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Global Claim-Staking and Latecomer Cost in the Orbit Spectrum Resource

by Harvey J. Levin

Columbia Institute for Tele-Information
Graduate School of Business
Columbia University
809 Uris Hall
New York, NY 10027
(212)854-4222

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This article first examines some research on and analysis of the origins and magnitude of latecomer cost handicap, and then turns to the claim-staking or land-rush hypothesis. Here a central question is why there should be latecomers in the first place, and further, what the cost consequences seem to be. The article concludes with a brief look at global claim-staking, some illustrative equations on the subject, and finally, at degrees of stability in satellite deployment over time.

Harvey J. Levin is University Research Professor in the Department of Economics and Director of the Public Policy Workshop, Hofstra University, Hempstead, NY 11550, USA, and Senior Research Associate at the Center for Policy Research.

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In the space satellite and information industries latecomer cost handicap is largely due to the inferior propagation characteristics (rain attenuation) of higher, newer frequency bands. It is due also to the relatively greater scale economies that equipment manufacturers now enjoy in the older, more fully utilized C-band, than in the higher Ku frequencies where equipment demand and supply are smaller. To mitigate this latecomer handicap, participating nations and firms stake out claims on orbital assignments by means of premature, excessive investment.

Here the question is not only why less developed countries (LDCs) should be latecomers in the first place, but what cost handicap results, and why they do not in fact claim-stake earlier. In particular, the article first examines some completed research on the origins and magnitude of latecomer cost handicap, after which it turns to the additional work needed to assess the claim-staking or land-rush hypothesis. Throughout, special attention is given to the control over entry into space satellite communication, grounded on controlled access to the geostationary orbit and space satellite frequencies, that is, on rights to use orbit spectrum assignments.

The main issue here is that of 'squatter's rights'. Once someone is in orbit, and transmitting, it is futile to challenge his occupancy by operating in his spectrum space, since he could in turn interfere with you, too. Indeed, once his satellite is in orbit it is easy to keep others out. On the other hand, if the satellite is 'dead' there can obviously be no physical (electronic) interference and hence no problem of restricted access to physical, orbital space. So the question is what techniques exist to interfere with someone else without yourself being interfered with.

If an AM broadcaster interferes with your AM signal, you could conceivably go to FM or turn instead to 'spread spectrum' and virtually 'shout' your message through. When a satellite goes dead, then, you can either emit no signal at all, or only unpredictable, uncontrollable ones. In either case you will lose the ability to move your hardware entirely out of orbit, or, indeed, if no fuel is left, at all.

Why be a latecomer?

There appear to be at least three reasons for this. First, latecomers may lack the know-how to establish a satellite system today, even if they

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need one. Second, though a latecomer has the know-how, it may just not need the system today, as where it may only need a quarter of a transponder when someone else with the capital (assuming you have none and the capital market is imperfect) provides the circuits and virtually sells them to you. Third, though LDCs have the know-how and the capital (where the capital market is good), there may simply be no more room left in the orbit, in which case technical scarcities will impede the accommodation of almost any potential entrant.

In sum, whatever the reason for coming in late, you may have to settle for an inferior orbital location, and one using higher satellite frequencies too, and thereby incur higher resultant capital and operating expenses. However, those higher costs may also be mitigated by the lower costs of satellite coordination, congestion and signal interference effects in those same higher frequences.[1]

Even though LDC latecomers can benefit from the innovation of others, there is necessarily a limit as to how much they can learn from any incumbent without themselves first using the ideas and the hardware. Also, they must use spectrum and orbital space the way water is often used, to retain rights to future use. This sounds very much like *de facto* squatter's rights, with matching variables sufficient to explain the space segment's capital costs in some designated year.

Legal systems do in any case differ. In Los Angeles water is sold at far less than the cost of holding rights for future use, so there is real claim-staking via cross-subsidy for premature use, and preemption. In short, any satellite administration may enter prematurely to claim-stake, and thereby learn by doing, though if it waits it might benefit from the technical innovation of others.

Stated otherwise, does the technological advantage of being a latecomer outweigh the cost disadvantage of being forced to operate a satellite in the higher Ku-band and frequencies instead of the lower C-band? Or are those observers correct who assert, without empirical back-up, that latecomers reap free-rider benefits from other countries' research and development? Do these alleged benefits outweigh any latecomer cost disadvantages in having to use less desirably located bands of orbital slots?

Part of the difference in the implications of affirmative answers to the questions being asked here follows from the options being compared. The first inquiry compares operations in C-band with those in Ku, and finds substantial cost advantages from operating on lower frequencies. Much of the second comparison seemingly involves early *versus* late entry in the same band. That may indeed be one reason why late entrants obtain the cost-reducing advantages of other countries' research and development.

In sum, this article estimates and compares the costs of early *versus* late entry into the satellite business. Specifically, it illustrates the cost advantage of using the lower frequency band operating with more mature technology, as well as of its lower transmitter power requirements.

But why are latecomer costs important anyway? Is it because latecomers (say, less developed countries) face higher costs than early entrants? If so, is this undesirable because the existence of latecomer costs leads to economically inefficient claim-staking of orbital slots? Or because it is 'unfair' that LDCs face higher costs than developed countries? Or somehow for both reasons?

[1] By coordination costs reference is normally made to the locational and power costs incurred by a latecomer to avoid interfering 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 the latter. Even at lower C-band frequencies, then, latecomers are disadvantaged when these bands fill up and become congested. Hence the origin of latecomer cost handicap lies in (a) the inferior 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. What my several estimates of latecomer handicap could well reveal, then, may be (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.

To determine how the regression results should in any case be used to test for the existence of claim-staking behaviour, the term must first be defined precisely. Does it mean constructing satellites in advance of current (or projected) demand? If so, how do we know whether this is an entirely appropriate and efficient strategy, or whether it is simply a bald attempt to secure property rights with no anticipated demand for satellite use?

If a poor fit to the equation is obtained predicting the demand for satellite transponders by country, is that poor fit due to an incorrectly specified equation, to forecasting errors, or to the fact that nations build satellites for reasons of national pride rather than for claim-staking purposes, just as nations sometimes build roads or steel mills where there is little or no consumer demand, and thus no economic justification for their construction? But do nations not also build satellites to claim-stake access rights and hence for national pride?

Do the costs of negotiating spectrum and orbital slot rights in a market context outweigh the benefits of such negotiations – unless, at least, transactions costs are zero, especially when compared to the current system of ITU regulation? We are offered no empirical proof of this proposition. Every transaction is likely to involve some costs, yet markets often allocate resources more efficiently than regulatory bodies or political decisions. So it is unclear why anyone would think spectrum markets will not work.

At the outset of satellite communication, as today, lower frequency bands were less costly to use than higher, more recently developed ones. Hence the latecomer suffered a cost disadvantage by being forced to use higher frequencies, or being subjected to greater congestion or coordination costs at lower frequencies, as, eg, the C-band filled up.

Accordingly, a major issue is whether the latecomer's cost handicap is largely, or entirely, offset by the mitigating benefits of any firstcomer's technical advance.

Preparation of satellite cost database

Initial data set for 1965–83

In exploring this issue I have worked with an initial satellite database of 103 sets of observations (ie of space segment costs for 1983) grounded on a NASA-funded study released in early 1984 at the Lewis Research Center.[2] These were the data required to explain capital and operating costs, which were then periodically updated, thereby enabling me to add still more observations to my database from the numerous satellite launches during 1984 and 1985. A copy of the 'NASA R&D Inflation Index' was also secured and helped me derive a set of real cost data most accurately reflective of cost and price inflation over time, and best for my analysis.

The data were in any case periodically updated by introducing actual new statistics, thereby adjusting the database, and keeping it homogeneous by applying the NASA R&D Inflation Index. In this regard a prime question is whether there is any productivity allowance for productivity increases in the R&D activity itself, an issue needing further scrutiny.

Historically, the NASA index has been higher than recognized inflation measures like the GNP price deflator, mainly because price movements in R&D are mostly driven by the rise in labour compensa-

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[2] NASA CR-168270.

tion. National labour compensation has itself tended to exceed growth in the GNP deflator by 1.4% points per year (1972–83), reflecting improved living standards for the workforce through increased compensation.

The historical NASA R&D Inflation Index has in any case moved closely with the BLS Compensation Index. The performance of R&D inflation relative to the GNP deflator must in fact be explained in two terms. First, the deflator usually measures price changes of goods and services that improve technology across the economy where labour cost increases are offset by innovation in the technology and hence by other improvements in productivity. Second, the NASA R&D Inflation Index 'directly measures (1) price change(s) for labor, much of which is highly skilled and working in non-repetitive type efforts, and (2) the price change(s) for unusual and often scarce materials and parts'.[3]

For the above reasons, the satellite cost data were alternatively deflated by an appropriate GNP price deflator and by the NASA R&D Inflation Index. Preliminary scrutiny of both sets of data further helped me derive a usable set of real cost figures per transponder year (CTY),[4] notwithstanding well-known imperfections in such comparative cost data across satellites bought by different countries, or built by different contractors.

In sum, all cost data were adjusted to a 1983 base, and the NASA R&D price deflator was used because the value of satellite- and spectrum-related outputs, with high research and development costs, could presumably be best adjusted by using that index. The year 1983 was chosen because that was the latest contract year in the data, and it was also the most recent date for which the NASA index was available at the start of the project.

Final revised data set for 1965–85

After examining the initial data set visually, as well as on the basis of statistical outliers, several cases appeared erroneous. Before making decisions on those items, however, additional data became available, and all of the data points questioned earlier could then be revised without having to use any statistical rationale to modify or eliminate those points. Actually, they were mainly explained by clerical errors.

Revised data for launches between 1965 and 1985 covered a total of 122 cases, including, however, several unusable ones. In some 12 instances, for example, the bird simply did not fly, and when this occurs the data set provides no information on life expectancy of equivalent transponders. Nor could cases be used in which certain variables lacked matching data. In other cases the satellite was of some special type which logic and the data suggested was a different kind of animal, say, a broadcast rather than fixed service satellite. Neither could those be used.

After reducing the data set to what appeared to be a reasonable number, 88 cases remained to estimate the cost function, and initial runs were based upon those observations. But then two additional (twin) birds which flew in 1970 also had to be eliminated. Those sets were very untypical in that they had only a five-year life expectancy, compared to a sample mean of eight years and a mode of seven. Further, they cost only $8 million compared to an average real cost of $44.8 million. Lastly, they had only four equivalent transponders, compared to a sample mean of 22.5 and a mode of 24.

[3] See 'NASA R&D Inflation Index', NASA mimeo, 1984.

[4] By 'costs per transponder year' reference is made to real 1983 R&D expenditures, scaled down next per transponder, and then further weighted by the equipment's design life. Here, therefore, I removed not only the effect of inflation on cost, and of variations in the number of equivalent transponders, but also of differences in expected life.

Accordingly, the initial equations were rerun with a final sample of 86 observations. The modified results showed some interesting differences due to removal of the two cases, in particular a reduced standard error in a new equation in which all of the variables were included (forced in), making for improved predictions.

Analysis

Such preliminary work helped uncover the relevance of several explanatory factors best explored by means of a major illustrative equation. In developing a final dependent variable for the study – cost per equivalent transponder year in 1983 R&D dollars – the actual cost of the satellites over time was first examined where a high correlation between actual cost and time was discovered. Because inflation was such a dominant influence on cost this was to be expected. Other factors, even if important, were literally swamped by the overwhelming effect of inflation.

In developing this final dependent variable, then, cost in 1983 R&D dollars was calculated first, where the effect of inflation was removed by using an R&D deflator. This explained only a much smaller amount of the variance, although this, too, could still be highly significant in relative terms. Remember that the raw-raw variable was 'cost', but as this was refined by adjusting for inflation some of the variance was removed, the part due solely to inflation.

In later equations the dependent variable was refined by using 'cost per equivalent transponder' and then 'cost per equivalent transponder year', each adjustment being comparable to introducing another variable into the equation. So while the series on actual cost explains a full 67.0% of the variance, after deflating it explains only 6.8%, which is to say that 60.2% of the variance in the original data is due to inflation, and removing this obviously leaves mich less variance to explain.

Turning next to cost per equivalent transponder in 1983 R&D dollars, the effects of inflation and variation in the number of transponders are both removed. By adjusting for the number of transponders we actually adjust for a factor with two components. The cost of additional transponders will increase the total cost of the satellite, but when we divide by the number of transponders to get the cost per equivalent transponder we 'share' the cost of the satellite. This will tend to result in a lower cost per transponder.

Finally, in regard to cost per equivalent transponder year in 1983 R&D dollars, we not only take out the effects of inflation on cost and variance due to variations in the number of equivalent transponders, but also due to differences in expected life.

In actuality, then, a satellite cost equation will focus on three dependent varaibles: (1) 1983 R&D cost, (2) cost per transponder, and (3) cost per transponder year. In this way, cost is scaled down first, per transponder, and then weighted by the equipment's expected design life. In effect, three types of equations are used: first, stepwise regressions based upon a stopping value of 0.05 significance; second, equations which include all of our primary independent variables (launch year, number of transponders, estimated life, the C-*v*-Ku dummy), and third, equations which include all of the primary independent variables plus their interactions with the dummy variable C-*v*-Ku.

Table 1. Two groups of forced variables.

Group 1	
VAR02	Launch year
VAR03	Equivalent number of transponders
VAR04	Expected life
VAR05	C-*v*-Ku combo dummy
Group 2	
VAR02	Launch year
VAR03	Equivalent number of transponders
VAR04	Expected life
VAR05	C-*v*-Ku combo dummy
VAR06	Dummy × expected life
VAR07	Dummy × equivalent number of transponders
VAR08	Dummy × launch year

Forced models versus *stepwise models*

In each of the two groups of variables listed in Table 1 we ran both the stepwise regression model (not reported here) and the forced variable model. In the latter case a simpler model was run first, one limited to the four major determinants of satellite cost, selected on *a priori* grounds. An alternative version of that model was then run, one which also included interactions between the C-*v*-Ku dummy and each other major determinant. The two groups listed are simply clusters of variables forced into different equations, listed here by group to allow for easier reporting of the regression analysis.

When Group 1 variables are forced into the equation the only signficant variable is 'Expected life', which indicates that the longer the life of satellite equipment, the lower its cost. This is really a proxy for technological reduction in cost since the longer-lived satellites are launched only in our sample's later years.

On the other hand, when Group 2 variables are forced in, VAR08, 'Dummy x launch year', cannot even be entered into the equation, and no single variable is significant. Nevertheless the whole 'set' of variables forced in does make an overall regression which is significant at the 0.0012 level. In other words, the total mix of independent variables does help predict satellite cost even though no one factor can be identified as the most important or a very important factor. These so-called moderator variables are logically and quite properly forced into the equation on the basis of prior knowledge.

In sum, cost per transponder year in 1983 R&D dollars would appear to be the ideal dependent variable, for here inflation is adjusted by dividing out the uneven number of transponders, and also the uneven number of years of expected equipment life, all of which gives us the nominal cost of flying one transponder for one year.

Further analysis with and without Hughes dummy variable

One final element was added to the several main equations, in the form of a dummy variable equal to 1 if the satellite contractor was Hughes, and equal to 2 otherwise. This would help determine whether the Hughes/other contractor relationship helps explain the residual (unexplained) variance in satellite cost.

As for the stepwise regressions run here, the Hughes dummy did not enter any of these and, therefore, each is exactly the same as previously. Similarly, our three forced main effects equations remain basically the same when the Hughes dummy is included, whether the dependent variable is 1983 R&D cost, cost per transponder or cost per transponder year. As before, the Hughes dummy is coded as 1, and all other contractors as 2. As for forced main and interactive effects, moreover, for each of the three dependent variables, there is a slight loss in R^2, probably due to the loss of one degree of freedom (see Table 2).

In short, in this crude form of the dependent variable the effect of the number of transponders is increased by approximately 19% when the Hughes dummy is included. Conversely, the effect of expected life is decreased by about 29%. That is to say, when we consider the Hughes dummy the effect of increasing the number of transponders raises cost faster for Ku than for C. When considering increased life expectancy, the increased cost for additional years of expected life increases more slowly for Ku than C.

Table 2. Results of regression equations with and without Hughes dummy variable.

Variable	No Hughes	Hughes
Expected life	−2799.57	−2593.06
Equivalent number of transponders	1010.37	1045.28
Power form of combo x launch year	467.50	Could not enter
Combo × equivalent transponders	−152.85	−181.36
Combo × expected life	521.06	372.10
Power form of launch year	59.49	504.54
Hughes dummy	Not used	479.26

The big differences are, in any case, in the impact of launch year and of the Hughes dummy itself. Remember that the power form of launch year inverts the effect/meaning of the coefficient. In the equation without any Hughes dummy we found that later years (as expected for this variable) resulted in higher total costs. With Hughes factored in, on the other hand, in the later years costs are lower.

The net finding, then, is that if your manufacturer were Hughes, after holding all of the other factors (in our equation) constant, you would pay $479 000 less for your bird.

Illustrative point estimates

Returning next to our analysis of satellite cost in Table 3, I derive illustrative point estimates for costs per transponder year for 1975, 1980 and 1985, and assuming both a seven- and ten-year life,[5] and further, satellite capacity of 12, 24 and 36 transponders.[6] These point estimates appear in Tables 4 and 5 and the comments that follow here are based upon their preliminary review.

Had an administration entered C-band in 1975 with an expected life (EL) of seven years, and standard transponder capacity of 24, in constant dollars a satellite would have cost $313 570 per transponder year, whereas if there were no room left in C-band the cost in Ku would have been $44 650 (or 14.2%) more, ie $358 220.

Suppose, however, the same administration waited five years until 1980, and sought comparable entry under the same parameters. By then, according to my estimation, technical advances would have lowered cost per transponder year (CTY) some $38 000 to $275 900 if C were in fact available. But if all Cs were occupied, the cost handicap in Ku would have risen from $44 650 (14.2%) to $48 000 ($17.4%), making a Ku cost of $323 966. By 1985 the cost penalty would rise still more, to $50 600 or 20.3% of C-band costs, for a Ku cost of $299 386.

Suppose further that by 1985 EL rose from seven to ten years, and that equipment scale economies could be better enjoyed using a 36-transponder capacity. Under those parameters (a polar bound in our model) two things must be noted. First C-band costs would have declined from $313 570 per TY in 1975 (for a seven-year life and 24 transponders), to only $36 516 in 1985 (with a ten-year life and 36-transponder capacity). This is only 11.6% of the cost level derived for 1975. By way of contrast, note also that Ku-band costs per transponder year for the same equipment parameters would have fallen only from $358 222 in 1975 to $118 507 in 1985, ie to 33.1% of the prior level.

Hence waiting would in one sense have paid off. If one were lucky to find a C-band location, the greater scale economies and higher expected life in 1985 over 1975 would yield a cost reduction per transponder year

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[5] My final working database of 86 satellites had a sample mean of eight years expected life, a mode of seven years and a current outer bound of ten years, in close line with the accounting life of Intelsat IVs (seven years) and Intelsat Vs (ten years).

[6] As for transponder capacity, the sample mean of my 86 cases was 22.5 equivalent transponders, the sample mode 24, with an outer bound of 36.

Table 3. Analysis of the determinants of satellite cost.

Dependent variable	
VAR 1 = COST	Satellite cost in constant dollars, divided by the number of 'equivalent' transponders, times the number of years of expected life, deflated by NASA's R&D Inflation Index (ie real cost per transponder year).
Independent variables	
VAR 2 = LY	Launch year, during which satellite was actually orbited.
VAR 3 = #ETs	Number of 'equivalent' transponders using 36 MHz each, in each satellite, where actual transponder capacity is normalized into transponders with frequency bandwidth of about 36 MHz, able to relay one TV signal or some 1000 voice circuits between Earth stations.
VAR 4 = EL	Expected years of life of the space satellite equipment once launched into orbit.
VAR 5 = BAND[a]	Dummy variable = 2 if satellite is Ku-combo, = 1 if C-combo.
VAR 6 = BAND × EL	Dummy variable = 2 if satellite is Ku, = 1 otherwise, each weighted by years of expected life.
VAR 7 = BAND × #ETs	Dummy variable = 2 if satellite is Ku, = 1 otherwise, each weighted by number of ETs in satellite.
VAR 8 = BAND × LY	Dummy variable = 2 if satellite is Ku, = 1 otherwise, each weighted by year in which orbited.

The coefficients in the final exploratory equation, with highest AR-squared, were these:[b]

$$X1 = 612.105 + 19.408X2 - 13.869X3 - 25.7555X4 - 3.899X6 - 1.629X8 \qquad [AR2 = 0.614]$$

Notes:

[a] Frequency band is a categorical variable which had 12 different values. Considering the limited number of data cases, it was apparent that this variable had to be collapsed into a smaller number of values. One primary interest is of course in the difference between C and Ku frequencies. BSS satellites are of a completely different type and therefore removed from the data set, as explained in detail. Some analysis is performed using only those satellites which were 'pure' Cs (49) or 'pure' Kus (15), *N* = 64. This severely restricts the number of cases, however. Therefore, to ensure adequate observations per cell and to use all 86 observations, on the basis of technical and economic information the entire sample is split into C-combo = (C+C/S= 49+3= 52 cases, or 60.5%), and Ku-combo = (Ku+C/Ku+C/Ku/L+C/Ku/X= 15+13+4+2= 34 cases, or 39.5%). However, the frequency distribution by satellite type was actually as follows:

Band	**Frequency**	**%**
C	49	57.0
C/Ku	13	15.1
Ku	15	17.4
C/S	3	3.5
C/Ku/L	4	4.7
C/Ku/X	2	2.3

[b] In this cost equation the coefficient of LY (X2) is positive, which implies, *ceteris paribus*, cost increases with time, but technological progress should presumably imply a decrease in costs. Indeed, to find the time coefficient for C-band satellites one should subtract the coefficient of X8 from that of X1, and twice the coefficient of X8 from X1's. Yet both of these are still positive. The explanation lies in the curvilinear character of the impact of launch year on satellite cost per transponder. It is self-evident, eg, that LY captures the cost-reducing effects of improved state of the art and new technology, and possibly even a small effect of learning by doing, provided of course that we first adjust for inflation so that time will not itself simply be a proxy for inflation.

To analyse and adjust for curvilinearity we used the Lotus 1–2–3 program to manipulate the data and the Graphwriter program by Graphic Communications, Inc, to the fitting and plotting. There are essentially three types of adjustment of this kind of data – exponential, logarithmic and power. The exponential and power curves are quite similar in their effect on r^2. On the basis of a visual examination of the graphs we preferred the power curve adjustment. But we actually adjusted the X-axis (launch year) for each of the three types of adjustment.

For both the power and exponential transformations the X values become negative, therefore the graph appears to be reversed. The year 1985 is at the left of the X axis and 1971 on the right. However, we can reform this scaling once we have decided on which graphs to use and how to explain the values. That is one of the problems of doing transformations.

Of great interest is that in the power graphs you can very clearly see the effect of time. Thus, as years go by there is less and less reduction in the cost of a transponder-year. The reason for the apparently inverted results is that we are using a transformed variable for launch year (LY). LY is raised to a negative power and the transformed value is used in the equation. Finally, LY, equivalent transponders (#ETs) and expected life (EL) all show decreased costs as their values increase (remember the reverse effect of LY), the first two reflecting innovation and perhaps learning, the #ETs reflecting scale economies.

of almost 90%. However, even if C-band were saturated, Ku costs per transponder year would under the same assumptions fall to $118 507, a decline of 66.9%. Hence waiting the ten years and enjoying the innovational advances in expected life, transponder capacity and basic know-how would seem to have offset the initial latecomer cost handicap

Table 4. Impact on satellite cost per transponder year of satellite transponder capacity, expected life and launch year.

Variable	Code	ARS coefficient	Significance
Launch year	VAR02	19.408	0.1916
Eq transponders	VAR03	−13.869	0.0203
Expected life	VAR04	−25.755	0.1692
Combo × exp life	VAR06	−3.899	0.7502
Combo × eq trans	VAR07	3.592	0.2567
Combo × launch yr	VAR08	−1.629	0.9114
Consant		612.105	

Note: Dependent variable is cost per transponder year.

in 1975. Upon closer scrutiny, however, this is not at all the case.

From another viewpoint at least, relative latecomer costs were even higher in 1985 than a decade earlier. In 1975, for 24 transponders and an expected life of seven years, it would only cost another $44 650 per transponder year (14.2%) to switch from C to Ku, compared to $50 584, or 20.3%, for a comparable switch in 1985. Indeed, even after more technological progress, yielding an expected life of ten years and a 50% larger transponder capacity (of 36), Ku costs per transponder year in 1985 would be a full $81 991 greater than similar C-band costs. In other words, the cost differential itself is over twice the size of the C-band costs, which clearly represents a substantial handicap for latecomer entrants.

In sum, to say that Ku-band technology progressed, and costs per transponder year dropped substantially for Kus as well as for C-band satellites over the 1975–85 period, in no way means that the latecomer cost handicap had disappeared. For if C-band could have been entered in 1985, relatively as well as absolutely more would have been saved over Ku than would have been true in 1975 ($50 584, or 20.3%, in 1985, compared to $44 650, or 14.2%, in 1975). That is, being deprived of the lower spectral location in 1985 would impose extra costs in using the then C-band technology of almost $82 000 per transponder year, or

Table 5. Predicted values for given independent variables.

No of transponders	C	Ku	Difference
Expected life seven years			
Launch year 1975			
12	436 894	438 440	1 546
24	313 570	358 220	44 650
36	190 246	278 000	87 754
Launch year 1980			
12	399 185	404 186	5 001
24	275 861	323 966	48 105
36	152 537	243 746	91 209
Launch year 1985			
12	372 126	379 606	7 480
24	248 802	299 386	50 584
36	125 478	219 166	93 688
Expected life ten years			
Launch year 1975			
12	347 932	337 781	−10 151
24	224 608	257 561	32 953
36	101 284	177 341	76 057
Launch year 1980			
12	310 223	303 527	−6 696
24	186 899	223 307	36 408
36	63 575	143 087	79 512
Launch year 1985			
12	283 164	278 947	−4 217
24	159 840	198 727	38 887
36	36 516	118 507	81 991

Note: This table was fully corrected for outliers. It was also corrected for non-linearity to avoid the results being dominated by one or two freak observations. Furthermore, error terms were plotted for actual and computed values for each of our variables. How many latecomers have a need for only 12 transponders anyway, especially when cost differences are negligible, and even go in the wrong direction? And could there additionally be a glitch in the estimating procedure used here? Clearly, data for small numbers of transponders may not be accurate or reliable.

some 225% of deflated costs assuming a ten-year life and satellite capacity of 36 transponders. This compares with extra costs of almost \$88 000 in 1975, but those costs were only 46% of C-band costs that year under the same assumptions.

In relative terms, then, the latecomer handicap rises notwithstanding technological advance, assuming each time what the potential C-band cost would have been, under postulated parameters, had access been available when sought.

One could of course contend that the LDCs which could not afford to enter either C or Ku band in 1975 did stand to benefit by waiting five or ten years whether they then entered C or Ku. This is because equipment in both bands will come down in cost substantially since growing demand may also raise design capacity (and hence scale economies) and, finally, because innovative advance may not only lower capital costs per circuit generated but also lengthen the expected life of satellite equipment.

Nevertheless there is really only one way to prevent a latecomer cost handicap, and that is to ensure that LDCs have access to lower (C-band) assignments from the very outset (1975), so that when a decade has passed the LDC can enjoy the now lower costs and longer-lived equipment of C-band, not Ku-band, systems. That is in fact what the adherents of allotment planning are implicitly doing today, and have indeed done over the last ten years. The only question is whether the innovational advance will proceed undeterred in the face of the preplanned assignment plan postulated, and this is not self-evident.

Tentative analysis of claim-staking

A further study relates directly to claim-staking, and will presently seek to explain the level of new transponder capacity orbited in any given year (in my sample), by reference to five sets of key factors.

Explanatory factors

The first factor is each orbited satellite's potential market size (satellite footprint in terms of area covered, and the country's real GDP that year, or the latter's annual percentage growth over the prior five years). The second is the state of the engineering arts, or rate of technological advance (as reflected in the expected life of satellite equipment and, most important, the latter's launch year). The third factor is the cost of space satellite equipment deflated by NASA's R&D inflation cost index. The fourth is spectral location (whether the C, Ku or Ka-band). And the fifth is the type of satellite owner (whether an LDC or DC government, a PTT, a regulated or unregulated firm).

In effect, the actual demand for transponders will be fit to a set of variables that at least crudely represent current economic value to the launching countries. The proposition would then be considered that claim-staking is indicated by a poor fit of this equation, admittedly a test that has major shortcomings:

- A poor fit may simply be due to a failure to specify the demand variable properly, or a linear fit poorly approximating a non-linear relationship between the variables.
- Even a good fit may not be decisive evidence that claim-staking does not exist. The coefficients may be totally incorrect in terms of

> economic analysis, or the good fit may simply reflect a correlation between the specified variables in the equation and other omitted variables which actually generate the claim-staking.

Be this as it may, however, the crude and imperfect equation in Table 6, and the hypothesis underlying it, provide a useful first step. Short of far more detailed information than is now even remotely available, the equation specified here ties in plausibly with claim-staking and preemption. For that reason at the very least, compiling and organizing the indicated data in this framework seem likely to provide building blocks for a more refined assessment at some later point.

The costs and benefits of delayed launching would well be compared with those of immediate launching. Here cost differences between bands could presumably be considered, as well as technological progress over time, and fuller utilization of capacity. There are, however, no obvious direct measures of benfits although Table 6 does contain some probable determinants of benefits.

True, there is available no *a priori* knowledge of the coefficients of such independent variables as any convincing calculation of benefits. Perhaps new satellite entry (and non-entry) could be fit to a larger set of variables. These might include both present and future expected values of the independent variables. The task would then be to determine the reasonableness of considering the calculations that result as though they reflect benefits of orbit spectrum utilization.

Suppose, for example, that the current income (and hence demand) level of two countries were such as fail to warrant launching a satellite. Probably the one that expected to find a satellite economically viable in

Table 6. Analysis of factors affecting space satellite investment in the orbit spectrum resource.[a]

Dependent variable	
var 1 = #ET	Number of equivalent transponders in each satellite launched for which we have adequate data, 1970–85.
Independent variables	
var 2 = COST	1983 cost of space satellite equipment adjusted for inflation with NASA's R&D cost index.
var 3 = EL	Expected life of satellite in years.
var 4 = BAND	Dummy var = 2 if Ku-band, = 1 otherwise.
var 5 = LY	Launch year.
var 6 = OWNER[b]	Dummy variable to distinguish between satellite launched by DC or LDC, and further, by PTT or rate-base-regulated firm.
var 7 = AREA	Satellite's required ground coverage area, estimated as country's territorial area where footprint is larger than country.
var 8 = GDP-A	Real GDP of country where satellite launched, during LY (1970 prices).
or	
var 9 = GDP-B	Average annual growth of real GDP during LY; or during period just before LY, or period which includes LY (eg 1960–70 or 1970–81, as in *World Tables*, 1983/84).
or	
var 10 = GDP-C	Average annual growth of real GDP in 1970 prices contributed by transport and communications during LY, or during 1960–70 or 1970–81, as in GDP-B, in country which launches satellite.

Notes:

[a] Markets and area estimates for this table were: Intelsat (Atlantic Region, Indian Ocean Region, Pacific Region), Eutelsat, Arabsat and Inmarsat. In each case (a) the investment share will be based on the traffic share of each signatory in these four consortia, and, in the Intelsat case, by region, for the years or periods in question; (b) the real GDP will then be estimated in vars 8, 9 and 10 for the weighted average of the countries in each consortium and region, adjusting as appropriate where some countries (say, the USA, Japan, etc) appear in more than one Intelsat region; (c) the footprints of each consortium's satellites will further be estimated by the weighted square mile area of all countries in each consortium, and each Intelsat region in respect of var 7.

[b] The following factors are discussed briefly in Harvey J. Levin, 'In search of common pool behaviour – the case of redundant satellite capacity', paper presented at Nineteenth Meeting of the International Atlantic Economic Association, Rome, 9–16 March 1985, reprinted in Columbia University Research Program in Telecommunications and Information Policy Series, 1985.

the near term would be the one with a higher income level today, and would on that count at least find claim-staking profitable. In contrast, the other country, say one with a lower income level, would find the satellite profitable only well into the future. The excess of discounted losses over the extra costs of inferior bands might therefore make claim-staking not seem worthwhile. Here, then, there might indeed be claim-staking even though statistical analysis found that income levels explained the decision to launch very well.

Hypothetical illustrative equation

The intial claim-staking variables can now be restated in the form of a second illustrative equation (specified in Table 6), which could then be fit to a new, expanded database. And here the question is: how uneconomic if at all is it for any country to create more transponder capacity (var 1) in any given year? Suppose, eg, the creation of such capacity is not adequately explained by the variables in Table 6. That is, suppose the new transponder capacity is excessively costly (var 2) given its expected physical life (var 3), its estimated ground coverage area (var 7) and the potential economic market it will serve (vars 8, 9, 10). And suppose also that this is true even when we take account of the satellite's frequency band (where Ku is known to be more costly than C-band, var 4) and irrespective of the form of ownership (var 6), and regardless, also, of launch year (var 5), where more recent launches are known to reflect more advanced technology and greater experience or learning. In that case I would contend that 'something else' may have induced the creation of this new transponder capacity, and that this 'something else' could well be the pursuit of positional advantage, or 'claim-staking'. At the least, in interpreting these results reference must be made to such well-known factors as these:[7]

- the lumpiness of investments and length of time horizons in regard to projected demand, and any relevance of a classic AT&T-type case where, before the break-up, that company was said to plan its terrestrial investments for a century, so that its presumably underutilized telecommunications capacity may have appeared excessive, wasteful or otherwise uneconomic, though in retrospect may just have been a transitional phase, and no evidence of any attempt to stake claims;[8]
- forecasting errors, which leave us with more excess capacity, for longer periods than initially anticipated, but once again constitute no indication of any common pool syndrome;
- a kind of 'inventory management strategy' which leaves us with some interim underutilization of transponders today, the better to enhance their subsequent value tomorrow, whether in outright resale or more time-limited sub-leasing to interested users;
- deliberate strategies to build redundant plant capacity so as to ensure reliability for safety, security and convenience. The central question here is whether the margin of planned redundancy is imposed by suppliers of circuits or simply offers users something they really want enough to pay extra for, and where, if the latter (where redundancy is not imposed beyond what users really want), its does seem less likely that suppliers are exercising their discretion to gain positional advantage;[9]
- a case of pricing failure in that there may be institutionally grounded intermodal preemption where the PTTs overinvest in one transmis-

[7] One question is whether the actors are countries or firms; and, if firms, whether regulated or unregulated; or if countries, DCs or LDCs. In each case, special structural incentives may explain tendencies for premature, excessive investment in claim-staking and redundant capacity. With LDCs which lack the wherewithal for substantial investment, claim-staking could take the form of paper rights in detailed long-term *a priori* plans imposed on DCs via a one-vote-one-nation formula. With DCs, on the other hand, regulated firms subject to rate base regulation may be more likely to undertake excessive, uneconomic investment to increase their returns, while unregulated private carriers may do so more to ensure their access rights when they are in a position to enter. Stated otherwise, excessive or premature investment may occur in all three cases just indicated, namely: in the LDCs which impose paper rights to safeguard future access rights in the face of premature investments by DCs; in unregulated firms which aim to establish claims (and secure grandfather rights and business equities) before their rivals do, or before LDCs impose detailed *a priori* plans on them; or in major regulated firms, not for claim-staking (since they are virtually assured assignments in the orbit spectrum) but in response to well-known incentives to expand their capital-intensive investments under rate base regulation, and to engage in short-run predatory pricing towards that end, with little reason to keep cost expenditures down insofar as they can recover any cost increment by charging more for services they sell to users with low elasticity demands, and have non-profit goals which can be furthered by 'unprofitable' cost-increasing outlays.

[8] See, generally, Harvey Averch and Leland Johnson, 'Behaviour of the firm under regulatory constraint', *American Economic Review*, December 1962, pp 1052–1068. These and related aspects of the Averch–Johnson formulation are nicely laid out in William Baumol, 'Reasonable rules for rate regulation: plausible policies for an imperfect world', paper presented at Brookings Rate Base Symposium, 7 June 1968, pp 3–6; and in Harry Trebing, ed, *Performance Under Regulation*, MSU Public Utilities Studies, Michigan State University Press, Lansing, MI, USA, 1968, pp 42–47, 74–78. On the possible manifestations of these alleged predispositions of regulated carriers, see further discussion and citations in Levin, *The Invisible Resource*, Johns Hopkins University Press, Baltimore, MD, USA, 1971, pp 292–294.

[9] Clearly related issues are examined in A.S De Vany and T.R. Saving, 'Product quality, uncertainty, and regulation: the trucking industry', *American Economic Review*, Vol 67, No 4, September 1977, pp 583–594. See also A.S. De Vany, 'Uncertainty, waiting time and capacity utilization: a stochastic theory of product quality',

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sion mode (say, satellites) over a rival facility like fibre-optic cable, even though the latter may be more cost-effective. The ostensible objective here is to get one's ministry of communications or other regulatory authority committed, say, to satellites over cable for the long haul, even at the expense of interim redundancy;

- strategic preemption, where excess capacity may be part of a larger competitive effort to keep potential satellite entrants out by making them fearful of predatory pricing. Most economists discount this hypothesis unless the carrier is a monopolist, since otherwise strategic preemption is a public good in that a carrier's potential satellite rivals would also benefit if, eg, such preemption deterred (say) AT&T from laying a fibre-optic cable;[10]
- time slippage in completing a system's Earth segment, due perhaps to engineering delays, financing problems, strikes, regulatory procedures, etc. Once again, however, the resulting unused capacity need not be evidence of any pursuit of positional advantage;
- finally, the desire to avoid any latecomer cost handicap further impels nations to stake out claims on orbit spectrum assignments by means of premature or excessive investment.

Still another task is to determine the relative impact on new transponder capacity of two conceivable entry strategies: first, the strategy of owners who desire to mitigate latecomer cost handicap by entering C-band today (even prematurely) to avoid higher capital and operating costs in Ku-band tomorrow; and second, the strategy of those who desire to postpone entry to enjoy greater cost-reducing benefits from learning by doing and third-party innovation, and thereby to mitigate any higher latecomer costs in Ku (over C-band) likely to result from such postponement.

In the equation in Table 6 a significant positive coefficient for var 5 (LY) would seemingly suggest that, *ceteris paribus*, the more recent the launch year the greater the chances for learning and innovation to have occurred. Accordingly, the lower the likely real satellite costs per transponder year in both C and Ku-band, the greater is the inducement to create new transponder capacity regardless of such other independent variables controlled for as economic market potential and ground coverage area. (This can be confirmed from prior results in the regressions of satellite cost of LY, EL, BAND and #ETs in Tables 3 and 4.)

By the same token a significant negative impact of LY on transponder capacity is consistent with the alternative hypothesis that entering earlier, even before the benefits of learning and innovation have occurred, may yield an overriding advantage in avoiding the likely higher capital and operating costs associated with latecomer entry and its concomitant need to invest heavily in narrower band spacing (at the intensive margins) or to invest also in facilitating a move up to Ku, or higher still to Ka (at the extensive margins of the spectrum). (This, too, can be further confirmed by reference to my earlier regressions of real satellite costs per transponder year of #ETs, EL, BAND and LY.)

In short, satellite cost data can be used to configure a 'simulation' model, as just suggested in Table 6. The task is to model together both segments of this inquiry, latecomer handicap and claim-staking. They can both be modelled and tested empirically, in regard to what it is worth if you enter now (in C rather than Ku) *versus* how far costs might

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Journal of Political Economy, Vol 84, No 3, 1976, pp 523–540. There De Vany demonstrates that, with waiting time as a form of product quality, excess capacity can exist in a market equilibrium. See, finally, Walter Y. Oi, 'Slack capacity: productive or wasteful?', *American Economic Association Papers and Proceedings*, May 1981, pp 64–69. Oi cites Hutt's eight categories of idleness, 'of which five can properly be classified as wasteful' (p 68). 'Productive slack' is illustrated by a concept of 'pseudo idleness', where resources are held intact (and not scrapped), because their capital value exceeds their 'net positive scrap value' (*ibid*).

[10] Some interesting analogies appear in the literature on preemptive invention, where firms may try to maintain monopoly power by patenting new technology before their potential rivals, though the patents remain unused by the patentholder, and unlicensed to others. The unused patent, in short, figures in precluding or inhibiting entry by rival firms, and in that sense would contribute to positional advantage: Richard J. Gilbert and David M.G. Newbery, 'Preemptive patenting and the persistence of monopoly', *American Economic Review*, Vol 72, No 3 June, 1982, pp 514–526.

come down via technological advance, and learning by doing, if you opt to postpone entry instead.

To be sure, technological progress could be offset by other causes of cost increase. That is, if you wait for unit costs to come down via innovation and scale economies you may also get a worse location. So the questions is: who can stand waiting, and who cannot?

Stability in satellite deployment over time

In assessing the claim-staking hypothesis, in any case, one final piece of evidence must first be gathered and presented. Do orbit spectrum assignments go back into the pool (a) if they are not used within a certain time period, or (b) if your equipment wears out after you have started to use them? That is, once your equipment wears out, must you go to the back of the line to replace it or to add a new system? Or, since there are in principle no permanent rights, do you intend normally to retain your same slot regardless of other potential entrants?

Before considering the latter two adjustments, the deployment of satellite orbital locations over time must be determined for mainly US but also some non-US geostationary satellites where information is available. Table 7 traces the orbital location of satellites launched by eight entities, by year, for which published information could be collected, mainly Intelsat (15 locations), RCA (10), Western Union (4), and abroad, Anik (5), Palapa (2), Insat (2), Symphonie (2), BSE and Sakura (4), and Marisat (3).

These data show marked stability in the deployment of satellites over time for most major entities: note, eg Westar 4 at 99°W for 1986, back to 1974 in that location; RCA Satcom 3R at 131°W, back to 1979; Anik-B at 109°W, back to 1973. Even more dramatic is the stability of Intelsat slot locations, most notable being the deployment of Early Bird at

Table 7. List of 28 orbital locations ranked in descending order of years occupied by the same entity for slots occupied three years or more, for US, Canadian and Intelsat satellites, at 1 January 1986.[a]

	Location	Entity	Years
1	325.5°E	Intelsat	21
2	329°E	Intelsat	18
3	174°E	Intelsat	17
4	60°E	Intelsat	16
5	335.5°E	Intelsat	16
6	341.5°E	Intelsat	15
7	109°W	Anik B, 4	13
8	99°W	Westar 4, 1	12
9	338.5°E	Intelsat	11
10	63°E	Intelsat	11
11	104°W	Anik D	10
12	359°E	Intelsat	8
13	57°E	Intelsat	8
14	179°E	Intelsat	7
15	76°W	Comstar 3	7
16	91°W	Westar 3	7
17	131°W	Satcom 3 (RCA)	7
18-	332.5°E	Intelsat	6
19	99°W	SBS 1	6
20	307°E	Intelsat 5	5
21	123°W	Westar 5	5
22	97°W	SBS 2	5
23	127°W	Comstar 4	5
24	95°W	SBS 3	4
25	87°W	Telstar 3A	4
26	143°W	Aurora 1	4
27	139°W	Satcom 1R (RCA)	3
28	97°W	Telstar 3	3

[a] In each case the current incumbent was the first and only occupant.

Sources: Derived from Intelsat, *Annual Reports*, 1965–85; TRW, *Space Log*, 1965–83; and President's *Aeronautics and Space Reports*, 1965–84.

325.5°E in 1965, a slot still occupied by a current Intelsat in 1986, with birds also today at 60°E, 174°E, 329°E, 335.5°E and 341.5°E, tracing the same occupancy (or very close to the same) as far back as 1969, 1968, 1968, 1970 and 1971, respectively. Stated otherwise, Table 7 ranks orbital locations in descending order by the number of years occupied by the same entity.

Another way to depict squatter's rights, or the relative stability of orbital slot occupancy over time, would be to order or locate satellites in a geographic sequence rather than by number of years in orbit. Here we would lay off degrees East and West longitude on the horizontal axis, and then for each installation a vertical location would be plotted which gives us the number of years in orbit. On this histogram, if there is a large number of very old satellites, that will pop up right away, more than if there were a large number of fairly new satellites, where we could see if they are concentrated in one place, or inserted among the new ones.

In short, these data on orbital locations show marked stability in the deployment of satellites over time for most major entities, and in Table 7 they do indeed suggest the advantage of early entry. At least, the stability indicates a *de facto* claim on location once you have entered. Furthermore, judging from the point estimates of satellite cost I would expect a greater chance for occupants to derive cost-reducing benefits from innovation, and, where the same birds are used, from learning by doing. Also, early entrants could enter at lower frequencies which were relatively less costly at the time than in higher spectral regions. But, by the same token, entering later may saddle you with a higher, more costly location and worse footprint.

Linkage of two models

Anyhow, the linkage of my two models – latecomer cost handicap and claim-staking – is fairly obvious. If a latecomer pays more higher up, it would want to operate elsewhere around the globe where unused assignments remain, and preferably in C-band rather than Ku. Otherwise it would at least move to the more profitable markets regardless of whether it will operate in C or Ku. In exploring this hypothesis, reference must initially be made to the illustrative equation in Table 6, using the World Bank data I proposed to collect there.

Conclusion

Latecomer cost handicap arises from five key factors:

- the inferior propagation characteristics of the more recently developed, higher radio frequencies in such services as space satellites and land mobile radio;
- the costly increases in transmission power and electronic equipment required to overcome the impairment of signal quality and information delivery to which latecomers are forced to turn when firstcomers saturate the lower, less expensive spectrum bands;
- the higher equipment costs associated with newer spectral bands where the economies of large-scale manufacturing have not yet been fully realized;
- the high non-recurring R&D and engineering costs incurred to open up newer spectral regions;

- the higher coordination costs incurred by latecomers who must bear the cost of adjusting their coverage patterns and equipment design to those of firstcomers under current legal–administrative practice.

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

In this article I have tried to uncover the relevance of several exploratory factors, in particular by regressing satellite cost on launch year, number of equivalent satellite transponders, expected years of life, satellite band and interactions between band, on the one hand, and expected life, number of equivalent transponders and launch year, on the other.

Here my presumption is threefold:

- that in resources without well-defined rules for property rights, only through actual entry, occupancy and use can *de facto* property rights be established, albeit on a first come, first served basis;
- that without special institutional safeguards there may result 'excessive' or 'premature' investment, entry and output, or 'economic waste';
- that users appear to engage in strategies for preemption and use. There, costs are in some sense bid up for all, firstcomers and latecomers alike, this being a kind of 'pure externalities' effect penalizing all entrants comparably, just as an overcrowded roadway slows down users to a like degree, whether they be early or late entrants. It is true, finally, where the incremental slowing effects have a wasteful time cost that falls on others, but only a negligible incremental effect on any given entrant.

The next study, still in an early planning stage, relates directly to claim-staking, and will try to explain the level of new transponder capacity orbited in any given year (in the sample used here), by reference to five sets of key factors (nine independent variables in all, as in Table 6):

- each orbited satellite's potential market size (cf the satellite footprint in terms of area covered, and the country's real GDP that year, or the latter's annual percentage growth over the prior five years, etc);
- the state of the engineering arts, or the rate of technological advance as reflected in the expected life of satellite equipment and, most important, in the latter's launch year;
- the cost of space satellite equipment deflated by NASA's R&D inflation cost index;
- spectral location (whether the C, Ku or Ka-band);
- fifth, type of satellite owner (whether an LDC or DC government, a PTT, a regulated or unregulated firm).