Realism, Ontology, and Latent Variables

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BEc BPsych(Hons), Macquarie University

Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree of

Master of Research

Department of Psychology

Macquarie University

October, 2014

Due date: 10 October 2014

Supervisor: Dr Simon Boag

Word Count: 19,957

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Summary

Drawing on scientific realism, recent psychometric literature presents a claim for ontology for latent variable analysis. The purpose of such presentation is to underlabourapurported causal relationship between psychological attributes and manifest outcomes, which is said to drive the use of these analyses in psychological research. This thesis examines the principles of this claim in three steps.Firstly, a meta-analysis of three approaches to philosophical realism is conducted with specific focus on causality and relations, clarifying the logical ground of the claim for a realist ontology for latent variables. The outcomes are used in conceptual analysis of the terms ‘ontology’, ‘causality’ and ‘latent variable’, and the assumptions of scientific realism are tested against theprinciples of philosophical realism. The implications of factor indeterminacy and realist measurement theory for latent variable modelling as measurement theory are set clear. Finally, the conceptual analysis and metaanalysis are brought together to examine a suggestion of interchangeability between observed and latent variables. These three forms of analysis, logical, conceptual and empirical together form a critical inquiry that indicates minimal support for the claim for a realist ontology for the use of latent variable modelling in psychological research.

Statement

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Acknowledgements

Thank you to my supervisor Dr Simon Boag for being the model of patient persistence and thoroughgoing discernment, my family for their ongoing support and particularly to Luke and Vanessa, who in listening and reflecting, teach.

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Chapter 1: Introduction

With the arrival of mainframe computing in the mid-twentieth century, and developments in the capability of statistical modelling software, psychological research stood as the beneficiary of a previously unknown power: the capacity to quickly and easily conduct complex calculations in statistical methods that analysed features of datato trackotherwise inaccessible patterns in the data. These developments are identified as mutually responsible for the prolific growth in the use of the *latent variable model*(LVM) in statistical psychological research(Cliff, 1983). A generalised definition of a LVM is a statistical model that specifies relationships between two types of variables, *manifest variables* and *latent variables* (Bollen, 1989; Maraun & Gabriel, 2013). Where avariable describes a rule, map or function, a manifest variable (MV) is a variable for which there is realisable or empirical data, often referred to as *observations* (Borsboom, 2005; Skrondal & Rabe-Hesketh, 2004). A latent variable (LV) on the other hand is one for which there is no sample realisation available (Bollen, 2002). The history of the LVM is typically traced to Spearman's (1904) unidimensional common factor model, which suggests that intelligence as measured by participant's test scores is partitioned into two elements, one part a specific factor related to the particular capability being tested, and another part, *g*, for general intelligence, which was purported to explain the positive manifold, or commonalities between the specific scores for different abilities, as tested (Michell, 1999; Borsboom, 2005).

Spearman's (1904) factor model however was not developed in isolation, and draws on earlier work such as Galton's (1869) regression models for individual differences in heritable traits such as height and strength, Pearson's (1895) development of the linear equation model and his subsequent work with the product-moment correlation coefficient which indexed the strength and type of relation between quantitative variables, and Yule's (1897) paper on multiple and partial correlations which linked the idea of weighting variables

to patterns of maximum correlation (Mulaik, 2010). From the earliest realisation that statistical correlations themselves merely demonstrated a relationship and did not demonstrate causation, psychology researchers have worked to develop statistical approaches that *can* link structural theory, or theory that takes attributes to be represented in a model of aggregates interrelated in lawful or causal ways, with statistical correlational evidence (Mulaik, 2010). Approaches developed over the next 100 years that rely on the blend of theory and analysis reflected in Spearman's (1904) common factor model include path analysis (Wright, 1918), item response theory (Guttman, 1950),latent class analysis (Lazarsfeld & Henry, 1968), confirmatory factor analysis (Jöreskog, 1971), structural equation modelling (Jöreskog, 1973), and latent profile analysis (Bartholomew, 1987). Applications of the LVM are diverse and extend to personality theory (e.g. NEO-PI-R, Costa & McCrae, 2008), intelligence testing (e.g. WISC-R: Kaufman, 1979), quality of life scales (Fayers & Hand, 1997) and meta-analyses of clinical trials (Eusebi, Reitsma & Vermunt, 2014).

As software continued to develop through time, the mathematical similarities of increasingly generalised versions of the LVMafforded the emergence of several common frameworks (cf. McDonald, 1999; Skrondal & Rabe-Hesketh, 2004; Bartholomew, Knott & Moustaki, 2011). Under these common frameworks parameters may be estimated in similar ways across different model types, regardless of whether the data structures for the MV and LV are continuous, ordinal, or categorical. The common framework takes different forms, for example, as a response model which contains a link function pertaining to variable distribution, and a linear predictor (Mellenbergh, 1994; Skrondal & Rabe-Hesketh, 2007) or a structural model (Muthén, 1984) such as a covariate regression of MVs on the LV. The implication of the common framework is that the response model and the structural model are directly substitutable, for each other, even though substantive considerations are given to

inform which type of model is most appropriate, given the research aims in question (Hershberger, 1994; Cliff, 1983).

The LVM common framework provides the apparatus for statistical *investigation of variables* in different forms, such as exploratory factor analysis, where the researcher may not have an a priori hypothesis about the way that MVs may be related (Finch & West, 1997), confirmatory factor analysis which makes explicit use of substantive theory regarding variable relationships (Kline, 2010), structural equation modelling, which both tests and estimates qualitative causal assumptions about variables (Pearl, 2000), true scores measured with error, otherwise known as classical test theory (CTT: Lord & Novick, 1968), random effects modelling for unobserved heterogeneity in longitudinal analyses (Laird & Ware, 1982) and item response theory which makes use of a hypothesised partition between an individual's responses and item difficulty in intelligence testing (Guttman, 1950).

Questions about the philosophical underpinnings of LVM common frameworks have followed their development. Approaches to philosophical underpinnings of psychometric research have recently been characterised as *local* or *global* philosophies of science, where global is taken to imply an overarching reference for theory to the whole of reality, such as logical positivism as developed by the Vienna Circle or Karl Popper's (1959) theory of falsification, while local admits what is important for fine-grained attunement of methodology for a specific field (Haig, 2014; Borsboom, 2005, Psillos, 2009). In "Measuring the Mind: Conceptual Issues in Contemporary Psychometrics", Denny Borsboom (2005) sets out arguments for interpreting statistical measurement theories as implementations of local "philosophies of science", in psychological research. In so doing, Borsboom (2005) declares grounds for realist ontology for a causal relation reflected between the LV and MV in the LVM, when used in psychometric research. This would imply, in regards to structural theory for example, that the LVM reflects a relationship between intelligence and test scores, where

intelligence is given to cause, the test scores, in an instance of test administration to individuals.

Realism, for philosophy and philosophy of science, typically coincides with the notion of a mind-independent world, which can be discovered, in this context by scientific methods (Hood, 2013; Maul, 2013; Haig & Borsboom, 2012). For Borsboom (2005, p. 6) realism

> gives the simplest interpretation of scientific theories because theoretical concepts refer directly to reality, so that intelligence and extraversion are conceptualized as having an existential status quite independent of the observations. The meaning of theoretical concepts derives largely from this reference to reality; general intelligence, for example, would be conceptualized by a realist as an unobservable, but causally relevant, concept. We learn about intelligence through its causal impact on our observations, and when we use the term 'intelligence', it is a causally efficient entity we indicate.

The theoretical concepts at question are psychological attributes, such as *intelligence* and *extraversion*. Psychological attributes "exist as emergent features of conscious beings" (Maul, 2013, p. 762), having a substantive aspect, as a generalised category for which there may be more than one instance of occurrence, a formal aspect, such as a quantitative, qualitative or other classificatory structure, and a range which sets out the domain over which possible realisations for that attribute may occur (Michell, 2005).

The realism referenced is scientific realism. Scientific realism for Borsboom (2005) is evidenced in adherence to any or all of the following principles: i) theories can be claimed as either true or false; ii) some theoretical entities exist; and iii) theoretical entities are responsible for observed phenomena, via causality(see Devitt, 1991; Hacking, 1983).

Ontology is not explicitly defined by Borsboom (2005), but is considered as a stance that can be derived from an interpretation of the way formal theory is used in practical applications, which implies for aLV that "one estimates something that is also part of the world" (p. 58). Causality has real-world implications for phenomena which are of empirical significance, leading to manifest effects, or data outcomes. Connecting these interpretations of ontology and causality to the LVM, the attribute reflected in the LV of interest is given to *cause* the outcomes in the MV. When evidence is accumulated for goodness-of-fit for the LVM, this is taken as affirming the existence, of this causal relationship (McDonald & Marsh, 1990).

1.1 Metaphysics

Recent psychology literature more broadly displays a revival of interest in philosophical issues, with a return to questions of *metaphysics*, or what it is *to be.* This has occurred as development of meta-theory in theoretical psychology has prompted conceptual examinations of the logical foundations of research (Robinson, 2007; Slaney & Racine, 2011; Lovett & Hood, 2011; Hibberd, 2014). Metaphysics addressesontology, or the study of *what there is*, and epistemology, or the study of *how we can know* about what there is (Robinson, 2007). A number of recent positions on metaphysics have been developed which are of relevance to the proposal for realist ontology for the LVM. For example, Lovett & Hood (2011) develop an account of ontological realism as logically independent of epistemic realism, as it is possible to hold that an entity ontologically exists while simultaneously denying that empirical evidence could support belief in such an entity; and, it is also possible to remain agnostic regarding the existence of an entity while simultaneously working to gather empirical evidence to support a hypothesis, regarding it. For other philosophically-informed realists, logical inquiry insists that a settled, defensible ontology is a conditioned basis from which epistemology rightly follows – the entity must exist, before how it can be known can be addressed (Hibberd, 2014; Robinson, 2007; Bhaskar, 2008). Even though

ontology and epistemology can be considered logically independent, they are also logically linked, with ontological commitments necessarily predicating epistemological commitments.

Metaphysical commitments serve as metaphysical assumptions when they logically and coherently underpin *methodology*. Methodology gives an informed understanding of methods by being "descriptive, critical and advisory" (Haig, 2014, p. 12). It provides a framework which facilitates discerning deployment of method, given alternatives and goals. Research is coherent when choice of method reflects a harmony between methodological assumptions and metaphysical assumptions (Hibberd, 2014). Researchers rely on metaphysical assumptions at every point in the research process, whether the researcher makes these assumptions explicit, or not (Robinson, 2007). For example, when intelligence is assumed to be an attribute that can be measured by test scores, intelligence is given the status of a knowable entity that occurs within the world and which has quantitative character such that it is measurable.

Metaphysics provides a framework by which researchers can ensure their claims demonstrate logical coherence when ontology, epistemology and methodology are viewed as an interlinked and interdependent system (Hibberd, 2014). Beyond criteria from philosophy of science which rest on empirical application, such as usefulness or success of theories, this framework stands to nurture sustainability in research outcomes by requiring explication of and evidence of commitment to, metaphysical bases. In psychological research, it has been proposed that the emphasis on empirical methods and statistical outcomes, following the probability revolution and its accompanying ideal of "certain knowledge" (Gigerenzer, 1987, p. 12)resulted in a proliferation of hypotheses that lack foundational moorings. The emphasis also led to institutionalisation of the use of inferential statistical methods, without encouraging self-reflection about the use of statistical methodology, in practice (Petocz & Newbury, 2010; Petocz, in press). Questions of metaphysics speak less to methodological

expedience than to a defensible foundation whereby the use of psychometric models and substantive research interests can coherently be brought together, arguably an aim of scientifically informed twenty-first century psychometricians (see Borsboom, 2006; McGrane, 2010).

While philosophy is concerned directly with questions about the nature of existence, philosophy of science is most concerned with the *scientific strategy* (Godfrey-Smith, 2003). Questions in philosophy of science pertain to, for example, what counts as science (for example, Popper, 1959) or as 'successful' science (for example, Laudan, 1984). Perspectives about what constitutes realist ontology and epistemology for philosophy versus philosophy of science can differ, given the different objectives of each, even though overall coherence can be consciously pursued between philosophical and scientific realism by any one researcher, or within any endeavour or field. Given the broader scope of philosophy, conditions set out under realist philosophy may formulate benchmarks by which any claims formulated under philosophy of science can be evaluated, for logical coherence. Logical, conceptual and empirical examination of research in light of metaphysical premises systematically work together to formulate a defence of science within reason (Haack, 2003), or *critical inquiry,* which has been described as the core of the scientific method, questioning unchallenged assumptions and subjecting hypotheses to scrutiny while using carefully applied error-detection tools (Petocz & Mackay, 2013; Michell, 1999).

1.2 Scientific Realism and the LVM

According to Borsboom (2005), the use of a mathematical model in psychological measurement requires: i) an ontological commitment, and ii) a claim about what measurement is. For the LVM, this is taken to imply the introduction of a priori hypotheses about the existence of theoretical entities, and an explanatory account of what the relations

between the model variables are, while holding the LVM as a measurement theory. The causal relation between the LV and the MV is set to serve in an explanatory role, regarding the data outcomes in the MV. Several questions present themselves, when considering scientific realism and the LVM in this regard. Firstly, what are the assumptions implicit in the concepts that underpin a LVM, and how might these be reconciled with the assumptions of causal realist ontology, adequate to *both* philosophy and philosophy of science? Secondly, how does the claim for a LVM as a measurement theory reconcile with the claim for a realist causal ontology for the LVM? Finally, given the metaphysical assumptions of philosophical realism, what might this mean for the LVM, as we return from considering the LVM *as* a local philosophy of science, to actually considering the LVM *from the viewpoint* of realist philosophy?

1.3 Aim

The aim of this thesis is: i) to clarify the assumptions underpinning the account of the LVM as a measurement theory as presented by Borsboom (2005); ii) draw out the implications for the LVM from a consensus of philosophical realist views; and iii) analyse the coherence of the conditions from i) against the outcomes from ii) with detailed attention to logical criteria for measurement, concepts, and applications.

The structure of this paper is as follows. A brief summary of the proposal from Borsboom (2005) for a causal, realist ontology for the LVM as a measurement theory will be firstly set out. This will be followed by a qualitative meta-analysis of three ‘global’ realist approaches, to clarify commonalities between realisms regarding metaphysical assumptions. Next, conceptual analyses for the terms‘ontology’, ‘latent variables’ and ‘causality’ will be conducted, and particular focus will be brought to the role for realism in scientific explanation. Factor indeterminacy and the principles of realist measurement will also be

referenced for implications for the LVM as a measurement theory. Finally, returning to practical applications, a claim for the exchangeability of latent and manifest variables from Borsboom (2008) will be considered in light of the principles and assumptions set clear through the process of examining the claim for realist ontology for the LVM, in psychological research.

Chapter 2: The Proposal for the LVM

2.1 Assumptions

Central to the account of the LVM as a measurement theory is the proposal that a psychological attribute, such as intelligence, is a *common cause* of data outcomes, such as test scores. This may be hypothesised as represented for example in a positive manifold – where positive correlations between scores from tests of different intellectual abilities are interpreted as indicating a common, underlying cause of those outcomes. In the literature a model with a latent cause and manifest outcomes is labelled as a 'reflective model' (Edwards & Bagozzi, 2000; Borsboom, 2005; Hood, 2013), and the choice to use such a model structure in psychological research is considered by the same authors to be dichotomised with a 'formative model'. In a formative model, the data values are considered to determine or cause the attribute – for example, measures of material wellbeing, personal development, recreation, social activity and relationships contribute to or 'form' an overall Quality of Life Scale score (Flanagan, 1978). Borsboom (2005) suggests that there is no reason for psychological researchers to prefer one model to another from a choice between these two models. Notably models under the LVM common framework are not limited to these two model structures, and in the methodological literature substantive considerations and theory are best indicators for model choice (Hershberger, 1994; Skrondal & Rabe-Hesketh, 2004; Schmittman et al., 2013). The following discussion will be limited to the reflective model structure with a single LV, given that this is the model for which realist ontology for the LVM is proposed. It should be noted however that the LVM common framework itself is of substantially broader scope (see McDonald, 1999; Skrondal & Rabe-Hesketh, 2004).

As a common cause, the psychological attribute as reflected in the LV is assumed to be *explanatory* for the outcomes in the MVs – it is the existence of the attribute of

intelligence that is taken to explain the correlation, for example, in test scores. In an *explanatory* role, where parsimony is an expected property of explanation (Thurstone, 1947), it is assumed there are fewer attributes than data outcomes, or fewer LVs than MVs in the model (Mulaik, 2010). The attribute is also assumed to exist as an entity that is independent of test scores. The question for the LVM as a measurement theory is *how* the LV can be assumed to reflect an independent entity, when it can only be calculated *given* the function-data relationship it has to the MVs.

The question is important, because mathematically, it is the property of *factor indeterminacy* which allows the researcher to say that there is more to the LV, than just the MV outcomes. Factor indeterminacy is a mathematico-grammatical issue that arises whenever a solution is found for a LVM, because the act of obtaining the solution logically applies for an infinite number of any other factors or LVs, which may be knowable, or not (Rozeboom, 1988; Maraun, 1996). It is only because factor indeterminacy is present *within the model* that more can be said about the psychological attribute, than could otherwise be said from evidence garnered from the solutions for the LV, or the fit of the hypothesised model, to the data. The LVM in mathematical form does not ascribe independent status to the LV, and the factor relationships modelled are a subset of an infinite number of other relations, which may or may not be knowable (Maraun, 1996). Borsboom (2005) therefore adds an assumption to the model, which can be understood as a strong assumption, given the *indeterminacy*of the LVM, of determinate or causal, realist ontology, for the relation between an independent LV and the MV(s).

The assumption of independence of the explanatory factor extends further to an assumption of invariance, which states the addition or removal of different MVs in the model should not change the LV. The LV is assumed then to be *unidimensional* – in a model it reflects only one and one consistent, psychological attribute, no matter the data outcomes that

are taken into consideration, or included, in the model. Parsimony in unidimensionality is reflected in the criteria of conditional independence for the MVs. Conditional independence ensures only those MVs that demonstrate a correlation pattern coherent with a parsimonious LV are included, with other MVs partialled out. Without the assumption of local, conditional independence for the MVs, no pattern of correlation between MVs which could be said to indicate the existence of a causal independent LV could be traced.

2.2 Rationale forCasual Realist Ontology

The assumption of unidimensionality for the reflective model excludes operationalism as a potential philosophical footing for the LVM. Operationalism blends verificationism, where the meaning of theoretical terms is given to be reducible to observations, and pragmatism, where the observations to be included are the ones making up scientific practice (Michell, 1990). For the operationalist, "we mean by any concept nothing more than a set of operations" (Bridgman, 1927, p. 5). Operationalism for Borsboom (2005) is inappropriate for the LVM because unidimensionality insists that the same concept or psychological attribute such as intelligence causes, for example, test scores, no matter which MVs or test outcomes are included, in the model. Under operationalism the LV would be different each time that a different MV is included or excluded, violating the practical assumption of unidimensionality.

Constructivism is also eliminated as an appropriate philosophical framework for the reflective LVM. Constructivism for Borsboom (2005) would indicate that the LV remains only as a fiction that is a function or construction of the researcher's mind.In this interpretation the LVM is understood to be merely an abstraction in no way connected to the real world or its entities. For Borsboom (2005) this sets constructivism as contrary to scientific realism, which is taken as endorsing a correspondence theory of truth, where there

is considered to be a natural tie between theory and reality. There is however some indication in Borsboom's (2005) formulation that this retains character as a constructed relationship: "[t]his theory *constructs* truth as a 'match' between the state of affairs as posed by the theory and the state of affairs in reality" [emphasis added] (p. 63).

2.3 Truth

For Borsboom (2005) it is truth, and the existence of true scores as conceptually related to estimation, thatserves as the basis for adopting a realist ontology for the LVM, because the concept of estimation is taken to imply that there is a real world entity to which 'truth' refers. Estimation is taken to admit the potential for error, and estimation may occur in different respects in relation to the LVM. For example, in estimating a solution for the LV, which for Borsboom (2005) is finding a position on the LV, it is suggested that there must be a true position, if an estimate of a position is admitted.

Estimation is also relevant to finding parameters for the MVs within the LVM in different ways. For example, for a researcher using frequencies data, parameters are an estimation in a normal distribution for a large number of repeated trials or samplings (cf. Hacking, 1965). For a researcher using Bayesian methods, parameters are estimated with a statement of certainty cohering in the estimating of probabilities across the parameters in question, totalling to the value of one (Skrondal & Rabe-Hesketh, 2004). Certainty, for Borsboom (2005), must refer, to real-world truth. There is a final point of relevance for truth, in estimation of model fit, where significance tests may use a likelihood ratio difference test between two hypothesised models, with the probability for the chi-square calculated against the most parsimonious model, which is the model that is taken to be 'true'. Because the structure of this model test implies that the truth of the most parsimonious model is never achieved, this leads Borsboom (2005) to conclude that the realist, with direct correspondence

for truth between theory and reality, must insist that all models are false. In practice, model adequacy is usually assessed with consideration given to possible misspecification of the model because of inappropriate assumptions or omitted variables, for example (see Skrondal & Rabe-Hesketh, 2004). This approach is deemed by Borsboom (2005) as constructivist, where "the whole concept of truth is judged as irrelevant" (p. 66), and for him this is problematic, because it leads to problems of empirical equivalence of models which cannot be judged in a straightforward way as true or false in light of the world. Realism is necessary for Borsboom (2005) to solve the problem of equivalent empirical models, where for him there is no reason to prefer one statistical model over another in psychological research, and this for him connects to the problem of underdetermination of theory by data.

2.4 Underdetermination

For Borsboom (2005), scientific realism is necessary to resolve the problem of equivalent models, or underdetermination. Underdetermination of theory by data, is a concept from philosophy of science that describes situations where two or more theories appear to be "logically incompatible and empirically equivalent" (Newton-Smith, 1978, p. 71). For Borsboom (2005, 2006, 2008) researchers are considered to have freedom of interpretation regarding which psychometric model to use, and which relations within the model or between the model and the world to hold, as ontological commitments. A causal relation is chosen as realist and ontological for the LVM between the LV and the MV because this is said to make the practice of using the LVM to model relations between psychological attributes and test scores semantically coherent (Borsboom, 2005; Maul, 2013).

Given the choice to interpret the relation between the LV and MV as reflecting a causal relationship, a question follows, which is, in what way can this causal relationship be coherent, when, if a solution is found for the LV for an individual, say of their intelligence

given their test scores, then the LV solution represents a constant, and a constant cannot be said to be a cause? With this, Borsboom (2005) sets out a case for ontology as a causal relation between the psychological attribute in question and the MV outcomes not at the level of an individual or within-subjects, but at a population level, or between-subjects. This approach assumes that the only way a causal relationship can coherently be said to exist is if a solution for the LV is interpreted to represent a random selection of an individual from a population of individuals that have the same solution. For a LVM of intelligence scores, for example, Jane's score for a continuous LV of 0.70 indicates Jane is a randomly selected member of a population of individuals that have a 0.70 solution.

Borsboom (2005) goes on to point out problems with this interpretation, such violation of the independence criterion that is necessary for causality, as the cause (LV) cannot be identified independently of the effects (the MVs), leading to circularity. The logical implications of such problems will be explored further in the conceptual analysis section of this thesis. Although the account of causality that is defended is between-subjects, it is a within-subjects relation or outcomes for individuals that are typically the subject of concern in psychological research. Within and between-subjects models are noted as not reducible to each other (Borboom, 2005; see Ellis & Van den Wollenberg, 1993). To continue to formulate a "plausible philosophy of measurement" (p. 84) for the LVM, then, on the grounds that research inquiry as it is currently conducted *relies* on a causal relationship between the LV and the MV, Borsboom (2005) draws on a form of pragmatism, and an argument structure known as the transcendental argument.

2.5Transcendental Arguments

The structure of transcendental argumentation has roots historically in Aristotle's proof of the principle of non-contradiction (Walker, 2006). It starts from an indubitable

feature of experience to derive a stronger conclusion about what must be the case, concerning the conditions of existence for the subject in question (Taylor, 1979). Transcendental arguments havecommon characteristics, including: i) world-directedness ; ii) an inquiry into what constitutes the necessary conditions for the world to be as it is; iii) reference to the possibility of extra-personal states of affairs (Stern, 2013); and iv) a statement to the effect that a given X is a necessary condition for the *possibility* of Y.

Transcendental arguments and realist claims have in common a reference to the external world, and reference to the conditions of existence. Transcendental arguments are frequently employed in the derivation of realist claims, as will be demonstrated in the meta-analysis below. A distinction can be drawn between the aims of transcendental arguments, and the objective of a realist claim. Transcendental arguments aim at *necessary coherence* in deriving a validity which is constrained according to the concept of unity. The argument form is represented throughout both realist and nonrealist philosophy throughout the twentieth century (Taylor, 1979). While transcendental arguments aspire to self-evidence they are paradoxical in that they aim beyond our own activity, and cannot therefore foreclose questions about ontology, rather perhaps, leaving ontology open to endless debate (Taylor, 1979). While transcendental arguments aim at validity for beliefs, asserted via coherence between statements in *necessity*(Psillos, 2009), realism aims to make ontological assertions about some state of affairs in *reality*, typically via correspondence between the statements, and some aspect of the world. An example of a transcendental argument structure is observed where Borsboom (2005) asks what must be the case, given current research practices that treat test scores as an outcome of intelligence differences, for the structure of the relationship between the LV and the MV? The conclusion presented is that a causal, realist and ontological relation must exist, between the LV and the MV.

2.6Pragmatism

In formulating the claim for a causal relation under realist ontology for LVs, Borsboom (2005) makes reference to what is "customary" in psychometrics,advancing claims for the LVM in a paper published with others specifically because "it is the most widely used model in psychology", being "the basis for some of the most influential latent variable models around" (Borsboom, Mellenbergh & Van Heerden, 2003, p.204). This attitude reflects *pragmatism,* which in recent philosophy is understood to be compatible with realism, nurturing an attitude towards practical activity that takes into account the *context* of descriptive focus and the *specific set of contrast classes* used in the formulation of a concept (Maul, 2013; Putnam, 1999). The spirit of pragmatism is reflected here with Borsboom's (2005) examination of use of the reflective model and employment of truth/estimation dichotomies in the LVM.

The orientation to practice at the heart of pragmatism, and the focus on necessity rather than realism in the structure of transcendental arguments together invite questions about the metaphysical premises suitable for the LVM, where strong foundations for methodology are best wrought when practical assumptions are reconciled with metaphysical premises. To examine what is of most concern for metaphysical premises relevant to a claim for a realist causal LVM as a measurement theory, a meta-analysis that clarifies the assumptions of realist, causal relations for philosophical realism follows.

Chapter 3: Meta-Analysis

3.1 Introduction to Meta-Analysis

In psychological research, meta-analysis is defined as a set of techniques and principles used to integrate the outcomes from a series of studies that pertain to similarissues (Cumming, 2013, p. 9). Usually this refers to an inductive-statistical technique, where multiple studies are combined and statistical analyses are performed of the effect sizes resulting from previous studies (Glass, 1976; Cumming, 2013). It is noted in the literature however, that in the first instance, *all* meta-analyses rely on qualitative techniques, insofar as some judgment must be applied in the selection of studies to be included in the analysis (Hedges, 1982; Petocz, in press). The meta-analysis of realism below follows the technique of Petocz (in press), extending principles of qualitative analysis throughout a meta-analytical framework.

The present meta-analysis aims to reveal commonalities and differences in the assumptions and principles of three philosophical realist approaches, specifically in regards to ontology, and causal relations. The realisms are critical realism, situational realism and speculative realism. A brief introduction to each is given, followed by a meta-analysis which sets out: i) a *taxonomy* of terms, looking specifically to concepts that inform approaches to ontology, causality and relations; ii) the *relations* between terms which are relevant to the conceptual fields for ontology, causality and relations within realist approaches; and iii) any *interaction* between realist approaches where there is direct comment in the literature, or where such an interaction can be reasonably inferred. This meta-analysis stands to clarify the conditions of existence that are vital to consider, in making any declarations about the ways that realist ontology is relevant to a LVM.

3.2 Introduction to the Realisms

The philosophical realisms analysed here have several common features. Firstly, they each utilise a form of argumentfollowing the structure of the transcendental argument, to make statements about conditions of existence based on some essential feature of reality. Ontology is considered as logically prior to epistemology for each, and each has the goal of stating a general theory of being. All three consider themselves to be anti-dualist and anti-idealist as set out in the taxonomy below, and all three rely on immanent critique, insofar as they each define themselves in criticizing, revealing or explaining some logical shortcoming of an opposing or earlier perspective (cf. Hibberd, 2009; Bhaskar, 2008; Morton, 2013).

3.2.1 Introduction to situational realism

Situational realism is a systematic realist philosophy indebted to John Anderson, Scottish-Australian Professor of Philosophy at Sydney University from 1927 to 1958, subsequently taken up by others (see Baker, 1986; Petocz & Mackay, 2013; Hibberd, 2009). Situational realism states there is only one way of being (Baker, 1986), and this existence occurs in one spatio-temporal universe, as irreducibly complex situations (Mackie, 1962). An examination of the *conditions of discourse* (Anderson, 1927/1962) sets out that these are "revealed to be also the conditions of *existence*, of *facts"* (Petocz & Mackay, 2013, p. 217).

Situational realism has roots in Anderson's reformulation of the metaphysical principles of Alexander (1920), adopting the principle of mutual entailment of space and time, while discarding commitments to hierarchies and levels of being (Anderson, 1927/1962; Anderson, 1929/1962; Hibberd, 2010). Situational realism is considered pre-Socratic in its emphasis on being and constant change, following Heraclitus, and pre-Cartesian in emphasising being as prior to knowing. It is set distinct from contemporary philosophies of 20th century logical positivism with its proclaimed anti-realism, and the

instrumentalism of 20th century pragmatism by virtue of its continual return to the question of the premises, of being (Hibberd, 2009).

3.2.2 Introduction to critical realism

Critical realism begins in the work ofOxford scholar Roy Bhaskar (1978, 1989, 1998, 2008; Collier, 1994) and addresses the philosophical underpinnings of social science by combining transcendental realism, critical naturalism and explanatory critique. Transcendental realism uses transcendental arguments to examine the *conditions of scientific experimentation* (Bhaskar, 1989), and critical naturalism explores the applicability of the conditions of scientific experimentation to human sciences, looking to what must be considered when subjects are *human beings,* distinct from natural phenomena (Bhaskar, 1998). Explanatory critique is a form of transcendental argument which gives an explanation of how an earlier or different argument or principle is in error (Bhaskar, 2008).

The ontological conditions of existence that follow are that the world must be structured, differentiated and changing, in order for experimental scientific activity to be considered to be intelligible, else, there would be no discernible purpose to the activity (Bhaskar & Hartwig, 2010). Critical realism stands contra to formulations of causality that rely on empirical assertions of ‘constant conjunctions’ or invariant regularities between *empirical events* of Hume (1739/1978), suggesting that such observationsare neither necessary nor sufficient in asserting causal events, as empirical experiences can at best only map a certain portion of causation.

3.2.3 Introduction to speculative realism

Speculative realism is reflected in the work of philosophers Graham Harman, Ray Brassier, Quentin Meillassoux and Iain Hamilton Grant, dating from a 2007 conference of the

same name. While the work of speculative realists varies in emphasis, commonality is found in critique of correlationism, "the idea according to which we only ever have access to the correlation between thinking and being, and never to either term considered apart from the other" (Meillassoux, 2008, p.5). This idea is distinctive in the idealist philosophy of Immanuel Kant, who in *Critique of Pure Reason* (1781/2009) concludes that thinking and being are inextricably intertwined.

Speculative realism develops its conditions of existence by transcendental arguments which enquire into the *conditions of the object,* considering, what must be the case, for independent objects in the world to be, as they are. Objects are considered as not exhausted by their relations with humans or other objects (Harman, 2002). For example, a hammer may come into brief contact with a nail, but neither object is reducible to this relation. This feature of a brief relation between objects is consonant with the theme of contingency, for speculative realism, and a proof is offered that suggests that the only necessity in existence iscontingency (Brassier, 2007; Meillassoux, 2008), to be further described, below.

3.3 Part I: Taxonomy, Categories and Synopsis

To facilitate exploration of the systematic links between concepts that are relevant for this study, a common taxonomy laying out the perspectiveof each realism is presented. This taxonomy makes use of certain terms in its categories. *Conditions of existence* are conferred for each realism by considering particular states of affairs. *Ontological stance* identifies the particular principle that follows from the state of affairs that is of concern. *Functional ontology* describes the functional outcomes that follow from consideration of the relevant state of affairs, which is closely linked to *functional analysis,* for each, that is, what sort of conclusions may be most closely linked to epistemology, following ontology. *Logic* addresses the means by which the statements are interlinked, for the given approach, while

core critique describes the earlier or opposing philosophical perspective against which the realism formulates itself. The categories of *causality, relations, approach to space-time* each give evidence of what the realist approach would imply for these categories of being, considered here to be closely connected to the subject matter of the LVM in psychological research.

Table 1

Taxonomy of Principles for Three Realist Schools

	Situational realism	**Critical Realism**	**Speculative Realism**
1. Conditions of existence	*Conditions of discourse* "It is worth noting that all theories of higher and lower realities are stated in terms of the common reality we all know – and indeed, can be stated in no other way" (Anderson, 1935/1962, p. 90)	*Conditions of scientific experimentation* Considers what must be the case, in order for scientific activity to be considered intelligible activity (Collier, 1994)	*Conditions of objects* Looks to assertion of complete mind-independence of the world and its objects to say that the deep reality of objects is always unavailable to us (and all other objects) (Harman, 2011)
2. Ontological stance	*ontological egalitarianism* All elements of being have equal ontological status and there is only one level of reality (Petocz & Mackay, 2013)	*ontological stratification* Change implies a preexisting co-presence of absence and presence, where change instantiates, as it shifts the balance between absence and presence, ontological stratification (Bhaskar, 2008)	*ontological democracy* Everything is an object and objects are understood as"equally existing but not existing equally" (Harman, 2013, p. 152)
3. Functional ontology	*situational complexity* Reality understood as conditions of infinite complexity within situations which are both particular and universal (Baker, 1986)	*a world that is structured, differentiated and changing* Transcendental inquiry as to what are the conditions that makes scientific practice possible reveals the conditions of the world as structured, differentiated and changing (Bhaskar, 2008)	*object-oriented* Objects are taken to have a deep reality and deep qualities, and surface or sensual reality and surface or sensual qualities, which humans indirectly access (Harman, 2013)
4. Functional analysis	*process orientation* There is no unilinear form of development but interaction at all points (Baker, 1986) Overcomes Cartesian dualism with ontology founded in propositional logic and one ultimate form of reality (Baker, 1986)	*process orientation* Fourfold orientation considering the product, the process, and combinations, product-in-process and process-in-product (Bhaskar, 2008) Overcomes Cartesian dualism with an ontology of co-presence - presence and absence arise together in a field characterised by absence (Bhaskar, 2008)	*process orientation* Retaining the principle of non-contradiction, the universe and being is considered not to always be in change rather, non-contradiction demands contingency (Meillassoux, 2008) Overcomes Cartesian dualism by critiquing the degree to which being can only be encountered by thinking and vice versa (Meillassoux, 2008)
5. Logic	*propositional logic* Ontology is co-extensive with logic which has a propositional structure (Baker, 1986)	*dialectical logic* Sequential and dialectical unfolding of the moment, or unity, a break in the moment, or disunity, a reuniting, and a shift into new totality which is never closed (Bhaskar, 2008)	*non-reducibility to propositional logic* Philosophical or propositional logic will always fall short of actual existent reality (Harman, 2009)
6. Core critique	*Humean rationalist empiricism* Defends complex pluralism beyond Humean causal conjunctions which do not serve as adequate ground to recognise change (Baker, 1986)	*Western modernity's positivism* Overcoming Western philosophy's totalising monovalence and the fundamentalism of the epistemic fallacy inherent in a purely positive account of reality by introducing an ontology of absence (Bhaskar & Hartwig, 2010)	*Kantian correlationism* Transcending Kantian correlationism - the idea that we never encounter the world in itself, that idea we can only consciously encounter the world via mind-bound correlative representations of objects (Meillassoux, 2008, p.5)
7. Causality	*field view* Causality not as a two-term linear sequence but occurs in a three-term complex relation of cause, causal field and effect (Petocz & Mackay, 2013)	*efficacy as a function of causality* All causes are in space time, and all effects are the outcome of a transformation that absences other absences; causality is understood as intrinsically tensed, and as a spatio-temporalising process. (Bhaskar, 2008)	*deep causality* Casual events only occur in the 'volcanic core' of objects (Harman, 2010); relations do not directly reveal this causality from one object to the other.
8. Relations	*relations as nonconstitutive* Objects are not constituted by relations or mind, and they cannot be described by virtue of the relation between them, which would represent the error of *reification* (Anderson, 1962)	*relations as fundamental aspect of co-presence* Relations arise where identity implies also non-identity, and these are inseparable (Bhaskar, 2008)	*relation as translation* Relations only exist as translation of qualities, between objects, and relations do not exhaust objects so translated - access for one object to another object is always indirect (Harman, 2012)
9. Approach to space-time	*container view* All objects occur in space and time (Baker, 1986)	*relational property* All change is spatio-temporal, and space-time is a relational property of material beings (Bhaskar, 2008)	*property of objects* Arises from objects or is a property of objects (Bryant, 2011)

3.4 Part II – Relations Between Categories

Regardless of the type of realism, it is noticeable that the categories in the taxonomy above have implications for each other. This section explores the relations between categories and addresses the implications of inter-category interactions, from the perspective of each realism. Particular focus is placed on relations, causality and ontology, in order to connect these features back to those most at question for a realist approach to the LVM.

3.4.1 Relations between categories – situational realism

The ontological stance of situational realism is one of *ontological egalitarianism* – where all elements of being exist on one ontological level as infinitely complex spatio-temporal situations that are always in process (Petocz & Mackay, 2013). This ontological stance is considered as a *precondition of discourse* and reality or existence is concomitant with a community of knowers and logical propositional statements, following Anderson: "[i]t is worth noting that all theories of higher and lower realities are stated in terms of the common reality we all know – and indeed, can be stated in no other way" (Anderson, 1935/1962, p. 90).

While situational realism implies determinism or causality between situations (Medlow, 2008) and everything is considered to be related to other things (Petocz & Mackay, 2013), nothing can be considered as constituted by its relations. Situations have independent ontological status, and the terms that enter into a relation are logically distinct – a term that is related to or identical with only itself is logically incoherent (Hibberd, 2014). Relations indicate the way that terms stand in connection to each other, and the terms in relation must have independent qualities of their own (Anderson, 1935/1962). A term can only enter into a relation with another independent but different term only by virtue of existing, independently, prior to the relation.

Reification is closely connected to the problem of independence in relations. Reification is identified elsewhere in the statistical literature as a problem within epistemology, in circumstances where hypothetical concepts are mistakenly treated as having material or ontological status (Skrondal & Rabe-Hesketh, 2004). For situational realism, such a situation occurs where differences between, for example, intelligence levels for individuals or population groups, are reified into entities (Boag, 2011; Passmore, 1935). In the between-subjects interpretation of a causal relation between the LV and the MV, the values of the LV are interpreted to be a function of, or a relation of, the differences in the values between population groups. To treat such a relational difference as an entity is an example of the logical fallacy, of reification, for situational realism.

Criteria for causality would also represent a challenge for the between-subjects causal relation account of the LVM, for situational realism. Causality inheres in a three-term relation, between the cause, the effect, and the space wherein the relation between the cause and effect occurs, called the *causal field* (Anderson, 1938/1962; Medlow, 2008; Hibberd, 2014). For inductive scientific methods, situational realism insists that terms in a causal relation must be logically distinct, with the cause, effect and causal field each described for their own intrinsic properties (Boag, 2007; Boag, 2011). A double verification is needed, both about the universality or generality of the causal relation, and the universality of the conditions of the causal field within which the causal relation can be said to occur. The causal field is considered to give the specifics which lead to the effects in any given event (Hibberd, 2014), while necessary and sufficient conditions indicate the universality of the cause (Medlow, 2008).

The logic of ontology for situational realism brings question to the status of the causal relation, or reflective model approach to the LVM. This is because the relation that is said to constitute the causality of the psychological attribute consists only as a difference between

instances of population groups. No term can be constituted by its relations, without being lost in the incoherence of reification. Further, there is question about the representation of the causal field for the LVM, because the conditions that specify the causal field cannot be contained in the statistical structure, of the relation between the LV and the MV in the LVM.

3.4.2 Relations between categories – critical realism

The ontological stance of critical realism is one of ontological stratification, which is derived in a transcendental argument that considers what must be the case, in order for scientific experimentation to be an intelligible human activity (Bhaskar, 2008). Critical realism acknowledges a gulf between what is manifest at the level of human discernibility, and what is functional in the patterns of nature which are the subject of scientific inquiry. Working to underlabour a philosophy of social science by critiquing experimentation in the natural sciences, critical realism stands counter to the idea that confirmation of causality could consist in empirical confirmation of Humean (1739/1978) constant conjunctions between cause and effect. Hume proposed that causality consisted in constant conjunctions of "atomistic events and closed systems" (Bhaskar, 2008, p. 205). If Humean causal conjunctions were experienced as "always conjoin'd" (Hume, 1739/1978) at the level of what was available empirically or to the senses, it would render experimental activity meaningless, because there would be no need for the experiment – the causal relationship would be readily observable. Ontological stratification in critical realism clarifies the logical distinction to be made, between nature's causal operations, and those causal operations created by human beings in the process of obtaining to scientific discovery, or experimentation.

Discernible in this account is the notion of the researcher as instrumental in creating observations, and critical realism contends that statistical analyses rely on instrumentalism, where practices such as modelling for use in data analysis is understood as essential to the

creation of scientific discovery. Borsboom (2005) defined instrumentalism as a philosophy which would say the LVM is merely a means to an end, and scientific realism is preferred because it provides an account of ontology to connect the model to the real world. However, the wider reach of critical realism as philosophical realism brings instrumentalism back into the account of relevant methods for the LVM, with an active role in formulating auxiliary theory. Auxiliary theory is necessary to account for the difference between the assumptions endemic to the empirical world of the scientist, and the qualitative assumptions about the natural world and the operation of cause, in that world. Without an account of these, researchers are subject to "systematic blindness" about relevant features of the human world, and any causality relevant to psychological attributes (Collier, 1994, p. 253).

The structured, differentiated and changing ontology of critical realism is founded in the concept of co-presence, which takes the existence of relations as central to ontology. The theme of co-presence signals dialectical logic, where relations are inherent wherever there is presence, because where there is presence, there must also be absence (Bhaskar, 2008). Rightfully then, whenever there is a relation, there is also non-relation. For a causal relation between a psychological attribute and empirical data, this implies that what is *not* the causal relation must be accounted for, in order to give an account of the change that marks the event of causality adequate to ontology. While a statistical model may be modified according to goodness-of-fit statistics to most closely describe the relations between its terms, the LVM itself does not proscribe anything about what falls outside of the modelled relation. Critical realism suggests that this is as important to the account of the causal relation as the account of the causal relation, itself.

Dialectical logic is also relevant to the question of factor indeterminacy for the LVM and the ways that underdetermination and indeterminacy come apart, for critical realism. Indeterminacy for critical realismconsidered co-present with determinacy, and characterises

reality as an always incomplete totality, indicating an ultimate lack of logical structure. Underdetermination on the other hand is considered as a function of an already existent logical structure (Bhaskar, 2008). The distinction parallels analysis in the philosophy of science, where a globalaccount of underdetermination is generated *because* the existence of any given theory implies the existence of its own negation (Stanford, 2001). In critical realism, this is parallel to the concept of indeterminacy, where negation is not just considered a finite negative; it refers to the incompleteness of totality. Local underdetermination in philosophy of science on the other hand parallels the same general underdetermination concept in critical realism, where the logical structures that lead to a LVM are assumed as given, but it is the *features* of the LVM or the theory, that are subject to underdetermination. Here what is referenced is the accuracy of the proposed model in light of other candidate models, and the correct model for the situation may be indicated by reference to auxiliary hypotheses and substantive knowledge regarding that which is modelled (Psillos, 2006).

In summary, ontological stratification insists that an account of causality must address the distinction between empirical patterns observable at the level of human perception, and the operation of causation as natural law in the world. Any mathematical model is underscored by auxiliary hypotheses, and the qualitative relationships that describe for example, how the MV test scores come into being are as essential to the account of causality as any relation that can be modelled in a statistical formula. Indeterminacy is considered co-present with determinacy, and indicates not just a choice among other determinate models, nor a choice from an infinite suite of similar models, but indicates the incompleteness of totality, where existence of a model is not determinable. In light of factor indeterminacy for the LVM, is signalled as a broader concern than those occurring under the guise of underdetermination, representing a strong challenge to the reflective LVM presently under consideration.

3.4.3 Relations between categories – speculative realism

The ontological stance of speculative realism is one of ontological democracy that includes any possible entity as an object, including those that have contradictory attributes, such as a square circle or the contents of a delusion (Harman, 2012; Morton, 2013). The LV of the LVM for example under speculative realist ontology *can* be an object, or entity. Speculative realism uses logical tests to ask and answer, what is the maximum independence under scientific rationality that is likely for the mind-independent world of objects and entities that we find (Harman, 2012). One such testbegins with consideration of the comprehensibility of ancestral statements. Ancestral statements are those made about features typically in the geological or bio-evolutionary domain, which say something about the nature of the world and its elements prior to the human inhabitation of the earth (Brassier, 2007; Meillassoux, 2008). Ancestral statements push mind-independence to its limits, because no human being could ever have seen a living dinosaur, for example, but it is deduced fromfossilised evidence that such a creature existed on earth (Meillassoux, 2008). Correlationism, the Kantian idea that being can only be encountered by sensing or thinking it, is thus refuted (Brassier, 2007, p. 62) by the existence of this network of indirect relations to the ancestral past.

Pushing mind-independence to its limits invites speculation on *possibility*, which in its logical form is taken to characterize reality, beyond mere mathematical *probability* (Brassier, 2007). In regards to infinity, it is recognised that this can be quantified, and it is treated as such in many statistical methods, for example, when probabilistic methods are used in the LVM. But utilising Cantor's theorem (Badiou, 2005), set theory is used to say that reality always escapes cardinality, or which can be quantified – something beyond what we can imagine as infinite is always possible (Brassier, 2007). The reality of objects reaches much further than probability, and the limits of logic in reality, are escaped. Probability is curtailed

by the surface structures of objects, and is limited by the shape of our own surfaces as human beings, while the true *possibility* of objects is their deep reality. The statistical LVM relies on probability, not possibility, and therefore cannot be said to reach to the real core of the object that it can be said to be in indirect relation with, that is, the psychological attribute.

Because objects have a deep reality, it is only indirectly that objects are considered to come into relation with other objects. In considering objects and causality, it remains unlikely that the full set of explanatory conditions for a causal relationship between for example a psychological attribute and empirical data could be completely determined. This is because for speculative realists, objects are characterised with both surface structure and deep structure. This follows an analysis of Heidegger's (1927/1962) approach to tool-objects as *ready-to-hand* with surface structure that is used by humans, for example when a hammer is used in hand to hit a nail, and*present-at-hand* with deep structure reflecting all possible states, beyond use,for example a broken hammer that cannot be used to hit a nail (Harman, 2002). It is only surface structures that have direct relations between objects: "individual objects within nature must be treated as mutually opaque and disruptive, as withdrawn and strange" (Harman, 2013, p. 205). Relations function as translations of surface structures, and do not reach to what is described as the volcanic core of objects, which is the home of causality (Harman, 2010).

While a LV is an object or entity for speculative realism, the logic of speculative realism would bring question to the degree to which the causal properties of a psychological attribute can be represented in any model. The LVM in particular is not only limited by its statements that reach only to a probability which cannot be said to reflect the totality of reality, it is also the case that causality for speculative realism is placed beyond the direct relations as would be suggested by the LVM between the LV and the MV, in the deep structures of objects.

3.5 Part III – Reflections Between Realisms

It should be apparent that the philosophical frameworks of different realisms do not necessarily coincide. Indeed, in the literature there is evidence of both disciplinary disunity and outright debate between realist schools featured above. This section will consider both literature evidence and logical arguments that are apparent between the different realist schools. As with the previous section, commentary is limited to brief accounts that address inter-realism relationships relevant to the question of a realist ontology for LVs.

3.5.1 Situational realism and critical realism

Commentary between situational and critical realism is detailed in Hibberd (2010), where an earlier critical realist explanatory critique of situational realism as positivist (Hartwig, 2007) is addressed. For critical realism, space-time situatedness cannot be considered to be a logical constraint on ontology, because things pass into and out of being – temporality ensures a relation between existence and non-existence, and an adequate ontology for critical realists must address this totality which includes absence, or non-being, as much as it addresses being, to fully account for causal states of affairs (Bhaskar, 2008). For critical realism then, logic does not determine the nature of being, but "at best establishes what the world must be like if we are to perform certain operations successfully" (Bhaskar, 2008, p. 72).

The early motivation for Bhaskar's (1978) critical realism was to clarify the reasons that economic modelling and measurement failed to address actual economic circumstances in developing world scenarios (Bhaskar & Hartwig, 2010). The vast gulf between ontological orientation for situational and critical realism may be matched by the difference between attitudes to logic and measurement theory, where situational realism offers a thorough-going and well developed realist theory of measurement coherent with propositional logic (see

Michell, 1990, 1999, 2005, 2009, 2011) while critical realism purports that the degree to which absence overreaches presence in dialectical logic means that totality cannot be considered to be limited by logic, or measurement theory. Critical realism lacks a realist account of measurement (see Collier, 1994).

Situational realism, with space-time situatedness and refutation of the coherence of critical realism's ontological stratification on the grounds that logically, existence rather than existence *and* non-existence is the basis of being, appears in the first instance to offer philosophical footing for an ontological and causal LV, in its marriage between a world-situated single form of existence, and ontology. Situational realism however views causality as non-linear and of plural origins, as does critical realism (Hibberd, 2010). Despite fundamental differences, there can be understood to be agreement between the two, that causality signals complexity (Hibberd, 2014; Bhaskar, 2008). Both realisms suggest more than a statistical model is necessary for a realist account of causality. For situational realism, the properties of the causal field within which the causal relation occurs must be addressed, and for critical realism, that which is not the causal relation must similarly be addressed for any causal account. The question then to be addressed in the conceptual analysis for causality below is whether the relations of the LVM can sustain, such complexity.

3.5.2 Critical realism and speculative realism

One thesis commensurate with the ontological stratification of critical realism is that the products of social activity can and should be distinguished from those of the mind-independent world, as even though they both occur in nature, they are different in kind (Bhaskar, 1978; Bryant, 2011). For critical realism, knowledge and social products cease to exist, if human beings cease to exist, whereas the natural world continues on effortlessly, without the presence of humans, and these different types of relation between existence and

non-existence form critical realism's logical ground, for ontological stratification. One critique to be extended from critical realism to speculative realism is that that democratic ontology ill affords acknowledgement of the distinct causal implications ofsocial products such as knowledge or statistical models, as compared to those of natural world objects such as rocks. Critical realism insists that ontological realism entails epistemological relativism (Bhaskar, 2008), where the intransitivity or fixity ofnatural ontology must be contrasted with the transitivity of human knowledge and meaning production, which may be demonstrated for example in the development of scientific knowledge, manifesting as improved experimental and research procedures, over time. What is necessary for an account of causal relations between any phenomena for critical realism is not only the model of the relations itself, such as the LVM, but also an account of the philosophical commitments and assumptions implicit in the transitive structures of knowledge, which disclose the phenomena. Such accounts facilitate the coherence of scientific discovery, with confirmation of methodology against metaphysical assumptions demanded, at every step. Some form of constructivism in light of epistemological relativism is implied, where different avenues of scientific discovery will draw on different methodology, and the premises of such methodology should be set out and reconciled with any metaphysical premises obtaining.

Referencing speculative realism's deep and inaccessible reality of objects (Harman, 2002, 2009, 2013), critical realism may argue that it is still the causal effect of our access to them in light of beliefs about the object that has efficacy in *describing* this ontological inaccessibility. Critical realism would argue that the most adequate philosophy for this task is one that properly accounts for the difference between social objects and natural objects at the level of what it is to *be*, that is, at the level of ontology. Stratification ensures the complexity of causality under realism is properly reflected and can be distinguished from the simplified empiricist or positivist account of causality as observed constant conjunctions (Collier, 1994).

On the other hand, the speculative realist's assertion of mind-independence of objects goes as far as to declare that *any* human interpretation of mind-independent objects must miss the mark, because human sense-making falls short of the true possibility of objects. In Harman's (2011) words, not one "of our images correspond to anything at all; none of them bear any isomorphic resemblance to the real objects that withdraw into darkness" (p. 178). Speculative realism maintains "hardcore realism because it takes real objects so seriously that it holds them to be irreplaceable by any conceptual model" (p. 179). The epistemological relativism of critical realism is perhaps a moot point, for speculative realists, and any model is unlikely to reflect the true nature of a psychological attribute. The ontological status of the LV is ensured under speculative realism, but the question may be, to what end? The inaccessibility of causality and the indirect nature of relations between objects bring a highly speculative nature to any interpretation of the relation between the LV and the MV in the LVM, under speculative realism.

3.5.3 Speculative realism and situational realism

Speculative realism, in its strong assertion about the complete mind-independence of the world, extends independence far enough so as to say realist ontology implies that objects in their deep natures remain *inaccessible.* This inaccessibility is not a human failing particularly, but is a failure rooted in the structure of *relations* for objects (Harman, 2011). When philosophy has considered the world, historically, it has either *undermined*objects, treating them "as composite things build of something more fundamental" (p. 172), relics of which are seen today in reductionist materialism that aims to reduce things to elements, such as atoms, quarks or reduction of attributes to statistical models, or *overmined* them, to say that they are nothing more than how they empirically appear, to an observer. The LVM has elements of undermining, in reducing complex causality to a set of direct relations between variables, and overmining, because in form it suggests that the MV data represents the full

implications of causal relations extending from the LV. For situational realism, the explanatory power of relations is over-assumed, given the true deep nature of causality and objects.

Situational realism tracks the infinite complexity of *situations,* to say that even though not all causes relevant to a given situation may be knowable, our best efforts and employment of error-detecting mechanisms aims at giving an account of causation in such a way that any relation between situations can be described with same logic running through cause, effect and causal field (Medlow, 2008). For situational realism, relation is a category of real-world existence, and all real-world categories are universal (Hibberd, 2014). Where an object could be described as a situation occurring in space and time, ontology for an object insists that the object must be circumscribed by relations, for situational realism. All real situations are given to exist, in relation to other situations.

The question of the structure of relations, as relevant to objects or situations can be seen as the item of core contention, between situational and speculative realism. "Science is knowledge of objects" (Mulaik, 2004), and the propositional logic of situational realism renders phenomena such as psychological attributes as fallibly knowable, with criteria in its ontological assumptions that the phenomena, as a situation, must meet, to be considered logically coherent. The strictures of speculative realism however places the real nature of the psychological attribute beyond our grasp, pronouncing an independence for the object that extends beyond infinity, and suggesting a unidimensionality for objects that in its depth is beyond our ken.

3.6 Conclusion For This Section

Referencing distinct conditions of existence, together, the philosophical realisms can be understood to each set criteria which must be met for ontology, even though different

formulations of ontology persist. Whether it is in the infinite complexity of situations, the deep generative mechanisms in nature or in qualities of objects that never come into full or direct relation with other objects, what can be understood from this brief survey of philosophical realism is that ontology less consists in a commitment to a surface relation such as a modelled causal relation between a LV and MV than it does in conditions that may give rise to the possibility of such a relation. All three philosophical realisms indicate conservatism in regards to the degree that human-developed logical systems can fully embrace reality, even though reality may be considered to be directly encountered in some formulations of realism. All three indicate that a causal relation consists in much more than a connection between a cause, and an effect. The next section reflects the findings of these criteria back to the scientific realist account of the LVM presented, in Borsboom (2005), in conceptual analysis.

Chapter 4:Conceptual Analysis

Despite longstanding calls for clarification of concepts in psychology specifically and science generally, conceptual analysis remains underutilised, in psychological research (see Rozeboom, 1977; Machado & Silva, 2007; Petocz & Newbery, 2010; Slaney & Racine, 2011). Conceptual analysis takes as object any elements relevant to statements made under the scientific method, which include"concepts, terms, variables, constructs, definitions, assertions, hypotheses, and theories" (Petocz & Newbery, 2010, p. 126). The process of conceptual analysis consists in such steps as:resolving semantic ambiguities; assessing concepts for clarity with particular attention to inappropriate classification of terms into categories or unjustified extension of meaning from categories to terms; evaluating hypotheses for precision and refutability; appraising the consistency of statements or laws relevant to theory; and revealing implicit assumptions in arguments and chains of inference (Machado & Silva, 2007; Haig, 2011; Rozeboom, 1977).

Conceptual analysis has benefits for research, by providing: i) justification for the particular interpretations of concepts andthe theoretical intuitions that are put forward for the concepts (Bealer, 1998);ii) grounds for resolving ontological questions about what is necessary for explanatory levels (Armstrong, 1968); and iii) normative guidance with respect to inference (Goldman, 1986) given the evidence and the logical method of scientific investigation. As a component of the *critical inquiry* that makes up the scientific method, conceptual analysis bridges the chasm between science and meaning to provide grounds for interpretation of empirical outcomes, enlarging the logical infrastructure by which the soundness of conclusions may be evaluated, incoherent theory rejected, and future research paths illuminated (Petocz & Mackay, 2013; Boag, 2011; Machado & Silva, 2007).

In this section, the terms ‘ontology’, ‘causality’ and ‘latent variable’ will be examined in light of realist criteria. Assumptions pertaining to entity realism under scientific realism will also be scrutinized. This is followed by an examination of the consistency of statements detailing the LVM as a measurement theory. Questions about the uniqueness of LVM solutions in light of the factor indeterminacy which is implicit in the LVM structure will also be addressed.

4.1 Assessing Clarity of Terms

4.1.1 Ontology

Ontology is not explicitly defined by Borsboom (2005), but from the meta-analysis above ontology for philosophical realism entails “the study of reality, or of what there is” (Hibberd, 2014, p. 3), including the study of differences in *kind*for phenomena, where *kinds* are delimited by *categories* with criteria that pertain to universal features of reality (Mulaik, 2004). For philosophical realism, metaphysics *belongs* to phenomena (Hibberd, 2014). Borsboom (2005) suggests that there is “freedom of choice” (p. 58) regarding ontology for the causal relation of the LVM, but for philosophical realism there are metaphysical *criteria* that must be met, for phenomena to have ontological status.

Independence is a criterion for ontology relevant to the philosophical realisms examined above. Speculative realism holds that objects remains so mind-independent that direct relations between real objects are impossible. Where causality is given to occur in the deep and inaccessible core of objects, a model of causal relations as reflected in that between LVs and MVs is unlikely to be deemed ontological, as it does not reach to the truth of the objects. For critical realism, ontological stratification demands distinction between the conditions of empirical determinations and patterns of causality in nature. Conditions of independence between these extend into ontology, and an account of how empirical patterns

do not reach to the causality in nature is necessary, which answer questions about how and in what way the LVM fails to describe causality. For situational realism, ontological independence addresses a difference between entities, such that relations can be said to exist between them. The criteria of difference and independence in situational realism suggest that relations themselves cannot constitute terms in the relation. To state that the psychological attribute occurs as a between-subjects population level difference is to reify relations between instances of the attribute, where no entity can be said to exist independently of the relation between instances. To use data outcomes in the LVM to represent such a relation is to falsely reify the differences. Independence as an ontological condition for the causal relation is questionable, under each philosophical realism. For each realism, there is question regarding the way that the attribute can be said to enter into causal relations, which brings question to the way that the LVM can model causal relations as proposed by Borsboom (2005).

4.1.2 Causality

A LVfor Borsboom et al., (2003) is defined as an unobservable attribute that is related to an observable outcome "by assigning to the unobservable attribute a causal role" in bringing about data realisations (p. 203). Borsboom et al. (2003) suggest that while the LVM does not "prove the existence of causally operating latent variables, the model does formulate this as a hypothesis" (p. 203). The statistical fit of the model is adduced as evidence corroborating the hypothesised LV. This shifts the focus from ontology for the LVM to epistemology, or *how* we know about the LV, given the LVM.

This approach to evidence for the LV indicates that its explanatory capacity is of inductive-statistical form. This means that the explanation statements are probabilistic, rather than conclusive, distinct from what would be the case if the explanation was of deductive-nomological form (Hempel, 1966). Deductive-nomological statements serve in 'covering

law' explanations, where all antecedent conditions are clarified as premises, so that the conclusion logically follows. For inductive-statistical explanations, following situational realism, the conclusion or *explanandum* is highly likely, but is not *implied* given the premises or *explanans* in the arguments (Bell, Staines, & Michell, 2001).

Inductive-statistical explanations became prevalent in the 1940s, and include strong forms, where, given B, A is *rendered more probable* than not, and weak forms, where, given B, A is rendered *more likely than comparable alternatives*. Their development followed that of deductive-nomological explanations, which have roots in mid-nineteenth century determinist or 'covering law' approaches to explanation (Rescher, 2006), where operation of the covering law is taken to be certain, given premises which set out antecedent conditions, and the conclusions are presented as truth statements (Bell et al., 2001). While deductive-nomological explanations render *certainty* in their conclusions, and *inductive-statistical* explanations render *probable* conclusions, causal explanations can perhaps best be described as rendering *possible* explanations. As noted under situational realism:

> One difference between [the causal explanation] and the [inductive-statistical] model is that it does not require the explanans to make the explanandum highly probable. It is in this sort of case that the link between explanation and evaluation (and hence prediction) is most clearly broken by this model. It allows an explanans to consist of causal information in the light of which the explanandum may be very unlikely. (Bell et al., 2001, p. 79)

For these authors and for others, care must be taken in causal explanation, because the broadening from probability to possibility means that what is potentially omitted from an explanation may have greater explanatory capacity, than the information included in the model (Bell et al., 2001, Bhaskar, 2008; Pearl, 2000; Psillos, 2002). That care implies that

what is needed over and above anything reflected in the inductive-statistical model is "*causally relevant information"* [emphasis original] (Bell et al., 2001, p. 79), which includes setting out a sufficient *causal history*, the *mechanism* that links cause and effect, and *contrastive explanations*. Causal historyindicates the antecedent conditions that must hold for cause to render an effect, for example, for intelligence to impact upon test scores. The causal mechanism explains the process of influence between cause and effect, while contrastive explanations work to explain why this effect occurs, or why for example intelligence leads to *these* test scores, rather than some other effect.

Setting out an empirical stance for the LVM, Borsboom et al. (2003, p. 207) note that the explanans (the model) can be "discussed separately" from the explanandum (the observed scores). Considered in light of issues for the LVM regarding ontological independence under philosophical realism as set out above, discussion itself cannot serve for verification of independence. The LVM as a model cannot be said to account for the antecedent conditions or *causal history* that would give rise to evidence of the *temporal precedence* for cause in relation to effect, an essential element of causal relations which distinguishes causation from mere covariation (Edwards & Bagozzi, 2000). Borsboom (2005) presents a between-subjects causal account of the psychological attribute, and posits that the causal relation can be stated in such a way as to be commensurate with Mill's uniformities of succession account of causality (1943), the counterfactual causation of Lewis (1973), and the graphed-theoretical causation of Pearl (2000). Each of these formulations of causation contains elements to address causal history, mechanisms and contrastive explanations, but to *state* a relationship between for example intelligence and test scores in such a way that is conversant with a given model of causality is not to *explain* causality, because it does not reference how connections can be coherently wrought for the between-subjects population level attribute and the LV in the LVM.

For each modelling instance, it is likely that different sets of factors, both quantitative and non-quantitative, would be functional to the instantiation of causation, and would formulate then part of the causal explanatory structure. The LVM itself ill affords capacity to address the way that a reflective LVM that models the relationship between intelligence and test scores differs from a reflective LVM that models intelligence and behavioural outcomes, for example. Presumably these are different types of relationships between a psychological attribute and outcomes, but the model doesn't facilitate the precision necessary to map the relevant structure.

Recent moves towards network modelling based on LVM principles (see Molenaar, 2010; Contractor et al., 2014) suggest there is advantage in distinguishing levels of statistical modelling, rather than generalising relations for models. A general definition of a model is a structure which represents another structure through abstract similarity (Godfrey-Smith, 2003). A mathematical model represents *dependence relationships*, and to accurately but abstractly represent phenomena such as intelligence and its impact on a test score, it may entail "a complicated network of dependence" (Godfrey-Smith, 2003, p. 188). In a complicated network there is value, for example, in maintaining distinction between causal relations in the dynamic system of the psychological attribute itself, such as causality between intelligence and verbal ability, and causal relationships leading say from intelligence to written test outcomes, because these are two distinct causal processes. An assumption about a direct causal relationship between the LV and MVs in the LVM obscures the complexity of the real relationships, generating the potential for confusion about the circumstances of how something like intelligence might be reflected in test scores.

4.1.3 Latent variables

Rozeboom (1961) distinguishes between the logical or syntactic versus substantive sense of the word ‘variable’, where, in the logical-syntactic sense it indicates a place-marker for the spot where some constant would occur in determinate circumstances, while the substantive sense is given to detail different abstract concepts, such as intelligence or extraversion. The place-marker sense means other variables could be substituted in the same place in a sentence without changing the sentence meaning, so ‘inch’ might be substituted with ‘centimetre’ and still refer to length measurement, for example. The substantive sense indicates variables cannot be interchanged in a statement without thoroughly changing statement meanings. Psychological attributes are generally considered to be substantive variables, where intelligence, for example, is not interchangeable with extraversion.

Rozeboom (1961) describes *partitioning* substantive variables, so that there is “a record not only of what properties its objects of study have been observed to have, but also what properties they have been observed *not* to have” (p. 345). This facilitates pursuit of the characteristics that allow discrimination of conceptually tractable states from observed regularities, leading to a “comprehensive theory of variables”, which addresses the quantitative-qualitative *relations* that hold for any given substantive variable, as well as an ontology of *kinds*, so that problems associated with for example conflating empirical structural properties with theoretical attributes, as with intelligence test results and ability attributes (see p. 364) are avoided. With a comprehensive theory of variables, the relations between a psychological attribute, LVs, MVs and observational criteria for the LVM can be properly set out, reducing the likelihood that empirical regularities are mistaken for causal operations, as was marked as essential for a realist account of causality in line with the metaphysical assumptions of critical realism.

Without clarification of the relations between the LV and the psychological attribute, the implication is that the LV and the psychological attribute are considered as one and the

same. Such treatment of LVs as psychological attributes is termed by Maraun and Gabriel (2013) as “illegitimate concept equating” (p. 32), with inappropriate synonymy presumed between theoretical concepts, and LVs. This synonymy is also demonstrated in statements that matchtheoretical concepts with LVs directly, such as “[a] researcher who views intelligence as a latent variable” (Borsboom, 2005, p. 4) and in later literature, such as “general intelligence is a latent variable.” (Borsboom, 2008,p. 27). While concepts such as general intelligenceare formulated in language, LVs exist as a function within a statistical or a mathematical model. Both the concept, and the mathematical function can be distinguished from that which can be said to be a cause, the psychological attribute, which arguably remains as a constituent of natural reality (Maraun & Gabriel, 2013). To conflate these terms together is argued to be an illegitimate but unchallenged and pervasive feature within the social sciences (Maraun & Gabriel, 2013). But just as Bennett & Hacker (2003) suggest that “conceptual clarification, not for experimental investigation” (p. 71) was called for to distinguish whether psychological attributes such as reasoning powers could be properties of the brain, so too might conceptual tests indicate the degree to which a psychological attribute can be said to be, a latent variable. A comprehensive theory of variables, combined with clarification of methodological assumptions in light of stated metaphysical premises may provide the qualitative scaffold, for well-founded quantitative confirmation, of causal relations.

4.2 Realism for the LVM

4.2.1 Entity realism

Borsboom (2005) follows Hacking’s (1983, 1999) distinctions between entity and theory realism, under scientific realism. Entity realism is assumed for the LV by Borsboom (2005), because the psychological attribute is “assumed to exist independent of

measurement" (p. 58). In this approach, the LV is given an ontological status of entity because this is considered an essential assumption that rationalises the choice of using the reflective LVM. Theory realism on the other hand is defined as consonant with a correspondence theory of truth, which suggests a "'match' between the state of affairs as posed by the theory and the state of affairs in reality" (p. 63). For Hacking (1983) entity status is given to phenomena when phenomena can routinely be used in the laboratory to investigate effects that can be investigated independently of the phenomena – manipulative success with the entity, in scientific experiments means that theory is considered to be no longer necessary, to support the existence of the entity (Gelfert, 2003; Kripke, 1972).

The distinction between entity realism and theory realism has been refuted from within philosophy of science. While formulations of realism hospitable to entities may be *serviceable* in the laboratories of physical science (Cartwright, 1983; Hacking, 1983), a split between theory and entity is misconceived, because auxiliary theory has a role in both the philosophical commitments of the researcher in their stance towards the phenomena, as well as the discriminative assessment of how an entity is conceptualised, in the first place. What must be addressed are the *relations* between theory and entity, in scientific realism, rather than *substitution* between theory and entity. Following Psillos (1999), it "is by the means of such theoretical descriptions that [experimenters] make the relevant identifications and discriminations" (p. 256) for the entities that are manipulated in scientific practice. Where critical realism underscored the essential role for the auxiliary hypotheses in a causal account for realist ontology, philosophy of science itself reinforces the way that theory and entity are intricately related, and themselves cannot be considered in isolation from each other.

There is also question regarding whether a LV can be said to have independent status from the MVs of the model, such that it could be considered an 'entity', at all. For Hacking (1999), the important test for entity realism is whether the entity can be "regularly

manipulated" (p. 154), in experimental procedures, regardless of whether the entity is observable, or hypothetical. A LV is defined by Borsboom (2005) as a between-subjects population level causal factor that determines outcomes for MVs, and in his final analysis it remains as an emergent property of an aggregate (a population) which cannot be said to be reflected in the individuals of the population. Presumably, the ability to manipulate an emergent population-level property with any generalised certainty must at best remain speculative. Where the problem of reification under situational realism rendered the status of the LV as an entity as at best circumspect, the substantive concerns about manipulability, added to ontological concerns from philosophical realism bring question to the status of the LV as an entity, and thus question to the case, for the relevance of entity realism.

4.2.2 Equivalent models

Borsboom (2005) makes a case for the necessity of entity realism for the LVM, "because this form of realism is needed to motivate the choice of model in psychological measurement" (p. 61). Borsboom (2005) goes on to say that there is no reason why one model should be preferred over any other model in psychological research, and this is a problem is called one of equivalent models, which is connected by the author to underdetermination of theory by data. It has two guises for Borsboom's (2005) analysis; the first is a choice of model from those available under the common framework, which is limited in his (2005) analysis to dichotomised choice between reflective and formative models. The second equivalence occurs where identical fit statistics may be found for one model type with differing numbers of LVs or MVs for example, included in the model. Earlier statistical literature addressed the problem of equivalent models, which occurs when parameter estimates imply identical covariance matrices with the same goodness-of-fit statistics, for different formulations of relations between variables (Pearl, 2000; Hershberger, 1994). For example, where model equivalence is found in empirical outcomes, it is argued by

Hershberger (1994) that solutions regarding model choice are found in assessing substantive knowledge regarding the psychological attribute, where the greatest benefit "lies in the ensuing obligation imposed on the researcher to gather further evidence" (p. 104) to justify the researcher's selection of model.

Hershberger's (1994) argument for referencing substantive knowledge parallels Newton-Smith's (1978) conclusion when considering a scientific realist approach to underdetermination of theory by data. Underdetermination of theory by data occurs where two theories appear to "be logically incompatible and empirically equivalent" (p. 71). In considering the strong assumption of Quine (1970), who suggests that all theories must be underdetermined by data, and then must be equally as likely to be suitable candidates to represent true relations, Newton-Smith (1978) suggests that the suggestion of equivalence is likely misconstrued – it is not ever the case that two theories are actually equal as a set of deductive postulates, because there are different auxiliary hypotheses for which the "definitional extension" of each theory has a distinct set of satisfying conditions (p. 78). Psillos (2009) indicates opportunity in this circumstance for balancing first-order evidence about the plausibility of the theory in light of substantive knowledge about its suppositions, with second-order evidence which references the soundness of methodological and metaphysical assumptions for the present theory, and the present theory in light of the historical trajectory for similar theory within the field.

Such an approach to evidence for model choice may provide substantive ground for the ways that the model is said to correspond, with truth. An analysis of the role of truth as a biconditional formulates the section on theory realism, where theory is considered as naturally tied to truth. Truth as a biconditional in this circumstance arises because estimates are used in various ways in statistical modelling, for example, in estimating solutions for the LV, parameters for the MV or in reasoning about a 'true' model fit. Estimation is interpreted

as indicating that there must be a true and real causal relation between the psychological attribute as a between-subjects population relation and the data outcomes, such that the model can be an estimate of this real thing. As indicated in the above section on causality, an inductive-statistical form of explanation, which is the origin of any relevant truth-concepts in this instance, falls short of a causal explanation. Truth and estimation inheres in the statistical model, and in itself does not refer to the causal explanation, which has conditions beyond those that can be included in the statistical model. Answers to the problem of equivalent models that reference substantive knowledge, where knowledge implies truth (Psillos, 2009), are more likely to address realist assumptions, particularly where the connection between metaphysical and methodological assumptions are clarified. The question of choice of model then is not solved merely via ontological assertion of a causal relation between the LV and MV, but the way that assumptions, knowledge of the phenomena and conditions of truth and fact come together is important, in resolving questions for perceived equivalence of models, with regards to LVMs.

4.3 Factor Indeterminacy

Philosophy of science approaches to underdetermination of theory by data suggest that for a local philosophy of science, there is most benefit in referencing substantive assumptions and background knowledge to address problems such as that of equivalent models (Psillos, 2005; Stanford, 2001; Hershberger, 1994). By referring to auxiliary hypotheses, and choosing a model form appropriate to the hypotheses and the background literature for a psychological attribute such as intelligence and its connection to test scores, for example, it can be envisaged that over time, the *exactness* of model fit is improved, so that relationships and properties which impact upon any modelled causal relation between the LV and the MV may come to be reflected in the overall statistical model or at least accounted for, in qualitative assumptions.

There is a further problem however, for the LVM. A focus on improving *exactness* does little to address the fact that not all elements of the LVM rely on true or approximate estimations, but may also require *unique* or *identified* solutions for variables, so that the model can legitimately be used in inductive inference (Rozeboom, 1988; Maraun, 1996; Mulaik, 2010). Identification of variables requires a canonical form for the variable such that *a contrast class of mutually exclusive and jointly exhaustive conditions* can be stated. This would mean that for any value or solution for the variable, whether quantitative or categorical, the value or solution is appreciably unique (Rozeboom, 1988). Such a canonical form cannot be provided for the LV in the LVM. The problem is not to do with error and resolution or removal of error by using goodness-of-fit adjustments, for example, but inheres in factor indeterminacy.

Factor indeterminacy has a long history. It was Wilson (1928, 1929) in reviewing Spearman's (1927) "The Abilities of Man", who noted a problem for Spearman's concept of *g,* or general intelligence, which involved more than the problem of error – it involved the impossibility of deriving a unique variable for *g*. Wilson (1928) conducted a vector space analysis that demonstrated that LVs or common factors lie partly outside the space described by the linear combinations of the MVs, and thus, cannot be uniquely determined. Part of the common factor or LV is estimable from the MVs, but part is not estimable (Wilson, 1928; Maraun, 1996; Mulaik, 2010). The problem extends beyond the vector space of the model – which is the space referred to in speaking of the problem of equivalent models - because the vector space itself cannot be made finite once a solution is obtained for the LV, where this solution involves estimating the LV from the MVs, given the correlation patterns of the MVs on the LV. What this means is that even for an estimated solution for the LV which is as exact as possible, there is no certain way to link this to the psychological attribute, or to exclude the solution from being itself any other potentially contradictory factor.

Spearman (1929) responded to Wilson's (1928) critique in a way that suggested he misunderstood the point regarding nonuniqueness for factor models. Spearman (1933) implied that indeterminacy could be solved with the addition of a variable that "was perfectly correlated with g to the set of observed variables" (Mulaik, 2010 p. 380) along with several other solutions that addressed error or exactness, but not uniqueness. In no way did the addition of a variable address the innumerability of solutions for *g*, and Mulaik and McDonald (1978) sets out a proof that simply increasing the number of variables following Spearman's suggestion and extending it all the way to infinity does not eliminate the problem of factor indeterminacy. Modifying statistical models does not address the logical problem inhering in any LVM solution, of factor indeterminacy.

Where ontology is declared for a relation between the LV and the MV, factor indeterminacy, which is otherwise described as an epistemological problem (Rozeboom, 1988; Haig, 2014), becomes an ontological concern. For critical realism, factor indeterminacy itself may not represent an ontological conflict, as even though indeterminacy references limits of logic, critical realism suggests that ontology is never closed in a dialectical logic where absence always outstrips presence. For critical realism, there are always new conditions emerging, in reality (Bhaskar, 2008) and the lack of determinability for a vector space, for example, in factor indeterminacy, is a feature of reality that may be included under ontology, for critical realism. A problem remains, though, for the LVM, because it is the LV in the model that is indeterminate, and no consistent relation can thus be justified, between the psychological attribute and the LV.

Factor indeterminacy has implications for the status of the LVM as a measurement theory. It means that the isomorphism, or one-to-one relations between empirical outcomes and variable values that could otherwise be demonstrated for the statistical model lapse into many-to-many *knowable and unknowable* structures, which cannot be described as a map.

Without a map to give an understanding of the *unit* that is measured whenever a solution is found for the LV, there is question about how it can be said that measurement occurs, a question to be pursued, in the next section.

4.4 Measurement Theory

The concerns of Rozeboom (1988) and Mulaik (2010) in reference to factor indeterminacy are relevant to the way the LVM coheres with the requirements of what it is to be a measurement theory. Situational realism sets out a realist theory of measurement, as "*the attempt to estimate the ratio between two instances of a quantitative attribute, the first being the magnitude measured, and the second being a known unit"* [emphasis original] (Michell, 2005, p. 287). For the LVM, this implies that while a particular instance of data scores, for example, may be input into the MVs to give an estimate or a solution for the LV, the solution should be coherent with a *known unit*. Factor indeterminacy brings question to the degree to which the unit can be known, as the many-to-many structure which may be both knowable and not-knowable implies that it is impossible to determine the character of the LV structure with any certainty.

In addressing certainty or what can be known, given a realist approach, the elements of the definition of measurement serve as a test, for an instantiation of measurement. The realist definition of measurement refers to a quantitative status, for an attribute (Michell, 2004). In practice, the quantitative status of an attribute can be understood as a *hypothesis*, which has empirical conditions that must be met, in order for the attribute to be deemed as quantitative, and thus, measurable. Quantitative attributes have several properties, which are not necessarily properties that are shared with psychological attributes. To test the hypothesis of quantitative structure for the psychological attribute is to ensure that the most suitable model given the data structure is chosen under the common framework. It contributes to the

sustainability of research outcomes, as the critical inquiry that is scientific discovery has been extended through the auxiliary hypotheses that support the application of the LVM to the present research question. Typically, hypotheses regarding quantitative structure are not either stated or confirmed in research practice, and Borsboom (2005) does not make mention of the confirmation of quantitative structure in the account of the LVM that is endorsed as realist. Without confirmation of this hypothesis, where an attribute is deemed quantitative this endorses operationalism, a philosophical orientation Borsboom (2005) clearly sought to avoid, in drawing a case for realism for the LVM.

The general characteristics of any realist attribute, suitable for either a psychological or a quantitative attribute include: i) generality or *universality*, such that the attribute may be expected to be present as characteristics or feature of different entities, so, for example, intelligence is commonly given to be a feature of human beings; ii) a *range*, over which the specific instances of the attribute can be said to be found, where for example, particular identifications of intelligence may be made for individuals at a certain point in space and time; iii) a *structure*, which will: a) describe the *number of terms* needed for an instance to be ascertained, for example, can intelligence be said to occur on its own, or are there other entities required for its existence; and b) make clear how specific instances of the attribute *relate* to each other to make the attribute an attribute, for example, answering how it can be known that different instances of the attribute of intelligence connect to each other (Michell, 2005). These characteristics may formulate *assumptions* for the psychological attribute at question for the LVM. Borsboom (2005) characterises a causal interpretation of the LV as an *entity* considered to occur between-subjects, where between-subjects is taken to mean between population groups that have the same solution for the LV, because a constant could not be a cause, as would be the case if a within-subject interpretation of the LV was endorsed. The universality, range and structure of such an entity is not set out in Borsboom's (2005)

account, and to say that such characteristics could be conferred by LVM fit to the data outcomes is to confuse what is measured with how it is measured. The confusion of what is measured with how it is measured is a problem occurring under the *operationalism* that is specifically sought to be avoided, in the realist account for a LVM.

Where the relation between the LV and the MV is described as a realist, causal relation, realist criteria for measurement should be met. A realist approach to measurement has several characteristics (Michell, 2004): i) it works to distinguish what is measured from how it is measured; ii) as a technique it is taken to measure attributes of objects and not objects, themselves, and iii) it employs methods of *discovery* in deriving numbers, rather than assigning them.In discovery, measurement relies on particular features of the *internal structure* of the attribute, where *numerical relationships* must sustain relations of *ratio,* that is to say, the attribute must be *quantitative* (Michell, 2005). Quantitative status is confirmed in the ratio obtaining in *two* instances of any attribute, these being the magnitude measured, and the unit. To be demonstrated as coherent with a unit, the LV would need to sustain the properties of ratio, or real number, where under realism these terms describe nearly identical concepts (Michell, 2003). Properties of ratio can be demonstrated by the operation of concatenation of equal parts, for example, or by *extensive procedures*, where the properties of the attribute, such as for example length, may be confirmed against real world properties. For example,extensive procedures are in play when we hold a ruler against items and use human observation to say that 1cm measured across an instance of paper and an instance of ribbon is the same distance, so to add 1cm of paper with 1cm of ribbon gives 2cm of *length*.

Properties of ratio can also be demonstrated by *intensive structure*, which reduces the dependence on real world properties observable at the level of human beings (Michell, 2005). An intensional theory of measurement gives the meaning of ratio by specifying the necessary and sufficient conditions for sustaining the property of ratio. Where an extensional theory of

measurement would require an infinite map of all possible instances to all empirically determinable outcomes so that the definition of ratio can be demonstrated to be held in all cases, an intensional theory of measurement says *what must be the case* to sustain ratio, so that magnitudes of a given attribute can be said to be measured, against the ratio (Michell, 2005).

Hölder (1901)set outaxioms or seven conditions that must be met to sustain the relations of ratio as continuous, unbounded quantitative structures (see Appendix A). Axiomatisation is considered to apply for a theory when "it is expressed as a set of (ideally logically independent) propositions (called 'axioms') from which the remainder of the theory deductively follows" (Michell, 1999, p. 194). Axioms are considered to serve in a realist sense as the fundamental hypotheses of theory, or conditions that data must meet, to be logically used in quantitative analysis, for example, in generating outcomes for the LV under the LVM. Hölder's (1901) axioms set out a system of ratios so that *isomorphism* can be demonstrated between the structure of the attribute and the structure of real numbers. An isomorphism gives direct one-to-one relations between numbers and empirical entities (Suppes & Zines, 1963). The problem of factor indeterminacy for the LVM means it is not a one-to-one but many-to-many structure which is both knowable and non-knowable that persists for the LV, meaning that there is no way to confirm the *known unit* which is necessary for confirmation of ratio data. The problem of many-to-many knowable and not knowable relations for the LV also brings question to the degree to which assumptions such as unidimensionality can be affirmed, as this would rely on homomorphic structure, or a many-to-one relational composition, which is impossible to affirm under factor indeterminacy.

Recent question has been brought to bear on the degree to which the conditions of isomorphism as axiomatically set out by Hölder (1901) must necessarily be proven, in order

for measurement to be possible. Rather, noting the axioms describe what the "empirical world must be like" in order for measurement to be possible, what may be of most concern is *structurally similarity* between a ratio, and empirical outcomes. For example, Sherry (2011) demonstrates that structural similarity rather than axiomatic confirmation was the characteristic that was generative with respect to the development of the thermometer which measures quantitative differences from the thermoscope, which measures only ordinal differences. However what is at question is a realist account of the LVM, predicated in Borsboom's (2005) account is reliance on true values, rather than approximations and similarities. Where the model is given to obtain to a real world set of true conditions, the realist theory of measurement requires reconciliation to an account of measurement consistent with isomorphism to real numbers. This is not given, in Borsboom's (2005) account of the LVM as a measurement theory.

In a realist approach to measurement "real numbers are ontological, they are spatio-temporally located relations" (Hibberd, 2014, p.15), which are not imposed by human meaning making or epistemological systems. If real numbers exist, they have order and additivity or homogenous degrees between them. There is no indication that psychological attributes necessarily exhibit the order or additivity which would qualify them as quantitative attributes (Michell, 2011), and some theorists hypothesise that psychological attributes in general are at the most ordinal, in data structure (Cliff, 1992; Michell, 2011). Where LVs are precisely latent, or unavailable to be spatio-temporally located, it remains questionable as to the means by which realist quantitative status, as spatio-temporally situated, could be attributed to them. Cliff (1983) points to naming fallacy in describing a LV as a psychological attribute, in that 'latent' signals a particular quality of hiddenness, suggesting that factors always remain obscured, they never actually emerge, for any type of verification. If the LVM is meant to give the measurements which provide meaning regarding what a

psychological attribute *is*, the quality of 'latent' itself for Cliff (1983) means there can be little or no agreement about what exactly it is that constitutes something like intelligence or verbal ability.

Following Rozeboom (1996), there is a problem with considering the LV as a causal factor, in the LVM in this regard. This is because intensional structures will need to be given, regardless of latency, for both the LV and any MVs, for measurement to be possible. Where the LV is meant to account for a causal and explanatory factor as a psychological attribute (such as the intelligence shared between subjects that causes sets of scores on an array of verbal reasoning tests), the relations semantically must be asymmetrical – passing from the intelligence as cause, to the scores as effects. For Rozeboom's (1996) analysis, the semantic structure of the LVM prohibits the overlay of the set of causal necessary and sufficient conditions for the intelligence on the necessary and sufficient intensional structures of the MV scores. The equals sign between the LV and the MVs means that there is not enough explanatory power in the LVM structure, for the relation between the LV and the MV to be deemed as both causal and for the LVM to be a measurement theory.

For Borsboom (2005), the LV "must be considered to function as a representative for the theoretical construct (to be distinguished from the function of fundamental measurement scales, which are representations of observed relations)" (pp.142-3). Further, the LVM has "the power to dispose of the problem that tests are valid for any attribute they are monotonically related to, because the dimensionality of the latent space can be specified in the model". The suggestion here perhaps is that the limits of quantitative structure, which constitutes a usual reference for the term measurement, aretranscendend and included in the structure of the LVM, because the LVM is considered by Borsboom (2005) to include the attribute *within* its formulation. Presumably the attribute itself is given to shape the vector space for solutions in the LVM model, but there is no indication in this of quantitative or

categorical structure, and given factor indeterminacy, no way to link the structure of the variable with certainty to the psychological attribute. Michell (2011) indicates that the quantitative structure of the data for the MV may be as much at question, as that of the LV, given that quantitative status is rarely hypothesised and confirmed for attributes, in psychological research. The unlikely extension for the model to causality given the strictures of intensional structures for the MVs and the LV raises doubt about the ways that a causally realist cake can be had and eaten as measurement, too. Factor indeterminacy and isomorphism to ratio structure remain as serious concerns for the status of the LVM as a measurement theory for a causal relation from the LV, to the MV.

4.5 Conclusion For This Section

In this section a conceptual analysis has been presented utilising meta-analysis outcomes, which tests the formulation of realism, the commitments implicit in ontology, the logical structure of causal explanations and LVs, the implications of factor indeterminacy, and the conditions of a realist theory of measurement, in connection to a LVM. The conditions of causal explanation bring perhaps strongest question to the capacity of the LVM to represent a causal relation, and the ontological criterion of independence represented a problem for the psychological attribute and the LV that represents it, for all three realisms analysed here. Factor indeterminacy is a frequently overlooked problem for the LVM, but raises substantial concern regarding an ontological status for the relation between the LV and MV, largely because factor indeterminacy violates the conditions necessary for measurement theory to apply. The next section draws out some implications of the conceptual and meta-analysis against a later proposal for the exchangeability of the LV and the MV, in LVMs.

Chapter 5: Application of Conceptual and Meta-Analysis

Having understood the implications of a conceptual analysis for a realist causal relationship between the LV and MVs in the LVM, and examined the conditions of a realist ontology for LVs from philosophical realist perspectives, the outcomes point towards the benefits of maintaining coherence with the broader set of relations that lead up to the use of a statistical measurement model that attempts to map elements of psychological attributes. In this section, the conceptual and meta-analysis conclusions in light of Borsboom's (2005) realist causal ontology for the LVM are considered in regards to a later proposal from Borsboom (2008) regarding the exchangeability, of latent and observed variables.

5.1 Latent Variables and Observed Variables

A perhaps unfortunate outcome of the legacy of the logical empiricism of the mid-twentieth century for psychological research has been the pervasive presence of a dichotomy between observable and unobservable phenomena (Maraun & Gabriel, 2013). What is emphasised in an 'observation' for logical empiricism are the statements about generalisable, surface level perceptual experiences with some phenomena of interest, such as a psychological attribute, which are then equated to the concept-term for the attribute, at the expense of *analysis* of the concept, including its historical scientific features and any ontological conditions that obtain, beyond mere observation (Maraun & Gabriel, 2013). In a later paper, 'Latent Variable Theory', the influence of a logical empiricist approach to observation appears present in Borsboom's (2008) metatheoretical framework for the LVM. This paper proposes that the difference between LVs and MVs is "purely *epistemological*", with no "*ontological* distinction" [emphasis original] (p. 30) between them. The conflation of concept terms and observations leads to the statement that true "observed variables probably

do not exist" (p. 50) for psychology, because psychological attributes typically are not readily available as empirical data.

The choice to use the term "observed variable" for the realisations or manifest variables in the LVM is hazardous because it feeds into a web of semantic relations that function as *concept equating,* as outlined in the conceptual analysisabove (see Maraun & Gabriel, 2013). An outcome of concept equating is that the characteristics of human *observation* come to be seen as essential elements of the structure of a variable, and then considered as a standard against which the status of the LV might be judged. For Borsboom (2008) variables are "not inherently latent or observed" (p. 30), and an extended analysis of epistemological relations follows, suggesting that observations must bear deterministic causal connections to only this variable in question under cardinality, to render the variable as observed.

Philosophical realism indicates that while there may be no need to make an ontological distinction between phenomena, ontological criteria are certainly a reference point regarding the status of phenomena. Ontology must be satisfied before epistemology can be answered, for each realist approach in the meta-analysis above. For situational realism, observation is a *relation* between that which is of interest to the researcher and the phenomena. Reference to the ontological categories of particularity and number in space and time as set out in Michell (2011) for example clarifies that the psychological attributes at question for psychometric techniques are categorical, or, at best "ordinal, non-quantitative attributes" (p. 248), because the differences that psychological attributes admit do not occur in *known units,* but admit differences in *kind* that cannot be quantified. Whatever can be said about the structure of the variable is determined by the properties inhering in the attribute. For critical realism, ontological stratification suggests that the gap between the patterns that facilitate human observation of phenomena and its own patterns in nature inhere in

ontology,and the chronicle of this gap is an essential part of any account of phenomena, rather than any criterion against which phenomena may be judged. For speculative realism, human observation merely maps the surface structures of objects and does not reach to their deep ontological nature, which has the character of possibility, less than observational structures of probability. No matter the epistemological plane or stance regarding observation, the ontological core of the object remains only indirectly available to the observer.

Borsboom (2008) suggests that the use of the LVM should be pervasive in psychology research, with all potential variables treated in the first instance as latent, and the "onus of proof lies with the researcher who wants to assume that his or her variables are observed" (p. 49). Curious here is the extent to which the fact that LV solutions can only be derived from MV outcomes is overlooked. The MV outcomes themselves are underscored by a set of methodological assumptions, including those pertaining to the formal status of the data, as quantitative or non-quantitative. The model itself cannot transform non-quantitative MV data into quantitative MV data, the real-world data which is input into the MV must in the first instance be hypothesised and demonstrated as quantitative where the structure of the MV is assumed as continuous, and where a realist theory of measurement is sought. The many-to-many knowable and unknowable relations implicit in the factor indeterminacy of the LVM suggests that treating the model as a measurement theory is a speculative rather than certain enterprise. While the prevalence of LVM in psychological research continues to grow, it is less likely that the LVM is a suitable tool for discerning between the status of variables as manifest or latent. What is indicated in the name of "scrupulous scientific endeavour" (Michell, 2011, p. 254) is confirmation of the status of variables in light of metaphysical assumptions, methodological assumptions and the empirical task.

Chapter 6: Conclusion

Borsboom (2006) states that theory for psychology does not indicate the type of statistical model or variable structure most suited for a given research question. This thesis suggests that theory *does* give indication regardingthe type of model and variable structure, by reference to i) substantive knowledge; ii) auxiliary principles and metaphysical and methodological assumptions on which it rests; and iii) its connection to real-world circumstances. The theory itself points to an interlinked system by which it comes into being, and this interlinked system can be both examined for coherence, and affirmed as consonant with the structures of any methodological assumptions or theoretical conclusions following from it. The principle of sustainability suggests that longevity for research outcomes is enhanced when metaphysical assumptions are clarified, and methodological assumptions and empirical determinations are rendered coherent against metaphysical assumptions. Longevity is supported because future researchers with expedience can ascertain any problematic assumptions in light of their own research endeavours,making theninformed methodological choices. Conceptual analysis in this regard is supported at every step of the research endeavour, including within statistical analysis phases (Petocz & Newbury, 2010).

Conceptual analysis as a component of *critical inquiry* regarding the LVM reveals several concerns and minimal support for the status of the model as measurement theory. Factor indeterminacy is a problem that stretches beyond exactness, to nonuniqueness, where the LV cannot be mapped to a specific attribute with any certainty. Factor indeterminacy alone brings question to the degree to which the LVM can be described as measurement theory. The isomorphism necessary to confirm the *known unit* for any quantitative status for a continuous LV, and the homomorphism where the magnitudes of many LV solutions can be mapped to the one psychological attribute asnecessary for the assumption of

unidimensionality both are violated by the many-to-many structure of factor indeterminacy.While the problem remains intractable to date, attempted solutions (cf. Guttman, 1955; Steiger, 1996; Mulaik, 2010) suggest that there may be benefit in setting ontology broadly, to admit many variables as research continues through time, rather than reduce ontology to a hypothesised causal relationship between LVs and MVs:

> It strikes me as tunnel vision to persist in focusing just on relation between the observed variables and the common factors once we have seen that the observed variables and the common factors will have to be embedded in the context of many more variables as research proceeds. (Mulaik, 2010, p. 398)

A framework facilitating confirmation of ontological conditions within a relational system of metaphysical, methodological and statistical assumptions nurtures capacity to present the relational structure of the variable in a comprehensive theory of variables (Rozeboom, 1961), and renders clarity regarding the nature of the relations for each research instance, between variables.

The causal relation between the psychological attribute and the test scores assumed to be reflected in the relation between the LV and the MV in the LVM also has minimal support, where the necessary and sufficient conditions of the intensional structures of the LV and the MVs in a statistical equation cannot be considered to adequately represent causality. The structure of inductive-statistical explanation always falls short of what is necessary for causal explanation, and the non-quantitative features of causality cannot be included within statistical models. Presumably, every measurement model relies in some way on cause, as there must be some set of real world activities that give rise to a set of outcomes that the researcher connects to their purpose of *scientific discovery.* Clarification regarding the particular conditions of each scientific endeavour against an interlinked system of

metaphysical, methodological and statistical assumptions can assist in disentangling causal conditions that belong to the circumstance, and causal conditions that may be present for the psychological attribute in question.

Philosophical realism brings several questions to the nature of causality that can be said to inhere in the LVM. Independence cannot be said to inhere in the LV, given that the LV has no value without the input of data and the functions applied to variables, in the model. Without independence, the LV does not have the properties logically necessary *for* causality. The criteria of ontology suggests that at best, psychological attributes are categorical or ordinal structures (Michell, 2011), so any assumption of a continuous ratio structure for the LV must be hypothesised and demonstrated. Empirical patterns and patterns inhering in the attribute come apart at the level of ontology, following critical realism, and the field within which the causal relation is said to occur is as ontologically relevant as the relation itself, for both speculative and critical realism. The causal field and the empirical conditions thus must be clarified, so that any causality that may be said to be present is less likely to be misattributed.

Several researchers note that where psychological theory once developed in concert with psychometric theory, a widening gap is over time is apparent with each becoming an independent field of scholarship (Borsboom, 2006) such that the relevance of psychometrics to psychology may be considered as at future risk (McGrane, 2010). *Unification* has been a theme prevalent within psychological research generally, with similar trends across the substantive fields leading to a fragmentation that does disservice to the production of coherent and integrated research (see Petocz & Mackay, 2013). Many of the recommendations emerging from this thesis regarding ontology speak of the need for a *unified* account that speaks for what both is, and what is not, for variables, for relations, for causal relations and causal models. What can be understood as of relevance to both calls for

unification is the degree to which there is: 1) scope for inclusion of contextual factors; 2) structure for pluralist approaches, for example to consider the strengths and weaknesses of different metatheoretical approaches to unifying psychology and psychometrics, or, to address relational and non-relational elements of phenomena; and 3) a logical framework to ensure cohesion.

A philosophy of realism, rather than philosophical realism may address these circumstances, as broad enough in structure to admit varied philosophical stances and methodological approaches. In this present review of Borsboom's (2005) LVM and its connection to psychological theory, instrumentalism, operationalism and constructivism each have featured as interacting in different ways within what was described by Borsboom (2005) a realist research orientation. With rubrics for attention to contextualisation already set forth by other researchers (see Maul, 2013; Hood, 2013), what is indicated for future inquiry is exploration of alternative forms of logic, such as many-valued logic (Haack, 1978) or paraconsistent logic (Priest, 2001) which extend beyond classical forms such as the propositional logic of situational realism and dialectical logic of critical realism. Such logics may be suitable as underscoring pluralist approaches to research rationales, and may admit*degrees* of plurality, such that even the problem of factor indeterminacy may be further addressed within logic structures. Such logics may empower the statistical researcher in turning to the whole of the generalised common framework for the LVM, ready to make model choices armed with a conceptual and logical framework that benefits research outcomes, not in creating immediacy or ease of findings, but by ensuring ongoing and thoroughgoingcontribution to the field of endeavour that is psychological research.

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Appendix

Hölder's (1901) axioms, as set out in Michell (1999)

1. Given any two magnitudes, *a* and *b*, of Q, one and only one of the following is true:

   (i) *a* is identical to *b* ($a = b, b = a$);

   (ii) *a* is greater than *b* and *b* is less than *a* ($a > b, b < a$); or

   (iii) *b* is greater than *a* and *a* is less than *b* ($b > a, a < b$)

2. For every magnitude, *a* of Q, there exists a *b* in Q such that $b < a$
3. For every ordered pair of magnitudes, *a* and *b*, from Q, there exists *c* in Q such that $a + b = c$
4. For all *a* and *b* in Q, $a + b > a$ and $a + b > b$
5. For any *a* and *b* in Q, if $a < b$ then there exists *x* and *y* in Q such that $a + x = b$ and $y + a = b$
6. For all *a*, *b* and *c* in Q, $(a + b) + c = a + (b + c)$
7. For every pair of classes of magnitudes in Q, Φ and Ψ, such that

   (i) each magnitude belongs to one and only one of Φ and Ψ,

   (ii) neither Φ nor Ψ is empty, and

   (iii)every magnitude in Φ is less than each magnitude in Ψ,

   there exists a magnitude *x* in Q such that for every *x'* in Q if $x' < x$ then *x'* is in Φ and if $x' > x$ then *x'* belongs to Ψ.