LATECOMER COST HANDICAP IN SATELLITE COMMUNICATIONS

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This article offers an overview of equity and efficiency in the management of global spectrum resources. It identifies latecomer cost handicaps and outlines a methodology to assess these costs empirically. The paper also considers the degree to which free-rider benefits offset any handicaps. Finally, eight possible arrangements are identified through which latecomer cost handicaps could be avoided or offset.

Keywords: Satellite communications; Orbit spectrum resource; Latecomer cost handicap

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At the Second Unispace Conference in 1982, a first Draft Report submitted by several developing countries proposed that certain developed countries vacate the lowest space satellite spectrum – the C-band – and move up and develop the higher KU and still higher KA bands. Those developing countries perceived this as a means to shunt off the higher development, capital, and operating costs of systems installed higher up, onto the advanced nations best able to bear them. This would supposedly leave the more congenial, less expensive lower spectral regions to the less affluent nations.[1] The proposal was subsequently withdrawn through a Brazilian initiative in the face of strong resistance by developed countries (DCs) determined to protect their investment equities.

More generally, Third World resentment to the practice of awarding rights to build space satellite systems on a first come, first served basis is seemingly based on what those nations perceive as the dwindling availability of needed assignments. The less developed countries (LDCs) also fear the handicaps they suffer due to the higher R&D and engineering costs incurred to open up new bands higher up.

Similar issues have in fact been raised *within* the USA. For example, UHF TV stations are more costly to build and operate than VHF stations in that they require far more signal power per 1000 TV homes reached, and to ensure signal quality comparable to that enjoyed by VHF stations. Furthermore, latecomer VHF entrants must also pay far more to buy an existing VHF as congestion grows than they would have had to spend to build a new one at the outset.[2] Similarly, AM radio latecomers had to buy existing AM stations in the market at inflated prices when that band became too saturated to accommodate new entrants. Furthermore, AM latecomers also had to pay a lot to avoid illegal interference with incumbent AM licensees in congested regions – hence the high coordination costs which latecomers incur, to which we return momentarily.

There is a third and final domestic analogy in land mobile radio where, once again, capital and operating costs appear to rise notably per square mile of area covered, as we move up from 50 to 800 MHz.[3] This seems to be true whether we hold power constant and increase antenna heights, or hypothetically hold antenna height constant and increase power. Here, too, in this important radio band, latecomer firms appear to suffer clear cost handicaps.

Within this framework this article examines five issues. First, it offers an overview of equity and efficiency in the management of global spectrum resources. Second, it identifies latecomer cost handicap and then analyses that hypothesis in theoretical terms. Third, it outlines a methodology through which to assess the hypothesis empirically. However, empirical studies could not be undertaken here, nor even summarized. Fourth, the paper considers the degree if any to which free rider benefits enjoyed by latecomers may at least mitigate their alleged cost handicap. Fifth, it briefly identifies no less than seven arrangements through which net latecomer cost handicaps (assuming such do exist) could be avoided or offset perhaps significantly, and concludes by describing an eighth, somewhat different approach.

Equity *v* efficiency

'Parking places' in the geostationary orbit, and the space satellite frequencies associated with them for purposes of information delivery, constitute precious communications resources. Guaranteed equitable and efficient access constitutes a kingpin of policy imperatives in the International Telecommunication Union (ITU) and other international organs today. Orbit spectrum is by no means unlimited in its current or projected availability, but its precise degree of scarcity is still subject to debate by engineers, technologists, lawyers and economists. However, identification of the services, spectral bands, and orbital regions to which access is already congested or seems likely to become so, is both possible and an urgent item of business for the first session of WARC–ORB–85.[4]

Among a large number of conceivable organizational, procedural and policy approaches for managing these precious resources, the dialogue in international decision making arenas has until recently focused increasingly on two polar bounds. First is the notion that the evolutionary process now in force will best serve the interest of all nations. It would allegedly do so by facilitating an economically efficient use of orbit spectrum consistent with flexible responses to changing telecommunications needs in a context of technological change, all on a first come, first served basis.[5] Second is the notion that some form of detailed *a priori* planning will best serve the interests of all nations in the equitable use of global orbit spectrum resources.[6]

Critics of present coordination procedures further observe that, under principles of first come, first served, those procedures impose sizable (and for the critics, unjustifiable) cost burdens on developing countries as latecomers or new entrants into space satellite communication.[7] Indeed this is said to be true even though those critics deem orbit spectrum to be a global resource belonging to all nations, and not just to a few with the technology and know-how to use it now.

For the critics of detailed *a priori* plans, on the other hand, those planning mechanisms will unavoidably operate to stifle or freeze the kind of technological advance and flexibility deemed to be highly essential to implementing the ITU directive that orbit spectrum be managed with economic as well as technical efficiency.

Finally, there is evidence that a far wider range of planning options are under review in both developed and developing countries and that

[1]See *Draft Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space*, UN Doc A Conf 101/10/PC/L20/Add 1,2, 1982. Latecomer developing countries urged that 'the newer and more expensive technolgies that lead to better utilization ... should be adopted by the developed countries and by international systems, so that the comparatively simple and cheap technologies (eg lower frequency bands 4 and 6 GHz) are freed for use by developing countries' (*Idem* at para 275). Significant cost reductions for LDCs would also be facilitiated if 'developed countries shift their satellite ... systems to a different frequency band (e.g., 11/14 GHz,) leaving the 4/6 GHz band basically for use by developing countries' (*Idem* at para 150).

[2]See Harvey J. Levin, *The Invisible Resource*, John Hopkins University Press, Baltimore, MD, 1971, pp 219–28; also Harvey J. Levin, *Fact and Fancy in Television Regulation*, Russell Sage Foundation, 1980, pp 120–23, especially Tables 4.5, 4.6.

[3]See generally Levin, 1971, *op cit*, Ref 2, pp 205–14.

[4]See Harold G. Kimball, 'Implications for the future of satellite communication', presented at 1984 Annual Conference of International Institute of Communications, Berlin, 21–23 September 1984, pp 2–3 (hereafter called 1984 IIC Berlin Conf.).

[5]A generous review of first come, first served under current coordination procedures of the International Telecommunications Union (ITU) appears in First Report of the Advisory Committee for the ITU's World Administrative Radio Committee on the Use of the Geostationary Satellite Orbit and the Planning of the Space Services Utilizing It, December 1983, sec 4D (The Current ITU Arrangements Ensuring Access to the Geostationary Orbit), pp 4–18 to 4–28 (hereafter called First Advisory Report).

[6]This position was recently expounded by T.V. Srirangan, Wireless Advisory to the Government of India, Ministry of Communications, New Delhi. See his 'Equity in orbit: planned use of a unique resource', 1984 IIC Berlin Conf, pp 8–10; and 'The World Administrative Radio Conference for the Planning of the High Frequency Broadcast Band – a viewpoint', 1983 IIC Annual Conference, Aruba, 24–27 September 1983, pp 2–5. For a further contrast of current first come, first served arrangements and planning alternatives at WARC–ORB–85 see varying perspectives of William H. Montgomery, 'Views of the 1985 space conference – perspectives on frequency planning in the ITU', 1984 IIC Berlin Conf, pp 1–6; and Kimball, *idem*, pp 1–6.

[7]See Srirangan, *op cit*, Ref 6, pp 3, 4, 7.

the initial rigid dichotomy between first come, first served and detailed long-term plans has begun to break down.[8]

Theoretical analysis of latecomer handicap

For analytical purposes I assume that firstcomers (in advanced economies) may enter prematurely for fear that rivals would do likewise. I further assume this may result in a land-rush type syndrome such that there will be: uneconomic excessive entry by developed country satellite entities, but also more competition in those markets on that count at least; latecomer cost handicap, and hence impeded entry for developing countries, domestically and internationally, when the latter are otherwise ready to enter such fields as high frequency radio, land mobile, terrestrial TV broadcasting, or fixed and broadcast satellites; and *a priori*, pre-engineered planning of direct broadcast satellites by LDCs to reserve orbit-spectrum assignments for themselves thereby further intensifying the developing countries' rush to enter and even to innovate for narrower spacing of satellites in the orbit arc, even if uneconomic.

The focus of this article is on the second and third issues. However, the paper also assesses the contention that technical advances by DCs, and resultant technology transfer, will act to reduce satellite capital and the operating costs at least enough to mitigate latecomer private cost handicap. Time and space do not allow me to deal with the related issue of the optimal size management unit for orbit spectrum resources generally, with special reference once again to the level of entry barriers which face new entrants.

In particular, then, the paper focuses on telecommunications market structures, all on the assumption that orbit-spectrum location has discernible effects upon entry barriers with special reference to the cost handicaps of latecomer users (firms, governments and other entities), as well as to the tendency towards premature entry, investment and occupancy by users in advanced economies.

A number of surprisingly neglected issues for review here are: the allegation that the developing countries claim-staking strategy will result in fuller and faster entry than otherwise, even if uneconomic; the further allegation that latecomers may be relatively if not absolutely precluded from orbit spectrum, due in large part to significant private cost handicaps, albeit partly offset by compensating free-rider benefits where the developing countries innovate new technology; and, the final allegation that LDCs press for detailed *a priori* pre-engineered allocation plans, so as to prevent serious entry-blocked cost handicaps, and to safeguard Third World access prospects, even though such plans may blockade developing country entry in certain regions and services, and also force developing countries to innovate uneconomically for narrower orbital spacing.

In regard to the relative position of latecomer and firstcomer users of orbit spectrum and other information resources where users may include firms, governments, and governmental agencies, the question is whether information systems suffer cost handicaps in using higher spectral regions, elliptical or random orbits, or in designing narrower orbit spectrum spacing; and whether latecomers therefore suffer such handicaps across countries as well as within their own. Or, from still another viewpoint, does the uncertainty of any future access at all (or at

[8]For a highly illuminating, devil's advocate case for *a priori* planning generally as the way to mitigate latecomer cost handicap, see FCC Space WARC Advisory Committee, *Interim Report of Proposal and Evaluation Test Group*, 20 November 1984, SWAC/DOC PEG #8, at secs I–IIIA; see also secs IIIB–IIIC. More specifically, the widest range of management arrangements appear in the eleven methods identified and reviewed in First Advisory Report, sec D, pp 5–19 to 5–35. These were reduced to seven at the CCIR's Conference Preparatory Meeting in Geneva, June 25–July 20 1984, including five methods laid out in the Report of IWP/1 contained in CPM doc no 30, a sixth submitted by the USSR (on loosely packed plans with minimum and maximum values for each assignment), and a seventh by China (focused on computerized decision making) [See Report of the CCIR Conference Preparatory Meeting (CPM), International Telecommunication Union, Geneva, June 25–July 20, 1984, Part II, pp 132–56.] Most recently, the International Regulations Working Group of the Space WARC Advisory Committee fashioned an illuminating 'Combined Planning Approach', drawing upon 'concepts associated with all of the Planning Methods identified in the CPM Report'. These included computerized modelling methods, the French interference harmonization method, the establishing of certain minimum–maximum values of technical parameters for flexibility, a basic 30-year *a priori* plan to implement which there would be an 8–10 year Consultation Conference, and a set of interim arrangements including simplified use of current coordination procedures (See Second Advisory Committee Report for ITU WARC–ORB–85, sec II D4).

least the fear of cost disadvantages due to less preferred locations) lead latecomers to seek detailed *a priori* planning and earmarked access rights, all at the expense of economic efficiency and flexibility for latecomers and incumbents alike?

In terms of a theoretical *a priori* microeconomic model, the divergence of private and social cost under current spectrum management arrangements must be discussed relative to three separate factors: first, the apparent zero price of spectrum to users permitted access to it under the present centralized non-market system of allocation on a first come, first served basis; second, the extra cost imposed on potential (next-best) users where, as latecomers, any prior usage denies them access to that spectrum in whole or in part, or reduces signal quality due to congestion and higher interference levels; and third, the lower resultant private than social cost of spectrum usage which will then be related to latecomer cost disadvantage by considering the process whereby entry continues until spectrum congestion and interference raise marginal private spectrum costs to a level where the demand for and supply of spectrum come into equality.

Microeconomic analysis then further enables us to hypothesize about latecomer cost disadvantage as it may in principle operate within nations at various stage of economic development, or across nations competing for limited orbit and spectrum resources.

Empirical assessment of latecomer cost handicap

To assess the latecomer hypothesis empirically, I am developing a database to probe the links between spectral location on one hand, and cost levels on the other, in particular as they impact on entry barriers and market structures in international space satellite communications and the US domestic land mobile radio service. Additionally, attention will be paid to the differences in component costs, power requirements, energy expenses and other operating costs in television broadcasting, for licensees using low VHF channels, high VHF or UHF channels. The resultant impact on several sets of transfer prices of station facilities traded in TV markets, all as the price of latecomer entry, will also be examined.

In each case, the hypothesis is tested that, *ceteris paribus*, the higher the spectral region (or radio frequency) within any service, the higher the capital and operating costs for any spectrum users. An additional objective must also be to determine whether there is quantitative evidence that latecomers benefit from cost-reducing innovations by firstcomers as much or more as they (the latecomers) suffer from handicaps in having to operate higher up. At issue there are so-called free-rider benefits to which I turn later, but a further word first on the economic/engineering evidence.

In moving up from C to KU, and again to KA, there are increasing problems caused by rain attenuation. As a consequence, more and more signal power is needed to sustain the same signal quality and area coverage as in a lower band. In going from C to KU, for example, there could in principle be a 6 to 1 cost increase due to the 6 to 1 power increase necessitated. Even mitigated by so-called modulation improvement, the power and hence cost increases could still be as much as 3 to 1.[9a]

True, if a lower degree of reliability is accepted – say, 99.7% instead

[9a]One interesting question here is whether spectrum allocation should in fact take climate into account, allocating the higher frequencies to arid countries where rainfall is scant (eg Libya or Algeria). Would this facilitate lower cost equipment design even at higher frequency levels?

of 99.9% – cost increases in the move from C to KU could be reduced to a doubling only. But how much reliability will the LDCs at most be willing to give up? The issue is a delicate psychological–political one, in part because the LDCs already resent what they view as second-class service in KU, subject as that is to loss of coverage due to heavy rainfall in the tropics where many of the LDCs are located. Similarly, they also resent being relegated to lower cost but pre-emptible INTELSAT transponders in the domestic leases they hold and have long sought access to satellites to escape sunspot-induced distortions in their use of HF broadcast spectrum. These developing country demands are no less intense even though pre-emptible, but lower-cost INTELSAT circuits may well be 'all they really need' today, and even though the aberrations of HF radio may also be cost-effective though seemingly unreliable and of poor quality.

Some of the cost handicap that latecomers incur may actually reflect the relatively greater scale economies which equipment manufacturers for C-band now enjoy; the relatively smaller scale economies at KU, where the demand for equipment is still small; and the much larger non-recurring R&D costs incurred in developing new bands like KA. Once again, this leaves the LDCs sensitive and resentful of their status as latecomers.

To test this latecomer cost hypothesis a number of preliminary statistical models are being developed and will soon be applied to a set of satellite cost data. These models are sketched briefly below, along with a few for land mobile radio. But let me turn first to the origin and incidence of so-called coordination costs, themselves a function of orbital and spectrum congestion, and current administrative–legal–regulatory practice.

Latecomer coordination costs

By coordination costs, reference is normally made to the locational and power costs incurred by a latecomer to avoid interferring with an incumbent user. Strictly speaking, it could also refer to the incumbent's extra cost in accommodating latecomers with minimal extra costs imposed upon them.

Even in lower spectral regions like C-band, then, as they fill up and are congested latecomers are disadvantaged. Hence, the origin of latecomer cost handicap lies in (a) the harsher propagation characteristics of higher spectral bands, and (b) the far smaller scale economies in producing new equipment for the newer, less fully utilized higher spectral bands. But these cost handicaps may be offset in part by the lower coordination costs in the less congested higher bands, than in the more congested lower bands.

At some point, then, this will undoubtedly lead to latecomers choosing between higher coordination costs in the lower congested bands (though with lower equipment costs due to better propagation conditions and larger scale economies), and lower coordination expenses but higher non-recurring engineering costs in the higher newer bands. My estimates of latecomer handicap could well reveal then, (a) costs that rise as increased power is needed to offset poor propagation conditions, while holding constant (b) scale economies in equipment manufacturing, and (c) non-recurring engineering plus R&D costs. Lastly, my latecomer cost estimates also hold constant (d) the incidence of coordination costs as between latecomers and incumbents.

and across the several spectral bands, reflective of their varying degrees of congestion.

The case of space satellites

To test this latecomer cost hypothesis in space satellites, one statistical model might first regress real cost of the space segment on the number of 'equivalent transponders' in each satellite, the assumption here being that, *ceteris paribus*, the greater the satellite capacity, the higher is the absolute cost (though not necessarily cost per transponder). Second, we would regress real cost on design life of satellite in years, the assumption being that, *ceteris paribus*, longer lived equipment would be more costly in absolute terms. Third, we could regress real cost on the frequency band in which these transponders operate. Lastly, to capture the full impact of band differences on cost, we might well interact the band dummy variables with the number of transponders besides.

A good place to start, then, is to fit equations with the following variables:

Y = spacecraft costs in 1983 dollars
X_1 = dummy variable equal to 1 if KU band, zero otherwise
X_2 = dummy variable equal to 1 if KA band, zero otherwise
X_3 = number of equivalent transponders
X_4 = satellite design lifetime in years
X_5 = number of equivalent transponders times dummy variable = 1 if KU, zero otherwise
X_6 = number of equivalent transponders times dummy variable = 1 if KA, zero otherwise
X_7 = number of years design lifetime times dummy variable = 1 if KU, zero otherwise
X_8 = number of years design lifetime times dummy variable = 1 if KA, zero otherwise

To calculate the impact of adding one more equivalent transponder in KU rather than C, or KA rather than C, I would next calculate the interacted coefficients for KU and KA. These would enable us to estimate: the impact of one more equivalent transponder on cost, if in KU and if in KA; the impact of a switch from C to KU, and from C to KA, at the mean level of transponders; the impact of one more year of design life, if in KU and if in KA; and, the impact of a switch from C to KU, and from C to KA, at the mean level of design life.

An alternative model might cast our dependent variable as real cost of spacecraft per equivalent transponder as such, or per year design life, and then regress simply on band differences and the number of equivalent transponders. The coefficients would then reveal the impact of a switch from C to KU, and C to KA, on real cost of spacecraft per indicated divisor. That is, the most revealing dependent variable would be real cost per transponder-year (adjusted for design life), or better still, per circuit-year, assuming 1000 voice circuits per transponder.[9]

Needless to say, many statistical problems must be resolved in developing either model – problems of functional form, multicollinearity, simultaneity bias, etc. Nonetheless, the variables specified in each model here do serve to illustrate a place to initiate the kind of empirical assessment that could help us determine the validity of Third World contentions that as latecomers they do suffer significant cost handicaps, albeit offset in part perhaps by innovational benefits they enjoy from

[9]See Robert R. Lovell and Samuel W. Fordyce, 'A figure of merit for competing communications satellite designs', *Space Communications and Broadcasting*, Vol 1, No 1, April 1984, p 57.

firstcomer investment, occupancy and use of orbit spectrum resources.

Time must in any case be introduced as an independent variable in some suitable form, perhaps by using pooled models for time series data. For INTELSAT, in any case, investment costs per circuit-year declined from $32 500 for INTELSAT I (in 1965) to $662 for INTELSAT VI (in 1986), whereas real cost per transponder-year declined from $12 480 000 to $440 000.[10] By the same token, real costs per transponder-year for US domestic satellites declined from $500 000 in 1972 to $280 000 in 1982.[11] Crude industry estimates are that perhaps half of this cost decline is due to innovation (extending transponder capacity and design life), and half due perhaps to greater familiarity with the technology in use (learning curve).[12]

Nonetheless, there is virtually no systematic published analysis of the impact of band location on real satellite capital and operating costs per transponder-year, or per circuit-year. Indeed the most one can discern from the above sources is that, among the 29 US fixed service domestic satellites reported in Lovell and Fordyce,[13] real costs per transponder-year for four KU-band SBS satellites (average = $930 000), are over twice the costs of 25 C-band satellites (average = $386 000, with only Spacenet operating a hybrid C/KU band satellite).

In contrast, Pelton reports the depreciated capital cost per transponder-year of fixed domestic C-band satellites to be $300 000–$350 000, compared to $350 000–$400 000 for an international fixed satellite service 'with expanded coverage and interconnectivity'. The latter is deemed more likely to use KU-band equipment,[14] which means, at worst, a cost penalty of 30% in the switch from C to KU.

Beyond this, Lovell and Fordyce estimate that a direct broadcast satellite, necessarily operating in KU, will have 'a figure of merit of better than $2 million per transponder-year'.[15] Yet DBS and fixed service satellite costs cannot be compared accurately because channels in each case vary considerably in number. Nonetheless, the switch of a fixed service satellite from C to KU band raised power requirements (a major cost component) 3½-fold, and another 5-fold for a KU-band broadcast service satellite.[16]

The above discussion relates to the space segment alone, including launch costs and insurance. However, there is reason to believe that ground segment costs may also be higher, *ceteris paribus*, for latecomers forced to enter the KU band, or eventually KA, in the form of growing C-band congestion. This, too, needs close scrutiny.[17]

The case of land mobile radio

Are the trade-offs similar in land mobile radio? To reach the same size area using equipment in different land mobile bands, in principle the range of cost increments are proportionate to the needed increments in antenna height, or transmission power. For argument's sake, let us hold antenna heights constant, say, at 200 feet, and assume flat terrain, a base/mobile radius of 30 miles, and zero man-made noise in the area. Then, in rising from the lowest land mobile band at 50 MHz, to the highest at 800 MHz, rough hypothetical engineering estimates are for a needed power increase from 35–75 watts at 50MHz, to 150–200 watts at 450 MHz and 800 MHz. This is roughly a six-fold increase over the whole range of land mobile frequency bands.

By the same token, holding power constant at 75 watts, and again, assuming flat terrain, no man-made obstructions, a base/mobile radius

[10] *Ibid*, pp 57, 60. This may superficially appear to constitute an offsetting latecomer *advantage*. But cost differentials across different spectral bands continue to operate at every point in time, in the face, ie of declining investment costs per transponder year. Thus latecomer cost handicap seems most appropriately measured in cross-sectional analysis, at a point in time, with technological advance and learning by use held constant, statistically.

[11] *Ibid*, p 59 and Figure 9; see also Joseph N. Pelton, 'Satellite telenets: a techno-economic assessment of major trends for the future', *Proceedings of the IEEE, Special Issue on Satellite Communications Networks*, November 1984, Figure 3, p 1447.

[12] See, eg comment on 'Learning curves and yields', in *International Competitiveness in Electronics*, Office of Technology Assessment of United States Congress, November 1983, pp 76–77; also, Pelton, *op cit*, Ref 11, especially at pp 1450–51.

[13] Lovell and Fordyce, *op cit*, Ref 9, Table 2.

[14] Pelton, *op cit*, Ref 11, p 1449.

[15] Lovell and Fordyce, *op cit*, Ref 9, p 63.

[16] Ibid, Table 3, p 62.

[17] See, generally, David H. Staelin, *et al*, *Satellite Network Architecture: Technology Issues*, 30 July 1982, MIT Research Electronics Laboratory, Figure 17 at p 52, Table 1 at p 54, and Figure 22 at p 83. Staelin also laid out an engineering–economic analysis of total systems configurations (space satellite plus ground segment plus terrestrial linkages). These are actually configured for all three bands – C, KU, and KA – though more for engineers than economists (*Ibid*, especially Chapter 3).

of 30 miles, and zero man-made noise, to cover the same square mileage antenna heights would ideally have to rise from 110 feet at 50 MHz, to 250 feet at 150 MHz, 475 feet at 450 MHz, and 650 feet at 800 MHz. Once again, this is a six-fold increase in antenna size over the full range of land mobile frequencies.

Transmission power and antenna heights are two major cost components in land mobile radio systems. Assuming, unrealistically to be sure, so-called mid-line mobile systems, operating on one frequency and one channel, the very crude hypothetical cost estimates on the assumptions just stated are $800, $850, $1100 and $1400, for systems operating at 50 MHz, 150 MHz, 450 MHz and 800 MHz respectively.

The less than doubling of cost, notwithstanding hypothetical increase of antenna heights and power by six-fold, may in part reflect the fact that cost-effective real-world systems normally vary both radiated power and antenna heights, not just one such input.

The question is why do latecomers not complain, even when they must enter higher bands with higher capital and operating costs, and when new equipment costs will also be higher because scale economies are smaller at 450 and 800 MHz than at the older lower 50 and 150 MHz bands. The answer may be that in higher bands, besides higher costs, there is also greater quality (no 'skip'), more reliability, and wider coverage as benefits. And also that, over time, the cost of next-best non-spectrum alternatives (fuel, vehicles, drivers) rises substantially, and so, too, does the magnitude of cost-savings in land mobile use, even at higher bands.

But do latecomers need such benefits? If not, the higher equipment costs would be hard to swallow without resentment and the latecomer may in fact be forced to pay more than the firstcomer, albeit for more benefits, but unwanted benefits at best.

There are additional factors which make for more costly antennas in the higher spectral regions. Reference is made here to the cost of scarce antenna sites, often on high buildings in congested urban environments, for example, the Sears Tower in Chicago, or World Trade Center in New York City. There is, then, a real estate issue in that locational rents are appropriated by landlords and these raise the cost of the antenna site even more than otherwise. Hence, in crowded urban centres, latecomers will move up from 50-150-450 MHz, and again to 800 MHz. They do so to ensure signal reliability and high signal quality in the face of man-made noise and artificial obstructions. Under those conditions, high antenna towers are increasingly important and, with them, much higher antenna costs including equipment and special sites.

Without probing all necessary details, an illustrative equation from which to initiate an estimation of the impact of mobile radio spectral location on the area covered by given transmission power and/or antenna heights, would be the following:

Y = square mile area covered in 75 mile radius from population centre of SMA
X_1 = transmitter power
X_2 = height above average terrain of antenna (HAAT), including where possible height of antenna tower
X_3 = dummy variable for terrain = 1 if mountainous, zero otherwise
X_4 = dummy variable for terrain = 1 if near water, zero otherwise
X_5 = dummy variable for terrain = 1 if congested with large urban structures, zero otherwise

X_6= frequency level used by base station
X_7= transmitter power × frequency level ($X_1 \times X_6$)
X_8= HAAT × frequency level ($X_2 \times X_6$)

Once more, my hypothesis is that (a) lower bands fill up first, (b) higher bands, though less congested and less subject to technical vagaries of their own than the low bands, require equipment with higher power and/or antenna heights, than in lower bands. Therefore, the higher band equipment should presumably be more costly, other things equal, a tendency which would be further underscored insofar as (c) scale economies are larger in the lower, older, more congested bands than in the less congested higher, newer bands for which equipment production is still limited.

The biggest problem in any such estimation of latecomer cost handicap in mobile radio, is that: (a) any really large sample requires the use of FCC's massive but notably flawed data base; (b) detailed equipment cost data are not in any case available there, or readily available elsewhere except in crude broad estimates. My present model, therefore, (a) works without explicit cost data; (b) specifies only the two major system cost components for a land mobile base station, *viz*. transmitter power (in kilowatts) and HAAT (height of antenna above average terrain); (c) interacts each of these variables with frequency level to permit an estimate of the full impact of spectral location. A major additional factor further modifying the coverage area of any base station in reality is (d) character of the terrain, whether mountainous, flat, near water, marked by urbanized structures, etc, to capture which it is necessary to devise dummy variables that distinguish between major classes of terrain, using the FCC's Digitized Terrain Map.

The most reliable and complete data records are for each base station's transmitter power (ERP). Records for antenna height above average terrain (HAAT) are far less so, except for the 470–490 MHz band where that information is recorded explicitly (including height of the antenna site too). Elsewhere it would be necessary to use antenna heights from base of site to top, plus elevation of site above sea level. (The existence of high towers on skyscraper sites can also be detected by devising a dummy variable to distinguish between differing degrees of clustering of base stations within SMAs. Where high building rooftops provide the antenna site, one would in fact expect to find a significant clustering of transmitters.)

A few suggestive pieces of empirical evidence drawn from well-known radio engineering data support my approach. Together this evidence indicates that land mobile signals will be delivered such that any given service area requirement can be met by varying combinations of antenna heights and transmitter power. The higher the one, the lower the other may be, with visible constraints imposed by frequency band location, and notable differences between suburban and urban environments and their respective man-made noise and artificial obstructions.

Thus, in Table 1, at the upper end of land mobile frequencies (851–866 MHz), for any given antenna height, a 20 mile service area radius will require some 2–3 to 4–5 more effective radiated power (ERP) in urban environments than suburban. This implies that the more congested the area with man-made noise and obstructions, then the more costly the operation in terms of required antenna height and transmitter power (*cf* variable X_5).[18]

This is still better indicated in Figure 1 where, for example, at the

[18]This is further confirmed in *FCC Rules & Regulations, Pt 90* (abridged), Tables 3–4. Once again, those tables provide estimates of antenna heights and radiated power for suburban and urban environments, separately, but this time for service area requirements which decline from a 20-mile radius to 5 miles or less. (*Cf* variables X_1, X_2, X_7, X_8).

Table 1. Equivalent power and antenna heights for base stations in the 851–866 MHz band, which have a requirement for a 32 km service area radius.

	Effective radiated power (watts)[1,2]	
Antenna height (ATT) (feet)	**Urban/ trunked**	**Suburban**
Above 5 000	65	15
4 501 to 5 000	65	15
4 001 to 4 500	70	29
3 501 to 4 000	75	25
3 001 to 3 500	100	30
2 501 to 3 000	140	35
2 001 to 2 500	200	50
1 501 to 2 000	350	80
1 001 to 1 500	600	160
501 to 1 000	1 000[3]	220
Up to 500	1 000	500[4]

Notes:[1]Power is given in terms of effective radiated power (ERP).
[2]Applicants in the Los Angeles, CA area who demonstrate a need to serve both the downtown and fringe areas will be permitted to utilize an ERP of 1 kw at the following mountaintop sites: Santiago Park, Sierra Park, Mount Lukens, and Mount Wilson.
[3]Stations with antennas below 1 000 ft (AAT) will be restricted to a maximum power of 1 kw (ERP).
[4]Stations with antenna below 500 ft (AAT) will be restricted to a maximum power of 500 W (ERP).
Source: FCC Rules & Regulations: Part 90 (abridged), para 90.635, Table 2, p 59.

upper extreme, antenna heights rise to 15 000 feet. There, at the left side, ERP is determined by varying levels of antenna height and transmitter power, such that at 10, 25, 50 and 100 watts, comparable ERP generated by the above input combinations could ostensibly deliver information a full 55 miles using the 30 MHz band, but only 50

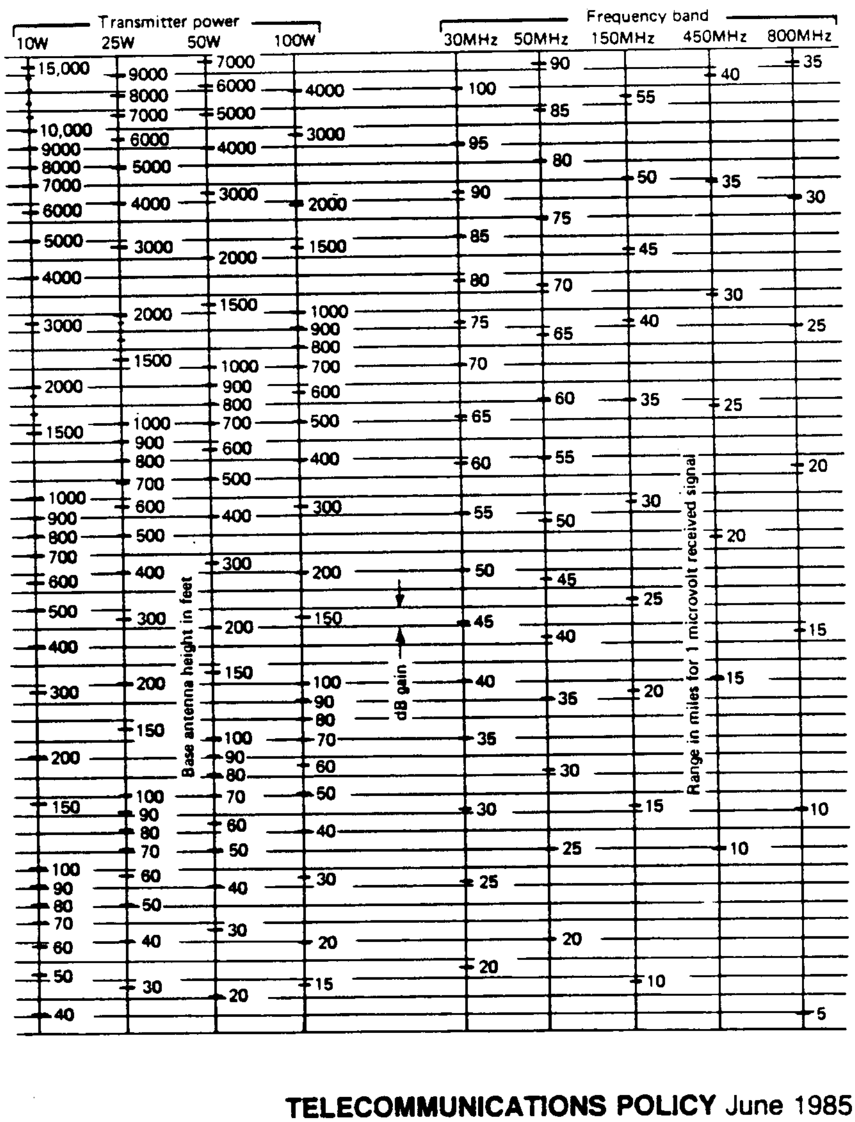

Figure 1: Radio range estimator chart.

Source: Midland Land Mobile Radio Co, Inc, 'Answers to most questions asked about FM two-way radio', p 13 (derived generally from *Reference Data for Radio Engineers*, 4th ed, ITT; see especially Chap 24).

miles at 50 MHz, 30 miles at 150 MHz, about 21 miles at 450 MHz, and just a scant 19 miles at 800 MHz (*cf* X_6).

Thus, whatever ERP is generated by the several combinations of transmitter power (10–100 watts, variable X_1), and antenna heights (15–15 000 feet, variable X_2), on the table's left-hand side, the distance that information can be delivered is smaller, the higher the frequency band used (*cf* X_6). Or stated otherwise, insofar as firstcomers ostensibly have access to the older, lower spectrum regions first, they enjoy the cost-savings associated with the smaller antenna heights and transmitter power needed there to cover any given service area radius (than at higher frequency levels).

By the same token, latecomers constrained to move up to less congested higher frequency band locations, must pay for higher antenna heights and/or transmitter power to cover the same service area radius.

In sum, the latecomer cost handicap hypothesized about in space satellites and land mobile radio, does seem consistent here with the basic propagation curves which underlie Figure 1. Together, finally, Table 1 and Figure 1, and the other cited tabulations from FCC Rules and Regulations, Pt 90, underscore the case for testing the latecomer hypothesis with the far larger database on actual land mobile radio records.

Free-rider benefits and the learning curve

The argument is that latecomers enjoy free-rider benefits from the costly and risky non-recurring R&D which developed country firstcomers perform in opening up spectral bands which LDC latecomers subsequently enter too, without themselves having to design and develop the newer equipment. Per unit equipment costs are also alleged to be lower on that score than they would be without the firstcomer's growing familiarity with the technology in question.[19]

On the other hand, there is contravening evidence that firstcomers secure an irretrievable advantage over latecomers who may follow, sustaining gains over time. We don't really know why this should be so, but it is so. According to this argument, therefore, it is by no means clear that the firstcomer's growing experience with technology will transmit any net advantage to latecomers, or significantly impair the firstcomer's initial advantage.[20]

Spence's cogent distinction between firm-specific and industry-wide (interdependent) learning curves is germane here. Assuming INTELSAT to be the incumbent, and LDCs the latecomers, firm-specific learning effects can indeed create substantial entry barriers to latecomers, with moderate rates of learning creating the greatest barriers.[21] In that case, latecomers will have greatest trouble in entering, their relative costs being larger than where the incumbent's learning is zero or negligible. By the same token, it is at best uncertain that the incumbent will suffer from excessive entry and resultant low output (experience and learning), and that its incentives to invest in learning or innovation must therefore be seriously impaired.[22] Accordingly, latecomer cost handicap would not seem likely to be mitigated by even sizable firm-specific learning effects.

In contrast, industry-wide or interdependent learning curves may, under certain conditions, cause 'more entry to occur . . . than is ideal', and, with such spillover effects, 'competition (will be) increased and market performance improved, despite the reduced incentives for

[19]This would be due to the rise in cumulative average output per man week with the cumulative growth in aggregate output, or, better still, in 'cumulative gross investment (the total output of capital goods) as an index of experience' (Kenneth J. Arrow, 'The economic implications of learning by doing', *Review of Economic Studies*, 1962, pp 156–57). During World War II, eg, a doubling of cumulative airframe output acted to reduce direct labour requirements by 20 percent (Armen Alchian, 'Reliability of progress curves in airframe production', *Econometrica*, October 1963). There appear to be cost advantages in being first to enter a new industry (Robert H. Smiley and S. Abraham Ravid, 'The importance of being first: learning price and stability', *Quarterly Journal of Economics*, Vol 18, No 2, May 1983, pp 353–57).

[20]*Idem*, pp 360–61.

[21]A. Michael Spence, 'The learning curve and competition', *Bell Journal of Economics*, Vol 12, No 1, Spring 1981, pp 57–62. Admittedly, of course, international telecommunications is not really a competitive regime. But with the advent of new private entrants (such as Orion), and regional consortia and 'intersatellite links', new competitive elements may eventually be infused into this service.

[22]*Ibid*.

investment in learning . . . for . . . firm(s)'.[23] Hence, 'the industry-wide cost-reduction process (for given output rates)' will become more efficient, even though such interdependence, by reducing 'the return to investing in (learning as) accumulated volume', will act to slow down the pace of cost reduction.[24]

For the analysis here, then, there may indeed be industry-wide learning effects which could mitigate latecomer cost disadvantages, the question being mainly one of relative size in each case and the frequency with which such postulated conditions do in fact recur.

Accordingly, at least two sets of hypotheses need to be tested; first, that moving to higher bands in the radio spectrum acts to raise capital and operating costs due to physical propagation problems, deficient scale economies in equipment manufacturing, etc; and second, that while the firstcomer's learning curve and innovational advance may help offset some latecomer handicaps, they by no means need impair the firstcomer's net competitive advantage.

A final issue relates to the contention that narrower orbital spacing offsets what LDCs would have enjoyed had they entered earlier, lower down. Today, for example, the latecomer cannot get older, cheaper antennas designed to work with wider orbital spacing, unless they are literally hand-tailored. So, what LDCs resent here is having missed the earlier windfalls to the firstcomer – before orbital spacing was narrowed, but after the scale economies in equipment production had materialized. Yet the firstcomers did risk venture capital, and spent a lot on non-recurring R&D.

Latecomer entry may be expensive, then, but if technical innovation helps bring down per unit costs of satellite technology for all countries, LDCs may also enjoy some compensatory measure of free-rider benefits. If so, the LDCs may be gratuitous beneficiaries of the communications activity of advanced country enterprises. The question is whether these compensatory benefits do or do not offset the entire cost handicap of latecomer entrants – no easy matter to determine. Much depends on whether free-rider benefits to LDCs would significantly blunt the developed countries' incentives for optimal research, development and use of orbit spectrum resources.

Just as traditional common pool problems may notably result in developed countries doing too much production, investment, entry and exploitation too soon, so the problem of LDC or DC free riders may result in too little entry, too late. One classic example relates to public goods generally, with benefit externalities so diffuse and hard to trace that not all who enjoy them can be charged directly, or refused access if they do not pay. Another example relates to DC technological advances, costly and risky to bring about, but which could be readily and cheaply copied by imitators but for patent protection without which innovators are reluctant to proceed.

Using *a priori* deductive microeconomic models and secondary sources in the technology transfer literature, finally, one could examine such issues as these:

- Insofar as free-rider benefits that lower entry costs may also hamper innovation, the question is which effect will prevail, and indeed, whether these two effects are even measurable, let alone separable.
- Can they in any case be reconciled – enough lag and appropriation for multinational corporations (MNCs) to retain incentives to

[23] *Idem*, pp 67–68.
[24] *Idem*, p 66.

innovate new technology, but quick enough transfer (diffusion) of old technology for LDCs to enjoy lower entry barriers than otherwise (via cost reduction)?[25]

- Can the MNC literature on technology transfer further help us assess the case of, say, an LDC hiring a DC concessionaire to develop the LDC's orbit spectrum? When and how, if at all, could DCs control the training, know-how, and software they must (or inadvertently may) leave behind with an LDC, and hence avoid losing their exclusive access to the technology? Could a DC avoid unwanted technology transfer here, ie compared, say, to when working through global or regional consortia of users?[26]
- Under what kind of arrangements, in what kind of industries, do license, consortium or joint venture agreements, or various kinds of contractual terms emerge? And where might these impair or facilitate technology transfer to LDCs, with or without disincentive effects on DC innovation?

Potential policy options

Finally, it is necessary to deal with potential policy options to mitigate the net latecomer handicap left even after partial mitigation by free-rider benefits.

First, a latecomer could presumably buy out another country's or firm's lower cost C-band satellite system. But the problem here is that an LDC may not really need a whole system, and that it is at best hard to find one that will precisely fill its requirements anyway. Still more important from an equity standpoint is that such a purchase would inevitably enable incumbents to collect orbit spectrum rents as firstcomers, all at latecomers' expense.

So it may be better, secondly, to buy into a consortium like INTELSAT or EUTELSAT, operating in part at least, in a lower satellite band. Participation there would also permit the LDC to enjoy scale economies through the magnitude of the service provided, at the same time benefiting from equipment designed to operate in the lower spectral region.

Or third, latecomers could just lease extra unused lower band satellite capacity, and hence avoid having to build their own system higher up or avoid having to develop narrower orbital spacing to squeeze themselves in.[27]

Fourth, latecomers could aim to alter the present coordination practice so that there would be a new, more equitable cost-sharing between latecomer and incumbent. This would presumably modify the *de facto* forcing of latecomers to bear the whole coordination cost themselves, under current arrangements, when they now try to enter a crowded band.[28]

Fifth, the latecomer could buy transponders outright from a private or common carrier-owned satellite facility capitalizing on lower spectral band location.[29]

A sixth option would be that of a joint venture where a poor LDC with limited resources provides an orbit spectrum assignment, and a DC entrepreneur invests the needed venture capital, with both sharing the revenues, much as Rupert Murdoch's proposal to finance a broadcast satellite system to be built on an assignment held by Luxemburg.

Seventh, and a variation of the above, is where an LDC could hire a

[25]This key issue is implicit in the discussion in R. Hal Mason, 'The multinational firm and the cost of technology to developing countries', *California Management Review*, Summer 1973, Vol 15, No 4, pp 5–13.

[26]See generally, R. Hal Mason, 'A comment on Prof Kojima's "Japanese type vesus American type of technology transfer"', *Hitotsubashi Journal of Economics*, February 1979.

[27]See generally, Harvey J. Levin, 'The political economy of orbit spectrum leasing', in 1984 Michigan Yearbook of International Legal Studies, *Regulation of Transnational Communications*, Clark Boardman, 1984, pp 41–70.

[28]See veiled allusion to such a conception in William H. Montgomery, *op cit*, Ref 6, pp 3–4. (Robert Tritt presented the paper in Berlin, and further expounded the concept in the ensuing panel dialogue).

[29]The issues here are concisely stated by Levin, 'Regional versus global strategies in orbit spectrum management – the global commons revisited', presented at December 1982 Meetings of the American Economic Association, New York Hilton, at footnote 30 and associated text. In its most recent form, latecomers could lease or buy transponders outright, and also enjoy free transponders to distribute public service programming. [See Application of Pan American Satellite Corporation for a Subregional Western Hemisphere Satellite System, before the Federal Communications Commission, May 31, 1984, part I] Specifically, PanAmSat proposes to sell or lease its transponders on a private, noncommon carrier basis to international news organizations, television networks, and to countries and other entities, thereby providing video and radio programming, videotext, electronic mail, telephone service, data and computer communications, etc. It would also provide free transponder capacity to a 21-nation Organization of Iberoamerican Television to encourage free exchange of its programming throughout the Western Hemisphere.

DC firm to build, operate and manage a system on the former's orbit spectrum assignment, much as where the ARABSAT consortium hired COMSAT for a similar purpose.

Eighth and last, we could work through ITU to enable all nations to recover orbit spectrum value as Ricardian rents which firstcomers can capture at C-band, rather than at KU or KA.

Among the mechanisms to diffuse these benefits widely among rich and poor nations, I am scrutinizing several to auction off-use rights, recovering the related economic rents and earmarking them to develop telecommunications infrastructure in the Third World. One approach just short of this is simply to devise empirical techniques to estimate the value of orbit spectrum assignments as a factor in international negotiations between DCs and LDCs in an intergovernmental framework.

In this latter regard, the analysis of latecomer cost handicap might indeed help develop such an empirical technique. When faced, say, with a 3 to 1 cost increment in operating space satellites at the higher KU rather than the lower C-band, and then another such increment going up to KA, the hypothetical latecomer should rationally be willing to pay something just short of this cost differential for access to the lower band. In principle, that is, latecomers should pay a sum just short of the cost savings C-band would have facilitated relative to KU, or KU relative to KA.

The spectral rents would be the sums that incumbents could hypothetically collect by selling assignments or systems to latecomers. Or, from another viewpoint, a lump-sum tax would be the optimal device to recapture these rents, ideally without distorting resource allocation, or creating disincentive effects on R&D and technological advance. At present, however, there is unfortunately no institutional mechanism for levying or collecting such a tax.

An alternative to such a once-and-for-all impost would be for a periodic but automatic diversion of value into some form of telecommunications infrastructure development. Automaticity raises a number of puzzling problems. These are not insuperable, but they require careful analysis of the merits. Although widely opposed in the USA, automaticity does now figure prominently in the Highway Trust Fund and, a few years ago, in well thought out proposals by television's Carnegie Commission II. In these cases, user charges and royalty fees collected from highway users and commercial TV licences are or would be earmarked for highway development and public broadcast service, respectively.

Nor, outside the USA, should we forget proposals for automatic annual diversion of some percentage of work GNP, or of global military expenditures, into Third World infrastructure development;[30] nor, finally, analogous mechanisms for similar purposes within the International Monetary Fund, *viz*, that of Official Development Assistance, Special Drawing Rights, and a Common Commodity Fund, all geared ostensibly to ease special development-related balance of payments difficulties of Third World countries.[31]

Note also that a political constituency must be built for automacity, eg by promising that recaptured orbit spectrum rents would be used to buy telecommunications hardware, say, from big US companies or other transnational corporations, and done so consistent with safeguards of First Amendment values. The latter might entail the bolstering of

[30]See *North–South: A Programme for Survival*, report of the Independent Commission on International Development Issues under the Chairmanship of Willy Brandt, MIT Press, 1980. See especially, pp 242–45.

[31]*Ibid*, pp 209–20. For a more detailed analysis see John Williamson, 'SDRs: the link', in Jagdish N. Bhagwati, ed, *The New International Economic Order: The North–South Debate*, MIT Press, 1977, Chapter 3.

multi-voice media structures in Third World countries, plus the funding of a specific cultural-educational facility, say, for hemisphere-wide programmes or news services.

Conclusion

Latecomer cost handicap arises in large part from five factors.

- First, the propagation characteristics of the more recently developed, higher radio frequencies in such services as space satellites and land mobile radio.
- Second, the costly increases in transmission power and facilitating electronic equipment required to overcome the impairment of signal quality and information delivery to which latecomers are normally forced to turn in the wake of firstcomer saturation of the lower, less expensive spectrum bands in specific services.
- Third, the higher equipment costs associated with newer spectral bands where the economies of large-scale manufacturing have not yet been fully realized.
- Fourth, the high non-recurring R&D and engineering costs incurred to open up newer spectral regions.
- Fifth, the higher coordination costs incurred by latecomers who must bear the cost of adjusting their coverage patterns and equipment design under current legal-administrative practice.

These cost handicaps are presumably offset, though only in part, by the benefits which latecomers derive from the firstcomer's cost-reducing innovations and learning curve. Furthermore, the firstcomer appears to gain an irretrievable advantage over latecomers which follow.

Accordingly, US efforts should direct far more attention than hitherto to conceivable arrangements to mitigate possible net cost handicaps of latecomer entrants, a disruptive issue that could well surface again at future space conferences.