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How Software Quality Mediates the Impact of Intellectual Capital on Commercial Open-Source Software Company Success

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ABSTRACT The recent surge in the number of commercial open-source software (COSS) companies shows the growing importance of COSS companies in the software industry. As knowledge-based firms, COSS companies' success depends heavily on the interplay among intangible resources such as human capital, relational capital, structural capital, and software quality. To observe these relationships, we conducted a hypothesis-testing questionnaire-type survey involving 200 software development experts and professionals working at 60 multinational COSS companies. Accordingly, the study unearthed two different but conjoint ways (i.e., direct and indirect) in which intellectual capital impacts COSS company's success. On the one hand, relational capital one of the intellectual capital components directly affects COSS company's success. On the other hand, relational and structural capital indirectly affect COSS company success through human capital, which, in turn, is itself mediated by software quality in a sequential mediation model. Therefore, COSS companies may need to prioritize software quality as it is the most critical variable impacting the success of COSS companies.

INDEX TERMS Commercial open-source software, company success, intellectual capital, software quality.

I. INTRODUCTION

The shift in the global economy from relying on tangible resources to a knowledge-based economy dates back to the beginning of the 1970s [1]. Thus, the knowledge-based economy is founded on a vital intangible resource (i.e., intellectual capital (IC)) critical for businesses to succeed [2]–[4]. IC is also considered a source of long-lasting competitive advantage [2], [4], [5]. Despite the wider acceptance of IC as a source of sustainable competitive advantage, companies struggle to practically understand and measure IC [6]. Several studies in other industries such as social cooperative enterprises (SCEs) that work in non-profit sectors, mobile telecommunications, information communication technology (ICT) firms, and high-technology firms have identified the relevance of IC in terms of value creation and improving organizational performance [1], [4], [7]. However, there is a dearth of studies focusing on commercial open-source software (COSS) companies.

In a knowledge-intensive activity such as software development, success demands the interaction between a large number of people within the firm coupled with organizational environment, infrastructure, processes, methods, and procedures that enables people to use their knowledge, skills, and abilities. Aside from an enabling environment, there is also a need for a functional relationship with external stakeholders [1], [3], [8]. These three aspects of IC (i.e., human capital, organizational capital, and social capital) must interact in the

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right way to enable the organization to reduce cost, create and innovate, efficiently utilize its resources, and ensure customer satisfaction [2], [9], [10].

In addition, studies indicate that IC might not directly affect company success see for example, [2], [3], [11]. Thus, software quality (SQ) is considered critical for the success of software companies [12]–[15]. However, the mediating role of SQ on the relationship between IC and company success has not yet been investigated in the COSS company context. Unlike traditional software companies, COSS companies often engage with the OSS community creating a hybrid business model [16]–[18].

As a hybrid business, COSS companies are affected by the activities of the OSS community, in addition to traditional business factors [16]–[18]. In relation to their structural capital (SC), for instance, the increase in bugs and vulnerability emanating from open-source software (OSS) impacts COSS companies' products [19], [20]. SC is further influenced by issues such as incapability to accurately schedule, budget, communication problems, and goal ambiguity [12], [21]. Aside from this, since COSS companies work with OSS communities, their relational capital is constrained by documentation problems, lack of sustainable participation, project abandonment, and failure to meet the demands of the OSS community [22]–[25]. Consequently, these problems can lead to the failure of COSS companies.

Therefore, the purpose of this study is to explore the interaction between IC components, software quality, and company success, to promote the survival of COSS companies. It also aims to show the critical role SQ plays in the success of COSS companies. Moreover, as the study involves multinational COSS companies offering various products and services, it can offer a good insight into the intellectual capital and software quality-related activities of COSS companies.

II. RELATED WORK

In this section, the theory underpinning the research and constructs such as intellectual capital, software quality, and company success are briefly discussed, in addition to the presentation of the research framework and hypotheses.

A. KNOWLEDGE-BASED THEORY

Knowledge-based theory (KBT) is concerned with firm competence and capabilities, new product development, and innovation [26]. KBT postulates that IC is a critical knowledge-based resource that facilitates efficiency, innovation, creativity, and effectively meeting or exceeding customer expectations [2], [13], [14]. This, in turn, translates into organizational performance and sustainable competitive advantage [2], [4], [5]. IC is popular among knowledge-based firms that heavily depend on the knowledge, skills, and experience of their workforces [6], [8], [27].

B. INTELLECTUAL CAPITAL

IC in its simplest form is the collective knowledge, skills, and behavioral attributes of individual employees and their willingness to work hard [10]. In general, earlier literature in IC paid attention to knowledge and competencies as a source of long-lasting competitive advantage [1], [27]. In contrast, recent studies take a broader perspective and state that IC includes all intangible assets of the organization coupled with all knowledge-based resources utilized in the transformation process to create value [1], [28]. Similarly, Osinski *et al.* [29] assume that IC is the capacity of an organization to create wealth and resources by applying its knowledge as well as its intangible assets. Thus, IC management is a mechanism for the extraction of the value of knowledge. Moreover, IC is characterized by valuableness, rarity, inimitability, and non-substitutability [4].

Previous literature reveals that there are divergent classifications of IC constructs. While some studies have considered IC as a unidimensional construct, others believe it is a multidimensional construct [3]. There are variants of multidimensional IC constructs, for instance, Bontis [30] classifies IC into three components: human, structural, and customer capital. In contrast, Moon and Kym [31] use a human, structural, and social capital taxonomy. Similarly, IC can also be categorized into human, social, and organizational capital [7], [8]. However, in recent years there seems to be a consensus among IC scholars in classifying IC components as human, structural, and relational capital [1], [3], [6].

Human capital (HC) refers to the aggregate wisdom, knowledge, innovativeness, competence, attitude, skills, commitment, and experience of employees that are difficult to imitate [1], [3], [4]. This collective knowledge of employees ensures the survival and growth of the firm in a rapidly changing business environment. Moreover, human capital is key to new product development, efficient improvement of management, and operations of the firm which translates into quality and productivity/success [1], [3], [4], [32].

Structural capital (SC), on the other hand, is an intangible resource of the firm that remains after the employees get off work or leave the organization [3], [29]. It is manifested through organizational capabilities, information systems, databases, software, processes, procedures, routines, trademarks, patents, etc., [1], [3], [6]. Investment in SC facilitates process improvement leads to an effective and efficient resolution of problems, quality enhancement, cost reduction, and improved communication. Overall, cost reduction, quality improvements, and a deeper understanding of the role of SC will gradually result in business success [3].

In contrast, relational capital (RC) refers to knowledge stemming from the external relations of the firm. An organization's external relations include shareholders, partners, customers, users, contributors, agents, competitors, industry associations, community members, government, society, and other informal networks [1], [6], [8]. Moreover, relational capital is the most difficult of the IC components to manage as it deals with parties external to the organization [10], [33].

C. SOFTWARE QUALITY

Software quality is the total characteristics of an entity that depends on its capacity to satisfy explicit and implicit needs [34]–[36]. Hence, poor software quality negatively impacts not only customer satisfaction but also software maintainability, economic gains, and human life in the real-world context [12], [34], [37], [38]. Software maintenance is the most expensive activity in the software development process, representing about 75% of the total cost. Investing in maintenance and defect prevention efforts is critical because software defects have a detrimental effect on the proper functioning of the software. For instance, the world economy has lost 1.1 trillion dollars in 2016 because of software defects, and an estimated 4.4 billion people were affected [38]. A recent report by the Consortium for Information and Software Quality puts the total financial damage caused by poor quality software at 2.08 trillion dollars in 2020 in the US alone [39].

In general, quality is considered as the most vital factor for meeting customer expectations and organizational growth [12], [34], [40]. More specifically, software quality is a critical success factor for software development companies [12], [13], [41]. Software development companies often depend on effective coordination of software development processes and quality management activities (engineering) to attain the desired level of software quality. In addition to effective coordination, software quality is also affected by cost and time constraints [12], [13], [42], [43].

In order to effectively coordinate and evaluate software quality management efforts, software companies use software quality models [34], [37], [44], [45]. The earliest software quality model was proposed by McCall in 1976. The McCall model was later revised by Boehm and Dromey [41], [44], [46], [47]. Recently developed software quality evaluation models include ISO/IEC 25010 which outlines 8 attributes to be used for software quality assessment. In contrast, the earlier version ISO/IEC 9126 adopts 6 characteristics [44], [45], [48].

Despite being viewed as a useful tool for quality assurance [44], software standards or models lack functionality and practical application owing to the ambiguity involved [37], [47]. Gorla and Lin as cited in [49] propose a software quality assessment model that includes relevance and usefulness (i.e., functionality), usability, maintainability, and reliability attributes. On the other hand, other scholars identify usability, reliability, functionality, performance efficiency, portability, and maintainability as important quality measurements [40], [46]. Similarly, several studies identify functionality, usability, reliability, performance efficiency, and maintainability as the most impactful measures of software quality [14], [41], [43], [45]. Consequently, functionality, usability, performance efficiency, reliability, and maintainability indicators are adopted for the evaluation of software quality in this study.

D. COMPANY SUCCESS

Success can be defined as a situation where a company attains the desired goals or objectives [50]. Company success is not directly observable as it is a hypothetical construct or latent variable [51]. Accordingly, company success should be assessed based on financial and non-financial indicators. The reason for the use of multiple measures is the fact that they are informative and are capable of capturing the complexity of the company success variable [7], [52]. In the context of COSS companies, success deals with non-financial measures such as customer satisfaction [52], [53], ratings/reviews, popularity, and reputation [54], [55]. Furthermore, financial success is assessed using a profitability indicator [51]. However, customers are also critical for the financial success of COSS companies [3], [12].

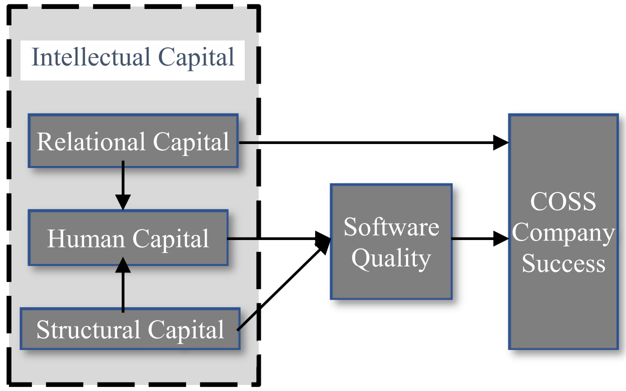

FIGURE 1. The research framework.

Therefore, in order to realize monetary rewards, the company needs to meet or exceed customer expectations [12], [53]. In addition to customer satisfaction, a mechanism to get customer feedback through ratings/reviews is also a good indicator of success [12], [55]. Closely linked with reviews/ratings, popularity and reputation are other measures of success observable via the number of downloads [54]. Consequently, COSS company success was observed via customer satisfaction, ratings/reviews, popularity and reputation, and profitability indicators.

III. RESEARCH FRAMEWORK AND HYPOTHESES

The earliest proposition in knowledge management states that corporate value creation depends on the interaction and effective management of human, relational, and structural capital [10]. More recent studies confirm that IC components interact or combine to influence company success, see for example, [1], [7], [9], [56]. A study by Cleary and Quinn [57] empirically establishes that relational capital directly impacts human capital. Since COSS companies use collaborative software development strategy, the influence of external actors such as peripheral developers, active users, and customers on core developers is significant [16], [17], [22], [58].

H1: The effect of relational capital on human capital is significant in the COSS company context.

As mentioned earlier, relational capital entails COSS companies' relationship with their customers, active users, and peripheral developers within the OSS community [16], [17], [58]. Therefore, COSS companies' success depends on their ability to satisfy not only the needs of customers and contributors [16], [22], but also active users to encourage them transform into paying customers [16]. Besides, previous empirical findings confirm that relational capital has a direct impact on company success [7], [11], [13].

H2: In COSS companies, relational capital is positively related to company success.

Structural capital in a COSS company context includes software development tools and techniques, knowledge infrastructure, software source code, processes, procedures, and development environment [8], [3]. Thus, the efforts of developers are affected by structural capital components such as scheduling, budgeting, and software development process and procedure [7], [57]. Therefore, structural capital directly impacts human capital.

H3: Structural capital significantly influences human capital in COSS company settings.

Past software quality literatures suggest that software quality is impacted by structural capital [13], [59], [60]. The effect of the software development process on software quality is also empirically established [14]. Hence, software quality depends on effective coordination of the software development process, efficient budgeting and scheduling, and the ability of software engineers to manage software [12], [13], [42], [60]. Consequently, software quality is influenced by structural capital.

H4: Structural capital positively influences software quality in COSS companies.

Similarly, empirical findings confirm that the human aspect of software development, such as experience, ownership of code, and structure of the organization, strongly influence software quality [38]. To elaborate, human resources in general, and developers in particular, play a critical role in influencing software quality [40], [59], [61]. This is because developers' experience and role in software development directly impact the quality of the software code [61]. Therefore, software quality is affected by human capital.

H5: Human capital positively impacts software quality in the COSS company milieu.

Furthermore, previous studies reveal that software quality is considered as a critical factor for success in the software industry [13], [15]. The reason behind such claims is the fact that software quality relates to meeting software requirements and offering defect-free software products to individual users or businesses [12], [13], [15]. Moreover, the detrimental effect of defects on software quality is duly noted [12], [38]. Therefore, software quality has a significant positive relationship with COSS company success.

H6: There is a significant positive relationship between software quality and COSS company success.

In addition to the findings obtained from other industries, taking the unique nature of COSS companies into account is important. COSS companies ''own some piece of software that they provide under an open-source license'' [16] p.68 and they are engaged with the OSS community and active users within the community [16]–[18]. However, the OSS community does not make a direct contribution to software development as it is subject to the transfer of its ownership rights [62]. Thus, the external contribution is mediated through human capital, which is regarded as the most important factor in influencing software quality [32], [61]. Therefore, relational capital impacts software quality via human capital.

H7: Human capital has a mediating effect on the relationship between relational capital and software quality in the COSS company settings.

Likewise, software quality depends on effective synchronization of the software development processes, software quality control activities, cost, and time [12], [13], [42], [43], [59]. Additionally, the mediating effect of human capital on the relationship between structural capital and software quality has also been empirically substantiated [14], [49]. Therefore, structural capital positively affects software quality through human capital.

H8: Human capital significantly mediates the relationship between structural capital and software quality in the COSS company context.

Past studies indicate that software quality plays an important role in mediating the relationship between IC components and company success see for example, [14], [49]. Specifically, software developers influence the software quality as they determine the software code quality [40], [61]. Studies further establish that software quality is crucial to the success of software development firms [13], [15]. Therefore, it is hypothesized that human capital is mediated by software quality to impact COSS company success.

H9: Software quality has a mediating effect on the relationship between human capital and COSS company success.

In addition, the relationship between structural capital and software quality has been empirically confirmed [14], [49]. Software quality, in turn, is the most important factor for software development companies to succeed in the software industry [13], [15]. Consequently, we hypothesize that software quality mediates the relationship between structural capital and COSS company success.

H10: Software quality has a mediating effect on the relationship between structural capital and COSS company success.

Based on the forgoing discussions, it is further hypnotized that there is a sequential mediation involving human capital and software quality impacting COSS company success.

H11: There is a sequential mediating effect from relational capital to COSS company success through human capital and software quality.

H12: There is a sequential mediating effect from structural capital to COSS company success through human capital and software quality.

IV. RESEARCH METHOD

In this section, we discuss the development and evaluation of our measurement instrument and the underlaying structural model.

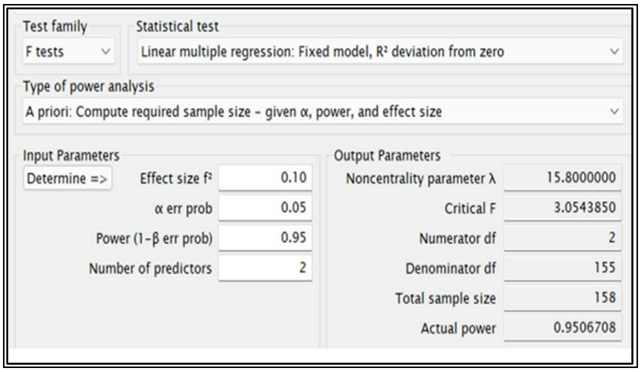

FIGURE 2. Power test: central and non-central distribution calculation.

TABLE 1. Sample professional profile.

Characteristics	Frequency	%
Years of Experience		
<1 year	6	3
1-5 years	63	31.5
6-10 years	46	23
>10 years	85	42.5
Role in Software Development		
Coding	160	80
Software Design	138	69
Software Requirement	98	49
Testing and Integration	83	41.5
Software Process Improvement	82	41
Version Management	66	33
Software Quality Assurance	49	24.5
User	47	23.5

A. QUESTIONNAIRE DESIGN

The survey tool was initially designed based on extant literature by adapting and adopting the questionnaire items. Following the initial design, the content and wording were assessed by 3 software development professionals and 2 academic experts with a computer science background. Therefore, the questionnaire was then revised three times based on their professional feedback. Second, the order of questions was also evaluated in order to see if the questions were sequenced in a way that makes conceptual sense to the respondent. Following the completion of the design process, survey invitations were sent to software development experts and professionals working in 60 multinational COSS companies.

B. POPULATION AND SAMPLE SIZE

The target population for this study is composed of software development experts and professionals working in multinational COSS companies. The sampling frame included 60 multinational COSS companies. The information gathered and compiled from online sources such as company official websites, the COSS company index [63], and professional networks (i.e., LinkedIn) indicate that these companies employ an estimated 56,768 workers. In order to determine the sample size, power analysis has been conducted using G*Power 3.1.9.4 (see figure 2). The power test was calculated using 2 predictors with an effect size of 0.10. According to Cohen as cited in [64], 0.10 shows a small effect size. Additionally, the power value in the power equation was set at 0.95 demonstrating the presence of adequate data points or a strong statistical power for analysis [64], [65]. Subsequently, the number of observations required for this study is at least 158.

A simple random sampling technique was used for the study. Furthermore, a total of 4,950 invitations were sent to randomly selected development experts and professionals working in 60 multinational COSS companies from the 19th of June to the 4th of November, 2020. Lastly, a total of 200 valid responses were garnered, indicating a return rate of 4%.

Table 1 depicts the sample's professional profile. The majority of the respondents (65.5%) have more than 6 years of experience in software development, while 31.5 have between 1 and 5 years of experience. Hence, the majority of the respondents are highly experienced software development experts. In addition, considering the roles of respondents 80% are engaged in coding, 69% are involved in software design, 49% in software requirements, 41.5% have taken part in testing and integration, 41% have worked in software process improvement, 33% have been involved in version management, 24.5% have participated in software quality assurance, and 23.5% have assumed a user role.

C. MODEL EVALUATION

1) MEASUREMENT MODEL EVALUATION

The initial design of the survey instrument was validated by software development experts and the reliability of items was assessed using a pilot test. Based on expert opinion and the pilot test, the questionnaire items were revised three times. Finally, following data collection, the measurement model was evaluated. Thus, assessing the measurement model represents the first phase of statistical analysis in the two-stage approach [66].

Specifically, measurement model estimation involves empirically ascertaining the validity and reliability of the relationship between indicators and their respective latent variable [64]. Therefore, convergent validity, internal consistency reliability, and discriminant validity entail model evaluation analysis [67], [68] (see Table 2).

a: CONVERGENT VALIDITY

The initial PLS algorithm result revealed that human capital and relational capital lack reliability and validity with a value of $\alpha = 0.495$ and 0.609 as well as AVE = 0.431 and 0.357 respectively. Thus, the two items with lowest outer loading have been removed from both human capital and structural capital constructs.

Following the removal, a second PLS algorithm was conducted. The result indicated that all AVE values except for the

TABLE 2. Construct validity and reliability.

Construct	Indicators	Convergent Validity		Internal Consistency Reliability		Discriminant Validity
		≥0.708	≥0.50	>0.70	>0.70	**HTMT** Inference Confidence Interval is less than 0.9
		Outer Loadings	**AVE**	**Composite Reliability**	**Cronbach Alpha**	
COSS Company Success	compS_1	0.709	0.530	0.848	0.776	Yes
	compS_2	0.828				
	compS_3	**0.678**				
	compS_4	**0.666**				
	compS_5	0.748				
Human Capital	hc_3	-	-	-	-	-
Relational Capital	rc_1	**0.649**	0.540	0.821	0.701	Yes
	rc_2	**0.577**				
	rc_3	0.837				
	rc_4	0.839				
Structural Capital	sc_1	**0.558**	**0.411**	0.860	0.818	Yes
	sc_2	**0.646**				
	sc_3	**0.636**				
	sc_4	**0.547**				
	sc_5	**0.685**				
	sc_6	0.795				
	sc_7	0.752				
	sc_8	**0.527**				
	sc_9	**0.566**				
Software Quality	sq_1	0.778	0.598	0.880	0.830	Yes
	sq_2	0.712				
	sq_3	0.849				
	sq_4	0.856				
	sq_5	**0.652**				

structural capital construct are above the threshold value of 0.5. Nonetheless, according to Fornell and Larcker [69], if the AVE is 0.4 and internal consistency reliability is above 0.58, the AVE is acceptable. Therefore, the AVE value of 0.411 for structural capital is acceptable since internal consistency reliability is above 0.58 (i.e., $\alpha = 0.701$ and CR = 0.821).

Furthermore, some of the outer loading values are below the 0.70 cut-off point. Therefore, outer loading values between 0.4 and 0.7 were considered for elimination [68]. However, since the indicators are conceptually relevant and elimination does not increase internal consistency reliability, they are retained [64].

b: INTERNAL CONSISTENCY RELIABILITY

Internal consistency reliability is measured using Cronbach alpha and composite reliability [64]. Thus, all the measures of internal consistency reliability show that composite reliability as well as Cronbach alpha values are above the 0.7 thresholds. Consequently, the result indicates that the indicators of latent variables are interrelated.

c: DISCRIMINANT VALIDITY

Discriminant validity was assessed through the bootstrapping procedure evaluating the HTMT confidence interval against a 0.90 threshold value [70], [71]. The result revealed that all HTMT confidence interval values are less than 0.9, establishing discriminant validity.

2) STRUCTURAL MODEL EVALUATION

Structural model evaluation represents the second phase of statistical analysis in the two-stage approach [67]. The analysis in this stage includes the VIF-multicollinearity test, β, σ, T-value, P-value significance and relevance, R^2 coefficient of determination, f^2 effect size, Q^2 predictive relevance, Q^2 effect size, and PLS predict [64], [70] (see figure 3).

TABLE 3. Inner VIF values.

Constructs	CompS	HC	SQ
HC			1.294
RC	1.069	1.132	
SC		1.132	1.294
SQ	1.069		

a: MULTICOLLINEARITY TEST

The first step in structural model evaluation is to check for multicollinearity among consecutive endogenous latent variables. The result indicates that all values are below the conservative threshold value of 3 recommended by Hair *et al.* [70]. Thus, there is no multicollinearity problem (see Table 3).

b: DIRECT EFFECT ANALYSIS

To observe the direct relationship amid latent variables, path coefficients of the structural model are evaluated. Path coefficients were obtained using the recommended 5000 bootstrap samples [64]. The result revealed that relational capital directly impacts human capital ($\beta = 0.321$, T-value = 5.367, P-value = 0.000) and company success ($\beta = 0.214$, T-value = 3.400, P-value = 0.001). Similarly, structural capital has a significant positive effect on human capital ($\beta = 0.368$, T-value = 4.281, P-value = 0.000) as well as software quality ($\beta = 0.494$, T-value = 5.210, P-value = 0.000). There is also

TABLE 4. Path coefficients.

Hypotheses	Relationships	Beta Value	Standard Deviation	T-value	P-values	Decision
H1	RC -> HC	0.321	0.059	5.367	0.000***	**Supported**
H2	RC -> CompS	0.214	0.063	3.400	0.001***	**Supported**
H3	SC -> HC	0.368	0.086	4.281	0.000***	**Supported**
H4	SC -> SQ	0.494	0.092	5.210	0.000***	**Supported**
H5	HC -> SQ	0.248	0.099	2.602	0.009***	**Supported**
H6	SQ -> CompS	0.581	0.055	10.482	0.000***	**Supported**
H7	RC -> HC -> SQ	0.079	0.036	2.289	0.022**	**Supported**
H8	SC -> HC -> SQ	0.090	0.041	2.276	0.023**	**Supported**
H9	HC -> SQ -> CompS	0.144	0.058	2.532	0.011**	**Supported**
H10	SC -> SQ -> CompS	0.288	0.063	4.337	0.000***	**Supported**
H11	RC -> HC -> SQ -> CompS	0.046	0.021	2.250	0.024**	**Supported**
H12	SC -> HC -> SQ -> CompS	0.053	0.025	2.195	0.028**	**Supported**

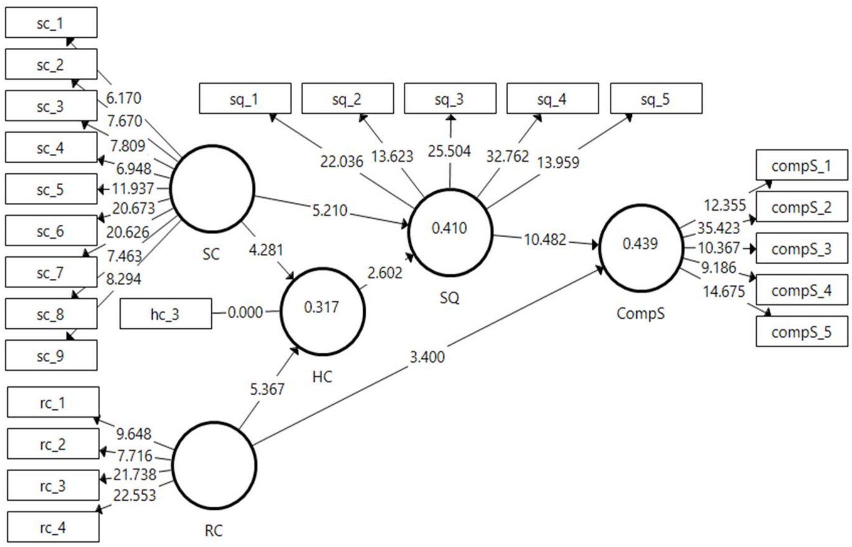

FIGURE 3. Structural model after a complete bootstrapping procedure.

a significant positive relationship between human capital and software quality ($\beta = 0.248$, T-value = 2.602, P-value = 0.009). Finally, there is a significant positive relationship between software quality and company success ($\beta = 0.581$, T-value = 10.842, P-value = 0.000). Subsequently, H1, H2, H3, H4, H5, and H6 are supported (see Table 4).

c: MEDIATION EFFECT ANALYSIS

The mediation effect of human capital on the relationship between relational capital and software quality as well as on the relationship between structural capital and software quality was assessed. The result indicates that the mediation effect of human capital is significant in both cases ($\beta = 0.079$, T-value = 2.289, P-value = 0.022) and ($\beta = 0.090$, T-value = 2.276, P-value = 0.023). In addition, software quality plays a significant mediating role between human capital and COSS company success ($\beta = 0.144$, T-value = 2.532, P-value = 0.011) alongside structural capital and COSS company success ($\beta = 0.288$, T-value = 4.337, P-value = 0.000). Therefore, H7, H8, H9, and H10 are supported (see Table 4).

Lastly, sequential mediating relations were examined. First, the sequential relationship from relational capital to company success through human capital and software quality indicates a significant positive relationship ($\beta = 0.046$, T-value = 2.250, P-value = 0.024). Secondly, the assessment of the sequential relationship from structural capital via human capital and software quality to company success also shows a significant positive relationship ($\beta = 0.053$, T-value = 2.195, P-value = 0.028). Consequently, we fail to reject H11 and H12 (see Table 4). Overall, since all direct and indirect paths are significant both human capital and software quality fully mediated the hypothesized relationships.

d: TOTAL AND SPECIFIC EFFECTS

The total effect is a measurement used to examine the strength of influence of all exogenous variables on the outcome variable [64]. The results show that the highest impact on COSS company success comes from software quality (0.576), followed by structural capital (0.329), relational capital (0.26), and human capital (0.148). Concerning software

TABLE 5. Total effects.

Constructs	Company Success	HC	SQ
HC	0.148		0.256
RC	0.260	0.318	0.082
SC	0.329	0.368	0.571
SQ	0.576		

TABLE 6. Outer weights.

Indicators	CompS	HC	RC	SC	SQ
compS_2	0.313				
hc_3		1.000			
rc_3			0.395		
sc_7				0.247	
sq_1					0.294

quality, structural capital (0.571) has the strongest effect compared to human capital (0.256) and relational capital (0.082). Lastly, human capital is more strongly influenced by structural capital (0.368) as compared to relational capital (0.318) (see Table 5).

In addition to the total effect, observing specific effects helps organizations identify specific activities that they should do exceptionally well in order to succeed. Therefore, the outer weight values indicate that COSS companies need to focus on hiring skillful and creative staff, followed by building a knowledgeable OSS community (0.395), paying attention to customer reviews/ratings (0.313), assuring the proper functioning of software products (0.294), and prioritizing critical software bugs (0.247) (see Table 6).

e: MODEL EXPLANATORY AND PREDICTIVE POWER ANALYSIS

The model was further examined using the coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), effect size (Q^2), and PLS predicate (RMSE and Q^2_Predict) [64], [70]. The results show that the R^2 value of 0.44 has a moderate explanatory power [70] (see Table 7). Compared to the result obtained for software project success ($R^2 = 0.47$) [9], the R^2 score for this study is slightly lower.

Similarly, the result obtained for knowledge transfer performance puts the R^2 value at 0.479 [72] which is also slightly higher than the current result. Nevertheless, in contrast to the $R^2 = 0.17$ value obtained in the study of engineering consulting firms [73], our result, that is $R^2 = 0.44$, is significantly higher. Thus, considering that this study is an original work that examines COSS company success, an R^2 value of 0.44 appears to be very good.

The change in R^2 is assessed using the f^2-effect size. Specifically, f^2 evaluates the impact of the removal of a specified exogenous latent variable on the endogenous latent variables in the model [64]. According to Cohen as cited in [70], f^2 values of 0.02, 0.15, and 0.35 are considered small, medium, and large effect sizes. Thus, human capital has a small effect ($f^2 = 0.086$) on software quality. Similarly, relational capital has a small effect on both COSS company success ($f^2 = 0.076$) and human capital ($f^2 = 0.131$). In contrast, structural capital has a medium effect on human capital ($f^2 = 0.176$) as well as software quality ($f^2 = 0.298$). However, the largest impact on COSS company success comes from software quality ($f^2 = 0.554$) (see Table 7).

In addition, a blindfolding procedure was conducted to assess model predictive relevance (Q^2). The result shows that all Q^2 values are above 0, confirming that the model has predictive relevance. Furthermore, the Q^2 values indicate the accuracy of prediction. Therefore, Q^2 values for COSS company success ($Q^2 = 0.222$), human capital ($Q^2 = 0.290$), and software quality ($Q^2 = 0.232$) reveal medium and slightly lower than medium predictive accuracy (see Table 7). Finally, model predictive power was evaluated using PLS-predict [64], [70].

The result of PLS-predict indicates that all Q^2_{Predict} values are greater than 0 showing that the model performs better than the most naïve benchmark [70]. Predictive power was also analyzed using RMSE (Root Mean Square Error) [74]. The result revealed that the majority (63.6%) of the indicators produce smaller prediction errors when using the PLS path model (PLS) than the linear regression model (LM) (see Table 7). Consequently, the model has a medium predictive power.

V. DISCUSSION OF EMPIRICAL FINDINGS

COSS companies are operating in a highly competitive knowledge-based industry dominated by multibillion corporations. In recent years, proprietary software companies such as Facebook, IBM, and Microsoft have been investing heavily in OSS projects [75]. Therefore, being successful in this market demands efficient and effective management of the most important knowledge-based resources that is IC and SQ. Thus, this study aimed to examine the relationship among IC components, and the mediating role of SQ on the relationship between IC components and COSS company success.

The result reveals that RC has a significant positive impact on HC and COSS company success (H1, H2). This result is consistent with previous empirical findings see for example, [7], [57], [73]. To elucidate further, in the context of COSS companies, RC refers to support and training provided by COSS companies along with support and contribution offered by the OSS community and active users within the community [16], [76], [77]. Therefore, the more contributions and support the OSS community and active users make, the more it assists internal software development experts in innovation and problem-solving activities. Additionally, since COSS companies earn revenue mainly via complementary products and services [16], satisfaction can lead to a boost in products and services requested, positively influencing COSS company success [12], [46].

Similarly, a direct positive relationship between SC and HC as well as SQ is substantiated (H3, H4). A study conducted among Canadian software development companies

TABLE 7. Model explanatory and predictive power analysis.

Constructs	Indicators	R^2	f^2				Q^2	RMSE	Q^2 predict
			HC	RC	SC	SQ			
COSS Company Success	compS_1	**0.439**	-	0.076	-	**0.554**	0.222	0.021	0.187
	compS_2							**-0.024**	0.188
	compS_3							0.071	0.092
	compS_4							**-0.001**	0.153
	compS_5							**-0.081**	0.168
Human Capital-HC	hc_3	0.317	-	0.131	**0.176**	-	**0.290**	**-0.028**	0.266
Software Quality-SQ	sq_1	0.410	0.086	-	**0.298**	-	0.232	0.017	0.292
	sq_2							0.069	0.120
	sq_3							**-0.034**	0.208
	sq_4							**-0.017**	0.310
	sq_5							**-0.035**	0.042

obtains the same result [14]. Furthermore, SC dimensions such as software development processes and procedures coupled with time and resources allotted can enhance the ability of software development experts to create and solve problems [7], [57], [32]. Equally important is the fact that the aforementioned SC attributes directly impact software quality [13], [15], [42], [78].

The study also finds that HC directly influences SQ (H5). Previous studies empirically confirm that software development experts' experience and role in the software development process directly affect code quality [15], [38], [40], [61]. Similarly, Vos *et al.* [60] state that SQ is directly influenced by software engineer's/programmer's ability. Moreover, a direct positive relationship between SQ and COSS company success was empirically verified (H6). This result is consistent with previous empirical findings and literature in SQ see for example, [13], [14], [41]. Thus, COSS company success depends on the ability of the software product to provide the needed functions, the ease with which customers can learn and use it, its ability to operate dependably, its capacity to perform within expected parameters and time frame, and its ability to be updated and upgraded.

The study has also examined the interactive relationships among IC components and their relationship with SQ. Thus, the mediating role of HC on the relationship between RC and SQ (H7) is supported. The mediating role of HC has been empirically established in similar other contexts see for example [57], [79]. More precisely, the result suggests that software development experts such as community managers and product managers liaison with an OSS community to assess and accept contributions, obtain suggestions for SQ enhancement, and get bug reports that have implications for SQ. Therefore, the result is consistent with the characterization of COSS companies, see [16], [17].

Additionally, HC plays a key role in linking SC to SQ (H8). There are no empirical findings that directly support the hypothesis that HC mediates the relationship between SC and SQ. However, previous empirical studies find that SC directly impacts HC see for example [7], [57]. Besides, the direct positive relation between HC and SQ has also been confirmed see for example, [14], [40], [61]. Against the backdrop of these empirical findings, H8 was hypothesized and confirmed. Consequently, the result suggests SC activities such as managing the software development process, meeting predetermined schedules and budget, and handling software bugs impact the software development expert's ability to create and solve problems, which, in turn, positively impacts SQ.

The second mediation theorized is the mediation effect of SQ between IC components and COSS company success. The result revealed that SQ fully mediates both the relationship between HC and COSS company success (H9) as well as SC and COSS company success (H10). A similar empirical result was also obtained in the Canadian software industry [14]. HC components such as the ability, skills, and creativity of software development experts impact SQ (i.e., quality of source code) [38], [60], [61], which subsequently influences COSS company success [13], [15]. In addition, SC elements, including the software development process (i.e., commits, adding lines of code, releases, and issues), bug-related activities (i.e., monitoring bugs, identifying severe bugs, and fixing bugs), scheduling, and budgeting also affect SQ [12], [14], [42], which, in turn, impacts COSS company success [13], [15].

Lastly, the hypnotized sequential mediation relationship was tested. First, the sequential mediation from RC to COSS company success through HC and SQ is empirically supported (H11). Furthermore, the sequential mediation from SC to COSS company success via HC and SQ is also confirmed (H12). The result suggests that the skills, ability, and creativity of software development experts play a key role in managing external relations with the OSS community, managing the software development process, bug-related activities, and organizational resources. This, in turn, has significant implications for the functionality, reliability, usability, performance efficiency, and maintainability of software products. Finally, having a quality software product positively affects customer satisfaction, profitability, reputation, and popularity of the COSS company.

VI. CONCLUSION

In a knowledge-based endeavor such as software development, knowledge-based resources, IC, and SQ, play a critical role in the success of software companies. As a unique type of software firm, COSS companies are engaged in collaborative software development and marketing: working with an OSS community and active users within the community. In spite of several studies addressing IC, SQ, and company success in other contexts, studies involving COSS companies are limited. Thus, to bridge this gap, responses were collected from a sample of 200 software development experts and professionals working in 60 multinational COSS companies. Additionally, the data was analyzed using PLS-SEM. The result confirmed that there is a significant positive relationship amid IC components. Moreover, SQ fully mediates the relationship between IC components and COSS company success.

After hypothesis testing, total and specific effects were examined. The result revealed that COSS companies should primarily focus on SQ, followed by SC, RC, and HC. In contrast to the total effect, observing the specific effects helps identify the most important activities that COSS companies may need to focus on in order to succeed. Therefore, the outer weight values suggest that COSS companies should focus on hiring skillful and creative personnel. Product and community managers may have to develop a good working relationship with a knowledgeable OSS community. Marketing and sales personnel may need to value customer reviews/ratings. Lastly, engineering managers may have to pay special attention to the functionality of the software products and prioritize severe software bugs.

Furthermore, the research model was evaluated for explanatory and predictive power. The results indicate that the model has predictive relevance. Additionally, the model possesses a moderate explanatory power, and the analysis of the model's predictive power using PLS-predict showed that the model has moderate predictive power. Therefore, this result can be regarded as a very good result, considering that it is one of the first works to examine IC, SQ, and company success in the COSS company context.

In conclusion, in addition to being an original work, the study makes some contributions. Since the study applies IC in the COSS company context, it enriches IC literature. It also contributes to software quality studies by substantiating the mediating role of software quality on the relationship between IC components and COSS company success. The study can benefit different stakeholders and COSS companies by identifying important activities they need to prioritize in order to be successful. Lastly, the study brings COSS companies to the forefront as they benefit society, (i.e., individuals, SMEs, private and public institutions) by offering affordable software products and services.

VII. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Although the study makes ample contributions, it has some limitations that future research may capitalize on. The study attempts to establish the cause-and-effect relationship among IC, SQ, and COSS company success using cross-sectional data that captures a specific period in time. However, the use of a longitudinal study that observes the cause-effect relationships over a considerable period may offer a more precise result.

Furthermore, the lack of a standard measurement and success model meant that the survey tool was adapted and adopted. Thus, designing and validating a standard COSS company success measurement tool as well as a model could be an avenue for future research. Besides, this study uses a quantitative explanatory design based on extant literature and theory. However, a qualitative study may offer a deeper understanding. Therefore, future studies may use a qualitative study to enrich the understanding of COSS companies' success.

APPENDIX

Commercial Open-Source Software (COSS)

In this study, COSS is defined/operationalized as software managed by a company, which develops and owns some or all of the software it offers under an open-source license. Moreover, COSS companies are companies that generate revenue through complementary products or services [16].

A. SECTION A: HUMAN CAPITAL

This section aims at gathering information regarding your experience in software development and related roles.

1) Years of experience as an IT or IS professional
☐ Less than 1 years ☐ 1-5 years ☐ 6-10 years ☐ More than 10 years
2) Previous and/or current role in software development (Please mark all applicable options)
☐ Software Requirements ☐ Software Quality Assurance ☐ Coding
☐ Software Design ☐ Version Management ☐ Test and Integration
☐ Software Process Improvement ☐ User Training ☐ Data Entry
Other please Specify: ....

(Question 1 and 2 are adopted from [14])

Please tick your best answer for each statement based on a scale of 1 to 7, where 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neutral, 5 = Somewhat Agree, 6 = Agree 7 = Strongly Agree

№	Items	1	2	3	4	5	6	7
3.	My company has a skillful and creative team of developers with the ability to solve problems [80].							

B. SECTION B: STRUCTURAL CAPITAL

Please mark on the scale from 1 to 7 where 1 = Strongly Disagree, 4 = Neutral, to 7 = Strongly Agree.

№	Items	1	2	3	4	5	6	7
4.	The developer team at my company makes commits frequently and timely [76].							
5.	The developer team at my company releases patches and features timely and frequently [76].							
6.	The developer team at my company fixes issues often timely [76].							
7.	My company adds more lines of code during the earlier stages of the software development cycle [81].							

Please mark on the scale from 1 to 7 where 1 = never, 4 = neutral, and 7 = Always

№	Items	1	2	3	4	5	6	7
8.	My company continually monitors open software bugs [74].							
9.	My company fixes software bugs often timely [74].							
10.	At my company, critical bugs are always prioritized [74].							
11.	My company often develops a software product within the planned time frame [53].							
12.	My company often develops a software product within the planned cost [53].							

C. SECTION C: RELATIONAL CAPITAL

Please mark on the scale from 1 to 7 where 1 = never, 4 = neutral, and 7 = Always

№	Items	1	2	3	4	5	6	7
13.	My company benefits from an active user community in terms of feature enhancement and bug reporting [82].							
14.	My company provides technical support, training, and development for paying customers [83].							
15.	My company works with a knowledgeable OSS community [84].							
16.	My company works with a dependable OSS community [84].							

Please mark on the scale from 1 to 7 where 1 = Strongly Disagree, 4 = Neutral, to 7 = Strongly Agree.

17.	A newly launched software product at my company attracts more users/customers than matured software products [76].							
18.	The development of complex software at my company often attracts more contribution as compared to less complex software [54].							

D. SECTION D: SOFTWARE QUALITY

Please mark on the scale from 1 to 7 where 1 = Strongly Disagree, 4 = Neutral, to 7 = Strongly Agree.

№	Items	1	2	3	4	5	6	7
19.	My company offers software products with functionalities that enable businesses and individuals to achieve their objectives [14, 85].							
20.	My company provides software products that are easy to understand, learn, and use [14, 85].							
21.	My company offers software products that are always up and running when needed [14, 85].							
22.	My company provides software products that have an acceptable response time [14, 85].							
23.	My company offers software products that need relatively little effort to modify, update or upgrade [14, 85].							

E. SECTION E: COMMERCIAL OPEN-SOURCE SOFTWARE COMPANIES SUCCESS

The goal of this section is to measure success in commercial open-source software.

Please mark on the scale from 1 to 7 where 1 = much less than expected, 4 = neutral, and 7 = greatly exceeding expectation

24.	The software products offered by my company satisfy customer expectations [53].							
Please mark on the scale from 1 to 7 where 1=very low, 4= Neutral, to 7=very high.								
25.	Customer/User ratings and reviews for my company's software products compared products in similar categories are [55].							
Please mark on the scale from 1 to 7 where 1=Strongly Disagree, 4= Neutral, to 7=Strongly Agree.								
26.	Software products offered by my company are more profitable compared to competitors' software products [51].							
27.	The software products provided by my company are popular and reputable [86].							
Please mark on the scale from 1 to 7 where 1=very low, 4= Neutral, to 7=very high.								
28.	The number of downloads my company's software products compared to products in a similar category is [54].							

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