Industry 4.0 Maturity as a Moderator of Industry 4.0's Impact on Company Financial Performance

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Abstract

Numerous studies advance the contemporary technologies of Industry 4.0. Yet, little is known about how Industry 4.0 implementation influences company financial performance. Using a survey and bootstrap sampling and PROCESS, we investigate links among Industry 4.0 maturity, supply chain performance, and company financial performance. A cross-sectional analysis of 93 companies across 14 industries with 10,000 bootstrap samples reveals that Industry 4.0 maturity positively moderates the relationship between supply chain performance and company financial performance. The research result demonstrates that the relationship between supply chain performance and financial performance is significantly stronger when Industry 4.0 maturity is higher. The finding indicates that Industry 4.0 magnifies the potential financial returns to companies through supply chain performance. We also discuss the managerial and research implications.

Keywords
Industry 4.0 maturity, Smart factory manufacturing, Financial performance, and Performance measurement.

1. Introduction
Technology advances, especially communication and information technology, are changing the manner in which business create and capture value, how and where people work, and how people interact and communicate (Cascio and Montealegre, 2016). Together, these advances are hurtling business and manufacturing enterprises toward a new industrial revolution, which is based on cyber-physical system—a revolution popularly known as Industry 4.0, or smart factory manufacturing. Savvy corporate leaders know they must either figure out how these technology advances will transform their businesses or face disruption by others who figure it out first (Murray, 2015). Not surprisingly, the area of this subject has received considerable attention not only in business, but also in engineering, sciences, and social sciences (e.g., Akdil et al., 2018; Hermann et al., 2016; Madsen et al. 2016; Moeuf et al. 2017; Shrouf et al., 2014).

Extensive studies seek to understand how to enforce Industry 4.0 effectively and/or how Industry 4.0 affects production processes/operations (e.g., Hermann et al., 2016; Liao et al., 2017; Shrouf et al., 2014; Ungurean et al., 2014). For example, Ungurean et al. (2014) present an IoT architecture based on the Open Platform Communications NET (OPC.NET) specifications from Gaitan et al.'s (2008) work to enhance the usage of both industrial environments and smart buildings. Mazak and Huemer (2015) address the importance of interoperability to the seamless exchange of data and information among different parties (e.g., manufacturing companies, suppliers, and specialist contractors) in value networks.

Subsequent work by Edmonds and Bradley (2015) investigates the impact of automation on the job markets and economy. They conclude that Industry 4.0 relaxes resources previously required to undertake mundane and routine tasks, allowing them to be employed in high value and high paid roles. Rüßmann et al. (2015) delineate the nine technology trends that are the building blocks of Industry 4.0 and investigate their potential financial economic benefits for manufacturers and production equipment suppliers.

Cascio and Montealegre (2016) investigate the potential impacts of electronic monitoring systems, robots, teleconferencing, and wearable computing devices on work and organizations based on a systematic literature review, and call for more research on how to maximize and minimize the positive and negative consequences for individuals and organizations, respectively. Frey and Osborne (2017) assess the effect of computerization (i.e., job automation by means of computer-controlled equipment) on corporate operations and job markets by using a Gaussian process classifier. They find that wages and educational attainment have a highly negative relationship with a job's possibility of computerization.

Brougham and Haar (2017) develop a method to appraise the extent to which employees feel their job might be replaced by computerization. Theorin et al. (2017) develop a prototype-oriented information model for integration of manufacturing devices and services on all levels, simplifying hardware changes and integration of new smart services as well as supporting continuous improvements on information visualisation and control.

Based on an extensive literature review, Mayr et al. (2018) delineate several perspectives of connections between lean manufacturing and Industry 4.0, and thus, outline a number of industry 4.0 tools that could support the implementation of eight specific lean methods. Recently, Büchi et al. (2020) employ regression analysis to examine how Industry 4.0 affects smart factory manufacturing performance. Using data from 231 manufacturing units, they conclude that Industry 4.0 significantly influences company performance that is measured by the extent of business opportunities the company obtains.

Nevertheless, despite the panoply of studies on Industry 4.0, most studies focus on advancing the contemporary technologies of Industry 4.0 such as big data and analytics, simulation, horizontal and vertical system integration, the industrial internet of things, cybersecurity, the cloud, and additive manufacturing (e.g., Rossit et al., 2019; Shrouf et al., 2014; Ungurean et al., 2014) or understanding how Industry 4.0 affects production processes and operations performance (e.g., Büchi et al., 2020; Lee et al., 2015; Mazak and Huemer, 2015). Relatively few investigate how Industry 4.0 influences business financial outcomes. As a result, little is known about how Industry 4.0 maturity impacts company financial performance.

2. Research Hypotheses

To investigate how Industry 4.0 maturity influences company financial performance, we propose a moderated model, shown in Figure 1. The model revolves around the notion that Industry 4.0 magnifies potential financial returns through supply chain performance (SCP). In other words, we argue that SCP has a stronger positive influence on company financial performance when Industry 4.0 maturity is higher.

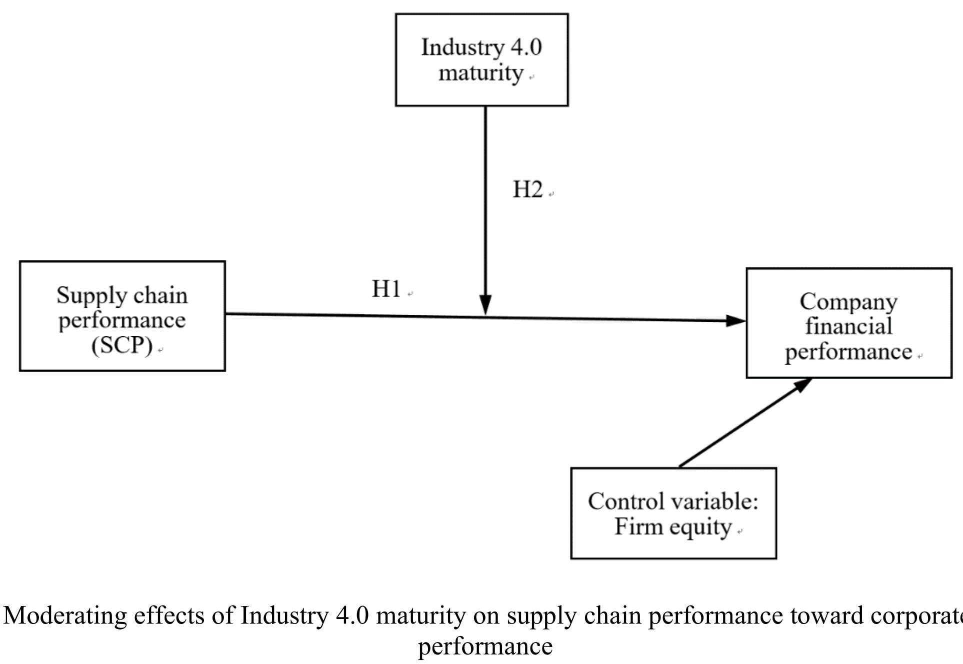

Figure 1. Moderating effects of Industry 4.0 maturity on supply chain performance toward corporate financial performance

Studies suggest that better SCP is more likely to produce favorable corporate financial outcomes (Ambroise et al., 2018; Liu et al., 2016; Rajapathirana and Hui, 2018). For example, Liu et al. (2016) employ resource-orchestration theory and fit-assessment methodologies to analyze data from 196 companies concerning how information technology (IT) competency affects corporations' supply chain integration (SCI) and performance. They conclude that deploying appropriate IT competency reinforces the relationship between SCI and operational and financial performance.

Subsequent work by Chen (2018) concludes that risks in supply chains affect SCP, which in turn influences company financial performance based on a structural equation modeling (SEM) analysis of 106 large manufacturing companies across 20 industries. Delic et al. (2019) employ SEM to examine how additive manufacturing adoption affects supply chain integration. Using data from 124 automotive manufacturers, they claim that SCI mediates the relationship between additive manufacturing adoption and SCP, which in turn improves company financial performance. Thus, we propose that:

Hypothesis 1: *SCP is positively related to company financial performance.*

In Industry 4.0, physical production plants are linked in an open network where machine communication enables efficient data exchanges among different parties both internal and cross-organizational services in value-chain networks (Ivanov et al, 2016). Given these interactive networks of Industry 4.0, it is conceivable that the maturity of a company's Industry 4.0 implementation (i.e., Industry 4.0 maturity) has important implications for business operations in today's business environments, which are characterized by ever-increasing competition and customer expectations.

We propose that Industry 4.0 maturity moderates the relationship between SCP and financial performance such that the relationship is stronger when Industry 4.0 maturity is higher. To understand the interaction, one should note that Industry 4.0 implementation creates what has been called "smart factory manufacturing" (Shrouf et al., 2014).

Within the smart factory, cyber-physical systems talk to and coordinate with each other and with humans in real time. Value chain participants provide and use internal and cross-organizational services, enabling them to monitor their environments and promptly take actions based on the information they receive (Cascio and Montealegre, 2016; Hermann et al., 2016). To this end, firms with a high degree of Industry 4.0 maturity are more likely to enhance the linkage of operations processes within and across organizations, as well as remove duplicate or redundant supply chain processes (Flynn et al., 2016; Napoleone et al., 2020). In turn, this generates favorable supply chain integration that enhances SCP and favorable financial outcomes (Delic et al., 2019). We thus argue that companies that display a high degree of Industry 4.0 maturity may reinforce the relationship between SCP and financial performance. We hypothesize:

Hypothesis 2: *Industry 4.0 maturity moderates the relationship between SCP and company financial performance, and the relationship strengthens when Industry 4.0 maturity increases.*

3. Research Methods

3.1 Participants

In order to explore the hypotheses, we employ a survey research design. In total, we identify and contact 834 potential participants from the databases of the Ministry of Economic Affairs that are implementing or planning to implement Industry 4.0. Of the 834 companies, 110 participated — a 13.20 % response rate.

The survey instrument is based on established item scales from an extensive review of literature in Industry 4.0, as well as in the supply chain management fields. The survey instrument consists of two sections. Section one consists of open-ended questions that collect background information on the respondents and companies, such as gender, work experience, company size, and the industries in which the company belongs. The second section is composed of multiple-choice questions in which respondents answer based on a five-point or a seven-point Likert scale.

Excluding survey responses with missing data results in 93 useful sample companies in 14 different industry sectors. These sectors include chemicals, biotechnology, petrochemical, automotive, textiles, food, rubber, optoelectronic, semiconductor, electrical distribution, electronics, iron and steel, electric machinery, and construction and building materials.

3.2 Measures and Analysis

Industry 4.0 maturity, financial performance, and supply chain performance variables are based on a systematic review of the literature. Key in this process is the use of explicit, reproducible criteria; evaluations of research quality; and the strength of the findings (Chen, 2018; Tranfield et al., 2003). We adopt much of the review methods in Tranfield et al. (2003) and in Colicchia and Strozzi (2012).

Industry 4.0 maturity. Ten-item scales in Agca et al. (2017) and Veza et al. (2015) measure the maturity level of a company's Industry 4.0. Sample item scales are "In1: Choose the best description of product development phase in the company," "In3: Choose the best description of work-order management in the company's production system," and "In5: Choose the best description of materials inventory management (raw materials and work in progress) in the company's production system." The Cronbach's α for *Industry 4.0 maturity* is 0.95.

Financial performance. Six-item scales in Chen (2018) and Grigoroudis et al. (2012) measure corporate financial performance. Sample items are "FP1: Our firm's return on sales over the last 12 months," "FP3: Our firm's earnings per share over the last 12 months," and "FP5: Our firm's return on assets over the last 12 months." The Cronbach's α for *Financial performance* is 0.95.

Supply chain performance. Eight-item scales in Agca et al. (2017), Lee and Billington (1993), and Noordewier et al. (1990) measure supply chain performance. Sample items are "SCP1: Our suppliers' ability to handle our volume demand changes," "SCP3: Our suppliers' ability to meet our quality requirements," and "SCP5: Ability of our production system to handle customers' volume demand changes." The Cronbach's α for *Customer performance* is 0.93.

As firm size may affect company financial performance due to the fact that size may reflect a variety of organizational attributes, as well as resource deployment (Aral and Weill, 2007). We thus control company size by using company equity used to finance various business operations of that company.

Our methodology to examine the hypotheses is twofold. First, we develop and validate the measurement model using confirmatory factor analysis (CFA) (Harrington, 2009) for testing our hypothesized model in Figure 1. Second, we employ the hypothesis testing procedure in Tangirala et al. (2007), as well as the bootstrap-sampling method and PROCESS (Hayes, 2012; Preacher and Hayes, 2008) to examine the hypothesized model.

4. Research Results

Our measurement model is congeneric, where the model's constructs correlate with one another. The model's constructs include Industry 4.0 maturity, financial performance, and SCP. The measurement model's overall fit suggests an adequate fit with the data. The value of the model chi-square/degrees of freedom is 1.62 that is smaller than 3; the respective values of incremental fit index (CFI), comparative fit index (CFI), and Tucker-Lewis index (TLI) are 0.94, 0.94, and 0.93, which are all larger than 0.90; and the value of the root mean square error of approximation (RMSEA) is 0.08 smaller than 1 (Harrington, 2009).

Hypothesis testing follows the procedure in Tangirala et al. (2007). We first regress the dependent variable (i.e., financial performance) on the independent variables (i.e.., SCP) with a control variable (i.e., equity) in the equations. Significance for an independent variable in such a regression equation indicates support for the level-one prediction (i.e., hypothesis 1). Second, we introduce Industry 4.0 maturity as a level-two moderator of the level-one relationships. Significance for the interaction term involving Industry 4.0 maturity using the bootstrap-sampling method and PROCESS (Hayes, 2012; Preacher and Hayes, 2008) suggests support for the cross-level prediction (i.e., hypothesis 2).

Table 1 reports the bootstrap-based hierarchical linear regression results with 10,000 bootstrap samples for the level-one (hypothesis 1) analysis. Table 2 exhibits the results of moderation (i.e., Industry 4.0 maturity) analysis using the bootstrap-sampling method and PROCESS (Hayes, 2012; Preacher and Hayes, 2008) with 10,000 bootstrap samples.

Table 1. Bootstrap-based hierarchical linear regression results for level-one analysis

Variables and Sources	Products of Coefficients			Bias-Corrected 95% CI	
	Estimate	SE	t-Statistic	Lower	Upper
Intercept	1.596	0.644	2.479**	0.404	2.922
Control variable					
Equity	-0.020	0.043	-0.470	-0.090	0.057
Independent variable					
SCP	0.656	0.115	5.717***	0.409	0.871
R-squared	0.270				

Note: 10,000 bootstrap samples. ***$P < 0.001$, **$P < 0.05$, and *$P < 0.10$.

As table 1 shows, the regression coefficient for SCP is 0.656 that is significant at the $P < 0.001$ level. The bootstrapping tests generate the bias-corrected 95% CI of 0.409 to 0.871, which excludes zero. This further confirms the significance of SCP to financial performance. The result supports Hypothesis 1 that SCP is positively related to company financial performance (Hypothesis 1).

As shown in table 2, the regression coefficient for the interaction term *SCP × Industry 4.0 maturity* is 0.307 at the $P < 0.05$ level. The bootstrapping tests produce the bias-corrected 95% CIs of 0.011 to 0.603 that excludes zero, confirming the significance of the interaction term. The result suggest that Industry 4.0 maturity moderates the relationship between SCP and company financial performance (hypothesis 2).

Table 2. Bootstrap-based analysis of moderators for level-two analysis

Variables and Sources	Products of Coefficients			Bias-Corrected 95% CI	
	Estimate	SE	t-Statistic	Lower	Upper
Intercept	5.630	2.114	2.663***	1.429	9.831
Control variable					
Equity	-0.035	0.0479	-0.7292	-0.130	0.060
Independent variable					
Industry 4.0 maturity	-1.533	0.797	-1.923*	-3.117	0.052
SCP	-0.144	0.400	-0.361	-0.938	0.650
Cross-level interaction effect					
SCP × Industry 4.0 maturity	0.307	0.149	2.060**	0.011	0.603
R-squared	0.306				
Improved R-squared due to interaction	0.034				

Note: 10,000 bootstrap samples. ***$P < 0.001$, **$P < 0.05$, and *$P < 0.10$.

5. Discussion and Conclusion

Previous studies of Industry 4.0 focus on how to advance the contemporary technologies necessary for developing Industry 4.0 (e.g., Imtiaz and Jasperneite,2013; Rossit et al., 2019; Shrouf et al., 2014; Ungurean et al., 2014) or understanding the influences of Industry 4.0 on business production processes (e.g., Büchi et al., 2020; Ivanov et al., 2019; Mazak and Huemer, 2015; Schlechtendahl et al., 2015). Few studies focus on how Industry 4.0 maturity affects corporate financial performance.

This study develops and examines the theory that Industry 4.0 maturity facilitates high-quality SCP, which in turn enhances company financial performance. The research results demonstrate that Industry 4.0 maturity moderates the relationship between SCP and financial performance.

Graphical representations of the moderating role of Industry 4.0 maturity in Figure 2 reveal interesting nuances in the relationships. Financial performance is lowest when there is poor performance in SCP but a high level of Industry 4.0 maturity. In other words, SCP at high levels of Industry 4.0 maturity has greater effects — both positive and negative

— on company financial performance. Industry 4.0 not only facilitates development of SCP, but also it fosters more positive and negative influences on financial performance.

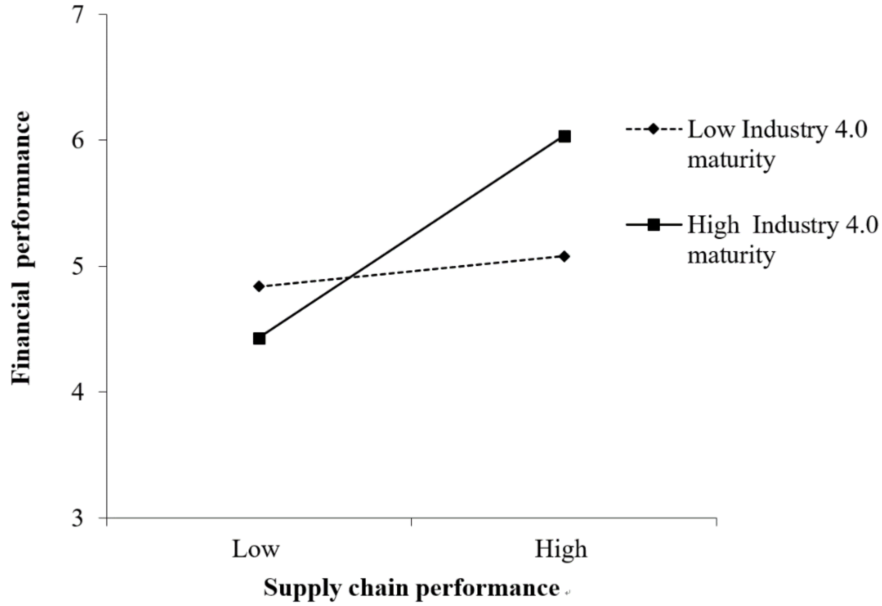

Figure 2. Relationship between supply chain performance and financial performance at low and high Industry 4.0 maturity (10,000 bootstrap samples)

Like any research, this study has some limitations. First, this study uses 93 samples for examining the hypotheses. Although this study integrates the bootstrap-based method with our analyses to ensure better generalization (Chen and Lin, 2018; Preacher and Hayes, 2008), future research should triangulate our research findings by using more samples. Second, it is possible that factors such as internal business process performance, customer performance, or technological management capacity (Hsiao et al., 2017) interact with Industry 4.0 maturity, which in turn affects financial performance. Our study does not explicitly explore these factors' relationships with Industry 4.0. Similarly, a company's organizational climate and structure might influence the company's Industry 4.0 implementation. Future research could investigate these effects on Industry 4.0 maturity and thereby on financial performance.

In sum, extensive research in the Industry 4.0 field develops innovative approaches and methods to achieve automation, as well as operational efficiency and effectiveness. However, little research explores how Industry 4.0 maturity affects financial performance. Our analysis via the bootstrap-based method and PROCESS (Hayes, 2012; Preacher and Hayes, 2008) shows that the relationship between SCP and financial performance is significantly stronger when Industry 4.0 maturity is higher. The finding indicates that Industry 4.0 magnifies the potential financial returns to companies through SCP.

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Biography

Hong Long Chen is a Full Professor in the Department of Business and Management at the National University of Tainan, Taiwan. Dr. Chen is a member of the Tau Beta Pi Engineering Honor Society. He holds a Ph.D. from the University of Florida, and has worked for several engineering firms. His papers have been published in various journals such as *Supply Chain Management: An International Journal*, *International Journal of Operations & Production Management*, *Journal of Real Estate Finance and Economics*, *Journal of Management in Engineering*, and *International Journal of Project Management*. He is also an editorial board of *International Journal of Project Management*.