An Integrated Model of Consortium-Based E-business Standardization: Collaborative Development and Adoption with Network Externalities*

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Abstract

E-business standards are critical for electronic transactions. In many industries, firms develop e-business standards collaboratively in a standard consortium. They can choose to become a leading developer, a passive adopter, or a non-adopter. Since firms' strategic choices at the development stage and the adoption stage are related due to the double-sided interactions between the two stages, we propose an integrated model of consortium-based e-business standardization. We find that firms' payoffs from standard adoption increase with their intrinsic value of the standard, but developers' benefits in-

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crease faster than passive adopters' benefits. The model examines the value of passive adopters to the standard development via network externalities, even though passive adopters do not contribute in the consortium directly. However, the existence of passive adopters is not inevitable. There are two possible equilibria for the endogenous formation of the developer network and the adopter network, one without passive adopters and one with passive adopters. How external conditions affect the endogenous formation of the consortium depends upon whether there are passive adopters in the equilibrium. Based on our analysis, we recommend strategies to e-business standard consortia to motivate firms' participation and enhance social welfare created by the standard.

Keywords: e-business standards, standard consortia, collaborative development, adoption, double-sided interactions, network externalities.

1 Introduction

As IT plays a significant role in facilitating companies' operations, especially business-to-business (B2B) communications, firms have realized the increasing importance of B2B standards. E-business standards specify business objects, data, and processes involved in Web-based interorganizational commerce. Setting and adopting a common standard for B2B transactions, therefore, is a natural step to enhance compatibility or interoperability among companies, generating great value for individual firms and the industry overall.

The arrival of XML (the eXtensible Markup Language), a standard foundation to share information electronically across heterogeneous programming platforms and over the Internet, has boosted the development of B2B standards [35]. In many industries, firms have convened quietly to form standard consortia to undertake B2B standardization initiatives [17].

Standard consortia are cooperative organizations that develop and/or approve standards based on formal agreements through communication, political negotiation and coordination among participants. For example, RosettaNet, a standard consortium that was formed by companies in the high-tech industry (e.g., IBM, Intel, DHL, Sony, Samsung, etc.), develops and promotes standards that define electronic data formats and business processes between partners in that industry. The Mortgage Industry Standards Maintenance Organization (MISMO), a forum set up by companies in the home mortgage industry (e.g., ABN AMRO Mortgage Group, CitiMortgage, etc.), works on mortgage-related e-business standards that formalize, for example, an applicant's credit report, which makes it possible for partners involved in a mortgage application to share information seamlessly in order to better serve the customer [34].

Most e-business standards set by a standard consortium, such as RosettaNet Partner Interface Processes (PIPs), are freely available for all potential users and thus exhibit public good features [19; 22]. Individual members need to decide whether to invest in the private provision of a public good. Based on publicly available reports and interviews with top officers of two e-business standard consortia, the Standard for Technology in Automotive Retail (a leading standard consortium in the automotive retail industry) and the Open Geospatial Consortium (a leading standard consortium in the geospatial and location based service industry), we identify several sources of benefits associated with the standard development. First, when contributing to technical proposals and lobbying other members, firms can orient the standard towards their own business practices and proprietary system specifications [8; 27]. Second, in e-business standard consortia, most developers are immediate future adopters and end users that will benefit tremendously from implementing the standard [14; 38]. The better the standard and the faster it is developed, the greater direct benefit there is for the developers. Therefore, the members have a strong incentive to contribute, rather than wait for others. For example, in 2002, Intel, a participant of RosettaNet, was using RosettaNet standard to conduct business via the Internet with all 90 of its trading partners in 17 countries [11]. Third, companies also benefit from in-depth discussions in the development process with their peers, often leading companies in the industry [30]. Furthermore, their better understanding of the standard's technical details from the participation helps reduce future implementation costs.

Nevertheless, there are firms that adopt the standard without joining the development process, and we call them "passive adopters". Firms recognize that along with the advantages in developing, consortium participation also has its costs and risks. They have to devote financial and personnel resources to the development and endure high uncertainty of market success of the new standard [28]. Since firms always have the option of becoming a developer, they have a choice to make when facing the opportunity to participate in the standard consortium. Firms will act as leading developers only if their payoffs satisfy two incentive compatibility constraints. The first is the development constraint, which ensures benefits from being an "insider" of the standard development exceed development costs and consortium participation costs and risks. The second is the adoption constraint, that is, developers should expect non-negative payoffs from implementing the standard later on. Firms choose to "wait-and-see" and become passive adopters, when only the adoption incentive constraint holds. Still others opt to not adopt at all as adoption cost surpasses the expected benefit.

Development and adoption each also have impacts on the other through the double-sided effects between the two stages. On the one hand, developers' contributions affect the output of the standard, which in turn will determine firms' stand-alone benefits from using the standard and thus the total number of adopters at the adoption stage. On the other hand, due to positive network externalities [7; 26], developers' expected payoff is also a function of the total number of adopters.

To examine the double-sided interactions between the development stage and the adoption stage, we propose an integrated three-stage model of consortium-based e-business standardization. Firms simultaneously decide whether to join the standard consortium at the first stage. During the second stage, developers in the consortium choose their optimal investments to develop the standard collaboratively. Finally, all firms decide whether to adopt the standards. While this analysis is inspired by the consortium-based e-business standardization phenomenon, it can also be generalized to to investigate other cases of private provision of public good production in which developers are also adopters, among whom network effects exist.

Our model investigates firms' choice of becoming a developer, a passive adopter, or a non-adopter, and the resulting endogenous formation of the developer network and the adopter network. We find that firms' payoffs from standard adoption increase with their intrinsic value of the standard, but developers' benefits increase faster than passive adopters' benefits. The integrated model examines the value of passive adopters to the standard development via network externalities, even though passive adopters do not contribute in the standard consortium directly. However, the existence of passive adopters is not inevitable. We identify two possible equilibria of the endogenous formation of the developer network and the adopter network, one with passive adopters and one without passive adopter. These two equilibrium structures behave quite differently. When there are no passive adopters, multiple equilibria may exist and it is ambiguous how the change of exogenous conditions will affect the size of the developer/adopter network and social welfare. With passive adopters, the game has a unique equilibrium, and the expected social welfare is negatively associated with the consortium participation cost. Based on our analysis, we recommend strategies to e-business standard consortia to motivate firms' participation and enhance social welfare created by the standard.

We organize our paper as follows. We review relevant literature in Section 2. Section 3 describes the basic three-stage model. Section 4 explores the equilibrium structures of the developer network and the adopter network, firms' optimal investment in the standard consortium, and social welfare implications. We compare two equilibrium structures in Section 5, one without passive adopters and one with passive adopters. Section 6 summarizes our theoretical and empirical contributions and outlines future research issues.

2 Literature Review

We first review previous studies on the economics of standards, which raise the concept of network externalities of standards and consequent problems in standard adoption. Then, we focus on literature of consortium-based standardization, the foundation of our model.

2.1 Prior Research on the Economics of Standards

Early works on the economics of standards focus on market-based standardization process and the inefficiency of the market. The literature can be traced back to David's [6] vivid account of the QWERTY keyboard story. The externalities of standards result in the so-called "path dependency" of their adoption, leading to premature standardization on socially sub-optimal systems,[1] which then is sustained by decentralized decision making of individual agents. A similar argument is made by Arthur [1]. Arthur [1] studies the dynamics of competition of technologies that exhibit increasing returns to adoption, particularly when two such technologies compete in the marketplace to be the dominant standard. Given the network externalities among end users, firms have to employ special strategies to win the competition of standard development [23]. In our model, firms' strategy at the development stage is associated with the future adoption of the standard due to network externalities among adopters. However, we focus on the collaborative development of the standard, and firms need to consider whether to join the standard consortium instead of how to compete with each other. In addition, in our model, firms which develop the standard are also adopters; while in prior research on the economics of standards, users and developers come from two separate groups.

2.2 Standardization in a Neutral Consortium Setting.

In addition to the market mechanism, economists also realize that many standards are set by committees, such as RosettaNet and MISMO. "How do the two mechanisms compare?" is naturally the first question. Farrell and Saloner [9] focus on the coordination role of the committees. They [9] model a two-firm coordination process as a "war-of-attrition" game. Farrell and Saloner [9] find that although the committee-based approach almost guarantees coordination, it is slower than the market approach. Farrell [8], recognizing the excessive

[1] Liebowitz and Margolis [13] suggest that the superiority of alternative keyboards has never been undisputedly confirmed. Their work underscores the difficulty to establish empirical evidence of the lock-in effect.

delays observed in standard committees, extends the same model to allow private information in firms. In the private information "war-of-attrition" model, each firm has some "vested interest" before joining the standardization committee. Through the model, Farrell [8] shows that the more firms' vested interest, the longer delays in the committee. Farrell [8] discusses ways to reduce individual firms' vested interest, such as early standardization, weakening the voting rule, and liberal licensing rules that reduce winner's payoffs. Simcoe [24] conducts a large-scale empirical study to examine consortium-based standardization. He [24] finds that the standard setting process within a standard consortium becomes longer with higher commercial pressure and tighter intellectual property rights protection.

The "war-of-attrition" model examines the conflicting interests between firms, when firms need to make a selection between competing proprietary specifications. By contrast, this paper emphasizes the collective development aspect of the standard consortium. In the e-business standard development, the importance of collaboration outweighs the conflicting interests among firms, especially in the early standardization case in which firms' vested interests are limited. Many e-business standard consortia, for example, Chemical Industry Data Exchange (CIDX) in the chemical industry and MISMO in the mortgage industry, employ the early standardization approach. They began to develop XML-based e-business standards right after W3C published the first version of XML specifications in 1998 [36], when few firms in the industry had adopted any XML-based e-business systems. By starting early, the standard consortia avoid or reduce potential conflicts between members. Another reason that we focus on the collaboration between developers is due to a major distinction between e-business standards and traditional IT standards [38]. E-business standards are used to share data among firms, which rarely compete with each other directly through standards. In contrast, other IT product standards can be used as a competitive weapon in the marketplace.

Chiao et al. [5] study the procedures within a standard consortium. A standard consortium needs to balance interests between developers and users. They find that if a consortium is oriented to developers, then the standard's quality is higher and the required developers' concession level, such as committing to license key intellectual property needed to users, is lower than a user-oriented standard consortium. They also investigate how competition among standard consortia affects their strategies. When consortia face more competitors, their market power is lower. It is more important for them to achieve user-friendliness by requiring developers' compromises. Their model examines both the development stage and the adoption stage, and the developer's action will determine the users' payoffs. In this paper, we go further by considering the fact that adopters can also influence developers' benefits due to positive network externalities.

3 A Three-Stage Model

In this section, we develop the basic framework for our model by explaining the rationale for each of our assumptions. We consider a large number of firms that are interested in the forthcoming standard. The per unit intrinsic value the standard delivers in interorganizational use, θ, is heterogenous among firms and is due to various firm characteristics, such as the volume and diversity of e-business transactions conducted based on the standard [15], the installed base of proprietary applications [8], and the firm's position within a supply chain network [38]. θ is a taste parameter and represents the type of a firm. We assume θ is uniformly distributed between zero and $\overline{\theta}$. A table on the modeling notation and definitions is provided in the appendix (Table 1).

3.1 Model Timeline

There are three stages in the model, simulating firms' strategic decisions at various phases of standard development and adoption.

First Stage: (Consortium Participation) Firms simultaneously determine whether to become active developers. As a result, a developer network, or a standard consortium, is formed.

Second Stage: (Standard Development) In the standard consortium, a type-θ firm will determine how much effort, q_θ, it wants to exert to develop the standard collaboratively with other consortium members. The standard is jointly supplied.

Third Stage: (Standard Adoption) Firms determine whether to adopt the standard, and an adopter network arises.

3.2 Formulation and Assumptions

Below we present our formulation and assumptions of the model, in the order of stages. After the standard consortium is formed, each developer needs to decide how much to invest in the consortium. The development cost, $c_d(q_\theta)$, is strictly increasing, convex, and twice continuously differentiable in the effort q_θ, and $c_d(0) = 0$, $c_d'(0) = 0$. The marginal development cost, c_d', reflects the difficulty level to establish the standard collectively. Intuitively, for example, c_d' is lower when the industry as a whole is more IT-savvy than otherwise. It is also lower for industries in which firms are more familiar with e-business applications.

From participating in the consortium, a developer obtains insider benefits, I. The insider benefits come from receiving advance knowledge of the direction of standard setting, accumulating standard related expertise to achieve a smooth future adoption [25], and skewing the standard towards their individual preferences [8]. $I(q_\theta, \theta)$ is strictly increasing, concave, and continuously differentiable in q_θ and θ respectively. $I(0, \theta) = 0$, since firms can only gain insider benefits via working in the consortium, such as joining the consortium meetings and working groups, submitting technical proposals, and lobbying other participants [33]. Firms which value the standard higher will appreciate the insider benefits more. For example, for a firm at the center of a supply chain network planning to install the standard with hundreds of its trading partners, it is very important for the firm to propose and develop standards reflecting its business needs and inter-firm business practices. On the contrary, if a firm only applies the standard with a few partners to a small set of transactions, the benefits from consortium negotiation and bargaining are limited. Consequently, firms' marginal insider benefits from investing at the development stage increase with θ (i.e., $\frac{\partial^2 I(q_\theta,\theta)}{\partial q_\theta \partial \theta} > 0$, $\forall \theta > 0$). When a firm places a zero value on the future standard, there will be no insider benefits, which means $I(q_\theta, 0) = 0$.

Developers also face exogenous costs and risks that are independent of their private provision of the standard. First, most standard consortia charge membership fees from participants, even though their standards are freely available for both members and non-members. Second, developers also have to bear the additional cost of being early adopters of a relatively immature standard, as well as risks of the unsuccessful diffusion of the upcoming standard. For example, the standard may be developed during a period of technological ferment [10]. Or, the standard may face competition from rival consortia or individual vendors [32]. Therefore, we use a parameter, E, to reflect the participation costs and risks incurred by all developers. For simplicity, we assume E to be homogeneous for all firms and can be observed by all. Firms need to balance between insider benefits and related risks and costs when they consider becoming a developer in the standard consortium.

At the end of the second stage, the resulting level of production of the standard, Q, is determined by the collective contribution from all developers. Q represents the standard quality as well as quantity measured by the number of interorganizational business processes covered by the standard [38]. Finally, firms make their adoption decisions. We assume the adoption cost, C_a, is homogeneous for all adopters, but the developers get a discount due to insider benefits. The standard, typically available to the public for free, can be regarded as a public good with positive network externalities. We use a linear function, $\alpha *$(the proportion of adopters), to represent the network benefit [37]. $\alpha > 0$, describes the strength of the network effect.

Depending on its intrinsic valuation of the standard, θ, a firm can choose to become a leading developer, a passive adopter, or a non-adopter (Figure 1). We assume the marginal developer to be a type-θ_d firm, which is indifferent between becoming a developer or not. Similarly, we assume the firm that is indifferent between adopting and not adopting the standards is the "marginal adopter" with θ_a. We need to solve for θ_d and θ_a to get the size of the two networks. By viewing the consortium-based e-business standardization as collective action [14], we can write Q as the total resources contributed by all developers, $Q = \int_{\theta_d}^{\overline{\theta}} q_\theta f(\theta) d\theta$, based upon the theoretical collective action model [16]. Since θ is assumed to be uniformly distributed between 0 and $\overline{\theta}$, $Q = \int_{\theta_d}^{\overline{\theta}} q_\theta \frac{1}{\overline{\theta}} d\theta$. The network benefit enjoyed by all adopters is equal to $\alpha(\overline{\theta} - \theta_a)$.

3.3 Payoff Functions

We summarize a firm's profit function in the following equations:

For a non-adopter:

$$\pi_\theta = 0 \tag{1}$$

For a passive adopter:

$$\pi_\theta = \theta Q + \alpha(\overline{\theta} - \theta_a) - C_a \tag{2}$$

An Adopter's Payoff = Per Unit Intrinsic Value of the Standard * Standard Output

+ Network Benefit - Adoption Cost

For an active developer:

$$\pi_\theta = \theta Q + \alpha(\overline{\theta} - \theta_a) - C_a + I(q_\theta, \theta) - c_d(q_\theta) - E \tag{3}$$

A Developer's Payoff = Adoption Benefit + Insider Benefit - Development Cost

- Consortium Participation Cost

A non-adopter's profit is zero. A pure adopter will incur the adoption cost while benefiting from the standards adjusted by its intrinsic valuation and network externalities. If a firm chooses to develop the standard in the standard consortium, it can obtain the insider benefit in addition to all benefits to passive adopters. However, developers have to face the development cost and the consortium participation risk.

In the following section, we will solve the three-stage model and identify the resulting equilibrium structures of the developer network and the adopter network.

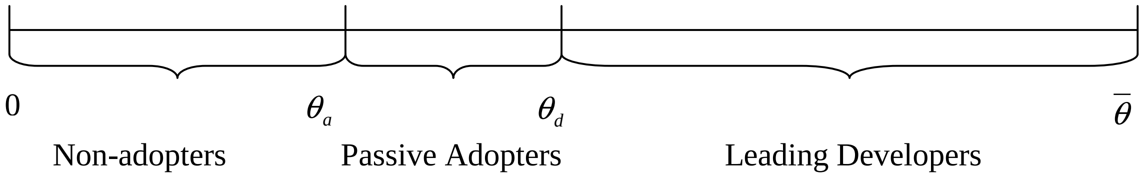

Figure 1: Firms' Three Strategic Choices

4 The Equilibrium of the Standardization Process

We apply backward induction to solve the three-stage model. We first find the marginal adopter, θ_a, and compute the expected size of the adopter network in Step 1. Then in Step 2, we calculate the optimal effort level for each developer. Finally, we locate the marginal developer, θ_d, and to determine the size of the developer network in Step 3.

4.1 Step 1: The Expected Size of the Adopter Network

The marginal adopter, θ_a, is indifferent between adopting and not adopting. Therefore, we have:

$$\pi_{\theta_a} = \theta_a Q^* + \alpha(\overline{\theta} - \theta_a) - C_a = 0 \tag{4}$$

We only consider the case where $C_a > \alpha\overline{\theta}$. If $C_a \leq \alpha\overline{\theta}$, network externalities are strong enough to cover the adoption cost. Any compatible standard is socially beneficial even when no firm contributes anything to develop the new standard (i.e., $Q = 0$). The collaborative development of the standard becomes a trivial issue. Therefore, we will not discuss the scenario where $C_a \leq \alpha\overline{\theta}$.

$\theta_a = \frac{C_a - \alpha\overline{\theta}}{Q^* - \alpha}$. If $Q^* > \frac{C_a}{\overline{\theta}}$, the expected size of the adopter network is, $\overline{\theta} - \theta_a = \frac{Q^*\overline{\theta} - C_a}{Q^* - \alpha}$. Since $\partial(\frac{Q^*\overline{\theta} - C_a}{Q^* - \alpha})/\partial(Q^*) = \frac{C_a - \alpha\overline{\theta}}{(Q^* - \alpha)^2} > 0$, $\partial(\frac{Q^*\overline{\theta} - C_a}{Q^* - \alpha})/\partial(C_a) = \frac{-1}{(Q^* - \alpha)} < 0$, and $\partial(\frac{Q^*\overline{\theta} - C_a}{Q^* - \alpha})/\partial(\alpha) = \frac{Q^*\overline{\theta} - C_a}{(Q^* - \alpha)^2} > 0$, we find that the number of adopters is positively related to the total output of the upcoming standard and the strength of the network effect, and is negatively related to the adoption cost. The higher network benefit indicates the larger value an additional user brings to the other adopters as well as to itself. As a result, the expected size of the adopter network grows as the network effect among adopters becomes stronger. If $Q^* \leq \frac{C_a}{\overline{\theta}}$, no passive adopter exists.

4.2 Step 2: Developers' Optimal Investment in the Standard Consortium

During the second stage, developers simultaneously determine how much to invest in the consortium in order to maximize their profits:

$$\max_{q_\theta} \quad \theta \int_{\theta_d}^{\overline{\theta}} q_u \frac{1}{\overline{\theta}} du + \alpha(\overline{\theta} - \theta_a) - C_a + I(q_\theta, \theta) - c_d(q_\theta) - E \tag{5}$$

When we differentiate the payoff on q_θ, the first term and the second term become zero. The reason is that the population is sufficiently large that the contribution of each individual member has no impact on the magnitude of Q, that is $\frac{\partial Q}{\partial q_\theta} = 0$.

The optimal investment, q_θ^*, satisfies the first order condition:

$$\frac{\partial I(q_\theta, \theta)}{\partial q_\theta}|_{q_\theta^*} - c_d'(q_\theta^*) = 0. \tag{6}$$

The second order condition, $\frac{\partial^2 I(q_\theta,\theta)}{\partial q_\theta^2} - c_d''(q_\theta) < 0$, ensures that q_θ^* is the unique global maximum of Equation (5). Since $\frac{\partial q_\theta^*}{\partial \theta} = -\frac{\partial^2 I/\partial q_\theta^* \partial \theta}{\partial^2 I/\partial q_\theta^{*2} - c_d''(q_\theta^*)} > 0$, $\forall \theta > 0$, we can conclude that firms evaluating the standard more will work harder in the consortium to develop the standard. Since $I(q_\theta, 0) = 0$, $q_0^* = 0$. It confirms the empirical observation that firms which stand to gain the most from a standard have the strongest incentive to contribute at the highest level [25].

4.3 Step 3: The Expected Size of the Developer Network

The payoff of the marginal developer, θ_d, must satisfy two incentive compatibility constraints: the development constraint (7) and the adoption constraint (8) [21]. The development constraint ensures that the marginal developer prefers weakly active development to passive adoption. The adoption constraint illustrates that developers should expect non-negative benefits before they join the collective development of the standard.

$$\theta_d Q^* + \alpha(\overline{\theta} - \theta_a) - C_a + I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E \geq \theta_d Q^* + \alpha(\overline{\theta} - \theta_a) - C_a \tag{7}$$

$$\theta_d Q^* + \alpha(\overline{\theta} - \theta_a) - C_a + I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E \geq 0 \tag{8}$$

Lemma: *There exists a unique threshold value, $\overline{\theta}_d$, of the development constraint (See Appendix 1 for proof).*

Firms would rather develop the standard than merely adopt it if their θ is higher than or equal to $\overline{\theta_d}$; otherwise, they will choose the "wait-and-see" strategy. If the development constraint is binding, passive adopters exist in the equilibrium; if the adoption constraint is binding, there are no passive adopters in equilibrium.

Proposition 1 (Equilibrium with Passive Adopters): *When passive adopters exist after the formation of the developer network and the adopter network reaches equilibrium (i.e., $\theta_a < \theta_d$), it must be the case that all firms with incentives to develop the standard join the standard consortium, that is $\theta_d = \overline{\theta_d}$ (See Appendix 2 for proof).*

Passive adopters bring additional network benefits for all firms implementing the standard. However, from Proposition 1, we know that it is very hard to convince these passive adopters to contribute to the standard development unless the external environment changes. In addition, the existence of passive adopters affects the equilibrium of the endogenous formation of the standard consortium. In the next section, we will compare the equilibrium without passive adopters to the equilibrium with passive adopters.

Based on further analysis, we find that several exogenous variables, such as the consortium participation cost E, the adoption cost C_a, and the strength of the network effect α, can determine whether passive adopters exist or not.

Proposition 2 (Participation Cost Effect Proposition): *There are no passive adopters when the standard consortium participation cost E is too large or too small compared to the development benefit (See Appendix 3 for Proof).*

The development benefit is the difference between the insider benefit and the development cost, that is $I(q_\theta^*, \theta) - c_d(q_\theta^*)$. The development benefit is a strictly increasing function of θ, since $\partial(I(q_\theta^*, \theta) - c_d(q_\theta^*))/\partial\theta = \frac{\partial I(q_\theta^*,\theta)}{\partial\theta} > 0$. Therefore, the range of the possible development benefit lies between $(I(q_{\underline{\theta_a}}^*, \underline{\theta_a}) - c_d(q_{\underline{\theta_a}}^*))$ and $(I(q_{\overline{\theta}}^*, \overline{\theta}) - c_d(q_{\overline{\theta}}^*))$, where $\underline{\theta_a}$ is the lowest possible taste parameter of the marginal adopter and $\underline{\theta_a} = \frac{C_a - \alpha\overline{\theta}}{\int_0^{\overline{\theta}} q_\theta^* \frac{1}{\theta} d\theta - \alpha}$ (see Appendix 3 for details). When the consortium participation cost is too large compared to the development benefit, only a limited number of high-end firms, which have a high value of the standard, will join the standard consortium. As a result, the output of the forthcoming standard is low and firms outside the standard consortium have no incentive to adopt the standard. When the participation cost is too small relative to the development benefit, most firms have incentives to join the standard consortium since their development constraint holds. However, the development cost and participation cost are irreversible, so only firms with positive *ex ante* profits by using the standard will join the consortium and adopt the standard. In both cases, firms are either non adopters or the consortium members that develop and adopt the standard.

Proposition 3 (Adoption Cost and Network Externalities Effects Proposition): *It is less likely to have passive adopters in the equilibrium, as the adoption cost, C_a, increases. Similarly, it is less likely to have passive adopters in the equilibrium, as the strength of the network externalities, α, decreases.*

From Equation (7) and (8), we find that C_a and α only have impacts on the adoption constraint, not on the development constraint. As the adoption cost increases, or the strength of network externalities among adopters decreases, the adoption constraint tends to bind. Consequently, we expect to see only firms in the standard consortium adopting the standard if the adoption of the standard is difficult and costly and the network effect among adopters is relatively weak.

Proposition 4 (Increasing Return Proposition): *For firms that use the standard, their profit function, π_θ, is a strictly increasing function of θ, that is $\frac{\partial \pi_\theta}{\partial \theta} > 0$. Active developers' expected benefits increase at a higher rate than passive adopters' expected benefits (See Appendix 4 for proof).*

Firms benefit from implementing a common standard to conduct Internet-based transactions with their trading partners. Firms' payoffs are ranked according to θ, since their benefits from adopting the standard are adjusted by their intrinsic valuation of the standard. Developers' payoffs increase faster than passive adopters' payoffs since firms' participation in the standard consortium brings them valuable insider benefits. The higher a firm's intrinsic value of the standard, the more effort it will invest at the development phase, leading to a higher insider benefit.

Proposition 5 (Network Size Effect Proposition): *Social welfare increases with the size of the developer network and the size of the adopter network (See Appendix 5 for* *proof).*

Why do we care about social welfare? The reason is that the goal of e-business standard consortia can be stated as enhancing the social welfare, since most of them aim to improve the interoperability and process efficiency across firm boundaries in a specific industry or cross industries. For example, the mission of the OpenTravel Alliance, an e-business standard consortium in the travel industry, is to "help the travel industry take full advantage of the near universal access to the Internet"(http://www.opentravel.org). A larger size of the developer network leads to a higher standard output, and a larger size of the adopter network leads to increased network externalities enjoyed by all firms.

5 Two Equilibrium Structures

The previous section indicates that there are two possible equilibrium structures, one without passive adopters and one with passive adopters. In this section, we will compare these two scenarios. We find that the equilibrium structure of the standardization process behaves differently depending upon whether passive adopters exist or not. Moreover, how the change of exogenous conditions will influence the size of the developer/adopter network and the social welfare also varies in two equilibrium structures.

5.1 Case 1: The Equilibrium Without Passive Adopters

From Proposition 2, we know that there are no passive adopters, if the consortium participation cost is too large or too small relative to the development benefit. We will discuss the special case in whicn E is zero and all firms would rather become an active developer than a passive adopter. The same analysis applies when E is equal to or smaller than the lowest possible development benefit, that is $I(q^*_{\underline{\theta_a}}, \underline{\theta_a}) - c_d(q^*_{\underline{\theta_a}})$, where $\underline{\theta_a} = \frac{C_a - \alpha\overline{\theta}}{\int_0^{\overline{\theta}} q^*_\theta \frac{1}{\theta} d\theta - \alpha}$ (see Appendix 3 for details). In this case, the marginal developer/adopter is determined by the binding adoption constraint as in Equation (8).

Our analysis shows that it is ambiguous how the size of the developer/adopter network, $\overline{\theta} - \theta_d$, is going to change with external conditions. Intuitively, we expect that fewer firms will join the standard consortium and adopt the standard if it is more costly to do so, and vice versa. However, that is not always the case. When E, the participation cost, is negligible compared to the development benefits, all firms have incentives to participate in the standard consortium. However, only those with positive *ex ante* payoffs from the standard adoption would do so. While the environment becomes worse off, it is possible that a sufficient large number of lower-end firms, whose intrinsic value of the standard is low, will be motivated to develop the standards in a highly collaborative atmosphere. Consequently, the enhanced standard output and increased network effect can offset negative impacts and make it feasible for these lower-end firms to adopt the standard.

Proposition 6 (Ambiguous External Impacts Proposition): *When E is equal to or smaller than the lowest possible development benefit, it is uncertain how exogenous factors, such as the adoption cost and the network externalities, affect the equilibrium developer network size, $\overline{\theta} - \theta_d$.*

The ambiguous external impacts come from two sources. First of all, multiple equilibria exist due to the highly interactive feature caused by the endogenous formation of the standard consortium and two types of interactions between the development phase and the adoption phase. For instance, assuming $I = \delta q_\theta \theta$ and $c_d(q_\theta) = c_d q_\theta^2$ and let $\overline{\theta} = 1, \alpha = 0.35, c_d = 0.25, C_a = 0.7, \delta = 0.8$, we can solve either $\theta_d = 0.68$ or $\theta_d = 0.87$.

Secondly, the change of θ_d exhibits two opposite forces upon the marginal developer's utility (see Equation (9)). We use (+) and (-) to indicate the change of the profit function:

(a)Positive impacts: the firm's intrinsic valuation and the development benefit increase with θ_d.

(b)Negative impacts: the total output of the standard, Q^* and the network effect decrease with θ_d, since $\frac{\partial Q^*}{\partial \theta_d} = -\frac{1}{\theta} q^*_{\theta_d} < 0$.

The marginal developer's profit function is:

$$\pi_{\theta_d} = \theta_d^{(+)} Q^{*(-)} + \alpha(\overline{\theta} - \theta_d)^{(-)} + (I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}))^{(+)} - C_a = 0 \tag{9}$$

It is uncertain which force will dominate, and we cannot tell how external factors, such as α and C_a, will influence the size of the standard consortium explicitly. It suggests when the participation cost is small compared to the development benefit, we should analyze the consortium-based standard development and adoption very carefully.

Without passive adopters, the endogenous formation of the standard consortium may have multiple equilibrium structures. However, the Network Size Effect Proposition (Proposition 5) suggests that the larger the network size is, the higher the social welfare will be. To achieve this goal, an aggressive consortium initiative effort is recommended. With better promotion, marketing, and member education, more firms especially those have a low value of the standard will be encouraged to join the consortium and adopt the standard later on [29]. Consequently, the equilibrium with a larger network size will be more likely to reach.

In reality, the case of small participation cost rarely happens since the cost to participate in consortium activities is nontrivial [25] and e-business standard initiatives are risky [14].

5.2 Case 2: The Equilibrium With Passive Adopters

From Proposition 2 and 3, we know that passive adopters may exist when the participation cost is not extreme compared to the development benefit, and the adoption cost is small or negligible relative to the highest stand-alone benefit of implementing the standard, $\overline{\theta}Q^*$. The stand-alone benefits firms expect to receive from common B2B standards include but not limited to technology value, process efficiency improvement, and enhanced relationship with trading partners [3].

In the equilibrium with passive adopters, both θ_a and θ_d are positively related to E (See Appendix 3). It means that when the risk and cost associated with participating in the standard consortium increase, the size of the developer network and the size of the adopter network will shrink simultaneously. Combined with Proposition 5, we have the following:

Proposition 7 (Participation Cost and Social Welfare Proposition): *If there are passive adopters in the equilibrium, social welfare is negatively associated with the consortium participation cost, E (See Appendix 6 for proof).*

As we discuss before, there are two primary sources of the consortium participation cost: (1) the membership fee charged by the standard consortium; (2)uncertainty towards the standard acceptance. In order to encourage participation in both standard development and adoption and increase social welfare, a standard consortium can apply the following two strategies. The first strategy is to cut the fixed adminstration and development costs shared by all members and only charge members the amount necessary to support the operation of the standard consortium. In reality, most standard consortia are formed as non-profit organizations. The second strategy is to reduce the uncertainties of the underlying technologies. For example, most e-business standard consortia started to work on XML-based standards after the W3C consortium published the first XML specification in 1998 [38]. Industry-specific standard consortia, such as RosettaNet and OpenTravel Alliance, collaborate with cross-industry standard consortia, such as ebXML, to ease firms' concern to apply the standard with supply chain partners in other sectors.

6 Concluding Comments

6.1 Theoretical Contributions

Our study has made several theoretical contributions to understanding the consortium-based e-business standardization process. First of all, we identify and examine the double-sided interactions between the development stage and the adoption stage. Firms develop e-business standards in order to share data electronically within and across firm boundaries. They have to make two important and related strategic decisions: whether to get involved in the standard development and whether to adopt the forthcoming standard. At the development stage, the aggregate contribution from all developers determines the total output of the standard, which directly relate to the stand-alone benefit firms can obtain from adopting the standard. Later on, the number of total adopters affects firms' payoffs from implementing the standard due to positive network externalities among them. Consequently, developers should envision the impact of their actions on firms outside the standard consortium.

Second, we conduct a cost-benefit analysis to study the endogenous formation of a developer network and an adopter network in the standardization process. Rational firms will join the standard consortium if and only if, *ex ante*, the expected payoff is higher than otherwise. Firms act as passive adopters if and only if doing so is better than being a developer or a non-adopter. To study firms' strategic choices, we first need to understand benefits as well as costs associated with the standard development and adoption. Compared to passive adopters, developers enjoy the insider benefit but they also incur the development cost and consortium participation cost. To become a developer, a firm's payoff must satisfy two incentive compatibility constraints: the development constraint and the adoption constraint.

Third, we characterize the equilibrium conditions of the e-business standardization process. There are two possible equilibrium structures, one without passive adopters and one with passive adopters, which behave quite differently. When there are no passive adopters, multiple equilibria may exist and it is ambiguous how the change of exogenous conditions will affect the size of the developer/adopter network and social welfare. With passive adopters, the game has a unique equilibrium. Since the expected social welfare is negatively associated to the consortium participation cost, a standard consortium should charge minimal membership fees and reduce underlying technological uncertainty faced by the standard.

Fourth, our approach emphasizes the collaborative feature of e-business standardization while most previous studies only focus on the negotiation aspect between competing standard proposals. In e-business, firms often need to develop the standard from scratch to capture the rapid technology development, in which case their vested interest is limited. E-business standards specify interfirm processes, which usually involve parties from multiple sectors. For example, a traveler's itinerary may be handled by airlines, hotels, and car rental companies. Consequently, the development of e-business standards requires inputs and cooperation from related companies. We model the cooperative development of e-business standards as a collective action, where the output of the standard is jointly supplied by developers' individual investments in the consortium.

Finally, our analysis reveals the important role of passive adopters. Although passive adopters do not contribute to the standard development directly, they provide value to developers through positive network effects. However, we do not necessarily observe passive adopters in the consortium-based standardization, which is counterintuitive. Our findings (Proposition 2 and Proposition 3) suggest conditions under which passive adopters are likely to exist in the equilibrium. The existence of passive adopters will determine how external environment affects the formation of the standard consortium and social welfare.

Our model setup is general and can be extended to study similar problems sharing two key features. First, a public good is produced with private provision from voluntary members. Second, developers of the public good benefit directly from their contribution in the consortium, and positive network externalities exist among adopters. An example is the open source software phenomenon.

6.2 Discussion of the Findings

In addition to theoretical contributions, we also shed lights on the management of e-business standard consortia, which coordinate developers' efforts to establish the standard.

Members' contribution is critical to the sustainability and success of standard consortia. Our analysis suggests three ways to enhance firms' individual investments in the consortium. The first is to increase firms' awareness of the potential benefits brought by the standard (i.e., θ), as firms that value the standard more will work harder. For example, on its website, RosettaNet clearly states the value of its standard as "reductions in cycle time, reductions in inventory cost, improves productivity through automation, standardizes and simplifies business processes, and measurable supply chain return on investment"(http://www.rosettanet.org). The standard consortium can also motivate firms' effort via improving the marginal inside benefit of its members. Standard consortia achieve this through assigning voting rights to members to shape the outcomes of the standard development, summarizing collective experience of standard implementation, and providing exclusive resources to members only [25; 30]. It is thus not surprising to observe many e-business standard consortia incorporate a "membership benefits" section in their websites. Finally, standard consortia need to reduce the marginal development cost incurred by its members. For instance, more and more standard consortia adopt Internet technologies, such as electronic mailing lists and online forums, to facilitate technical collaboration among geographically dispersed members [20].

Empirical observations show that many e-business standard consortia have passive adopters, who use the standard but do not contribute to its development [18]. It is very challenging to convince passive adopters to participate in development, since all firms with incentives to develop the standard have already done so in equilibrium (Proposition 1). We have interviewed the IT director at a regional hospital, which is implementing the standard published by Health Level 7 (HL7, http://www.hl7.org), a healthcare standard consortium. While being enthusiastic about the potential benefits of the HL7 standard, the IT director showed little interest in participating in HL7 since he saw limited value from doing so. In order to have a growing membership, a standard consortium must change external environment it works in, such as reducing the consortium participation cost and enhancing firms' intrinsic valuation of the standard through promotion and education.

Network externalities are an important concept in the literature of standards [1; 6; 9; 13]. Our model indicates that network externalities not only affect firms' payoffs from the standard adoption, but also influence the equilibrium structure of the formation of the developer network and the adopter network (Proposition 3). However, it has no impact on firms' optimal investment level in the standard consortium.

In the model, we assume that there are a large number of firms interested in the forthcoming standard. For a large N, an individual firm's contribution has negligible impacts on the overall output of the standard, and firms' optimal investment in the standard consortium is a continuous function of their type, θ. However, in some cases, the number of potential standards adopters is limited. For example, AgXML is a standard consortium in the grain and oilseed industry, itself a narrow industry sector. When N is small, a firm's effort within the consortium not only changes its development cost and insider benefit, but also alters the resulting standard output in a much more significant way. We can easily extend our analysis to the discrete case, in which the number of firms is limited. Using a two-firm game as an example, we can illustrate that our results are robust in the case of a small N [2].

6.3 Limitations and Future Research

There are several limitations in our model setup which require further exploration. In our model, firms are heterogenous only due to their intrinsic valuation towards the standard.

[2] Proof can be provided based on request.

However, there also exist major distinctions between the users groups and IT vendors, such as the purpose to join the standard consortium and gains from the standard compliance. Both users and IT vendors play important roles in e-business standardization. For instance, in the Association for Cooperative Operations Research and Development (ACORD), a standard association in the insurance industry, nearly half of its members are insurance companies while the other half are solution providers (http://www.acord.org). We need future studies to examine strategic interactions between these two types of firms at both the development stage and the adoption stage, since traditional IT standard studies only analyze the interdependence between vendors and users in standard adoption [12].

In this paper, we only consider the formation of a single standard consortium among firms sharing similar interests in the upcoming standard. However, certain industries, such as the financial services industry, have more than one standard consortium working on e-business standards that may have significant overlap over one another. Multiple consortia may emerge due to various reasons, such as the lack of industry-wide coordination and intensive rivalry among firms. Consortia competition affects procedures and strategies employed by standard consortia [5] and firms' participation strategies [2]. Additional work should examine how consortia competition will influence the development and adoption of e-business standards. One possible extension of the current model is to move beyond the static model to include the sequential formation of multiple consortia.

We implicitly assume that firms make their adoption decisions simultaneously and voluntarily. In reality, many firms, especially passive adopters, implement the standard due to the strong influence or even enforcement from their trading partners [4]. Leading adopters or initiators can also use a subsidizing policy to encourage followers to install new e-business standards [31]. Also requiring further investigation are developers' tactics deployed in the standard adoption stage, which will affect the endogenous formation of the developer network as well as the adopter network.

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Appendix

Appendix 1 (Proof for Lemma): *There exists a unique threshold value, $\overline{\theta}_d$, of the development constraint.*

A developer's development constraint is: $I(q^*_\theta, \theta) - c_d(q^*_\theta) - E \geq 0$. Since $\partial(I(q^*_\theta, \theta) - c_d(q^*_\theta) - E)/(\partial\theta) = \frac{\partial I(q^*_\theta, \theta)}{\partial\theta} > 0$, the development constraint is a strictly increasing function of θ. Let $\overline{\theta_d}$ denote the value where the development constraint (Equation (7)) is binding. Firms would rather develop the standard than merely adopt it if their type, θ, is higher than or equal to $\overline{\theta_d}$; otherwise, they will choose to "wait-and-see".

If $I(q^*_0, 0) - c_d(q^*_0) - E \geq 0$, then the development constraint holds for all firms, and $\overline{\theta_d} = 0$.

If $I(q^*_{\overline{\theta_d}}, \overline{\theta_d}) - c_d(q^*_{\overline{\theta_d}}) - E = 0$ and $0 < \overline{\theta_d} < \overline{\theta}$, the development constraint holds for all θ, s.t. $\overline{\theta_d} \leq \theta \leq \overline{\theta}$.

If $I(q^*_{\overline{\theta_d}}, \overline{\theta_d}) - c_d(q^*_{\overline{\theta_d}}) - E = 0$, and $\overline{\theta_d} \geq \overline{\theta}$, no firm has the incentive to develop the standard. $\square$

Appendix 2 (Proof for Proposition 1): *When passive adopters exist after the formation of the developer network and the adopter network reaches equilibrium (i.e., $\theta_a < \theta_d$), it must be the case that all firms with incentives to develop the standard join the standard consortium, that is $\theta_d = \overline{\theta_d}$*

From Appendix 1, we know that $\theta_d \geq \overline{\theta_d}$. There are two possible scenarios of the equilibrium network structure (Figure 2).

Table 1: A Table of Notation

Notation	Explanation
θ	Firms' intrinsic value of the standard, representing the type of a firm.
q_θ	A type-θ firm's effort invested in the standard consortium.
$c_d(q_\theta)$	The development cost incurred by a type-θ firm.
$I(q_\theta, \theta)$	The insider benefit obtained by a type-θ firm.
E	The consortium participation cost and risk incurred by all developers.
Q	The resulting level of production of the standard.
C_a	The adoption cost incurred by all adopters.
α	The strength of the network effect among standard adopters.
θ_a	The marginal adopter.
θ_d	The marginal developer.
π_θ	A type-θ firm's profit function.
$\overline{\theta_d}$	The unique threshold value of the development constraint.
Π	The social welfare.

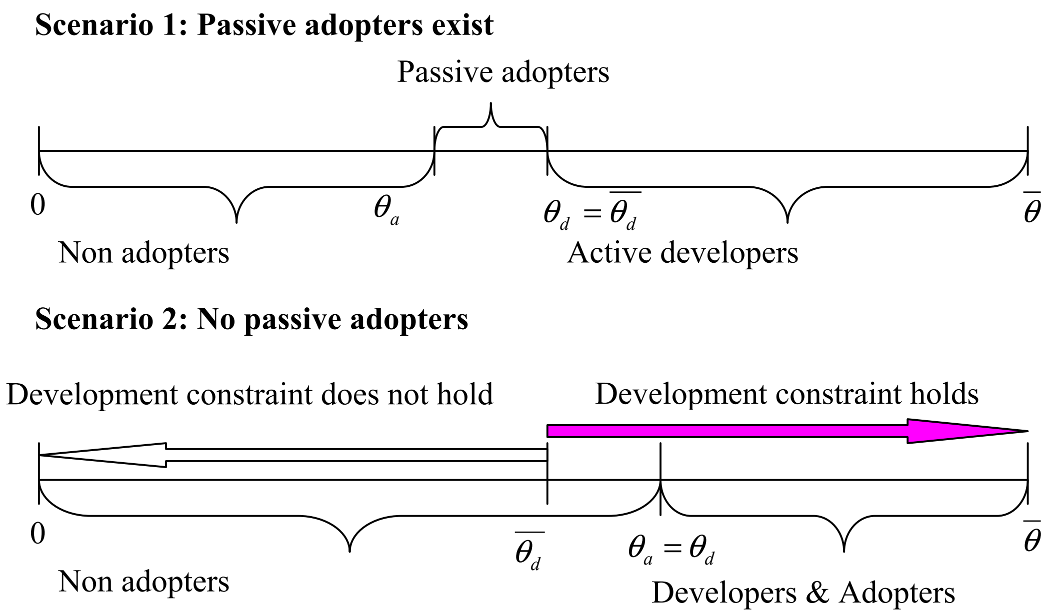

Figure 2: Two Scenarios of the Equilibrium Network Structures

Figure 2: Two Scenarios of the Equilibrium Network Structures

Scenario 1: $\theta_d = \overline{\theta_d}$. When the development constraint is binding, all firms with incentives to develop the standard join the consortium. If $\theta_a < \theta_d$, passive adopters exist, whose proportion is, $\theta_d - \theta_a$. Otherwise, $\theta_a = \theta_d$, there are no passive adopters in the network.

Scenario 2: $\theta_d > \overline{\theta_d}$, it must satisfy that $\theta_a = \theta_d$. Assume that $\theta_a < \theta_d$, then there exist passive adopters whose types are between $\overline{\theta_d}$ and θ_d. The development constraint holds for these firms, which contradicts the equilibrium conditions. □

Appendix 3 (Proof for Proposition 2): *There are no passive adopters when the standard consortium participation cost E is too large or too small compared to the development benefit.*

From the proof in Appendix 1, we know that $I(q^*_\theta, \theta) - c_d(q^*_\theta)$ is a strictly increasing function of θ.

If $E \geq I(q^*_{\overline{\theta}}, \overline{\theta}) - c_d(q^*_{\overline{\theta}}) = \overline{E}$, no firm has the incentive to develop the standard. The standard will not be developed at all ($Q^* = 0$), and there are no adopting firms.

$\underline{E} = I(q^*_0, 0) - c_d(q^*_0) = 0$. If there is no participation cost (i.e., $E = \underline{E} = 0$), every firm has the incentive to become a developer rather than a passive adopter. Therefore, firms either choose to become a developer in the standard consortium or they choose not to adopt the standard at all, that is $\theta_a = \theta_d$.

If $0 < E < \overline{E}$, the development constraint holds for firms whose $\theta \geq \overline{\theta_d}$. The larger the E is, the larger the threshold of the development constraint, since $\frac{\partial \overline{\theta_d}}{\partial E} = \frac{1}{\partial I / \partial \overline{\theta_d}} > 0$. From Proposition 1, we know that the only condition under which passive adopters exist in equilibrium is:

$$0 \leq \theta_a < \theta_d = \overline{\theta_d} \leq \overline{\theta}$$

$\theta_a = \frac{C_a - \alpha\overline{\theta}}{Q^* - \alpha}$, where $Q^* = \int_{\overline{\theta_d}}^{\overline{\theta}} q^*_\theta \frac{1}{\overline{\theta}} d\theta$. Since $\frac{\partial Q^*}{\partial E} = q^*_{\overline{\theta_d}} \frac{1}{\overline{\theta}} (-\frac{1}{\partial I / \partial \overline{\theta_d}}) < 0$, Q^* is a decreasing function of E. Therefore, for $0 < E < \overline{E}$, $0 < Q^* < \int_0^{\overline{\theta}} q^*_\theta \frac{1}{\overline{\theta}} d\theta$. Define $\overline{Q^*} = \int_0^{\overline{\theta}} q^*_\theta \frac{1}{\overline{\theta}} d\theta$, which is the highest possible outcome of the standard production.

There exists E_1, s.t. $Q^* = \frac{C_a}{\overline{\theta}}$, and $E_1 < \overline{E}$.

If $E \geq E_1$, there is no valid solution for θ_a. Therefore, no passive adopter exists. We should expect $\overline{Q^*} > \frac{C_a}{\overline{\theta}}$, for a well defined problem. Otherwise, firms' intrinsic valuation of the standard is smaller than the adoption cost even when all firms join and contribute to the standard development.

For $\overline{Q^*} > \frac{C_a}{\overline{\theta}}$, $0 < \underline{\theta_a} < \overline{\theta}$, where $\underline{\theta_a} = \frac{C_a - \alpha\overline{\theta}}{\overline{Q^*} - \alpha}$. There exists E_2, s.t. $I(q^*_{\underline{\theta_a}}, \underline{\theta_a}) - c_d(q^*_{\underline{\theta_a}}) - E_2 = 0$, and $E_2 > \underline{E}$. As E increases from $\underline{E}$ to E_2, $\overline{\theta_d}$ increases from 0 to $\underline{\theta_a}$. However θ_a is strictly larger than $\underline{\theta_a}$, since $\frac{\partial \theta_a}{\partial E} = \frac{-C_a + \alpha\overline{\theta}}{(Q^* - \alpha)^2} \frac{\partial Q^*}{\partial E} > 0$. Therefore, there are no passive adopters if $E \leq E_2$. We can think $\underline{\theta_a}$ as the lowest possible taste parameter of the marginal adopter. By the same token, $I(q^*_{\underline{\theta_a}}, \underline{\theta_a}) - c_d(q^*_{\underline{\theta_a}})$ or E_2 represents the lowest possible development benefit a firm can obtain.

In summary, (1) if $E \leq E_2$ or $E \geq E_1$, all firms adopting the standard have the incentive to develop the standard. There are no passive adopters exist in equilibrium. (2) If $E \geq \overline{E}$, the standard will not be developed at all. (3) If $E_2 < E < E_1$, passive adopters may exist. □

Appendix 4 (Proof for Proposition 4): *For firms that use the standard, their profit function, π_θ, is a strictly increasing function of θ, that is $\frac{\partial \pi_\theta}{\partial \theta} > 0$. Active developers' expected benefits increase at a higher rate than passive adopters' expected benefits.*

We prove it in two scenarios:

Scenario 1: no passive adopters ($\theta_a = \theta_d$).

A firm's profit function is:

$$\pi_\theta = \theta Q^* + \alpha(\overline{\theta} - \theta_d) - C_a + I(q^*_\theta, \theta) - c_d(q^*_\theta) - E,$$

$$\frac{\partial \pi_\theta}{\partial \theta} = Q^* + \frac{\partial I(q^*_\theta, \theta)}{\partial \theta} > 0.$$

Scenario 2: with passive adopters ($\theta_a < \theta_d$)

A passive adopter's profit function is:

$$\pi_\theta = \theta Q^* + \alpha(\overline{\theta} - \theta_a) - C_a,$$

$$\text{where } \frac{\partial \pi_\theta}{\partial \theta} = Q^* > 0,$$

Developers' profit function is:

$$\pi_\theta = \theta Q^* + \alpha(\overline{\theta} - \theta_a) - C_a + I(q^*_\theta, \theta) - c_d(q^*_\theta) - E.$$

$$\text{Therefore, } \frac{\partial \pi_\theta}{\partial \theta}|_{\theta_d \le \theta \le \overline{\theta}} = Q^* + \frac{\partial I(q^*_\theta, \theta)}{\partial \theta} > Q^* = \frac{\partial \pi_\theta}{\partial \theta}|_{\theta_a \le \theta < \theta_d}.$$

□

Appendix 5 (Proof for Proposition 5): *Social welfare increases with the size of the developer network and the size of the adopter network.*

Again, we prove it in two scenarios:

Scenario 1: no passive adopters ($\theta_a = \theta_d$).

The social welfare, Π, defined as the sum of all members' payoffs, is:

$$\begin{aligned} \Pi &= \int_{\theta_d}^{\overline{\theta}} \pi_\theta f(\theta) d\theta \\ &= \frac{1}{\overline{\theta}} \int_{\theta_d}^{\overline{\theta}} (\theta Q^* + \alpha(\overline{\theta} - \theta_d) - C_a + I(q^*_\theta, \theta) - c_d(q^*_\theta) - E) d\theta \end{aligned}$$

Then,

$$\begin{aligned} \frac{\partial \Pi}{\partial \theta_d} &= \frac{1}{\overline{\theta}} [\frac{\overline{\theta}^2 - \theta_d^2}{2} \frac{\partial Q^*}{\partial \theta_d} - \alpha(\overline{\theta} - \theta_d)] \\ &- \frac{1}{\overline{\theta}} [\theta_d Q^* + \alpha(\overline{\theta} - \theta_d) - C_a + I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E] \end{aligned}$$

Since $\theta_d Q^* + \alpha(\overline{\theta} - \theta_d) - C_a + I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E = 0$, we have:

$$\frac{\partial \Pi}{\partial \theta_d} = \frac{1}{\overline{\theta}} [\frac{\overline{\theta}^2 - \theta_d^2}{2} (-\frac{1}{\overline{\theta}} q^*_{\theta_d}) - \alpha(\overline{\theta} - \theta_d)] < 0.$$

Scenario 2: with passive adopters ($\theta_a < \theta_d$)

$$\Pi = \frac{1}{\overline{\theta}} [\int_{\theta_a}^{\overline{\theta}} (\theta Q^* + \alpha(\overline{\theta} - \theta_a) - C_a) d\theta + \int_{\theta_d}^{\overline{\theta}} (I(q^*_\theta, \theta) - c_d(q^*_\theta) - E) d\theta]$$

Then,

$$\frac{\partial \Pi}{\partial \theta_a} = \frac{1}{\overline{\theta}} [-\alpha(\overline{\theta} - \theta_a) - (\theta_a Q^* + \alpha(\overline{\theta} - \theta_a) - C_a)]$$

$$\frac{\partial \Pi}{\partial \theta_d} = \frac{1}{\overline{\theta}} [\frac{\overline{\theta}^2 - \theta_d^2}{2} \frac{\partial Q^*}{\partial \theta_d} - (I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E)]$$

Since $\theta_a Q^* + \alpha(\overline{\theta} - \theta_a) - C_a = 0$, and $I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E = 0$, we have:

$$\frac{\partial \Pi}{\partial \theta_a} = \frac{-\alpha}{\overline{\theta}}(\overline{\theta} - \theta_a) < 0$$

$$\frac{\partial \Pi}{\partial \theta_d} = \frac{-1}{\overline{\theta}^2}(\frac{\overline{\theta}^2 - \theta_d^2}{2} q^*_{\theta_d}) < 0$$

□

Appendix 6 (Proof for Proposition 7): *If there are passive adopters in the equilibrium, social welfare is negatively associated with the consortium participation cost, E.*

With passive adopters ($\theta_a < \theta_d$):

$$\Pi = \frac{1}{\overline{\theta}}[\int_{\theta_a}^{\overline{\theta}} (\theta Q^* + \alpha(\overline{\theta} - \theta_a) - C_a) d\theta + \int_{\theta_d}^{\overline{\theta}} (I(q^*_\theta, \theta) - c_d(q^*_\theta) - E) d\theta]$$

Then:

$$\begin{aligned} \frac{\partial \Pi}{\partial E} &= \frac{\partial Q^*}{\partial E}\frac{(\overline{\theta}^2 - {\theta_a}^2)}{2} + \frac{\partial \theta_a}{\partial E}[-\alpha(\overline{\theta} - \theta_a) - (\theta_a Q^* + \alpha(\overline{\theta} - \theta_a) - C_a)] \\ &- \frac{\partial \theta_d}{\partial E}[I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E] - (\overline{\theta} - \theta_d). \end{aligned}$$

Since

$$\begin{aligned} \frac{\partial Q^*}{\partial E} &< 0 \\ \frac{\partial \theta_a}{\partial E} &> 0 \\ \frac{\partial \theta_d}{\partial E} &> 0 \\ \theta_a Q^* + \alpha(\overline{\theta} - \theta_a) - C_a &= 0 \\ I(q^*_{\theta_d}, \theta_d) - c_d(q^*_{\theta_d}) - E &= 0, \end{aligned}$$

we have:

$$\frac{\partial \Pi}{\partial E} < 0.$$

□