

# Attenuation Bias, Measurement Error & Principal Component Analysis

Isaac Liu, Nicolás Martorell & Paul Opheim

May 23, 2021

## **Abstract**

Shorter version of the abstract (I would say 4-5 sentences in a single paragraph max) goes here

Many variables of interest in economics are not directly available as empirical data. Instead, economists often use other variables that are imperfect measurements of the true focus of their analysis. These available variables are known as *proxies* or “variables measured with error”, and, if they suffer from classical measurement error, their use causes *attenuation bias* when they are used as independent variables in econometric estimation. Traditionally, instrumental variables are used as a shock of exogeneity to get rid of this bias, but finding truly exogenous variables that satisfy the exclusion restriction is difficult, and so this method can often not be feasibly applied.

As an alternative to dealing with attenuation bias, we propose the use of Principal Component Analysis (PCA) over several variables measured with error. When there are multiple observed variables driven by a single “true” one, we propose to use PCA over these variables to extract the “true” variable. We then use this extracted value and use it in a standard OLS regression, thus providing a solution to attenuation bias that does not require the strong assumptions of instrumental variable analysis.

To show the properties and behaviour of our estimator on large samples under standard assumptions, we present a theoretical framework and a Monte-Carlo analysis. Additionally, we explore a basic empirical application to our method, by estimating the effect of economic development on life expectancy at birth. Since there is no consensus on how to measure economic development, we take a sample of different variables that may measure economic development with error (GDP per capita, GNI per capita, Household Income Per Capita, among others) over which we apply PCA to apply our identification strategy.

## Literature

Brief discussion of <https://warwick.ac.uk/fac/soc/economics/staff/knagasawa/PartialEffects.pdf>, as well as anything else important that comes up on Google Scholar

So it actually kind of seems like we are doing something unique, but it’s not clear that what we are doing is better than existing approaches to measurement error. Like averaging or instrumenting variables with each other.

Nagasawa 2020 theoretically develops the use of a proxy variable to deal with unobserved heterogeneity in line with the definitions in the measurement error literature. Uses an imperfect measurement of the error, the proxy problem is in nuisance parameters has a single proxy variable nonparametric approach mentioned as having limited usefulness due to curse of dimensionality and restrictive common support kernel first stage new partial effects method of proxy

Schennach 2016 focuses on nonclassical measurement error and nonlinear cases- classical cases ‘uninteresting’ because IV is very easy to use relaxing common assumptions origins and simple approaches validation data or repeated measurements proxies are related to the variable of interest but maybe nonlinearly... indicators may be instruments time series and panel repetition factor high and low dimensional relations multivariate linear regression- worse than attenuation bias... and nonlinear models lead IV to fail. repeated measurements- old lemma. nonparametric density estimation moments approach and polynomials, basis and transforms, etc. symmetric kernel smoothing factor models- x is informed by factor loadings plus noise- latent covariance identification. normalization is needed. SEE HECKMAN 2010A control variables- NO need for normalization with the matrix known construct vectors of repeated measurement and decompose nonlinear extension. iv more general and can be biased... polynomial parametric identification is difficult in this nonlinear

situation quantile regression possibility panel data- future values can give information.

factor analysis can handle measurement errors in multiple ways exploratory factor analysis can be used to explore dimensionality of measurement instrument (like prof mentioned i guess). I think this is like just the PCA step and looking at the Loadings confirmatory factor analysis-test if constructs influence responses some unique observation factors there is discussion of the variance of the true variable and the variance of the measurement error. i think there might be misuse of the term measurement errors/this is not clear overall not very related

latent variable models... are really basically mathematically the same as measurement error simple and standard me explanation reminder- standardized coefficient is very similar to correlation coefficient reminder that there is no impact of measurement error in y on unstandardized coefficient multiple regression- x1 coeff can indeed be biased, middle of p.2 lower statistical power no bias in the mean of x bad impact on the regression use Structural Equation Modelling to estimate path coefficients among latent variables need three or more measures to estimate a latent variable in a footnote it mentions a case with only two indicators not always me but sometimes uniqueness... really it's just items unaccounted for by the factor latent variance is independent.. classical assumption

Wegge measurement error regression models are factor analysis models, with the correct regressors being the factors. indeed. but no common stat method, because true factors not known- no clear coefficient linkage. instead, grouping dependent variables and latent factors uncorrelated with errors counting rules data grouping remedies- structural equations grouped regression model- ivs and weighted averages of ivs if there is very little credible info about the variance of measurement errors or the covariance of equation errors, factor loading restrictions are needed for identification this paper is about identification and IVs really

schoefield mixed effects structural equations model combine structural equations and item response theory attenuation, or nonclassical bias in any direction clear misestimation consequences solutions in IV or nonparametric bounds. here IRT error structure assumed by IV often violated bayesian structural framework and model this paper is focused on ME in the main regressor

heckman 2010 the abstract makes it very clear that this is a paper in a similar situation, except involving matching it is incomplete, however matching estimators can be harmed by mismeasured conditioning variables however, average treatment effects can be identified using factor models with quality proxies there often is not a need for normalization

\*perhaps note somewhere that government spending is less likely to have measurement error because it's an official statistic... though health spending in the denominator could have error... ow.

## Theoretical framework

Consider a model where the outcome is denoted by  $y_i$ . This outcome depends on a variable of interest denoted by  $t_i$  and a vector of covariates denoted by  $X_i = (x_{i,1}, x_{i,2}, \dots, x_{i,p})'$ . Additionally, consider a vector of variables  $X_i^* = (x_{i,1}^*, x_{i,2}^*, \dots, x_{i,p}^*)'$  that correspond to the covariates  $X_i$  but observed with measurement error, where  $x_{i,k}^* = x_{i,k} + \eta_{i,k}$  with  $\eta_{i,k} \sim iid(0, \sigma_{\eta_k}^2)$ ,  $E(x_{i,k}' \eta_{i,k}) = 0, \forall i$ ,  $E(x_{i,k}' \eta_{j,l}) = 0, \forall i \neq j$  and  $k \neq l$ , and  $E(\eta_{i,k}' \eta_{j,l}) = 0, \forall i \neq j$  and  $k \neq l$ . Therefore, each  $x_{i,k}^*$  suffers from classical measurement error. Note that  $E(x_{i,k}) = E(x_{i,k}^*) = \mu_{x_k}$  and that  $V(x_{i,k}) = \sigma_{x_k}^2$  while  $V(x_{i,k}^*) = \sigma_{x_k}^2 + \sigma_{\eta_k}^2 \geq \sigma_{x_k}^2$ .

## Data Generating Process

Assume that the outcome  $y_i$  is determined by the following Data Generation Process (DGP):

$$y_i = \gamma t_i + X_i' \beta + \epsilon_i \quad (1)$$

where  $\gamma$  is the parameter of the variable of interest  $t_i$ ,  $\beta = (\beta_1, \beta_2, \dots, \beta_p)'$  is the vector of the parameters of the covariates  $X_i$  including a constant and  $\epsilon_i \sim \text{iid}(0, \sigma_\epsilon^2)$ . Under this specification, the coefficients are such that:

$$\begin{pmatrix} \gamma \\ \beta \end{pmatrix} = \begin{pmatrix} \sigma_t^2 & \Sigma_{tX} \\ \Sigma_{Xt} & \Sigma_X \end{pmatrix}^{-1} \begin{pmatrix} \Sigma_{yt} \\ \Sigma_{yX} \end{pmatrix} \quad (2)$$

Suppose that the econometrician has access to  $t_i$  but, instead of  $X_i$  she observes  $X_i^*$ . Then, she specifies the following linear model

$$y_i = \gamma^* t_i + X_i^{*'} \beta^* + \zeta_i \quad (3)$$

the coefficients would be such that

$$\begin{pmatrix} \gamma^* \\ \beta^* \end{pmatrix} = \begin{pmatrix} \sigma_t^2 & \Sigma_{tX^*} \\ \Sigma_{X^*t} & \Sigma_{X^*} \end{pmatrix}^{-1} \begin{pmatrix} \Sigma_{yt} \\ \Sigma_{yX^*} \end{pmatrix} \quad (4)$$

$$= \begin{pmatrix} \sigma_t^2 & \Sigma_{tX} \\ \Sigma_{Xt} & \Sigma_X + \Sigma_\eta \end{pmatrix}^{-1} \begin{pmatrix} \sigma_t^2 & \Sigma_{tX} \\ \Sigma_{Xt} & \Sigma_X \end{pmatrix} \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (5)$$

To see the implications of the of this measurement error in the covariates, consider a simple case where the DGP depends only of the variable of interest and a covariate such that:

$$\begin{pmatrix} \gamma \\ \beta \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad (6)$$

and with  $\sigma_t^2 = \Sigma_X = \Sigma_\eta = 1$  while  $\Sigma_{Xt} = 0.6$ . Then

$$\begin{aligned} \begin{pmatrix} \gamma^* \\ \beta^* \end{pmatrix} &= \begin{pmatrix} 1 & 0.6 \\ 0.6 & 2 \end{pmatrix}^{-1} \begin{pmatrix} 1 & 0.6 \\ 0.6 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \\ \begin{pmatrix} \gamma^* \\ \beta^* \end{pmatrix} &= \begin{pmatrix} 1.37 \\ 0.39 \end{pmatrix} \end{aligned}$$

Clearly, both coefficients shows bias when the econometrician assumes a DGP with  $X_i^*$ : while there is attenuation bias on the coefficient of the covariate, the coefficient of the variable of interest is biased upward given that some of the effect of the covariates is “omitted” given this attenuation.

## Instrumental Variables Regression as a Bias-Correction Method

The classical solution for the measurement-error induced bias in econometrics has been the usage of instrumental variables. Suppose an instrument  $Z_i$  that satisfies the relevance condition  $E(Z_i' X_i) \neq 0$

and  $E(Z_i' t_i) \neq 0$ , and also the exclusion restriction  $E(Z_i' \epsilon_i) = E(Z_i' \zeta_i) = E(Z_i' \eta_{i,k}) = 0$ , for all  $i$  and  $k$ . Then premultiplying by  $Z_i$  we have

$$Z_i' y_i = Z_i' \gamma^* t_i + Z_i' X_i^{*'} \beta^* + Z_i' \zeta_i \quad (7)$$

and so

$$\begin{pmatrix} \gamma^{IV} \\ \beta^{IV} \end{pmatrix} = \begin{pmatrix} \Sigma_{Zt} & \Sigma_{ZX,Zt} \\ \Sigma_{Zt,ZX} & \Sigma_{ZX} + \Sigma_{Z\eta} \end{pmatrix}^{-1} \begin{pmatrix} \Sigma_{Zt} & \Sigma_{ZX,Zt} \\ \Sigma_{Zt,ZX} & \Sigma_{ZX} \end{pmatrix} \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (8)$$

$$= \begin{pmatrix} \Sigma_{Zt} & \Sigma_{ZX,Zt} \\ \Sigma_{Zt,ZX} & \Sigma_{ZX} \end{pmatrix}^{-1} \begin{pmatrix} \Sigma_{Zt} & \Sigma_{ZX,Zt} \\ \Sigma_{Zt,ZX} & \Sigma_{ZX} \end{pmatrix} \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (9)$$

$$\begin{pmatrix} \gamma^{IV} \\ \beta^{IV} \end{pmatrix} = \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (10)$$

However, finding a reliable source of exogeneity is difficult, and it is impossible to conclusively prove a suitable exclusion restriction. The use of IV as a bias-correction method is thus often unfeasible.

## Principal Component Regression as Bias-Correction Method

Alternatively, we propose an alternative bias-correction method for when there are several mismeasured variables for each covariate; that is, when we have more than one  $x_{i,k}^*$  for every  $x_{i,k}$ . Given that in all the mismeasured variables the underlying value is the real value, one could think of extracting the underlying true  $x_{i,k}$  through a linear combination of the different  $x_{i,k}^*$ . Then, we could treat all the  $x_{i,k}^*$  as variables that share components as follows:

$$h_j = \underset{h'h=1, h'h_1=0, \dots, h'h_{j-1}=0}{\operatorname{argmax}} \operatorname{var}[h'X_k^*] \quad (11)$$

where  $h_j$  is the eigenvector of  $\Sigma$  associated with the  $j^{th}$  ordered eigenvalue  $\lambda_j$  of  $\Sigma_{X_k^*}$ , and the principal components of  $X_k^*$  are  $U_j = h_j' X_k^*$ , where  $h_j$  is the eigenvector of  $\Sigma$  associated with the  $j^{th}$  ordered eigenvalue  $\lambda_j$  of  $\Sigma$ .

Under our assumptions, the vector of mismeasured values  $X_k^*$  of  $x_{i,k}$ , share only one principal component which is precisely  $x_{i,k}$ . Then, we only have one principal component,  $x_{i,k}$ , and so the  $x_{i,k}$  is such that

$$x_{i,k} = h_k' X_k^* \quad (12)$$

Finally, we could then retrieve the vector of true variables  $X_i$

$$X_i = H X_i^* \quad (13)$$

where  $H$  is a matrix such that

$$H = \begin{pmatrix} h_1 & 0 & 0 & \dots & 0 \\ 0 & h_2 & 0 & \dots & 0 \\ \vdots & \ddots & h_3 & \ddots & \vdots \\ 0 & \dots & \dots & \dots & h_p \end{pmatrix}$$

and  $h_k$  is the vector of eigenvalues for the variable  $x_{i,k}$ .  
Our new linear model then becomes

$$y_i = \gamma^{PCR} t_i + H X_i^{*'} \beta^{PCR} + \epsilon_i \quad (14)$$

where the coefficients are as follows

$$\begin{pmatrix} \gamma^{PCR} \\ \beta^{PCR} \end{pmatrix} = \begin{pmatrix} \sigma_t^2 & \Sigma_{t, HX^*} \\ \Sigma_{HX^*, t} & \Sigma_{HX^*} \end{pmatrix}^{-1} \begin{pmatrix} \Sigma_{yt} \\ \Sigma_{y, HX^*} \end{pmatrix} \quad (15)$$

$$= \begin{pmatrix} \sigma_t^2 & \Sigma_{t, HX^*} \\ \Sigma_{HX^*, t} & \Sigma_{HX^*} \end{pmatrix}^{-1} \begin{pmatrix} \sigma_t^2 & \Sigma_{tX} \\ \Sigma_{Xt} & \Sigma_X \end{pmatrix} \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (16)$$

$$= \begin{pmatrix} \gamma \\ \beta \end{pmatrix} \quad (17)$$

where the last equality comes from (13).

## Properties of the Estimator: Monte Carlo Simulations

We then complement our theoretical analysis by using Monte Carlo Simulation to analyze the effects of using Principal Components Regression as a method of bias correction. For these simulations, we assume that the true DGP for the data is:

$$y_i = \beta_1 x_i + \beta_2 z_i + u_i$$

... where  $x_i$  and  $z_i$  are single variables drawn from  $\mathcal{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}\right)$ , where  $\rho$  is some covariance between our main variable of interest ( $x_i$ ) and the covariate ( $z_i$ ). The  $u_i$  is drawn from a white noise distribution ( $\mathcal{N}(0, 1)$ ) that is uncorrelated with both  $x_i$  and  $z_i$ . We then assume (as with the theoretical analysis) that  $z_i$  is not directly observable and instead the researchers only have access to  $p$  many measurements  $z_{i,j}^*$  where  $z_{i,j}^* = z_i + \eta_j$  where  $\eta_j$  is drawn from a white noise distribution  $\mathcal{N}(\mathbf{0}, \Sigma)$  where  $\mathbf{0}$  is a  $p$ -vector and  $\Sigma$  is a diagonal  $p$  by  $p$  matrix with only 1s on the diagonal.

In our simulations, we assume default values of  $\rho = 0.5$ ,  $\beta_1 = \beta_2 = 1$ , and  $p = 5$ . We then vary each factor while holding the others fixed, and perform 1,000 simulations of the DGP followed by an OLS regression on either the PCA value from the  $p$  measurements of the true  $z_i$ , or on a single one of the measurements of  $z_i$ . For each simulation, we generate 100 observations of  $y_i, x_i$ , etc. Below are the results for different values of  $p$ :

We can see that using PCA to extract the latent covariate driving the mismeasured covariates noticeably outperforms using a single mismeasured covariate across several values of  $p$ . Both the average coefficient on  $\beta_1$  obtained when including the PCA output in the regression, and the mean absolute percentage error obtained on the 1,000 simulations are both much closer to the target values with the PCA-based regression than with the single measurement regression. Additionally, we can see that as  $p$  increases the estimated  $\beta_1^*$  coefficient in the PCA regression gets steadily closer to the true  $\beta_1$  value of 1. Appendix 1 contains charts that show that this increase in performance is also true for different values of  $\beta_1$  and  $\beta_2$ .

	<i>Number of p</i>			
	5	10	20	50
	<i>Coefficient on Main Variable</i>			
PCA	1.105 (0.121)	1.066 (0.122)	1.033 (0.119)	1.022 (0.117)
Single Measurement	1.280 (0.124)	1.283 (0.129)	1.282 (0.131)	1.292 (0.167)
	<i>Absolute Percentage Error</i>			
PCA	13.1% (9.3 ppts)	11.1% (8.3 ppts)	10.0% (7.3 ppts)	9.4% (7.3 ppts)
Single Measurement	28.2% (12.6 ppts)	28.5% (12.6 ppts)	28.3% (12.6 ppts)	29.3% (12.7 ppts)
Observations	1,000	1,000	1,000	1,000

However, there are certain circumstances where the PCA method does not lead to more accurate estimates of  $\beta_1^*$ . Let's now look at the simulation results for different values of  $\rho$  (the covariance between the main variable of interest  $x_i$  and the true latent covariate  $z_i$ ):

	<i><math>\rho</math> Value</i>				
	-1	-0.5	0	0.5	1
	<i>Coefficient on Main Variable</i>				
PCA	-0.006 (0.238)	0.900 (0.120)	0.996 (0.111)	1.105 (0.121)	2.009 (0.242)
Single Measurement	-0.002 (0.142)	0.720 (0.130)	0.998 (0.127)	1.280 (0.129)	2.003 (0.147)
	<i>Absolute Percentage Error</i>				
PCA	100.6% (23.8 ppts)	12.7% (9.1 ppts)	8.9% (6.6 ppts)	13.1% (9.3 ppts)	100.9% (24.2 ppts)
Single Measurement	100.2% (14.2 ppts)	28.1% (12.7 ppts)	10.2% (7.6 ppts)	28.2% (12.6 ppts)	100.3% (14.7 ppts)
Observations	1,000	1,000	1,000	1,000	

When the covariance between  $x_i$  and  $z_i$  is equal to 0,  $-1$ , or  $1$  then there is no notable improvement from using the PCA-extracted latent variable (and notice that since the variances of  $x_i$  and  $z_i$  are 1, this means that the covariance is equal to the correlation in these simulations). These simulation results suggest that so long as the correlation between  $x_i$  and  $z_i$  is not close to  $-1, 0$ , or  $1$ , there are noticeable performance gains from using PCA to extract the true covariate from a collection of observed variables that try to measure that true covariate.

However, the performance advantages that we see from using PCA could be driven by the benefit of having multiple measurements of our true covariate of interest, as opposed to any special advantages from PCA specifically. We test this question by comparing the estimated  $\beta_1^*$  in our PCA regressions with the estimated  $\beta_1^*$  when we include all  $p$  measurements as separate covariates in the regression, and the  $\beta_1^*$  obtained when the covariate is the mean of all  $p$  measurements of the true covariate. The results from these regressions for different values of  $p$  is shown below:

	<i>Number of <math>p</math></i>			
	5	10	20	50
<i>Coefficient on Main Variable</i>				
PCA	1.105 (0.121)	1.066 (0.122)	1.033 (0.119)	1.022 (0.117)
All Measurements	1.100 (0.124)	1.061 (0.129)	1.025 (0.131)	1.010 (0.167)
Average of Measurements	1.100 (0.121)	1.060 (0.122)	1.026 (0.119)	1.015 (0.117)
<i>Absolute Percentage Error</i>				
PCA	13.1% (9.3 ppts)	11.1% (8.3 ppts)	10.0% (7.3 ppts)	9.4% (7.3 ppts)
All Measurements	12.9% (9.3 ppts)	11.4% (8.5 ppts)	10.7% (7.9 ppts)	13.2% (10.2 ppts)
Average of Measurements	12.8% (9.2 ppts)	10.9% (8.2 ppts)	9.8% (7.2 ppts)	9.3% (7.2 ppts)
Observations	1,000	1,000	1,000	1,000

As one can see from these results (and results for different values of  $\beta_1$ ,  $\beta_2$ , and  $\rho$  in Appendix 2), there does not seem to be a noticeable difference between these three regression methods (across any values of  $p$ ,  $\beta_1$ ,  $\beta_2$ , and  $\rho$ ). Thus, our simulations suggest that there are major benefits to having multiple measurements of a latent covariate of interest, but that using PCA, taking the average of these measurements, and including all measurements as separate covariates seem to give similar benefits to the performance of the regression.

## Application: Government Share of Healthcare Spending and Life Expectancy

Explain economic importance/interesting-ness of the chosen application

Mini literature review on this question

We now examine the implications of the principal components estimator in an empirical setting with measurement error. One interesting question in public economics and public health is the comparison between publicly and privately funded healthcare systems and outcomes such as life expectancy. To measure the public or private nature of a healthcare system we use the continuous variable of the government's share of total health expenditure in a given country and year.



In this regression it is important to account for the role that a country's level of economic development. There is an extensive literature linking economic development to life expectancy. cite gapminder etc. Somewhat less obvious is the linkage between government provision of healthcare and development. In general, public goods provision in fields such as healthcare has been linked to prosperity (cite)

However, economic development as it is often conceptualized using GDP is liable to be measured with error. GDP measurements rely on surveys Informal economy and non-monetary but productive work Particularly in developing economies subject (nonclassical problem?) Hence, this setup, with a covariate in regression subject to measurement error, fits the situation described in the theory and simulations in the previous sections. In this case, we aim to to accurately reduce possible bias in the coefficient of the government's share of health spending by reducing bias in the coefficients for development indicators.

Our data on all measures comes from the World Bank, though we also make usage of OECD government health share data to fill in missing years, and average World Bank and OECD measurements when both are available. We standardize all variables by subtracting the mean and dividing by the standard deviation, linearly interpolate data between known observations, and remove country-years with missing values for any of the economic indicators.

In the left column in the table begin with an OLS regression. In the middle column we include the economic controls/covariates of GDP per capita (PPP), GNI per capita (PPP), Survey Mean Income/Consumption Per Capita, ILO GDP per person employed, and Net Foreign Assets Per Capita. In the rightmost column we instead use the first principal component combining these covariates.

	<i>Life Expectancy at Birth (Years)</i>				
	(1)	(2)	(3)	(4)	(5)
Govt. Share of Health Exp.	0.564*** (0.018)	0.365*** (0.019)	0.256*** (0.018)	0.382*** (0.019)	0.298*** (0.018)
Covariates	None	GDP PC	Econ Indicators	Mean	PCs
Observations	1,995	1,995	1,995	1,995	1,995
$R^2$	0.319	0.456	0.573	0.429	0.518
Adjusted $R^2$	0.318	0.455	0.569	0.428	0.517
Residual Std. Error	0.826	0.738	0.656	0.756	0.695
F Statistic	931.676***	833.433***	176.737***	747.175***	1069.682***

*Note:*

\*p<0.1; \*\*p<0.05; \*\*\*p<0.01  
All variables are standardized.

The results clearly demonstrate that the principal components method achieves a noticeably different coefficient on the government health share coefficient relative to multivariate OLS; in this case, a larger one.

The univariate omitted variable bias formula yields that  $\beta_{OLS} = \beta_{true} + \delta\gamma$  where  $\delta$  is the effect of GDP on the government share and  $\gamma$  is the effect of GDP on life expectancy, OLS naturally provides an overestimate. It is likely  $\delta, \gamma > 0$ , but mismeasurement leads to an attenuated  $\gamma$

NOTE- the math as worked out in the previous paragraph doesn't make sense.

## Conclusion

## Appendix 1

<i>True <math>\beta_1</math></i>				
	0.1	1	10	100
<i>Coefficient on Main Variable</i>				
PCA	0.207 (0.121)	1.105 (0.121)	10.104 (0.123)	100.117 (0.124)
Single Measurement	0.383 (0.128)	1.280 (0.129)	10.278 (0.131)	100.289 (0.133)
<i>Absolute Percentage Error</i>				
PCA	131.1% (95.1 ppts)	13.1% (9.3 ppts)	1.3% (0.9 ppts)	0.1% (0.1 ppts)
Single Measurement	283.6% (126.6 ppts)	28.2% (12.6 ppts)	2.8% (1.3 ppts)	0.3% (0.1 ppts)
Observations	1,000	1,000	1,000	1,000

<i>True <math>\beta_2</math></i>				
	0.1	1	10	100
<i>Coefficient on Main Variable</i>				
PCA	1.018 (0.115)	1.105 (0.121)	2.112 (0.477)	12.171 (4.555)
Single Measurement	1.034 (0.107)	1.280 (0.129)	3.865 (0.703)	29.751 (7.231)
<i>Absolute Percentage Error</i>				
PCA	9.4% (7.0 ppts)	13.1% (9.3 ppts)	111.6% (47.0 ppts)	1,119.6% (449.4 ppts)
Single Measurement	8.9% (6.8 ppts)	28.2% (12.6 ppts)	286.5% (70.3 ppts)	2,875.1% (723.1 ppts)
Observations	1,000	1,000	1,000	1,000

## Appendix 2

## Appendix 3

<i>Number of p</i>				
	5	10	20	50
<i>Coefficient on Main Variable</i>				
PCA	1.105 (0.121)	1.066 (0.122)	1.033 (0.119)	1.022 (0.117)
Single Measurement	1.280 (0.124)	1.283 (0.129)	1.282 (0.131)	1.292 (0.167)
<i>Absolute Percentage Error</i>				
PCA	13.1% (9.3 ppts)	11.1% (8.3 ppts)	10.0% (7.3 ppts)	9.4% (7.3 ppts)
Single Measurement	28.2% (12.6 ppts)	28.5% (12.6 ppts)	28.3% (12.6 ppts)	29.3% (12.7 ppts)
Observations	1,000	1,000	1,000	1,000

<i><math>\rho</math> Value</i>					
	-1	-0.5	0	0.5	1
<i>Coefficient on Main Variable</i>					
PCA	-0.006 (0.238)	0.900 (0.120)	0.996 (0.111)	1.105 (0.121)	2.009 (0.242)
Single Measurement	-0.002 (0.142)	0.720 (0.130)	0.998 (0.127)	1.280 (0.129)	2.003 (0.147)
<i>Absolute Percentage Error</i>					
PCA	100.6% (23.8 ppts)	12.7% (9.1 ppts)	8.9% (6.6 ppts)	13.1% (9.3 ppts)	100.9% (24.2 ppts)
Single Measurement	100.2% (14.2 ppts)	28.1% (12.7 ppts)	10.2% (7.6 ppts)	28.2% (12.6 ppts)	100.3% (14.7 ppts)
Observations	1,000	1,000	1,000	1,000	

<i>True <math>\beta_1</math></i>				
	0.1	1	10	100
<i>Coefficient on Main Variable</i>				
PCA	0.207 (0.121)	1.105 (0.121)	10.104 (0.123)	100.117 (0.124)
All Measurements	0.201 (0.123)	1.100 (0.124)	10.098 (0.126)	100.11 (0.127)
Average of Measurements	0.202 (0.121)	1.100 (0.121)	10.098 (0.123)	100.111 (0.124)
<i>Absolute Percentage Error</i>				
PCA	131.1% (95.1 ppts)	13.1% (9.3 ppts)	1.3% (0.9 ppts)	0.1% (0.1 ppts)
All Measurements	128.9% (93.6 ppts)	12.9% (9.3 ppts)	1.3% (1.0 ppts)	0.1% (0.1 ppts)
Average of Measurements	127.9% (93.1 ppts)	12.8% (9.2 ppts)	1.3% (0.9 ppts)	0.1% (0.1 ppts)
Observations	1,000	1,000	1,000	1,000

<i>True <math>\beta_2</math></i>				
	0.1	1	10	100
<i>Coefficient on Main Variable</i>				
PCA	1.018 (0.115)	1.105 (0.121)	2.112 (0.477)	12.171 (4.555)
All Measurements	1.02 (0.118)	1.100 (0.124)	2.067 (0.477)	11.664 (4.519)
Average of Measurements	1.017 (0.115)	1.100 (0.121)	2.061 (0.470)	11.625 (4.415)
<i>Absolute Percentage Error</i>				
PCA	9.4% (7.0 ppts)	13.1% (9.3 ppts)	111.6% (47.0 ppts)	1,119.6% (449.4 ppts)
All Measurements	9.7% (7.0 ppts)	12.9% (9.3 ppts)	107.1% (46.8 ppts)	1,069.3% (445.0 ppts)
Average of Measurements	9.4% (6.9 ppts)	12.8% (9.2 ppts)	106.5% (46.0 ppts)	1,065.2% (435.0 ppts)
Observations	1,000	1,000	1,000	1,000

	<i>Number of p</i>			
	5	10	20	50
	<i>Coefficient on Main Variable</i>			
PCA	1.105 (0.121)	1.066 (0.122)	1.033 (0.119)	1.022 (0.117)
All Measurements	1.100 (0.124)	1.061 (0.129)	1.025 (0.131)	1.010 (0.167)
Average of Measurements	1.100 (0.121)	1.060 (0.122)	1.026 (0.119)	1.015 (0.117)
	<i>Absolute Percentage Error</i>			
PCA	13.1% (9.3 ppts)	11.1% (8.3 ppts)	10.0% (7.3 ppts)	9.4% (7.3 ppts)
All Measurements	12.9% (9.3 ppts)	11.4% (8.5 ppts)	10.7% (7.9 ppts)	13.2% (10.2 ppts)
Average of Measurements	12.8% (9.2 ppts)	10.9% (8.2 ppts)	9.8% (7.2 ppts)	9.3% (7.2 ppts)
Observations	1,000	1,000	1,000	1,000

	<i><math>\rho</math> Value</i>				
	-1	-0.5	0	0.5	1
	<i>Coefficient on Main Variable</i>				
PCA	-0.006 (0.238)	0.900 (0.120)	0.996 (0.111)	1.105 (0.121)	2.009 (0.242)
All Measurements	-0.007 (0.249)	0.904 (0.122)	0.996 (0.112)	1.100 (0.124)	2.011 (0.249)
Average of Measurements	-0.005 (0.243)	0.905 (0.120)	0.996 (0.110)	1.100 (0.121)	2.010 (0.246)
	<i>Absolute Percentage Error</i>				
PCA	100.6% (23.8 ppts)	12.7% (9.1 ppts)	8.9% (6.6 ppts)	13.1% (9.3 ppts)	100.9% (24.2 ppts)
All Measurements	100.7% (24.9 ppts)	12.6% (9.0 ppts)	9.0% (6.7 ppts)	12.9% (9.3 ppts)	101.1% (24.9 ppts)
Average of Measurements	100.5% (24.3 ppts)	12.4% (8.9 ppts)	8.9% (6.6 ppts)	12.8% (9.2 ppts)	101.0% (24.6 ppts)
Observations	1,000	1,000	1,000	1,000	

Figure 1: Correlations Between Covariates and Life Expectancy

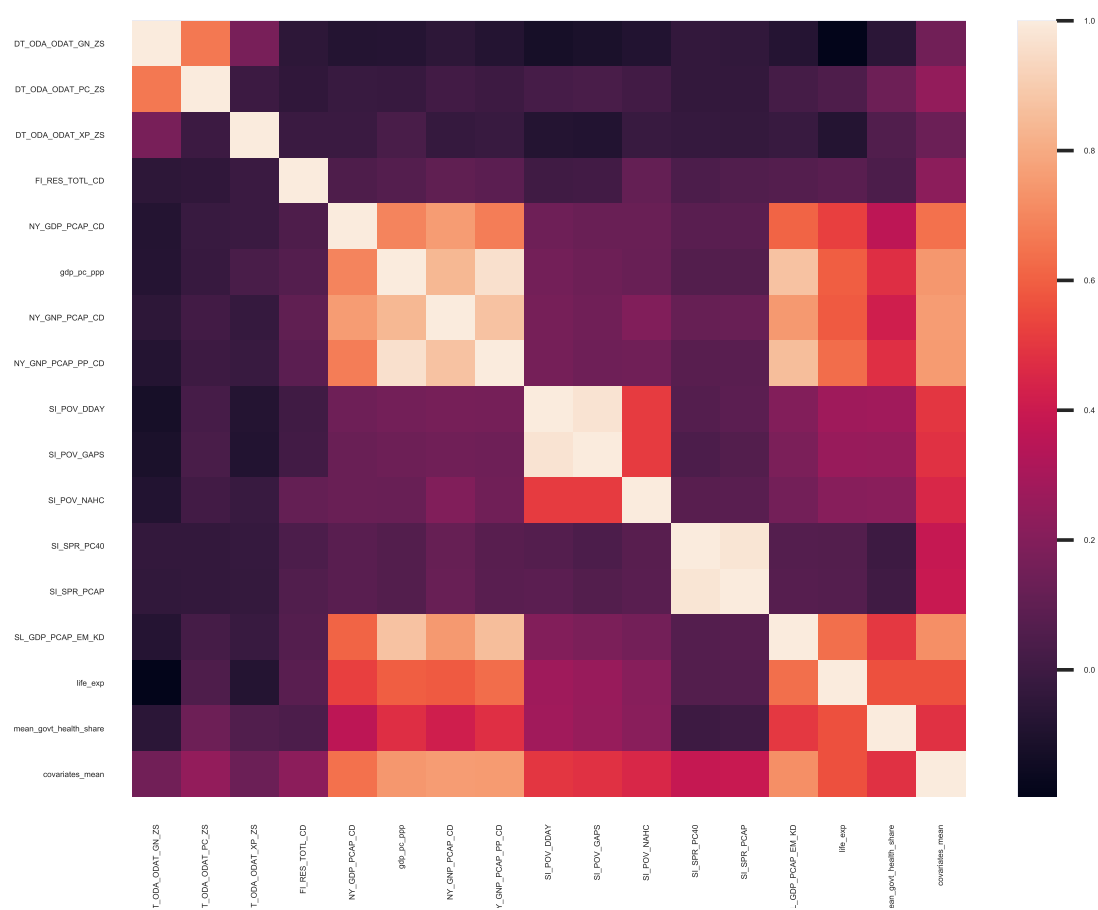


Figure 2: Economic Measures PCA Loadings

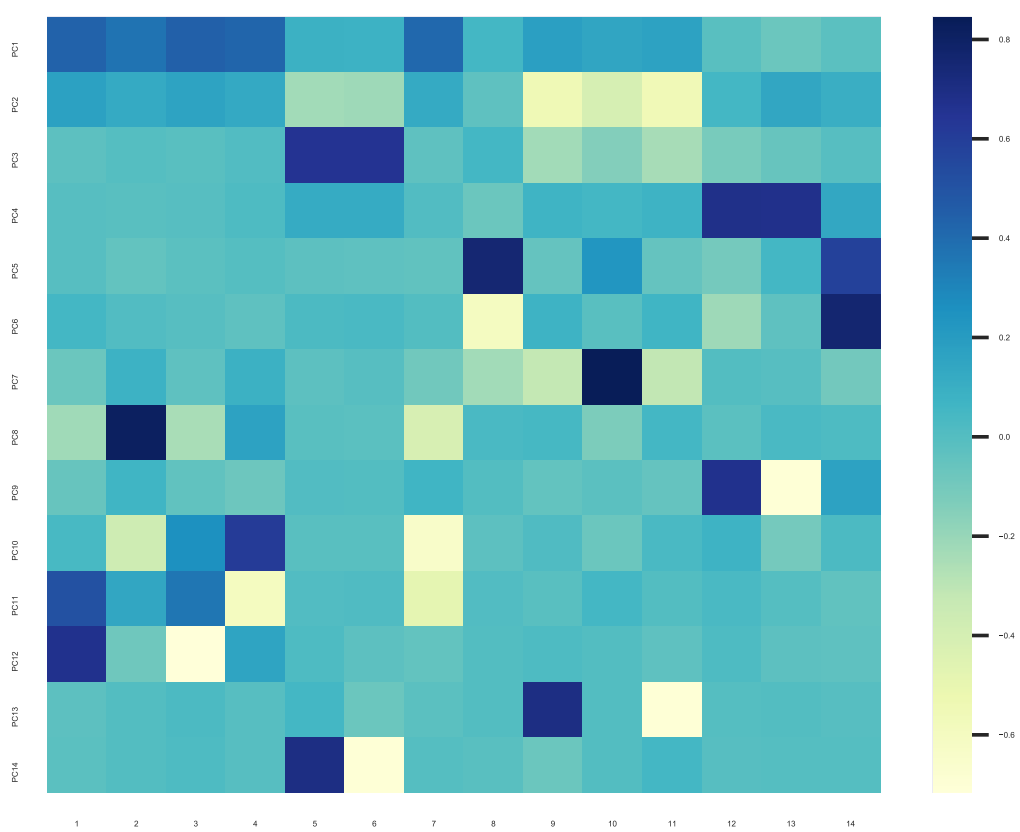




Figure 3: Economic Measures PCA Share of Variance Explained

