Formative Measurement Models in Covariance Structure Analysis: Specification and Identification

Lutz Hildebrandt*
Dirk Temme*

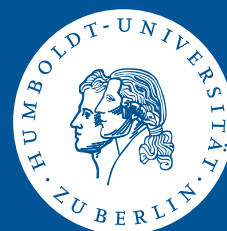* Institute of Marketing, Humboldt-Universität zu Berlin, Germany

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Formative measurement models in covariance structure analysis: Specification and identification[1]

Dirk Temme, Lutz Hildebrandt
Institute of Marketing, Humboldt University Berlin
Spandauer Straße 1, 10099 Berlin
{temme, hildebr}@wiwi.hu-berlin.de

Abstract

Many researchers seem to be unsure about how to specify formative measurement models in software programs like LISREL or AMOS and to establish identification of the corresponding structural equation model. In order to make identification easier, a new, mainly graphically-oriented approach is presented for a specific class of recursive models with formative indicators. Using this procedure it is shown that some models have erroneously been considered underidentified. Furthermore, it is shown that specifying formative indicators as exogenous variables rises serious conceptual and substantial issues in the case that the formative construct is truly endogenous (i. e. influenced by more remote causes). An empirical study on the effects and causes of brand competence illustrates this point.

Keywords: Formative indicators; Latent variables; Covariance structure analysis; Identification

JEL-Codes: C31, C51, C52, M31

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1. Introduction

At least since the seminal papers by Diamantopoulos and Winklhofer (2001), Rossiter (2002), and Jarvis, MacKenzie, and Podsakoff (2003) researchers in marketing are sensitized for thinking thoroughly about the conceptualization and operationalization of their theoretical constructs as either reflective or formative (or possibly some combination of both). Simultaneously, the broadened perspective on the specification of measurement models has begun to alter the researchers' decisions on the statistical method to be used for the estimation of structural equation models with latent variables (SEM). Whereas the "Churchill paradigm" (Churchill, 1979) with its focus on reflective constructs has prompted the researchers to apply – almost exculsively – covariance structure analysis (CSA), researchers now more and more turn to the partial least squares approach (PLS; Wold, 1966) if formative constructs are involved. The most important driver of this development is arguably the fact that many researchers are unsure about how to specify formative measurement models in software programs like LISREL or AMOS and to establish identification of the corresponding SEM (Jarvis, MacKenzie, & Podsakoff, 2003). This uncertainty is even echoed in claims that CSA is not able to handle formative indicators (e.g., Dellande, Gilly, & Graham, 2004). Although such claims can be easily refuted, they contribute to a widespread impression that accomodating formative constructs in the CSA framework is a rather difficult task which should better be avoided. In contrast, with PLS the user does not have to bother with the identification of such models and estimation is fairly easy with the new generation of software (e.g., PLSGraph, SmartPLS).

Given the apparent advantage that PLS has for SEM with formative constructs, one might ask why to deal with the specification of such models in CSA anyway. There are several reasons which can be put forth: First, if the manifest indicators of (reflective) latent variables are contaminated by measurement error, unbiasedness of the parameter estimates in PLS rests on the "consistency at large" condition with respect to the number of indicators (Wold, 1980). Since such a requirement is almost never fulfilled in empirical studies, PLS parameter estimates are typically biased to a certain degree (Dijkstra, 1984; McDonald, 1996). Second, beyond the fundamental linear predictor specification PLS does not impose any restrictions on the data. Therefore, no overall test of model fit is available so far. Third, in contrast to CSA the PLS approach is restricted to recursive models, i. e. no feedback loops or reciprocal relationships can be estimated.

Consequently, there are some important arguments not to abandon CSA in the case of formative constructs. However, in order to make CSA a reasonable alternative to the PLS approach from the researcher's point of view, easy-to-apply rules to assess the identification status of her/his models must be established. Unfortunately, identification of formative measurement models is still an underresearched issue. With the exception of some unpublished work by Bollen and Davis (1994) all identification rules discussed in the relevant iterature (Bollen & Lennox, 1991; MacCallum & Browne, 1993; Edwards & Bagozzi, 2001; Jarvis, MacKenzie, & Podsakoff, 2003) are restricted to the case of a single formative construct and even here the stated rules can be misleading. Our paper contributes to the research on formative constructs by suggesting a graphically-oriented approach for identifying a specific class of models. We also show that this approach allows to identify models which have formerly been regarded as underidentified.

Whereas the identification of formative measurement models in CSA has at least been identified as an important problem, another issue is almost completely neglected in the literature. If model specification for formative constructs embedded in extensive nomological nets is covered at all, most articles exclusively focus on "exogenous" formative constructs (i.e. constructs without any further causes except their indicators/components). Even if "endogenous" formative constructs (i. e., constructs influenced by more remote causes than their indicators) are involved, the corresponding indicators are still considered exogenous (e.g., MacCallum & Browne, 1993). This paper aims to show that such a specification gives rise to serious conceptual and substantial issues. As a consequence, we propose to specify both direct and indirect effects (via the formative indicators) of the remote causes on the formative construct.

In the following, we first deal with the identification of SEM including formative constructs. Secondly, we discuss some specification problems for truly endogenous formative constructs. The consequences of misspecifying the relationships in this case are finally illustrated by an empirical study on the causes and effects of brand competence. We finish with some concluding remarks.

2. Identification

For our purpose, a formative construct η_j ($j = 1, ..., m$) is defined as follows (for a discussion of different perspectives see Bollen & Lennox, 1991; Diamantopoulos & Winklhofer, 2001):

$$\eta_j = \gamma_{j1}x_1 + \gamma_{j2}x_2 + \ldots + \gamma_{jq}x_q + \zeta_j,$$

where x_s ($s = 1, \ldots, q$) are the formative indicators. At least conceptually, the stochastic disturbance ζ_j represents those facets of the construct which have not been observed (for a more thorough treatment concerning the interpretation of ζ_j see Diamantopoulos (2006)). For ζ_j the typical assumptions apply: The indicators are uncorrelated with ζ_j and $E(\zeta_j) = 0$. Formative constructs will also be refered to as composite latent variables (CLV; Jarvis, MacKenzie, & Podsakoff, 2003). As a further extension, the indicators in the equation above can be substituted by multiple reflective constructs representing the various components of the formative construct (Edwards, 2001).[2]

Just as with reflective constructs, identification of formative measurement models in CSA is bound to two basic conditions. First, the number of free parameters t in the overall model must not exceed the number of non-redundant elements in the empirical variance-covariance matrix (t-rule; Bollen, 1989). Second, each latent variable needs to be scaled. In the literature different options (e.g., fixing the path of the CLV to a reflective indicator or the variance of the CLV to 1) are disucssed (Bollen & Davis, 1994; MacCallum & Browne, 1993).

Beyond the necessary but insufficient requirements presented above, further conditions discussed in the literature are often not very helpful for identifying models of practical relevance or might even be misleading. For instance, Jarvis, MacKenzie, & Podsakoff (2003) note that for the error terms of formative constructs to be identified it is necessary that they "emit paths to (a) at least two **unrelated** [emphasis by the authors] latent constructs with reflective indicators […], (b) at least two theoretically appropriate reflective indicators […], or (c) one reflective indicator and one latent construct with reflective indicators […]." (p. 213). Based on this rule, MacKenzie, Podsakoff, & Jarvis (2005) erroneously conclude for the model by Law and Wong (1999) depicted in Fig. 1 that "[…] the error term for the job perception construct was not identified when job perception was specified as having formative indicators. This is because the job perception construct did not have two paths emanating from it that led to independent constructs. It had two paths leading from it, but the two constructs were causally related." (p. 716). Although it is true that at least two paths leading to other variables are necessary for a CLV to be identified, the former need not be unrelated in a larger model.

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[2] For ease of exposition we only consider formative observed indicators here. However, the identification issues dealt with in this section also apply to the case that reflective constructs make the CLV appear.
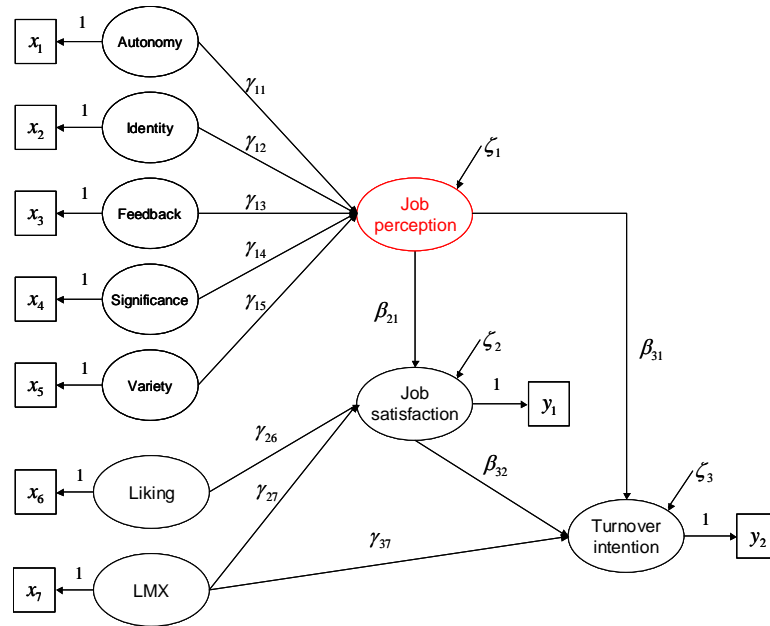
Fig. 1. Model on job perception by Law & Wong (1999)

In order to show that the model by Law and Wong (1999) is indeed identified, we introduce a a new, mainly graphically-oriented approach which consists of the following three steps (for a related but completely algebraic procedure see Cantaluppi (2002)):

I. Transform the original model into a model without CLVs.

II. Check identification of the transformed model.

III. Check that the parameters of the original model can be unambiguously derived from the parameters of the transformed model.

Our procedure is meant to be applied if structural relationshsips have been defined between those variables which are directly dependent from the CLV. However, it is assumed that the model is recursive, i. e. there are no feedback loops or correlated disturbances.

We now illustrate the approach for the model by Law and Wong (1999). Starting from the graph in Fig. 1, substep (1) in transforming this model consists in choosing a CLV (in the case at hand only one is present: job perception). In substep (2) all variables directly influenced by this CLV (i. e. job satisfaction and turnover intention) are connected by double-headed arrows. All arrows emenating from the CLV are then eliminated in substep (3). In substep (4) the CLV is substituted by its formative indicators. Finally, for each of these indicators an arrow is drawn to those variables which were originally influenced by the CLV. The output of substep (5) in our example leads to the graph in Fig. 2. In the case of more than one CLV, steps (1) to (5) are repeated as long as there are CLVs in the partially transformed model.
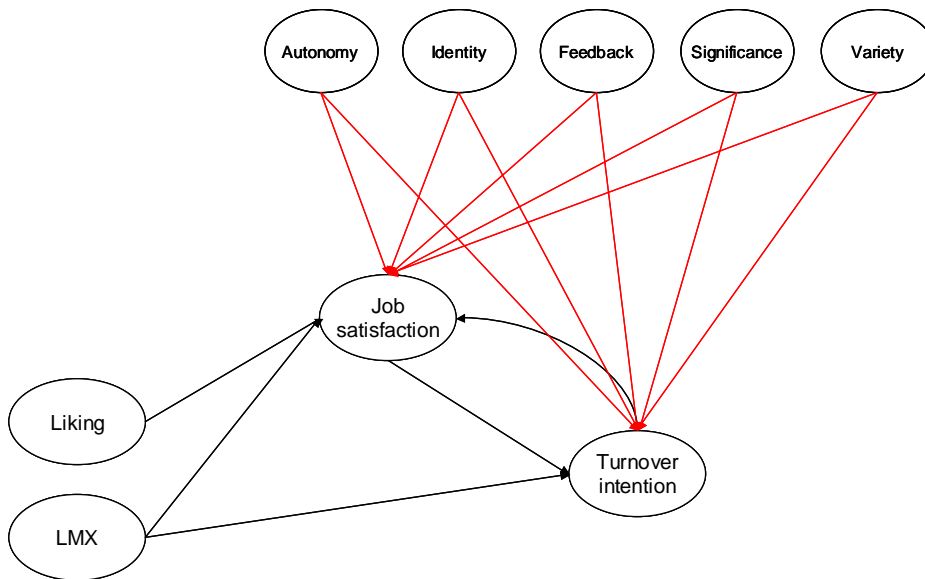
Fig. 2. Transformed model resulting from step II

Step II now requires to show that the transformed model is identified. Since the graph exhibits a so-called bow-pattern (Brito & Pearl, 2002), i. e. the model is not identified per se, we rely on Rigdon's (1995) identification rules for nonrecurisve blocks of two endogenous variables. Because our transformed model resembles his case 8, the model has to be re-classified: The formative indicators influence both job satisfaction and turnover intention and therefore do not contribute to model identification. Eliminating the indicators finally leads to the graph depicted in Fig. 3. Because this model corresponds to Rigdon's case 3, identification of the transformed model has been established. Since it can be shown that the transformed model's parameters allow for an unambiguous derivation of the original parameters (not shown here because of space limitations), also the original model is identified.
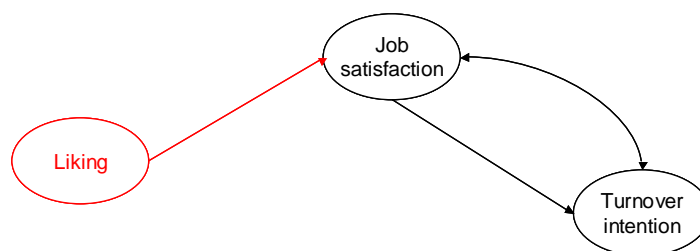

Fig. 3. Re-classified graph

3. Specification of quasi-exogenous and endogenous CLV

In the literature, formative indicators/components[3] are almost ever considered as exogenous independent from the causal status of the formative construct. However, although formative constructs are by definition endogenous, two cases need to be distinguished here: First, the CLV is only determined by its indicators (and some disturbance term which captures the neglected facets of the construct). We will use the notion quasi-exogenous to refer to such kind of CLV. In this case, the covariances between the formative indicators and the other exogenous variables (i. e. other constructs' formative indicators or latent variables) are typically estimated freely (MacCallum & Browne, 1993). Second, above beeing formed by its indicators, the formative construct is influenced by other, more remote causes (e.g., reflective latent constructs or quasi-exogenous CLV). Such a variable will be called an endogenous CLV from now on. In this case, the habitual supposition of exogenous formative indicators raises serious issues both conceptually and substantially.

From a conceptual point of view, if some remote causes are assumed to influence the CLV but its indicators are specified as exogenous variables, it remains unclear how a causal process can actually take place. If we take the view that formative indicators produce the CLV serious, such an effect should mainly operate via all or some of the formative indicators, thus turning the latter into endogenous variables. An example might further clarify this issue: Let us assume that we are interested in how a salary increase impacts on an employee's job satisfaction. Would'nt we expect that job satisfaction raises mainly as a consequence of pay satisfaction (one of the construct's components) beeing improved?

From a substantial perspective, specifying only the "direct" effect of a remote cause on a CLV will almost inevitably lead to a biased estimate. The two models A and B in Fig. 4 illustrate this issue. In both models the latent exogenous variable ξ_1 exerts a direct effect (γ_{31}) on the endogenous CLV η_3^F. For model A, effects of ξ_1 on the formative indicators y_1 ($\equiv \eta_1$) and y_2 ($\equiv \eta_2$) are specified in addition to the direct effect (γ_{11} and γ_{21}). Altogether, this leads to a total effect of $\gamma_{31} + \gamma_{11}\beta_{31} + \gamma_{21}\beta_{32}$ for ξ_1. In contrast, model B reflects the common approach of specifying covariances between ξ_1 and the "exogenous" formative indicators. Here, the influence of ξ_1 is restricted to the direct effect γ_{31}. Dependent from the signs of the coefficients γ_{11}, γ_{21}, β_{31}, and β_{32}, the true impact of ξ_1 is either under- or overestimated.[4]

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[3] Again, in the following we will only use the term indicator but the reader should keep in mind that our exposition also applies to reflective constructs specified as components of a formative construct.

[4] It should be noted that the two alternative specifications are empirically undistinguishable (i. e. they show the same overall fit).
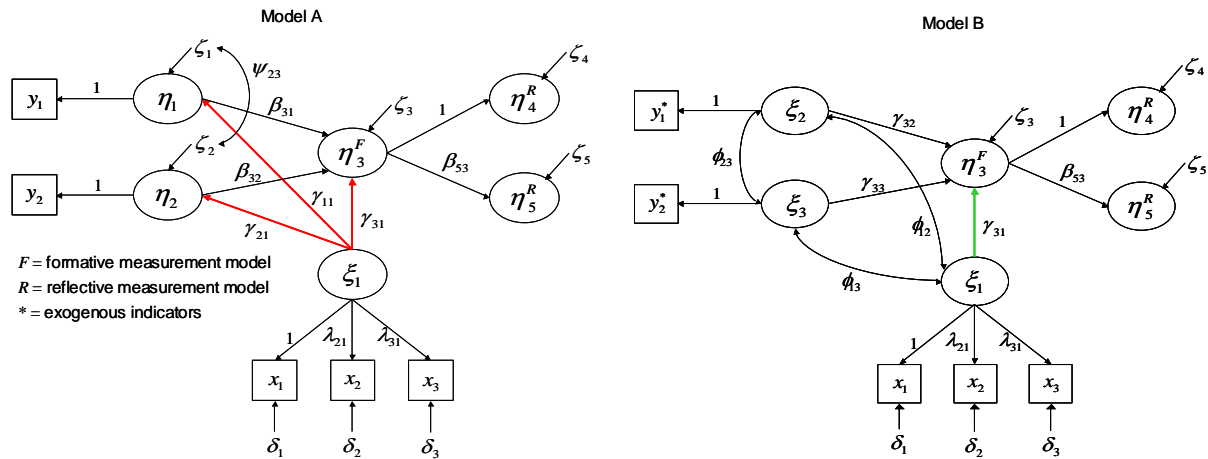
Fig. 4. Specifying endogenous CLV with either endogenous or exogenous indicators

4. Empirical study on the causes and effects of brand competence

In order to show how specifying exogenous indicators in the case of truly endogenous formative constructs can produce misleading results, we shortly present an empirical study on the causes and effects of brand competence. Results are based on survey data for 261 consumers collected by GfK Market Research. Respondents were requested to evaluate various brands in the fixatives and denture cleansers market. Specifically, we were interested in how perceived advertising intensity for the leading brand in the two product categories as well as the perceived extent to which denists recommend this brand influence its perceived competence. A brand can be considered competent if it has "the ability to solve a consumer's problem and to meet his or her need" (Lau & Lee, 2000). In addition, the effect of brand competence on brand strength has been analyzed (see Fig. 5 which represents model 1).

Brand competence in our study is supposed to be formed by four indicators (e. g., "stands for hygiene and cleanliness", "stands for attractiveness and beauty"). The exogenous variables advertising ("really advertsises a lot") and recommendations ("is recommended by dentists") are measured by a single indicator. The perceived attractiveness of the brand (i. e. brand strength) is reflected by eight indicators which capture the affective, cognitive, and intentional responses toward the brand. In order to identify the model, overall brand competence is additionally measured by two reflective indicators.
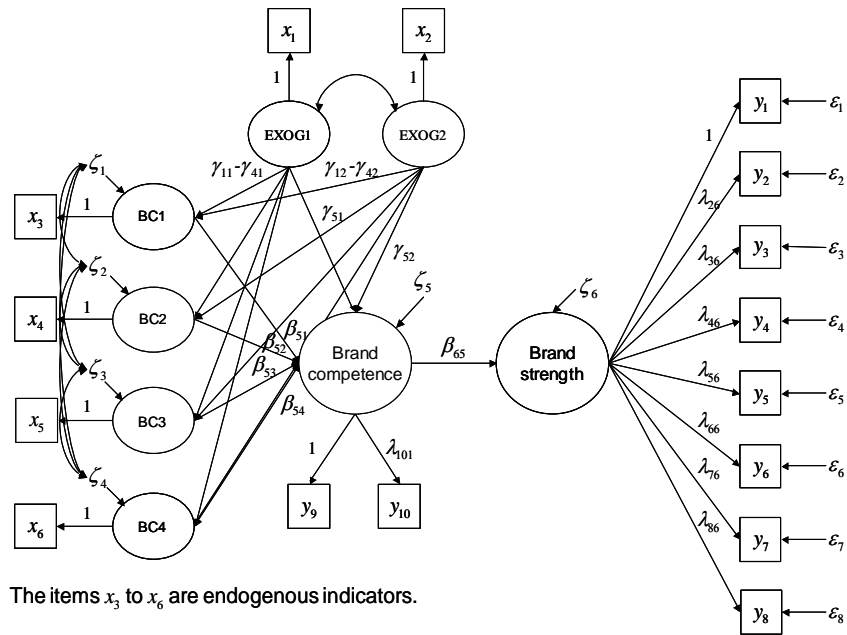
Fig. 5. Structural equation model of brand competence – Causes and effects

Maximum likelihood estimation of the model in Fig. 5 using LISREL 8.72 leads to an excellent model fit (χ^2 = 158.05, df = 87, RMSEA = 0.052, CFI = 0.987). Selected parameter estimates can be found in Table 1. Advertising has both a significant and positive direct effect (γ_{51}) on brand competence and on one of the components (γ_{21}). Overall, a significant positive total effect emerges (Table 2). In contrast, recommendations by dentists only exert an indirect effect on brand competence by increasing two of its indicators (at the 5 % level). Although the indirect influence is significantly positive, in total recommendations do not seem to have an impact on brand competence.

In contrast to the former model, in model 2 the formative indicators have been specified as exogenous variables. Since only direct effects of the two exogenous variables are estimated (see Table 1) and the indirect effects have been shown to be positive, the total effects are therefore underestimated (see Table 2). A closer look at the coefficients for model 1 reveals that the insignificant total effect for recommendations can be explained by the fact that the direct effect, albeit not significant, is negative. Therefore, we tested an alternative specification where this direct effect has been fixed to zero (together with the parameter γ_{41} which was likewise almost nil). Since model fit showed almost no deterioration (χ^2 = 158.66, df = 89), it seems justified to conclude that dentists recommending a brand indeed exert a positive influence on brand competence.

Table 1
Direct effects of the exogenous variables

Explanatory variable	Parameter	Model 1	Model 2	Model 3
Advertising (EXOG1)	γ_{11}	0.077 *0.102*	–	0.076 *0.101*
	γ_{21}	0.133*** *0.160*	–	0.131*** *0.158*
	γ_{31}	0.081 *0.099*	–	0.080 *0.098*
	γ_{41}	0.005 *0.005*	–	–
	γ_{51}	0.155*** *0.261*	0.155*** *0.261*	0.148*** *0.250*
Recommendation (EXOG2)	γ_{12}	0.097* *0.120*	–	0.097* *0.121*
	γ_{22}	0.194*** *0.220*	–	0.194*** *0.220*
	γ_{32}	0.088 *0.102*	–	0.089 *0.102*
	γ_{42}	0.160** *0.161*	–	0.162*** *0.163*
	γ_{52}	−0.030 *−0.048*	−0.030 *−0.048*	–

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$; standardized parameter estimates in italic

Table 2
Total and indirect effects

	Model 1	Model 2	Model 3
Indirect effects			
Advertising → Brand competence	0.056** *0.094*	–	0.054** *0.092*
Recommendation → Brand competence	0.073** *0.116*	–	0.072** *0.114*
Total effects			
Advertising →			
Brand competence	0.211*** *0.356*	0.155*** *0.261*	0.203*** *0.341*
Brand strength	0.193*** *0.222*	0.142*** *0.163*	0.186*** *0.214*
Recommendation →			
Brand competence	0.043 *0.068*	−0.030 *−0.048*	0.072** *0.114*
Brand strength	0.039 *0.043*	−0.028 *−0.030*	0.066** *0.074*

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$; standardized parameter estimates in italic

5. Conclusion

In this paper we have shown that established identification rules for models including formative constructs in part can be misleading. To remedy this issue a new procedure has been proposed which allows the user to establish model identification mainly by graphical criteria. It has been shown that even two related variables influenced by a formative construct can suffice to identify that construct if it is embedded in a larger network. Since so far our approach is restricted to recursive models, further research should consider the case of nonrecursive models. Furthermore, we have identified the shortcomings of the almost standard practice of specifying exogenous indicators in the case of truly endogenous formative constructs: For all practical purposes, the influence of the remote causes will be under- or overestimated. In our empirical study, this might have lead managers to undervalue the positive effect recommendations by dentists have on the perceived competence of a brand for fixatives and denture cleansers.

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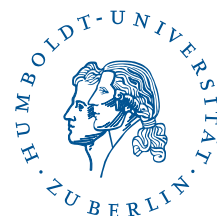
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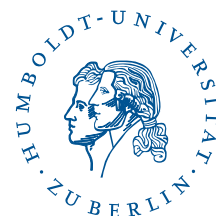
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