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Choosing Standards

Otto Toivanen
HECER, University of Helsinki and ETLA

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HECER – Helsinki Center of Economic Research, P.O. Box 17 (Arkadiankatu 7), FI-00014 University of Helsinki, FINLAND, Tel +358-9-191-28780, Fax +358-9-191-28781,
E-mail info-hecer@helsinki.fi, Internet www.hecer.fi

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Abstract

In many industries, including telecommunications, a government decision on a standard is needed for the society to reap the benefits from the diffusion of new goods. Delays induced by regulatory bodies either in standard choice or its implementation can be extremely costly. I study governments' choice of first generation (1G) mobile telephony standards using an international dataset. Larger and richer countries are faster to adopt. Countries take indirect network effects into account in their timing decisions. Political institutions systematically affect the speed of adoption: Democracies give telecom human capital and indirect network effects more weight.

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Otto Toivanen

HECER
P.O. Box 17 (Arkadiankatu 7)
FI-00014 University of Helsinki
FINLAND

e-mail: otto.toivanen@helsinki.fi

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1. Introduction

Standard choices are of great - and arguably of growing - importance in modern economies,[1] yet to the best of my knowledge, almost no quantitative empirical research exists on how and when standards are chosen.[2] In many industries, telecommunications being the paramount example, standards are a prerequisite for the diffusion of a new technology and therefore also for the ensuing welfare gains. As argued forcefully by Hausman (1997, 2002), regulatory delays can be extremely costly in such situations. Whether the delay is due to regulatory wrangling on how to implement a standard once a it has been nominally chosen (as was the case in the U.S. regarding first generation mobile phones), or due to regulatory indecision as to what standard to choose (as was the case in France, the UK and Germany, for example, regarding the same decision),[3] is of second order importance from a welfare point of view. The delay between the first (or optimal) possible date of adoption, and the actual implementation is what counts. Hausman estimates that delays in the introduction of the 1st generation mobile phone standard lead to an annual welfare loss in the order of tens of billions of dollars in the U.S..[4] It is therefore important to understand what determines the timing of actual standard choice, and that is the objective of this paper. Using an international dataset, I estimate the determinants of timing for (more precisely, hazard rate of) standard adoption in 1st generation (1G)

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[1] For theoretical work, see Farrell and Saloner (1988), and Farrell (1996), who also discusses several examples of delay. For surveys that discuss standard choice, see e.g. Katz and Shapiro (1994), Shapiro and Varian (1999), and Gandal, (2002).

[2] Indeed, a recent survey on the economics of technology policy (Mowery, 1997) does not mention standardization issues at all. Simcoe (2003) is the only paper known to me that empirically analyzes standard making decisions. His data comes from the Internet Engineering Task Force. For qualitative analyses on mobile phone standards, see e.g. Funk and Methe (2001), Kano (2000), and on High-Definition TV, Farrell and Shapiro (1992).

[3] There is a third possible delay, that of the firm(s) being slow to build the network after been given permission to go ahead. Given that in first generation mobile telephony firms were either government owned monopolies or heavily regulated, this delay for all practical purposes is part of the first one.

mobile phones – the very standard whose delay lead to huge estimated welfare losses in the U.S..

Costs and benefits of adoption should naturally affect the timing of standard choice. I link country demographics, data on worldwide mobile phone diffusion, and data on telecommunications patenting onto data on standard choice to capture benefits and costs. To study whether different political governance structures affect the timing of standard choice after controlling for costs and benefits, I match these data to widely used measures of political institutions (see e.g. Easterly and Levine, 1997, La Porta et al., 1997, 1999, Djankov et al., 2002). These have been shown to systematically affect other regulatory decisions, such as ease of entry; one would therefore expect them to be informative as to how conducive a given country's political institutions are to fast/slow decision-making in standard choice.

I find that the political institutions of a country do indeed affect the timing of 1G standard adoption even after controlling for benefits - geography, population, and gdp per capita, and costs - indirect network effects, and the country's technological level (human capital) in telecommunications. The hazard rate of standard adoption increases more in response to having at least some telecoms human capital, the better the political rights. Countries of French legal origin, which according to La Porta et al. (1999) have inferior government performance, decrease their hazard rate in response to an increase in telecoms human capital. I interpret this to reflect the effects of lobbying by the domestic telecoms industry for its preferred standard. Such effects have been documented in qualitative research to have resulted in a rather substantial delay in many countries (e.g. France, UK, and Germany). I find that governments do take indirect networks effects into account as predicted, increasing the hazard rate in

[4] Gruber and Verboven's (2001a,b) empirical work establishes another cost: Apparently, diffusion of

response to increases in installed base, and decreasing it in response to increases in future growth of the installed base. These effects are stronger, the better are political rights.

The decision to look at 1G standard timing is based on the following features of that decision: i) it is well-defined, and therefore comparable over time and over countries; ii) during the period I study, effectively all countries had a government owned telecom monopoly and those that didn't, such as the U.S., had heavy government regulation. It is not always clear whether it is a government body (say, the Ministry for Post and Telecommunications) or the telecom monopoly that chooses the standard, but for my purposes this distinction is irrelevant: both can be viewed as arms of the government; iii) unlike the 2nd and 3rd generation mobile phone standards, 1G was widely and rightly perceived to be a national decision, and qualitative evidence exists that suggests that the decision was politicized in many countries. Issues like international compatibility or roaming were generally not considered important.[5] This also means that any international network effects that exist are indirect, i.e., choosing a widely spread standard may allow the population access to cheaper phones, and the telecom monopoly access to cheaper network equipment. Therefore one can argue that the welfare optimizing decision would have been to adopt some standard (several of which were technically ready to be implemented by the mid to late 70's) relatively early; and iv) there is variation in actual decisions taken. U.S. and Japan were the first countries to adopt an analog (1G) standard in 1977 (Advanced Mobile Phone System, AMPS, in the US) and 1978 (Nippon Telegraph and Telephone, NTT, in Japan). In the U.S., however, the services did not

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mobile phones was slower initially in countries where a standard was chosen later. Whether this can be attributed to other forms of regulatory inefficiencies is not clear.

[5] A known exception to that are the Nordic countries who did take international roaming within the area into account.

start until 1983 (e.g. Hausman, 1997, pp. 17). Some advanced industrialized countries reached a (different) decision many years later (e.g. France in 1985).[6] Less developed countries introduced standards even later.

There are three major potentially complicating factors in studying this particular decision. First, mobile telephony is a network good (Katz and Shapiro, 1994). Second, technical progress during the observation period lead to the introduction of new technologies after the observation period: in particular digital 2G. Third, governments were potentially playing a game instead of making decisions in isolation (see Gandal and Shy, 2001, for such a theoretical analysis).

As argued above, the network nature of the final good plays only a limited role in the current analysis. As any user can testify, in most instances she does not care (to a first degree) what standard the receiver is using, as long as a connection can be established. The only network effects that might affect the current analysis are that phones using one standard may not operate in areas where the network is built for another standard; however, 1G phones were used nationally, and therefore this problem does not surface as long as the networks are national. Naturally there are exceptions to this rule, the U.S. and Brazil being examples of countries where networks were regional or local rather than national. Indirect network effects from economies of scale in production, and increased competition on the supply side are taken into account in the analysis.

I deal with technical progress in two ways. First, I allow the baseline hazard to change over time, thereby allowing technical change to affect the hazard rate (conditional probability) of adoption. Second, I end the observation period in 1987 to

[6] In the empirical analysis, I define the year of actual adoption as the year prior to the year in which EMC registers the first users. The idea is that an irreversible decision is taken only at the point of building the network. Thus in the data, the U.S. adoption date is coded as 1982, and that of France as 1984.

avoid having 1G decisions being affected by the oncoming 2G. The first 2G networks were established in 1991, and the European Union governments coordinated their 2G decision on the GSM standard in the late 80's.

As is clear from above, I model the standard choice as a government decision. Unlike 2G and 3G, 1G decisions were (largely) uncoordinated between governments. The main reason for that most likely is that the "mobile" phones of the late 70's and early 80's were very unlike the ones in use today. They were heavy, had limited battery life, lower quality of voice, and were mostly used from some base such as a car. There was little expectation that they would change in nature to the extent that they have over the last 20 years.[7] I take the view that an individual government was not affected by the decision of any other particular government, but only by the aggregate choice(s) of all the other governments, i.e., that the interdependence between governments is more alike monopolistic than oligopolistic competition.

Throughout the world, governments actively affect the way markets operate. A larger literature exists (see e.g. Joskow and Rose, 1989, Laffont and Tirole, 1993) that studies how to optimally regulate markets or individual firms. Though more infrequent and the object of less research, governments' effect on markets through institutional choices is probably as pronounced. All these choices reflect the objectives of a government. The ”new” political economy literature (Drazen, 1999, Grossman and Helpman, 2001, and Persson and Tabellini, 2000, 2002) takes the view that governments' decisions, too, are affected by the institutional setting in which they operate. In particular, the institutional setting determines by how much, and in what direction, government decisions may deviate from welfare optimizing ones.

[7] For example, Kano (2000) cites Financial Times, July 26, 1999, reporting that the ex-CEO of Ericsson (one of the leading firms in 1G and 2G mobile phone technologies), Kurt Hällström, stated: "When I joined Ericsson in 1984, Radio Communications was something odd happening on the outskirts of Stockholm".

Earlier papers that combine industrial organization questions with a political economy approach and econometric analysis include several that study telecommunications:[8] Donald and Sappington (1995) analyze U.S. deregulation, Duso (2001) the effects of political regime within U.S. states on the incidence and effectiveness of regulation, Duso and Röller (2001) deregulation in OECD countries using political economy variables, and Henisz and Zelner (2001) the effects of political institutions on telecommunications infrastructure investment using data from 147 countries. Gruber and Verboven (2001a,b) and Liikanen, Stoneman and Toivanen (2004) study the diffusion of mobile phones without controlling for political institutions. To the best of my knowledge, no study addresses standard choice and timing.

In the next section, I discuss the technologies, i.e., the choices that governments faced, and characterize the environment in which these decisions were reached. The data is presented and discussed in section three. Section four contains the econometric analysis and section five the conclusions.

2. Mobile Telephony

Based on earlier radiotelephony technologies, analog standards for what is now called mobile telephony began to emerge in the 1970's.[9] The standard describes how the handset communicates with the network, and is a crucial ingredient to how the network operates. Handsets designed for a particular standard do not operate within a network designed for another standard. The first countries to adopt such a standard were U.S. in 1977 and Japan in 1978. U.S. adopted the Advanced Mobile Phone System (AMPS) standard, but diffusion of mobile phones was delayed until 1983

[8] Several analyses exist that do not use econometrics: see e.g. Spiller and Cardilli (1997).

because of regulatory delays. Thus Japan was the first country to introduce the new good. The adopted standard was developed in Japan, and the Japanese state telecoms monopoly (NTT) retained rights over the standard. The Scandinavian countries followed in the early 1980's with a standard of their own (NMT). The decision was one clearly made by governments. International organizations such as International Telegraph and Telephone Consultative Committee and International Telecommunications Union do not have decision making powers. For example, (see Funk and Methe, 2001), accounts exist that attribute France's and Germany's relatively late adoption of any standard to politics (and lobbying). They were reluctant to adopt the Scandinavian NMT standard as they wanted a standard they, and their domestic firms, could dominate. Initial efforts to adopt a common standard failed, and France ended adopting its own standard (RC2000) in 1985. Germany adopted its own standard (C-450), too, in 1985.

All in all, eight different analog standards have been adopted by 1998 by at least one country. Other standards may have been considered, but were never adopted. Of these eight standards, the Scandinavian NMT, AMPS and TACS dominate with adoption shares of 38, 38 and 13 per cent respectively. As in my data only a few countries adopt any other standard than NMT, I concentrate on the timing aspect of this decision.

No quantitative analysis of these decisions exists, and the qualitative analyses all underline the political nature of the process. It is commonly argued that lobbying for one or the other standard was sometimes pronounced. For example, Funk and Methe (2001) mention that the "initial sponsors" for NMT were the four Scandinavian PTTs; that of RC2000 France Telecom only, and so on. Nobody however mentions

[9] Hausman (2002) offers a survey of mobile telephony.

lobbying by consumer organizations. Discussions with technical experts suggest that although there were technical differences between standards, these were not drastic from consumers' point of view. Also, it is probably fair to state that at the time when decisions on standards (both analog and digital) were made, consumers were more or less ignorant (indifferent) about the matter.

3. The Data

The key standards and other mobile telephony data come from EMC.[10] The country level economic and demographic variables come entirely from the World Bank's World Development Indicators. Main (fixed) telephone line data is from the International Telecommunications Union (ITU) publications. The legal origin – variables and latitude come from La Porta et al. (1997), the political rights and civil rights data from Freedom House (2000), Henisz (2001) and Jaggers and Marshall (2000).[11] All other variables are standard; the Freedom House variables are on a seven point Likert scale (1 = full rights, 7 = smallest possible rights); the political constraints variable of Henisz is on a scale of 0-1 (1 = highest political constraints),

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[10] See http://www.emc-database.com/.

[11] Political rights and civil rights are defined by Freedom House as follows (http://www.freedomhouse.org/research/freeworld/2003/methodology.htm, accessed April 30th, 2004): To answer the political rights questions, Freedom House considers to what extent the system offers voters the opportunity to choose freely from among candidates and to what extent the candidates are chosen independently of the state. However, formal electoral procedures are not the only factors that determine the real distribution of power. In many countries, the military retains a significant political role, while in others, the king maintains considerable power over the elected politicians.

In answering the civil liberties questions, Freedom House does not equate constitutional guarantees of human rights with the on-the-ground fulfillment of these rights. For states and territories with small populations, particularly tiny island nations, the absence of trade unions and other forms of association is not necessarily viewed as a negative situation unless the government or other centers of domination are deliberately blocking their establishment or operation.

For more information, see the above mentioned www-site.

and the polity variable of Jaggers and Marshall is on a scale of -10 to 10 (-10 = worst political rights, 10 = best political rights).[12]

The US patent data is from NBER (Hall, Jaffe, Trajtenberg, 2001). I first computed the number of US patents per country in three patent categories: 178 (Telegraphy), 379 (Telephonic Communications), and 455 (Telecommunications), assuming that all patents are held for their maximum number of years (20). I do not discount patents by their age, the idea being that the patent stock is a measure of both the amount of accumulated human capital in telecoms, and a measure of intellectual property rights in possession. In addition to the patent count, I calculated averages for two measures of the quality of the patent, both devised by Trajtenberg, Jaffe and Henderson (1997): originality, and generality. Both are Herfindahl-type measures that use citations. Originality uses citations made by a patent. Originality is increasing in the number of patent fields to which citations are made. Generality uses citations received by a patent, and is increasing in the number of fields from which a patents receives citations. I use the values reported in the NBER data file, and calculate averages for yearly country-level stocks of patents. I use two measures of human capital/intellectual property rights in the analysis. First, a simple dummy for a country having telecom patents; second, the direct (and, alternatively, quality weighted) number of patents. The quality weighted number of patents is defined as the number of telecom patents times average originality times average generality.

Political and civil rights have been used in many macroeconomic studies (e.g. Easterly and Levine, 1997, Rodrik, 2000). These are known to be highly correlated (correlation in the current sample 0.90, significant at 1% level), and I follow previous studies in combining the two measures. Countries with highest rated political rights

[12] In the estimation analysis, I transform these to be decreasing in political rights in order to produce

“come closest to the ideals suggested by the checklist questions, beginning with free and fair elections. Those who are elected rule, there are competitive parties or other political groupings, and the opposition plays an important role and has actual power. Minority groups have reasonable self-government or can participate in the government through informal consensus” (http://www.freedomhouse.org/research/freeworld/2003/methodology.htm, accessed May 20th, 2004). Countries with highest civil rights “come closest to the ideals expressed in the civil liberties checklist, including freedom of expression, assembly, association, education, and religion. They are distinguished by an established and generally equitable system of rule of law. Countries and territories with this rating enjoy free economic activity and tend to strive for equality of opportunity (same source as in the previous quotation). As alternative measures, I use Henisz’ (2001) measure on constraints on executive power (see e.g. Djankov et al., 2002), and the ‘polity’ measure of Jaggers and Marshall (2000). As shown by La Porta et al. (1999), legal origins of a country are a key determinant of the quality of government. They show that French legal origin countries have inferior government performance compared to common law (English origin, but also German and Scandinavian origin) countries.

The socio-economic data is from World Development Indicators, and includes standard measures such as population, surface area, measures of age-structure, gdp per capita, and others. I use ITU data on fixed line telephones.

The needed telecoms data is available for 207 countries but, as is to be expected, I do not have all the other data for all the countries, or else (as in the case of former Soviet Union republics and Eastern Europe) the political system during my

comparably signed coefficients with the base regression that uses the Freedom House measures.

observation period meant that no decision was even contemplated. Concentrating on the analog standard prior to the introduction of first digital (2G) standards in early 1991 and on those countries on which I have the needed data from the above sources and which make a clear country-level decision leaves 85 countries, and a total of 842 country-year observations.

These are naturally very heterogenous with respect to demographics and economic indicators, as the sample descriptive statistics in Table 1 reveal. Notice especially that only slightly more than twenty per cent of my observations are ones where the country in question had at least one U.S. telecom patent. The relatively high mean is the results of a few countries (most notably, the U.S. and the UK) having large patent stocks. As will become clear below, this has an effect on estimation results. Table 2 reports the descriptive statistics of my measures of political institutions. On a scale from 1 (best) to 7 (worst), the average political and civil rights are 4. The other measures of political rights are highly correlated with the Freedom House measures.[13] There is wide variation especially across countries, but in some cases, also within countries. 60% of observations are from countries with French legal origin, and only 1.2% from countries with German legal origin.

[TABLES 1 AND 2 HERE]

Of the 85 countries, 23 adopt an analog standard by end of my observation period.[14] Table 3 gives the descriptive statistics both for my sample, and the whole world during the observation period. Only nine countries that adopted an analog standard within the observation period are excluded; the number of countries that did

[13] Correlation between the aggregated political rights and civil rights measure and the Henisz measure of political constraints is -0.81; that between the first and the Jaggers and Marshall measure -0.51. Both the Henisz and Jaggers and Marshall measures are increasing in political rights, the Freedom House measure is decreasing in political rights.

[14] The countries and their adoption dates, both within and after the observation period of this study, are listed in the Appendix.

not adopt but are excluded is naturally much higher. Of the 23 adopting countries in the sample, 14 adopted the Nordic NMT standard, 4 the AMPS standard, and 5 each a unique standard (e.g. France RC2000, Germany C-450 and so on). In addition to NMT, Sweden adopted (simultaneously) a standard of its own (Comvik).[15] Of the 85 countries, 66 adopted a 1G standard by end of 1998, and several of those that did not adopt a 1G standard adopted a 2G standard by 1998 (e.g. Greece). Although it is clear that the non-adopters are poor countries, being poor clearly does not directly imply that no 1G standard was chosen, as many of those countries which (eventually) adopt are poor (e.g. Papua New Guinea adopted AMPS in 1994). Also, some developing countries were early adopters (e.g. Tunisia and Malaysia both adopted NMT in 1984).

In the empirical analysis, I define the year of actual adoption as the year prior to the year in which EMC registers the first users. The idea is that an irreversible decision is taken only at the point of building the network. Thus in the data, the U.S. adoption date is coded as 1982, and that of France as 1984. I check the robustness of my results to this definition by estimating a model where I use a two-year lag.

As can be seen from Table 3, the average adoption times are very similar for the three possibilities (NMT, AMPS, other). Note that the number of users of mobile phones of a given standard, and the number of potential users are both calculated using world, not sample, figures.

[TABLES 3 AND 4 HERE]

Table 4 reports the average adoption year conditional on having either below or above median political and civil rights, and on legal origin, with some sample descriptive statistics.[16] Political and civil rights seem to have a large effect on standard adoption: of those countries with median or below median rights, only 10%

[15] Comvik never took off: in my sources (ITU, EMC), it is always reported to have zero adopters.

adopt by 1987. The comparable figure for above median countries is 47%. The difference in adoption times, conditional on adopting, is only one year (1983 vs. 1984). Countries with German legal origin are on average fastest to adoption (conditional on adoption), closely followed by countries with Scandinavian legal origin. All countries with Scandinavian and German legal origin also adopt a standard; the proportion of English (French) legal origin countries adopting are 25.7% (16.7%). There seems to be a clear pattern in that countries with Scandinavian and German legal origin adopt, and adopt early, relative to countries with other legal origins.

As is clear from this description, the data would not allow one to estimate a model where a distinction was made between different standards. I therefore concentrate on estimating the decision to adopt a standard.[17]

4. Econometric Model and Results

A. The Model

I aim to explain the determinants of the timing of 1G standard adoption. A natural way to model this econometrically is to use a hazard model. That is, I study what determines the probability of adopting a 1G standard in country i in year t, given that no standard has been adopted earlier in that country. I estimate discrete time hazard models, and allow for a time-varying baseline hazard.[18] In these models, the period specific hazard rate takes the form

(1) $$h_j(X_{ij}) = 1 - \exp[-\exp(X_{it}\beta + \gamma_j)].$$

[16] There are no countries with socialist legal origin in our data set.
[17] One could build a structural dynamic discrete choice model; indeed, an earlier version of this paper estimated such a model. Alternatively, one could estimate reduced form competing risk models. Identification of standard specific effects in either case would hinge on only a few (or just one) actual choice. This was deemed unsatisfactory, and I therefore concentrate on the adoption decision of a standard (versus not adopting a standard yet).

Where $h_j(X_{ij})$ is the discrete time hazard in the jth time interval, X_{it} is a vector of possibly time-varying covariates, β is a vector of parameters that are to be estimated, and $\gamma_j = \log \int_{a_{j-1}}^{a_j} \lambda_0(\tau)d\tau$ ($\lambda_0(\tau)$ = baseline hazard function) captures the period specific effect on the hazard parametrically (and would in principle allow a non-parametric baseline hazard; see fn. 21). The model thus allows to control for unobservable cost and other changes over time. The associated log-likelihood function takes the form

(2) $$\log L = \sum_{i=1}^{n} \sum_{j=1}^{t_i} \{ y_{ij} \log h_j(X_{ij}) + (1 - y_{ij}) \log[1 - h_j(X_{ij})] \}$$

where y_{ij} is an indicator taking value one if country i adopted a standard in period j, and is zero otherwise. One can also add unobserved heterogeneity into the model.

I include five types of explanatory variables into the model: first, country (and year) level demographics such as population, geographic area, and gdp per capita that mainly control for benefits of mobile telephony. A country's geography and population may have affected the timing of standard choice: indeed, in the Nordic countries, the decision to start to develop the NMT standard was at least partly based on the objective of providing telephone services to the remote areas of these sparsely populated countries; something which was deemed uneconomical using fixed lines. Gdp per capita is a self-explanatory independent variable. I also include the number of fixed line phones per 1000 inhabitants. I expect geography, population and gdp per capita to have positive coefficients. The sign of the coefficient of fixed line phones is hard to predict, as on the one hand, fixed line phones are a substitute to mobile

[18] For details on the econometric model, see e.g. Jenkins (2004), especially chapters 6 and 9.

phones, and on the other, the more there are fixed line phones, the larger are the direct (within-country) network effects.[19]

Second, I include measures of the telecom human capital of the country, using the above explained U.S.-patent based variables. These will capture both the costs of building the network and providing the services, and the potential of a country's firms to capture a share of the global surplus. The idea behind the latter is that firms in more technologically advanced countries will be able to go down the learning curve faster if their home country adopts a standard early, and to then benefit from this when competing in other markets (=countries) against firms from other countries. To allow for a nonlinear effect, I include both the direct (potentially quality-weighted) patent measure, and an indicator taking value one if a country has at least one telecoms patent. If lobbying by local industry resulted in a delay of standard adoption, one would expect a negatively signed coefficient for the telecom patent count.

Third, I include measures that aim to capture both the existing and future level of the indirect network effects between countries. Indirect network effects are related to costs of building the network, and providing the handsets and services. I include both the number of existing users worldwide, and the population in the countries that by end of the previous year had adopted a standard. The former measures the existing size of the market, whereas the latter is a measure of the potential size of the market. The former should obtain a positive coefficient, as it captures realized cost reductions. The latter may obtain a negative coefficient, as it indicates a higher option value for waiting. The idea is that a higher potential stock means that in the future, indirect

[19]Gruber and Verboven (2001a,b) include the fixed line stock as an explanatory variable into their mobile phone diffusion equation. Liikanen, Stoneman and Toivanen (2004) study how fixed line phones' and 1G (2G) penetration rate affects the diffucsion of 2G (1G) phones. All three studies find that fixed line phones are a substitute for mobile phones.

network effect will be larger, and therefore, the cost of adopting lower. In measuring these variables, I make no distinction between standards.

My fourth category of explanatory variables is the political economy ones. These include latitude as a control; I expect it to get a positive sign as the early adopters were all industrial countries. Further, I include the Freedom House measures of combined political and civil rights, and the legal origin variables. The expectation is that countries with better political rights have a higher hazard rate: given that the Freedom House measures are decreasing in political rights, I thus expect a negative coefficient. As it is known that Nordic countries adopted 1G standards early, I expect the Scandinavian legal origin dummy to carry a positive coefficient, but would hesitate to give it any political interpretation. The French legal origin dummy however may obtain a negative coefficient, given that earlier research has documented that French legal origin is associated with inferior government performance.

The fifth category is interactions between the political economy and network and technical variables. Democracies may put more weight on costs of adoption. If domestic human capital decreases costs, one would expect a negative coefficient for the interaction between political and civil rights, and the number of telecom patents as better democracies give more weight to lower costs of adoption. On the other hand, if the number of domestically owned U.S. telecom patents measures the incentive of the domestic telecom industry to lobby for a particular standard (as seems to have been the case in France and Germany, for example), one might expect a positive coefficient if lobbying leads to a delay in decision making. One would expect that more democratic governments are less likely to be affected by such lobbying, and therefore should not be delayed in their decision making to the same extent as less democratic countries. I would expect that countries with better political rights take both realized and potential indirect network effects better into account: i.e., that countries with better political rights increase their adoption probability more when there is an increase in the world-wide number of current users, and delay more when there is an increase in the world-wide number of potential future users.

B. Estimation Results

Estimation results are presented in Table 5. Column (1) displays the main equation, estimated allowing for a time-dependent (Weibull) hazard. Looking first at socio-economic controls for benefits of mobile telephony, we find that gdp per capita has a positive, but decreasing effect on the hazard of adopting a 1G standard; population has a positive effect, too. Fixed line penetration has a positive effect on the hazard. This means that the direct network effects generated by a larger number of fixed line phones outweigh any substitution effects (which have been reported by Gruber and Verboven, 2001a,b, and Liikanen, Stoneman and Toivanen, 2004) between mobile and fixed phones regarding the timing of standard choice.

[TABLE 5 HERE]

On the cost side, the measures of indirect network effects seem to work as expected: the world stock of actual adopters increases the hazard, while the number of potential users decreases it. The former captures indirect network effects, i.e., the costs of building a network, and of acquiring handsets. The larger the installed base, the further down the learning curve the industry has reached, resulting in lower costs. The logic behind the latter result is that a larger potential market (conditional on the size of the actual market) means that indirect network effects will likely grow fast. This is turn means that a delay, though costly in terms of foregone consumer surplus, also means potential cost savings in implementing the standard.

The indicator variable for a country having at least one telecom patent has a large positive coefficient. This means that countries with at least some domestic human capital in telecoms (R&D) have a higher hazard rate of adoption than countries without any, ceteris paribus. Contrasting this result, the coefficient on the number of patents is negative and significant. This means that conditional on having at least some patents, the higher the level of human capital in telecom R&D, the less likely a country is to adopt. This could be an indication of the kind of explanations put forward in qualitative research. Countries with relatively high amounts of telecoms human capital, such as France, the UK, and Germany, were late to adopt as they tried (unsuccessfully, in these cases) to convince other countries to adopt their standard. Importantly, this result (see columns (5) and (6)) is not robust to excluding the U.S. and the UK, countries that are clear outliers regarding the patent stock variable. I therefore view this evidence as weak. For the mean of the patent variable, when excluding those two countries, the aggregate effect of these two human capital variables is large and positive.

Turning to the political economy variables, we find that only the Scandinavian legal origin dummy carries a significant (positive) coefficient. This was expected as all the Scandinavian countries adopted a 1G standard early on. I would however hesitate to give this coefficient a political interpretation, given these countries' demonstrated high preference for mobile communications from late 60's onwards. The direct effect of political and civil rights is insignificant but positive, indicating that worse political rights would lead to a higher hazard rate. However, one cannot interpret the direct effect alone as the interaction effects have to be taken into account. At the means of the other variables, the effect of increasing political and civil rights is to decrease the hazard rate. This is however largely driven by the positive and significant coefficient of the interaction with the number of patents. Keeping all other interaction variables at their sample means, a patent count of six or more yields a positive effect on the hazard (meaning that worse political rights lead to a higher hazard rate of adoption). However, only 10% of the sample's country-year observations have six or more US telecom patents, and this effect is again not robust to excluding the US and UK (see column (6)).[20] The sample mean of the patent count for other countries than the U.S. and the UK is two. Ignoring the insignificant coefficients (the linear political and civil rights coefficient, and the interaction with the world potential stock of adopters) yields a patent threshold of 44. Thus, even with the results in column (1), the effect of increased political and civil rights is to increase the hazard rate of standard adoption for the majority of observations and countries. To quantify the effects of political institutions I calculated the effect of changing the political and civil rights from their mean values to their minimum (best) values while keeping other variables at their sample means, and the patent count at five (the 90th percentile). The effect of this experiment is to increase the hazard rate by 5%.

The interactions of political and civil rights with other variables produce interesting results by themselves. The interactions between the French legal origin dummy and the patent count variable carries a negative and significant coefficient, reinforcing the interpretation given above for the patent count coefficient. La Porta et al. (1999) have shown that French legal origin correlates strongly (and negatively) with political rights: the effect in our data is strong enough to overcome that correlation. The interaction between political and civil rights, and the patent dummy obtains a negative and significant coefficient. This means that the higher the political rights (the lower the Freedom House measure), the larger is the positive effect of

[20] Countries with at least 6 U.S. telecom patents are Argentina, Australia, Austria, Belgium (max. 6

having at least some telecom human capital on the hazard rate of adoption. As with the direct measures, the interaction with the patent count carries a positive coefficient. Its interpretation is that the worse are political and civil rights, the bigger the decrease in hazard rate induced by having telecom human capital. This is consistent with the French legal dummy-patent count interaction's coefficient, and the interpretation that in countries with less well performing governments, the stronger the domestic telecom lobby, the lower the adoption hazard. However, as results reported in columns (5) and (6) demonstrate, this result is strongly dependent on having both the UK and the U.S. in the sample and this result is therefore as weak as that on the direct effect of the patent stock. Finally, the interactions between political and civil rights and the indirect network variables (only the one with the actual stock of users is significant – at 7% level) suggest that countries with better political rights take indirect network effects more into account..

Finally, I find positive duration dependence, i.e., the hazard rate of adoption increases over time, even after conditioning on the covariates. I also attempted to estimate the model using a fully flexible baseline hazard. This turned out not to be possible, as a necessary condition for this is that for each year, there is at least one realization of the hazard (i.e., a country adopts a standard). This is not the case with the current data.[21]

In column (2), the patent count is replaced by a quality weighted patent count. The results are well in line with those in column (1). In columns (3) and (4) the main measure of political rights is replaced by Henisz' and Jaggers' and Marshall's measures. I rescaled their measures to be decreasing in political rights so as to be in

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patents), Canada, France, Italy, Japan, Netherlands, Norway (6), Sweden, UK and U.S., representing 15% of all countries (13 out of 85) in the sample.

line with the Freedom House measures.[22] While some coefficients do not retain their significance (foremost the stock and potential stock of adopters), the political economy results are robust to this change in measurement. The exception is the interaction with world stock of adopters, the coefficient of which is not significant in columns (3) and (4). In column (5) the U.S. is excluded, and in column (6) both the U.S. and the UK. The reason for this robustness test is that these countries, and the U.S. in particular, are clear outliers regarding the patent count(s). One would expect that excluding them would weaken the results on the patent count variable and its interactions. That indeed happens: the direct patent count variable coefficient isn't significant anymore, and the coefficient of the interaction between political and civil rights and the patent count remains significant (and does not drop in absolute value) only if at least the UK is included in the sample. At the means of other variables, the effect of an increase in political and civil rights (a decrease in the value of that variable) is to increase the hazard rate of adoption. Otherwise, the results are very close to those in column (1). As a final robustness check, I experimented with changing the assumption of a one-year lag between the de facto decision on a standard and its implementation (measured as the first year with mobile phones in use) to a two-year lag. The results remain qualitatively identical to those in column (1), with all the same coefficients being statistically significant.

As an additional robustness check, I also estimated models that control for unobserved heterogeneity using random effects. These essentially reproduced the reported results, and the Null of no unobserved heterogeneity could never be rejected.

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[21] To implement the non-parametric baseline hazard would have necessitated the pooling of three consecutive periods' indicators, meaning that within each such (somewhat arbitrary) three–year interval, the hazard would have been assumed constant.

[22] This was done by multiplying Henisz' measure by -10, and by multiplying Jaggers' and Marshall's measure by -1. There is a slight reduction in sample size as neither measure is available for all sample

Summing up, the robust results of the above analysis are that i) larger and richer countries have a higher hazard rate of adopting a standard; ii) existence of telecom human capital increases the hazard; iii) increases in the world stock of users decreases, increases in the world stock of potential users increases the hazard; iv) democracies put more weight on telecom human capital and world stock of adopters, and v) French legal origin countries put less weight on telecom human capital than countries of other legal origins. Other robust findings are that the hazard is increasing over time, most likely reflecting decreased (quality-adjusted) costs of building a network, and that Scandinavian legal origin countries have a higher hazard rate of adoption, most likely reflecting more their preferences than differences in governmental decision making processes.

5. Conclusions

The objective of this paper was to study standard decisions empirically: to the best of my knowledge, despite the acknowledged importance of standard decisions in industries with network effects, actual standard decisions have not been studied quantitatively using international country level data (but see Simcoe 2003 for an empirical study of Internet Engineering Task Force). I chose to study 1G standard decisions as this has been highlighted (Hausman, 1997, 2002) as an example where regulatory indecision lead to large welfare losses, and because it displays several attractive features: a well defined and internationally comparable decision, clear decision making authority (governments), little or no (achieved) coordination between decision makers, and large variation in outcomes.

countries. I have checked the results on the reduced samples using the Freedom House measures of political and civil rights, and they are in line with those reported in column (1).

Richer and more populous countries adopt earlier, as was expected. The results show that countries with some telecom human capital adopt a standard earlier. Countries did take indirect network effects into account: the larger the potential stock of adopters, the lower the hazard. This indicates that countries chose to trade off (current) consumer surplus with future lower prices induced by indirect network effects. Also, the larger the current world stock of adopters, the higher the hazard. A higher stock measures the degree to which the industry has moved down the learning curve, and thus lowered the costs of both building and operating a network, and producing handsets. Thus it seems countries did react to costs of building a network. It turned out that political variables do exert a systematic, statistically robust influence on standard adoption: countries with better political rights increased their hazard more in response to there being at least some telecom human capital in the country; and countries with better political rights put more weight on indirect network effects. Scandinavian legal origin countries had a higher hazard rate than English legal origin countries, although this probably cannot be attributed to politics but to a government preference for mobile telephony; and countries with French legal origin decreased their hazard rate more in response to an increase in the amount of domestic human capital in telecoms. The latter result was interpreted as less successful lobbying by domestic industry in countries with better political rights. The results in sum suggest that more democratic governments reacted more forcefully to current and future costs and benefits.

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Table 1
Sample Descriptive Statistics

Variable	Mean (s.d.)
Population (Millions)	28.500 (85.200)
Proportion of 15-65 year olds	0.424 (1.550)
GDP/Capita (1000 USD/year PPP)	3271.502 (3188.014)
Surface Area	91.620 (179.856)
Main Telephone Lines/ 1000	72.547 (120.545)
World Stock of Adopters	421682 (799483)
Latitude	.233 (.167)
World Stock of Potential Adopters	3.79E8 (5.82E8)
Telpat. Indicator variable taking value one for a country having US telecom patents, zero otherwise.	0.218 (0.413)
Number of US telecom patents registered in country i in year t.	66.646 (588.845)
Quality weighted number of US telecom patents Defined as # pat x avg. originality x avg. generality x 100000	77.400 (780.066)

NOTES: there are 85 countries and 842 country-year observations in the data. Data from World Bank's World Development Indicators (Population, GDP/Capita, Proportion of 15-65 year olds, surface area), ITU publications (Main telephone lines), EMC (world stock and potential stock of adopters) and NBER (telpat, wpat).

Table 2
Institutional Environment of Government

Variable	Mean (s.d.).
Political Rights	3.988 (2.123)
Civil Rights	4.017 (1.854)
Political and Civil Rights	8.006 (3.874)
Political Constraints	0.162 (0.213)
Polity	-2.539 (15.585)
English legal origin	0.342 (0.475)
French legal origin	0.601 (0.490)
German legal origin	0.012 (0.107)
Scand. legal origin	0.033 (0.180)

NOTES: Political Rights and Civil Rights data from Freedom House (2000); Legal origin data from La Porta et al. (1997); Political constraints from Henisz (2001); Polity from Jaggers and Marshall (2000).

Table 3
Descriptive Statistics of Standard Adoption and Within Standard Diffusion

Standard	NMT	AMPS	Other
Number of countries adopting by end of 1987 in sample (world)	14 (22)	3 (6)	6 (9)
Average year of adoption in sample (world) during sample period	1983.643 (1983.647)	1985.333 (1983.833)	1983 (1983.444)
First/last adoption within sample (world) during sample period	1981/1986 (1981/1986)	1984/1986 (1983/1986)	1978/1985 (1978/1985)
Stock of adopters in world (s.d.). Defined as worldwide number of mobile phone connections (millions) using standard h in period t-1 .	4.738 (15.613)	19.369 (63.958)	0.160 (0.396)
# Potential adopters in world (s.d.). Defined as population (millions) in countries that have adopted standard h by t-1.	49.700 (99.159)	110.836 (133.030)	241.984 (438.032)

NOTES: Adoption year is defined as the year with the first recorded mobile phone users in country i-1. The difference between the sample and year average adoption times, and the first adoption year for AMPS are explained by Brunei which is excluded from the sample, and adopted AMPS in 1979.

Table 4
Standard Adoption and Political and Civil Rights, and Legal Origin
1977-1987

	Political and Civil Rights in 1977		Legal Origin			
Variable	Above Median	Median or below	English	French	German	Scand.
# countries	38	48	29	50	2	5
Prop. of obs. (%)	-	-	34.2	60.1	1.1	3.3
Avg. year of adoption conditional on adopting by 1987	1983.5	1984.8	1984.6	1984.9	1981.0	1981.8
# Countries adopting by 1987 (Probability of adopting by 1987)	19 (.47)	4 (.10)	8 (.29)	8 (.16)	2 (1.00)	5 (1.00)

Table 5
Determinants of the Timing of Standard Adoption

Variable	(1) Baseline Specification	(2) Using Quality Weighted Patents	(3) Using Political Constraints	(4) Using Polity	(5) Excluding USA	(6) Excluding USA and UK	(7) Two Year Lag
Geographic Area	-.820	-.925	-.348	-.4005814	-.964	-5.760**	-.820
	(1.375)	(1.380)	(1.243)	(1.432)	(1.463)	(2.451)	(1.375)
Population	00007**	.00007**	.00004**	.00009***	.00006	.00009**	.00007**
	(.00003)	(.00003)	(.00001)	(.00003)	(.00004)	(.00004)	(.00003)
Population Squared	-2.15e-07	-2.19e-07	-6.34e-08	-3.31e-07*	-1.31e-07	-3.13e-07	-2.15e-07
	(1.97e-07)	(2.06e-07)	(5.49e-08)	(1.97e-07)	(2.20e-07)	(2.24e-07)	(1.97e-07)
Proportion of 15-65 Year Olds	.0002	.0002	.0001	.0003	.0002	-.0008	.0002
	(.0004)	(.0005)	(.0004)	(.0003)	(.0004)	(.002)	(.0004)
Gdpcap	.928***	.863***	.831**	.972**	.878**	1.219***	.928***
	(.367)	(.348)	(.418)	(.416)	(.367)	(.452)	(.367)
Gdpcap Squared	-.058**	-.057**	-.056**	-.046	-.052**	-.071**	-.058**
	(.026)	(.026)	(.026)	(.034)	(.027)	(.033)	(.026)
World Potential Stock	-.0009*	-.0012*	-.0008	-.0010	-.0011**	-.0011**	-.0009*
	(.0005)	(.0006)	(.0006)	(.0008)	(.0005)	(.0006)	(.0005)
World Stock	.445**	.481**	.024	.229	.582***	.553**	.445**
	(.196)	(.218)	(.210)	(.232)	(.233)	(.247)	(.196)
Fixed Phones	.010*	.011*	.002	.008	.008	.011	.010*
	(.006)	(.006)	(.006)	(.009)	(.006)	(.008)	(.006)
Telecom Patents	-.036***	-0.383***	-.039***	-.060***	-.025	.012	-.036***
	(.013)	(0.132)	(.012)	(.023)	(.019)	(.025)	(.013)
Telecom Patent Indicator	8.205***	8.079***	7.041**	4.400	7.621***	8.797***	8.205***
	(2.864)	(2.878)	(2.902)	(3.251)	(2.867)	(3.298)	(2.864)
Latitude	2.283	1.860	2.447	2.117	2.800	-4.773	2.283
	(2.834)	(2.832)	(2.703)	(3.173)	(2.914)	(4.053)	(2.835)
Political and Civil Rights	.506	.458	.263	.290	.472	.483	.506
	(.325)	(.363)	(.431)	(.432)	(.337)	(.366)	(.325)
French Legal Origin	.331	.114	-.383	.713	.312	-.273	.331
	(.910)	(.882)	(.74)	(.833)	(.915)	(.947)	(.910)
German	2.315	1.943	1.230	3.498*	2.744	1.866	2.315
	(1.646)	(1.741)	(1.256)	(2.053)	(1.850)	(2.017)	(1.646)
Scandinavian	5.111***	5.543***	3.647**	11.208***	5.160***	7.197***	5.111***
	(1.874)	(1.907)	(1.616)	(3.819)	(1.993)	(2.337)	(1.874)
French*Patents	-.014**	-0.168**	-.011*	-.025***	-.011	-.020**	-.014**
	(.007)	(0.875)	(.007)	(.010)	(.008)	(.010)	(.007)
Scand*Patents	-.016	-4.869	.004	-.031	-.015	-.039*	-.016
	(.017)	(6.194)	(.017)	(.025)	(.017)	(.023)	(.017)
Pol&Civ*Patents	.018***	0.192***	.019***	.030***	.014*	.003	.018***
	(.006)	(0.656)	(.006)	(.011)	(.008)	(.010)	(.006)
Pol&Civ*Patent Indicator	-2.577***	-2.317**	-2.638**	-2.156**	-2.410**	-2.395**	-2.577***
	(1.034)	(.956)	(1.144)	(1.113)	(1.038)	(1.071)	(1.034)
Pol&Civ*World Stock	-.055*	-.061*	-.031	-.040	-.067**	-.067**	-.055*
	(.030)	(.033)	(.046)	(.035)	(.032)	(.035)	(.030)
Pol&Civ*Potential Stock	.00005	.00007	-.0004	.00004	.00007	.00007	.00005
	(.00007)	(.00008)	(.0001)	(.00009)	(.00007)	(.00008)	(.00007)
Log(Time)	12.882***	17.053***	12.367***	20.795***	12.871***	15.720***	12.882***
	(3.659)	(4.908)	(3.538)	(7.277)	(3.922)	(4.691)	(3.659)
Constant	-38.053***	-45.036***	-29.039***	-51.905***	-37.347***	-41.852***	-38.053***
	(7.860)	(9.566)	(6.756)	(14.074)	(7.965)	(9.880)	(7.860)
Nobs.	870	870	837	839	863	855	784
LogL.	-41.931	-38.513	-45.383	-34.155	-39.937	-35.142	-41.931
LR	0.000	0.000	0.000	0.000	0.000	0.000	0.000

NOTES: Number presented are coefficient and (standard error). *, **, and *** indicate statistical significance at 10, 5 and 1% level.
LR = p-value of a likelihood ratio test of the joint significance of all explanatory variables.

APPENDIX

In this Appendix, I list the countries in the data set, and present details on which countries adopted or didn't adopt a 1G standard and when they did so.

Table A.1
Standard Choice and Timing for Countries that Adopt within the Observation Period

Country	Year	NMT	AMPS	TACS	C-450	Comvik	NTT	RTMS	RC2000	all standards
Japan	1981	0	0	0	0	0	1	0	0	1
Denmark	1981	1	0	0	0	0	0	0	0	1
Finland	1981	1	0	0	0	0	0	0	0	1
Norway	1981	1	0	0	0	0	0	0	0	1
Sweden	1981	1	0	0	0	1	0	0	0	2
United States	1982	0	1	0	0	0	0	0	0	1
Austria	1984	1	0	0	0	0	0	0	0	1
Canada	1984	0	1	0	0	0	0	0	0	1
France	1984	0	0	0	0	0	0	0	1	1
Italy	1984	0	0	0	0	0	0	1	0	1
Malaysia	1984	1	0	0	0	0	0	0	0	1
Netherlands	1984	1	0	0	0	0	0	0	0	1
Saudi Arabia	1984	1	0	0	0	0	0	0	0	1
Tunisia	1984	1	0	0	0	0	0	0	0	1
United Kingdom	1984	0	0	1	0	0	0	0	0	1
Iceland	1985	1	0	0	0	0	0	0	0	1
South Africa	1985	0	0	0	1	0	0	0	0	1
Thailand	1985	1	0	0	0	0	0	0	0	1
Turkey	1985	1	0	0	0	0	0	0	0	1
Australia	1986	0	1	0	0	0	0	0	0	1
Belgium	1986	1	0	0	0	0	0	0	0	1
Indonesia	1986	1	0	0	0	0	0	0	0	1
New Zealand	1986	0	1	0	0	0	0	0	0	1

NOTES: Countries are listed in order of adoption. The adoption year is the year prior to first registration of users as listed in the EMC database.

Table A.2
Standard Choice and Timing for Countries that Adopt after the Observation Period

Country	Year	NMT	AMPS	TACS	C-450	Comvik	NTT	RTMS	RC2000
Bahrain	1987	0	0	1	0	0	0	0	0
Congo	1987	0	1	0	0	0	0	0	0
Dominican Republic	1987	0	1	0	0	0	0	0	0
Morocco	1987	1	0	0	0	0	0	0	0
Venezuela	1987	0	1	0	0	0	0	0	0
Chile	1988	0	1	0	0	0	0	0	0
Costa Rica	1988	0	1	0	0	0	0	0	0
Cyprus	1988	1	0	0	0	0	0	0	0
Gabon	1988	0	1	0	0	0	0	0	0
Mauritius	1988	0	0	1	0	0	0	0	0
Mexico	1988	0	1	0	0	0	0	0	0
Sri Lanka	1988	0	0	1	0	0	0	0	0
Algeria	1989	1	0	0	0	0	0	0	0
Guatemala	1989	0	1	0	0	0	0	0	0
Malta	1989	0	0	1	0	0	0	0	0
Pakistan	1989	0	1	0	0	0	0	0	0
Peru	1989	0	1	0	0	0	0	0	0
Philippines	1989	0	1	0	0	0	0	0	0
Brazil	1990	0	1	0	0	0	0	0	0
Jamaica	1990	0	1	0	0	0	0	0	0
Uruguay	1990	0	1	0	0	0	0	0	0
Argentina	1991	0	1	0	0	0	0	0	0
Bangladesh	1991	0	1	0	0	0	0	0	0
Ecuador	1991	0	1	0	0	0	0	0	0
El Salvador	1991	0	1	0	0	0	0	0	0
Ghana	1991	0	0	1	0	0	0	0	0
Guyana	1991	0	1	0	0	0	0	0	0
Kenya	1991	0	0	1	0	0	0	0	0
Paraguay	1991	0	1	0	0	0	0	0	0
Colombia	1993	0	1	0	0	0	0	0	0
Trinidad and Tobago	1993	0	1	0	0	0	0	0	0
Benin	1994	0	1	0	0	0	0	0	0
Burundi	1994	0	1	0	0	0	0	0	0
Gambia	1994	0	0	1	0	0	0	0	0
Papua New Guinea	1994	0	1	0	0	0	0	0	0
Senegal	1994	0	0	0	0	0	0	0	1
Central African Republic	1995	0	1	0	0	0	0	0	0
Honduras	1995	0	1	0	0	0	0	0	0
Madagascar	1995	0	1	0	0	0	0	0	0
Zambia	1995	0	1	0	0	0	0	0	0
Mali	1996	0	1	0	0	0	0	0	0
Niger	1996	0	1	0	0	0	0	0	0

Table A.3
Non-Adopting Countries

country
Botswana
Burkina Faso
Cameroon
Egypt
Fiji
Greece
India
Iran
Jordan
Malawi
Mauritania
Mozambique
Nicaragua
Panama
Seychelles
Sudan
Swaziland
Togo
Zaire