Quantifying the Trade Impact of Compatibility Standards and Barriers: An Industrial Organization Perspective

by

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Abstract

The goal of this paper is to help set a research agenda for examining the effect of compatibility barriers to trade. The paper explores the relationship between compatibility standards and international trade flows from an industrial organization perspective. I provide a brief survey of the literature on the economics of compatibility and standardization, as well as a brief survey of the literature on how standards affect international trade. I then discuss several industries that provide "natural experiments" to measure the effect of compatibility standards on international trade.

Keywords: Standardization Policy, Trade Policy, Network Effects, Empirical Study

JEL Classification: F13, L5

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1. Introduction

The goal of this paper is to help set a research agenda for examining the effect of compatibility barriers to trade. In doing so, the paper brings together two separate literatures:

- The economics of compatibility and standardization: Despite the fact that many industries characterized by "network effects" (personal computers, telecommunications, consumer electronics products) are global, this literature has almost exclusively focused on closed economies. The analysis of compatibility standards differs between closed-economy and open-economy contexts for several reasons. One difference (which also applies to a setting where there are no network effects) is that in the case of open-economies, foreign firms' profits do not contribute to the domestic country's welfare. A perhaps more important difference is that the analysis of closed economies ignores any gains that might come from international coordination of standards. When there are network effects the benefits from standardization increase in the size of the network, regardless of whether the consumers are foreign or domestic.

- The literature on barriers to international trade: This literature has focused for the most part on the strategic effects and welfare consequences of "traditional" trade barriers such as tariffs, quotas, and VERs. To the extent that the effects of strategic standardization policy have been examined in the trade literature, they have been considered primarily in the context of minimum quality (vertical) standards, rather than compatibility standards.

Section 2 discusses the standard setting process. In section 3, I survey the economics of compatibility and standardization, while section 4 provides a survey of the trade literature on the effect of standards. Section 5 discusses empirical (trade) implications of standardization policies. In section 6, I discuss two industries that provide "natural experiments" to measure the effect of compatibility standards on international trade. Section 7 discusses two additional industries where compatibility seems important, but where it may be difficult to empirically test for the effects of compatibility on trade. Section 8 provides brief conclusions.

2. Setting Standards

Broadly speaking, there are three ways that standards get set:

I. De facto standards, i.e., standards set primarily by market. These standards are often proprietary:

- The PC operating system industry provides an example. Due to a bandwagon effect, Microsoft has succeeded in setting standards in the PC operating systems industry. In 1992, it was estimated that seventy-two percent of all new personal computers sold throughout the world were shipped with the MS-DOS operating system.[1]

- In the case of video cassette recorders (VCRs), two incompatible proprietary standards competed. Sony, the initial leader, did not offer attractive licenses for its Betamax technology to other firms that wished to make VCRs, while JVC, a relatively unknown firm did just that. The Betamax technology was apparently---"on its own" ---as good as the competing incompatible VHS technology.[2] Nonetheless, by 1981, VHS held a 66-percent share of the VCR installed base.[3] When pre-recorded video cassettes became important in the early 1980s, rental stores preferred to carry VHS tapes because of their compatible installed-base advantage. The dearth of Betamax tapes "tipped" the market to VHS, which became the de facto standard in 1988. See Grindley (1995) for more details.

II. Voluntary industry agreements, where standards are often jointly developed. These standards are typically open standards, that is, they are not proprietary.

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[1] See Baseman, Warren-Boulton, and Woroch (1995) and the references cited within.

[2] Park (1997) cites a 1982 *Consumer Reports* publication that tested various VCR models. The report concluded that there was no significant difference in the characteristics or qualities of the two platforms.

[3] See Gabel (1991). The JVC lead was due in part to the fact that JVC cassettes initially had a longer playing time and in the early adoption period (1976-1980), consumers primarily used VCRs to record television programs in order to replay them at a later time.

- Compact-disc (CD) technology was developed by Philips in 1979 and introduced to the United States by Philips and Sony in 1983. In order to encourage adoption as well as sell their software products (Philips owned Polygram Records and Sony owned CBS Records of Japan), Sony and Phillips licensed their technology quite liberally. McGahan (1991) and Grindley and McBryde (1992) note that by 1981, more than 30 firms had signed licensing agreements to use the Philips technology and that other firms had withdrawn competing prototypes. Consequently, by the early 80's, CD-players had become a fairly standardized product produced by many firms.

- The DVD (digital video disc) industry provides an example of a jointly developed standard. Throughout the 1990s, video hardware and software manufacturers sought a digital format to replace videocassettes. In order to avoid another Beta/VHS format war, hardware manufacturers led by Sony, Toshiba, and Panasonic, and movie studios, led by Warner and Columbia (a division of Sony), worked together to establish a single standard. The result was the non-proprietary DVD standard.

III. Standards imposed by National Standards Bodies (NSBs), or agreed upon by regional or international standards development organizations (SDOs):

- NSBs such as the U.S. Federal Communications Commission (FCC) coordinate national standardization activity for all industries and use of their standards is mandatory. SDOs, on the other hand, are specialized along industrial organization lines (i.e., by industry). Examples of SDOs include the International Telecommunications Union (ITU), the oldest international standards body in the world, and the International Electrotechnical Commission (IEC). In the case of telecommunications, governments typically feel compelled to require compatibility and inter-operability standards. Given the importance of compatibility among international phone networks, the standards are set by the ITU are done so by international consensus. Similarly, IEC standards are typically set by international consensus.

- David and Shurmer (1996) provide qualitative evidence that there has been an increase in international standards production. The evidence includes a doubling of number of IEC standards between 1986-1990. They also note that there has been a shift from national standards to regional/international standards. The shift towards regional/international standards is due, in large part, to advances in information & communications technologies (ICTs) and the importance of technical compatibility within products (such as computer operating systems & applications software and consumer electronics products) that employ these new technologies. According to the authors, "the ICT impact upon the standardization regime have been profound (p. 797)."[4]

Two important welfare implications of network effects are that (i) markets may fail to achieve standardization when it is socially desirable and (ii) even if the market or regulators do agree on a standard, the chosen standard may be inferior. Both of these "failures" are due to coordination problems.

3. The Economics of Compatibility and Standardization: Network Effects

A network effect exists when the value that consumers place on a particular product increases as the total number of consumers who purchase identical or compatible goods increases. In the case of an **actual (or physical) network**, such as the telephone network, the value of the network depends on the total number of subscribers who have access to the network.

In the case of virtual networks that are not linked physically the network effect arises from **positive feedback from complementary goods**. Examples of virtual networks in which the value of the "base" product increases as the variety of complementary products increases include computer operating systems, videocassette recorders (VCRs), compact disc players (CD-players), and Digital Versatile Disc players (DVD-players). In the case of computer operating systems, the complementary goods are the applications software programs, while in the case of VCRs, the complementary goods are the VCR cassettes or tapes; similarly in the case of CD-players, the

[4] This shift includes developing countries to the extent that they produce or employ these hi-tech products.

complementary goods are the compact discs, while in the case of DVD-players, the complementary products are the DVD-discs.

The positive feedback mechanism works as follows: the value of the base product is enhanced as the variety of (compatible) complementary products increases; hence consumers will be more likely to purchase a base product with many compatible complementary products. The variety of complementary products, in turn, will depend on the total number of consumers that purchase the base product. As the number of consumers that purchase the base product increases, there is a greater demand for compatible complementary products. This increases the profitability of supplying complementary products. Since there are typically fixed or sunk entry costs, production of the complementary products is characterized by increasing returns to scale. Hence more complementary products will be produced or developed for a base product with a large share of the market. This further enhances the value of the base product. Thus there is positive feedback in such a system: an increase in the sales of the base product leads to more compatible complementary products, which further increases (the value of and) sales of the base product.

As Katz and Shapiro (1994) note, the positive feedback means that there is a "natural tendency towards de facto standardization" (p.105). They note that these system markets are often characterized by tipping: once a system has gained an initial lead, there is a snowball effect. One system ends up being the market standard with large amounts of compatible complementary products; the other system has a very small market share, if any at all. The value of the base product with little or no complementary software is essentially zero, since the base product itself provides little or no standalone benefits.

3.1 Theoretical Literature

The idea of network effects was first enunciated by Rohlfs (1974). In the mid-eighties Katz and Shapiro (1985), (1986) and Farrell and Saloner (1985) extended this idea to the oligopoly context, and examined the social and private incentives to achieve compatibility in a single product network. Matutes and Regibeau (1988) examined similar issues in a setting in which products consist of components that must be used in a fixed (one to one) proportion. Chou and Shy (1990)

and Church and Gandal (1992) examined related issues in systems markets. The two critical welfare issues discussed above (suboptimal standardization & choice of an inferior standard) have been examined in these and other papers.

While the theoretical literature of the economics of compatibility and standardization is quite large, nearly all of the literature has examined closed economies. See David and Greenstein (1990), Gilbert (1992), and Matutes and Regibeau (1996) for more detailed surveys.

3.2 Empirical Literature

A small but growing literature has empirically (statistically) found evidence of virtual network effects. In a study of the mainframe computer market, Greenstein finds that other things being equal, a firm with an IBM 1400 was as likely as any other firm to purchase an IBM when making an additional purchase. On the other hand, he finds that a firm with an IBM 360 was more likely to purchase an IBM than a firm that did not own an IBM 360. Software for the IBM 1400 could not run on the following generations of IBM models (360, 370, 3000, and 4300), while software for the IBM 360 could run on the 370, 3000 and 4300. Hence, Greenstein's results can be interpreted as a demand for compatibility.

Gandal (1994) estimates quality adjusted price equations for computer spreadsheet programs from the 1986-1991 period and then uses the analysis to empirically test whether network effects exist in this industry. The study finds that, other things being equal, consumers were willing to pay a significant premium for spreadsheets that were compatible with the LOTUS file compatibility standard.

Saloner and Shepard (1995) test for the existence of network effects in the adoption of automatic teller machines (ATM's). In particular, they test whether banks with a larger expected number of ATM locations will adopt the ATM technology sooner. Since expected network size is not an observable variable, they used the number of branches as a proxy. Their results indicate the presence of network effects.

Gandal, Greenstein, and Salant (1999) provide empirical evidence that the personal computer operating system market exhibits (positive feedback) virtual network effects. They examined the early micro or personal computer market (the 1978-1986 period) in which CP/M, the early de facto standard operating system, was subsequently replaced by the DOS operating system. The paper found statistically significant two-way feedback between advertisements for the operating system and advertisements for applications software for both CP/M (for the 1978-1986 period) and DOS (for the 1981-1986 period).

Gandal, Kende, and Rob (2000) examine the diffusion of the CD player/disks "hardware/software system." For such systems there is interdependence between the hardware-adoption decisions of consumers and the supply decisions of software manufacturers. Hence there can be bottlenecks to the diffusion of the system. Using a structural model, they estimate the (direct) elasticity of adoption with respect to CD-player prices and (the cross) elasticity with respect to the variety of CD-titles. The results show that the cross elasticity is significant.[5]

Despite the fact that many goods characterized by network effects are traded internationally, the literature on network effects has almost exclusively focused on closed economies. Indeed, to the best of my knowledge, there is no empirical work on the relationship between compatibility standards and international trade. This is most likely due to the fact that the relevant theoretical literatures (the industrial organization literature on network effects & the trade literature on the effect of standards) have not addressed the international trade issues. Although systematic empirical work in this field is demanding, the data to examine the relationship between compatibility standards and international trade are available.

4. Trade Literature on the Effect of Standards

The literature on standardization policy and international trade has primarily examined the effects of imposing minimum quality (vertical) standards. Recent contributions on the effect of imposing

[5] Unpublished manuscripts that provide empirical evidence of virtual network effects include Park (1997), the VCR market, Shankar and Bayus (1997), the Home Video Game Industry, and Berndt, Pindyck, and Azoulay (1999), the pharmaceutical industry.

minimum quality standards include Barrett (1994), Boom (1995) and Lutz (1996). The latter two authors employ a model of vertical product differentiation to examine the effect of minimum quality standards. Barrett (1994) examines the incentives for governments to impose environmental protection standards on industries that compete in oligopolistic international markets. Casella (1996) reviews the literature on minimum quality (vertical) standards.

The small theoretical literature on compatibility standards and international trade includes Kende (1991a) and Shy (1991), who respectively consider the effect of compatible international standards on licensing and on the incentives for conducting R&D. Kende (1991b) shows that standardization increases a domestic firm's profits internationally because of the increase in the product's gross utility. Jensen and Thursby (1996) examine strategic incentives for setting standards. In their paper, governments set standards in order to improve the chances of domestic firms in R&D competition.

None of the above papers examine governments' strategic standardization policies with network effects in an international environment. The extension of the industrial organization literature on compatibility and standardization to an international environment means that there are domestic and foreign firms. The key consideration is that the foreign firms' profits do not contribute to domestic country's welfare. Hence, optimal standardization policies may be different between open and closed markets. Sykes (1995) verbally discusses (in a trade context) the "standardization" tradeoff between network effects and increased costs for foreign producers.

Gandal and Shy (2000) formally examine strategic aspects of governmental standardization policy and the welfare implications when products and standards are horizontally differentiated. They analyze governments' incentives to recognize foreign standards when there are potentially both network effects and conversion costs. Network effects provide consumption benefits, while requiring foreign firms to comply with domestic standards may raise the costs of foreign producers.[6]

[6] In Gandal and Shy (2000), governments cannot explicitly choose to restrict international trade. They can, however, reduce the amount of international trade by not recognizing foreign standards. Kubota (2000) examines related issues. In her setting, each country already has an existing incompatible standard. Due to the assumption of homogeneous

They employ a three-country, three-variety, single-industry model. Each of three horizontally differentiated brands is produced in one of the three countries. Using an industrial organization, intra-industry trade framework, they examine a setting in which countries can form standardization unions. The interaction takes place in stages. In the first stage, each government decides whether or not to recognize foreign standards. In the second stage, each firm sets profit maximizing prices in each country and consumers make purchases.

When conversion costs are large, relative to network effects, two countries can increase their welfare by forming a standardization union which recognizes the standards of both member countries, but does not recognize the standard of the third (nonmember) country. When network effects are large, relative to conversion costs, all countries will mutually recognize all standards, that is, they have no incentive to form exclusionary standardization unions.

The results as to when countries form or do not form exclusionary standardization unions are somewhat specific to the setting considered. The main message of the paper is that in a setting in which network effects dominate conversion costs, there is more international trade than in the setting where network effects are small relative to conversion costs. This conclusion is likely quite robust.

5. Empirical Implications of the Effect of Standards on International Trade

Modern international trade theory recognizes that most industries are characterized by product differentiation and economies of scale. These two effects typically lead to some type of imperfect competition. Using standard industrial organization models, it is straightforward to show that economies of scale and product differentiation give rise to intraindustry trade.

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consumers, if international trade takes place, only one of the international standard survives. The benefit from a single standard is a larger network, while the cost is the "switch" from the domestic to international standard.

Despite the fact that there is virtually no theoretical literature on the effect of compatibility standards on international trade, the industrial organization (imperfect competition) framework provides several testable predictions regarding intraindustry trade:

1. In an oligopoly setting with differentiated products, compatibility i.e., standardization should lead to an increase in product sales. This is because of the network effect, i.e., an increase in the number of consumers using compatible products increases the value of the product itself. This in turn leads to additional sales.

Thus when there is free entry into the provision of a standardized product, compatibility typically will lead to the entry of additional firms into the market as a response to the increase in market size. Since firms generally produce differentiated products, open standards should lead to increased international trade.

2. Firms in developing countries are more likely to enter industries where standardization has been achieved due to the larger market size. This is a corollary of the prediction discussed above. The OECD (1996) attributes the growth of developing countries exports in the consumer electronics industry, in part, to the fact that these countries are low-cost producers of **standard** products.[7]

3. The entry of additional firms means that compatibility should in general lead to increased price competition. This is a straightforward result from an imperfect competition, discrete choice model of product differentiation. The successful "cloning" of the IBM PC is an example of this effect. See section 7.1.

It is important to point out, however, that under settings in which firms sell systems composed of components, incompatibility may actually lead to lower prices than compatibility.[8] Given that the number of firms is fixed in these settings, this effect is likely temporary.

[7] It's not clear whether the OECD's use of the word "standard" means largely undifferentiated in terms of demand characteristics, or whether "standard" means electronics products which are compatible.

[8] This is because under incompatibility, a firm that loses a sale of a particular component loses the sales of all other components of its system. This makes firms price more aggressively.

6. Industries to Study

Ideally, one would like to control for all other variables and examine the trade implications of compatible vs. incompatible standards. Since such controlled settings do not exist, the second best alternative is to examine industries in which the course of events was such that it is possible to isolate the effects of compatibility on trade. I refer to such settings as "natural experiments." In this section, I briefly describe two industries that provide natural experiments to measure the effect of compatibility standards on international trade. In both of these industries, it should be possible to collect the relevant data.

6.1 Television Industry

The National Television Standards Committee (NTSC) system was developed in the U.S. in 1954. The Sequential Couleur Avec Memoire (SECAM) system and the Phase Alternate Lines (PAL) system were developed in the early 1960s, SECAM in France and PAL in West Germany. All three standards are incompatible. The U.S. and Japan adopted NTSC, while the PAL system was adopted by most countries in Western Europe (except France). France and Eastern European countries adopted SECAM.

This fragmentation likely slowed the development of a global market for television receivers. Indeed, European governments in part adopted color television standards that were different from the U.S. standard in part to protect the interests of domestic firms. In order to sell television sets in France, foreign manufacturers had to adapt (convert) the receivers to the SECAM standard.[9]

Burton and Saelens (1987) note that Japanese entry into the US occurred before Japanese entry into the European markets, in part, because both countries were on the NTSC standard. Table 1 shows that Japanese sales (Japanese imports and local Japanese production) in the U.S. took off in the mid 1970s. In 1974, Japanese color television receiver sales (imports plus local Japanese production) accounted for 15.6 percent of color television sets sold in the U.S. By 1976, Japanese color television receiver sales accounted for 47.3 percent of color television sets sold in the U.S. Despite

[9] See Crane (1979) & Pelkans and Beuter (1987).

the decrease in Japanese imports, the increase in local production by Japanese subsidiaries insured that the Japanese manufacturers continued to account for a significant portion of television sales in the U.S. In 1981, sales by Japanese firms accounted for 43.5 percent of color television sales in the U.S. In contrast, sales by Japanese firms accounted for only 15.2 percent of color television sales in Western Europe in 1983.[10]

Burton and Saelens (1987) remark that "access to European markets was impeded by technical and licensing barriers," (p. 289) where the technical barrier refers to the incompatible standards and the licensing barrier refers to the fact that Telefunken, owner of the PAL technology, refused to provide Japanese firms with licenses until 1970. The 1988 world-wide installed base for the three competing systems were

NTSC: (established 1954): 280 million (US 195 million, Japan 71 million, and Canada 14 million).

PAL (established 1967): 270 million (UK 30 million, Germany 23 million, Italy 22 million, Spain 13 million, plus all other European countries besides France.)

SECAM (established 1967): 150 million (USSR 107 million, France 22 million, Eastern Europe 22 million).

Year	Demand	Japanese Imports	Local Japanese Production
1974	8.02	1.00	0.25
1975	6.65	1.22	0.58
1976	7.89	2.96	0.77
1977	9.40	2.14	1.16
1978	10.50	1.54	1.77
1979	10.24	0.69	2.27
1980	10.90	0.57	3.21
1981	11.16	1.02	3.83

Table 1. Television Sales in Millions in U.S. (Source: Burton and Saelens (1987))

[10] See Burton and Saelens (1987).

Given the size of the U.S. market and the early entry of Japanese firms into the U.S. television market, it is likely that television prices (adjusted for quality) were higher in Europe (especially France) than in the U.S. Data should be available to test this hypothesis. Gordon (1990) provides several quality-adjusted price indices for television sets for the U.S. for the 1952-1986 period. As long as "compatible" data are available from a subset of European countries, it will be possible to empirically test this hypothesis.

According to Burton and Saelens (1987), by the early 1980s, "the technical barrier created by competing transmission systems had virtually disappeared because of advances in microelectronics. (p. 289)" Hence, it may be possible to examine whether the elimination of the technical (compatibility) barriers facilitated entry of developing country firms into the television receiver industry. The data necessary to examine this issue include export sales data for television receivers by country and year, as well as total sales data by country and year for the main markets for developing country exports. Such data is almost certainly available for the U.S. and the U.K. and possibly other European countries. It will be important to control for the general trend of increased exports from developing countries over time by using overall export sales data for these countries.

Additionally, it would be interesting to examine how compatibility between the U.S. and Japanese systems affected Japanese entry into the U.S. It may not be possible to conduct this test because other likely explanations for early Japanese entry into the U.S. market.[11] Nevertheless, it will be worthwhile to measure trade flows in this industry.

6.2 Consumer Electronics: Compatible CD players vs. Incompatible VCRs

According to the OECD, worldwide exports of consumer electronics products increased from approximately $17 billion in 1982 to $40 billion in 1992. The growth rate in exports for consumer electronics has been much higher among developing countries than among developed countries

[11] Alternative explanations are that the European television industry began a decade later than the U.S. industry and that European countries adopted policies to keep Japanese television receivers out of their markets.

over the 1980-1990 period. The OECD (1996) attributes this growth, in part, to these countries being low cost producers of standardized products.

While there was standardization within many consumer electronic product categories, in the case of videocassette recorders (VCRs), incompatible proprietary standards competed. In the case of CD players a single worldwide open standard was agreed upon before product introduction.

A testable empirical implication is that other things being equal, firms in developing countries entered the CD industry more than quickly than the VCR industry. This hypothesis could be tested by collecting overall market sales data and export data from developing countries for both the CD and VCR industries by year. In order to conduct this test, one would have to control for variables such as prices, Gross National Product, and the availability of complementary products.[12]

7. Additional Industries

In this section, I briefly discuss two industries where compatibility seems important, but where it may be difficult to empirically test for the trade effects.

7.1 Personal Computers Operating on DOS/Windows Operating Systems

CP/M was the dominant open operating system during the 1976-1980 period.[13] It was used on more than 50 microcomputers including Commodore, Hewlett Packard, and Zenith. CP/M's market share was between 20-30 percent in 1980 (Gabel 1991).[14]

The introduction of the IBM PC occurred in late 1981. The IBM personal computer used a 16-bit chip from Intel and the DOS operating system. The operating system, developed under contract by Microsoft, was called MS-DOS. Under the contract with IBM, Microsoft had the copyright to

[12] In the case of CD-players, the discs are the complementary products, while in the case of the VCRs, the cassettes are the complementary products.

[13] Discussion in this section primarily comes from Gandal, Greenstein, and Salant (1999) and the sources cited within.

[14] The other dominant operating system was the proprietary Apple II operating system. Apple served a hobbyist market from the beginning and never successfully moved into the business market, as did CP/M and DOS. See Gabel (1991), Langlois (1992), and Gandal, Greenstein, and Salant (1999).

MS-DOS and also had the right to sell it or variants to other producers of microcomputers. By 1984, IBM's share of the personal computer market reached 33 percent. (Gabel, 1991). By this time, the IBM PC with the DOS operating system had supplanted the CP/M operating system as the industry standard.

Gabel (1991, p.26) notes that during the IBM PC's first few years, IBM was able to earn a "digital handshake" premium. Grindley (1995) notes that in 1983, the IBM PC was priced at approximately $4000, while a clone was priced at about $2000, or half that level (pp. 134-135). Hence the digital handshake premium was quite a significant proportion of the IBM price. Gabel (1991, p.26) notes that the IBM premium was approximately $1570 in 1985.

There was a significant premium because, the early "clones" (PC-like machines) were not perfectly compatible, that is, they were not able to run all of the applications software written for the IBM PC and MS-DOS operating systems (Gabel 1991). This was due to the one feature of the PC that was proprietary: The ROM BIOS (Read-Only Memory Basic Input/Output System.) Once competitors managed to reverse engineer the IBM proprietary ROM BIOS, clones that were fully compatible with the IBM platform became available and they captured a very large share of the PC market.[15] As a consequence, the digital handshake premium for IBM machines declined. "But as the clones established a reputation for perfect compatibility, the premium attached to the IBM brand name diminished" (Gabel (1991), p.26).

Since virtually all PCs used the DOS/WINDOWS operating systems, they were all fully compatible. Did compatibility lead to large flows of international trade in the PC industry? Did standardization lead to the entry of firms from developing countries in the PC market? While there are no obvious empirical tests, it would be interesting to quantify trade flows in this industry over time.

7.2 Wireless Telecommunications

[15] Since Microsoft kept the rights to the MS-DOS/PC-DOS operating system that it developed under contract for IBM, Microsoft was able to sell it to the other computer manufacturers.

In the fast growing world on wireless communications, several proprietary incompatible technologies have been competing throughout the world. (The discussion in this section is based on Funk (1998) and Grindley, Salant and Waverman (1999).) The "first generation" of analog cellular standards came into being in the early 1980s. The dominant standard was the advanced Mobile Phone Service Standard (AMPS) which operated at 800MHz. AMPS had its origin in the U.S. in 1983, and was adopted by the U.K. in 1984. By 1992, AMPS had 17.6 Million subscribers. This grew to 75.0 Million in 1996, with more than half of the AMPS subscribers in the U.S.

In 1987, the operators from the major European countries agreed to deploy digital Group Speciale Mobile (GSM) at the same frequency in order to enable roaming, that is, in order to enable consumers to be reached outside of their home service area. The European Telecommunications Standards Institute (ETSI), which was formed in 1988, facilitated this process. GSM was introduced in 1992. By 1996, GSM had 32.5 Million subscribers. By 1999, it had 70 million subscribers and was being used in 70 networks.

No formal digital standard was set in the U.S. The Telecommunications Industry Association (TIA) recognized GSM, as well as two additional "second generation" digital standards that were developed in the U.S.: Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA). Hence, there are currently three incompatible digital standards operating in the U.S. market, where incompatible means that users of one standard cannot roam to the other. Both TDMA and CDMA have near national coverage, while GSM's coverage is quite extensive also.

Funk (1998) provides some qualitative evidence that firms are likely to dominate domestically, where the "home" standard is dominant, that is firms by and large have not succeeded in markets with "non-domestic" standards. Funk (1998) quotes Yano research estimates that Motorola's share of the world market dropped from 40% to 32% from 1994 to 1995, as the installed base on GSM grew. He cites Nomura Research Institute estimates that Motorola's 1996-1997 average market shares were 23% for GSM subscribers and 70% for AMPS subscribers. Hence Motorola dominated in the U.S., while Nokia/Ericcson dominated in Europe.

It is interesting to note that 63% of all mobile phones sold in the U.S. are produced domestically. In the case of audio equipment, domestic U.S. manufacturers have only 19% of the U.S. market; similarly, domestic U.S. manufacturers of video equipment have only 26% of the U.S. market. [16] While this difference may be due in part to the fact that the consumer electronics industry is more mature than the mobile phone industry, it is possible that incompatibilities in the mobile phone networks delayed (reduced) international trade. This may be difficult to test empirically. In any case, it would be interesting to quantify the trade flows and the entry (or lack of entry) of developing country firms into this industry.

8. Conclusion

This paper has tried to lay out a framework for quantifying the trade impact of compatibility standards from an industrial organization perspective. The paper also discussed several industries that provide natural experiments to measure the effect of compatibility standards on international trade. The next step is to begin collecting the necessary data.

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