Cellular

An Economic and Business History of the International Mobile-Phone Industry

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CELLULAR

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INTRODUCTION

This book presents a compact history of the international mobile-phone industry. Although it explores the technical dimensions of cellular systems, it emphasizes the economic and business dimensions of the industry's history.

Our book is structured in four major parts, each corresponding to a generation of cellular phones up to the present. These generations, in turn, are reasonably well matched to decades: the 1980s was the decade of the first cellular generation (1G), the 1990s the decade of the second (2G), the 2000s the decade of the third (3G), and the 2010s the decade of the fourth (4G). The caveat is that generations started at different points in time in different parts of the world. Two of the most widely diffused first-generation standards, for example, were the Advanced Mobile Phone Service (AMPS), created in the United States, and the Nordic Mobile Telephone (NMT) system, developed in Scandinavia. Both became operational in the early 1980s in their countries of origin. A few years later, they were exported to, and adopted by, countries around the world. AMPS became widely used all over Central and South America and the Caribbean, whereas NMT was heavily adopted in European countries outside Scandinavia. In practice, 1G cellular started later—and sometimes several years later—in standard-importing countries than it did in standard-creating countries.

Similarly, the second-generation Global System for Mobile Communications (GSM) standard was launched in several Western European countries in the early 1990s and later was adopted in Eastern Europe and other parts of the world. Thus, 2G cellular started later in Eastern Europe than it did in Western Europe. Further, some countries in Africa were still launching 1G systems in the early 1990s while some European countries were already operating on 2G standards.

Lags of this sort happened also in third-generation cellular, which started in many Organisation for Economic Co-operation and Development countries at the beginning of the 2000s. In China, however, and due mainly to industrial policy factors, 3G cellular was not introduced until the very late 2000s. Almost a full decade went by between the launch of 3G cellular systems in several Western European countries and 3G adoption in China.

With this caveat, each of the four parts in our book corresponds to a cellular generation and thus roughly to a decade. Each part, in turn, is organized into three chapters. The first chapter in each part presents an introduction to the relevant generation and its corresponding standard or standards. Thus, each part's first chapter identifies the novel elements associated with each generation (and its standards), including new technologies, new users, and new functions. In the second chapter of each part, we study in more detail the evolution of cellular in different countries, emphasizing the role that national governments played in shaping the cellular industry and fostering cellular growth. The final chapter of each part examines cellular product and service markets in the context of each standard, highlighting the markets for cellular infrastructure, cellular handsets, and cellular network services. In the last two parts of the book, which cover 3G and 4G, we also study the market for mobile semiconductors and the market for mobile operating systems.

THEMES OF THE BOOK

Although our book is organized chronologically, we focus on several important themes that have defined the cellular industry to thread our narrative. These themes include the importance of cellular standards, differences between closed and open standards, competition among standards

and among firms within standards, the impact of technological change, and the role of national governments in shaping the evolution of the cellular industry. We also consider the changing roles that cellular phones have played in the everyday lives of people around the world and across time.

Although we usually associate the word *cellular* with the mobile devices we carry around every day, the cellular industry is a system-type industry. This means that different components of the cellular ecosystem have to interact smoothly with one another for us to be able to communicate with one another. It also means that companies operating in different markets have to cooperate with one another. From the early 1980s through the late 1990s, the cellular industry comprised three groups of companies. The first group supplied the cellular infrastructure, the second group the cellular devices, and the third group the cellular network services. Starting in the late 1990s, two additional groups of companies started playing an important role in the cellular industry: developers and sponsors of smartphone operating systems, and designers and makers of mobile semiconductors, especially baseband processors.

Because the interactions between base stations and cellular devices are especially crucial, organizations and companies have, from the beginning of cellular history, formed committees to define the rules governing such interactions (and other technical details). Those rules of interaction, usually called standards, are codified in detailed technical documents. Standards have contributed to defining the way the cellular industry has evolved because they have laid down the rules dictating how the various components of the cellular system interoperate. Without standards, the cellular industry would have been infeasible.[1]

A few standards in the early years of the industry were closed: they were developed by a single company, which owned all of the intellectual property—the technical specifications—associated with the standard. In such cases, only the standard owner was able to manufacture, or license other firms to manufacture, equipment adhering to the standard. In other cases, however, cellular standards were open. In such cases, several organizations interacted (often in committees) to create technical specifications, which were then made available to all comers, such that multiple companies were able to produce technology that adhered to the rules of interaction.

In the history of the cellular industry, standards have competed with one another and firms have competed with one another within specific standards. Between-standard competition happened when promoters of different standards competed with one another to gain adoption for their own standard in different countries and regions of the world. Within-standard competition happened when companies competed with one another by selling products, such as infrastructure technology and handsets, that adhered to a specific standard. By their very nature, closed standards tended to suppress within-standard competition, whereas open standards tended to promote it. Because they encouraged within-standard competition in the supply of cellular technology, open standards fostered wider adoption.

Open standards encouraged cellular adoption in two ways. First, the fact that firms competed with one another within specific standards led to lower prices for cellular technology, which in turn made it possible for wider segments of a country's population to access cellular products, handsets especially. Second, "network effects" kicked in. As more people acquired mobile phones and became cellular subscribers, cellular networks became more valuable for both existing and future subscribers. Large, and rapidly increasing, numbers of users attracted new users, and the size of cellular networks exploded. Both effects—lower technology prices and network effects—had an impact across countries as well. Closed standards were almost never adopted outside the country where they were created, but several open standards were widely adopted in countries other than the ones where they were developed. During the 1G era, AMPS and NMT were the main examples of open standards that were widely adopted outside the countries where they were created. During the 2G era, GSM was the leading example.

It has been argued that, with full interconnection among cellular networks and between each of the cellular networks and the fixedline telephone system, network effects should not matter. (Fixedline telephony is the traditional system of wired telephones, also known as the wireline system or the public switched telephone network.) Why would somebody benefit more from subscribing to a cellular system that has more subscribers if all systems are interconnected with one another and with the fixedline network? Historically, however, network effects have played a role in fostering the growth of cellular systems, among other things because

carriers have implemented pricing structures in which calls that terminate on competing networks are more expensive than calls that terminate on each carrier's own network. These pricing structures have given rise to network effects based on differential pricing of services that, from the subscriber's perspective, are identical.[2]

Standards also exist in other high-tech industries, such as computers and semiconductors. Cellular standards, however, are different from computer standards in a fundamental way. Computer standards tend to be market based: a computer system, such as the IBM System 360, became an industry standard because it was successful in the marketplace.[3] Many cellular standards, by contrast, are committee based: they have been shaped by committees consisting of representatives of various organizations, and governments have frequently intervened to promote the adoption of a particular cellular standard.

This government involvement highlights another theme we explore in this book: the role national governments have played in shaping the way the cellular industry evolved in each country. First, they have allocated portions of the spectrum to cellular communications. The timing of this allocation and how generous it was shaped the evolution of cellular services in each country. Second, during the early years of the industry, some of the first cellular operators were often subsidiaries of a government-owned fixedline incumbent. Third, governments promoted the adoption of specific cellular standards—often just a single standard—in each country. Fourth, in some countries, governments encouraged the rise of "national champions"—large domestic corporations that became leading producers of cellular technology with government support. Fifth, governments licensed cellular operators and, by doing so, often shaped the structure of the network-services market in each country. Finally, government regulators frequently intervened in interconnection disputes between cellular operators and the incumbent fixedline telephone operator. In the early days of cellular, such disputes were frequently conflicts between private corporations (or consortia) and a state-owned entity. In short, national governments have played a much more influential role in the cellular industry than in other high-tech industries.

Another major theme in our book is the impact technological progress has had on the cellular industry. One aspect of this theme is the influence

of changing semiconductor technology on the size, weight, and functionality of mobile devices. Semiconductor components became smaller over time, and this facilitated the transition from bulky, heavy, and rudimentary mobile phones to the smaller, lighter, and more sophisticated smartphones in use today. Another dimension of this theme, largely invisible to consumers, involves the changing approaches for allocating radio frequencies to multiple users so that many calls can be completed simultaneously. The cellular industry moved from frequency division multiple access, used in all 1G (analog) systems, to time division multiple access and code division multiple access, both used in the digital cellular systems adopted from the beginning of the 1990s. More recently, the 4G Long-Term Evolution (LTE) standard has relied on yet another approach, orthogonal frequency division multiple access.

A final theme we explore in our book is how people have used their mobile phones over time and across regions of the world. During the 1980s, in the 1G era of cellular, cellular devices facilitated voice communications when users were on the move. During the 1990s, in the 2G era, cellular subscribers started using short messaging service (texting), but voice communications continued to play a crucial role. Change accelerated during the 3G era of cellular, starting in the early 2000s, when texting became pervasive and mobile devices started supporting versions of the Internet and email. Change accelerated again in the late 2000s with the introduction of the Apple iPhone and the Android smartphones. These mature smartphones had many of the functions of a true computer. After Apple introduced the iPhone in 2007, and especially after it introduced the second version in 2008, mobile apps became the core feature of mobile phones. Apps captured the attention of users and shaped their choices in many areas of everyday life, from transportation to banking to entertainment, to mention just a few.

STRUCTURE OF THE BOOK

As explained earlier, our book is divided into four parts, each with three chapters. The first part covers roughly the 1980s and focuses on the first generation of cellular phones, also known as the 1G or analog era. Chapter 1 argues that cellular systems did not come into existence out of the

blue: wireless telegraphs existed before there were wireless phones, and mobile phones existed before there were cellular phones. We track the evolution of mobile communications before the rise of cellular phones and explain the originality of the cellular concept. Chapter 2 focuses on the launch of the early cellular systems in Japan, Scandinavia, and the United States, as well as in other Western European countries that created their own standards. Among the countries that developed cellular standards, the United States and Britain were peculiar because they introduced competition in cellular services from the very beginning. Chapter 3 explores the early markets for cellular infrastructure, handsets, and network services.

The second part covers roughly the 1990s and focuses on the transition from first-generation to second-generation cellular, or from 1G to 2G. Second-generation cellular was the first generation of digital cellular systems. Chapter 4 highlights some of the new features of 2G cellular networks. In the 2G era, the existing standards for analog transmission were replaced with those for digital transmission. In addition, mobile phones were adopted widely by consumers (rather than just by business users and wealthy subscribers). Chapter 5 examines the transition from analog to digital cellular in some of the pioneering cellular countries, including the United States and Japan, as well as in several other large cellular markets in Europe. It also explores the rise of cellular systems in two countries that would eventually become massive cellular markets: China and India. In many of the countries studied in chapter 5, the evolution from 1G to 2G also involved the transition from monopoly to competition in cellular network services. Chapter 6 examines the dynamics of cellular product and service markets—infrastructure, handsets, and network services—during the 2G era.

The third part covers roughly the 2000s and focuses on the transition from second-generation to third-generation cellular networks, or from 2G to 3G. Chapter 7 explores how the 3G cellular standards were developed and the novel features they introduced. During the third cellular generation, feature phones and smartphones replaced voice-only phones, and data-related applications on mobile phones slowly became pervasive. Chapter 8 compares the evolution of cellular systems in several markets in the Asia-Pacific region, the Middle East, and Latin America. Chapter 9 analyzes changes in cellular product and service markets during the 3G

era, tracking the growing importance of two ancillary markets: mobile semiconductors and mobile operating systems.

Lastly, the fourth part covers roughly the 2010s and examines the transition from third-generation to fourth-generation cellular systems, or from 3G to 4G. Chapter 10 tracks how the LTE standard was developed, and how smartphones came to play an increasingly important role in the cellular industry, especially after the introduction of Apple's iPhone in 2007 and of the first Android phones in late 2008. Chapter 11 analyzes cellular markets in Africa. Chapter 12 studies the dynamics of cellular product and service markets during the 4G era, highlighting the growing importance of Chinese companies in several of those markets.

In the concluding chapter of our book, we summarize the main themes developed in the book and reflect on 5G, the new generation of cellular systems. At the time of writing, the fifth cellular generation has become a topic of intense debate, not only because of its technical dimensions and the lifestyle changes it is expected to introduce but also for its national-security and geopolitical implications.

RELATED LITERATURE

Among the histories of mobiles phones, three excellent books stand out: Garry Garrard's *Cellular Communications* (1998), Guy Klemens's *The Cellphone* (2010), and Jon Agar's *Constant Touch* (2013).[4] Garrard presents a wealth of information on the evolution of cellular communications all over the world but covers only the first generation and a fraction of the second generation of cellular phones. Klemens devotes substantial portions of his book to the technical foundations of wireless and cellular communications. Agar tends to emphasize the cultural and social dimensions of mobile phones. In addition, Martin Cooper's *Cutting the Cord* (2020) contains valuable insights on the business and technological developments that led to the introduction of cellular systems in the United States.[5] We have also consulted dozens of peer-reviewed articles and books on the evolution of cellular networks in specific countries and regions of the world, as well as a variety of technical books on wireless and cellular communications. These sources are reflected in the endnotes for each chapter.

Two short and carefully written introductions to the history of cellular phones are John Meurling and Richard Jeans's *The Mobile Phone Book* (1994) and Karyn Poupée's *La téléphonie mobile* (2003).[6] The former covers the first generation and the beginning of the second generation of cellular systems, whereas the latter focuses on the second generation and the early years of the third generation.

Among the books that highlight the economic and business dimensions of cellular phones, four have been especially useful to us: Jeffrey Funk's *Global Competition between and within Standards* (2002), Harald Gruber's *The Economics of Mobile Telecommunications* (2005), Peter Curwen and Jason Whalley's *The Internationalisation of Mobile Telecommunications* (2008), and Curwen and Whalley's *Mobile Telecommunications in a High-Speed World* (2010).[7] We have also drawn from a collection of excellent book chapters, including Jerry Hausman's "Mobile Telephone" (2002), Jeffrey Church and Neil Gandal's "Platform Competition in Telecommunications" (2005), and Joshua Gans, Stephen King, and Julian Wright's "Wireless Communications" (2005).[8] Two books are full of insights on telecommunications economics more generally: Jean-Jacques Laffont and Jean Tirole's *Competition in Telecommunications* (1999) and Carlo Cambini, Piercarlo Ravazzi, and Tommaso Valletti's *Il mercato delle telecommunicazioni* (2003).[9]

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NOTES

INTRODUCTION

1. On cellular standards, see especially J. Funk, *Global Competition between and within Standards: The Case of Mobile Phones* (Houndmills, UK: Palgrave, 2002); and R. Bekkers, *Mobile Telecommunications Standards: GSM, UMTS, TETRA, and ERMES* (Boston: Artech House, 2001). On the history of the standard-setting movement since the late nineteenth century, see especially J. Yates and C. Murphy, *Engineering Rules: Global Standard Setting since 1880* (Baltimore: Johns Hopkins University Press, 2019).

2. See J. Laffont, P. Rey, and J. Tirole, "Network Competition: I. Overview and Nondiscriminatory Pricing," *RAND Journal of Economics* 29, no. 1 (Spring 1998): 1–37; and J. Laffont, P. Rey, and J. Tirole, "Network Competition: II. Price Discrimination," *RAND Journal of Economics* 29, no. 1 (Spring 1998): 38–56.

3. See M. Campbell-Kelly and D. Garcia-Swartz, *From Mainframes to Smartphones: A History of the International Computer Industry* (Cambridge, MA: Harvard University Press, 2015), 57–102.

4. G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998); G. Klemens, *The Cellphone: History of the Gadget That Changed the World* (Jefferson, NC: McFarland, 2010); J. Agar, *Constant Touch: A History of the Global Mobile Phone* (London: ICON Books, 2013).

5. M. Cooper, *Cutting the Cord* (New York: RosettaBooks, 2020).

6. J. Meurling and R. Jeans, *The Mobile Phone Book* (London: Ericsson Radio Systems, 1994); K. Poupée, *La téléphonie mobile* (Paris: Presses universitaires de France, 2003).

7. Funk, *Global Competition*; H. Gruber, *The Economics of Mobile Telecommunications* (Cambridge: Cambridge University Press, 2005); P. Curwen and J. Whalley, *The Internationalisation of Mobile Telecommunications: Strategic Challenges in a Global*

Market (Cheltenham, UK: Edward Elgar, 2008); P. Curwen and J. Whalley, *Mobile Telecommunications in a High-Speed World: Industry Structure, Strategic Behavior and Socio-economic Impact* (Farnham, UK: Gower, 2010).

8. J. Hausman, "Mobile Telephone," in *Handbook of Telecommunications Economics*, vol. 1, *Structure, Regulation, and Competition*, ed. M. Cave, S. Majumdar, and I. Vogelsang (Amsterdam: Elsevier, 2002), 563–604; J. Church and N. Gandal, "Platform Competition in Telecommunications," in *Handbook of Telecommunications Economics*, vol. 2, *Technical Evolution and the Internet*, ed. S. Majumdar, I. Vogelsang, and M. Cave (Amsterdam: Elsevier, 2005), 119–53; J. Gans, S. King, and J. Wright, "Wireless Communications," in Majumdar, Vogelsang, and Cave, *Handbook of Telecommunications Economics*, 241–285.

9. J.-J. Laffont and J. Tirole, *Competition in Telecommunications* (Cambridge, MA: MIT Press, 1999); C. Cambini, P. Ravazzi, and T. Valletti, *Il mercato delle telecomunicazioni* (Bologna: Il Mulino, 2003).

CHAPTER 1

1. A. Mehrotra, *Cellular Radio: Analog and Digital Systems* (Boston: Artech House, 1994), 146–150. In his recent book on the origins of cellular phones, Martin Cooper argues that there were proto-cellular systems many years before 1978. He mentions a system set up in the late 1960s for the New York City–Washington, DC, Metroliner train that included a "handoff" feature from one system to another. He also mentions a system that Motorola set up for the Chicago Police Department in the 1960s and that included all the cellular features with the exception of the call "handoff." See M. Cooper, *Cutting the Cord* (New York: RosettaBooks, 2020), esp. 49–50, 57–64. These systems may well have been precursors of cellular networks, but they were not nearly as fully developed as the Chicago system of 1978.

2. As of mid-1988, forty-two countries had cellular systems, according to US Department of Commerce, *A Competitive Assessment of the U.S. Cellular Radiotelephone Industry* (Washington, DC: US Department of Commerce, 1988), 37–38, 76. There were forty-five countries with at least one cellular system by the end of 1988, according to J. Funk, *Global Competition between and within Standards: The Case of Mobile Phones* (Houndmills, UK: Palgrave, 2002), 43–45. The 2.5-million subscriber number comes from US Department of Commerce, *Competitive Assessment*, xi. According to the International Telecommunications Union (ITU) database, there were more than four million cellular subscriptions by the end of 1988.

3. The story of how an NMT 450 system came to be launched in Saudi Arabia very early in the history of cellular networks can be found in J. Meurling and R. Jeans, *The Mobile Phone Book* (London: Ericsson Radio Systems, 1994), 55–57.

4. On the history and economics of spectrum allocation in the United States, see especially T. Hazlett, *The Political Spectrum* (New Haven, CT: Yale University Press, 2017).

5. H. Aitken, *Syntony and Spark: The Origins of Radio* (New York: John Wiley and Sons, 1976), 179–297. This book also has excellent chapters on Heinrich Hertz and Oliver Lodge. On electromagnetic experimental and theoretical developments in the

nineteenth century, see B. Hunt, *Pursuing Power and Light: Technology and Physics from James Watts to Albert Einstein* (Baltimore: Johns Hopkins University Press, 2010); and "Electrical Theory and Practice in the Nineteenth Century," in *The Cambridge History of Science*, vol. 5, *The Modern Physical and Mathematical Sciences*, ed. M. Nye (Cambridge: Cambridge University Press, 2003), 311–327. For the mathematics of Maxwell's equations, see D. Fleisch, *A Student's Guide to Maxwell's Equations* (Cambridge: Cambridge University Press, 2008).

6. Aitken, *Syntony and Spark*, 202.

7. Marconi's patent, No. 763,772, "Apparatus for Wireless Telegraphy," was filed on November 10, 1900. This patent generated disputes with the Serbian-born American engineer Nikola Tesla, whose two important radio-related patents were granted in 1900: No. 645,576, "System of Transmission of Electrical Energy," and No. 649,621, "Apparatus for Transmission of Electrical Energy." The patent office denied Marconi's patent in 1903 on the basis of Tesla's preexisting patents. However, in 1904, and without any explanation, the patent office reversed its decision and granted Marconi's patent. The disputes continued for decades. See G. Klemens, *The Cellphone* (Jefferson, NC: McFarland, 2010), esp. 34–37.

8. When the *Titanic* hit an iceberg on April 14, 1912, the crew used a Marconi wireless telegraph system to send distress signals to other ships. The system, which was capable of transmitting signals as far as 350 miles, was used on the ship for two purposes: to send "marconigrams" (wireless telegrams) on behalf of the first-class passengers, and to send and receive weather reports and ice warnings. See J. Ouellette, "US Court Grants Permission to Recover Marconi Telegraph from *Titanic* Wreckage," Ars Technica, May 28, 2020, https://arstechnica.com/science/2020/05/us-court-grants-permission-to-recover-marconi-telegraph-from-titanic-wreckage/.

9. H. Aitken, *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton, NJ: Princeton University Press, 1985), esp. 1–27.

10. For details on these devices, see Aitken, 28–161; and F. Nebeker, *Dawn of the Electronic Age* (Hoboken, NJ: John Wiley and Sons, 2009), 23–24, 27, 37.

11. W. Young, "Advanced Mobile Phone Service: Introduction, Background, and Objectives," *Bell System Technical Journal* 58, no. 1 (January 1979): 1–14; H. Kargman, "Land Mobile Communications: The Historical Roots," in *Communications for a Mobile Society*, ed. R. Bowers et al. (Beverly Hills, CA: Sage, 1978), 19–34; G. Calhoun, *Digital Cellular Radio* (Norwood, MA: Artech House, 1988), 23–37; E. F. O'Neill, ed., *A History of Engineering and Science in the Bell System: Transmission Technology (1925–1975)* (Murray Hill, NJ: AT&T Bell Laboratories, 1985), 401–418.

12. D. Noble, "The History of Land-Mobile Radio Communications," *Proceeding of the IRE* 50, no. 5 (May 1962): 1405–1414.

13. For details on technical terminology, see especially H. Newton, *Newton's Telecom Dictionary*, 26th ed., with S. Schoen (New York: Flatiron, 2011).

14. Calhoun, *Digital Cellular Radio*, 27–28. See also R. Macario, *Cellular Radio: Principles and Design* (Houndmills, UK: Macmillan, 1993), 18–20.

15. Noble, "History," 1408–1409.

16. Young, "Advanced Mobile Phone Service," 2.

17. Young, 3.

18. Calhoun, *Digital Cellular Radio*, 32–35; Young, "Advanced Mobile Phone Service," 3–5.

19. Kargman, "Land Mobile Communications," 29–31.

20. Young, "Advanced Mobile Phone Service," 6. The number of fixed-telephone subscriptions in the United States comes from the ITU database.

21. G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998), 15–16.

22. Garrard, 17.

23. B. Mölleryd, *The Building of a World Industry: The Impact of Entrepreneurship on Swedish Mobile Telephony* (Stockholm: Teldok, 1997).

24. Garrard, *Cellular Communications*, 20.

25. T. Pempel, "Land Mobile Communications in Japan: Technical Developments and Issues of International Trade," in Bowers et al., *Communications for a Mobile Society*, 317–343.

26. V. Mac Donald, "The Cellular Concept," *Bell System Technical Journal* 58, no. 1 (January 1979): 15–41; Calhoun, *Digital Cellular Radio*, 39–44.

27. S. Gibson, *Cellular Mobile Radiotelephones* (Englewood Cliffs, NJ: Prentice-Hall, 1987), 7, argues that, before cellular systems, at most seven hundred customers could be accommodated in New York City, and those customers could complete one out of every two telephone calls the first time they tried. Other sources refer to about a dozen simultaneous conversations.

28. Young, "Advanced Mobile Phone Service," 7–8. See also A. Madrigal, "The 1947 Paper That First Described a Cell-Phone Network," *Atlantic*, September 16, 2011, https://www.theatlantic.com/technology/archive/2011/09/the-1947-paper-that-first-described-a-cell-phone-network/245222/.

29. On the clustering of cells in cellular systems, see, for example, Mehrotra, *Cellular Radio*, 31–46.

30. It can be shown that clusters contain C cells, where C is an integer given by the expression $C=i^2+j^2+ij$. In this expression, $i=0, 1, 2, \ldots$ and $j=0, 1, 2, \ldots$ The AMPS system uses a frequency-reuse cluster of 7, whereas GSM uses 3 or 4. See M. Schwartz, *Mobile Wireless Communications* (Cambridge: Cambridge University Press, 2005), 66–67.

31. The dictum comes from G. Box and N. Draper, *Empirical Model Building and Response Surfaces* (New York: John Wiley and Sons, 1987), 424.

32. Calhoun, *Digital Cellular Radio*, 92–111. On coverage problems in Britain, see Garrard, *Cellular Communications*, 188.

33. On the technicalities of cellular-system design, see Mehrotra, *Cellular Radio*. Other technical sources include Gibson, *Cellular Mobile Radiotelephones*; and V. Garg and J. Wilkes, *Wireless and Personal Communications Systems* (Upper Saddle River, NJ:

Prentice Hall, 1996). An excellent summary of the technical dimensions of cellular phones is in W. Webb, *Understanding Cellular Radio* (Boston: Artech House, 1998).

34. The traditional unit of telephone traffic is the Erlang, and measures of spectral efficiency include Erlangs/MHz, Erlangs/channel, and Erlangs/MHz/square mile. On the spectral efficiency of precellular mobile-phone systems compared with that of early cellular systems, see especially J. Frey and A. Lee, "Technologies for Land Mobile Communications: 900-MHz Systems," in Bowers et al., *Communications for a Mobile Society*, 60–63.

35. The fixedline density numbers come from the ITU database. In 1989, there were 67.20 fixed-telephone subscriptions per 100 people in Sweden, 51.97 in Finland, 49.06 in Norway, 55.52 in Denmark, and 52.20 in the United States. There were 43.05 in Japan.

36. Meurling and Jeans, *Mobile Phone Book*, esp. 24–26.

37. In addition, inexpensive frequency synthesizers, which allow mobile phones to switch across frequencies, were developed only starting in the 1970s. See, for example, Young, "Advanced Mobile Phone Service," 7.

CHAPTER 2

1. See J. Meurling and R. Jeans, *The Mobile Phone Book* (London: Ericsson Radio Systems, 1994), esp. 7–14, 99–100.

2. Here we follow G. Brock, *The Telecommunications Industry: The Dynamics of Market Structure* (Cambridge, MA: Harvard University Press, 1981).

3. Between 1902 and 1912, fixedline density in the United States grew from 2.3 percent to 8.8 percent, much faster than in Europe, where it rose from 0.3 to 0.7 percent. See AT&T, *Telephone Statistics of the World* (New York: AT&T, 1912), 8. In Europe, the Scandinavian countries were the ones with the highest telephone density; see AT&T, 15.

4. See United Nations, *Core ICT Indicators* (November 2005), https://www.itu.int/ITU-D/ict/partnership/material/CoreICTIndicators.pdf.

5. G. Calhoun, *Digital Cellular Radio* (Norwood, MA: Artech House, 1988), esp. 35–36.

6. E. Noam, *Telecommunications in Europe* (New York: Oxford University Press, 1992), 3–25.

7. Noam, 4.

8. S. Vogel, *Freer Markets, More Rules* (Ithaca, NY: Cornell University Press, 1996), 139–142. See also Y. Ito and A. Iwata, "Japan: Creating the Domestic and International Network," in *Telecommunications in the Pacific Basin: An Evolutionary Approach*, ed. E. Noam, S. Komatsuzaki, and D. Conn (New York: Oxford University Press, 1994), 440–457.

9. Calhoun, *Digital Cellular Radio*, 39–49.

10. The key references on the evolution of the US cellular system in the 1980s include G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston:

Artech House, 1998), 30–47; and H. Gruber, *The Economics of Mobile Telecommunications* (Cambridge: Cambridge University Press, 2005), 123–135. For a business history focused on Craig McCaw, one of the most successful cellular entrepreneurs of the 1980s, see O. Corr, *Money from Thin Air* (New York: Crown Business, 2000). An excellent company history centered on Pacific Telesis is in L. Galambos and E. Abrahamson, *Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World* (Cambridge: Cambridge University Press, 2002).

11. For details, see A. Mehrotra, *Cellular Radio: Analog and Digital Systems* (Boston: Artech House, 1994), 146–150.

12. The Federal Communications Commission licensed cellular operators in 734 markets—306 MSAs and 428 rural statistical areas. See Federal Communications Commission, *Annual Report and Analysis of Competitive Market Conditions with Respect to Mobile Commercial Services* (August 18, 1995), 4, https://us-fcc.app.box.com/s/47g5d49y4d2jfarnhrcy2npj7hu17w5k.

13. The seven Regional Bell Operating Companies were Ameritech, Bell Atlantic, Bell South, Nynex, Pacific Telesis, Southwestern Bell, and US West.

14. S. Gibson, *Cellular Mobile Radiotelephones* (Englewood Cliffs, NJ: Prentice-Hall, 1987), 19–22.

15. S. Hultén and B. Mölleryd, "Mobile Telecommunications in Sweden," in *Mobile Telecommunications: Emerging European Markets*, ed. K. Schenk, J. Müller, and T. Schnöring (Boston: Artech House, 1995), 1–28; Meurling and Jeans, *Mobile Phone Book*, 27–33; Garrard, *Cellular Communications*, 48–61. See also T. Haug, "A Commentary on Standardization Practices: Lessons from the NMT and GSM Mobile Telephone Standards Histories," *Telecommunications Policy* 26, nos. 3–4 (April–May 2002): 101–107; and J. Lehenkari and R. Miettinen, "Standardisation in the Construction of a Large Technological System—the Case of the Nordic Mobile Telephone System," *Telecommunications Policy* 26, nos. 3–4 (April–May 2002): 109–127.

16. US International Trade Commission, *Global Competitiveness of U.S. Advanced-Technology Industries: Cellular Communications* (Washington, DC: US International Trade Commission, 1993), esp. 4–4; Garrard, *Cellular Communications*, 359–361.

17. Noam, *Telecommunications in Europe*, 103–132. On the deregulation process in Britain more generally, see M. Armstrong, S. Cowan, and J. Vickers, *Regulatory Reform: Economic Analysis and British Experience* (Cambridge, MA: MIT Press, 1994).

18. See especially T. Valletti and M. Cave, "Competition in UK Mobile Communications," *Telecommunications Policy* 22, no. 2 (March 1998): 109–131. See also Gruber, *Economics of Mobile Telecommunications*, 98–105; Garrard, *Cellular Communications*, 95–124; Meurling and Jeans, *Mobile Phone Book*, 89–97.

19. In France, a competing network was allowed to operate in the late 1980s.

20. M. Berlage and T. Schnöring, "The Introduction of Competition in German Mobile Communications Markets," in Schenk, Müller, and Schnöring, *Mobile Telecommunications*, 29–49; US International Trade Commission, *Global Competitiveness*, 4–6, 4–7; Gruber, *Economics of Mobile Telecommunications*, 105–108.; Garrard, *Cellular Communications*, 74–76.

21. Gruber, *Economics of Mobile Telecommunications*, 108–111.; US International Trade Commission, *Global Competitiveness*, 4–7; Garrard, *Cellular Communications*, 76–79.

22. Gruber, *Economics of Mobile Telecommunications*, 112–115; US International Trade Commission, *Global Competitiveness*, 4–7; Garrard, *Cellular Communications*, 79–83.

23. Another discussion of the French system is in J. Manguian, *Les radiocommunicatons* (Paris: Presses universitaires de France, 1993), chap. 4.

24. In Hong Kong, a TACS system was launched in 1984, even before one was formally introduced in Britain in 1985. This was possible because TACS was simply a modified version of an existing standard, the American AMPS. The fact that Cable & Wireless, a British telecommunications company, owned the cellular firm that introduced TACS in Hong Kong likely helped as well. See Garrard, *Cellular Communications*, 394.

25. K. Lyytinen and V. Fomin, "Achieving High Momentum in the Evolution of Wireless Infrastructures: The Battle over the 1G Solutions," *Telecommunications Policy* 26, no. 3–4 (April–May 2002), 149–170; J. Funk, *Global Competition between and within Standards: The Case of Mobile Phones* (Houndmills, UK: Palgrave, 2002), 36–92.

26. It happens to be the case that the United States, Sweden, and Britain were among the few countries that had duopolistic competition in cellular network services in the 1980s. This likely helped to foster cellular adoption during the 1980s, not so much by lowering subscription tariffs—at the time, nominal tariffs were stable in Britain and Sweden, and declined slowly in the United States—but rather by increasing network capacity.

CHAPTER 3

1. On the equipment manufacturers, see D. Steinbock, *Wireless Horizon* (New York: Amacom, 2003), chaps. 8–10; D. Steinbock, *The Nokia Revolution* (New York: Amacom, 2001); J. Meurling and R. Jeans, *The Mobile Phone Book* (London: Ericsson Radio Systems, 1994); and J. Morone, *Winning in High-Tech Markets* (Boston: Harvard Business School Press, 1993), chap. 3.

2. F. Nebeker, *Dawn of the Electronic Age* (Hoboken, NJ: John Wiley and Sons, 2009), esp. 298–302.

3. E. Noam, *Telecommunications in Europe* (New York: Oxford University Press, 1992), 206–209.

4. Meurling and Jeans, *Mobile Phone Book*, 45–49.

5. Steinbock, *Wireless Horizon*, 242.

6. M. Haikio, *Nokia: The Inside Story* (London: Prentice Hall, 2002), 54–61.

7. C. Palmberg, "Industrial Transformation through Public Technology Procurement? The Case of Nokia and the Finnish Telecommunications Industry," in *Public Technology Procurement and Innovation*, ed. C. Edquist et al. (New York: Springer Science, 2000), 167–196.

8. Steinbock, *Wireless Horizon*, 213–241; Morone, *Winning in High-Tech Markets*, 65–124.

9. A. Affrunty Sr., *A Personal Journal: 50 Years at Motorola* (Rolling Meadows, IL: Motorola University Press, 1994), esp. 1–41.

10. Affrunty, 42–46.

11. N. Linge and A. Sutton, *30 Years of Mobile Phones in the UK* (Gloucestershire, UK: Amberley, 2015), 8.

12. For a description of the technical details of the "first cellular call," see M. Cooper, *Cutting the Cord* (New York: RosettaBooks, 2020), esp. 105–130.

13. The distinction between committee-based and market-based competition comes from J. Funk, *Global Competition between and within Standards: The Case of Mobile Phones* (Houndmills, UK: Palgrave, 2002). We draw frequently from this book in our study of competition in infrastructure and handsets in the 1980s and 1990s.

14. US International Trade Commission, *Global Competitiveness of U.S. Advanced-Technology Industries: Cellular Communications* (Washington, DC: US International Trade Commission, 1993), esp. 5–12 through 5–23.

15. US International Trade Commission, 5–12, 5–13.

16. US International Trade Commission, esp. 5–25 through 5–37.

17. US Department of Commerce, *A Competitive Assessment of the U.S. Cellular Radiotelephone Industry* (Washington, DC: US Department of Commerce, 1988), 3.

18. US International Trade Commission, *Global Competitiveness*, 5–25 through 5–37.

19. US International Trade Commission, 5–30.

20. Morone, *Winning in High-Tech Markets*, 77.

21. US International Trade Commission, *Global Competitiveness*, 5–31.

22. T. Merriden, *Rollercoaster: The Turbulent Life and Times of Vodafone and Chris Gent* (Oxford: Capstone, 2003), esp. 11–35.

23. G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998), 112–124.

24. T. Valletti and M. Cave, "Competition in UK Mobile Communications," *Telecommunications Policy* 22, no. 2 (March 1998): 109–131.

25. We draw frequently from L. Galambos and E. Abrahamson, *Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World* (Cambridge: Cambridge University Press, 2002), esp. 34–40; and O. Corr, *Money from Thin Air: The Story of Craig McCaw, the Visionary Who Invented the Cell Phone Industry, and His Next Billion-Dollar Idea* (New York: Crown Business, 2000).

26. C. Lazzareschi, "Pacific Telesis Closes Deal for Cellular Firm," *Los Angeles Times*, March 1, 1986, https://www.latimes.com/archives/la-xpm-1986-03-01-fi-13297-story.html.

27. E. Tucker, "Mobile Phone Rivals Are Being Consolidated," *Washington Post*, August 11, 1986, https://www.washingtonpost.com/archive/business/1986/08/11/mobile-phone-rivals-are-being-consolidated/629b5593-4311-41cf-8f2e-ad3926c224a6/.

28. R. Gregson, "McCaw's Mark," *RCR Wireless News*, March 12, 2001, https://www.rcrwireless.com/20010312/carriers/mccaws-mark-2.

29. G. Fabrikant, "Lin Backs Takeover by McCaw," *New York Times*, December 5, 1989, https://www.nytimes.com/1989/12/05/business/lin-backs-takeover-by-mccaw.html. See also Corr, *Money from Thin Air*, 178–192.

30. G. Barth, "Cellular Phones: Is There Really Competition?" (incidental paper, Harvard University, Center for Information Policy Research, 1994), 21–22.

31. US General Accounting Office, *Concerns about Competition in the Cellular Telephone Service Industry* (Washington, DC: US General Accounting Office, July 1992).

32. P. Parker and L. Röller, "Collusive Conduct in Duopolies: Multimarket Contact and Cross-Ownership in the Mobile Telephone Industry," *RAND Journal of Economics* 28, no. 2 (Summer 1997): 304–322. See also M. Busse, "Multimarket Contact and Price Coordination in the Cellular Telephone Industry," *Journal of Economics and Management Strategy* 9, no. 3 (2000): 287–320.

33. US General Accounting Office, *Concerns about Competition*, 2.

34. US International Trade Commission, *Global Competitiveness*, 3–3.

35. For this analysis, we rely on data presented in H. Fullerton, "Duopoly Market Structure in a Communications Industry: The U.S. Cellular Telephone Experience" (PhD diss., University of Florida, 1996), appendix A.

36. On the evolution of subscription tariffs in the United States, see especially Parker and Röller, "Collusive Conduct in Duopolies"; and Busse, "Multimarket Contact." On Britain, see Valletti and Cave, "Competition in UK Mobile Communications." On Sweden, see S. Hultén and B. Mölleryd, "Mobile Telecommunications in Sweden," in *Mobile Telecommunications: Emerging European Markets*, ed. K. Schenk, J. Müller, and T. Schnöring (Boston: Artech House, 1995), 1–28. For a detailed analysis of subscription tariffs in Britain, Sweden, the United States, Germany, and Israel in the 1980s and 1990s, see N. Garcia-Vicente, D. Garcia-Swartz, and M. Campbell-Kelly, "What Do We Know about Duopolies? Insights from the History of Cellular Phones," *Telecommunications Policy*, published ahead of print, October 7, 2021, https://www.sciencedirect.com/science/article/abs/pii/S0308596121001634.

CHAPTER 4

1. D. Geradin and M. Kerf, *Controlling Market Power in Telecommunications* (Oxford: Oxford University Press, 2003), esp. 134–136.

2. J. Meurling and R. Jeans, *The Mobile Phone Book* (London: Ericsson Radio Systems, 1994), 99–100; G. Calhoun, *Digital Cellular Radio* (Norwood, MA: Artech House, 1988), 143–196.

3. The process is called speech coding; see W. Webb, *Understanding Cellular Radio* (Boston: Artech House, 1998), 102–106.

4. A. Mehrotra, *Cellular Radio: Analog and Digital Systems* (Boston: Artech House, 1994), 264–267.

5. H. Gruber, *The Economics of Mobile Telecommunications* (Cambridge: Cambridge University Press, 2005), 22–23; V. Garg and J. Wilkes, *Wireless and Personal Communications Systems* (Upper Saddle River, NJ: Prentice Hall, 1996), chaps. 2–3.

6. Webb, *Understanding Cellular Radio*, 118–132.

7. D. Mock, *The Qualcomm Equation* (New York: Amacom, 2005), 70–72.

8. There is a reasonably large literature on the GSM standard. We rely on Meurling and Jeans, *Mobile Phone Book*, 101–111; G. Cattaneo, "The Making of a Pan-European Network as a Path-Dependency Process: The Case of GSM versus IBC (Integrated Broadband Communication) Network," in *Global Telecommunications Strategies and Technological Changes*, ed. G. Pogorel (Amsterdam: North-Holland, 1994), 59–79; R. Bekkers, *Mobile Telecommunications Standards: GSM, UMTS, TETRA, and ERMES* (Boston: Artech House, 2001), 261–362; F. Hillebrand, *Die Pionierzeit des GSM-Standards und des D1-Netzes* (Wilburgstetten, Germany: Schlembach, 2013); F. Hillebrand, ed., *GSM and UMTS: The Creation of Global Mobile Communication* (New York: Wiley, 2002); G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998), 125–170; and T. Haug, "A Commentary on Standardization Practices: Lessons from the NMT and GSM Mobile Telephone Standards Histories," *Telecommunications Policy* 26, nos. 3–4 (April–May 2002): 101–107. See also A. Manninen, "Elaboration of NMT and GSM Standards: From Idea to Market" (PhD diss., Faculty of Humanities of the University of Jyväsklylä, Finland, 2002). Some of the most important GSM original documents are still available online: "History of GSM: Birth of the Mobile Revolution," accessed January 8, 2018, http://www.gsmhistory.com/rare-gsm-documents/.

9. Department of Trade and Industry, "Phones on the Move: Personal Communications in the 1990s" (Department of Trade and Industry, London, 1989). See T. Valletti and M. Cave, "Competition in UK Mobile Communications," *Telecommunications Policy* 22, no. 2 (March 1998): 109–131; and Bekkers, *Mobile Telecommunications Standards*, 296–299.

10. The details are in Mock, *Qualcomm Equation*, 21–134. Shorter treatments are in Garrard, *Cellular Communications*, 313–355; and Bekkers, *Mobile Telecommunications Standards*, 347–358.

11. Gruber, *Economics of Mobile Telecommunications*, 131–132.

12. Bekkers, *Mobile Telecommunications Standards*, 353–355.

13. We draw mainly from T. Salmon, "Spectrum Auctions by the United States Federal Communications Commission," in *Auctioning Public Assets*, ed. M. Janssen (Cambridge: Cambridge University Press, 2004), 147–176; and P. Cramton, "Spectrum Auctions," in *Handbook of Telecommunications Economics*, vol. 1, *Structure, Regulation, and Competition*, ed. M. Cave, S. Majumdar, and I. Vogelsang (Amsterdam: Elsevier, 2002), 605–639.

14. On auction formats, see, among others, P. Milgrom, "Auctions and Bidding: A Primer," *Journal of Economic Perspectives* 3, no. 3 (1989): 3–22.

15. Y. Yim, A. Kanafani, and J. Ygnace, "Expanding Usage of Cellular Phones: User Profile and Transportation Issues" (PATH Research Report, Institute of Transportation Studies, University of California at Berkeley, December 1991), 3–4.

16. Yim, Kanafani, and Ygnace, 3.

17. T. Parish, *Case Studies of Market Research for Three Transportation Communication Products* (Cambridge, MA: Arthur D. Little, March 1994), 35.

18. Yim, Kanafani, and Ygnace, "Expanding Usage of Cellular Phones," 2.

19. Garrard, *Cellular Communications*, 259.

20. Organisation de coopération et de développement économiques (OCDE), *Téléphonie mobile: Structures et tendances en matière de prix* (Paris: OCDE, 2000).

21. FCC, *6th Annual Commercial Mobile Services Competition Report* (Washington, DC: FCC, 2001), 27–34.

22. For background on the dissolution of the Soviet Union, see especially S. Kotkin, *Armageddon Averted: The Soviet Collapse, 1970–2000* (Oxford: Oxford University Press, 2008).

23. Garrard, *Cellular Communications*, 377–378.

24. OCDE, *Téléphonie mobile*, 69–75; A. Taylor and J. Vincent, "An SMS History," in *Mobile World: Past, Present and Future*, ed. L. Hamill and A. Lasen (New York: Springer, 2005), 75–91; P. Curwen, *The Future of Mobile Communications: Awaiting the Third Generation* (New York: Palgrave Macmillan, 2002), 16–18.

25. On the very first text message, see OCDE, *Téléphonie mobile*, 69. The source of the statement regarding the very first SMS appears to be S. Buckingham, "Success 4 SMS," Mobile Streams, February 2001, https://ftp.unpad.ac.id/orari/library/library-ref-eng/ref-eng-2/physical/wireless/cellullar/sms/sms.pdf.

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27. Taylor and Vincent, "SMS History," 82–84.

CHAPTER 5

1. Sweden, France, and Japan also had competitive markets in network services during the 1980s, but with restrictions.

2. T. Valletti and M. Cave, "Competition in UK Mobile Communications," *Telecommunications Policy* 22, no. 2 (March 1998): 109–131; H. Gruber, *The Economics of Mobile Telecommunications* (Cambridge: Cambridge University Press, 2005), 98–105; G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998), 171–217.

3 Department of Trade and Industry, "Phones on the Move: Personal Communications in the 1990s" (Department of Trade and Industry, London, 1989).

4. R. Bekkers, *Mobile Telecommunications Standards: GSM, UMTS, TETRA, and ERMES* (Boston: Artech House, 2001), 297.

5. Bekkers, 296–298.

6. For details on the evolution of prices in the British cellular market, see Valletti and Cave, "Competition in UK Mobile Communications," esp. 128–131.

7. The key references on the evolution of cellular in the United States are the Federal Communications Commission Commercial Mobile Radio Services Competition reports, the first one of which was published in 1995. Excellent summaries are in Gruber, *Economics of Mobile Telecommunications*, 123–135; and Garrard, *Cellular Communications*, 313–355.

8. M. Berlage and T. Schnöring, "The Introduction of Competition in German Mobile Telecommunications Markets," in *Mobile Telecommunications: Emerging European Markets*, ed. K. Schenk, J. Müller, and T. Schnöring (Boston: Artech House, 1995), 29–49; Gruber, *Economics of Mobile Telecommunications*, 105–108; Garrard, *Cellular Communications*, 252–265. See also M. Stoetzer and D. Tewes, "Competition in the German Cellular Market? Lessons of Duopoly," *Telecommunications Policy* 20, no. 4 (May 1996): 303–310.

9. Whether BMPT was a truly independent regulator is a matter of debate in the literature. See, for example, D. Gillick, "Telecommunications Policies and Regulatory Structures," *Telecommunications Policy* 16, no .9 (December 1992): 726–732. Gillick suggests that, because BMPT was a government ministry, it was not a truly independent regulator.

10. On interconnect and leased-line fees, see Garrard, *Cellular Communications*, 228–229.

11. See esp. Stoetzer and Tewes, "Competition?"

12. Gruber, *Economics of Mobile Telecommunications*, 108–111; Garrard, *Cellular Communications*, 287–293.

13. C. Gambini, P. Ravazzi, and T. Valletti, *Il mercato delle telecomunicazioni* (Bologna: Mulino, 2003), 123–126.

14. On the confrontations between the European Commission and several European countries regarding telecommunications liberalization issues, see P. Curwen, *Restructuring Telecommunications: A Study of Europe in a Global Context* (New York: St. Martin's, 1977), 64–68.

15. Gruber, *Economics of Mobile Telecommunications*, 116–117; Garrard, *Cellular Communications*, 278–280.

16. H. Sousa, "Telecommunications Reforms in Portugal and the European Union," *Telecommunications Policy* 20, no. 9 (November 1996): 653–667.

17. For an excellent history of China up to the early 2010s, see K. Mühlhahn, *Making China Modern: From the Great Qing to Xi Jinping* (Cambridge, MA: Belknap Press of Harvard University Press, 2019). For background on the Chinese economy, see esp. B. Naughton, *The Chinese Economy: Transitions and Growth* (Cambridge, MA: MIT Press, 2007). On the evolution of the Chinese telecommunications system, see L. Xiong-Jian and Z. You-Nong, "China," in *Telecommunications in the Pacific Basin: An Evolutionary Approach*, ed. E. Noam, S. Komatsuzaki, and D. Conn (New York: Oxford University Press, 1994), 73–85; K. Zita, "China: Steps toward Political and Financial Reform," in Noam, Komatsuzaki, and Conn, *Telecommunications in the Pacific Basin*, 86–105; M. Mueller and Z. Tan, *China in the Information Age: Telecommunications and the Dilemmas of Reform* (Westport, CT: Praeger, 1997); X. Yan and

D. Pitt, *Chinese Telecommunications Policy* (Boston: Artech House, 2002); D. Lu and C. Wong, *China's Telecommunications Market: Entering a New Competitive Age* (Cheltenham, UK: Edward Elgar, 2003); S. Guan, *China's Telecommunications Reform: From Monopoly towards Competition* (New York: Nova Science, 2003); and esp. E. Harwitt, *China's Telecommunications Revolution* (Oxford: Oxford University Press, 2008). On mobile phones in China, see esp. X. Wang, "Mobile Communications in China: An Analysis of the Diffusion Process" (PhD diss., Ohio State University, 1995); and J. Wang and C. Cheng, "The History of the Mobile Phone in China," in *Mobile Communication and Greater China*, ed. R. Chu et al. (London: Routledge, 2012), 64–79. For a recent summary of the evolution of Chinese telecommunications generally, see J. Xia, "China's Telecommunications Evolution, Institutions, and Policy on the Eve of 5G: A Two-Decade Retrospect and Prospect," *Telecommunications Policy* 41, no. 10 (November 2017): 931–947.

18. Harwitt, *China's Telecommunications Revolution*, 67–69.

19. For background on the Indian economy, see V. Joshi and I. Little, *India: Macroeconomics and Political Economy, 1964–1991* (Washington, DC: World Bank, 1994); and V. Joshi and I. Little, *India's Economic Reforms, 1991–2001* (Delhi: Oxford University Press, 1998). On the telecommunications system in India, see B. Mody, "Liberalization of Telecommunications in India in the Mid-1990s," in *Telecommunications in Western Asia and the Middle East*, ed. E. Noam (New York: Oxford University Press, 1997), 3–19; and T. Chowdary, "Telecommunications in India," in Noam, *Telecommunications in Western Asia*, 20–37. On the reforms of the 1990s, see M. Athreya, "India's Telecommunications Policy: A Paradigm Shift," *Telecommunications Policy* 20, no. 1 (January–February 1996): 11–22. Important sources on cellular phones in India are A. Desai, *India's Telecommunications Industry: History, Analysis, Diagnosis* (New Delhi: Sage, 2006); and A. Doron and R. Jeffrey, *The Great Indian Phone Book* (Cambridge, MA: Harvard University Press, 2013), esp. 39–62.

20. For a complete list of the companies that received licenses, see Desai, *India's Telecommunications Industry*, chap. 2, appendix 2, and appendix 3.

21. Desai, 84–89.

22. On the US regional markets during the 1980s, see P. Parker and L. Röller, "Collusive Conduct in Duopolies: Multimarket Contact and Cross-Ownership in the Mobile Telephone Industry," *RAND Journal of Economics* 28, no. 2 (Summer 1997): 304–322; and M. Busse, "Multimarket Contact and Price Coordination in the Cellular Telephone Industry," *Journal of Economics and Management Strategy* 9, no. 3 (2000): 287–320. On Britain, see Valletti and Cave, "Competition in UK Mobile Communications." On Sweden, see S. Hultén and B. Mölleryd, "Mobile Telecommunications in Sweden," in Schenk, Müller, and Schnöring, *Mobile Telecommunications*, 1–28. In Sweden, there was a duopoly from the early 1980s, but one of the duopolists (the PTT) was much larger than the other (Comvik) in number of subscribers. Comvik remained a small cellular carrier throughout the 1980s.

23. On price declines during the 1990s in the US regional markets, especially after 1995, see J. Hausman, "Cellular Telephone, New Products, and the CPI," *Journal of Business and Economic Statistics* 17, no. 2 (April 1999): 188–194. On price changes in

the British market in the 1990s, see Valletti and Cave, "Competition in UK Mobile Communications," esp. 128–131. On price declines in the German market in the 1990s (in the transition from monopoly to duopoly first and to oligopoly with more than two carriers later), see Stoetzer and Tewes, "Competition?" On price changes in the Swedish market in the 1990s, see Hultén and Mölleryd, "Mobile Telecommunications in Sweden."

CHAPTER 6

1. The distinction between committee-based and market-based competition in cellular phones comes from J. Funk, *Global Competition between and within Standards: The Case of Mobile Phones* (Houndmills, UK: Palgrave, 2002).

2. In our analysis of the history of AirTouch, we draw from L. Galambos and E. Abrahamson, *Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World* (Cambridge: Cambridge University Press, 2002).

3. G. Garrard, *Cellular Communications: Worldwide Market Development* (Boston: Artech House, 1998), 377–387.

4. Garrard, 368–377.

5. C. Lazzareschi, "AT&T Near Deal to Buy Third of McCaw Cellular," *Los Angeles Times*, November 5, 1992.

6. "Company News; PacTel Will Change Name to AirTouch after Spinoff," *New York Times*, February 17, 1994.

7. See "A Brief History of 2-Way Radio Communications & Push-to-Talk," *Peak PTT Blog*, April 17, 2021, https://blog.peakptt.com/a-brief-history-of-2-way-radio-communications-push-to-talk/. See also M. O'Brien, "Looking Back while Going Forward: How the Early Days of Nextel Reflect on Today," RCRWireless, February 17, 2009, https://www.rcrwireless.com/20090217/wireless/looking-back-while-going-forward-how-the-early-days-of-nextel-reflect-on-today. For details on the evolution of Nextel, see the FCC's Commercial Mobile Radio Services Competition reports for the 1995–2001 period.

8. L. Helm, "Evolving Wireless World: AirTouch, US West to Merge Domestic Cellular Operations," *Los Angeles Times*, July 26, 1994.

9. E. Andrews, "Company News; AT&T Completes Deal to Buy McCaw Cellular," *New York Times*, September 20, 1994.

10. FCC, *2nd Annual Commercial Mobile Services Competition Report* (Washington, DC: FCC, 1997), 11–13. See also "National Alliance Places First Call on PCS System," PR Newswire, October 31, 1995.

11. FCC, *2nd Annual*, table 4.

12. "PCS PrimeCo Picks Wireless Technology," *New York Times*, June 7, 1995.

13. D. Mock, *The Qualcomm Equation* (New York: Amacom, 2005), 128–130.

14. For details on the history of Vodafone, see T. Merriden, *Rollercoaster: The Turbulent Life and Times of Vodafone and Chris Gent* (Oxford: Capstone, 2003); and C. Ibbott, *Global Networks* (New York: Palgrave Macmillan, 2007).

15. "AT&T Launches Flat-Rate Wireless Service," *Los Angeles Times*, May 8, 1998.

16. L. Laird, "US Authorities Clear Vodafone Merger with AirTouch," *Guardian*, June 24, 1999.

17. L. Cauley, "Bell Atlantic and Vodafone Plan IPO of Verizon Wireless Joint Venture," *Wall Street Journal*, April 5, 2000.

18. G. Naik and A. Raghavan, "Vodafone, Mannesmann Set Takeover at $180.95 Billion after Long Struggle," *Wall Street Journal*, February 4, 2000. For a retrospective from a German perspective, see F. Hubik, "Wie der 'Haifisch' das 'Hirn' besiegte," *Handelsblatt*, April 2, 2015.

19. Here we draw from I. Schmideg, "Mobile Telecommunications in Hungary," in *Mobile Telecommunications: Emerging European Markets*, ed. K. Schenk, J. Müller, and T. Schnöring (Boston: Artech House, 1995), 89–118; and Garrard, *Cellular Communications*, 378–382.

20. Garrard, *Cellular Communications*, 378.

21. Garrard, 382–386; M. Kets de Vries et al., *The New Russian Business Leaders* (Northampton, MA: Edward Elgar, 2004), 176–197.

22. This section draws from Garrard, *Cellular Communications*, 231–237.

23. Organisation de coopération et de développement économiques, *Téléphonie mobile: Structures et tendances en matière des prix* (Paris: Organisation de coopération et de développement économiques, 2000), 87. The countries included in figure 6.3 are the following: the United States, Japan, South Korea, the Netherlands, Canada, Denmark, Germany, Britain, Australia, Austria, Sweden, Italy, Belgium, Finland, France, Greece, Ireland, Mexico, Poland, Portugal, Spain, Switzerland, Hungary, Turkey, the Czech Republic, Iceland, Luxembourg, New Zealand, and Norway.

24. Funk, *Global Competition*, 93–205.

25. R. Bekkers, *Mobile Telecommunications Standards: GSM, UMTS, TETRA, and ERMES* (Boston: Artech House, 2001), 313–347.

CHAPTER 7

1. R. Bekkers, *Mobile Telecommunications Standards: GSM, UMTS, TETRA, and ERMES* (Boston: Artech House, 2001), 583–584.

2. This paragraph is based on calculations made by the authors on the basis of information presented in P. Curwen and J. Whalley, *Mobile Telecommunications in a High-Speed World: Industry Structure, Strategic Behavior and Socio-economic Impact* (Farnham, UK: Gower, 2010), 68–69. A distinction needs to be made between networks that were launched on a specific standard and networks that were operating on that standard at any given point in time. A network that was originally launched on a standard but was later converted to one of the standard's "evolutions" was no longer operating on the original standard from the time of the conversion—it was operating on the standard's evolution.

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CHAPTER 12

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CONCLUSIONS

1. In the United States during the 1980s, there was frequently a short lag between the launch of the first cellular network in each regional market and the entry of the competitor.

2. In some contexts, competition between carriers did not lead to lower subscription tariffs. During the 1980s, for example, there was duopolistic competition in the United States, Britain, and Sweden. Nominal subscription prices remained stable in Britain and Sweden and declined slowly in the American regional markets. But duopolistic competition during the 1980s led to more awareness of cellular phones among consumers and also to increased capacity. Enhanced competition among carriers during the 1990s usually led to more substantial tariff declines.

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