Institutional Constraints in the Initial Deployment of Cellular Telephone Service on Three Continents

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Submitted for
Kai Jakobs, ed., *Information Technology Standards and Standardization: A Global Perspective,* Philadelphia: Idea Group, 2000.

June 30, 1999

The author wishes to acknowledge the valuable comments on earlier drafts of this article provided by Jason Dedrick, Jeffrey Funk, Kalle Lyytinen and John King.

Abstract: Product compatibility standards both create and are shaped by economic and political institutions. This paper examines a particular innovation, cellular mobile telephone service, which was commercially introduced on three continents during the early 1980's. Focusing on the U.S. case, it outlines the institutional context for the initial deployment of cellular telephone service, contrasting it to the other regions. The paper concludes with a discussion of the implications for diffusion and standardization.

The influence of institutional pressures on standards and standardization are readily apparent in their most direct form. For example, in the mid-1990's, both the European Union and the United States issued new wireless communications licenses in the 1.8-2.0 GHz band: the EU countries mandated use of their decade-old communications standard, while the U.S. authorized three competing standards not yet widely used in the U.S. (Mehrotra, 1994).

However, institutional pressures can also shape standardization efforts in a less direct fashion. For example, in a regulated industry such as telecommunications, existing economic and political institutions constrain the diffusion of a new technology. Such diffusion mediates the impact of product compatibility standards upon society. If producers adopt standards for their goods and services, and if users adopt the products that incorporate such standards, only then such standards can have an economic or social effect upon society at large. Therefore, it is important to understand the impact of institutional pressures on diffusion of the innovation that incorporates a standard if we wish to explain the eventual success or failure of such a standard.

Here a particular standards-based innovation, analog cellular telephone service, provides an opportunity to contrast the effects of institutions on diffusion and thus standardization. Over a four year period, three independent design centers deployed mutually incompatible standards in three continents. While the technical solutions were similar, differences in institutional context between the regions influenced both the nature of the respective standards and their corresponding diffusion. In particular, the systems were deployed in a period of shifting telecommunications competition policies and priorities for radio frequency allocation.

Prior research has examined the causal links between standards and institutions, both the institutional context of standards development (e.g., Besen, 1990) and also how established standards themselves function as institutions (Kindleberger, 1983). But rarely do we have the opportunity to examine the diffusion of the same innovation in differing institutional contexts.

This paper will focus on the most complex institutional context for the deployment of cellular telephone service, the United States, which despite having invented cellular technology, was the third region to deploy cellular service due to regulatory delays. The experience of Japan and Northern Europe are offered as contrasts to highlight the importance of the institutional context in the adoption of both standards and standardized products.

DIFFUSION OF STANDARDIZED TECHNOLOGY PRODUCTS

Institutional Context of Standardization

Although sometimes viewed as merely technical in nature, product compatibility standards are tightly interwoven with economic and political institutions, as they can be both the consequence and antecedent of such institutions.

Standards normally originate in institutions, whether economic, political or a hybrid thereof. Economic standards-setting institutions can be either a single firm or a coalition of firms, while political institutions sponsoring standards may be national, regional and international governments. Other standards originate from hybrid organizations, committees of individuals or firms to whom the government delegates responsibility, such as the American National Standards Institute (Farrell & Saloner, 1988; David & Shurmer, 1996).

Many standards stem from institutions whose scope is the nation-state. Some standards — such as those for broadcasting — are implicitly dependent on governmental institutions for the arbitration of competing claims and the promulgation of uniformity within a national market. Strong national institutions may also be a prerequisite for the adoption or substitution of standards, such as the standardization of railroad gauges. Global standards may originate with such national standards, or developed by explicitly multinational institutions such as the International Telecommunications Union (Kindleberger, 1983; Besen & Farrell, 1991).

Whatever their source, standards themselves serve as economic institutions: they fit the class definition of a public good, available to all and not depleted through use. Indeed, developing such public goods often falls to government by default (Kindleberger, 1983; Cowan et al., 1991; Antonelli, 1994). These economic institutions can constrain industry structure, defining the basis for both vertical supply relationships (e.g., Intel to IBM) and horizontal competition (IBM vs. Compaq).

These two aspects of institutionalization — institutions driving standards and standards acting as institutions — are often joined in the *ad hoc* institutions that are inevitable for multi-vendor *de facto* standards. Such institutions seek to promote the common goals of standards adherents while dampening their inevitable competitive rivalries (Gabel, 1987).

“Technology Push” Diffusion Strategies

The pattern for deployment of cellular telephones highlights an ongoing debate over the appropriate balance between two alternatives for diffusing technological innovation: developing solutions in response to perceived demand, or offering new solutions based on what has become technologically possible. The “technology push” approach used for launching cellular technology was consistent both with other discontinuous innovations, and also with the institutional constraints under which telecommunication companies operated during this period.

While contrary to accepted normative rules of product marketing, the deployment and diffusion of radically new technology-based products and services have for decades have been based on a “technology push” strategy (Levitt, 1960). Mowery and Rosenberg (1979) long ago observed the timing and availability of new technologies are more often determined by supply availability rather than demand pull. Dosi (1984: 9-10) notes the inadequacy of “market pull” strategies in explaining radical innovation: “the range of ‘potential needs’ is nearly infinite and it is difficult to argue that these would-be demands can explain why, in a definite point in time, an invention/innovation occurs.”

Key problems in doing market research for radical innovation come in the assumptions of the eventual target market. As Lynn et al. (1996: 11) observe, “the familiar admonition to be customer-driven is of little value when it is not at all clear who the customer is.” Even after the first customers, the early feedback can be misleading given the major differences between initial enthusiasts and the early majority (Moore, 1995). This failure to correctly identify the ultimate customer was present in all of the initial cellular markets, although some operators and manufacturers were quicker than others to recognize the eventual mass market.

The tendency towards technology push strategies can be accelerated not only by the nature of the innovation, but also the institutional framework under which it is deployed. In the century since the invention of the telephone, monopoly carriers in the developed world commonly deployed new telecommunications services using a technology push strategy. In most countries, these monopoly carriers were government-owned Post, Telephone and Telegraph (PTT) companies, organized as a government department or state-owned enterprise; in a few countries (such as the U.S. and Canada), the carrier was a regulated private firm.

New telecommunications offerings thus faced a path markedly different than for unregulated (and competitive) technological industries such as personal computers or software (Langlois, 1992). For telephone companies, the diffusion of innovations was institutionally constrained either through the PTT's government sponsors, or through government regulation of private telephone companies. The deployment of cellular telephone service was a clear example of such a "technology push" approach, particularly given that demand was consistently underestimated in the U.S. and Japan (Noda, 1996: 178; Funk, 1996).

At the same time, crucial differences in the regulatory frameworks between regions contributed to early differences in the diffusion patterns. The initial deployment of cellular telephone service in the U.S. (when contrasted to Europe and Japan) starkly highlights the impact of regulatory institutions upon supply-push technological innovation. The necessity for exclusive allocation of a scarce resource — radio frequency spectrum — provides the government with absolute control over market entry by cellular telephone service providers.

DEPLOYMENT OF CELLULAR TELEPHONE SERVICE

Evidence of institutional moderators and path dependencies in standards adoption can be seen in the development and deployment of cellular telephone service in the United States, particularly when contrasted to parallel developments in Japan and Europe.

The cellular telephone concept was invented by AT&T's Bell Laboratories in the 1940's, but the U.S.' first fully-licensed system did not become operational until 1983. Three major factors accounted for this delay: maturation of the technology (supply), the changing role of AT&T and the long-delayed FCC decisions on allocating frequency spectrum. As we will see, the latter two factors help account for why the U.S. deployment lagged other nations — despite its role in inventing the technology.

Technology Supply: Development of Mobile Cellular Telephony

AT&T launched the world's first commercial mobile telephone service in 1946. In developed countries, such systems were operated in large cities for a decade or more prior to the introduction of cellular telephones (Young, 1979). These initial car telephone systems used one set of frequencies for an entire metropolitan region (thus limiting capacity) and also required manual operator connections (increasing the cost per call). What we now recognize as cellular mobile telephony reflects the combination of two subsequent technological advances:

- *switched mobile radio,* which allowed customers to directly dial outgoing connections to the public switch telephone network: in the U.S., this began in 1964.

- *cellular radio,* which subdivides an urban area into smaller geographic cells, allowing the same frequency to be re-used within an urban area. Although a Bell Laboratories scientist invented the cellular concept in 1947, AT&T did not put it into service until 1983 (Young, 1979; Seybold & Samples, 1986).

Despite early recognition of the key concepts necessary for cellular telephony, the technology necessary to implement commercial cellular telephone systems did not become available until the 1970's. Three key developments were:

- *Frequency synthesizers.* Early mobile telephones used oscillator crystals, and were limited to a dozen pairs of transmit /receive frequencies. To increase capacity, additional frequencies were need to avoid interference between cells and to increase trunking efficiency within cells. These problems were solved beginning in the early 1970's, low-cost frequency synthesizers allowed telephones to support a large number of frequencies, e.g., the 832 channels used by the AT&T's Advanced Mobile Phone Service (AMPS) (Young, 1979; Calhoun, 1988; Macario, 1997).
- *Digital Switching.* Computerized telephone exchange switches (not available until the mid-1970's) were essential for the complex requirements of mobile telephone service, including billing, finding the mobile terminal for incoming calls, keeping calls as the mobile moved between cells, and allowing customers to use their telephones ("roam") outside their home service territory (Meurling & Jeans, 1994).
- *Microprocessors.* Nearly as much computing power was required in the mobile telephone as in the land-based switch. The solution came with the 1971 introduction of the microprocessor. The car telephone of AT&T's 1978 Chicago field trials used the same Intel 8080 microprocessor used in the Altair 8800 — the personal computer credited with launching the U.S. PC revolution (Fisher, 1979; Langlois, 1992)

By the mid-1970's, the key technical obstacles were overcome: these technologies were sufficiently mature to support large-scale urban cellular systems. All were incorporated by telecommunications operators in the U.S., Japan and Northern Europe as they developed their respective cellular technologies — but U.S. deployment lagged due to two institutional factors: the changing role of AT&T and the FCC consideration of frequency spectrum for mobile telephony.

Liberalization and AT&T's Declining Role

In the U.S., cellular telephone technology was developed by AT&T and, to a lesser degree, Motorola. As such, the deployment of cellular telephone service in the U.S. must be understood in the context of AT&T's traditional role, which evolved during the telecommunications liberalization that culminated in its 1984 breakup.

The Bell Company was organized in 1877 by Alexander Graham Bell and others to license the Bell's patents, and then integrated horizontally and vertically during the next 50 years. The resulting "Bell System" (1925-1983) linked three national resources — Bell Labs (research), Western Electric (manufacturing), and AT&T Long Lines (inter-exchange telephone service) — to some two dozen local operating companies, which were monopoly utilities regulated by individual states. AT&T accounted for the majority of U.S. local telephone service and nearly all long distance revenues (Chandler, 1977; Temin, 1987; Friedlander, 1995).

AT&T was accused by rival telephone manufacturers of using its service monopoly to monopolize the equipment market. In 1949, the Justice Department filed an anti-trust lawsuit to force divestiture of Western Electric and require the Bell System to buy equipment by competitive bidding. In settling the lawsuit with the 1956 Consent Decree, AT&T retained its vertically integrated Western Electric subsidiary only by restricting its manufacturing and operations to common carrier telephone services (Temin, 1987). In particular, it forfeited the right to build and operate private mobile radio systems, thus limiting its experience with FM radio propagation — a crucial core competence needed in the subsequent development of fixed and mobile cellular telephone equipment (Young, 1979; Calhoun, 1988).

Facing no direct competitors in a regime of gradually increasing demand and declining costs, AT&T and its subsidiaries had virtually no layoffs and below-average turnover. This stability facilitated a strong corporate culture that was driven by service rather than marketing. Unlike most companies of comparable size, powerful marketing executives were unheard of until the 1980's. For local operating companies, the leading executives before World War II were engineers that had built the system, while postwar executives were primarily from customer relations ("commercial") and operations ("traffic") divisions (Feldman, 1986; Temin, 1987).

As with monopoly PTT's in other countries, the incentives for the local operating companies neither encouraged nor rewarded risk-taking and innovation. Feldman (1986) concluded that the guaranteed rate of return system gave managers no incentive to increase revenues and profits. Protected from competition but not from the losses of over-expansion, risk-averse monopoly managers delayed deploying unproved new technology until demand developed. So the technology push did not come from the local companies, but from Bell Laboratories. Arguably the U.S. leader in corporate basic research from 1945-1983, Bell Labs invented the transistor, laser, communications satellites, among other technologies. It continued to develop the cellular concept, demonstrating an experimental system to FCC regulators in 1962.

But the role of AT&T — then the world's largest corporation — changed dramatically in the 25 years leading up to 1984. Temin (1987: 7) argues that "the process was dominated by changing ideology, not changing technology," an ideology that later spilled over into FCC decisions about mobile telephony. It was also reflected in the decisions (1959-1977) by federal courts hearing challenges to AT&T's dual monopolies on equipment provisioning and inter-exchange service. The courts granted firms like Motorola, Carter Electronics and MCI the right to directly compete in AT&T's previously monopoly markets (Kahaner, 1986; Temin, 1987).

The last phase of change began in 1974, when the U.S. Justice Department filed an anti-trust suit alleging AT&T's horizontal and vertical integration were anti-competitive. Facing a likely court defeat, AT&T executives preferred voluntary horizontal divestiture of local operations to increased regulation and vertical divestiture of Western Electric. The resulting 1982 Modification of Final Judgment divested AT&T's monopoly local service but allowed it to compete in long distance services, equipment sales and new areas. The existing 22 local operating companies were divided into seven groups, the only configuration that would allow approximately equal size. The resulting regional holding companies (or "Baby Bells") became seven separate companies on January 1, 1984 (Tunstall, 1985; Temin, 1987).

AT&T and its offspring eventually began to compete for the same service customers. As the Baby Bells became increasingly reluctant to buy equipment from their competitor, AT&T undertook a second, entirely voluntary breakup. In September 1995, it announced that AT&T Technologies would be spun off, and on Oct. 1, 1996 the new Lucent Technologies became fully independent, incorporating the former Western Electric and Bell Laboratories. Descended from the single AT&T in 1983, today these companies — AT&T, Lucent and the surviving Baby Bells — are central players in U.S. (and global) cellular telephone industry.[1]

Resource Supply: FCC's Spectrum Allocation Policies

Providing mobile telephone service differs from other telecommunications services in one key way: it requires the exclusive allocation of radio frequency spectrum.[2] In the U.S., this has been performed by the Federal Communications Commission, established by the Communications Act of 1934 and responsible for "establishing policies to govern interstate and international communications by radio, television, wire, satellite, and cable" (FCC, 1997: 14).

As an independent Federal regulation agency, the FCC's commissioners are appointed by the president but it must report to Congress. As such, the FCC is always at least indirectly considering competing interest groups — and directly if such groups have made themselves heard through a specific congressional mandate. In this regard, U.S. telecommunications policy prior to the 1980’s was very different from most of Europe and Japan, where government PTT departments traditionally had both policy-making and operational responsibilities — which proved to be a crucial difference in the deployment of initial cellular telephone systems. The particular nature of the FCC, its procedures, and its permeability to a wide range of competing political influences explains why the U.S. was the first nation to invent cellular telephony but possibly as late as the 10th nation to commercially deploy it.[3]

Any mobile radio service depends on the exclusive allocation of frequency spectrum by the appropriate government agency. The availability of mobile telephony in the U.S. was unarguably delayed in the 1950’s and 1960’s due to limited spectrum allocated by the FCC. Unfortunately for mobile telephone operators and users, their spectrum requests usually lost as part of zero-sum lobbying game with one of Washington’s most powerful lobbies, television broadcasters. Mobile telephone operators were also divided, between conventional wireline telephone companies (AT&T and smaller operators) and the numerous radio common carriers (RCCs). The RCCs were small (often under-capitalized) local firms licensed by the FCC beginning in the 1950s to provide public and private mobile radio services, which were also allowed to provide limited mobile telephone service in competition with AT&T.

Repeatedly, AT&T applied for VHF and UHF spectrum for mobile telephone service in the range 10-1,000 MHz (Table 1). From 1945 until the mid-1960s, the FCC usually decided in favor of television broadcasters, approving only 54 channels split between wireline carriers and the RCCs (Young, 1979: 6). Even with short and infrequent telephone calls, because each frequency could support only one call at a time AT&T’s 23-channel service for metropolitan New York was limited to 543 paying customers with a waiting list of 3,700 potential users (Calhoun, 1988: 31). Even with increased spectrum, it was clear that such mobile telephone systems would be inadequate in major metropolitan areas. Therefore, AT&T had based its long-term mobile telephony plans since 1947 on the assumption it would use cellular radio.

Insert Table 1 here

The preferences received by a small number of broadcasters over land mobile use (public safety, private commercial services and common carriers) were challenged during the mid-1960s, as land mobile users reached 2.3 million transmitters in 1965 (Telecommunication Science Panel, 1966: 13).[4] In 1965-1966, both by the FCC and a government advisory board advocated reform in spectrum allocation policies. In 1968 a House of

Representatives committee noted that mobile communications received only 4% of the spectrum below 960 MHz (1% for mobile telephony), vs. 87% for broadcasters (Calhoun, 1988: 48).

In response to escalating political pressure, in 1968 the FCC opened related policy-making inquiries, one of which (Docket 18262) became the basis for eventual U.S. cellular telephone service. Not surprisingly, the case brought intense lobbying on the one side by mobile radio operators, manufacturers and users, and on the other side by broadcasters. In 1970, the FCC tentatively allocated 75 MHz in the range 806-947 MHz to cellular mobile telephony and dispatch services, which Calhoun (1988: 49) terms "the second great watershed (after the invention of FM) in the development of mobile telephony."

Based on detailed technical plans for cellular systems submitted by Bell Laboratories and Motorola, in 1974 the FCC reduced the spectrum for cellular telephony to 40 MHz, but, as in the 1970 plan, assumed a single cellular system in each market to be operated by the local telephone company. A 1975 revision allowed applications by any qualified entity, including RCCs. Although the cellular license was not guaranteed to the local wireline carrier, at this point the FCC still felt, as Carson (1979: 320) put it, that "the expense, spectrum, requirement and wide coverage of a mature cellular system dictated that only one system in each urban area would be feasible." AT&T appealed the 1974 spectrum reduction, but it based its plans (as did the FCC) on the assumption that the full 40 MHz would be available to a single carrier.

Two teams applied for permits to build experimental ("development") cellular systems and were granted permission by the FCC in 1977; these were the later only two systems to officially come online in 1983, the first year of official U.S. cellular service (Seybold & Samples, 1986). A local AT&T operating company, Illinois Bell Telephone Co., applied for a license to build a system in Chicago, using equipment designed by Bell Laboratories and built by Western Electric (Huff, 1979); a radio common carrier, American Radio Telephone System, asked permission to operate a system in the Washington/Baltimore area to be designed and built by Motorola (Mikulski, 1986).

While AT&T had been planning cellular telephone systems for years, its role in radio system design was limited by two factors. First, by surrendering rights to manufacture and operate private mobile radio systems in the 1956 Consent Decree, it had only minimal radio expertise compared to leading U.S. maker, Motorola (Calhoun, 1988). Secondly, the FCC allowed Western Electric to manufacture base station equipment but not mobile equipment.[5] Therefore, when Illinois Bell and Bell Labs began validation of the Chicago system with an "equipment test " (July-December 1978), the test used 135 car-mounted mobile telephones manufactured by Oki

Electric of Japan using a combined AT&T/Oki design. The second phase — service test with nearly 2,000 customers that began on December 12, 1978 — used leased telephones manufactured by Oki, Motorola and E.F. Johnson (a maker of 2-way mobile radios for RCCs) (Fisher, 1979; Huff, 1979; Blecher, 1980). Motorola, in fact, developed four generations of portable cellular phones before the 1983 commercial launch, with each generation smaller and lighter than its predecessor (Lynn et al., 1996).

Based on quarterly operations reports from both the AT&T and Motorola systems, the FCC began regulatory proceedings that set the rules for operating cellular systems. Not only did the rulings define the competitive landscape until the mid-1990's, but they also are the clearest explication of U.S. policy in cellular communications for that period. The first ruling noted the changes in U.S. (wireline) telecommunications policy since it began examining cellular telephone systems, specifically the liberalization in private lines and terminal equipment. It also acknowledged the concerns of a Federal appeals court that AT&T would ultimately "operate most, if not all, of the cellular systems put into operation " (FCC, 1980: 987).

In light of these new developments, in 1981 the FCC proposed that the 40 MHz of spectrum be split between multiple applicants in each market, eventually allotting 20 MHz to two operators per market: one license reserved for an existing ("wireline") telephone in the market, another for a non-wireline carriers.[6] Subsequent rulings rejected nearly all challenges to the plans by AT&T, other telephone companies, RCCs and equipment makers.

The FCC gave the top priority to 306 metropolitan markets which accounted for 77% of the U.S. population; the rest of the country was divided into 428 rural service areas. Except for the most isolated rural markets, two bands were to be licensed for each market (Paetsch, 1993; Cellular Telephone Industry Association, 1996). In 1982, the FCC began by accepting applications for the 30 most populous markets. A flood of non-wireline applications were driven by "gold rush" forecasts of cellular wealth; by the June deadline, the FCC received 138 A block (non-wireline) and 52 B block (wireline) applications (Dizard, 1982; FCC, 1983: 62).

For the 30 B block licenses, 12 were uncontested; the remaining 40 applications (by AT&T, GTE and small independent local telephone companies) were quickly resolved by a series of joint venture agreements for the remaining 18 markets. With all 30 wireline license awards thus uncontested, rivals worried that the B block operators would be quickly licensed while the A block applicants were delayed by fights at the FCC and the courts (Dizard, 1982). These fears were realized: in 24 of the markets, the B block carrier was online first (by an average of 18 months); in only four markets was the A block carrier first (Seybold & Samples, 1986).

GTE gained control of the B block license in 7 markets; AT&T gained the remaining 23, but these were divided among the seven regional holding companies in the 1984 AT&T break-up. Among the radio carriers, no company controlled more than three licenses, although two firms (MCI and McCaw) had at least minority stake in six licenses (Table 2).

Insert Table 2 here

For the 30 largest markets, the FCC awarded contested licenses based on detailed business and technical plans, and accepted applications for the next 60 markets based on similar rules. With the difficulty choosing the most qualified applicant — and the certainty of a legal challenge by the losing party — it became quickly apparent that awarding licenses in all 306 MSA markets would take many years (except where competing applicants negotiated their own solution). Instead, the FCC awarded only the 30 largest markets based on competitive applications, but used a lottery of existing applicants for the next 60 markets. This brought a flood of speculative applications — 96,000 for markets 91-306, as compared to 1,200 for markets 1-90; the lottery was also used for the rural service areas (Paetsch, 1993: 152-153).

Coupled with the AT&T break-up, the FCC achieved one of its primary goals of assuring that no single carrier dominated cellular service nationwide. The price was a complex system of technical and contractual solutions that were needed to allow users to roam between states (or even neighboring cities), delaying such mobility for at least five years. The FCC allocation schemes also gave a clear head start to the incumbent telephone companies as many non-wireline applicants fought for each A block license.

Experience in Other Regions

The three major sources of technological innovation in the early cellular telephone industry were North America, Japan and Europe (principally Northern Europe).[7] These three research centers were constrained by identical laws of physics and similar availability of enabling technologies such as microprocessors. In addition, competitive intelligence transferred technical knowledge between rival firms — primarily from AT&T to its challengers through the mid-1970’s, but in many more directions as the Japanese, Nordic and rival US makers challenged AT&T’s technical monopoly.

So if the determinants of technological diffusion were primarily technical, we would expect convergence of outcomes between these three pioneering regions (if not other laggards such as France and Germany). However, differing outcomes — particularly the speedy deployment of cellular systems outside North America —

demonstrate the effect of differing policies which effectively delayed introduction of cellular service in the U.S. behind the other two regions.

Japan. As in the U.S. the central issue for the development of mobile telephony in Japan was the changing role of the dominant wireline telecommunications provider. However, unlike the U.S., that service provider began cellular service as a government PTT. Telephone service was provided by a succession of government ministries from 1889 until after World War II. In 1952, the Diet transferred telephone responsibilities to Nippon Telegraph and Telephone (NTT), a newly-created government corporation with a monopoly over domestic telephone sales and service, while the new Kokusai Denshin Denwa (KDD) was awarded a monopoly on international service. The NTT budget was approved annually by the Diet, and NTT workers were considered civil servants and thus denied the right to strike (Vogel, 1996: 139-140).

This structure was retained through the 1980's, when the liberalization (and breakup of AT&T) in the U.S. prompted Japanese regulators, telecommunications executives and users to study increased competition in the domestic market. The end result was that in April 1985, NTT became a quasi-private non-monopoly provider under the regulation of the Ministry of Posts and Telecommunications (MPT), although the majority of its shares continue to be government owned (Vogel, 1996; West et al., 1997). Vogel (1996) notes that while liberalization in Japan meant an increase in competition, it did not mean deregulation: outside North America, liberalization has meant a shift from PTT government departments (with both regulatory and service responsibilities) to government regulation of (partially or wholly) privatized telephone companies.

While NTT was horizontally integrated and contained its own research laboratories, unlike AT&T it relied on outside manufacturers (the "den-den" companies) to produce its equipment (West et al., 1997). NTT researchers developed their own analog cellular standard in the 1970's and began operating in Tokyo in December 1979 — the world's first commercial cellular system. By 1985, its 43,000 subscribers were primarily in the Tokyo and Osaka regions (Kuramoto & Shinji, 1986).

While analog licenses were allocated in each market between the monopoly wireline carrier and one rival, the similarity to the U.S. ends there. NTT held a nationwide monopoly in local services, lacked competition in pre-cellular mobile service and began its cellular service long before the existence of rival telecommunications companies. NTT was also effectively unregulated: the small size of MPT's telecommunications bureau prior to 1985 meant that NTT made its own autonomous policy decisions with little oversight (Johnson, 1989; Vogel, 1996).

Japan’s 1985 telecommunications liberalization brought competition both to wireline and mobile services. Two other systems were granted licenses to compete with NTT’s mobile services (MPT, 1996):

- Nippon Idô Tsûshin (IDO) began service in Tokyo in December 1988 and was also licensed for the Nagoya region; it is controlled by Toyota Motors.
- The “Cellular” group of companies, which began with Kansai Cellular Telephone in July 1989, and by 1990 covered seven of nine regions — all except the two served by IDO. Each local company is approximately 60% owned by DDI, in turn is a partly-owned subsidiary of Kyocera Corporation .

IDO used NTT’s second-generation, higher capacity analog system while the DDI companies employed a variant of the Anglo-American TACS promoted by Motorola (Tyson, 1993).

Europe. As in the other developed countries, for Europe the mid 1980’s marked a gradual liberalization of competition in telecommunications: as in Japan, the PTT’s gradually shifted from government departments to public corporations, or even independent firms. Most European countries, however, lagged the U.S. and Japan in telecommunications liberalization and the introduction of cellular service.

Two major multi-country standards quickly gained most of Europe’s analog cellular subscribers. Nordic Mobile Telephone (primarily in Northern Europe, Netherlands and Switzerland) and Total Access Communications System (U.K., Ireland, Spain and Italy) each held about 40% share of European subscribers in 1991, with proprietary systems in Germany, France and Italy accounting for most of the rest. The four Nordic countries (Sweden, Finland, Norway and Denmark) held 75% of the total subscribers in 1985, but this dropped to 31% in 1990, with the more populous United Kingdom accounting for 33% of the total (Paetsch, 1993: 280-283). These two regions — Nordic countries and the U.K. — were the most innovative in the first decade of European cellular systems.

Like the U.S., the Nordic countries possessed vast unpopulated stretches where a car-mounted telephone provided the only reliable communications technology. To cope with this demand, Swedish Telecom introduced three non-cellular different mobile telephone systems: MTA (1956), MTB (1967) and MTD (1971). Meanwhile, the Nordic PTT’s, seeking the economies of scale possible from a common pan-Nordic system, evolved the MTC system towards a microelectronic-based cellular system which became NMT (Hultán & Mölleryd, 1995). Sweden introduced the first NMT system in the 450 MHz band in October 1981, followed by Norway, Denmark and Finland. Unexpectedly high demand prompted the four countries to deploy the NMT technology in a new 900 Mhz band in December 1986 (Paetsch, 1993).

The NMT-450 and NMT-900 systems were exported to several other European countries, promoted by PTT's and Nordic manufacturers seeking export sales. Historical path dependencies had already brought limited telecommunications deregulation to Sweden and Finland:

- In Sweden, telecom equipment for domestic use was manufactured by a joint venture of the PTT and private firm Ericsson, which derived the rest of its revenues from exports. Meanwhile, Swedish Telecom encouraged manufacturers and resellers to market mobile telephones because it lacked the capital to finance them (Noam, 1992; Hultán & Mölleryd, 1995).[8]
- In Finland, wireline service territories were divided between the PTT (Telecom Finland) and a coalition of 51 smaller local operators. Its leading telecom manufacturer, Nokia (and its Mobira radio subsidiary) faced strong competition from Ericsson in its home market and thus was also forced to concentrate on exports (Noam, 1992).

However, what liberalization that existed did not extend to arms-length licensing of frequency spectrum use by the PTT. For example, Sweden did not fully separate telecommunications and radio spectrum regulation from Telecom Sweden until July 1993 (Hultán & Mölleryd, 1995).

Meanwhile, the innovations in the U.K. were regulatory rather than technical. Lagging the research efforts in the U.S., Japan and the Nordic countries, and lacking domestic firms strong in mobile radio, British regulators instead selected a slight modification of the off-the-shelf American AMPS system (Taylor, 1985). By doing so, their analog systems enjoyed far greater success than those countries (e.g., Germany and France) which domestically developed their own cellular technology rather than employ proven technology from one of the three major design centers.

However, the U.K. led Europe and most of the world in competitive innovations with its aggressive liberalization and regulation of the previously monopoly British Telecom.[9] From the beginning, it licensed two competing systems, Cellnet and Vodafone which both began service in January 1985; it also limited BT to a 50% share of the former system. It continued to be Europe's most competitive market in the early 1990's with seven licensed carriers.

European technical, producer and regulatory institutions converged with the introduction of a second-generation, digital cellular system, GSM. Development of a pan-European standard was begun in 1982, and was transferred in 1989 to the new European Telecommunications Standards Institute, which represented countries in the European Community as well as non-EC countries such as the four NMT sponsors. First deployed in 1991, GSM uses a common standard and 900 MHz spectrum allocation throughout the European Union, allowing customers to roam between countries. Most national governments agreed to license two competing systems in each country (Besen, 1990; Cheeseman, 1991; Paetsch, 1993).

Subsequent Standardization Efforts

Japan and the U.S. trailed Europe in their efforts to develop digital cellular standards. By being the first digital service, and focusing early on a multi-vendor, multi-country solution, the GSM developed the largest market share in third country markets.

The most direct competition between rival standards was seen in the new 1.9 GHz PCS spectrum licensed in the U.S. beginning in 1995. As with analog service, the FCC issued licenses on a market-by-market basis, but unlike AMPS, a total of six licenses were auctioned and no firm was assured incumbent “wireline” status. Also unlike the AMPS period, the FCC adopted a market-oriented standards policy for the new PCS bands, authorizing multiple standards. Operations quickly settled upon three standards: GSM and two digital extensions to AMPS. In early 1999, the two most compatible standards (GSM and IS-136) agreed to develop mutual gateways to allow roaming by their respective customers (Luna, 1999).

Beyond this competition in various U.S. markets, the rivalry between digital standards emerged as a full-fledged battle with the 1998 efforts to develop a so-called “third generation” (3G) global wireless standard. Two rival alliances — aligned with the GSM standard led by Ericsson and the CDMA standard developed by Qualcomm — fought to win support for rival proposals. With European firms seeking a single standard and key U.S. firms pushing for multiple standards, the 3G standards battle brought threats of patent lawsuits and trade sanctions, which were only resolved through a March 1999 cross-licensing agreement and asset sale between Ericsson and Qualcomm.

Such 3G efforts typify calls for “harmonization” of standards, where “harmonization” is defined by proponents as agreement upon a single, monopoly standard. Despite such frequent calls, standards rivalries continue in many aspects of mobile telephony. Competition between air interface standards has been extended into outer space with new low-earth orbiting satellite telephone systems such as Iridium and Globalstar. Rival standards continue to be promoted for transmitting data via mobile telephones. Finally, as firms view to hasten the convergence of cellular telephones and handheld computers, alliances have formed around rival cellular telephone operating systems such as Windows CE, Palm OS, Geoworks, and the planned Symbian joint venture.

IMPLICATIONS AND CONCLUSIONS

Evolving Spectrum Resource Allocation Policies

A combination of different policies were used by national regulatory bodies to allocate the scarce spectrum resource for cellular mobile telephony. They include:

- *No policy.* In most early cases where the PTT was a government corporation, little or no formal regulation existed and the PTT/operator decided what spectrum it needed, and gained all the spectrum for its own use by default. Even where regulation exists, in most countries the incumbent wireline carrier was assured a cellular license (or, in many cases, for each successive frequency band of cellular service).
- *Competitive allocation.* Based on some combination of technical, economic or political merit, this was the policy used for allocating spectrum in the 30 largest markets for 800 MHz service in the U.S., and also for most licenses in Japan and the U.K. However, as the FCC discovered, it can be a very costly and time-consuming process, particularly if separate subnational licenses are awarded and if the political system permits appeals of the regulatory award (Taylor, 1985; Calhoun, 1988).
- *Collaboration and collusion between applicants.* In some cases, the government delegated resolution of competing claims to the applicants themselves. In the 800 MHz U.S. cellular licenses, the FCC encouraged vendors to pool applications for individual markets to minimize the contested applications — which resulted in a hodgepodge of fractional ownership shares that differed for each market (Seybold & Samples, 1986). Similarly, in Japan the MPT encouraged the weakest applicants for the final 1,900 MHz PHS nationwide system to consolidate into what became the Astel group.[10]
- *Random allocation.* When the FCC bogged down in its technical allocation of 800 MHz licenses, it switched to a lottery award (with post-selection verification of minimal qualification criteria). Such an approach assures a flood of unqualified applicants and prevents any bidder from achieving economies of scale.[11]
- *Market allocation.* The use of a public auction had been considered by the FCC for allocating the original 800 MHz spectrum (cf. FCC, 1980: 1001). Such market mechanisms have theoretical advantages of fairness and efficiency, although these advantages had never been tested on such a scale. Critics — such as foreign operators and regulators — pointed out a key disadvantage: raising the cost of service to operators, which theoretically would be passed onto consumers. Other, more serious disadvantages would not become obvious until after the PCS auctions were completed — most notably, the bankruptcies of entrepreneurial

bidders who failed to obtain financing after overbidding (Cramton, 1996; Congressional Budget Office, 1997).

The choice of policy is influenced by the priority given competing goals — efficient use of spectrum, high diffusion, low consumer prices and equity between license applicants. But the selection process is also dependent upon the path-dependent institutional context for a given country — both in terms of the transparency of political institutions to rival applicants, but also in terms of the incumbent roles of various potential applicants. For example, the RCCs — independent radio carriers predating liberalization of the 1980s — have no real analog outside the U.S. and the U.K. Similarly, only in the U.S. and Finland did independent wireline incumbents play a significant role in challenging the dominant carrier's monopoly.

The allocation of radio spectrum (e.g. for broadcasting) has traditionally included regulatory specification of the communication standard to be used for that spectrum. That was the pattern for the NMT, AMPS and TACS analog services, as well as the digital services in Europe and Japan; as with broadcast standards, the mobile telephone standards were selected based on proposals by the prospective operators and/or manufacturers. However, trade friction in Japan and a modified *laissez faire* standards policy in the U.S. provided operators with a choice of standards; current trends in 3G standardization suggest that such intramarket standards competition may have been a temporary aberration rather than a trend for the future.

Competition and Consolidation

Operators. In determining competition policies for cellular telephone service, regulators measured market power (or its inverse, competitiveness) in two ways: at the national level (i.e., the share of the overall market), and in each individual market (i.e., the number of competing choices available to a potential subscriber). As a consequence of anti-trust concerns related to AT&T, U.S. policies emphasized both forms of competition. In most other countries, only the latter competition was emphasized and licenses were issued nationwide.[12] Even in Japan, the 58 licenses issued for nine local regions were effective controlled by six groups which operated a total of nine systems.

The FCC licensing policies resulted in the initial fragmentation of U.S. licenses. For the wireline licenses, the divestiture of cellular licenses to the Baby Bells prevented what would have been an AT&T-led oligopoly (in concert with GTE and various rural telephone companies); instead, the seven "Baby Bells" started with roughly similar cellular assets (Noda, 1996). On the non-wireline side, the plethora of entrepreneurs and the FCC allocation process assured that the initial industry structure was even more fragmented than the eight major wireline carriers.

This fragmentation was gradually reversed through a process of mergers and acquisitions from 1985 to 1996. The mergers were sanctioned by the FCC, the Justice Department and Federal Judge Harold Greene, who approved all modifications to the 1982 AT&T anti-trust settlement.[13] The only merger limitation was that no firm could acquire a stake in both licenses in a local market, forcing some firms to sell or trade specific licenses before an acquisition. The result was that the largest initial carrier (GTE) had by 1996 dropped to fourth place. The largest carrier was AT&T, serving about one-fourth of the country, after having bought its way back into the cellular market through the acquisition McCaw Cellular — a new radio common carrier that had grown by acquiring other RCC cellular operators.

As cellular systems were deployed, most developed countries sought to encourage competition of the second type, allowing each consumer a choice between multiple cellular systems. Liberalization in wireline telecommunications encouraged competition in mobile telephony — which, in turn, encouraged further wireline liberalization. This helped erode the century-old concept of telephone service as a “natural monopoly” (Friedlander, 1995; Vogel, 1996).

The U.S., Canadian and British cellular systems were designed from their initial deployment to be duopolies, a pattern followed by second-generation systems in many (but not most) other countries. Successive generations of cellular technologies gave regulators the opportunity to increase competition beyond the duopolies as new spectrum was granted to a combination of new and existing entrants. For example, the FCC awarded six new licenses for 1,900 MHz Personal Communications Service for each market, based on three successive auctions from 1994 to 1997 (Cramton, 1996; Congressional Budget Office, 1997). With 800 Mhz and mobile radio operator Nextel, a U.S. market had a maximum of nine licensed cellular systems, compared to seven in Japan and the U.K. In each of these countries, regulators promoted new entrants on the belief that increased competition spurred price cuts and diffusion of service.

Despite the lead of these three countries in promoting cellular competition, the highest market penetration rates through 1996 were achieved in the Nordic countries.[14] Except for Sweden, these countries began analog cellular service with government PTT monopolies, and were much slower in expanding the number of operators to the levels seen in the U.S., Japan or the U.K. Roos (1993) contends that policies based on competition between private operators inherently *reduce* diffusion of the technology — arguing instead that strong state-owned monopolies in the Nordic welfare states facilitated the universal deployment of cellular infrastructure, and thus, Northern Europe's exceptional cellular telephone diffusion rates. Knuutitila (1996) attributes successful demand-push diffusion to a high level of cultural cohesion built through shared understanding. Between countries, Nordic PTT representatives countries had worked closely together for many years; within countries, the PTT operator, private manufacturers and government had a long history of cooperation.

Manufacturers. The industry structure of manufacturing has changed surprisingly little during the 18 years since the launch of the first cellular systems. This stability is a testament both to the high barriers to entry in telecommunications manufacturing, as with the estimated $300 million AT&T and Motorola paid to develop cellular systems prior to system launch (Taylor, 1985). But it is also a testament to the permanence of core competencies based on tacit knowledge which shape the acquisition and production of new knowledge (Cohen & Levinthal, 1990).

Throughout the period, the leading makers of mobile terminals (sold to individual users) remain Motorola and Nokia — which aggressively introduced handheld portables to AMPS and NMT respectively as their corresponding rivals (AT&T and Ericsson) focused on car-mounted telephones. While Japanese makers as a group made significant inroads into the mobile terminal market (utilizing proprietary miniaturization and battery technologies), no one firm achieved a global presence to match Motorola, Nokia and Ericsson.

The market for cellular infrastructure — sold to system operators — consisted of two major components, mobile telephone switches and radio base stations. Not surprisingly, the leading infrastructure vendors corresponded to the major makers of digital switches for wireline telephony when cellular began: AT&T (now Lucent) and Ericsson. AT&T of course began as the largest maker of telephone equipment in the world, and launched its cellular products with the largest share of the largest market. Meanwhile, Ericsson proved to be the only firm to successfully combine both halves of the infrastructure puzzle, aided by its purchase of radio pioneer Svenska Radioaktiebolaget (Hultán & Mölleryd, 1995). The cellular infrastructure product lines for other vendors were strong only in their original, pre-cellular competency — either telephone switches (AT&T, Northern Telecom, NEC) or radio equipment (Motorola, Nokia).

Conclusions

The initial deployment of cellular telephone service followed the pattern of technology push often seen in technology-driven industries. Unlike many of these industries, the government possessed effective technology policy instruments to facilitate or delay deployment of cellular services. In particular, the inherent requirement for exclusive allocation of scarce radio frequency spectrum gave the government absolute control over the number and timing of new market entrants. When contrasted with other countries that pioneered cellular technologies, three specific path dependencies help explain the timing and eventual industry structure for cellular telephone service in the United States.

First, policies for mobile telephone entry were heavily influenced (if not determined) by changing ideology of telecommunications policy — specifically, the role of the near-monopoly national (“wireline”) telecommunications carrier, AT&T. While other countries (notably Japan and the U.K.) emulated U.S. liberalization in wireline services (Vogel, 1996), the unique complexity of U.S. mobile telephone regulation and industry structure depended on the specific path taken by AT&T — both in its original vertical and horizontal integration, and its subsequent 1984 and 1996 break-ups.

Secondly, while technological limitations prevented the introduction of cellular telephone service before the mid-1970’s, the time required by the Federal Communications Commission to establish cellular policies delayed deployment of cellular telephone service in the U.S. by at least five years to its eventual 1983 start (Calhoun, 1988). In almost every country that launched its cellular system before October 1983, the operator was a government PTT that possessed the *de facto* (if not *de jure)* authority to determine its own policies for spectrum allocation and market entry.

Finally, two groups of competing claimants for spectrum allocation exploited the transparency of the pluralistic FCC regulatory policies to delay its allocation of mobile telephone spectrum between 1946 and 1983. During the initial 25 years, established television broadcasters prevented the reallocation of under-utilized spectrum from broadcasting to mobile communications, until a shift in Congressional policies increased the salience of the latter. After that, incumbents in the mobile radio industry (both RCCs and manufacturers like Motorola) fought every attempt by AT&T to obtain a wireline monopoly for cellular telephone service, accounting for most of the delays during the 1970s. The final delays came as potential applicants for cellular licenses (including AT&T and the RCCs) fought to obtain advantage in the FCCs eventual licensing policies.

The moderate success of cellular deployment in the U.S. despite these liabilities is a testament to the familiar American advantages of advanced technological capabilities and a large domestic market (Chandler, 1990). The diffusion of cellular telephones to U.S. consumers — and the major role played by U.S. manufacturers and operators in the global market — also stand as testament to the fundamental competence of the FCC and private firms despite the complexities of U.S. telecommunications policy regimes.

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TABLES

Date	Action
1946	AT&T begins (non-cellular) commercial mobile telephone service in St. Louis
1947	AT&T proposes a 150-channel mobile telephone system using 40 MHz
1949	AT&T proposes a UHF mobile telephone system, but the FCC allocates spectrum for television broadcasts
1958	AT&T proposes a 75 MHz system at 800 MHz
1962	AT&T demonstrates for FCC a test UHF cellular system in Murray Hill, NJ
Oct. 1966	Commerce advisory panel report questions FCC allocation priorities
1968	Congressional hearings on "crisis in land mobile communications"
July 1968	*Notice of Inquiry and Notice of Proposed Rulemaking* (14 FCC 2d 311) Proposes to reallocate UHF channels 70-83 for mobile radio use
May 1970	*First Report and Second Notice of Inquiry* (35 FR 8644) FCC allocates 75 MHz for wireline cellular telephone carrier
Dec. 1971	AT&T, RCA and Motorola file proposals to use 800 MHz band for cellular mobile telephone systems
May 1974	*Second Report and Order* (46 FCC 2d 752) FCC allocates 40 MHz per market for a single wireline cellular telephone carrier
March 1975	*Memorandum Opinion and Order on Reconsideration* (51 FCC 2d 945) FCC opens cellular licensing to any qualified common carrier
July 1975	Illinois Bell applies for permission to build Chicago development system
Feb. 1977	American Radio Telephone System applies for permission to build Washington/Baltimore development system
March 1977	FCC authorizes Illinois Bell's Chicago development system (63 FCC 2d 655)
Oct. 1977	FCC authorizes ARTS' Washington development system (66 FCC 2d 481)
Nov. 1979	*Notice of Inquiry and Notice of Proposed Rulemaking* (78 FCC 2d 984) The FCC begins process of setting policies for building and operating cellular telephone systems
April 1981	*Report and Order* (86 FCC 2d 469) FCC adopts rules for cellular applicants, providing for two carriers (a wireline and a non-wireline) to each operate a 20 MHz system
Feb. 1982	*Memorandum Opinion and Order on Reconsideration* (89 FCC 2d 58) FCC reaffirms application procedures, except AT&T is only wireline required to maintain a separate cellular subsidiary
July 1982	*Memorandum Opinion and Order on Further Reconsideration* (90 FCC 2d 571-582)
June 1982	FCC accepts applications for two licenses in each of 30 largest metropolitan markets
1983	FCC grants first commercial cellular licenses
Oct. 13, 1983	Ameritech Mobile Communications (an AT&T subsidiary) launches the nation's first commercial cellular system in Chicago
1986	FCC increases cellular spectrum allocation from 30 Mhz (666 channels) to 40 Mhz (832 channels)

Table 1: U.S. mobile telephone regulatory milestones, 1946-1986

Company	First Market	Date	Markets†	Largest Market	Remarks
AT&T Spin-oiffs					
Ameritech	Chicago	Oct. 83	4 (1)	Chicago (3)	Acquisition by Southwestern Bell proposed, 1998
Bell South	Miami	May 84	3	Miami (12)	
NYNEX	Buffalo	Apr. 84	3	New York (1)	Merged with Bell Atlantic 1997
Bell Atlantic	Washington	Apr. 84	4 (1)	Philadelphia (4)	
US West (New Vector)	Minneapolis	June 84	4 (1)	Minneapolis (15)	Wireless assetts acquired by AirTouch, 1998
Pacific Telesis	Los Angeles	June 84	2 (2)	Los Angeles (2)	Wireless spun-off as AirTouch Communications, 1993; acquired by Vodafone (U.K.), 1999
Southwestern Bell	St. Louis	July 84	3 (1)	Dallas (9)	
Independent Wireline					
Centel			(2)		Acquired by Sprint, 1993
Contel			(2)		Acquired by GTE, 1991
GTE	Indianapolis	May 84	7 (5)	San Francisco (7)	Acquisition by Bell Atlantic proposed, 1998
United Telephone			(2)		Wireless assets acquired by Centel, 1988
Radio Carriers					
Cellular Communications			(4)		Entered 50/50 JV with Pacific Telesis, 1990
Communications Industries (Gencom)	San Diego	Apr. 86	1 (2)	San Diego (18)	Acquired by Pacific Telesis, 1986
Graphic Scanning			(2)		Acquired by Bell South, 1990
LIN Broadcasting	Philadelphia	Feb. 86	2 (2)	Philadelphia (4)	Control acquired by McCaw Cellular, 1990
McCaw Cellular	Kansas City	Feb. 86	1 (5)	Kansas City (24)	Acquired by AT&T, 1994
MCI AirSignal			3 (3)	Pittsburgh (13)	Assets acquired by McCaw, 1986
Metro Mobile CTS	Phoenix	Mar. 86	1 (4)	Phoenix (26)	Acquired by Bell Atlantic, 1992
Metromedia	Chicago	Jan. 85	1 (3)	Chicago (3)	Acquired by Southwestern Bell, 1986
Mobile Communications Corp. of America			(1)		Acquired by Bell South, 1989

† Majority owned (minority share) licenses
Note: Top 30 markets based on 1980 census

Source:Adapted from Seybold & Samples (1986); excludes Los Angeles A block license

Table 2: Original wireline and non-wireline AMPS licensees in top 30 markets

NOTES

1 In 1997, the SBC Communications/Pacific Telesis and Bell Atlantic/NYNEX mergers reduced the Baby Bells to five; mergers pending as of this writing would reduce the number to four.

2 Spectrum allocation is also essential to other services such as pagers, cellular data and satellite phones, but here I focus on cellular telephony, the largest mobile service in terms of revenues and spectrum allocation.

3 The first system was in Japan (1979), followed by Saudi Arabia, Sweden, Norway (1981), Denmark, Spain (1982) and Finland (1983); less clear are Canada and Italy (Betteridge & Pulford, 1981; Paetsch, 1993; Meurling & Jeans, 1994). A detailed investigation of all systems would be necessary to determine whether

each start date is more comparable to the Chicago service test with 1,900 paying customers (1978-1983) or its first year (1983-1984) of "official" service with 13,000 customers (Blecher, 1980; Cooper, 1985).

4 Most of these were mobile two-way radios; as of December 1977, there were still only 143,000 mobile telephone units in service (Young, 1979: 6).

5 A subsequent order (86 FCC 2d: 497-498) allowed AT&T to make mobile terminals if they were sold by an AT&T subsidary separate from the local cellular service provider — a plan rendered moot by the AT&T break-up. However, this policy shift came after the launch of AT&T's Chicago development system.

6 The 1981 ruling specified 666 channels using a total of 40 MHz in the range 825-890 MHz; in 1986, the FCC expanded this to 50 MHz and 832 channels.

7 Canada adopted the U.S. technology, radio frequencies and duopoly approach. The exception was the pioneering Aurora system in Alberta, which began service in 1982 before the U.S., but like Sweden's Comvik, quickly became a technological dead-end (Betteridge & Pulford, 1981; Mehrotra, 1994).

8 AT&T similarly encouraged rival radio manufacturers to compete in the production of mobile telephones — not because of lack of capital, but because the 1956 Consent Decree prohibited it from making mobile radios (Calhoun, 1988: 51).

9 Vogel (1996) notes that liberalization does not always translate to deregulation. In fact, outside the U.S. and Canada, liberalization has meant a shift from PTT government departments (with both regulatory and service responsibilities) to government regulation of (partially or wholly) privatized telephone companies.

10 Interview with Noriko Karaki, Deputy Director, Land Mobile Communications Division, Ministry of Posts and Telecommunications, Dec. 18, 1996.

11 However, such economies can be achieved through subsequent mergers and acquisitions, as occured in the U.S. throughout the late 1980's.

12 One must allow for a certain amount of geographic determinism. Fragmenting licenses by region spread the capital costs for infrastructure development in the U.S. and Canada, but most European countries were too small in terms of population or geography to justify such fragmentation.

13 Greene's oversight was ended by passage of the Telecommunications Reform Act of 1996, which returned primary control of telecommunications policy to the FCC.

14 Diffusion rates in Norway and Denmark were surpassed by Iceland, a fifth Nordic country that did not participate in the NMT development but adopted the NMT and successive systems.