\beta_2 - \beta_3$. Thus, the estimated coefficient on SUB would have to be multiplied by s to measure the effect of the policy change on telephone penetration.

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to 1984? It is not clear *a priori* how this source of specification error might bias the estimated effects of the low income subsidies. G&T show in their study that inclusion of lagged penetration does not much matter.

Table 4: Effectiveness of low income subsidies

study	G&T[55]	EKM[56]	C&W[57]
data source	1990 census	1985-93 CPS	1990 census
dependent variable	$\ln\frac{penetration}{1-penetration}$	$penetration$	$penetration$
(test statistic)	(standard error)	(t-statistic)	(t-statistic)
constant	3.35* (0.728)	0.54622* (16.879)	1.003* (146.6)
local service price	0.009 (0.008)	−0.00103* (4.103)	0.00017 (0.94)
installation charge	−0.003 (0.003)	−0.00032* (3.824)	−0.00070* (9.51)
long distance price		−0.10593* (6.064)	0.00096 (0.44)
p.c. income			0.00048* (7.09)
% poor	−8.757* (0.728)	−0.00200* (7.041)	−0.282* (6.43)
% poor squared			0.292* (2.83)
% urban	0.473* (0.132)		
% rural		−0.00013 (1.628)	
population density			0.0047* (5.22)
% black		−0.00040* (4.0060)	−0.034* (5.30)
% Hispanic		−0.00039* (2.926)	−0.032 (5.82)
penetration in 1984		0.50301* (16.036)	
p.h. LL-LU subsidy		−0.00605* (2.142)	
p.h. LL-LU subsidy×%poor		0.00059* (2.482)	
p.h. LL-LU subsidy÷%poor	0.017* (0.002)		
LL dummy×%poor			0.016 (1.30)
LU dummy×%poor			−0.098* (5.06)
p.h. high cost payments		−0.00009 (0.413)	
R^2	-	.8424	0.736
# observations	44	432	1,897

* Statistically significant at 0.05 level.

A priori, C&W seems the most interesting of the three studies because it relies on more disaggregated data. The study matches price data to census data on towns (cities, or designated places). The price data were obtained directly from large local exchange carriers, resulting in 1896 observations. The study measures the effect of LL subsidies with a dummy variable for the state's implementation of the program interacted with the poverty rate. Effectively, this is measuring whether poor communities in states who have LL programs in place have higher penetration rates than similar poor communities in states lacking LL programs. The regression analysis does not find a significant effect of LL on the measured penetration rate. This seems consistent with their related finding that the effect of local service prices is not significant either.

[55]This is regression (2) in Table 4 of Garbacz and Thompson (1997).

[56]Model A in Table 2 of Eriksson, Kaserman, and Mayo (1998).

[57]Model (1a) in Table 5-5 of Crandall and Waverman (2000).

These results suggest that LL has not been an effective policy tool for advancing universal service. It is possible that the supporting estimates suffer from endogeneity bias, although this seems less likely than in G&T and EKM, because in C&W the regulated prices and subsidy policies are set at the state level while penetration is measured at the town level.

C&W measure the effect of LU simply as a dummy variable interacted with poverty, effectively comparing penetration rates of poor towns in states with and without the LinkUp program. The regression equation finds that the LinkUp policies have a statistically significant *negative* effect on telephone penetration. This paradoxical result seems hard to explain, and appears inconsistent with the finding that higher installation charges reduce penetration. C&W suggest that the result is due to the fact that only two states, Delaware and Illinois, lacked LU programs and that the regulators in these states declined to implement LU because penetration rates were already high. In other words, the estimated coefficient suffers from an endogeneity bias. In view of this potential problem, the C&W study does not appear to provide very convincing evidence on the effectiveness of LinkUp.

4.3 High cost subsidies

Telephone companies serving high-cost areas in the U.S. receive direct subsidies. Federal subsidies to companies serving high-cost areas have been paid out under a variety of mechanisms (Federal Communications Commission 1999). "High-cost loop support" has been given to companies with above average non-traffic sensitive costs. Additional "long term support" subsidizes a uniform below-cost carrier line rate for participating companies. Finally, "local switching support" defrays some of the traffic sensitive costs of companies serving small market areas. Taken together, these mechanisms provided \$1.7 billion in assistance in 1999. A new high-cost program established in 2000 consolidated the subsidies to larger companies in a new cost fund, and established intrastate subsidies based on forward-looking economic cost and targeted to high-cost wire centers within the receiving state. The Telecommunications Act requires that implicit universal subsidies be made explicit and financed by taxes ("contributions") on the revenues of telecommunications companies. The federal programs are financed by taxes on interstate and international revenues.

Eriksson, Kaserman and Mayo (1998) studied the effectiveness of high-cost support on the prices of Bell Operating Companies (BOCs) with the following regression equation

$$PRI = 15.53250 + 0.014660 \cdot CST - 20.20702 \cdot BUS - 0.13469 \cdot USF$$

where PRI is a weighted average flat rate for residential service, CST is the historical cost of "outside plant" for providing local access in the rate base, BUS is the ratio of business and residential lines, and USF is high cost support per household paid from the Universal Service Fund. These variables are measured at the state level. Although the coefficients are all statistically significant, the R^2 of this regression equation is only 0.20. The regression indicates a negative correlation between the amount of high cost support and the price of local service. This estimated equation suggests that an extra dollar of high-cost support translates into only a 13 cent reduction in the price of local service. Thus, given a low price elasticity for local access, this suggests that high-cost subsidies paid to companies are not very effective at increasing penetration rates. Indeed, Eriksson, Kaserman and Mayo (1998 p. 498) conclude that a \$10,000 increase in BOC high-cost support would add only 15 subscribers at a cost of

$666 per new subscriber. As above, this "policy experiment" is suggestive, but not definitive because the estimated parameters lack clear structural interpretations.

Recent FCC policy has left the problem of high-cost support largely to the state jurisdictions. Rosston and Wimmer (2000a) ask what level of state universal service funds would be necessary to cover the forward-looking economic costs of local service under the assumption that telephone companies earn $32 per line, which is a benchmark revenue level that the FCC had considered previously as relevant for establishing high-cost support levels. They estimate that the state high-cost subsidies would come to almost $3 billion in the aggregate, the financing of which would require consumers to pay an weighted-average tax rate of 2.41% on intrastate revenues. They further estimate that, if instead of establishing high-cost subsidies, the states rebalanced rates to reflect costs, then telephone penetration rates would drop by only one-half of one percent nationwide. This calculation leads them to question whether this modest effect on penetration is worth the efficiency loss created by the distortionary revenue taxes, and to recommend that high-cost support be targeted better to low-income households.

5. CONCLUSIONS

A number of conclusions can be drawn from this survey of issues about universal residential telephone service. First, the two important "underserved" populations in the United States are the poor and Native Americans. These populations have substantially lower residential telephone penetration rates even after controlling for locational, demographic, and cost factors. Second, although penetration rates for similar communities are different in different parts of the United States, differences in state regulatory policies account for no more than 1-2% of this variation. Third, the extent to which "taxes" on long distance usage are an inefficient means of public finance for universal service programs depends on details of the industrial organization of long distance telephone services. Fourth, while scale economies and especially network externalities provide potentially important theoretical rationales for universal service policies, the empirical evidence on their quantitative significance is scant and inconclusive. Fifth, optional tariffs governing local and long distance toll services potentially are effective devices for targeting implicit subsidies for local access. Sixth, there is some econometric support for the proposition that business rates have cross-subsidized residential rates, according to the formal economic definition of a cross-subsidy, but the frequent claims that long distance cross-subsidizes local and that urban cross-subsidizes rural services rest on more casual appraisals. Seventh, although economic theory provides rationales for well-designed low-income and high-cost support policies for promoting universal service, the limited empirical evidence on the issue suggests that low income and high-cost subsidies have at best a quantitatively small impact on penetration rates relative to their cost.

The main conclusion of the chapter, though, is that there remains a shortfall of research on the economics of universal service. First, the determinants of telephone penetration are still not completely understood. For example, it is unclear why Native American populations suffer lower telephone penetration even after controlling for poverty, climate, and costs. It is also unclear to what extent price regulation and universal service policies explain state-specific variations in telephone penetration. Second, the empirical importance of scale economies and network externalities as rationales for universal service remains cloudy. For example, more information on usage profits earned by service providers on marginal subscribers would permit a better calculation of the economic opportunity cost of expanding basic access services. A serious attempt to estimate the quantitative significance of "long distance network externalities" from price elasticities for long distance services would contribute usefully to the policy debate. Evidence on the significance of offsetting call externalities is also sorely needed. Third, an empirical quantification of the potential welfare gains from implementing optional tariffs, or other forms of second-degree price discrimination, seems to be within reach of modern structural econometrics with a sufficiently rich data set (Miravete 2000). Fourth, well-crafted tests of the propositions that long distance has cross-subsidized local services and that urban have cross-subsidized rural services are long overdue. Fifth, a fully convincing appraisal of the performance of low-income and high-cost programs in advancing universal service awaits better data and more careful econometrics. Settling these issues for the paradigm problem of maintaining and advancing basic universal residential telephone service will strengthen the foundations for debating and evaluating the next generation of universal service policies.

Only a few qualified lessons can be drawn for policy-makers. First, while state regulators should "benchmark" their regulatory and universal service policies to other states, the adoption of "best practices" might increase residential telephone penetration by only a few percent. Second, even though policy-makers can in good faith remain hesitant to embrace too closely the chorus of calls for strict cost-based pricing of local access services, the economic case for a significant markup of usage prices is debatable. Third, while the FCC and the states should consider optional arrangements for universal service contributions as a better way to target universal service support, the quantitative significance of such policies remains an open question. Fourth, the FCC most likely should exempt service provided to Lifeline and LinkUp recipients from universal service contributions. All such advice is tentative, of course, pending further economic research.

Although beyond the scope of this chapter, it is worth mentioning, in closing, a few upcoming issues. One new issue is universal service auctions. The 1996 Telecommunications Act opens the door for the FCC to consider auctions as an alternative mechanism for high-cost support. The FCC has so far refrained from doing so, although in its 1997 *Universal Service Order* expressed an intention to open a proceeding on the matter. In the mid 1990s, California considered but did not adopt auctions for awarding state high-cost support. Other places, including Europe and Australia, have also considered auction mechanisms for high cost support. There is a new theoretical literature on the topic (Laffont and Tirole 2000; Sorana 2000). Another new issue for which there is an emerging literature is the effect of universal service policies on competition (Gasmi, Laffont, and Sharkey 2000; Choné, Flochel, and Perrot 2000). The Telecommunications Act requires that universal service policies in the United States be competitively neutral. In the U.S. and even more blatantly in other countries, new competitors pay taxes to incumbents to help finance the incumbents' universal service obligations. Armstrong (2001a, 2001b) argues that a well-designed universal service policy, together with cost-based access pricing, nevertheless can provide efficient incentives for entry and make-or-buy decisions. A third emerging issue is a broader definition of universal service, discussed by Crandall and Waverman (2000). There is considerable and growing political pressure to further expand the definition of universal service to encompass Internet access. Downes and Greenstein (1999) show empirically that access to Internet services is already widely available, albeit at very different speeds in different places. Cremer (2000) develops a theoretical argument that network externalities might be particularly strong for broadband Internet service. These are all likely to be among the important universal service policy issues in the coming decade.

6. APPENDIX: VARIABLE DEFINITIONS AND SUMMARY STATISTICS FOR TABLE 1

6.1 Census data

The following variables were created from the 1990 Census STF-3 files. Each variable is measured at the Census Block Group (CBG) level.

Penetration is the fraction of occupied housing units in the CBG with a telephone in the housing unit.

% Poor is the fraction of CBG population living below the poverty line.

Median income is the median household income of the CBG, measured in thousands of dollars.

% Female head of household is the fraction of households in the CBG with a female head of household.

% Senior the fraction of CBG population that is 65 years of age or older.

% Children the fraction of CBG population that is 15 years of age or younger.

% High school is the fraction of CBG population with a high school degree, including those with some college but no college degree.

% College is the fraction of CBG population with a college degree.

% Black is the fraction of CBG population that is black.

% Hispanic is the fraction of CBG population that is of Hispanic origin. If a person is black, white, Asian, etc., and also of Hispanic origin, then they are counted only as being Hispanic.

% Native the fraction of CBG population that is Native American.

% Asian the fraction of CBG population that is Asian.

% Other nonwhite the fraction of CBG population that is nonwhite and not a member of the aforementioned race categories.

Population density is the number of people, measured in thousands, per square kilometer living in the CBG.

Wire center population is the number of people, measured in thousands, living in the area serviced by the same wire center that services the CBG. This variable was created from the 1990 Census STF-3 files, but only after linking the CBGs to wire centers using data obtained from the FCC.

6.2 Climate data

In order to measure the effect of climate on telephone penetration, data from the United States Historical Climatology Network (U.S. HCN) was linked to the census data.[58] The U.S. HCN data is measured at the station level, identified by its latitude and longitude. Each CBG was assigned to the station with the minimum product of absolute differences between latitude and longitude. Data is available from 1221 stations for the 48 contiguous state, although data from Tennessee was missing. Data for Alaska, Hawaii, and the District of Columbia are not available from this source. A fully quadratic form was specified for the following variables:

Temperature is the annual mean temperature in 1989 recorded by the station, within state, nearest to the CBG.

Precipitation is the total precipitation in inches in 1989 recorded by the station, within state, nearest to the CBG.

6.3 Cost Data

The FCC has published an economic-engineering model that estimates, among other things, the forward-looking economic cost of providing basic local service.[59] This model incorporates locational data and 1996 quantity and price data into an optimization model. The cost estimation procedure is based on the FCC's TELRIC (total element long run incremental cost) methodology. The CBGs are matched to wire centers. Given the relatively small increase in telephone penetration rates in recent years, the relative forward-looking costs probably have not changed too much between 1990 and 1996, except that boundaries of wire centers do change occasionally. For given wire center assignments locational data, e.g. terrain, which are a critical determinant of cost differences, certainly remain constant.

Not every CBG can be matched to a wire center. The model uses a selection of wire centers in Bellcore's LERG database. Only wire centers which were listed as end offices, hosts or remotes, and which were not owned by wireless, long distance or competitive access providers were used. This left roughly some 12,000 wire centers, covering roughly half of the original sample of CBGs. When wire centers are matched to the CBGs for which weather data is available, roughly forty percent of the original sample of CBGs were left.

The cost variables used in the estimation are defined as follows.

Loop length is an estimate of the average length of the connection of the customer to the wire center, including distribution (the cable connecting a customer to a Serving Area Interface (SAI)) and feeder (the cable connecting an SAI to a wire center) distances.

Average forward looking cost is the FCC's estimate of the average monthly forward-looking cost of providing basic local service, including distribution, feeder and end-office switching costs, measured in dollars.

[58] The U.S. HCN data is made publicly available by the Carbon Dioxide Information Analysis Center. For more information see: Easterling, D. R., T. R. Karl, E. H. Mason, P. Y. Hughes, D. P. Bowman, and R. C. Daniels, T. A. Boden (eds.). "United States Historical Climatology Network (U.S. HCN) Monthly Temperature and Precipitation Data." ORNL/CDIAC-87, NDP-019/R3. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory. Oak Ridge, Tennessee, 1996.

[59] See Sharkey (2001) for a description of the FCC's Hybrid Proxy Cost Model.

6.4 Summary statistics

Table 5: Summary Statistics

	(I)		(II)		(III)-(V)	
	mean	s.d.	mean	s.d.	mean	s.d.
Penetration	93.9	9.0	94.4	7.9	94.3	7.8
% Poor	14.0	14.1	12.8	12.6	12.7	12.5
Median income	31.2	16.4	31.9	15.9	31.7	15.7
% Female h.o.h.	11.8	10.4	10.6	8.9	10.7	9.0
% Senior	13.3	9.2	12.9	9.0	13.1	8.8
% Children	23.8	9.2	23.7	9.0	23.6	8.8
% High School	31.8	9.5	32.1	8.9	32.2	8.7
% College	16.3	12.3	17.0	12.2	16.7	12.0
% Black	12.4	25.1	10.1	21.2	10.9	22.0
% Hispanic	7.6	16.5	7.4	15.8	5.7	13.6
% Native	0.9	4.9	0.7	3.8	0.7	3.4
% Asian	2.2	6.3	2.4	6.5	1.9	5.0
% Other nonwhite	0.1	0.6	0.1	0.5	0.1	0.5
Pop. density	2.9	4.8	1.9	5.0	2.0	5.4
W.c. population			29.7	26.3	28.3	25.7
Loop length					21.0	19.0
Average f.l. cost					31.4	25.2
Temperature					53.8	8.2
Precipitation					42.0	16.0
# Observations	222,264		116,715		95,171	

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