The Structural Equation Model (SEM)
The PLS approach
What is formative/reflective in PLS
Projection properties of the LV’s
Implication for evaluation and assessment

Formative and reflective modelling in PLS Path models
new insights and new questions

Jörg Betzin

WG SEM, February 26/27, 2009, Berlin
The Structural Equation Model (SEM)

The PLS approach

What is formative/reflective in PLS

Projection properties of the LV’s

Implication for evaluation and assessment
Outline

1. The Structural Equation Model (SEM)
2. The PLS approach
3. What is formative/reflective in PLS
4. Projection properties of the LV’s
5. Implication for evaluation and assessment

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The basic linear model

\[ \text{Model:} \]

- Formative (MES): \[ Y_m = \beta_m X_m + \epsilon_m \]
- Reflective (SES): \[ H = (H_1, \ldots, H_M) = \gamma_H + \epsilon_W \]

**LISREL**

- Formative and reflective modelling in PLS Path models
The basic linear model

\[ m = Y_m + \delta \]

\[ H = (1; \ldots; M) = \delta + \epsilon \]

SES
The basic linear model

\[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]
The basic linear model

MES

\[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]
The basic linear model

**MES** \[ Y_m = \eta_m \lambda_m + \theta_m \]

**SES** \[ H = (\eta_1, \ldots, \eta_M) = H \Gamma + E \]
The basic linear model

MES: $Y_m = \eta_m \lambda_m + \theta_m$

SES: $H = (\eta_1, \ldots, \eta_M) = H\Gamma + E$

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Formative and reflective modelling in PLS Path models
The basic linear model

\[
\begin{align*}
\text{MES: } & \quad Y_m = \eta_m \lambda_m + \theta_m \\
\text{SES: } & \quad H = (\eta_1, \ldots, \eta_M) = H_\Gamma + E
\end{align*}
\]
The basic linear model

MES: \[ Y_m = \eta_m \lambda_m + \theta_m \]

SES: \[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]

WES: \[ \hat{\eta}_m = Y_m \omega_m \]
The basic linear model

**MES**
\[ Y_m = \eta_m \lambda_m + \theta_m \]

**SES**
\[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]

**WES**
\[ \hat{\eta}_m = Y_m \omega_m \]
The basic linear model

**PLS**

- MES: \( \eta_m = Y_m \omega_m + \tau_m \)
- SES: \( Y_m = \eta_m \lambda_m + \theta_m \)
- WES: \( \hat{\eta}_m = Y_m \omega_m \)

**LISREL**

\( H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \)
The basic linear model

**MES**
\[ \eta_m = \gamma_m \omega_m + \tau_m \]  
(formative)

**SES**
\[ \gamma_m = \eta_m \lambda_m + \theta_m \]

**WES**
\[ \hat{\eta}_m = \hat{\gamma}_m \omega_m \]

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Formative and reflective modelling in PLS Path models
The basic linear model

**PLS**

**MES**
\[ \eta_m = Y_m \omega_m + \tau_m \]
\text{formative}

**SES**
\[ Y_m = \eta_m \lambda_m + \theta_m \]
\text{reflective}

**WES**
\[ \hat{\eta}_m = Y_m \omega_m \]

**LISREL**
\[ H = (\eta_1, \ldots, \eta_M) = HG + E \]
The basic linear model

**PLS**

- **MES**
  \[ \eta_m = Y_m \omega_m + \tau_m \]  
  formative

- **SES**
  \[ Y_m = \eta_m \lambda_m + \theta_m \]  
  reflective

- **WES**
  \[ \hat{\eta}_m = Y_m \omega_m \]  

**LISREL**

- **H**
  \[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]

---

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Formative and reflective modelling in PLS Path models
The basic linear model

\[ \eta_m = Y_m \omega_m + \tau_m \]  
formative

\[ Y_m = \eta_m \lambda_m + \theta_m \]  
reflective

\[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]  

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The basic linear model

\[ \eta_m = \gamma_m \omega_m + \tau_m \]  \quad \text{formative}

\[ \gamma_m = \eta_m \lambda_m + \theta_m \]  \quad \text{reflective}

\[ H = (\eta_1, \ldots, \eta_M) = \hat{H} \Gamma + E \]

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Formative and reflective modelling in PLS Path models
The common path model

The Structural Equation Model (SEM)
- The PLS approach
- What is formative/reflective in PLS
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Formative and reflective modelling in PLS Path models

Diagram: A common path model with latent variables $\eta_1$, $\eta_2$, $\eta_3$, and $\eta_4$ connected by paths $\gamma_{13}$, $\gamma_{23}$, $\gamma_{24}$, and $\gamma_{34}$. Manifest variables $y_{11}$, $y_{12}$, $y_{13}$, $y_{14}$, $y_{21}$, $y_{22}$, $y_{23}$, $y_{31}$, $y_{32}$, $y_{33}$, $y_{41}$, $y_{42}$, and $y_{43}$ are associated with the latent variables through error terms $\varepsilon_3$, $\varepsilon_4$, $\omega_{11}$, $\omega_{21}$, and $\omega_{34}$. Path coefficients $\theta_1$, $\theta_2$, $\theta_3$, and $\theta_4$ are indicated.
Estimation of PLS LV’s
Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ Y_m = \eta_m \]

Component approach

\[ \rho_m = \text{corr}(b_m; b_{m0}) \] (correlation)

OLS-Regression

\[ m = \rho_m m_0 + \omega_{mij} \]

Instrumental variable

Formative and reflective modelling in PLS Path models
Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ \hat{\eta}_m = Y_m \omega_m \] (Component approach)
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Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ \hat{\eta}(m) = Y(m)\omega(m) \]  (Component approach)

\[ \rho_{m,m'} = \text{corr}(\hat{\eta}_m, \hat{\eta}_{m'}) \]  (correlation)
The Structural Equation Model (SEM)

The PLS approach

What is formative/reflective in PLS

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Jörg’s imagination of the PLS circus

\[ \hat{\eta}(m) = Y(m)\omega(m) \] (Component approach)

\[ \rho_{m,m'} = \text{corr}(\hat{\eta}_m, \hat{\eta}_{m'}) \] (correlation)

\[ \eta^*_m = \sum_{m' \in C_m} \hat{\eta}_m \rho_{m,m'} \] (instrumental variable)
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Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ \hat{\eta}(m) = Y(m)\omega(m) \]  (Component approach)

\[ \rho_{m,m'} = \text{corr} (\hat{\eta}_m, \hat{\eta}_{m'}) \]  (correlation)

\[ \omega_m = f(Y_m, \eta_m^*) \]  (OLS-Regression)

\[ \eta^*_m = \sum_{m' \in c_m} \hat{\eta}_m \rho_{m,m'} \]  (instrumental variable)
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Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ \hat{\eta}(m) = \mathbf{Y}(m)\omega(m) \] (Outer approximation)

\[ \rho_{m,m'} = \text{corr}(\hat{\eta}_m, \hat{\eta}_{m'}) \] (correlation)

\[ \mathbf{Y}(m) \]

\[ \eta_{(m)} \]

\[ \rho_{m,m'} \]

\[ \omega_{(m)} \]

\[ \dot{\eta}_{(m)} \]

\[ \eta_{(1)} \]

\[ \eta_{(2)} \]

\[ \eta_{(M)} \]

\[ \omega_{(m)} \]

\[ \eta^*_m = \sum_{m' \in c_m} \hat{\eta}_m \rho_{m,m'} \] (inner approximation)

\[ \omega_m = f(\mathbf{Y}_m, \eta^*_m) \] (OLS-Regression)
Estimation of PLS LV’s

Jörg’s imagination of the PLS circus

\[ \hat{\eta}(m) = Y(m)\omega(m) \] (Outer approximation)

\[ \rho_{m,m'} = \text{corr} (\hat{\eta}_m, \hat{\eta}_{m'}) \] (correlation)

\[ \eta^* = \sum_{m' \in C_m} \hat{\eta}_m \rho_{m,m'} \] (inner approximation)

\[ \omega_m = f(Y_m, \eta^*_m) \] (OLS-Regression)
Estimation of PLS LV’s

The basic iteration algorithm


deinitions:

$S_0: \mathbf{b}_m = \mathbf{Y}_m$

$S_1: \mathbf{m}_l = f(\mathbf{b}_m; \mathbf{b}_l)$

$S_2: \mathbf{m} = \mathbf{P}_l \mathbf{C}_m \mathbf{b}_l \mathbf{m}_l$

$S_3: \mathbf{Y}_m = \mathbf{m}_0 + \mathbf{U}_m$

Mode R (reflective)

$S_4: \mathbf{b}_m = \mathbf{Y}_m^f \mathbf{m}_f$

goto $S_1$, until a Stop criteria is fulfilled.
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]
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Estimation of PLS LV's

The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]

S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]
S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]
S2: \[ \eta_m^* = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]
The Structural Equation Model (SEM)

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The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]

S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]

S2: \[ \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

S3:
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0: $\hat{\eta}_m = Y_m \omega_m f_m$

S1: $\rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l)$

S2: $\eta^{*}_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml}$

S3: $Y_m = \eta^{*}_m \omega'_m + U_m$
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]

S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]

S2: \[ \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

S3: \[ Y_m = \eta^*_m \omega'_m + U_m \] Mode R(A)
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0: \[ \hat{\eta}_m = Y_m \omega_m f_m \]

S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]

S2: \[ \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

S3: \[ Y_m = \eta^*_m \omega'_m + U_m \] Mode R(A)

\[ \eta^*_m = Y_m \omega_m + u_m \]
Estimation of PLS LV’s

The basic iteration algorithm (without iteration indices)

S0:
\[ \hat{\eta}_m = Y_m \omega_m f_m \]

S1:
\[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]

S2:
\[ \eta_m^* = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

S3:
\[ Y_m = \eta_m^* \omega'_m + U_m \quad \text{Mode R(A)} \]
\[ \eta_m^* = Y_m \omega_m + u_m \quad \text{Mode F(B)} \]
The basic iteration algorithm (without iteration indices)

S0: \( \hat{\eta}_m = Y_m \omega_m f_m \)

S1: \( \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \)

S2: \( \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \)

S3: \begin{align*}
Y_m &= \eta^*_m \omega'_m + U_m & \text{Mode R(A)} \\
\eta^*_m &= Y_m \omega_m + u_m & \text{Mode F(B)}
\end{align*}

S4: \( \hat{\eta}_m = Y_m \omega_m f_m \)
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S0: \[ \hat{\eta}_m = Y_m \omega_m \]

S1: \[ \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \]

S2: \[ \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

S3: \[ Y_m = \eta^*_m \omega'_m + U_m \quad \text{Mode R(A)} \]
\[ \eta^*_m = Y_m \omega_m + u_m \quad \text{Mode F(B)} \]

S4: \[ \hat{\eta}_m = Y_m \omega_m \]

goto S1, until a Stop criteria is fulfilled.
The basic iteration algorithm (without iteration indices)

S0: \( \hat{\eta}_m = Y_m \omega_m f_m \)

S1: \( \rho_{ml} = f (\hat{\eta}_m, \hat{\eta}_l) \)

S2: \( \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \)

S3: \( Y_m = \eta^*_m \omega'_m + U_m \)
\( \eta^*_m = Y_m \omega_m + u_m \)

Mode R(A)

Mode F(B)

goto S1, until a Stop criteria is fulfilled.
The basic iteration algorithm (without iteration indices)

\[ S_0: \quad \hat{\eta}_m = Y_m \omega_m f_m \]

\[ S_1: \quad \rho_{ml} = f (\hat{\eta}_m, \hat{\eta}_l) \]

\[ S_2: \quad \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \]

**S3:**
\[
\begin{align*}
Y_m &= \eta^*_m \omega'_m + U_m \\
\eta^*_m &= Y_m \omega_m + u_m
\end{align*}
\]

Mode R(A) (reflective)

Mode F(B)

\[ S_4: \quad \hat{\eta}_m = Y_m \omega_m f_m \]

goto S1, until a Stop criteria is fulfilled.
The basic iteration algorithm (without iteration indices)

**S0:** \( \hat{\eta}_m = Y_m \omega_m f_m \)

**S1:** \( \rho_{ml} = f(\hat{\eta}_m, \hat{\eta}_l) \)

**S2:** \( \eta^*_m = \sum_{l \in C_m} \hat{\eta}_l \rho_{ml} \)

**S3:** \[
    \begin{align*}
    Y_m &= \eta^*_m \omega'_m + U_m \\
    \eta^*_m &= Y_m \omega_m + u_m
    \end{align*}
\]
    Mode R(A) (reflective)
    Mode F(B) (formative)

**S4:** \( \hat{\eta}_m = Y_m \omega_m f_m \)

goto **S1**, until a Stop criteria is fulfilled.
The reflective way - Mode A
The **reflective way** - Mode A

S3: \[ Y_m = \eta_m^{*\langle t\rangle} \omega_{m\langle t+1\rangle} + U_m \]
The **reflective way** - Mode A

S3:

$Y_m = \eta^*_m(t) \omega'_{m(t+1)} + U_m$

solution of S3:

$\omega = Y'\eta^*(\eta'^*\eta^*)^{-1}$
The reflective way - Mode A

S3: \[ Y_m = \eta^*_m\omega'_m + U_m \]

solution of S3: \[ \omega = Y'\eta^*(\eta^*\eta^*)^{-1} \]

corresponding LV: \[ \eta = c \cdot \sum_{j=1}^{J} \omega_j y_j = c \cdot \sum_{j=1}^{J} \frac{\eta^*_j y_j}{\eta^*_j \eta^*} y_j. \]
The **reflective way** - Mode A

S3:

\[ Y_m = \eta^*_{m(t)} \omega'_{m(t+1)} + U_m \]

solution of S3:

\[ \omega = Y' \eta^* (\eta^* \eta^*)^{-1} \]

corresponding LV:

\[ \eta = c \cdot \sum_{j=1}^{J} \omega_j y_j = c \cdot \sum_{j=1}^{J} \frac{\eta^* y_j}{\eta^* \eta^*} y_j. \]

Projections of \( \eta^* \) on \( y_j \):

\[ P_{y_j} (\eta^*) = \frac{\eta^* y_j}{y_j' y_j} y_j \]
The reflective way - Mode A

S3:

\[ Y_m = \eta_{m(t)}^* \omega_{m(t+1)}' + U_m \]

solution of S3:

\[ \omega = Y' \eta^* (\eta^* \eta^*)^{-1} \]

corresponding LV:

\[ \eta = c \cdot \sum_{j=1}^{J} \omega_j y_j = c \cdot \sum_{j=1}^{J} \frac{\eta^* y_j}{\eta^* \eta^*} y_j. \]

Projections of \( \eta^* \) on \( y_j \)

\[ P_{y_j} (\eta^*) = \frac{\eta^* y_j}{y'_j y_j} y_j \]

\[ \eta = c \cdot \sum_{j=1}^{J} (\eta^* y_j) \cdot y_j = c \cdot \sum_{j=1}^{J} ||y_j||^2 P_{y_j} (\eta^*). \]
Relations between MV and LV

Mode A (reflective): $Y_m = \beta h + \epsilon_m = \beta h + \epsilon_m / P_i = 1 P_L(y_j)$

Mode B (formative): $m_h i = Y_m / P_L(Y_m)$
Relations between MV and LV

Mode A (reflective):

\[ Y_m = \eta^*_m \omega'_m + U_m \]
Mode A (reflective):

\[ Y_m = \eta^*_m \omega'_m + U_m \]

\[ \eta_m(t) \propto \sum_{j=1}^{J_m} \mathbb{P}_L(y_j) \left( \eta^*_m(t) \right) \]
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Relations between MV and LV

Mode A (reflective):

\[ Y_m = \eta^*_m \omega'_{m(t+1)} + U_m \]

\[ \eta_{m(t)} \propto \sum_{j=1}^{Jm} \mathbb{P}_L(y_j) \left( \eta^*_m \right) \]

Mode B (formative)

\[ \eta^*_m = Y_m \omega_{m(t+1)} + U_m \]
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Relations between MV and LV

Mode A (reflective):
\[ Y_m = \eta^*_m \omega'_m + u_m \]

\[ \eta_{m\langle t \rangle} \propto \sum_{j=1}^{J_m} \mathbb{P} \mathcal{L}(y_j) \left( \eta^*_m \langle t \rangle \right) \]

Mode B (formative)
\[ \eta^*_m = Y_m \omega_m \langle t+1 \rangle + u_m \]

\[ \eta_{m\langle t \rangle} \propto \mathbb{P} \mathcal{L}(Y_m) \left( \eta^*_m \langle t \rangle \right) \]
The formative way - Mode B

Formative = projection onto the space!
The **reflective** way - Mode A

**Reflective** = projection into the space!
Summary

Formative and reflective modelling in PLS Path models
Summary

Mode R(A) | Mode F(B)
---|---
influenced from the context | influenced from set of indicators
scale effect | no scale effect
covariances are meaningful | no meaning of covariances
MV should be correlated | MV may be uncorrelated
Summary

Mode R(A)  Mode F(B)

influenced from the context
Summary

Mode R(A)  
- influenced from the context

Mode F(B)  
- influenced from set of indicators
Summary

Mode R(A)  Mode F(B)

influenced from the context

influenced from set of indicators

scale effect
Summary

Mode R(A)  Mode F(B)

influenced from the context

influenced from set of indicators

scale effect  no scale effect
### Summary

<table>
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</tr>
</thead>
<tbody>
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Summary

Mode R(A)                      Mode F(B)

influenced from the context

influenced from set of indicators

scale effect                  no scale effect

covariances are meaningful    no meaning of covariances
Summary

Mode R(A)  
- influenced from the context
- influenced from set of indicators
- scale effect
- covariances are meaningful
- MV should be correlated

Mode F(B)  
- no scale effect
- no meaning of covariances

Formative and reflective modelling in PLS Path models
Summary

Mode R(A) Mode F(B)

- influenced from the context
- influenced from set of indicators
- scale effect
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Summary

Mode R(A)                  Mode F(B)

influenced from the context

influenced from set of indicators

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MV should be correlated     MV may be uncorrelated

maximizing:

variance explanation and correlations between LV’s

correlations between LV’s
Summary

Mode R(A) Mode F(B)

- influenced from the context
- influenced from set of indicators
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- no scale effect
- covariances are meaningful
- no meaning of covariances
- MV should be correlated
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LV’s:
- variance explaining canonical variables
- canonical variables
Discussion

- not a right picture of reflective and formative modelling (?)
- interpretation in an optimization context
- in reflective models we have to take balance with
  - high correlations of variables and
  - moderate correlations to allow model fitting
- ...

...
Discussion

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Formative and reflective modelling in PLS Path models
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- ...

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Formative and reflective modelling in PLS Path models
General remarks / questions
General remarks / questions

What should we do with the following problem:

\[ WES^b \]

\[ m = Y \]

\[ SES^H = (1; \ldots; M) = H + E \]

Why should we use PLS?

What happens in the finite mixture approach in PLS?

What makes the Moderator/Mediator approach in PLS?

...
General remarks / questions

What should we do with the following problem:

\[ \hat{\eta}_m = Y_m \omega_m \]
General remarks / questions

What should we do with the following problem:

WES: \( \hat{\eta}_m = Y_m \omega_m \)

SES: \( H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \)
General remarks / questions

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WES  \[ \hat{\eta}_m = Y_m \omega_m \]

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What makes the Moderator/Mediator approach in PLS?
The Structural Equation Model (SEM)
The PLS approach
What is formative/reflective in PLS
Projection properties of the LV’s
Implication for evaluation and assessment

General remarks / questions

What should we do with the following problem:

\[ \hat{\eta}_m = Y_m \omega_m \]
\[ H = (\eta_1, \ldots, \eta_M) = H\Gamma + E \]

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We need a basic methodological research in PLS!
Thank You for Your Attention !