Empirical Issues in Testing Complementarities within Management Control Systems

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Abstract

With the growing number of management accounting studies that investigate the complementarities between multiple management control practices as a system, it becomes crucial to address several conceptual and empirical issues in this evolving area of research. In this paper, we address conceptual and empirical issues in relation to: (1) higher-order complementarities; and (2) the idea of balance versus complementarities. First, this paper shows the higher restrictions associated with testing complementarities between three or more choices compared to pair-wise complementarities. Second, this paper draws the similarities and differences between the concept of balance in Simons' (1995) levers of control (LOC) framework and complementarities from complementarity theory, using theoretical models and provide empirical insights that extends from complementarities to balance. Additionally, we address the issue of correlated omitted variable in empirical applications for both concepts. Our analysis provides a clearer theoretical perspective for future empirical studies that examine higher-order complementarities, as well as balance and complementarities, and guidance on addressing key statistical challenges in this line of empirical research.

1. Introduction

This study presents formal models for management control (MC) studies that investigate two key areas: (1) the interdependencies of management control practices a system of three choices or more, or higher-order complementarities; and (2) the interdependencies of management control practices through the concept of balance in the levers of control (LOC) framework (Simons, 1995) and complementarity in complementarity theory (Grabner & Moers, 2013; Milgrom & Roberts, 1995). The aim is to bridge the gap between theory and empirical research by addressing several conceptual issues, particularly in the context of testing higher-order complementarities and balance. Through the development of theoretical models, this paper also seeks to guide future empirical research, highlighting potential statistical challenges when examining these complex relations.

The study of the combination or interdependencies between multiple management control practices has been one of the forefront topics in management accounting literature (Chapman et al., 2020). The fundamental idea is that one MC practice may be interdependent with another as complements or substitutes. If firms take these interdependencies between different management control practices into account in their design choices, these practices form a management control "system" and it is important to study them together (Grabner & Moers, 2013; Milgrom & Roberts, 1995). The study of management control as a system draws upon complementarity theory in explaining the interdependences between the practices, where two practices are complements as they positively reinforce one another and substitutes when they negatively reinforce one another (Grabner & Moers, 2013; Milgrom & Roberts, 1995).

In management accounting, this line of literature has developed over the years starting from theorists extending the original work of complementarity on multiple areas and developing models to address different issues empirical studies may face in testing complementarities (Brynjolfsson & Milgrom, 2013; Grabner & Moers, 2013; Malmi & Brown, 2008; Masschelein & Moers, 2020; Milgrom & Roberts, 1995) to empiricists studying the interdependencies between different combinations of management control choices such as delegation and incentives (Indjejikian & Matějka, 2012; Moers, 2006), performance measurement system (PMS) diversity and use (Chen et al., 2023), as well as information and incentive pay (Manthei et al., 2023). The importance of this line of literature on management control, especially from Grabner and Moers (2013), has extended to the 2020 *Accounting, Organizations and Society* special issue on management control as a system or package, in which several theoretical and empirical papers, as well as discussion papers in this topic have emerged. Studies have recognised the importance of studying multiple management control practices simultaneously and not in isolation from each other.

Despite such development, some authors in the 2023 Journal of Accounting Research (JAR) conference, have highlighted that theory and empirical studies often advance separately despite the need for tighter integration (Breuer et al., 2024). Empirical studies are continuously testing the interdependences of different management control choices in different environments without fully incorporating theoretical insights, while theorists continue to develop models as the first-order building blocks or articulating explanations based on issues found in empirical studies without testing whether the models or proposed suggestions hold when applied in real-world, descriptive settings. Thus, this paper aims to bridge that gap and respond to the call in Breuer et al. (2024) by linking theory and applying this theory to an empirical setting with descriptive data in management accounting, particularly with complementarity studies.

This paper specifically looks into two main frameworks used in the management control literature when studies examine the combination of MC practices as a system, complementarity theory (Grabner & Moers, 2013; Milgrom & Roberts, 1995) and the levers of control (LOC) framework (Simons, 1995). Speklé and Widener (2024) call for future research to extend dyadic or pair-wise control systems to non-dyadic or higher-order complementarities based on existing frameworks such as LOC (Simons, 1995). Balance and complementarities are also common topics that have been adopted by empirical studies that examine the interdependencies based on the control levers in Simons'(1995) LOC framework (Bedford, 2015; Cao et al., 2009; He & Wong, 2004). Despite its popularity and importance in the management control literature, these topics in relation to the study of complementarities between control practices are theoretically and data-wise demanding topics of study. There are multiple empirical challenges and issues that have yet to be formally addressed, such as problems of common method bias and measurement validity. Speklé and Widener (2024) highlight how important it is for future research to address those challenges in this line of literature.

In this paper, we aim to address that call and theoretically address the empirical issues in relation to (1) higher-order complementarities, and (2) the relation between balance based on the LOC framework and complementarity from complementarity theory, as well as addressing the correlated omitted variable bias for the two topics. First, this paper examines the challenges many empirical studies face when studying higher-order complementarities of three or more choices simultaneously. Although some studies have successfully found the presence of three-way complementarities (Aral et al., 2012; Carree et al., 2011; Tambe et al., 2012), many studies have also faced challenges and empirical issues due to the complexity of detecting the presence of higher-order complementarities (Ballot et al., 2015; Choi & Lee, 2012; Kreutzer et al., 2015). Several studies have pointed towards the importance of moving from two-way to higher-order interdependencies and that this is an interesting area of development for the management control literature (Friis et al., 2015; Speklé & Widener, 2024). However, the growth of studies that examine higher-order interdependencies is still relatively slow in the current management control literature space. Second, this paper clarifies the notion of balance and complementarities, both conceptually and empirically. While these two streams have been treated as two independent streams of literature, we show that the theoretical predictions are the same. Finally, this paper shows the potential correlated omitted variable bias in relation to higher-order complementarities, which also extends to balance for more than two choices. This paper aims to guide future research and address the above issues by illustrating them with formal models. It also makes several assumptions explicit, as understanding these assumptions is crucial for grasping the problems and knowing how to address them (Chenhall & Moers, 2007).

The structure of this paper is as follows. Section 2 reviews prior literature relevant to the two topics. Section 3 develops the theoretical models for both topics. Section 4 addresses common biases (i.e. correlated omitted variables problem) empirical studies face in relation to the two topics. Section 5 concludes the paper.

2. Literature Review

2.1 Higher Order Complementarities

With the increasing number of studies in management accounting that investigate two-way complementarity and higher-order complementarities[1] in management accounting, it becomes important to clearly state the assumptions and clarify the problems in relation to testing these higher-order complementarities. Prior studies, such as Grabner and Moers (2013) and Masschelein and Moers (2020), have only focused on a set of two management control

[1] Another term for higher-order complementarities in a system is nondyadic systems as used in Speklé, Verbeeten and Widener (2022), which refers to a system that comprises three of more control practices where all the practices are either directly or indirectly related.

practices and not more than two or higher-order interdependencies. This study extends these studies to higher-order interdependencies, starting from three-way complementarities and then to more than three-way complementarities, by explicitly stating assumptions and clarifying the potential correlated omitted variable problems and robustness of testing higher-order complementarities with the demand and performance specification tests.

There are three ways that empirical literature has argued how three or more MC practices can be considered as an MC system. To simplify the explanation, this paragraph will illustrate the argument with a combination of three MC practices within the same control environment. The first argument is an MC system of three MC practices can be formed through multiple two-way combinations (eg. *A*, *B*, and *C*). According to Grabner and Moers (2013), a combination of interdependent management control practices forms an MC system when firms take these interdependencies into account. This means that there may be multiple interdependencies happening at the same time within a single system. However, the condition where all choices need to be connected with two-way interdependencies is not a necessary condition for the three MC practices to be considered part of the same MC system. For example, as illustrated in Figure 1, if *A* and *B* are complements, and *B* and *C* are complements, then these practices form part of the same MC system and firms need to consider them simultaneously. Thus, the presence of three-way complements between *A*, *B*, and *C* is not a necessary condition for *A*, *B*, and *C* to be part of the same MC system, as there will be an interdependency between *A* and *C* even if B is ignored and the three practices still need to move simultaneously regardless.

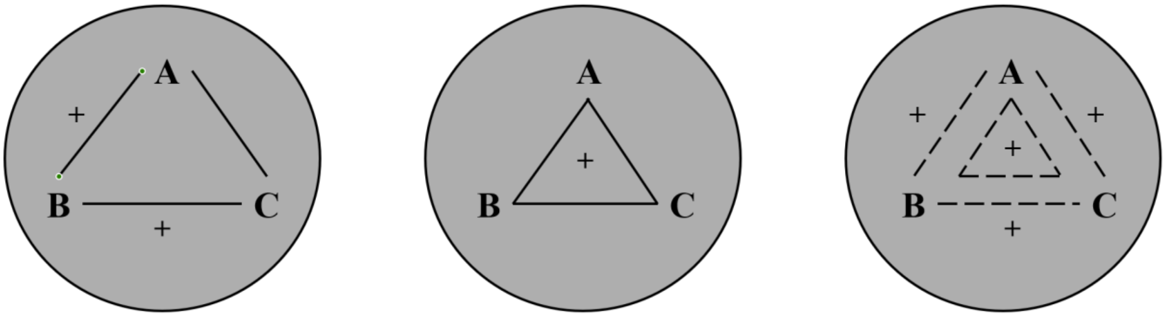

Figure 1: MC systems with two-way and three-way complementarities between a set of 3 MC practices (A = IT, B = Incentives, C = HR Analytics, based on Aral et al. (2012))

Circles represent the MC systems, lines represent the interdependency effects, dotted lines represent weaker interdependency effects, and positive signs represent that the interdependence effect is a complementary effect.

MC system 1 shows that if A = IT and B = Incentives are complements, and B = Incentives and C = HR analytics are also complements, then these practices form an MC system. This is true regardless of whether they form three-way complements or whether A and C are complements, as they would be interdependent through B. A positive effect between A and C would be observed even if B is absent. MC system 2 shows that A = IT, B = Incentives, and C = HR analytics form an MC system through three-way complementarities. MC system 3 shows that if A = IT, B = Incentives, and C = HR analytics form an MC system through two-way and three-way complementarities. However, there may be trade-offs regarding which of the two types of complementarities may be stronger.

Prior studies have investigated many different combinations of pair-wise complementarities, such as between information as a decision-facilitating tool and performance pay or incentives as a decision influencing tool (Holmstrom & Milgrom, 1991; Manthei et al., 2023), incentive design and delegation of decision-making (Indjejikian & Matějka, 2012; Moers, 2006), delegation of decision-making and culture (Malmi et al., 2022), culture and creativity work, such as R&D, and employee satisfaction (Bol et al., 2024), diverse tasks and incentive design (Zhang, 2003) and performance measurement system use and diversity to support innovation (Chen et al., 2023). The findings from these studies indicate that there are two-way complementarities between these choices. If all these interactions are true, then according to (Grabner & Moers, 2013), these interactions should form a management control system and must be examined simultaneously. However, how this is practically and truly feasible is a question that is yet to be formally addressed. This is because different studies claim that incentive pay complements different management control practices, for example with delegation (Malmi et al., 2020; Moers, 2006), performance measures (Baker, 2002; Gibbs et al., 2004; Grabner, 2014), job design (Milgrom & Roberts, 1992), intrinsic motivation (Osterloh & Frey, 2002), trust or norms (Baker et al., 1988), if they are really complements, then they all need to be studied together as an MC system in a single study, which is perfectly feasible with a survey study as it can capture multiple factors simultaneously (Speklé & Widener, 2024). However, the problem here is whether each of these pair-wise relations will remain complements after all other choices are included and whether the effects will remain the same. Friis et al. (2015), for instance, find that some of the complementary pair-wise relations for incentive pay with other MC practices, turn out to be substitutes when all the other MC practices are included. What does it mean if they are all related and how true of an effect is it if all the two-way complementarities that are claimed to be found are true? (Mouritsen et al., 2022)

The second argument is that an MC system can be formed through the presence of higher-order complementarities (i.e. three-way complementarities). Instead of simply having two-way complementarities, there is a stronger three-way effect between MC practices *A*, *B*, and *C* when the three are considered together than the sum of all main effects and all two-way interdependencies and they form a system based on the presence of the three-way effect (Speklé & Widener, 2024). For instance, Aral et al. (2012) find three-way complementarities between the use of IT, human resource analytics, and performance pay, but not necessarily two-way complementarities between the three practices. This means that the three practices form a management control system through higher-order effects and the three need to be adopted together as the use of two practices without the other will lower the marginal benefits. Then, the three practices need to also be examined simultaneously as a system. However, this second view is relatively harder to identify.

The third argument is that an MC system can be formed based on the combination of two-way and three-way complementarities, as illustrated in Figure 1. This line of argument puts forth that there may be both two-way and three-way complementarities between MC practices *A*, *B*, and *C*. This paper explains and shows why in such a system the strength of the complementarities is weaker in section 3.1.

As illustrated in Figure 1, these are the three combinations of interdependency effects within an MC system that some empirical literature has argued. Under our definition of a MC system, all three combinations of interdependency effects between choices, lead to the conclusion that the choices are to be considered as a system. The three combinations are the types of interdependencies that can be formed between MC practices in an MC system as hypothesised by empirical studies. However, the management accounting literature has also argued that there are important differences between two-way and more than two-way, higher-order complementarities and that it is important to study the latter as most empirical studies only examine the former (Friis et al., 2015; Speklé et al., 2022; Speklé & Widener, 2024). Thus, this study addresses the two types of interdependencies, two-way and higher-order complementarities, with different combinations.

Some literature has attempted to investigate higher-order complementarities (Aral et al., 2012; Ballot et al., 2015; Carree et al., 2011; Choi & Lee, 2012; Kreutzer et al., 2015; Speklé et al., 2022; Tambe et al., 2012). Aral et al. (2012) investigate three-way complementarities between performance pay, human resource analytics, and information technology and report that the three choices are three-way complements. They empirically test the presence of complementarities using two types of statistical tests[2]: (1) demand (or conditional correlation) specification, and (2) performance (or productivity) specification. Ballot (2015) looks into three-way complementarities between product, process, and organisational innovation in French and UK firms using both demand and performance specification methods, but finds that there are no three-way complementarities between the three despite finding two-way complementarities between product and process innovation, and organisational and product innovation.

Carree et al. (2011) use a Monte Carlo experiment as an improved simulation testing framework to test for complementarity or substitutability. They use the performance specification with one pair-wise relation of two practices and all pair-wise relations of four practices, to test for complementarities between two, three, and four practices, and find that pair-wise tests perform especially poor for four practices but relatively okay for three practices. However, these tests do not necessarily consider different situations where there may be complementarities for some environments and not for the other. Choi and Lee (2012) examine how the combination of different forms of knowledge-sourcing strategy improves firm performance. They attempt to extend it further to investigate four-way complementarities between system-, person-, external- and internal-oriented knowledge-sourcing strategies. They

[2] Aral et al. (2012) included an additional test, the systems test or the cube view, which is a graphical framework to understand the complementarities among three practices. However, as the cube view is simply a visual model or another way of modelling the performance specification tests for three practices, the system test or the cube view has been excluded as part of the discussion of statistical tests.

find support for several two-way and three-way interactions but fail to find support for the four-way complementarities.

Kreutzer et al. (2015) examine how there is complementary use between organisational controls in the presence of organisational politics on strategic initiatives performance and hypothesizes that there is a three-way interaction between behaviour control, outcome control, and managerial/group politics on strategic initiatives performance. They find a two-way complementarity between behaviour and outcome control on strategic initiatives performance and three-way complementarities between behaviour, outcome control, and managerial politics, but fail to find three-way complementarities between behaviour, outcome control and group politics. Tambe et al. (2012) examine two and three-way complementarities between IT investment, external information, and decentralisation in increasing productivity and find that all two-way and three-way complementarities are supported. Speklé et al. (2022) find that there is a three-way complementarity between performance measures for operational, incentive-oriented, and exploratory purposes in low contractability settings where there is a poor-developed predictive model of outcomes, activities, and processes involved in goal achievement, but no three-way complementarities in a high-contractability setting as the condition is well developed and the three measures do not need to combine as a system to address the directional challenges.

A pattern that emerges between these studies that examine higher-order complementarities is that it is rather challenging to find the presence of three-way complementarities with the right combination of practices in comparison to two-way complementarities, even though many prior studies suggest two-way interdependencies being present between the three choices. There may be two possible reasons as to why the empirical support for three-way complementarities has been rather limited and is only found in some studies. The first one is that there are no three-way or higher-order interactions present in practice, which perfectly justifies the absence of such findings. There are simply many two-way interdependencies in the system, but no three-way or higher-order complementarities are present. The second reason is that there is a three-way or higher-order effect, but there are also two-way effects present at the same time. This will result in a lack of power in the results as multiple interactions are happening simultaneously. If this is the case with only three-way complementarities, this will be more challenging as we add more management control practices into the picture as the effect of the complementarities will be diminished and harder to detect.

It becomes important then to formally address and provide an explanation from a statistical point of view of what is at play when such situations occur.

This paper aims to provide a clear and consistent explanation as to why many studies find it hard to detect higher-order interdependencies and only very few studies have successfully proven otherwise. Section 3.1 formally addresses these issues and clarify them by illustrating potential scenarios that might occur when testing higher-order complementarities using mathematical models. Section 4 extends this discussion and addresses potential issues in relation to omitted variable bias in empirical tests for higher-order complementarities.

2.2. Balance and Complementarity

Prior studies have noted the importance of studying management control practices in combination (Grabner & Moers, 2013) and there are two streams that emerge. One stream draws upon the concept of balance from Simons' (1995) LOC framework and the other stream uses complementarity theory. However, these two streams have largely been studied in isolation from one another, even though both examine the same underlying concept, the combination of management control practices. This section examines the two streams together side-by-side and sets out the similarities and differences in their formal tests and how this impacts their empirical applications.

2.2.1. Balance and the LOC Framework

By definition, the word "balance' means an even distribution of weight or a situation in which different elements are equal or in the correct proportions (Oxford Dictionary). In management accounting literature, the concept of balance is introduced in the Levers of Control (LOC) framework (Simons, 1995) and is centred upon the idea that control systems must be in balance to manage competing tensions that normally arise when there are competing organisational demands. The exact definition of balance and how it can be applied to control systems have not been set out very clearly in the framework (Mundy, 2010; Henri 2006), which allows room for different interpretations and empirical applications. Thus, we rely on subsequent empirical studies following this framework that apply the concept of balance to examine how balance is formally addressed and applied empirically. The concept of balance is often applied when studying two or more choices with opposing forces, and as these opposing forces continuously pull towards opposite directions, they create a dynamic tension that eventually will turn into a steady state or balance (Andriopoulos & Lewis, 2009; Bedford, 2015).

The concept of balance has been explored in the management control literature, particularly in how organizations balance or combine different management control practices to support two modes of innovation: exploitation and exploration (Bedford, 2015; He & Wong, 2004; March, 1991; O'Reilly & Tushman, 2008; Tushman & O'Reilly, 1996). There are two levels of arguments of balance underlying this line of literature: (1) balance between exploitation and exploration innovation; and (2) balance between MCS or the control levers. The first concept of balance comes from the innovation literature, when a firm pursues both exploitation and exploration modes of innovation learning. Exploitation focuses on building on existing processes and capabilities and exploration focuses on experimentation and innovation outside of a firm's existing know-how. The basic conceptual argument is that ambidextrous firms that pursue both exploration and exploitation simultaneously place two contradicting demands and create a dynamic tension in which firms must learn to balance to optimise firm performance (He & Wong, 2004). He and Wong (2004) examine this and find that the interaction between explorative and exploitative innovation is positively related to sales growth rate and the imbalance between the two is negatively related to sales growth rate.

The second concept of balance is at the management control level, where balance can be created from the dynamic tension from the joint use of the control levers in Simons' (1995) LOC framework – belief, boundary, diagnostic, and interactive controls (Bedford, 2015; Cao et al., 2009; He & Wong, 2004). Some studies examine how firms balance or combine use of these levers in different organisational aspects to enhance organisational performance. For instance, Henri (2006) examines the joint use of diagnostic and interactive PMS on four different types of capabilities (innovativeness, organisational learning, market orientation and entrepreneurship) and organisational performance. In addition, many studies apply the combined use of the control levers in the setting of firms that pursue exploitative and exploration innovation goals, thus extending the first line of literature. Each of the levers possesses either a positive or negative force and they create a dynamic tension that is necessary to stimulate and control the exploration or exploitation side for profitable growth when used in combination (Simons, 1995). As an ambidextrous firm simultaneously pursue both exploitative and explorative innovation goals, different control levers are used to support each goal. For instance, the combination of diagnostic (negative controls used to motivate, monitor and reward achievement of specified goals) and interactive (positive controls used to stimulate organisational learning and the emergence of new ideas and strategies) control systems have been found to best enhance the overall organisational performance of an ambidextrous innovative company (Henri, 2006; Bedford, 2015; Bedford et al., 2019).

Bedford (2015) examines how different combinations of the four control levers in the LOC framework are used when firms pursue either or both exploration and exploitation. The results show that diagnostic and boundary control systems benefit exploitative innovation, while interactive control systems support explorative innovation. The balanced and combined use of diagnostic and interactive control levers help to enhance organisational performance as it helps to balance the demands for innovation and predictable goal achievement in firms that pursue both exploitation and exploration. Bedford et al. (2019) focus on how performance measurement systems (PMS) use for top management team decision-making help to transform competence ambidexterity (simultaneous pursuit of exploitation and exploration) into innovation ambidexterity outcomes (radical and incremental innovations). They find that balanced use of PMS and the use of PMS for debate within top management combines to generate cognitive conflict, which is associated with enhancing ambidextrous innovation outcomes. Chen et al. (2023) seem to contribute in this line of literature as well, but they focus on the complementarities between the PMS use (diagnostic or interactive) and PMS diversity on product innovation instead of the balance between the two.

The balance literature conceptually and empirically distinguishes the conceptualisation of organisational ambidexterity into two dimensions: “balanced” and “combined” use of control levers (Bedford, 2015; Cao et al., 2009; He & Wong, 2004). Some studies treat the two conceptualisations as separate, some treat them as two ends of one continuum (Ylinen & Gullkvist, 2012). The literature defines and empirically tests “balanced” use as the relative magnitude or the absolute difference between the two forces, while “combined” use as the combined magnitude or product term or sum or the interaction effect of the two forces (Bedford, 2015; Ylinen & Gullkvist, 2012; Cao et al., 2009; He & Wong, 2004). The first one suggests that “balanced” use is a point where performance is most optimal with the zero absolute difference being the most optimal or when the two choices are in the right proportions. This is further illustrated in Cao et al. (2009), if Firm A has a score of 10 and 5 and Firm B has a score of 5 and 5 for their exploration and exploitation activities respectively, then Firm A will receive a higher score for "combined" use and Firm B will receive a higher score for "balanced" use if they pursue the two simultaneously. This is obtained by taking the absolute difference between the two in the empirical tests (Bedford, 2015). The latter suggests that it is the interdependent effect between two forces, which is obtained by interacting the two in the empirical tests (Bedford, 2015).

However, even after many of these studies investigating the simultaneous use of multiple management control practices in MCS, how the concept of balance is supposed to be tested or how it differs from the study of complementarity is still arbitrary (Mundy, 2010). This is one of the issues that we aim to clarify in this paper.

2.2.2. Balance and Complementarity Theory

The idea of balance in the levers of control (LOC) framework (Simons, 1995) and complementarity theory (Grabner & Moers, 2013; Milgrom & Roberts, 1995) have been studied widely in management accounting literature, but the distinction between the two remains unclear as they are often studied in isolation of each other. The idea of balance in the LOC framework puts forth that when two or more choices with opposing forces interact or are used in combination, a dynamic tension will arise and firms must learn how to balance this to enhance organisational performance (Simons, 1995; Smith & Lewis, 2011). Complementarity theory focuses on the interaction of two or more forces that results in a combined effect that is greater than the sum of their individual effects (Brynjolfsson & Milgrom, 2013). It centres upon interdependencies in a firm's choice of organisational practices and establishes that when the use of one choice increases the marginal benefit of the other, those choices are considered complements (Milgrom & Roberts, 1995).

The two have a common theme in that they examine the interaction or interdependence between the management control practices and emphasize that a combined effect enhances performance. Conceptually, the difference boils down to where the "combined" effect is coming from. For balance, the interaction is between two opposite forces (positive and negative, e.g. exploration and exploitation), and as those two opposite forces keep pulling the other way, the forces reach a stable or balance point (Bedford, 2015). The dynamic tension in balance is maintained by having a combination of multiple management controls (e.g. diagnostic and interactive controls) that work together to keep opposite forces in balance, which will positively reinforce the overall performance of the organisation. Whereas for complementarity, the interaction is between two choices that reinforces each other to create a positive synergy to enhance the overall performance. Complementarity does not focus on the dynamic tension from the forces, but on the choices. The opposite of complementarity is substitution, and in this case, the interaction is a negative relationship between two choices and these choices replace one another.

Several studies indicate that there is an overlap between balance that is proposed in the LOC framework and complementarity. Henri (2006, p. 531) states that "these two types of use (diagnostic and interactive) work simultaneously but for different purposes. Collectively, their power lies in the tension generated by their balanced use which simultaneously reflects a notion of competition and complementarity". Mundy (2010) mentions how management control systems have two complementary and interdependent roles, controlling and enabling roles, and when these roles are combined, they create a dynamic tension that is necessary for balance. In support of this, Bedford (2020) discusses how the diagnostic and interactive uses of PMS in increasing performance in ambidextrous firms uses two mechanisms of causal relations for which complementary is generated, compensating or controlling and enabling roles. These studies collectively point towards the idea that balance is a subset of complementarity, but through different causal mechanisms for complements. Balance uses the combination of (1) *compensating effect*, in which a "MC practice counteracts the weakness of another MC practice in resolving a control problem" (reducing the pursuit of innovation without achieving financial goals); and (2) *enabling effect*, where the "MC practice creates the conditions for another MC practice to contribute to resolving a control problem" (e.g. creating a dynamic tension between diagnostic and interactive, leading to simultaneous pursuit exploration and exploitation) (Bedford, 2020, p. 2). Whereas a typical complementarity study between two choices (e.g. delegation and incentives) uses a *reinforcing effect*, where one "MC practice enhances the effectiveness of another MC practices in resolving a control problem" (enhancing financial performance) (Bedford, 2020, p. 2).

Despite these selected explanations from multiple studies, there still seems to be a lack of coherence between its conceptual definition and the way that they are tested. As such, this paper aims to examine this in more detail in section 3.3 using a formal model and formally address how the two intersect. The empirical application of balance and complementarity follows the definitions and empirical tests in prior literature. However, the clear empirical comparison between balance and complementarity has never been formally established. The balance literature have adopted two different methods in testing the interdependences of the control levers: "balanced" and "combined" use of control levers (Bedford, 2015; Cao et al., 2009; He & Wong, 2004). This paper proposes that "combined" use is essentially the same concept and underlying argument of interdependence from complementarity theory. The method that is used to test the combined magnitude is also similar to the method used in testing the presence of interdependence in studies that use complementarity theory (Henri, 2006).

In this paper, the terms "combined" use and "complementarity" are used interchangeably. The term "complementarity" is used going forward. Prior literature indicates that balance is different from complementarity and conducts the test for balance using the absolute difference score, in our model, we show that these tests for balance are similar to the traditional tests for complementarity. Balance is simply a subset of complementarities, which reverts to the earlier discussion where studies implied this notion. As a result, the problems that arise in complementarities, such as the correlated omitted variable problems (Masschelein & Moers, 2020) and the problems that are shown in the multiple choices and higher-order complementarities section are going to persist (i.e. examining 7 choices simultaneously in balance is impossible or going to create problems). This is evident when studies examine the balance of four control levers simultaneously compared to only examining two control levers simultaneously.

3. The Theoretical Models

3.1 Modelling Three-way Complementarities

The main argument in complementarity is the use of one control choice increases the value of the other. Taking the example from Aral et al. (2012), assume that a firm makes three management control choices, x_1, x_2 and x_3, the use of IT, incentive pay and HR. The profit function y for the three choices can be written as follows:

$$y = \beta_0 + (\beta_1 + \gamma_1 z + \epsilon_1)x_1 + (\beta_2 + \gamma_2 z + \epsilon_2)x_2 + (\beta_3 + \gamma_3 z + \epsilon_3)x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \beta_{123}x_1x_2x_3 - \frac{1}{2}(\sigma_1 x_1^2 + \sigma_2 x_2^2 + \sigma_3 x_3^2) + v \quad (1)$$

The parameters β_{12}, $\beta_{13}$and β_{23} represent the coefficients for the two-way complementarities between each respective control choice combination and β_{123} represents the three-way complementarities between x_1, x_2 and x_3. The marginal effect for each control choice is represented by σ_i.

The model assumes that firms are profit maximisers and will adopt the optimal level of practices. To illustrate a realistic scenario from the profit function above, this study assumes that the profit function does not allow for infinite profits. This study argues that firms face trade-offs and costs when making management accounting decisions. This assumption puts certain restrictions on which combination of parameters are allowed. For a choice of three variables (x_1^*, x_2^* and x_3^*), the Hessian matrix H of the profit function y in equation (2) tells us whether the profit function is at a local maximum, minimum, or saddle point. For the profit to be at a local maximum point, the condition that needs to be satisfied when a firm makes three choices (x_1, x_2 and x_3) is when the Hessian matrix H is negative definite.[3] However, as it is easier to work with positive numbers, this study uses $-H$, where $-H$ needs to be positive definite:

$$-H = \begin{bmatrix} \sigma_1 & -\beta_{12} - \beta_{123}x_3^* & -\beta_{13} - \beta_{123}x_2^* \\ -\beta_{12} - \beta_{123}x_3^* & \sigma_2 & -\beta_{23} - \beta_{123}x_1^* \\ -\beta_{13} - \beta_{123}x_2^* & -\beta_{23} - \beta_{123}x_1^* & \sigma_3 \end{bmatrix} \tag{2}$$

The determinant for the Hessian matrix $-H$ above can also be written as determinant D below, in which $D > 0$ is one of the conditions that need to be satisfied for $-H$ to be positive definite. The condition that $-H$ is a positive definite implies and satisfies the second-order condition for optimality that is usually applicable to two choices, $\sigma_1 > 0$, $\sigma_1\sigma_2 > \beta_{12}^2$ and equation (3) for a condition of three choices, which needs to be positive definite. This means that the marginal effects (σ_1, σ_2 and σ_3) need to be as large as possible so that $-H$ remains positive definite and profit is at the maximum point.

$$D = \sigma_1\sigma_2\sigma_3 - \sigma_1(\beta_{23} + \beta_{123}x_1)^2 - \sigma_3(\beta_{12} + \beta_{123}x_3)^2 - \sigma_2(\beta_{13} + \beta_{123}x_2)^2 - 2(\beta_{12} + \beta_{123}x_3)(\beta_{23} + \beta_{123}x_1)(\beta_{13} + \beta_{123}x_2) > 0 \tag{3}$$

[3] For a function *f* of two variables, the condition that must be satisfied in a second partial derivative test for a local maximum of function *f* is $D > 0$ and $f_{xx} < 0$. However, for a function *f* of three or more variables, there is generalisation of the rule above, where instead of looking at the determinant of the Hessian matrix *H*, this study looks at the eigenvalues of the *H* at critical point, as the determinant of the *H* does not provide sufficient information to classify the critical point. The alternative condition for a function of three or more variables that must be satisfied for a local maximum at critical point is when the *H* is negative definite.

In the next few sections, this study introduces a few assumptions to illustrate the different conditions, interpretations, and implications of management accounting studies that investigate higher-order complementarities of three or more choices. First, it is assumed that the three-way complementarities are absent (β_{123}= 0). Second, the assumption is made that the three-way complementarities are present ($\beta_{123} \neq 0$). Third, the discussions focus on the implications of higher-order complementarities of more than three choices.

3.1.1. When Three-way Complementarities Are Absent *(β_{123}= 0)*

In the absence of a three-way complementarities (β_{123}= 0), then the IT (x_1^*), incentive pay (x_2^*) and HR (x_3^*), in our example are only related to each other through two-way complementarities (β_{12}, β_{13} and β_{23}). To simplify, it is further assumed that the marginal effects for a firm adopting IT, incentive pay, and HR are the same (i.e. σ_1= σ_2= σ_3=1) and assume that the two-way complementarity effects are the same β_{12}= β_{13}=β_{23}= β, meaning that the complementary effects of doing any two out of the three choices simultaneously are the same. This condition for β places more restrictions on complements than substitute relationships, $-1 < \beta < \frac{1}{2}$, which is more restrictive than the condition $-1 < \beta < 1$ for two choices from Masschelein and Moers (2020). This study illustrates the condition for three choices visually below in Figure 1 when the assumptions are relaxed, specifically when β_{123}= 0, β_{12}=β_{13} is varied between 0-1 and β_{23} is varied between 0-1.

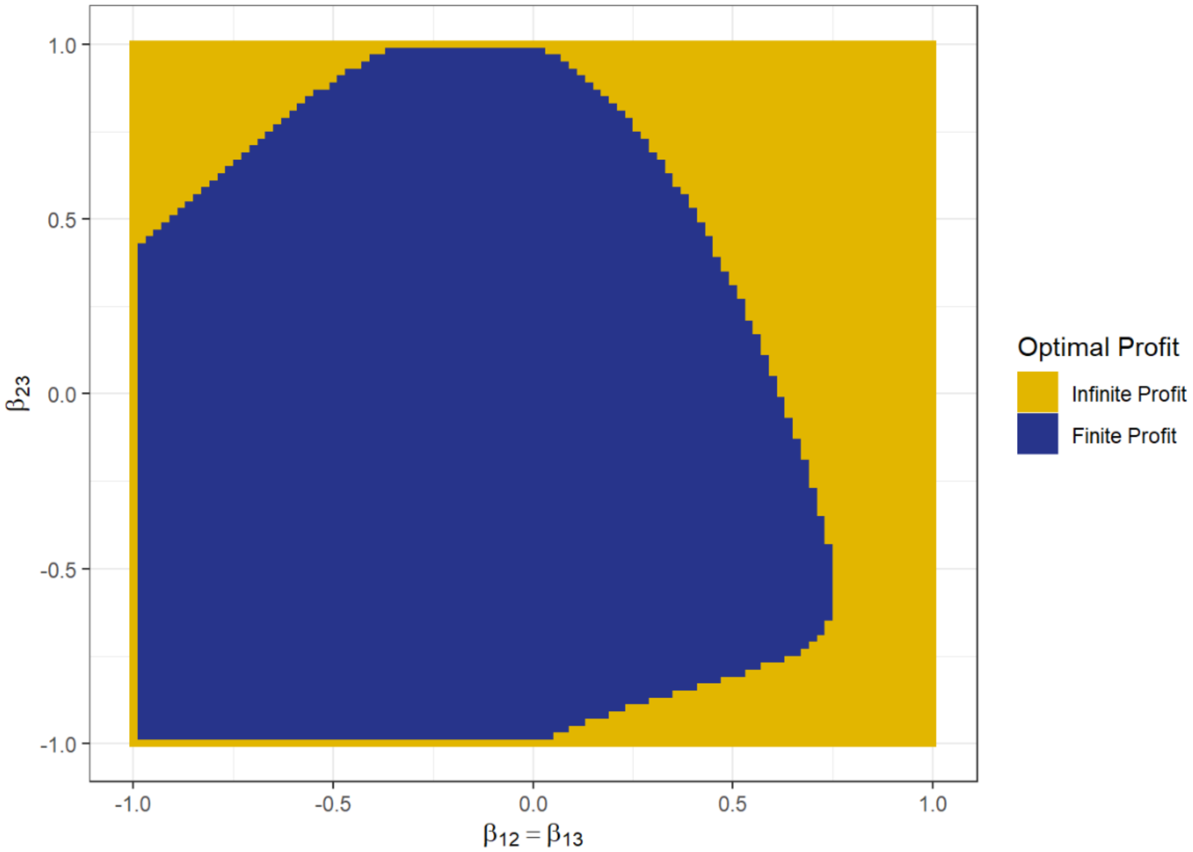

Figure 2: Two-way Complementarities, when $\beta_{123} = 0$

Figure 2 shows the two-way complementarity conditions for parameters β_{12}, β_{13} and β_{23} when there are no three-way complementarities ($\beta_{123} = 0$). To simplify the illustration, the figure assumes that β_{12}=β_{13}. The blue area shows the complementarity parameters and extremes for β_{12}, β_{13} and β_{23} when $D > 0$ or optimal profit is finite. This area indicates the optimal profit parameters for two-way complementarities between three choices. The yellow area shows the parameters for β_{12}, β_{13} and β_{23} where the profit is infinite. This indicates an unrealistic and impossible scenario for our given two-way complementarity β_{12}, β_{13} and β_{23} parameters. Several conclusions can be drawn from the plot.

First, there are more restrictions on the parameters for complementarities compared to substitutes. The blue area for negative values β_{12}, β_{13}, β_{23} has a larger area compared to the positive side, which means that there are more options for the choices to be substitutes than complementarity when examining two-way complementarities for 3 choices. It shows that when there are two of the two-way complementarities of the same value present for 3 choices (i.e. β_{12}= β_{13}), there are limits as to the magnitude and sign of the other choice β_{23} can be for the profit function to still have a maximum. When β_{12} and β_{13} are at their extreme positive value of 0.75, the parameters allowed for β_{23} is approximately $-0.6 < \beta_{23} < -0.4$, while the extreme for a positive $\beta_{23} < 1$, the maximum point for β_{12} and β_{13} is approximately between -0.2 and 0.1. Whereas for substitutes, the extreme negative allowed for β_{12}, β_{13}, β_{23} is -1.

Second, there is a higher likelihood for complementarities to be present when the coefficients of the βs are closer to zero, meaning the effect is smaller, when considering 3 choices. Thus, as the number of choices increases to 3 choices, the probability of strong higher-order complementarities is more restricted, and it is more likely that the options are substitutes or independent. This implies that theoretically, there will be a lot of problems and restrictions to consider when looking into higher-order complementarities of 3 or more choices, compared to two-way complementarities, and these problems are heightened and prominent when three-way complementarities are present ($\beta_{123} \neq 0$). This ties back to our initial argument in the literature review where not everything can be a (strong) complement to everything else even if it looks like that in the literature.

This is why it is important to study all these factors together to gain a complete understanding of the system and identify which ones are genuinely interdependent in driving the same phenomenon. Applying this to a practical research setting, if there is a positive interdependency between incentive pay (x_2) and HR (x_3), and between IT (x_1) and HR (x_3), then there is a limit given by the theory on how strong the complementarity between IT (x_1) and incentive pay (x_2) can be. There are only so many complementarity effects possible, where it is impossible to have many significant two-way complementarities existing at the same time within a system, otherwise, the effect will be simply too small or if studies do claim to find a significant effect for every two-way complementarities within the same system then the results might be exaggerated. Similar conclusions have also been established in the statistics literature (Tosh et al., 2021). In other words, if the βs are small, they are harder to detect in empirical tests in small samples, which makes it an important issue to address. Thus, a "structure of the system" or how these MC practices fit within the same strategy, structure, and managerial process of the firm must be established to maintain a level of statistical quality control and put a limit on which interactions can happen within a structure or an environment (Milgrom & Roberts, 1995; Tosh et al., 2021).

3.1.2. When Three-way Complementarities Are Present ($\beta_{123} \neq 0$)

In the presence of three-way complementarities ($\beta_{123} \neq 0$), the optimal level of IT (x_1^*), incentive pay (x_2^*) and HR (x_3^*), are related to each other through two-way complementarities and three-way complementarities. As a result, the magnitude of the two-way complementarity effects will be further restricted by the strength of the three-way complementarity, and vice versa. This is because the coefficients for the two-way (β_{12}, β_{13}, β_{23}) and three-way (β_{123}) complementarities are both in H in equation (2) and D in equation (3). Assuming the firms aim to maximise profits and do not make infinite profits, then there will be a stronger restriction placed on both two-way (β_{12}, β_{13}, β_{23}) and three-way complementarities (β_{123}) compared to when the three-way complementarity is absent ($\beta_{123} = 0$) as the combination of the two-way and three-way complementarities need to be smaller than the marginal effects (σ_1, σ_2, σ_3). If assumptions are further restricted such that $\beta_{12} = \beta_{13} = \beta_{23} = \beta$ and $\sigma_1 = \sigma_2 = \sigma_3 = 1$, and $D > 0$ or $-H > 0$, then all interactions between the two-way β and the three-way β_{123} complementarities for profit-maximising firms.

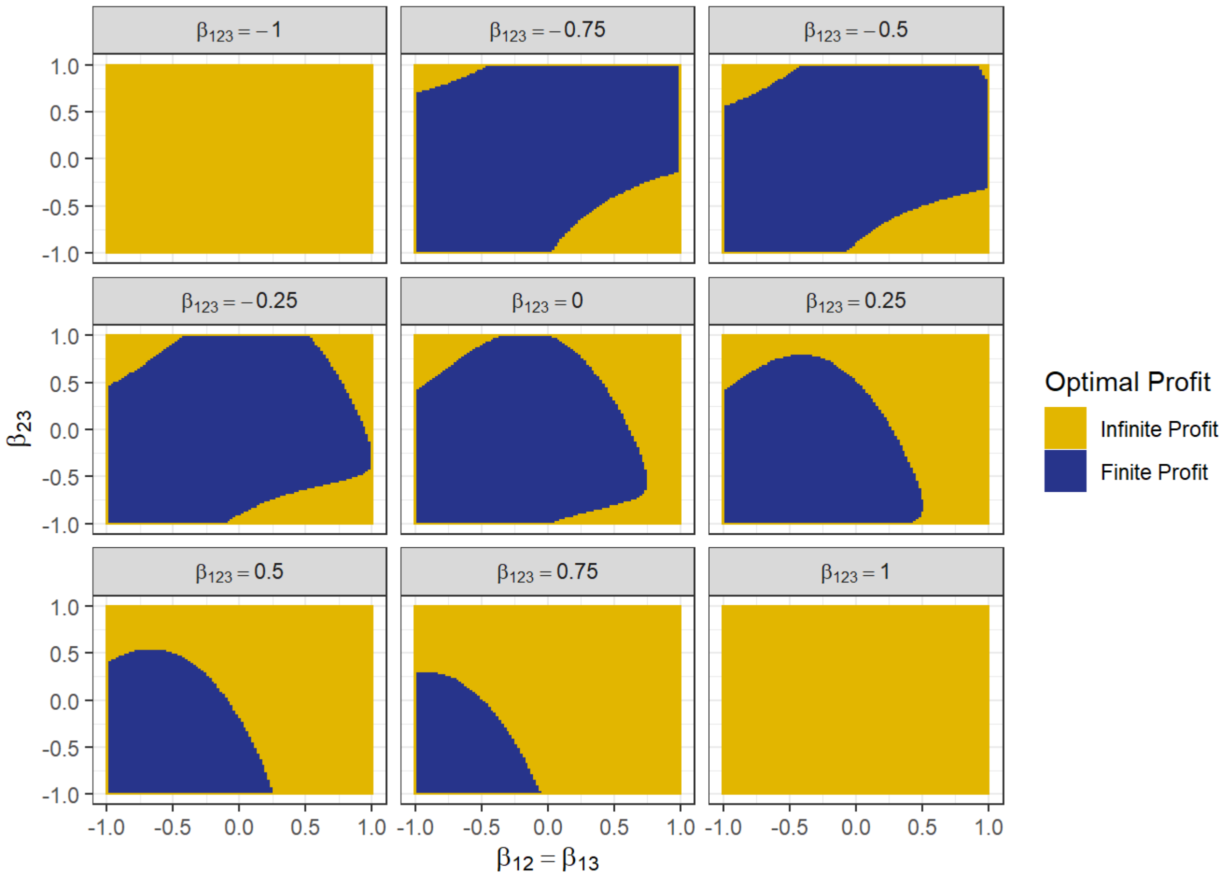

Figure 3: Two-way Complementarities, when β_{123} changes

There is a trade-off between the parameters βs and β_{123}, so when β is stronger, then β_{123} will have to be weaker, and vice versa. The reason for this is because the three-way effect is related to all the two-way effects in D. This effect is shown in Figure 3. All the conditions are held constant ceteris paribus to Figure 2 and simply vary the level of three-way complementarities β_{123}, which is shown in the upper part of each of the graph. The blue section shows when the two-way complementarities parameters when the optimal profit is finite. The graph shows how the two-way interdependencies can vary with different levels of β_{123}. For β_{123} = 0, this is simply the same graph as the one in Figure 2, however the two-way interactions become more restrictive when β_{123} is positive, compared to when it is negative. Moreover, when β_{123} = 0.75, the two-way interactions are mostly negative, indicating that two-way complementarities are less likely to be observed when the three-way complementarity is also present. In contrast, when β_{123}= -0.75, or when the three-way interaction between the three choices is negative or substitutes, there is a higher chance that there might be two-way complementarities between the three choices.

Then, what does this imply for existing and future literature that examines three-way complementarities? From the existing literature, only very few studies have successfully reported the presence of three-way complementarities, such as Aral et al. (2012) and Tambe et al. (2012). Other studies, such as Choi and Lee (2012), Kreutzer et al. (2015), and Ballot et al. (2015), can only find three-way complementarities for some of their proposed hypotheses. For the rejected hypotheses, some of the results even indicate that the choices are substitutes rather than complements when they are examined simultaneously. This is in line with the results in Figure 3, that there are more restrictions placed on complementarities compared to substitutes when studying a choice of three management control practices simultaneously. Hence, this study recommends that future studies that study three-way complementarities be more vigilant and heed more caution when reporting the presence of three-way complementarities to make sure that this effect is true and be rigorous in their analysis for potential three-way complementarities, but not also be deterred from reporting an absence of three-way complementarities when there are no strong effects.

3.2. Higher-Order Complementarities with Three or More Choices

In the previous sections, the analysis focuses on three choices, but what if there are more choices in the system? The issues that were discussed previously will be elevated and restrictions will be stronger with more choices involved. In this section, we show how the restrictions on both complementarities and substitutes will increase as the number of choices, n, increases.

In section 3.1, it was shown that the restrictions placed on two-way complementarities are higher for 3 choices when a three-way complementarity is also present as opposed to when a three-way complementarity is absent. In order for complementarities with finite profits to take place for three choices, the complementary condition between two choices need to be satisfied. Assume that all two-way complementarities are of the same size. For a set of 2 choices, the following $-H$ matrix condition needs to hold:

$$\begin{bmatrix} \sigma_1 & -\beta_{12} \\ -\beta_{12} & \sigma_2 \end{bmatrix} \tag{4}$$

Equation 4 shows how the condition $\sigma_1\sigma_2 - \beta_{12}^2 > 0$ that needs to be satisfied an optimal condition for a set of two choices, $x_1$and x_2 (Masschelein & Moers, 2020). The equation indicates that the increase in marginal cost of the two choices needs to be relatively large so that the interdependency still satisfies the condition for a finite solution. Another way of looking at it is that $\sigma_1\sigma_2$ in equation 4 needs to be positive and relatively large, so that $D > 0$ or $-H > 0$ is satisfied for the matrix in equation 4. For a set of 3 choices, the following $-H$ matrix condition needs to hold:[4]

$$\begin{bmatrix} \begin{bmatrix} \sigma_1 & -\beta_{12} \\ -\beta_{12} & \sigma_2 \end{bmatrix} & \begin{matrix} -\beta_{13} \\ -\beta_{23} \end{matrix} \\ \begin{matrix} -\beta_{13} & -\beta_{23} \end{matrix} & \sigma_3 \end{bmatrix} \tag{5}$$

Note that the condition for two choices in equation (4) still needs to hold for the three choices in equation 5, because every major diagonal matrix (i.e. $\begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix}$) of a positive definite matrix (i.e. -H matrix) needs to be a positive definite as well, with several additional conditions to be accounted for as we increase to three choices. The condition for finite profits with three choices also implies that only finite profits with two choices are profitable. Similar to equation 4, $\sigma_1\sigma_2\sigma_3$ needs to be positive and relatively large, so that $D > 0$ or $-H > 0$ is satisfied for the

[4] To simplify the equations for 3 choices and above, the matrices will only show the β coefficient for two-way interactions, however, the three-way for 3 choice, four-way for 4 choices, etc. interactions are implicitly included here. For instance, the three-way effect shown in equation 2 is implicitly included in equation 5 albeit not explicitly shown.

matrix in equation 5. This shows the additional restrictions placed on the complementarities for three choices on top of the two choices that was previously mentioned in section 2.4.1.2.

This restrictions on complementarities will increase as the number of choices increase. If the number of choices increases to 4, the $-H$ matrix conditions for two-way in equation 4 and three-way in equation 5 needs to hold, as shown in equation 6 below and so on as the number of choices, n, increases:

$$\begin{bmatrix} \sigma_1 & -\beta_{12} & -\beta_{13} & -\beta_{14} & \cdots & -\beta_{1n} \\ -\beta_{12} & \sigma_2 & -\beta_{23} & -\beta_{24} & \cdots & -\beta_{2n} \\ -\beta_{13} & -\beta_{23} & \sigma_3 & -\beta_{34} & \cdots & -\beta_{3n} \\ -\beta_{14} & -\beta_{24} & -\beta_{34} & \sigma_4 & \cdots & -\beta_{4n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & -\beta_{nn} \\ -\beta_{1n} & -\beta_{2n} & -\beta_{3n} & -\beta_{4n} & -\beta_{nn} & \sigma_n \end{bmatrix} \quad (6)$$

For finite optimal conditions $D > 0$ or $-H > 0$ to be satisfied, $\sigma_1\sigma_2\sigma_3\ldots\sigma_n$ needs to constantly be relatively large and positive. This shows how the restrictions on both complementarities and substitutes will increase as the cost of adding another choice, n, increases. Specifically, how the previous conditions need to hold as n increases and the complementary or substitute effect will be smaller as it would be $\frac{1}{n-1}$. Thus, it would be even more problematic and complicated to find support for a complementary effect especially when examining higher-order complementarities involving more than 3 choices.

3.3. Modelling Balance and Complementarity Theory

In this section, the modelling of balance and complementarity theory within a firm's objective function will be illustrated. It is shown that the distinction is moot when investigating the empirical relation between two balanced or two complementary choices starting from the formalism in the complementarity theory literature. For complementarity theory, the main argument is that the use of one control choice increases the effectiveness of the other. Assuming that a firm only makes two control choices, x_1 and x_2, the basic elements that satisfy the theoretical argument in complementarity can be captured in the performance function (Grabner & Moers, 2013; Masschelein & Moers, 2020) in equation (7) below:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 - \frac{1}{2}(\beta_{11} x_1^2 + \beta_{22} x_2^2) \quad (5)$$

This model shows the profit or performance of a firm y is dependent on two control choices, x_1 and x_2, and β_{12} captures the complementary effect between x_1 and x_2. The remaining parameters are other factors that affect the performance of each choice independently β_1 and β_2 and the increase in marginal costs of each control practice, β_{11} and β_{22}, which are assumed to be positive.

The theoretical argument for balance is less formally developed in the literature, but it can be illustrated mathematically. The idea of balance suggests that perfect balance is when the difference between the ideal difference Δ^I and the actual difference $(x_1 - x_2)$ between the control choices equals zero. Mathematically, this means minimizing the difference by taking the absolute ideal difference and the actual difference between the two control choices $|\Delta^I - (x_1 - x_2)|$ in order to maximize performance. Alternatively, minimizing the difference using the quadratic functional form $(\Delta^I - (x_1 - x_2))^2$ also satisfies the main argument. To simplify this in an equation, it is assumed that the ideal difference $\Delta^I = 0$. If we model performance y, based on this assumption and argument of balance, equation (7) can be rewritten as equation (8):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 - \frac{1}{2}\beta_{12}(x_1 - x_2)^2 - \frac{1}{2}((\beta_{11} - \beta_{12})x_1^2 + (\beta_{22} - \beta_{12})x_2^2) \qquad (6)$$

The term $-\frac{1}{2}\beta_{12}(x_1 - x_2)^2$ formalises balance between x_1 and x_2 if β_{12} is positive because if x_1 and x_2 are not equal (or in balance) the firm's profit is lower. Remark that the condition that β_{12} is positive for balance in equation (2) is exactly the same condition for complementarity in equation (1). The main difference between balance and complementarity lies in where the "combined" effect is coming from, where the "combined" effect in balance comes from having a combination of multiple management controls to keep the opposite forces in balance, and in complementarity, the "combined" effect comes from the interaction between two choices that positively reinforces each other. However, based on the formulation in equation (7) and (8), the property of balance can be treated as a subset of the bigger umbrella of complementarities. For two choices to be complements, the choices can "balance" each other out or their "combined" use can produce a synergistic effect. The latter one is what is normally used in complementarity studies (Milgrom & Roberts, 1995). If this is the case, then the distinction between balance and complementarities is moot and they can be interchangeably used to test balance or complementarities, as they estimate the same parameter β_{12}.

This conclusion then indicates that the issues that persist in complementarity tests, such as the correlated omitted variable bias or demand specification being more robust in testing the presence of complementarities or how it gets more complicated as 3 or more choices are tested simultaneously, as what is demonstrated in section 3.1, will also transfer to balance equations.

4. From Theory to Empirics

This paper aims to connect the theory and empirics for the study of interdependencies between management control practices in the management accounting literature. This study is interested in clarifying issues in relation to the study of a combination of MC practices as a system both theoretically and empirically. The previous section 3.1 explains why studies that examine higher-order complementarities face issues in detecting complementarities and the similarity between balance and complementarities using theoretical models. This section discusses the implications for empirical studies and addresses potential empirical issues that studies may face as they test for higher-order complementarities, or the balance between more than two choices.

So why are these two topics within the study of MC interdependencies of interest in this paper? First, the study of higher-order complementarities has gained attention, but empirical studies have also found it challenging to report the presence of complementarities as with 3 or more choices, which is subsequently followed by a decline in empirical studies investigating higher-order effects. The distinction between a system of more than two choices and higher-order complementarities is going to be valuable for future studies to understand how complementarity tests will be different when studies empirically examine a system of two management control practices versus three or more management control practices. By formally explaining why this is the case, it provides a clearer explanation of the higher restrictions imposed on complementarities as more choices are examined as a management control system. The formal models also provide a better picture for future literature on how to approach studying higher-order effects and understanding of why higher-order effects may or may not be present.

Second, the study of balance and complementarities between multiple MC practices has been widely studied in the management accounting literature. Although many empirical studies have studied the two widely, the two are often studied separately and the distinction where the two topics overlap is unclear. The empirical tests for complementarities have been established more strongly theoretically in the management accounting literature (Grabner & Moers, 2013; Malmi & Brown, 2008; Masschelein & Moers, 2020; Milgrom & Roberts, 1995) and used more often in empirical studies than the balance counterpart. The balance literature seems to indicate that there is a potential overlap with complementarities, and its empirical tests seem to overlap as well with the "balanced" and "combined" of control levers (Bedford, 2015, 2020; Cao et al., 2009; He & Wong, 2004; Henri, 2006; Mundy, 2010). A number of empirical studies have stated that the definition and empirical implications of balance Simons' LOC (1995) is unclear in the study of multiple management controls and voiced out the need for future studies to clarify how balance is supposed to be tested (Kruis et al., 2016; Mundy, 2010). Thus, it is important to clearly set out the distinction and similarities between the two. Based on section 3.3, the theoretical models suggest that the properties of balance can be considered as a subset of complementarities. If this theory is true, this indicates that balance can be tested using similar tests as complementarities. Although conceptually, balance and complementarities can be argued differently as they examine different combinations of management control practices that supports different goals, the two can empirically be tested in a similar way. This means that if there are more than two choices examined in a balanced setting, they can be tested similarly as in our previous section on higher order complementarities and are exposed to similar restrictions as previously stated. Balance between two choices can be tested in a similar way as two-way complementarity, which can then be extended to a system of four levers, for instance the levers in Simons' (1995) LOC framework, and balanced in two-way relations (Bedford, 2015).

The next section discusses potential issues that empirical studies commonly face when testing complementarities, specifically on correlated omitted variable biases. Since the theoretical findings suggest that balance can be empirically tested in the same way as complementarities, the focus will be simply on complementarities, in the understanding that all conclusions will also be applicable to balance. As prior literature has discussed the correlated omitted variable problem for two choices in detail (Chenhall & Moers, 2007; Masschelein & Moers, 2020), the next section focuses on higher-order complementarities or systems of more than two choices, but can be extended to balance if more than two management control practices are examined.

4.1. Correlated Omitted Variables

Correlated omitted variable bias is a common issue in complementarity tests, such as demand and performance specification, which stems from not appropriately controlling for contingency factors (Chenhall & Moers, 2007; Grabner & Moers, 2013; Masschelein & Moers, 2020). Although the demand specification is known to be the most vulnerable to the correlated omitted variable bias, the performance specification is equally vulnerable to the same omitted variable bias (Masschelein & Moers, 2020). For two management control choices, the relation between (x_1, x_2) or β_{12} is driven by a contingency factor, z. If that z is not appropriately controlled for, β_{12} will be biased from the covariance of x_1 and z, as well as the covariance of x_2 and z, and an effect will be found even if $\beta_{12} = 0$, which is a type I error (see (Chenhall & Moers, 2007; Masschelein & Moers, 2020)

This section extends prior literature that only looks at omitted variable problem for two choices and shows that the same omitted variable problem can emerge with a third choice in the complementarity tests. The focus is on the demand specification because prior research has demonstrated its robustness and the performance specification is just as exposed to similar biases (Masschelein & Moers, 2020). Assuming that firms optimise their performance by choosing the optimal level of x_1, x_2 and x_3 and that the three choices form an MC system. The demand specification version of equation (1) to test the presence of complementarity between x_1, x_2 and x_3 can be written as:

$$x_1 = \alpha_1 + \alpha_{12}x_2 + \alpha_{13}x_3 + \alpha_{123}x_2x_3 + \epsilon \tag{9}$$

where α_{12} and α_{13} are the coefficients that capture the two-way complementary effect of $(x_{1,}, x_2)$ and $(x_{1,}, x_3)$ respectively, and α_{123} captures the three-way complementarity effect of $(x_{1,}, x_2, x_3)$. According to Chenhall and Moers (2007) and Masschelein and Moers (2020), control variables z must be included to prevent bias in the estimated α due omitted factors. Failure to control for these, in addition to the correlated omitted variable bias, would result in biased estimates. To focus on the complementarities in the equation, the assumption is made that control for z has been incorporated through α_1.

Initially, assume that $\alpha_{123} = 0$ and that $\{cor\,(x_1, x_2),\ cor(x_{1,}x_3),\ cor(x_{2,}x_3)\} \neq 0$. This means the focus is only on the two-way complementarity effects between $x_{1,}, x_2$ and x_3. The bias, when using the ordinary least square (OLS) regression method to estimate α_{12}, when omitting x_3 is given by:

$$E[\hat{\alpha}_{12}] - \alpha_{12} = \alpha_{13}\frac{cov(x_2, x_3)}{var(x_2)} \tag{10}$$

If x_3 is omitted when it is also complementary with x_2, that bias will be reflected in the $\hat{\alpha}_{12}$ estimate. The size and effect of the bias in $\hat{\alpha}_{12}$ will depend on the magnitude and sign of α_{13} and $cov\ (x_2, x_3)$. If x_3 is also interdependent with x_1, then $\alpha_{13} \neq 0$ and the bias in estimate $\hat{\alpha}_{12}$will be further elevated. As $cov\ (x_2, x_3)$ and α_{13} becomes stronger, it will also increase the bias in α_{12}, which will elevate the effect in $\hat{\alpha}_{12}$, which is not a true effect of α_{12}. If α_{13} and $cov\ (x_2, x_3)$ are sufficiently small, then it will not pose a serious problem. If $\alpha_{13} \neq 0$, then it is likely that $cov\ (x_2, x_3) \neq 0$. Another effect to consider is when $cov\ (x_1, x_3)$ and $cov\ (x_2, x_3)$ has almost equal and opposite effects, the bias will be negative.

Thus, it is important to include all the possible interdependent choices within a management control system in the regression when testing for the presence of complementarity within a management control system using the demand specification. If a study tests one two-way interdependency, ideally that study needs to control for other choices that have two-way interdependencies with the two choices of interest to avoid any possible correlated variable bias. This is a potential explanation as to why prior studies have found many different combinations of pair-wise complementarities as mentioned in section 2.2, but it is difficult to find support for three or more choices for complementarities, which is consistent with the theoretical explanation in section 2.4. If multiple empirical studies claim a strong effect between multiple two-way complementarities that happen to be interrelated within a single MC system, then these interaction effects may be smaller than what is claimed, or these interactions are measuring the same phenomenon. There is a possibility that there is a correlated omitted variable bias in the pair-wise complementarities, where the necessary contingency effect is not fully controlled for, which results in a bias in the complementary effect (β_{12}) between the choices (x_1 and x_2). This poses problem as what is claimed to be true might be an elevated type I error. Under the assumption that the demand specification is correct, the correlated omitted variable problems in the demand specification are going to be similar or even elevated in the performance specification when firms optimise as shown in Masschelein and Moers (2020).

5. Conclusion

This paper addresses issues in relation to the study of interdependencies between multiple management control practices as a system, specifically on (1) higher-order complementarities, and (2) balance and complementarities. Based on the theoretical discussions in this paper, several conclusions and empirical implications can be drawn for future applications.

First, this paper provides a formal explanation using theoretical models on the reason why it is challenging for studies to find higher-order complementarities with 3 or more choices. There is a higher restriction placed on the strength of complementarities than substitutes as the number of choices increases from two choices to three choices and more, which means that it will be more difficult to identify the presence of complementarities as we add more management control practices into the system. This is consistent with what is happening in the management control literature landscape where some empirical studies that test three-way complementarities do not find higher-order effects and empirical studies that find support for higher-order effects tend to have a smaller effect compared to two-way complementarity effects. This paper also emphasizes the importance of appropriately controlling for contingency effects to minimise the correlated omitted variable bias in higher-order complementarity tests. The findings in this paper can be used as a guidance for future studies on understanding the mechanisms and what it means to test for higher-order complementarities and to appropriately control for all possible contingency factors.

Second, this paper provides a formal explanation on the similarities and distinction of balance and complementarities. Although the two are conceptually different, they can be empirically tested in the same way as the theoretical models show that balance shares similar properties to complementarities and can be considered as a subset of complementarities. This means that the issues in complementarities in relation to correlated omitted variable is also applicable in the case of balance, and thus future studies need to appropriately control for all possible contingency factors to minimize the omitted variable bias.

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