The role of online leadership in open collaborative innovation

Evidence from blockchain open source projects

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Abstract

Purpose – The purpose of this paper is to investigate the roles of online leadership in open collaborative innovation success by extending functional leadership theory in the context of open source projects.

Design/methodology/approach – This study uses negative binomial regression models to empirically test the proposed hypotheses with samples of blockchain open source projects on GitHub.

Findings – The results indicate that task-oriented leadership behaviors in forms of technical contributions have little influence on open collaborative innovation success; relation-oriented leadership behaviors embedded in internal social capital and external social capital contribute to open collaborative innovation success prominently. Furthermore, the joint effects of technical contributions, internal social capital and community commitment with openness orientation are positively significant on open collaborative innovation success, respectively.

Practical implications – For leaders and participants of open collaborative innovation projects, they should attach importance to both leadership behaviors and the joint effects with openness orientation so as to make informed decisions.

Originality/value – This study offers a new fine-grained framework of open collaborative innovation success by investigating specific dimensions of task-oriented and relation-orientated leadership behaviors, as well as their joint effects with openness orientation.

Keywords Open source, Online leadership, Blockchain innovation, Functional leadership theory, Open collaborative innovation, Openness orientation

Paper type Research paper

1. Introduction

Advances in information and communication technologies have transformed innovation approaches (Faraj *et al.*, 2011; Li *et al.*, 2018; Von Krogh *et al.*, 2012; Zhu *et al.*, 2013). Traditional producer-centered and closed innovation is being replaced by internet-mediated open collaborative innovation, which involves participants distributed worldwide sharing their knowledge and skills, cooperating with each other to accomplish a common innovation goal (Baldwin and von Hippel, 2011; Levine and Prietula, 2014; Luther and Bruckman, 2011).

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Open source software, Wikipedia and crowdsourcing are among the most representative types of open collaborative innovation. Although large quantities of innovative products such as Linux, MySQL and OpenOffice have been generated by means of open collaborative innovation (Daniel and Stewart, 2016; Johnson *et al.*, 2015), the high failure rate has also received much attention (Ehls, 2017; Lee *et al.*, 2019). Thus, what contributes to the success or failure of open collaborative innovation has become a fascinating and urgent question to explore.

Compared with traditional innovation activities, open collaborative innovation is characterized by self-organizing, voluntary participation, flattened hierarchies and loose coordination (Dahlander and O'Mahony, 2011; Faraj *et al.*, 2015; Von Krogh *et al.*, 2012). In fact, open collaborative innovation mostly takes place in online communities where members can freely participate or leave with no mandatory punishments or monetary incentives (Johnson *et al.*, 2015; Oh *et al.*, 2016). Evidence shows that the rate of membership turnover is extremely highly for open collaborative innovation (Qin *et al.*, 2014; Ransbotham and Kane, 2011). Meanwhile, peer influence instead of formal authority plays a critical role in the coordination of open collaborative innovation activities (Oh and Jeon, 2007). As a result, open collaborative innovation projects seem to be "fluid" and "leaderless" organizations (Faraj *et al.*, 2011; Johnson *et al.*, 2015; Oh *et al.*, 2016). Nevertheless, leaders do exist in open collaborative innovation projects, and the influence of online leadership is even stronger than in traditional face-to-face contexts (Fleming and Waguespack, 2007; Purvanova and Bono, 2009).

In open collaborative innovation, leaders are defined as those who initiate projects, inherit the ownership or administrative rights of projects from others, or become leaders because of peer-based recognition (Bock *et al.*, 2008; Li *et al.*, 2012; Oh *et al.*, 2016). For instance, open source software projects have at least one project leader who sets up the overall project agenda, coordinates software development procedures and retains more participants (Dahlander and O'Mahony, 2011; Xu *et al.*, 2009). Existing research tends to concentrate more on the emergence of online leadership than its effectiveness (Dahlander and O'Mahony, 2011; Faraj *et al.*, 2015; Fleming and Waguespack, 2007). Meanwhile, even though a few studies have begun to examine the effectiveness of online leadership, they fail to go deeper by distinguishing specific dimensions of online leadership (Bock *et al.*, 2008; Oh *et al.*, 2016). As a result, we still lack a good understanding of the roles of online leadership in open collaborative innovation.

We set out to investigate how online leadership influences open collaborative innovation success with a comprehensive framework. Drawing on functional leadership theory, leadership is a set of leader behaviors that contribute to the goals, processes and outcomes of an organization (e.g. a team, a project, etc.) (Burke *et al.*, 2006; Johnson *et al.*, 2015; Morgeson *et al.*, 2010). Although different taxonomies of leadership behaviors exist (Yukl *et al.*, 2002; Yukl, 2012), task-oriented leadership behaviors which provide guidance for problem solving and relation-oriented leadership behaviors which promote member interaction and commitment best fit for the context of open collaborative innovation (Baldwin and von Hippel, 2011; Bock *et al.*, 2008; Levine and Prietula, 2014). Meanwhile, the taxonomy of task-oriented and relation-oriented leadership behaviors originates from the classical Ohio State and Michigan research streams of functional leadership theory, which is most widely accepted in academia (Fleishman *et al.*, 1991; Stogdill, 1950). Therefore, we mainly focus on project leaders' task-oriented leadership behaviors and relation-oriented leadership behaviors in this study.

Besides task-oriented and relation-oriented leadership behaviors, leadership effectiveness also depends much on the design of a team' work (Hackman *et al.*, 2009; Hernandez *et al.*, 2011). Regarding open collaborative innovation projects, openness orientation is a prominent feature which reflects the principles and requirements for collaboration, acting as an enabling structure for project success (Belenzon and Schankerman, 2015; Singh and Phelps, 2013; Stewart *et al.*, 2006). Nevertheless, whether openness is blessing or curse for open collaborative

innovation requires deeper investigation and more evidence. What is more, according to functional leadership theory, the effectiveness of leadership behaviors varies under different levels of situational factors (Burke *et al.*, 2006; Hernandez *et al.*, 2011; Morgeson *et al.*, 2010). As the institutional arrangement for collaboration and resource sharing within open collaborative innovation projects, openness orientation also intervenes in the functioning of leadership behaviors (Baldwin and von Hippel, 2011; Belenzon and Schankerman, 2015; Shaikh and Vaast, 2016). Therefore, we further integrate literature on openness orientation with functional leadership theory by investigating both the direct and contingent effects of project-level openness orientation, so as to draw a full picture of leadership effectiveness in the contexts of open collaborative innovation.

2. Theoretical background

2.1 Open collaborative innovation

Open collaborative innovation is defined as a system of innovation that involves loosely coordinated participants sharing knowledge, generating creative outputs collectively and making the outputs available to contributors and non-contributors alike through internet-mediated platforms (Baldwin and von Hippel, 2011; Levine and Prietula, 2014; Luther and Bruckman, 2011). The sustainability of open collaborative innovation greatly depends on continued participation and contribution of participants (Ho and Rai, 2017; Oh *et al.*, 2016). There are basically two research streams focusing on the determinants of open collaborative innovation success. The first research stream investigates motivations of participants. For instance, Von Krogh *et al.* (2012) categorized open source developers' motivations into specific dimensions including intrinsic motivations, extrinsic motivations and internalized extrinsic motivations. Belenzon and Schankerman (2015) examined the roles of pure intrinsic motivations, reputation and labor market signaling in open source projects. Another research stream concentrates on network ties of participants. If participants are involved in more than two different open collaborative innovation projects, then network ties will be built between these projects (Peng *et al.*, 2013; Wasko and Faraj, 2005). Singh *et al.* (2011) distinguished the effects of internal cohesion and external cohesion for open source projects. Daniel *et al.* (2018) argued that internal social capital and external social capital complement each other in open collaborative innovation.

Although these two research streams on motivations and network ties illuminate the sources of open collaborative innovation success to some extent, they consider all participants have equal influence, which contradicts the core-peripheral participation structures in open collaborative innovation (Preece and Shneiderman, 2009; Setia *et al.*, 2012). Existing research tends to focus more on the general participants, giving inadequate attention to the roles of leaders. Leaders in open collaborative innovation, because of their central location or expertise, are bound to exert more prominent influence (Hernandez *et al.*, 2011; Kayworth and Leidner, 2002; Lee *et al.*, 2019). A few studies have begun to attach importance to the roles of leaders in online contexts. For instance, Bock *et al.* (2008) examined the influence of perceived leadership styles on members' motivations in non-work-related virtual communities and concluded that the perception of leaders' consideration and initiating structure positively influences members' motivation. In the context of open collaborative innovation, because of knowledge intensiveness and participant diversification, project leaders play indispensable roles (Dahlander and O'Mahony, 2011; Fleming and Waguespack, 2007; O'Mahony and Ferraro, 2007).

2.2 Functional leadership theory

According to traditional functional leadership theory (Burke *et al.*, 2006; Fleishman *et al.*, 1991; Stogdill, 1950), leadership is considered as a set of behaviors that complete tasks and

contribute to the goals of an organization (Johnson *et al.*, 2015; Koohang *et al.*, 2017; Morgeson *et al.*, 2010). Morgeson *et al.* (2010) summarized 15 types of leadership functions including defining missions, training and developing teams, and supporting social climate. Different leadership functions correspond to task-oriented or relation-oriented leadership behaviors (Burke *et al.*, 2006; Fleishman *et al.*, 1991). These two categories of leadership behaviors have been included as critical dimensions in the hierarchical taxonomy of leadership behaviors (Yukl *et al.*, 2002; Yukl, 2012). Nevertheless, the effectiveness of leadership behaviors is not always consistent and it is contingent on factors such as task dependence and the design of work (Burke *et al.*, 2006; Morgeson *et al.*, 2010). These studies build strong foundations to understand leader behaviors and complement existing trait-based leadership theories (Hernandez *et al.*, 2011).

Functional leadership theory has much potential to be applied in the internet-mediated online contexts. For instance, Fan *et al.* (2014) distinguished between direction-giving instructions and empathetic language of leaders in virtual teams, which is similar to task-oriented and relation-oriented leadership behaviors in functional leadership theory. Faraj *et al.* (2015) concluded that participants with more knowledge contributions and higher level of structural social capital have a better chance of being identified as leaders in Usenet newsgroups. Dahlander and O'Mahony (2011) discovered that individuals' technical contributions and coordination work positively affect developers' progress toward bilateral authority in open source communities.

As open collaborative innovation is knowledge intensive (Levine and Prietula, 2014; Luther and Bruckman, 2011), project leaders with more technical expertise are assumed to be better at task-oriented leadership behaviors (Dahlander and O'Mahony, 2011; Fleming and Waguespack, 2007). Relation-oriented leadership behaviors embedded in the social capital and community commitment of project leaders are also critical for open collaborative innovation success (Bateman *et al.*, 2011; Daniel *et al.*, 2018), as they help align participants' motivations with the goals of projects (Peng *et al.*, 2013; Von Krogh *et al.*, 2012). Meanwhile, compared with traditional innovation, internet-mediated open collaborative innovation is featured with openness orientation which sets basic rules of value creation and value appropriation and acts as a critical antecedent for project success (August *et al.*, 2018; Singh and Phelps, 2013). As openness orientation also resembles contingency factors of the design of work in functional leadership theory (Burke *et al.*, 2006; Morgeson *et al.*, 2010), it is meaningful to juxtapose both the direct and contingency effects of openness orientation in the same framework. By integrating leadership behaviors with projects' openness orientation, we thus extend traditional leadership theory into the relatively new context of open collaborative innovation.

3. Hypotheses

Extending functional leadership theory into the context of open collaborative innovation (Burke *et al.*, 2006; Fleishman *et al.*, 1991; Morgeson *et al.*, 2010), we propose a comprehensive research framework to elaborate leadership effectiveness in open collaborative innovation success by distinguishing between task-oriented and relation-oriented leadership behaviors. Meanwhile, the direct and contingent effects of openness orientation will also be investigated.

3.1 Task-oriented leadership behaviors

Task-oriented leadership behaviors provide directions and solutions for tasks within teams or projects (Bock *et al.*, 2008; Fleishman *et al.*, 1991). Tasks of open collaborative innovation are usually knowledge intensive, requiring leaders equipped with much expertise and experience (Fleming and Waguespack, 2007; Luther and Bruckman, 2011). For project leaders who have made substantial technical contributions in open collaborative innovation communities, they can engage themselves in effective task-oriented leadership behaviors,

thus attracting more contributors and leading to project success. Such kind of effect can be explained with both modeling and signaling effects.

On the one hand, open collaborative innovation communities think highly of technical expertise and technical contributions (Fleming and Waguespack, 2007; Zhu *et al.*, 2013). Open collaborative innovation is a complex system composed of modules with labor divisions (Baldwin and Clark, 2006; Baldwin and von Hippel, 2011). Leaders with strong technical expertise are capable of integrating different modules efficiently (Daniel and Stewart, 2016). It is widely acknowledged that peer pressure and herding are common in online communities (Oh and Jeon, 2007). Participants in open collaborative innovation communities tend to make inferences about others', especially leaders' behaviors before making their own contributions (Dabbish *et al.*, 2012). Thus, technical contributions of project leaders will incentivize other participants' contributions.

On the other hand, leaders' technical contributions also signal the quality and trustworthiness of open collaborative innovation projects (Dahlander and O'Mahony, 2011). With the proliferation of projects in open collaborative innovation communities, choosing projects with great potential can be a big challenge for participants. Technical contributions of project leaders can mitigate such information asymmetry, as leaders who have contributed more in open collaborative innovation communities are better at project quality control (Ho and Rai, 2017; Lerner and Tirole, 2005). Evidence shows that leaders with more contributions usually have more expertise and provide satisfactory feedback, thus helping attract more participants (Moon and Sproull, 2008). Therefore, task-oriented leadership behaviors in the form of technical contributions can promote open collaborative innovation project success:

H1. Technical contributions of project leaders are positively related to open collaborative innovation project success.

3.2 Relation-oriented leadership behaviors

Relation-oriented leadership behaviors involve creating supportive environment and building commitment within a project, a team or a community (Bock *et al.*, 2008; Fleishman *et al.*, 1991; Yukl *et al.*, 2002; Yukl, 2012). Leaders in open collaborative innovation communities are required not only to make technical contributions, but also to act as bond connectors among different participants, as well as between participants and the communities (Huffaker, 2010; Kayworth and Leidner, 2002; Luther and Bruckman, 2011). Thus, relation-oriented leadership behaviors are embedded in project leaders' social capital and community commitment.

Social capital is defined as potential resources that individuals or groups have access to through their networks of relationship (Nahapiet and Ghoshal, 1998). Adler and Kwon (2002) further distinguished between internal and external social capital. Within an open collaborative innovation community, the leader of a focal project usually attracts a certain number of followers who share common interests, and these followers tend to support what the leader does. They are considered as sources of internal social capital for the focal project leader. Meanwhile, a focal project leader also proactively follows other participants who share similar interests or possess complementary resources, but are not directly involved in the focal project. These participants are where external social capital of project leaders exists. Besides, a focal project leader also builds community commitment, which refers to the psychological bond between the focal project leader and the community he/she is embedded in (Bateman *et al.*, 2011; Meyer and Allen, 1991). Drawing on functional leadership theory, the effectiveness of these three components of relation-oriented leadership behaviors (i.e. internal social capital, external social capital and community commitment) will be illuminated as follows.

3.2.1 Internal social capital. Internal social capital reflects the cohesiveness between project leaders and (potential) participants for a focal open collaborative innovation project (Daniel *et al.*, 2018; Singh *et al.*, 2011). In open collaborative innovation communities, only a small number of participants make actual contributions, the majority of others are lurkers or peripheral participants who make few contributions (Lee *et al.*, 2017; Setia *et al.*, 2012). As internal social capital of project leaders promotes trust, reciprocity and shared identities between participants and the focal project leader (Ren *et al.*, 2012; Stewart *et al.*, 2006), more peripheral participants will contribute to the focal open collaborative innovation project to enhance project performance (Preece and Shneiderman, 2009; Setia *et al.*, 2012):

H2a. Internal social capital of project leaders is positively related to open collaborative innovation project success.

3.2.2 External social capital. External social capital reflects the bridging roles of project leaders that connect a focal project to other participants in open collaborative innovation communities (Daniel *et al.*, 2018; Singh *et al.*, 2011). Because of its knowledge-intensive nature, open collaborative innovation sometimes requires expertise out of a focal project's boundaries (Baldwin and von Hippel, 2011; Luther and Bruckman, 2011). For project leaders with external social capital, they are capable of bringing in new knowledge from outside (Daniel and Stewart, 2016; Singh *et al.*, 2011). In particular, modern communication technologies facilitate interaction between individuals online, even if they are unfamiliar with each other in the real world (Baldwin and von Hippel, 2011; Faraj *et al.*, 2011). From standpoints of other participants, such kind of external cohesion also sends out positive signals that the focal project leader is capable of leveraging external knowledge and resources (Ho and Rai, 2017). Thus, open collaborative innovation projects will greatly benefit from leaders' external social capital:

H2b. External social capital of project leaders is positively related to open collaborative innovation project success.

3.2.3 Community commitment. Community commitment refers to the psychological bonds of project leaders to the communities they are involved in (Bateman *et al.*, 2011; Bock *et al.*, 2008; Meyer and Allen, 1991). As open collaborative innovation is accompanied by potential risks such as loss of intellectual property and opportunism (Islam *et al.*, 2017), project leaders with strong community commitment are more likely to engage themselves in innovation (Ren *et al.*, 2012). Through long-term commitment to the community, leaders are familiar with the coordination among different stakeholders and procedures of complicated innovation activities (Bateman *et al.*, 2011; Ray *et al.*, 2014). Meanwhile, due to the lack of formal control structures (Faraj *et al.*, 2015; Johnson *et al.*, 2015), the success of open collaborative innovation requires strong commitment of participants to the community (Bateman *et al.*, 2011). Since participants in online communities tend to follow behaviors of leaders (Dabbish *et al.*, 2012; Oh and Jeon, 2007), the strong community commitment of project leaders will motivate the contributions of more participants, thus leading to open collaborative innovation success:

H2c. Community commitment of project leaders is positively related to open collaborative innovation project success.

3.3 Openness orientation

"Openness" is the key for differentiating open collaborative innovation from traditional innovation (Baldwin and von Hippel, 2011; Levine and Prietula, 2014). We define openness orientation as the closeness of collaboration among different contributors and the accessibility to innovation outputs (e.g. source codes, technical solutions) by all contributors and non-contributors involved in internet-mediated open collaborative innovation projects

(August *et al.*, 2018; Shaikh and Vaast, 2016; Zhu *et al.*, 2013). For instance, openness orientation of open source projects can be reflected in the license choices which elaborate how codes should be deployed and distributed based on others' previous work (Singh and Phelps, 2013; Stewart *et al.*, 2006; Wang, 2012).

Openness orientation not only reflects project-level task design (Shaikh and Vaast, 2016; Singh and Phelps, 2013), but also indicates project leaders' attitudes toward the collaboration within open collaborative innovation projects. Therefore, openness orientation can be strategically utilized to stimulate contributions from participants with diversified motivations (Belenzon and Schankerman, 2015). As highly open projects facilitate knowledge sharing and reputation building (Nagle, 2018; Stewart *et al.*, 2006), they can attract more participants with intrinsic motivations (Wang, 2012), which is especially important for open collaborative innovation projects targeting at tough problems. Taking blockchain open source projects as an example, blockchain technology is still in its infant stage with many unsolved challenges, which requires deep and wide cooperation among experts (Iansiti and Lakhani, 2017). Therefore, high level of openness orientation will attract more contributors and promote project success:

H3. Openness orientation is positively related to open collaborative innovation project success.

3.4 Joint effects of task-oriented leadership behaviors and openness orientation

Drawing on functional leadership theory, the effectiveness of leadership behaviors is contingent on some team-level, organizational and environmental factors (Bock *et al.*, 2008; Hernandez *et al.*, 2011; Morgeson *et al.*, 2010). Regarding open collaborative innovation, openness orientation as a kind of project-level institutional arrangement not only acts as an antecedent for project success as stated above, but also complements the functioning of leadership behaviors. On the one hand, openness orientation strengthens the proposed positive relationship between task-oriented leadership behaviors and open collaborative innovation project success. Although projects with experienced leaders who have made great technical contributions are assumed to be promising and of high quality (Dahlander and O'Mahony, 2011; Faraj *et al.*, 2015), it not necessarily results in project success without large numbers of participants. Nevertheless, highly open projects usually attract more participants with intrinsic motivations whose goals and interests are highly aligned with project leaders' (Belenzon and Schankerman, 2015; Sen *et al.*, 2008), thus enhancing the effectiveness of task-oriented leadership behaviors in open collaborative innovation success.

On the other hand, highly open projects are also more likely to succeed with efficient task-oriented leadership behaviors. Open collaborative innovation projects with a higher degree of openness can attract more participants (Sen *et al.*, 2008; Wang, 2012). Nevertheless, more participants also mean diversified knowledge bases, which makes it difficult to communicate ideas and to coordinate tasks (Daniel *et al.*, 2018). For project leaders with more experience and expertise in task coordination, they can make good use of diversified knowledge sources to promote project success (Dahlander and O'Mahony, 2011; Fleming and Waguespack, 2007). Therefore, we propose positive joint effects of task-oriented leadership behaviors and openness orientation in open collaborative innovation:

H4. The joint effects of project leaders' technical contributions and openness orientation are positive on open collaborative innovation project success.

3.5 Joint effects of relation-oriented leadership behaviors and openness orientation

Extending functional leadership theory into the context of open collaborative innovation (Fleishman *et al.*, 1991; Morgeson *et al.*, 2010), we further investigate the joint effects of

relation-oriented leadership behaviors that are embedded in internal social capital, external social capital and community commitment of project leaders and project-level openness orientation on project success. First, through building internal social capital within a focal project, the project leader can motivate contributions from followers because of trust, reciprocity and shared identities formed between them (Dabbish *et al.*, 2012; Ho and Rai, 2017; Lerner and Tirole, 2005), as is stated in *H2a* above. Such kind of effect can be more prominent for highly open projects with large numbers of participants (Belenzon and Schankerman, 2015; Wang, 2012), as participants tend to follow steps of leaders to make contributions (Oh and Jeon, 2007). At the same time, internal social capital of project leaders means strong cohesion within focal projects (Daniel *et al.*, 2018; Singh *et al.*, 2011), which facilitates coordination among participants with diversified backgrounds, even if there are large numbers of participants because of project openness. In this way, the joint effects of project leaders' internal social capital and openness orientation are proposed to be prominent.

Second, project leaders' external social capital and openness orientation complement with each other to promote open collaborative innovation success. Project leaders with more external social capital have more outward connections within online communities, which are potential sources of complementary knowledge and resources (Daniel *et al.*, 2018; Singh *et al.*, 2011). Similarly, high level of openness orientation is believed to be effective in attracting large numbers of participants with intrinsic motivations (Wang, 2012). As open collaborative innovation relies on diversified resources, knowledge and expertise (Baldwin and von Hippel, 2011; Faraj *et al.*, 2011; Islam *et al.*, 2017), projects with both high level of openness orientation and leaders who have more external social capital simultaneously will be more likely to achieve success.

Third, the joint effects of project leaders' community commitment and openness orientation are also assumed to be beneficial for open collaborative innovation project success. While highly open projects attract participants with diversified motivations (Sen *et al.*, 2008; Von Krogh *et al.*, 2012), project leaders who are deeply committed to the community are good at motivating and coordinating these participants (Bateman *et al.*, 2011; Ray *et al.*, 2014). That is to say, such kind of open collaborative innovation projects can not only benefit from increasing in participants, but also capable of solving coordination problems at the same time. Therefore, project leaders' community commitment complements with openness orientation in stimulating open collaborative innovation project success. On the whole, we propose positive joint effects of relation-oriented leadership behaviors and openness orientation as follows:

H5a. The joint effects of project leaders' internal social capital and openness orientation are positive on open collaborative innovation project success.

H5b. The joint effects of project leaders' external social capital and openness orientation are positive on open collaborative innovation project success.

H5c. The joint effects of project leaders' community commitment and openness orientation are positive on open collaborative innovation project success.

4. Methodology

4.1 Data and sample

Data sets for this study were collected from GitHub, which is the largest open source collaboration platform based on Git version control systems in the world and has been widely used in existing research (Dabbish *et al.*, 2012; Lee *et al.*, 2017; Lindberg *et al.*, 2016). To mitigate variability of diversified projects, we used web scraping tools to collect data on blockchain-related projects with five keywords including "Blockchain," "Bitcoin," "Ethereum," "Hyperledger" and "Corda" in November 2018. Among them, "Blockchain" is

the most general terminology for blockchain technology; "Bitcoin," "Ethereum," "Hyperledger" and "Corda" are among the most common platforms or applications of blockchain technology (Iansiti and Lakhani, 2017; Swan, 2015). Thus projects searched with these five keywords are representative for blockchain projects on GitHub. This study focuses on projects with individual leaders instead of organizational leaders to capture multiple dimensions of leadership behaviors. Besides, projects with no open source licenses are excluded. After merging data sets of all projects, there were 1,024 projects in the initial samples. To alleviate potential bias caused by outliers in the following regression analyses, we winsorized the number of contributors and commits at the 1 percent level (Tukey, 1962), resulting in 1,012 projects as the final samples.

4.2 Measurement

4.2.1 Dependent variable. The dependent variable Project Success is measured by the number of contributors for each project (Islam *et al.*, 2017). As the sustainability of open collaborative innovation depends on the continued contribution of participants (Ho and Rai, 2017; Oh *et al.*, 2016), more contributors can predict a higher likelihood of project success. Although some studies have used measurements of the number of modified codes and bugs reported (Daniel and Stewart, 2016; Peng *et al.*, 2013), they are less appropriate proxies of project success. The reasons are that modifications of many projects are only contributed by a few core developers, especially project leaders (Lee *et al.*, 2017) and such kinds of projects may not be considered as really successful.

4.2.2 Independent and moderator variables. Task-oriented leadership behaviors can be reflected in Technical Contributions of project leaders in open collaborative innovation communities (Dahlander and O'Mahony, 2011; Faraj *et al.*, 2015). We measure technical contributions by the number of projects that a focal project leader has been involved in. Regarding relation-oriented leadership behaviors embedded in internal/external social capital, we follow literature of network degree centrality (Ahuja *et al.*, 2003; Daniel and Stewart, 2016; Wu *et al.*, 2017; Wasko and Faraj, 2005). Specifically, Internal Social Capital is measured as the number of followers for a focal project leader on GitHub; External Social Capital is measured as the number of participants that the focal project leader follows proactively on GitHub. Similarly, Community Commitment is measured by the number of projects a focal project leader has starred, i.e. adding bookmarks to certain projects (Meyer and Allen, 1991; Ren *et al.*, 2012).

Openness Orientation is measured by open source licenses of projects on GitHub. Open source licenses usually include both copyleft clauses and viral clauses. The copyleft clauses require source code to be kept generally available when modifying original programs; the viral clauses prohibit mixing the software with other software using different licenses (Singh and Phelps, 2013; Wang, 2012). Licenses with strong copyleft clauses and strict viral clauses such as GNU General Public License (GPL) are considered as highly open, which is closest to the original spirit of open source, while other types of licenses such as MIT and BSD allow commercialization and are considered as less open (Belenzon and Schankerman, 2015; Stewart *et al.*, 2006). Following prior studies (Belenzon and Schankerman, 2015; Lerner and Tirole, 2005; Sen *et al.*, 2008), openness orientation of project leaders is coded as follows: projects with highest level of openness (i.e. AGPL and GPL licenses) are coded as 3; projects with medium level of openness (i.e. LGPL and MPL licenses) are coded as 2; projects with lowest level of openness (i.e. MIT, BSD, Apache and EPL licenses) are coded as 1.

4.2.3 Control variables. We include both project-level and leader-level factors that may influence open collaborative innovation success and that have been investigated in existing studies as control variables (Ho and Rai, 2017; Wang, 2012). On project level, Watch is a feature on GitHub that registers users to receive notifications of project updates (Dabbish *et al.*, 2012). Star is a feature that allows users to bookmark projects on GitHub, which signals

project quality (Jarczyk *et al.*, 2014). A Fork is a personal copy of a project, which allows users to freely change the project without affecting the original copy (Dong *et al.*, 2019). A Branch is an active line of development for a focal project. Release shows the history of updating versions for a focal project (Daniel and Stewart, 2016; Daniel *et al.*, 2018). Project Age and Programming Language are also controlled (Islam *et al.*, 2017; Stewart *et al.*, 2006). On leader level, as we mainly focus on the roles of project leaders in open collaborative innovation, it is necessary to control the characteristics of project leaders (Faraj *et al.*, 2015; Ray *et al.*, 2014). Following prior literature, Leader Tenure is controlled and calculated as the number of years since the focal leader created the first repository/project (Bateman *et al.*, 2011; Qin *et al.*, 2014). We have also controlled geographical location-related variables such as the countries where project leaders come from (Li *et al.*, 2012; Sen *et al.*, 2008).

4.3 Analyses and results

As the dependent variable Project Success is a non-negative count variable with overly dispersion, negative binomial regression is considered as an appropriate method (Cameron and Trivedi, 2013). Other variables, including Technical Contributions, Internal Social Capital, External Social Capital, Community Commitment, Watch, Star, Fork, Branch and Release, have been transferred into logarithm formats to mitigate skewness. Because the value of 0 exists in most of these variables, a 1 is added to these data sets before the logarithm transformation. Given that joint effects of task-oriented/relation-oriented leadership behaviors and openness orientation will be tested, relevant variables are mean-centered before generating the interaction value to mitigate potential multicollinearity (Daniel and Stewart, 2016). Analyses are conducted with StataMP 14. Descriptive statistics and correlations are displayed in Table I. The average number of contributors for projects in the sample is about 5. The majority of correlations are neither too large nor too small. We have also estimated variance inflation factors with a mean value of 2.9, which is below the threshold level of 10, further demonstrating multicollinearity is not a big concern.

Table II shows regression results for hypotheses testing with nine models. Model 1 includes control variables and Technical Contributions, which corresponds to *H1*. However, the coefficient of Technical Contributions ($\beta = 0.027$, $p > 0.1$) is positive but not significant. Therefore, the proposed positive influence of task-oriented leadership behaviors is not supported. Models 2–4 are used to test *H2a–H2c*, respectively. As project leaders possess both task-oriented and relation-oriented leadership behaviors simultaneously, we have controlled Technical Contributions in these three regression models, as well as other control variables. Model 2 shows a positive and significant relationship between project leaders' internal social capital ($\beta = 0.079$, $p < 0.05$) and project success; Model 3 reveals the significantly positive influence of external social capital ($\beta = 0.087$, $p < 0.01$); Model 4 shows that the influence of community commitment ($\beta = 0.042$, $p > 0.1$) on project success is positive but not significant. Therefore, *H2a* and *H2b* are supported; *H2c* is not supported. *H3* proposes that openness orientation positively influences open collaborative innovation success. Counterintuitively, the results of Model 5 show a negative and significant relationship ($\beta = -0.204$, $p < 0.01$).

Models 6–9 are used to examine the joint effects of leadership behaviors and openness orientation. In Model 6, the interaction of technical contributions and openness orientation is positive and significant ($\beta = 0.083$, $p < 0.1$). Thus, *H4* is supported. Model 7 shows that the interaction of internal social capital and openness orientation is positively significant ($\beta = 0.106$, $p < 0.01$), indicating *H5a* is supported. Model 8 shows a negative and non-significant interaction value of external social capital and openness orientation ($\beta = -0.006$, $p > 0.1$). Thus, *H5b* is not supported. At last, the interaction between community commitment and openness orientation in Model 9 is positively significant ($\beta = 0.065$, $p < 0.01$), indicating *H5c* is supported.

Table I. Descriptive statistics and correlations

Variables	Mean	SD	1	2	3	4	5	6	7	8
1. Project Success	4.792	9.831	1							
2. Technical Contributions (TC)	3.157	1.184	−0.025	1						
3. Internal Social Capital (ISC)	3.125	1.909	0.012	0.607*	1					
4. External Social Capital (ESC)	1.651	1.630	−0.009	0.600*	0.455*	1				
5. Community Commitment (CC)	3.008	2.135	−0.024	0.659*	0.600*	0.728*	1			
6. Openness Orientation (OO)	1.331	0.732	−0.033	−0.004	0.090*	−0.022	0.006	1		
7. Watch	1.766	1.167	0.067*	0.110*	0.528*	0.078*	0.254*	0.214*	1	
8. Star	2.882	2.005	0.009	0.214*	0.636*	0.196*	0.399*	0.189*	0.888*	1
9. Fork	2.334	1.637	0.042	0.183*	0.606*	0.144*	0.319*	0.211*	0.850*	0.896*
10. Branch	0.961	0.482	0.281*	0.082*	0.088*	0.065*	0.067*	0.038	0.156*	0.158*
11. Release	0.467	0.955	0.260*	0.077*	0.161*	0.003	0.087*	0.074*	0.243*	0.261*
12. Project Age	27.58	23.2	0.105*	0.128*	0.299*	0.023	0.143*	0.217*	0.343*	0.343*
13. Language	3.689	2.026	0.017	−0.111*	−0.073*	−0.078*	−0.106*	0.026	0.025	−0.014
14. Leader Tenure	5.957	2.733	−0.025	0.454*	0.493*	0.270*	0.455*	0.100*	0.356*	0.386*
15. Country	7.777	4.213	−0.022	−0.199*	−0.276*	−0.209*	−0.242*	0.108*	−0.132*	−0.221*

Variables	Mean	SD	9	10	11	12	13	14	15
9. Fork	2.334	1.637	1						
10. Branch	0.961	0.482	0.167*	1					
11. Release	0.467	0.955	0.247*	0.363*	1				
12. Project Age	27.58	23.2	0.428*	0.090*	0.163*	1			
13. Language	3.689	2.026	0.002	0.013	0.015	0.062	1		
14. Leader Tenure	5.957	2.733	0.384*	0.054	0.133*	0.507*	−0.008	1	
15. Country	7.777	4.213	−0.177*	−0.029	−0.048	−0.118*	0.032	−0.205*	1

Notes: $n = 1{,}012$. *Significant at 5 percent level

Table II.
Regression results

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Watch	0.390***	0.394***	0.414***	0.406***	0.433***	0.423***	0.387***	0.432***	0.419***
	(5.879)	(5.954)	(6.191)	(6.041)	(6.505)	(6.319)	(5.684)	(6.470)	(6.249)
Star	−0.250***	−0.276***	−0.272***	−0.273***	−0.275***	−0.270***	−0.260***	−0.275***	−0.275***
	(−5.544)	(−5.991)	(−5.909)	(−5.771)	(−5.749)	(−5.645)	(−5.429)	(−5.719)	(−5.740)
Fork	−0.023	−0.040	−0.019	−0.018	−0.041	−0.039	−0.031	−0.042	−0.030
	(−0.449)	(−0.790)	(−0.362)	(−0.349)	(−0.807)	(−0.766)	(−0.606)	(−0.817)	(−0.594)
Branch	0.609***	0.611***	0.584***	0.603***	0.577***	0.571***	0.572***	0.577***	0.580***
	(7.563)	(7.622)	(7.221)	(7.509)	(7.188)	(7.122)	(7.187)	(7.184)	(7.249)
Release	0.241***	0.246***	0.256***	0.244***	0.260***	0.259***	0.244***	0.260***	0.253***
	(6.479)	(6.612)	(6.809)	(6.559)	(6.876)	(6.860)	(6.507)	(6.881)	(6.731)
Project Age	0.017***	0.016***	0.018***	0.017***	0.018***	0.018***	0.018***	0.018***	0.018***
	(8.594)	(8.450)	(8.977)	(8.707)	(9.330)	(9.321)	(9.062)	(9.330)	(9.204)
Language	0.009	0.008	0.008	0.010	0.004	0.004	0.009	0.004	0.004
	(0.462)	(0.422)	(0.397)	(0.539)	(0.211)	(0.195)	(0.454)	(0.211)	(0.236)
Leader Tenure	−0.086***	−0.091***	−0.086***	−0.091***	−0.091***	−0.090***	−0.082***	−0.091***	−0.088***
	(−4.852)	(−5.098)	(−4.896)	(−5.056)	(−5.085)	(−5.053)	(−4.562)	(−5.076)	(−4.906)
Country	−0.019**	−0.015	−0.014	−0.017*	−0.006	−0.006	−0.007	−0.006	−0.006
	(−2.016)	(−1.570)	(−1.522)	(−1.856)	(−0.591)	(−0.632)	(−0.719)	(−0.581)	(−0.639)
Technical Contributions (TC)	0.027	−0.031	−0.037	−0.012	−0.079	−0.074	−0.088*	−0.080*	−0.076
	(0.768)	(−0.727)	(−0.892)	(−0.281)	(−1.645)	(−1.533)	(−1.833)	(−1.655)	(−1.585)
Internal Social Capital (ISC)		0.079**			0.070**	0.072**	0.082***	0.069**	0.076**
		(2.502)			(2.212)	(2.278)	(2.589)	(2.189)	(2.403)
External Social Capital (ESC)			0.087***		0.091***	0.094***	0.100***	0.091***	0.090***
			(3.016)		(2.607)	(2.695)	(2.865)	(2.610)	(2.589)
Community Commitment (CC)				0.042	−0.014	−0.017	−0.017	−0.013	−0.017
				(1.622)	(−0.445)	(−0.532)	(−0.551)	(−0.432)	(−0.554)
Openness Orientation (OO)					−0.204***	−0.207***	−0.252***	−0.204***	−0.213***
					(−3.727)	(−3.783)	(−4.515)	(−3.733)	(−3.899)
TC × OO						0.083*			
						(1.695)			
ISC × OO							0.106***		
							(3.291)		
ESC × OO								−0.006	
								(−0.197)	
CC × OO									0.065***
									(2.602)
Constant	0.919***	1.027***	0.886***	0.951***	0.858***	0.865***	0.822***	0.858***	0.844***
	(5.466)	(5.916)	(5.263)	(5.630)	(4.834)	(4.882)	(4.655)	(4.829)	(4.763)
Pseudo R^2	0.055	0.056	0.057	0.055	0.060	0.061	0.062	0.060	0.061

Notes: $n = 1{,}012$. t-Statistics are in parentheses. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

We have also plotted the joint effects of Technical Contributions, Internal Social Capital and Community Commitment with Openness Orientation, respectively. Figure 1 shows that with openness orientation changing from low level to high level, there is a trend of positive relationship between technical contributions and project success, which further supports *H4*. In Figure 2, the line of high openness orientation shows a positive relationship and it is much steeper than the line of low openness orientation. Thus, *H5a* is supported. Similarly, Figure 3 corroborates the positive joint effects of community commitment and openness orientation on open collaborative innovation success as proposed in *H5c*.

4.4 Robust tests

To strengthen the robustness of empirical results, we have conducted more analyses. First, we conducted regression analysis with a sub-sample of projects with two or more contributors. Second, we measured openness orientation with a dummy variable instead of the continuous measurement above. More specifically, blockchain open source projects with licenses of AGPL, GPL, LGPL and MPL are coded as 1; otherwise, sampled projects are coded as 0. On the whole, these robust tests have generated consistent results.

5. Discussion and conclusions

This study investigates how online leadership influences open collaborative innovation success. With empirical evidence from blockchain open source projects on GitHub, we

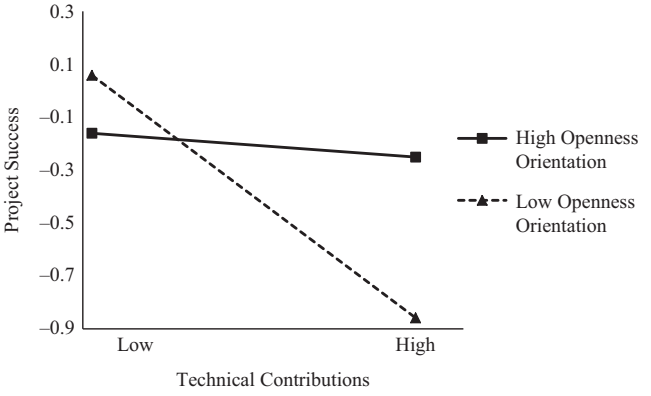

Figure 1.
Joint effects of technical contributions (TC) and openness orientation (OO)

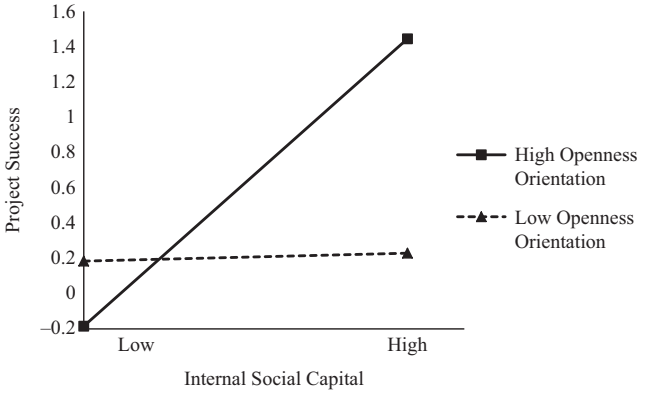

Figure 2.
Joint effects of internal social capital (ISC) and openness orientation (OO)

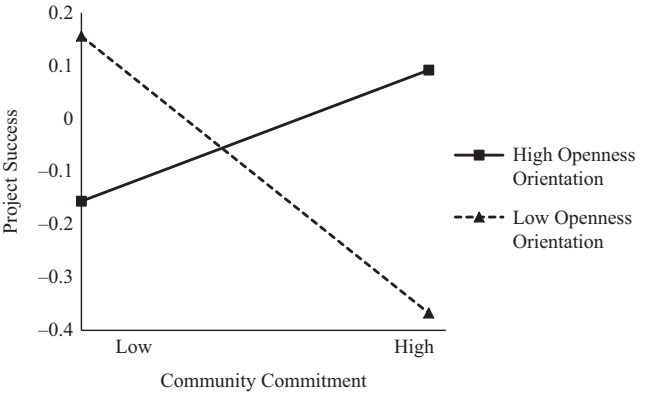

Figure 3.
Joint effects of community commitment (CC) and openness orientation (OO)

discovered that task-oriented leadership behaviors contribute little to open collaborative innovation success; in contrast, relation-oriented leadership behaviors, especially leadership behaviors embedded in internal and external social capital, positively influence open collaborative innovation success. Furthermore, we have also examined the direct and contingent effects of openness orientation. The findings support a negative relationship between openness orientation and open collaborative innovation success. Meanwhile, the joint effects of task-oriented leadership behaviors and openness orientation, internal social capital and openness orientation, as well as community commitment and openness orientation on open collaborative innovation success are prominent.

Some proposed hypotheses are not supported and potential explanations are as follows. First, the proposed positive effect of task-oriented leadership behaviors on project success is not supported. It can be attributed to the fact that open collaborative innovation depends more on "crowd intelligence" instead of the expertise of single project leaders (Mollick and Nanda, 2015; Müller-Trede *et al.*, 2018). Second, the proposed positive relationship between leader's community commitment and project success is not supported. One reasonable explanation is that project leaders' community commitment enhances other participants' attachment to the whole community (Bateman *et al.*, 2011; Dabbish *et al.*, 2012), but not to those focal projects that leaders are involved in, thus having little influence on project success (Ren *et al.*, 2012). Third, the proposed positive relationship between openness orientation and project success turns out to be negative. We contend that openness not only encourages wide participation, but also constrains the commercialization of blockchain open source projects (Belenzon and Schankerman, 2015; Singh and Phelps, 2013). Such kind of negative effect of openness orientation is consistent with Lerner and Tirole (2005) and Stewart *et al.* (2006). At last, the proposed positive joint effects of external social capital and openness orientation are not supported. We conjecture that the positive influence of external social capital (Daniel *et al.*, 2018; Singh *et al.*, 2011) can be offset by the constraints of openness orientation (Von Krogh *et al.*, 2012), resulting in non-significant joint effects.

5.1 Theoretical contributions

This study delivers theoretical contributions in three aspects. First, it contributes to open collaborative innovation research by highlighting the roles of project leaders rather than the general participants. Prior research in this field mostly focuses either on the diversified motivations (Belenzon and Schankerman, 2015; Von Krogh *et al.*, 2012) or network structure of participants (Daniel *et al.*, 2018; Peng *et al.*, 2013; Singh *et al.*, 2011). Nevertheless, they overlook the fact that leaders do exist and play a more influential role (Dabbish *et al.*, 2012;

Setia *et al.*, 2012). Thus, by examining the roles of project leaders, it complements existing research on the antecedents of open collaborative innovation success.

Second, it adds to functional leadership theory by delineating new contents of task-oriented and relation-oriented leadership behaviors in the context of open collaborative innovation (Burke *et al.*, 2006; Fleishman *et al.*, 1991; Johnson *et al.*, 2015; Morgeson *et al.*, 2010). Unlike traditional face-to-face contexts, online leadership is influence based rather than relying on hierarchical authorities (Faraj *et al.*, 2015; Huffaker, 2010; Lee *et al.*, 2019). Therefore, task-oriented leadership behaviors in forms of technical contributions are assumed to be influential. Meanwhile, facilitated by internet-mediated communication technologies, relation-oriented leadership behaviors are also embedded in new forms such as internal social capital, external social capital and community commitment.

Third, we provide a new fine-grained framework to analyze the success or failure of online-based open collaborative innovation. The high failure rate of open collaborative innovation requires reasonable explanations and effective solutions to achieve project success (Ehls, 2017; Lee *et al.*, 2019). By integrating functional leadership theory with openness orientation literature, this study investigates not only the direct effects of leadership behaviors but also their joint effects with openness orientation, which generates more nuanced conclusions regarding leadership effectiveness in open collaborative innovation.

5.2 Practical implications

This study has practical implications for both project leaders and general participants involved in open collaborative innovation projects. For project leaders, one of the biggest challenges is how to attract more contributors. According to empirical findings in this study, project leaders should strategically deploy the combination of leadership behaviors and openness orientation so as to motivate the contribution of participants and achieve open collaborative innovation success. As for general participants, they always face situations of choosing the most promising projects to contribute. Our suggestions are that participants should attach enough importance to project leaders when choosing targeting open collaborative innovation projects.

5.3 Limitations and future research directions

This study has limitations that should be improved in the future. First, it mainly concentrates on leader behaviors, leaving other mechanisms of online leadership unexplored. According to Hernandez *et al.* (2011), leadership takes effects through four mechanisms including traits, behaviors, cognition and affect, which calls for the integration of multiple leadership frameworks in the future. Second, it tests those proposed hypotheses with samples from blockchain open source projects, and future studies may examine other open collaborative innovation projects (e.g. crowdsourcing projects) to enhance generalizability. Third, motivation and network structure-related variables are not controlled because of the constraints of web crawling method and the relatively small sample size of blockchain projects, which should be improved in future studies.

5.4 Conclusions

Overall, this study suggests that open collaborative innovation success is determined by both task-oriented leadership behaviors in forms of technical contributions and relation-oriented leadership behaviors embedded in internal social capital, external social capital and community commitment. Meanwhile, leadership effectiveness also depends much on the direct and contingent effects of project-level openness orientation, thus providing comprehensive understanding of the roles of online leadership in the context of open collaborative innovation.

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