

Raunig, Burkhard

Article

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Econometrics

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Suggested Citation: Raunig, Burkhard (2017) : On the interpretation of instrumental variables in the presence of specification errors: A causal comment, *Econometrics*, ISSN 2225-1146, MDPI, Basel, Vol. 5, Iss. 3, pp. 1-6,
<https://doi.org/10.3390/econometrics5030031>

This Version is available at:

<https://hdl.handle.net/10419/195480>

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Comment

On The Interpretation of Instrumental Variables in the Presence of Specification Errors: A Causal Comment

Burkhard Raunig [†]

Economic Studies Division, Central Bank of Austria, Otto-Wagner-Platz 3, Vienna 1090, Austria;
burkhard.raunig@oenb.at; Tel.: +43-1-404-207-219

[†] The views expressed in this paper do not necessarily reflect those of the Central Bank of Austria or the Eurosystem.

Academic Editors: In Choi, Steve Cook, Marc S. Paoella, and Jeffrey S. Racine
Received: 22 March 2017; Accepted: 11 July 2017; Published: 18 July 2017

Abstract: Swamy et al. (2015) argue that valid instruments cannot exist when a structural model is misspecified. This note shows that this is not true in general. In simple examples valid instruments can exist and can help to estimate parameters of interest.

Keywords: causal inference; instrumental variable; omitted variable; structural model

JEL Classification: C18; C26

1. Introduction

Does an efficient financial system enhance growth? Does uncertainty depress private investment? Do private schools provide better education than public schools? In answering these and many other empirical questions instrumental variables play a central role.

In a recent paper [Swamy et al. \(2015\)](#) argue that valid instruments cannot exist in the presence of *any* model misspecification. Such mis-specifications include wrong functional form, omission of relevant explanatory variables, and the presence of measurement error in explanatory variables. As a consequence, instrumental variables (IV) and generalized method of moments (GMM) would not work.

No doubt, instruments may be hard to find or difficult to justify in empirical applications. The claim that instruments cannot exist appears to be too strong, however. This note discusses three simple examples where valid instruments can exist and where IV methods will work.

This note proceeds as follows. The next section reproduces the derivations in [Swamy et al. \(2015\)](#) for a simple linear model. This example helps to explain the logic of their nonexistence result for instrumental variables.

Section 3 briefly discusses the nature of structural models. The aim is to clarify some misconceptions that bedevil the interpretation of structural models.

Section 4 reexamines the basic arguments of [Swamy et al. \(2015\)](#) in the context of three extremely simple structural models. All three regressions for estimating the structural parameter of interest are misspecified in these cases. In the first two cases one of the two explanatory variables has been omitted. In the third case the single explanatory variable contains measurement error.

The following will be shown. In the first case the existence of a valid instruments depends on the purpose of the analysis. In the second case instruments can exist and will produce consistent estimates of the structural parameter of interest. In the third example instruments can solve the measurement error problem.

2. Non-Existence of Instruments

The central argument in [Swamy et al. \(2015\)](#) is that the explanatory variables that must be instrumented in an empirical model to obtain consistent estimates are at the same time also part of the error term of the model. All potential instruments are therefore necessarily correlated with the error term. The requirement that instruments must be uncorrelated with the error term is always violated. Hence, valid instruments cannot exist.

[Swamy et al. \(2015\)](#) start with a very general theoretical relationship

$$y_t^* = f_t(x_{1t}^*, \dots, x_{L(t)t}^*) \quad (1)$$

with unknown functional form, where a possibly time dependent number $L(t)$ of variables x_{it}^* determine y_t^* . This theoretical relationship is assumed to be exact. Thus there is no need for an error term.

The derivations in [Swamy et al. \(2015\)](#) are now repeated for a simple linear model where y_t^* is exactly determined by two variables x_{1t}^* and x_{2t}^* . This model can be written as

$$y_t^* = \alpha_0 + \alpha_1 x_{1t}^* + \alpha_2 x_{2t}^*. \quad (2)$$

Equation (2) is the true model.

Let us assume that we can only observe the measurements $y_t = y_t^* + v_{0t}$ and $x_{1t} = x_{1t}^* + v_{1t}$ where v_{0t} and v_{1t} are measurement errors. Thus, the model that we can estimate has the correct functional form, but suffers from measurement error and an omitted variable.

[Swamy et al. \(2015\)](#) argue that the relationship between the unobserved and the observed determinant can always be written as

$$x_{2t}^* = \lambda_{0t} + \lambda_{1t} x_{1t}^* \quad (3)$$

where λ_{0t} is the portion of x_{2t}^* that remains after the effect of x_{1t}^* is removed. Substituting (3) into (2) yields

$$y_t^* = \alpha_0 + \alpha_2 \lambda_{0t} + (\alpha_1 + \alpha_2 \lambda_{1t}) x_{1t}^*. \quad (4)$$

Accounting for the measurement errors in (4) gives

$$y_t = \alpha_0 + \alpha_2 \lambda_{0t} + v_{0t} + (\alpha_1 + \alpha_2 \lambda_{1t}) \left(1 - \frac{v_{1t}}{x_{1t}}\right) x_{1t} \quad (5)$$

This equation includes the bias arising from omitting x_{2t}^* , the bias from measurement error in x_{1t} , and the measurement error in y_t . It is a simple version of the fully general expression (8) in [Swamy et al. \(2015\)](#). This model can be written as $y_t = \gamma_{0t} + \gamma_{1t} x_{1t}$ where the parameters $\gamma_{0t} = \alpha_0 + \alpha_2 \lambda_{0t} + v_{0t}$ and $\gamma_{1t} = (\alpha_1 + \alpha_2 \lambda_{1t}) \left(1 - \frac{v_{1t}}{x_{1t}}\right)$ are time-varying.

Let us now consider two of the cases discussed in [Swamy et al. \(2015\)](#). In the first case the model is linear. Adding and subtracting the constant parameter model $\beta_0 + \beta_1 x_{1t}$ to (5) yields

$$y_t = \beta_0 + \beta_1 x_{1t} + (\alpha_0 + \alpha_2 \lambda_{0t} + v_{0t} - \beta_0 + (\alpha_1 + \alpha_2 \lambda_{1t}) \left(1 - \frac{v_{1t}}{x_{1t}}\right) - \beta_1) x_{1t} \quad (6)$$

where the last two terms become the error term in the model to be estimated. A valid instrument must be correlated with x_{1t} and uncorrelated with the error term. But x_{1t} is also in the error term of (6). Thus, every instrument for x_{1t} must be correlated with the error. No valid instrument exists in model (6).

The other case is a simple example of a model with a measurement error in the explanatory variable. This model is

$$y_t^* = \beta x_t^* \quad (7)$$

where the measured value of the explanatory variable is $x_t = x_t^* + v_t$. The model that can be estimated is

$$y_t^* = \beta x_t - \beta v_t \quad (8)$$

where $-\beta v_t$ is the error term. Written as time-varying coefficient model (8) becomes

$$y_t^* = \beta_t x_t \quad (9)$$

where $\beta_t = \beta(1 - \frac{v_t}{x_t})$. Adding and subtracting a fixed coefficient model where $\beta^{**} \neq \beta$ yields

$$y_t^* = \beta^{**} x_t + (\beta_t - \beta^{**}) x_t \quad (10)$$

and x_t is again also in the error term of Equation (8). No instrument for x_t would work.

3. Structural Models

Before we reexamine the arguments in Section 2 we need to clarify what structural models are and what kind of assumptions they encode. This note cannot give a full exposition, of course. Pearl (2009a) provides a comprehensive treatment of structural models and causal inference in general. In particular, Chapter 5 in Pearl (2009a) discusses the interpretation of structural parameters and the error term in structural models in great detail. This section draws heavily on Pearl (2009b) which gives an excellent overview of the foundations of causal modeling with structural equations.

Let us consider the simple linear structural equation

$$y = \beta x + v_0. \quad (11)$$

where y depends on x and v_0 , a variable that stands for all other factors that affect y when x is held constant. Particular values of x and v_0 assign a particular value $y = \beta x + v_0$.

Equation (11) encodes the causal assumption that *changing* or *manipulating* x causes y to vary. The strength of this effect is β . Note that the interpretation of β does not depend on v_0 . The equation says that the effect of a unit change in x on y is β , regardless of the values taken by the other variables in the model. Whether or not x is correlated with v_0 plays no role. Equation (11) describes a causal mechanism, not statistical associations. The correlation between x and v_0 becomes important, however, when one attempts to estimate the causal parameter β from observational data.

Furthermore, the relation between x and y is *asymmetric*. The equality sign is therefore somewhat misleading. Rewriting (11) as

$$x = (y - v_0) / \beta \quad (12)$$

would lead to the miss-interpretation that y causes x . For example, when y is a symptom of a disease x than (12) would imply that the symptom causes the disease. This makes of course no sense.

The graph in Figure 1 makes the causal relationship between x and y explicit. The arrow that points from x to y shows the direction of causality between these variables. The solid nodes indicate that x and y are observable variables. The hollow node indicates that the variable v_0 is unobserved. The absence of a link between x and v_0 in this graph indicate that these two variables are assumed to be independent.

Another important assumption in Equation (11) is the invariance of the target parameter β . This is an identifying assumption. The assumption implies that the causal link between x and y is stable. One could of course assume that β changes over time in some way. But this would imply a very different structural model.

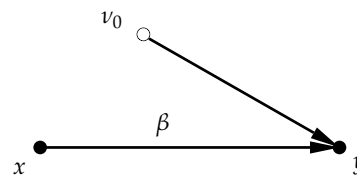


Figure 1. Graph of the structural relationship (11).

Until now nothing was said about estimating Equation (11). The question is whether the causal effect β can be estimated from observational data. When x is uncorrelated with v_0 then β is identified and consistently estimable from data on y and x . When x and v_0 are dependent, however, then we need additional information to consistently estimate β . This information may come from an instrumental variable.

4. Non-Existence Revisited: Instruments Do Exist

Let us now turn again to our simple model given by Equation (2) and let us assume that we can only observe y^* and x_1^* . We cannot observe x_2^* . For simplicity the intercept α_0 is set to zero. The time subscript t is superfluous and therefore dropped.

Figure 2 shows two possible structural models. In model (a) x_1^* affects y^* directly and indirectly via its effect on x_2^* . In model (b) the variable x_2^* is a confounding variable that jointly affects y^* and x_1^* . In both graphs z is an instrumental variable.

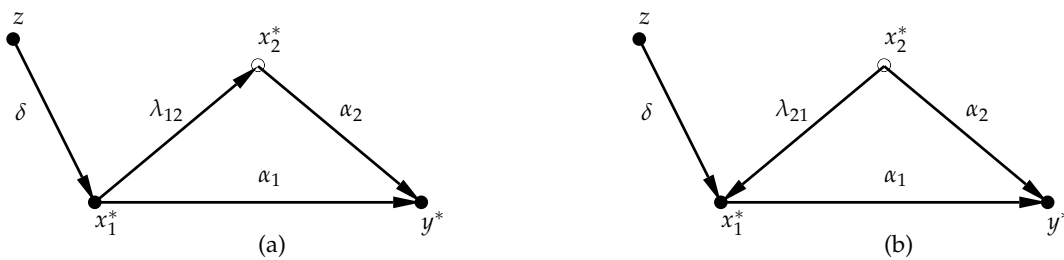


Figure 2. Two possible structural relationships.

The regression model that is actually estimated is

$$y^* = \beta x_1^* + \epsilon \tag{13}$$

where the error term $\epsilon = \alpha_2 x_2^*$. Thus, the model is misspecified because x_2^* is omitted. In both cases x_1^* is correlated with the error. Let us now compute the ordinary least squares (OLS) and IV estimates for both cases.

Case (a): Easy computations show that OLS yields

$$\beta_{(a)}^{OLS} = \frac{Cov(y^*, x_1^*)}{Var(x_1^*)} = \frac{(\alpha_1 + \alpha_2 \lambda_{12}) Var(x_1^*)}{Var(x_1^*)} = \alpha_1 + \alpha_2 \lambda_{12} \tag{14}$$

This is the total (i.e., direct + indirect) effect of x_1^* on y^* . The IV estimate for β is

$$\beta_{(a)}^{IV} = \frac{Cov(y^*, z)}{Cov(x_1^*, z)} = \frac{(\alpha_1 + \alpha_2 \lambda_{12}) \delta Var(z)}{\delta Var(z)} = \alpha_1 + \alpha_2 \lambda_{12} \tag{15}$$

and therefore the same as the OLS estimate. When the goal is to estimate only the direct effect of x_1^* on y^* no instrument for x_1^* works as argued in Swamy et al. (2015). If one is interested in the total effect no instrument is needed anyway.

Case (b): Now x_2^* is a confounding variable. As already mentioned, this model is misspecified and Swamy et al. (2015) would conclude that a valid instrument cannot exist. But in fact a valid instrument can exist. OLS won't work but IV estimation will.

OLS yields

$$\beta_{(b)}^{OLS} = \frac{\alpha_1 \lambda_{21}^2 \text{Var}(x_2^*) + \alpha_2 \lambda_{21} \text{Var}(x_2^*)}{\lambda_{21}^2 \text{Var}(x_2^*)} = \alpha_1 + \alpha_2 (1/\lambda_{21}) \quad (16)$$

where the second term is the well known omitted variable bias. The term $(1/\lambda_{21})$ is the coefficient from a regression of x_2^* on x_1^* . Note that this auxiliary regression has no causal content. The regression just measures the statistical association between x_2^* and x_1^* . Some simple algebra shows that IV estimation yields now

$$\beta_{(b)}^{IV} = \frac{\alpha_1 \delta \text{Var}(z)}{\delta \text{Var}(z)} = \alpha_1 \quad (17)$$

which is the structural parameter that we wanted to estimate.

Why can an instrument work in case (b) but not in case (a)? In case (a) the error term $\epsilon = \alpha_2 x_2^* = \alpha_2 \lambda_{12} x_1^*$ is caused by the included variable. The error term is thus indeed a function of x_1^* . No instrument for x_1^* will therefore work if one wants to estimate the direct effect of x_1^* on y^* .

Case (b) is quite different. In Figure 2b the error is *not* a function of the included explanatory variable. Equation (3) in Section 2 is thus not consistent with the underlying structural model. Varying x_1^* does not affect x_2^* . Instead the omitted variable x_2^* in the error term is a cause of the explanatory variable x_1^* . The instrument z is another cause of x_1^* that is independent of x_2^* . Thus the error and the instrument are uncorrelated. Moreover, the instrument affects the dependent variable y^* only via x_1^* . IV estimation works with a proper instrument.

Let us now turn to the second example in Section 2 where $y_t^* = \beta x_t^*$ and the explanatory variable $x_t = x_t^* + v_t$ is measured with error. If $y_t^* = \beta x_t^*$ is the true structural model then the causal effect of x_t^* on y_t^* is stable. The constant parameter β reflects this. Hence, we cannot simply transform this model into a time-varying coefficient model. Such a model states that the causal effect is unstable and changes over time. The transformed model is therefore inconsistent with the true structural model that we want to estimate. The transformed model has very different implications for the causal link between x_t^* and y_t^* . It is a different structural model.

To be consistent with the original structural model one should estimate the model $y_t^* = \beta x_t - \beta v_t$. Here the error is not a function of x_t and instruments can in principle be found. For example, any cause of x_t^* that is unrelated to the measurement error v_t and does not directly cause y_t^* would be a valid instrument for x_t .

5. Conclusions

The examples presented in this note demonstrate that instruments can exist. The arguments in Swamy et al. (2015) hold when the structural error is indeed a function of the included explanatory variables. But this is rarely the case in a structural model. For instance, omitted confounding variables are not functions of included variables. The three variable model (b) in Figure 2 provides a simple example. The model is misspecified, but a valid instrument exists since the omitted confounding variable is not a function of the included variable.

Furthermore, Swamy et al. (2015) assume that any model can be expressed as a time varying coefficient (TVC) model. The true model would then be a special case of this general model.

Of course, a constant parameter model is a special case of a TVC model. A true structural model with constant parameters cannot be turned into an equivalent TVC model, however. A structural model with constant parameters cannot at the same time be expressed as a model where the parameters vary over time. The later model has very different causal implications.

Conflicts of Interest: The author declares no conflict of interest.

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