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Coordination on formal vs. de facto standards: a dynamic approach

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Abstract

Formal standards arise out of deliberations of standards-writing organizations, while de facto standards result from unfettered market processes. Therefore, the former are of a higher quality and legitimacy but are slower to develop than the latter. To address this trade-off, we analyze a dynamic game where two players choose between one evolving formal standard and one mature de facto standard. The outcome of the game relies on the coordination mechanism used by the players on the relative value they attach to successful coordination and on the formal standard's performance at the end of the game. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Over the past two decades, information and communications technologies (ICT) have evolved from stand-alone or closed systems to mass-market products. This development of ICT products and services, notably through the emergence of networks, has highlighted the need for *compatibility* and *interoperability*, i.e., the ability of products from different manufacturers to work one with another.

Standardization is one important way to achieve this much sought-after compatibility. Standards (i.e., particular technical specifications to be adopted by everyone) may arise from different processes. A useful distinction can be made between *formal* and *de facto*

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standards: formal standards are mandated by government bodies or arise out of deliberation of voluntary standards-writing organizations; de facto standards, on the other hand, are produced through unfettered market processes, which are either "sponsored" or "unsponsored" (depending on whether there exists or not an identified originator with a proprietary interest).[1]

Because these two types of standardization process lead to standards with contrasting economic performance, the following trade-off confronts the ICT sector in its need for compatibility. On the one hand, formal standards should be preferred over de facto standards because they are developed through agreed, open and transparent procedures based on a consensus of all interested parties. They present thereby a particular legitimacy and avoid the costs associated with de facto standards of adopting privately profitable but socially undesirable technologies. On the other hand, formal standards suffer a major drawback: the pace of reaching them is often too slow in a context of rapid technological progress compared to the rather quick emergence of de facto standards. As Lehr (1992) judiciously puts it, "the irony of industry standardization is that the rapid pace of technical change simultaneously increases the social costs both from delay and from adopting the wrong standards."[2]

In practice, the trade-off entails two phenomena: (i) formal standards often appear under the form of successive versions that are increasingly effective, and (ii) these successive versions have to compete with well-established de facto standards. It is therefore of great interest to investigate *how users choose in a dynamic setting between competing standards that result from different standardization processes*. This is precisely the issue I want to address in the present paper. With this aim in view, I develop a specific model to analyze the dynamic choice between de facto and formal standards in situations where the above two phenomena are observed.

Specifically, I assume that two players have to choose between one formal and one de facto standard. Both players prefer to adopt a common standard but their preferences diverge about which particular standard to choose. In game-theoretic jargon, they play a game having the features of the classic 'battle of the sexes' (which is subsequently denoted by BoS).[3] Moreover, I assume that the de facto standard is 'mature' in the sense that it has constant performance over the game period, while the formal standard undergoes a development process: successive versions of increasing value are released and, in particular, the formal standard performs worse today than the de facto standard but is known (with certainty) to perform better in the future. Since players have a strong incentive to reach an agreement, it is assumed that they will follow some dynamic

[1] For more on this distinction, see, e.g., David and Greenstein (1990).

[2] See also European Commission (1996) and David and Shurmer (1996) for a discussion on this trade-off. For instance, David and Shurmer report that "the average time taken [by the formal standardization process] to produce a standard varies from 2 1/2 years at the national level through to 4–5 years regionally and 7 years or more at the international level."

[3] In this classic coordination game, a man and a woman are choosing between the ballet and a football game. The main concern of each is to be in the company of the other (regardless of where they go), but he prefers the ballet and she the football game (or *vice versa*).

coordination mechanism. In particular, I consider either that players can explicitly communicate and negotiate before irrevocable choices are made, or that no such communication is allowed and that coordination depends instead on unilateral irrevocable choices. These two mechanisms are compared with a benchmark that selects the solution with the highest sum of players' payoffs.

The resolution of the dynamic game reveals the following features. First, from a technical point of view, because the stage games have the features of the BoS, multiple pure-strategy Nash equilibria (PSNE) are often encountered. To go on with backward induction, I need thus to apply some criterion to select a unique Nash equilibrium to be considered as the solution of the stage game. In particular, the refinement I resort to is *risk dominance*. Second, it turns out that the outcome of the game crucially relies on three key factors: (i) the particular coordination mechanism used by the players, (ii) the relative value for the players of successful coordination and (iii) the performance of the formal standard at the end of the game. Regarding the adoption of the formal standard, the higher the latter two values, the lower the minimal degree of patience players should have to both adopt this standard. Third, in terms of comparison with the solution that would maximize total payoffs, both coordination mechanisms are imperfect but entail contrasting failures: verbal negotiation leads to an excessive adoption of the formal standard, while unilateral adoption excessively favors the de facto standard. If firms have the opportunity to choose beforehand which coordination mechanism to resort to (and if we assume that they agree to sit round a negotiation table only if they both find it profitable to do so), they come closer to the benchmark than if they were imposed to use a single mechanism in all instances. However, because of preference asymmetry, there always remains a region of parameters where players go for unilateral adoption and immediately adopt the de facto standard, while total payoffs would be larger if they opted instead for negotiation and adopted the formal standard at the deadline.

Before turning to the model, let me put my contribution into perspective by relating it to the literature and by providing some concrete examples that demonstrate the pervasiveness of the issue I address. Regarding the literature, while the market process generating de facto standards and the formal standardization process have been widely studied,[4] very little attention has surprisingly been paid to the potential rivalry between formal and market-driven standardization. To the best of my knowledge, the issue has only been investigated by Swann and Shurmer (1994). They account for the rivalry between the two types of standards by using a simulation model of the emergence of standards in the

[4] The abundant literature on de facto standardization has stressed how *positive network externalities* (which refer to the idea that the performance of a standard as well as its utility increases with the growth of the community of users) raise technical problems (equilibrium may not exist, or multiple equilibria may exist) and affect market performance (the fundamental theorems of welfare economics may not apply; in particular, markets may generate too little or too much standardization). For recent surveys of this literature, see Katz and Shapiro (1994), Besen and Farrell (1994), Economides (1996) and Matutes and Régibeau (1996). The literature about formal standardization is, comparatively, rather scarce and often of a more descriptive or political nature (see Greenstein, 1992; Lehr, 1992; Weiss and Cargill, 1992; Foray, 1994; David and Shurmer, 1996). Exceptions are Farrell and Saloner (1988), Swann and Shurmer (1994) and Goerke and Holler (1995).

spreadsheet software market and examine the effects of some simple policy interventions by a standards-setting institution. They examine the case where an institution is attempting to 'sell' its standard by pre-announcement, while individual producers market their own proprietary designs before the institutional standard is available. They show that an improved quality of institutional standard will usually increase average consumer surplus and the institution's market share, but earlier pre-announcements need not necessarily achieve this. It must be noted that not only is my focus different from theirs, but also my methodology differs: while their approach is basically non-strategic, I explicitly consider strategic interaction by using a repeated coordination game in the spirit of Farrell and Saloner (1988).

As for concrete applications of the issue considered in this paper, it is worth describing some topical cases. A first illustrative case is the development of the *Small Computer System Interface* (SCSI) standard. SCSI is a parallel interface standard used by Apple Macintosh computers, PCs and many UNIX systems for attaching peripheral devices (e.g., printers, disk drives, display monitors, keyboards, mouse, ...) to computers. Although SCSI is a formal standard established by the American National Standards Institute (ANSI), there are several variations: the original SCSI standard was approved by ANSI in 1986 and was followed by SCSI-2 in 1994. The SCSI-3 specification was drafted in 1996 and should be approved soon.[5] Thus, SCSI has grown and evolved to keep pace with the demands of the most sophisticated systems to recognize virtually every peripheral type and to take advantage of newer hardware and more intelligent controllers. These successive variations of SCSI have been or are competing with other de facto interface standards. Moreover, the coexisting standards are imperfectly compatible with each other and even successive SCSI interfaces are not fully backward compatible.[6]

The diffusion of *Electronic Data Interchange* (EDI) provides a second example. EDI is a technology that allows business documents and other communications to be automatically interpreted by computers in different organizations, thereby avoiding the time-consuming and error-inducing rekeying of information. Standardized business messages are clearly the precondition for such an automated exchange and interpretation of message contents. This task is performed by 'message standards,' that is, standardized ways of describing the component parts of trading documents and of grouping and presenting them in the form of messages or trade information (invoice, purchase order and so forth). Various message standards coexist. On the one hand, a number of de facto standards have been elaborated by large companies or self-sufficient trading communities to address their

[5] At the time of this writing.

[6] For an authorized opinion on that matter, see "Confusion over SCSI standards," *PC Magazine Online* (5/5/98) at http://www.zdnet.com/pcmag/pctech/content/solutions/hw1709a.htm. One can also read the following in *Webopedia*: "While SCSI has been the standard interface for Macintoshes, the iMac comes with IDE, a less expensive interface, in which the controller is integrated into the disk or CD-ROM drive. Other interfaces supported by PCs include enhanced IDE and ESDI for mass storage devices and Centronics for printers. You can, however, attach SCSI devices to a PC by inserting the SCSI board in one of the expansion slots. Many high-end new PCs come with SCSI built in. Note, however, that the lack of a single SCSI standard means that some devices may not work with some SCSI boards." (See http://webopedia.internet.com/Hardware/Buses/SCSI.html).

specific business needs. On the other hand, public institutions have also taken an active part in the definition of formal standards which go beyond the sectorial needs. In the latter category, the most prominent formal standard is the Electronic Data Interchange for Administration, Commerce and Transport (EDIFACT). This standard has been sponsored, since the late 1980s, by the International Standards Organization (ISO) and the United Nations Economic Commission for Europe (UN/ECE) and aims to become the single international EDI standard, flexible enough to meet the needs of governments and private industry. To achieve this goal, however, is anything but simple and the elaboration of EDIFACT is inevitably a slow process. Thus, since the approval of the first message in 1988, the standard has constantly been widened to cover a growing number of industry sectors. To date, around 160 messages have been approved as "United Nations Standard Messages" (UNSMs) and approximately 100 have been approved as "Messages in development." Standard directory sets containing UNSMs are issued twice each year.[7]

A third example can be found in the standardization process of the *56-kbps modems*. The standard for 56-kbps modems known as V.90 was completed by the International Telecommunication Union in February 1998 and officially stamped for approval in September 1998. Industry analysts concurred in pointing out that this standard was coming too late. The lengthy standard battle, which preceded the approval, was deemed to have long-lasting damaging effects. Before V.90 was established, consumers had to choose between 56-kbps modems using either 3Com's x2 or Rockwell's K56 flex technology. Users then had to find an Internet Service Provider (ISP) that supported the modem technology they had purchased. It also caused many ISPs to refrain from supporting 56-kbps modems because of the reigning confusion at that time. Still, the formal adoption of the V.90 standard did not appear as a panacea for modem vendors. While hailed by industry players as a solution to compatibility issues between the two existing technologies, V.90 was still exhibiting teething issues as glitches with the iMac from Apple computer showed. Additionally, there were reports of other lingering compatibility issues between 3-Com and Rockwell-based V.90 technologies.[8] Boardwatch Magazine described the situation that prevailed in March 1998 in the following way: "We think 56-kbps modems will be getting better. And now we have a standard—V.90. But the battle is not precisely over. There will likely be ongoing performance differences in this round (...). [V.90 modems] may interoperate, but you will most likely get the best performance using a modem and technology that matches the one supported by your ISP."[9]

The rest of the paper is organized as follows. Section 2 outlines the model; Sections 3 and 4, respectively, analyze the 'negotiation' and 'bandwagon' games. Section 5 compares

[7] Belleflamme (1999) applies the methodology developed in this paper to the case of EDI.

[8] See "V.90 modem standard approved," by Miles at http://www.news.com/News/Item/0,4,26486,00.html (17/09/1998).

[9] See "The 56K modem battle," by Richard at http://www.boardwatch.com/mag/ 98/mar/bwm24.html.

the results of the two games with the benchmark and derives some policy implications and Section 6 concludes.

2. The model

2.1. Basic setup

In the spirit of Farrell and Saloner (1988), I study a two-player game with the payoff structure of the classic BoS: the players (noted 1 and 2) have to choose one of two possible standards (noted X and Y). The situation is such that each player would prefer any proposed coordinated outcome to the result of each going her own way. However, the players disagree on which of the coordinated outcomes is better (say that player 1 [resp. 2] prefers coordination on standard X [resp. Y]). The interesting issue is whether the players will manage to coordinate their choices and, if they do, on which standard.

To address this issue, I assume that there are three periods in the game and that the choice of standards by the players can be achieved through two different dynamic procedures. In both procedures, periods 1 and 2 are the 'coordination rounds' and period 3 is the deadline. In other words, while the period 3 stage game is common, the form of the game in periods 1 and 2 depends on the coordination mechanism used by the players. Two such mechanisms are considered and compared.

A first coordinating principle is to use verbal negotiation. In the *Negotiation game*, the players have two chances to reach verbal agreement before the game of period 3 must be played. That is, each player can (simultaneously) announce 'insist' (i.e., stand firm with one's preferred standard) or 'concede' (i.e., accept to adopt the other player's preferred standard). If just one player insists, then she gets her way, while if both insist or if neither does, then they meet again in the following period. If no agreement has been reached after two periods, then the players play the game of period 3.

A second possible coordinating principle is to use unilateral adoption rather than negotiation. We have then a market mechanism which is usually called 'bandwagon' in the literature (see, for instance, Farrell and Saloner, 1985). In this so-called *Bandwagon game*, each player can either commit unilaterally to her preferred standard (and hope that the other will then follow) or simply wait. In contrast with the previous mechanism, it is only when both players decide to wait that they meet again at the following period.

Finally, to assess the relative performance of the two coordination mechanisms, I use as a benchmark the solution that maximizes the sum of the players' (discounted) payoffs (see Section 5). It is important to stress that the purpose of the paper is to highlight the interplay between various key forces, as well as to draw out some policy implications. The model that I present is therefore kept as simple as possible.

2.2. Payoff structure

Let a denote the value for a player of being on one's preferred standard, and c the additional value of successful coordination. Because each player would prefer any proposed coordinated outcome to the result of each going her own way, it is assumed that $c>a>0$ (since otherwise each player simply adopts her preferred alternative).[10] Furthermore, suppose that in period t, the values a and c are multiplied by a factor x_t if the player adopts standard X, or by a factor y_t if the player adopts standard Y. These additional factors allow the two standards to offer benefits that evolve differently through time. In particular, it is assumed that standard X, a de facto standard, is 'mature' (in the sense that its performance is constant over the game period) while standard Y, a formal standard, undergoes a development process (and, in particular, performs worse than X today but is known to perform better in the future). Accordingly, the following assumptions are made:

- $x_1 = x_2 = x_3 = x$ (i.e., standard X's performance is constant);
- $y_1 < x$; $y_2 = x$; $y_3 > x$ (i.e., the first version of standard Y lags behind standard X, the second version has just caught up and the third version is ahead of X); and
- without any loss of generality, $x = 1$.

It is important to note that, as in Farrell and Saloner (1988), a and/or c accrue to a player "once and for all, at the time she actually adopts a particular standard." It is also assumed that payoffs are discounted for each period that decisions are postponed.[11] The passage of time has thus two opposite effects in the model, on the one hand, because of discounting, players would rather reach an agreement sooner than later. On the other hand, technical progress and the formal standardization process make standard Y's adoption more attractive tomorrow than it is today.

Among the above three concrete examples, the case of EDI is probably the one that fits best our set of assumptions. In the light of the description given in Section 1, one could indeed imagine the following situation. Players are firms: firm 1 is a car manufacturer and firm 2, an upholsterer. Because firm 1 is going to equip its new car with seats manufactured by firm 2, the two firms wish to agree on a common EDI standard. Nevertheless, each firm would prefer that the standard elected be the one used in its own industry: the mature ODETTE standard in the automotive industry (i.e., standard X), or the evolving EDIFACT standard in the textile industry (i.e., standard Y). The following interpretation can then be given to explain the formation of the payoffs. It is emphasized in the literature that the economic advantages that can be derived from the use of EDI are positively related to the volume of the message exchange. We can then say that (i) c and a are, respectively, the total number of transactions firms 1 and 2 are going to conduct with each other or with trading partners from their respective industry during their business relationship, and that (ii) x_t and y_t are, respectively, the per transaction benefit derived from

[10] This formulation implies that when both players choose the standard they dislike (and fail thus to coordinate), they both get a payoff of zero, that means that we implicitly assume that the technology embodied in the standard has no value per se. I could relax this assumption by letting d (with $0<d<a$) denote the stand-alone value of being on one's *less preferred* standard. I show (in an appendix available upon request) that this does not change the nature of the results (only the typology of the cases and some threshold values for the parameters need to be adapted).

[11] I assume (for simplicity) that the two players have the same discount factor, $\delta \in [0,1]$ (the closer δ from 1, the more patient the players become).

the use of standard X or Y if the standard is adopted in period t. It must be stressed that the timing of adoption determines not only *when* the payoffs accrue (firms derive benefits from EDI once they have adopted a standard), but also *how much* firms earn (it is indeed assumed that the firms that adopt standard Y at time t get locked into the specific generation of Y available at that time).

I am now in a position to delineate the whole game tree. This is done in Fig. 1 for the negotiation game and in Fig. 2 for the bandwagon game.

For the sake of illustrating the payoff structure, let us detail the stage game of period 3 which is common to the two settings. This game is called the 'final game' since it will be played if the players can reach no agreement in period 1 or 2. It is represented by the payoff matrix of Table 1.[12]

2.3. Equilibrium concept and resolution of the final game

I now turn to the resolution of the dynamic game. The equilibrium concept I use is subgame-perfection. One important comment is in order about the method I follow to derive a subgame-perfect equilibrium. Because the stage games (in periods 1–3) have the features of the BoS, multiple pure-strategy Nash equilibria (PSNE) are often encountered. To go on with backward induction, I need thus to apply some criterion to select a unique Nash equilibrium to be considered as the solution of the stage game.

The criterion I apply is *risk dominance*. This criterion has been axiomatically developed by Harsanyi and Selten (1988) for the case of pure-strategy equilibria in two-by-two games. Roughly speaking, the idea behind this concept is that the players are more likely to focus on the equilibrium that consists of the *less risky* choice for them.[13] The rationale for using this criterion is threefold.

(1) There is the *relevance* of the criterion in the case of coordination games like the BoS as revealed by experimental evidence: Cabrales et al. (2000) have given support for the use of risk dominance as an equilibrium selection in the BoS. They further show that the higher the degree of asymmetry of the game, the higher the predictive power of the risk dominance criterion.[14]

(2) There is *the bite* of the criterion. Most standard criteria of selection among multiple equilibria (such as perfectness, properness, strategic stability and Pareto dominance) may fail having any selective power in the stage games considered here. The criterion of risk dominance is an exception: when there are two PSNE in a stage game, the payoff asymmetry (induced by the evolution through time of standard Y's performance) always allows us to state that one PSNE 'risk dominates' the other.

[12] In this matrix, as well as in all of the following matrices, player 1's choices appear in rows, and player 2's in columns. The first entry in each box is player 1's payoff, and the second is player 2's.

[13] Harsanyi (1995) explains the notion of risk that is at stake here: "A rational player will try to choose a strategy that is a *best reply* to the other players' strategies. But he will incur the *strategic risk* that the strategy he actually chooses will not have this property because his expectations about the other players' strategies will turn out to have been mistaken." More formally, the less risky equilibrium is the one with the widest 'basin of attraction,' which has to be understood as the range of randomized strategies for which the pure strategies composing the PSNE are optimal (see Appendix A).

[14] See also Cooper et al. (1989, 1992, 1993) for other experimental research on similar games.

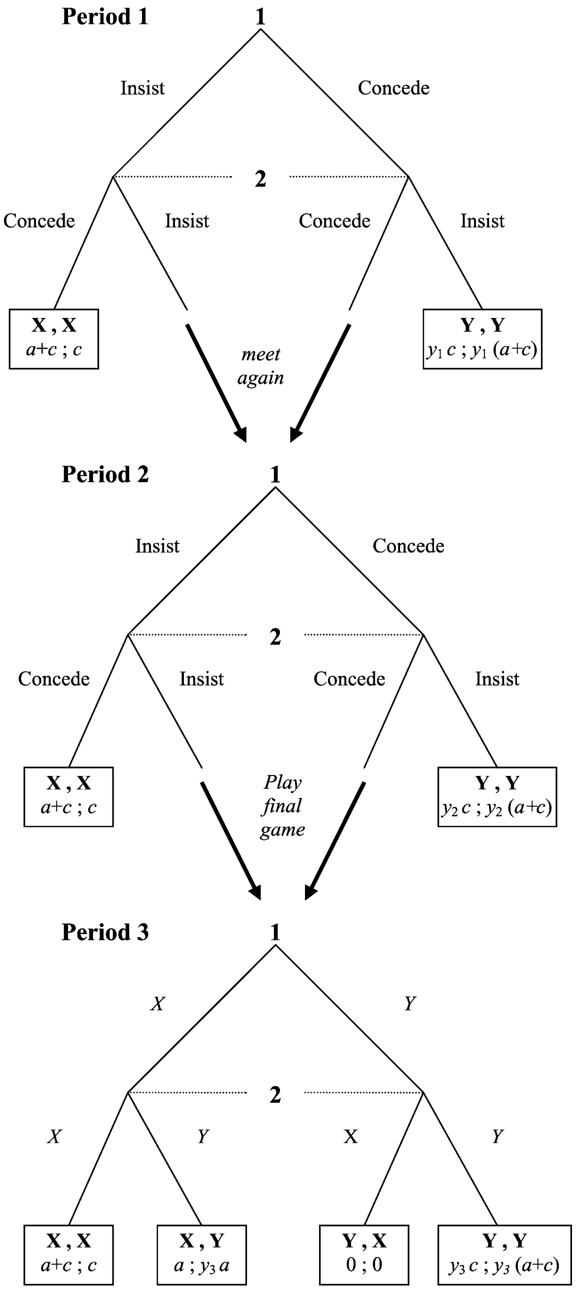

Fig. 1. Game tree for the negotiation game.

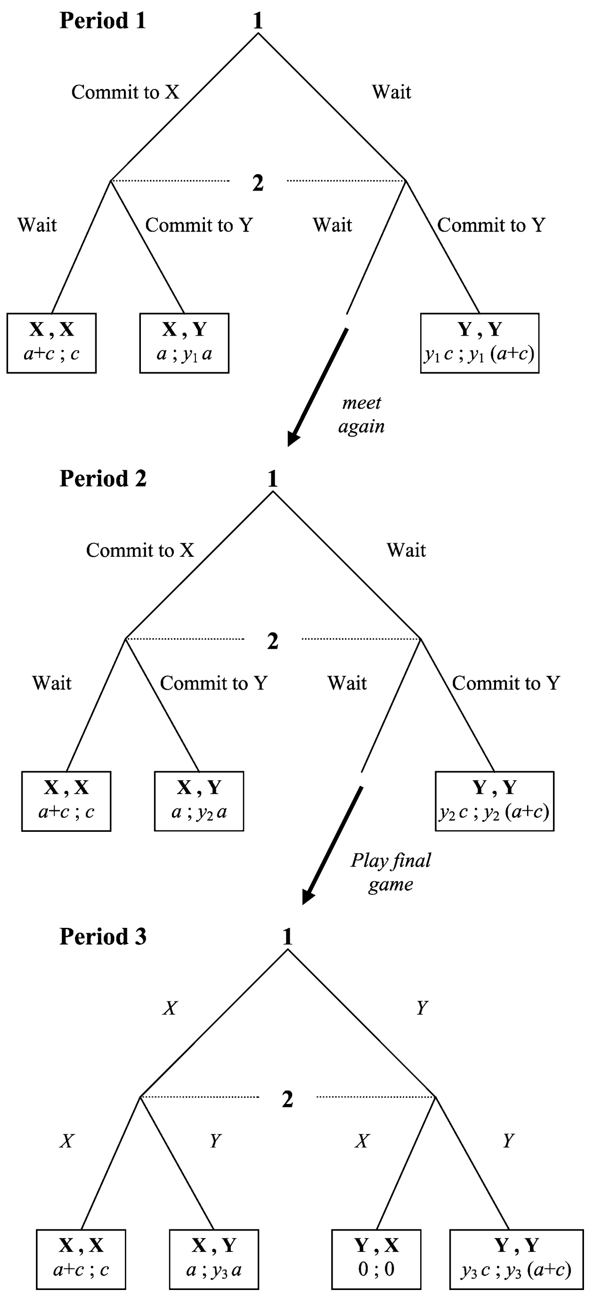

Fig. 2. Game tree for the bandwagon game.

Table 1
The final game

	X	Y
X	$a+c$, c	a , y_3a
Y	0 , 0	y_3c , $y_3(a+c)$

(3) There is the *convenience* of the criterion. As will become clear below, the application of risk dominance as a selection criterion yields a clear-cut and intuitive description of the equilibrium path in all possible configurations of parameters. Keeping in mind that the objective of the paper is to highlight particular aspects of the rivalry between formal and de facto standards, the clarity of the results plays a decisive role in the choice of the model specification and resolution.[15]

In what follows, I call the equilibrium *Risk-dominant Subgame Perfect* (RDSP) in order to bear in mind that risk dominance is applied to select among multiple PSNE in the stage games (which implies that players expect to coordinate in the future). Solving the game backward, I start thus with the stage game of period 3 which is common to the two coordination mechanisms. It is represented by the payoff matrix of Table 1. From the assumptions that (i) standard Y performs better than standard X at the deadline (i.e., $y_3>1$), and (ii) the value of coordination is higher than the value of adopting one's preferred standard (i.e., $c>a$), it follows that (Y, Y) is a PSNE of the final game. The other possible PSNE is (X, X), provided that $y_3<c/a$. There are thus two cases to distinguish: (i) if $y_3>c/a$, then (Y, Y) is the unique equilibrium in the final game, (ii) otherwise, (X, X) and (Y, Y) are both PSNE.

As announced above, I apply the risk dominance criterion to select one of the two PSNE in the latter case. Straightforward computations (based on the methodology described in Appendix A) show that (Y, Y) is the risk-dominant equilibrium. It seems thus legitimate to consider that if the deadline is reached, the players will coordinate their choices on the formal standard Y (because this situation will be either the unique PSNE in the final game or the focal PSNE in terms of risk dominance).

I can now turn to the resolution of the subgames corresponding to the two coordination mechanisms.

3. Negotiation game

In the negotiation game, the coordinating principle is to use verbal negotiation: the players have two chances to reach verbal agreement before the final game must be played.

[15] An alternative is to select the mixed-strategy Nash equilibrium. Farrell and Saloner (1988) advocate this in a similar game. (Yet, they consider symmetric payoffs and their aim is to model institutions that promote coordination.) However, this leads to a division of the parameter space and to equilibrium paths that are hard to interpret intuitively.

That is, each player can (simultaneously) announce 'insist' (i.e., stand firm with one's preferred standard) or 'concede' (i.e., accept to adopt the other player's preferred standard). If just one player insists, then he gets his way, while if both insist or if neither does, then they meet again in the following period. If no agreement has been reached after two periods, then the players play the final game (see Fig. 1). Folding back the game tree, I first solve the stage game of period 2 and then the stage game of period 1.

3.1. Period 2

The payoffs for the negotiation game in period 2 are reported in the matrix of Table 2 (where the assumption that $y_2 = 1$ has been taken into account). Because the players meet again in period 3 when they both insist or concede, the payoffs in these two cells of the matrix correspond to the discounted period 3 equilibrium payoffs: $(\delta y_3 c, \delta y_3(a+c))$.[16]

Comparing the payoffs in Table 2, I can determine which PSNE were obtained according to the value of δ. In the regions where multiple PSNE are observed, the risk dominance criterion is applied. The following lemma summarizes the results.[17]

Lemma 1. *The (unique or risk-dominant) PSNE in the period 2 negotiation game is (Concede, Insist) for* $0 \leq \delta \leq y_3^{-1}$ *or (Insist, Insist) for* $y_3^{-1} \leq \delta \leq 1$.

In words, in the case where period 2 is reached, the players will either coordinate on standard Y if they are relatively impatient or prefer to meet once again if they are relatively patient. Here, players are said to be patient when their discount factor is such that $\delta y_3 > y_2 = 1$; that is, when the standard Y's performance is higher (in present value) in period 3 than in period 2.

3.2. Period 1

Let $V_i(2)$ denote the value for player i of having two meetings remaining. This 'continuation payoff' is what player i gets in period 1 if both players concede or insist (that is, the discounted period 2 equilibrium payoff). From Lemma 1, we have the following values: $[V_1(2), V_2(2)]$ is equal to $[\delta c, \delta(a+c)]$ if $0 \leq \delta \leq y_3^{-1}$ or to $[\delta^2 y_3 c, \delta^2 y_3 (a+c)]$ if $y_3^{-1} \leq \delta \leq 1$. The matrix of Table 3 describes the payoffs for the negotiation game in period 1.

I will not set out the technicalities of solving this stage game. I confine myself to stating which (unique or risk-dominant) PSNE are obtained according to the values of the parameters. To organize the results, I distinguish between four main cases, defined in terms of standard Y's performance at the beginning and at the end of the game. As far as

[16] Recall that no payoff accrues to the players until they have adopted one or the other standard. Therefore, if they both concede or insist in period 2 (meaning that they have also done so in period 1), they only earn payoffs in period 3.

[17] The proof of Lemma 1, as well as those of other lemmas and propositions, can be found in an appendix available from the author.

Table 2
Negotiation game in period 2

	Concede	Insist
Insist	$a+c\,,\ c$	$\delta y_3 c\,,\ \delta y_3(a+c)$
Concede	$\delta y_3 c\,,\ \delta y_3(a+c)$	$c\,,\ a+c$

starting performance is concerned, the value of y_1 has to be compared with the ratio $c/(a+c)$ that gives the relative value for a player of successful coordination: for y_1 just equal to $c/(a+c)$, player 2 gets the same payoff in period 1 whether choices are coordinated on X or on Y—i.e., c vs. $y_1(a+c)$. Similarly, final performance y_3 is appraised with respect to the inverse ratio, $(a+c)/c$: for y_3 just equal to $(a+c)/c$, player 1 obtains the same payoff in period 3 whether choices are coordinated on X or on Y—i.e., $a+c$ vs. y_3c. Accordingly, I will refer to the following taxonomy:

Case LL. (Low/Low): $y_1<c/(a+c)$ and $y_3<(a+c)/c$;

Case LH. (Low/High): $y_1<c/(a+c)$ and $y_3>(a+c)/c$;

Case HL. (High/Low): $y_1>c/(a+c)$ and $y_3<(a+c)/c$;

Case HH. (High/High): $y_1>c/(a+c)$ and $y_3>(a+c)/c$.

In what follows, I will focus on cases LL, LH and HH. Case HL is omitted because it is not really relevant for our purpose since it assumes away the difference in the standards' performance that we precisely want to address.

The main results gathered from the resolution of the period 1 negotiation game can be summarized as follows. When the initial performance of standard Y is low (cases LL and LH), the players either coordinate on standard X (for 'low' values of the discount factor, player 1 insists while player 2 concedes), or go for a second meeting (for 'high' values of δ, they both insist). In contrast, when Y's initial performance is high (case HH), the latter two outcomes are observed only for 'extreme' values of δ, while for 'intermediate' values of δ, the players prefer to coordinate on standard Y (since at the equilibrium, player 1 concedes and player 2 insists).

The boundaries between *low*, *intermediate* and *high* values of the discount factor vary from one case to the other, but always have some instructive intuitive meaning.

Table 3
Negotiation game in period 1

	Concede	Insist
Insist	$a+c\,,\ c$	$V_1(2)\,,\ V_2(2)$
Concede	$V_1(2)\,,\ V_2(2)$	$y_1c\,,\ y_1(a+c)$

In case LL, the cutoff is where $\delta = c/(a+c)$; remembering that standard Y's performance in period 2 (y_2) is, by assumption, equal to one, the latter equality is equivalent to $\delta y_2(a+c) = c$, which means that in the present value, player 2 is indifferent between coordinating on Y in period 2 or on X in period 1. Similarly, in case LH, the equality between δ and the cutoff can be rewritten as: $\delta^2 y_3(a+c) = c$, which is the indifference condition for player 2 between coordinating on Y in period 3 or on X in period 1.

In case HH, the cutoff between 'intermediate' and 'high' values of δ also expresses a condition about the evolution of Y's performance: $\delta = \sqrt{y_1/y_3} \Leftrightarrow \delta^2 y_3 = y_1$ is equivalent to say that Y's performance (in the discounted value) is the same in period 3 than in period 1. Finally, the cutoff between 'low' and 'intermediate' values of δ follows from a technical condition for the risk dominance relation between multiple PSNE. Formally, I define the following threshold:

$$\gamma = \frac{c(a+c)(1-y_1^2)}{a^2 + 2c(a+c)(1-y_1)}.$$

It can be shown that this threshold plays a critical role to determine whether (Insist, Concede) or (Concede, Insist) is risk-dominant in the regions of parameters where they are both PSNE. More precisely, in the case where $y_3 < \gamma^{-1}$, the relevant cutoff is γ; otherwise, the relevant cutoff is $\sqrt{\gamma/y_3}$.

In summary, let us adopt the following notation for the various cutoffs (where the subscript n stands for 'negotiation'):

$$\bar{\delta}_{\mathrm{n}} = \begin{cases} c/(a+c) & \text{(case LL),} \\ \sqrt{c/y_3(a+c)} & \text{(case LH);} \end{cases}$$

$$\tilde{\delta}_{\mathrm{n}} = \sqrt{y_1/y_3} \text{ (case HH);}$$

$$\hat{\delta}_{\mathrm{n}} = \begin{cases} \gamma & \text{if } y_3 < \gamma^{-1}, \\ \sqrt{\gamma/y_3} & \text{otherwise;} \end{cases} \quad \text{(case HH).}$$

Lemma 2 states the results for the negotiation game in period 1.

Lemma 2. *The (unique or risk-dominant) PSNE in the period 1 negotiation game is:*

- *(Insist, Concede) for* $0 \le \delta \le \bar{\delta}_n$ *in cases LL and LH, and for* $0 \le \delta \le \hat{\delta}_n$ *in case HH; HH;*
- *(Concede, Insist) for* $\hat{\delta}_n \le \delta \le \tilde{\delta}_n$ *in case HH;*
- *(Insist, Insist) for* $\bar{\delta}_n \le \delta \le 1$ *in cases LL and LH, and for* $\tilde{\delta}_n \le \delta \le 1$ *in case HH.*

3.3. Summary

We can now collect the previous results in order to answer the following question: on which standard—and when—do the players coordinate in the negotiation game? The following proposition states the answer for all combinations of parameter values.

Proposition 1. *The standard adopted by the players and the timing of adoption at the RDSP equilibrium of the negotiation game depend on the values of the parameters in the following way.*

- *For low discount factors, players adopt standard X in period 1 (i.e., for $0 \leq \delta \leq \bar{\delta}_n$ in cases LL and LH, and for $0 \leq \delta \leq \hat{\delta}_n$ in case HH).*
- *For intermediate discount factors, players adopt standard Y either in period 1 (i.e., for $\hat{\delta}_n \leq \delta \leq \tilde{\delta}_n$ in case HH) or in period 2 (i.e., for $\bar{\delta}_n \leq \delta \leq y_3^{-1}$ in case LL).*
- *For high discount factors, players adopt standard Y in period 3 (i.e., for $y_3^{-1} \leq \delta \leq 1$ in case LL, for $\bar{\delta}_n \leq \delta \leq 1$ in case LH and for $\tilde{\delta}_n \leq \delta \leq 1$ in case HH).*

In other words, Proposition 1 shows that very impatient players immediately coordinate on X and very patient players wait for the deadline and coordinate on Y, *whatever the (initial and final) performance of standard Y.* In contrast, ambiguous outcomes prevail when players are relatively (im)patient: according to Y's performance, the players either coordinate immediately (on X or on Y) or adopt Y in period 2. Let us now analyze whether similar results obtain under the alternative coordinating principle.

4. Bandwagon game

Unilateral adoption is now substituted for negotiation as the coordinating principle used by the players. Under this market mechanism (called 'bandwagon'), each player can either commit unilaterally to its preferred standard (and hope that the other will then follow) or simply wait. Hence, in contrast with the negotiation game, it is only when both players decide to wait (i.e., 'concede,' in the terminology of the negotiation game) that they meet again at the following period. As above, the game is solved by backward induction, starting with period 2.

4.1. Period 2

The payoffs for the bandwagon game in period 2 are reported in the matrix of Table 4. The difference with the negotiation game (see Table 2) is that there is now only one cell where the discounted period 3 equilibrium payoffs are reported.

It is straightforward that both players committing to their preferred standard cannot be a PSNE of this stage game (because by assumption, $c>a$). Furthermore, it can be shown that if (Wait, Commit to Y) is a PSNE, it is necessarily risk dominated by (Commit to X, Wait). There are thus two possible outcomes for the game: either (Commit to X, Wait) if

Table 4
Bandwagon game in period 2

	Wait	Commit to Y
Commit to X	$a+c,\ c$	$a,\ a$
Wait	$\delta y_3 c,\ \delta y_3(a+c)$	$c,\ a+c$

$\delta<\bar{\delta}_b\equiv(a+c)/(y_3c)$, or (Wait, Wait) otherwise. It is clear, however, that the latter PSNE cannot be observed if $(a+c)/(y_3c)>1\Leftrightarrow y_3<(a+c)/c$ (i.e., in case LL). The following lemma summarizes these results.

Lemma 3. *The (unique or risk-dominant) PSNE in the period 2 bandwagon game is:*

- *(Commit to X, Wait) in case LL for all $\delta\in[0,1]$, and in cases LH and HH for $0\leq\delta\leq\bar{\delta}_b$;*
- *(Wait, Wait) in cases LH and HH for $\bar{\delta}_b\leq\delta\leq 1$.*

A major difference with respect to the negotiation mechanism immediately appears: *whatever their degree of patience*, the players will not wait for the deadline if the final performance of standard Y is poor (more precisely, if y_3 is such that player 1 is better off in period 3 when choices are coordinated on X rather than on Y—i.e., if $a+c>y_3c$). The deadline will be reached only if (i) Y's final performance is high, and (ii) players are relatively patient.

4.2. Period 1

Let $W_i(2)$ denote the value for player i of having two periods remaining. This 'continuation payoff' is the discounted period 2 equilibrium payoff that player i gets in period 1 if both players decide to wait. From Lemma 3, $[W_1(2), W_2(2)]$ can be equal either to $[\delta(a+c), \delta c]$ or to $[\delta^2y_3c, \delta^2y_3(a+c)]$. The matrix of Table 5 describes the payoffs for the period 1 bandwagon game.

Defining $\hat{\delta}_b$ as $\sqrt{(a+c)/(y_3c)}$, I can state the main results drawn from the resolution of this game as follows.[18]

[18] Note that the taxonomy developed for the negotiation game cannot be exactly transposed to the bandwagon game for all configurations of parameters. In particular, the threshold determining whether standard Y's initial performance should be considered as low or high is now given by the maximum of $c/(a+c)$ and a/c. This maximum is $c/(a+c)$ provided that $c/(a+c)>(\sqrt{5}-1)/2\approx 0.62$. In other words, it is only when the coordination benefits (c) represent at least 62% of total benefits ($a+c$) that the same taxonomy of Y's performance can be used for the negotiation and bandwagon games. In order to ease comparisons and further resolution of the game, I will by now assume that this inequality holds.

Table 5
Bandwagon game in period 1

	Wait	Commit to Y
Commit to X	$a+c\,,\ c$	$a\,,\ y_1 a$
Wait	$W_1(2)\ ,\ W_2(2)$	$y_1 c\,,\ y_1(a+c)$

Lemma 4. *The (unique or risk-dominant) PSNE in the period 1 bandwagon game is:*

- *(Commit to X, Wait) in case LL for all $\delta \in [0,1]$, and in cases LH and HH for $0 \leq \delta \leq \hat{\delta}_b$;*
- *(Wait, Wait) in cases LH and HH for $\hat{\delta} \leq \delta \leq 1$.*

Three instructive conclusions can be drawn from Lemma 4. (i) As in the negotiation game, very impatient players immediately coordinate on standard X in every case. (ii) However, even patient players do so when Y's performance is low at the initial and at the final periods (case LL). (iii) It is only when Y's final performance is high that patient players agree to wait.

The cutoff between 'patience' and 'impatience' is given by $\hat{\delta}_{\mathrm{b}} \equiv \sqrt{(a+c)/(y_3 c)}$. This threshold expresses the indifference condition for player 1 between coordinating on X in period 1 (yielding a payoff of $a+c$) or on Y in period 3 (yielding a payoff of $\delta^2 y_3 c$).

4.3. Summary

Comparing the results of Lemmas 3 and 4, and noting that in cases LH and HH $\hat{\delta}_{\mathrm{b}} > \bar{\delta}_{\mathrm{b}}$, one easily finds out on which standard and when players coordinate in the bandwagon game. The following proposition summarizes the results.

Proposition 2. *The standard adopted by the players and the timing of adoption at the RDSP equilibrium of the bandwagon game depend on the values of the parameters in the following way.*

- *In case LL, players adopt standard X in the first period whatever their degree of patience.*
- *In cases LH and HH, impatient players adopt standard X in the first period (i.e., for $0 \leq \delta \leq \hat{\delta}_b$) and patient players adopt standard Y in the third period (i.e., for $\hat{\delta}_b \leq \delta \leq 1$).*

The major difference with the negotiation game has already been emphasized: when unilateral adoption is substituted for verbal negotiation as the coordinating principle, players are more eager to coordinate as early as in period 1 (it is only in the case where they are very patient and that Y's final performance is high that they delay their decision up to period 3). As a result, the chances for standard Y to be adopted become lower: since standard X performs better at the beginning of the game, it is most often adopted by both players.

5. Policy implications

The objective of this section is to draw some policy implications from the analysis of the two games. The first issue we would obviously like to address is the following: *for given standard qualities and players' degree of patience, should the regulator encourage players to sit round a table and negotiate, or rather, to go their own way?* To answer this question, we compare the equilibria with the solution that would maximize the sum of the players' payoffs (in present value). It is readily checked that this benchmark involves the common adoption of X in period 1 if $\delta^2 y_3 < 1$, and of Y in period 3 otherwise.[19]

The examination of all possible cases (see below) allows us to bring both good and bad news to the regulator. Let us first break the *bad news*: *unless players are very impatient, each coordination mechanism might lead to an outcome that does not maximize the sum of players' discounted payoffs*. In particular, it turns out that the negotiation game leads to an excessive (late) adoption of the formal standard, while the bandwagon game leads to an excessive (early) adoption of the de facto standard. In other words, verbal negotiation might entail too much waiting while unilateral adoption might entail excessive precipitation. Therefore, it does not make much sense to contend that the regulator should unquestionably prefer one coordination mechanism over the other. There are nonetheless some *good news*: the two mechanisms never go wrong at the same time, i.e., *for every combination of parameters, the benchmark can be achieved through one or the other mechanism*. In sum, a successful intervention consists in imposing on the players one coordination mechanism or the other according to the circumstances. However, such intervention might be quite costly in the sense that it requires a detailed knowledge of the standard qualities and players' degree of patience in order to always select the right mechanism.

Next question that arises naturally is whether a suitable alternative could not be to let the players choose themselves the coordination mechanism they prefer to use. That would amount to add some kind of 'period zero stage game' during which players would choose whether to play the negotiation or the bandwagon game. If we rule out the possibility of side-payments between players, it seems then natural to assume that verbal negotiation will *not* be chosen as a coordination mechanism if at least one firm refuses to sit round the table. In other words, negotiation will take place only if it is Pareto-dominant (i.e., if the RDSP equilibria of the subgames are such that *each firm* obtains a higher present value payoff in the negotiation rather than in the bandwagon game). As shown below, this form of *laissez-faire* is undoubtedly preferable to a simple rule that would impose the same

[19] The two incompatibility outcomes are clearly dominated. Moreover, since $\delta \leq 1, y_1 < 1, y_2 = 1$, adoption of X in period 1 (yielding a joint payoff of $a + 2c$) dominates adoption of X in periods 2 or 3, and of Y in periods 1 or 2. Thus, the remaining contender is the adoption of Y in period 3, which yields a total discounted payoff of $\delta^2 y_3(a + 2c)$.

Table 6
Comparison of the coordination mechanisms in case LL

$\delta\in$	$\left[0,\frac{c}{a+c}\right]$	$\left[\frac{c}{a+c},\frac{1}{y_3}\right]$	$\left[\frac{1}{y_3},\sqrt{\frac{1}{y_3}}\right]$	$\left[\sqrt{\frac{1}{y_3}},1\right]$
Negotiation	**X in 1***	*Y in 2*	*Y in 3*	**Y in 3**
Bandwagon	**X in 1***	**X in 1***	**X in 1***	*X in 1**

coordination mechanism no matter what. However, in all three cases, there is a range of the discount factor where it fails to achieve the benchmark. Specifically, for δ comprised between $\sqrt{1/y_3}$ and $\sqrt{(a+c)/(y_3c)}$ (in cases LH and HH) or 1 (in case LL), players go for the bandwagon mechanism and immediately adopt standard *X*, while total payoffs would be larger if they opted instead for negotiation and adopted standard *Y* at the deadline. This divergence simply results from preference asymmetry: the fact that total payoffs are larger in the negotiation game does not mean that both players are better off in this game. Actually, in these regions of parameters, player 1 prefers to go her own way, whereas player 2 prefers to sit round the negotiation table.

Tables 6–8 detail the results of the comparison for cases LL, LH and HH. As before, the range of the discount factor (i.e., the unit interval) is divided into separate areas, and for each area, the outcomes of the two games are reported. The tables read as follows: the outcomes appearing in bold face coincide with the benchmark. The outcomes appearing in italic differ from the benchmark. A star (*) indicates that the corresponding mechanism would be chosen at the 'period zero stage game.'

A last question we could ask is about other interventions that could possibly reduce the likelihood of the discrepancy laissez-faire might entail. In the simple model used here, only the manipulation of standard *Y*'s performance seems to be within the grasp of the regulator. Allocating more resources to the formal standards-writing organization responsible for standard *Y* would increase y_3 and have the triple effect of (i) discarding case LL, (ii) enlarging the range of discount factors for which both mechanisms lead to efficient late adoption of standard *Y* and (iii) narrowing the discrepancy area identified above. Obviously, the cost of improving standard *Y* must be taken into account to assess the desirability of such policy.

Two other modifications of the parameters of the model could help alleviate the possible discrepancy of laissez-faire. First, it can be shown that an *increase in the relative value the players attach to successful coordination (i.e., an increase in c with respect to a) narrows (or, at worse, leaves unchanged) the discrepancy area in all three cases*. Second,

Table 7
Comparison of the coordination mechanisms in case LH

$\delta\in$	$\left[0,\sqrt{\frac{c}{y_3(a+c)}}\right]$	$\left[\sqrt{\frac{c}{y_3(a+c)}},\sqrt{\frac{1}{y_3}}\right]$	$\left[\sqrt{\frac{1}{y_3}},\sqrt{\frac{a+c}{y_3c}}\right]$	$\left[\sqrt{\frac{a+c}{y_3c}},1\right]$
Negotiation	**X in 1***	*Y in 3*	**Y in 3**	**Y in 3***
Bandwagon	**X in 1***	**X in 1***	*X in 1**	**Y in 3***

Table 8
Comparison of the coordination mechanisms in case HH

$\delta\in$	$[0, \hat{\delta}_n]$	$\left[\hat{\delta}_n, \sqrt{\frac{y_1}{y_3}}\right]$	$\left[\sqrt{\frac{y_1}{y_3}}, \sqrt{\frac{1}{y_3}}\right]$	$\left[\sqrt{\frac{1}{y_3}}, \sqrt{\frac{a+c}{y_3 c}}\right]$	$\left[\sqrt{\frac{a+c}{y_3 c}}, 1\right]$
Negotiation	**X in 1***	*Y in 1*	*Y in 3*	**Y in 3**	**Y in 3***
Bandwagon	**X in 1***	**X in 1***	**X in 1***	*X in 1**	**Y in 3***

if we are concerned with fostering the efficient adoption of the formal standard, it is obvious that any *increase in the players' patience* (i.e., in the discount factor δ) will be favored. Of course, the relative value attached to successful coordination and the degree of patience is a matter of players' preferences. The simple model used here only indicates the direction for intervention, but suggests no means by which the regulator could achieve such intervention. A richer model should then be elaborated to endogenize these two factors and make them sensitive to policy interventions. Here follow suggestions which are left for further research.

- One could imagine, for instance, that the relative value attached to successful coordination on a particular standard (or, in the spirit of Footnote 10, the stand-alone benefit of each standard) follows the evolution of the global "market share" of the standard in question. This would force us to consider that other sets of players choose between the two standards and that network externalities are at work.[20]
- One could also allow a standards body to shorten the time that elapses between the release of two successive versions of a formal standard (instead of considering fixed and equally spaced periods, as done here). Such efforts are indeed increasingly made in the international standards community. For instance, JTC 1[21] publicly announced in 1994 that as the focal point for IT standardization, it will provide the capability of accepting standard solutions to IT problems that have been developed outside JTC 1. This has resulted in a fast-track process for the definition of *Publicly Available Specifications* (PAS), i.e., specifications that satisfy certain criteria, making them suitable for processing as an international standard. European standards organizations have also developed a number of similar fast-track procedures.

6. Conclusion

In the information and communications technology (ICT) markets, standards represent much more than a technical question: they ensure the compatibility and interoperability between products of different manufacturers, and consequently, the way in which all users will benefit from them. Standards may arise either out of deliberations of voluntary or governmental standards-writing organizations, or out of an unfettered market process. The former are called "formal" standards and the latter "de facto" standards.

[20] David and Foray (1994) develop a model that follows this line for the case of EDI standards diffusion.

[21] JTC 1 is the Joint Technical Committee 1 of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). JTC 1's scope is the standardization in the field of Information Technology.

It is widely recognized that formal standards present the following trade-off with respect to de facto standards: formal standards have a particular legitimacy and avoid the costs of adopting privately profitable but socially undesirable technologies. Yet, in terms of the ICT industry, the time scales of their development do not always sit comfortably with the need for competitive use of the latest technology as early as possible. In a nutshell, formal standards "develop slowly but are eventually better," while de facto standards "are available sooner but might be inferior."

In such a context, it is important to understand how users choose in a dynamic setting between formal and de facto standards that compete with each other. To address this question, this paper has analyzed a model where two players have to choose between one formal and one de facto standard, and where both players prefer to adopt a common standard but disagree about which common standard should be adopted. Moreover, it is assumed that the de facto standard is 'mature' in the sense that it offers constant performance over the game period, while the formal standard undergoes a development process: successive versions of increasing value are released and, in particular, the formal standard performs worse at the beginning of the game than the de facto standard but is known (with certainty) to perform better at the end. It is further assumed that players can either explicitly communicate and negotiate before irrevocable choices are made, or make coordination depend instead on unilateral irrevocable choices.

It turns out from the resolution of this dynamic game that the outcome crucially relies on three key factors: (i) the coordination mechanism used by the players, (ii) the relative value for the players of successful coordination and (iii) the performance of the formal standard at the end of the game. Regarding the adoption of the formal standard, the higher the latter two values, the lower the minimal degree of patience players should have to both adopt this standard. In terms of comparison with the outcome that maximizes the sum of the players' discounted payoffs, the two coordination mechanisms are imperfect but entail contrasting failures: verbal negotiation leads to an excessive adoption of the formal standard, while unilateral adoption excessively favors the de facto standard. However, if firms non-cooperatively choose beforehand which mechanism to use, they almost always succeed in reaching the highest possible sum of payoffs.

Besides the extensions already outlined in Section 5, the model could be further developed along four lines in order to explore more closely the trade-off between formal and de facto standardization. A first line would consider that players are asymmetric with respect either to their degree of patience or to their valuation of successful coordination. The second line of research would be to study the possibility of re-assessing the choice of standard (at the price of a switching cost). The third line would be to introduce uncertainty about the future performance of the formal standard. Finally, the assumption of once-and-for-all payoffs could be questioned and intermediary payoffs (which accrue to the players during the coordination process) could be introduced.

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Appendix A. Risk dominance relation between equilibria

Consider the following general two-player game in strategic form in which each player has two pure strategies (see Table 9). Suppose that there are two pure-strategy Nash equilibrium, say (A, A) and (B, B). This is the case if (i) $a_{11} \geq a_{21}$ and $b_{11} \geq b_{12}$ and (ii) $a_{22} \geq a_{12}$ and $b_{22} \geq b_{21}$.

Define the *basin of attraction* of a PSNE as the range of randomized strategies for which the pure strategies composing this PSNE are optimal. More formally, let λ_i be the probability that player i places on strategy B. Player 1 is indifferent between choosing strategy A or strategy B if λ_2 is such that:

$$(1-\lambda_2)a_{11} + \lambda_2 a_{12} = (1-\lambda_2)a_{21} + \lambda_2 a_{22}$$

$$\Leftrightarrow \lambda_2 = \frac{a_{11}-a_{21}}{a_{11}+a_{22}-a_{12}-a_{21}} \equiv \hat{\lambda}_2.$$

Accordingly, player 1 prefers strategy A [resp. B] if $\lambda_2 <$[resp.$>$]$\hat{\lambda}_2$.

Similarly, player 2 is indifferent between strategies A and B if λ_1 is such that

$$\lambda_1 = \frac{b_{11}-b_{12}}{b_{11}+b_{22}-b_{12}-b_{21}} \equiv \hat{\lambda}_1;$$

player 2 prefers strategy A [resp. B] if $\lambda_1 <$[resp.$>$]$\hat{\lambda}_1$. Note that ($\hat{\lambda}_1$, $\hat{\lambda}_2$) is nothing but the mixed-strategy equilibrium of the game.

Applying the definition, we have that the basin of attraction of (A, A) is defined as the surface in the unit square (λ_1, λ_2), where both players prefer strategy A. Since player i prefers A for values of λ_i which are no greater than $\hat{\lambda}_i$, we have that the basin of attraction of (A, A) is equal to $\hat{\lambda}_1\hat{\lambda}_2$. By analogy, the basin of attraction of (B, B) is equal to $(1-\hat{\lambda}_1)(1-\hat{\lambda}_2)$. We can now define the relation of risk dominance in terms of these basins

Table 9
A general two-player game in strategic form

	A	B
A	a_{11} , b_{11}	a_{12} , b_{12}
B	a_{21} , b_{21}	a_{22} , b_{22}

of attraction. We will say that one equilibrium "risk dominates" the other if its basin of attraction is wider that the basin of the other. In the present case, (A, A) is risk-dominant if $\hat{\lambda}_1\hat{\lambda}_2 > (1-\hat{\lambda}_1)(1-\hat{\lambda}_2) \Leftrightarrow \hat{\lambda}_1 > 1-\hat{\lambda}_2$, which is equivalent to:

$$(a_{11} - a_{21})(b_{11} - b_{12}) > (a_{22} - a_{12})(b_{22} - b_{21}). \tag{1}$$

Each side of this inequality represents the product of the two players' incentives for complying to a particular equilibrium when they expect that the other player is doing so as well. This is another interpretation for the basin of attraction of a particular PSNE. Naturally, if expression (1) holds with the opposite inequality, then (B, B) is risk-dominant, and if it holds with equality, then there is no relation of risk dominance between the two equilibria.

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