Structural Benefit Transfer for the Valuation of Ecosystem Services

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**Motivation**

- Benefit transfer is the most widely-used method for environmental valuation (Richardson et al. 2015 *EcolEcon*).
- Approaches: unit vs. function transfer [(i) meta-analysis, (ii) structural benefit function] (e.g. Johnston et al. 2015).
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Meta-regressions are the dominant method, but have limitations. In particular, many applications lack a formal connection to consumer theory (Phaneuf/Requate 2017)⇒ Calls for more theory-driven approaches (e.g. Bateman et al. 2011 *ERE*).

Smith et al. (2002, 2006) pioneered a structural approach to benefit transfer that addresses these limitations⇒ Hardly applied in practical policy analysis, probably due to the required advanced micro-economic skills (Phaneuf/Requate 2017).
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⇒ This presentation’s contribution: Present ready-to-use, structural benefit transfer factors for the valuation of (local) public ecosystem services and natural capital (⇒ easy to implement, e.g. in a spreadsheet).
Outline

1. Pure public ecosystem services
   (a) Model
   (b) Transfer factors
   (c) Convergent validity

2. Local public ecosystem services

3. Natural capital

4. Summary and Conclusion
1. Pure public ecosystem services: model

- two regions $i$: $s$ (’study site’) and $p$ (’policy site’)
- infinitely many individuals
- two (composite) goods:
  - private consumption good $X_i^i$, traded on a market at exogenously given price $P_i^i$
  - pure public environmental good $E_i^i$, exogenously fixed at uniform level $E_i^i$
- all individuals have identical preferences over $(X_j^i, E_i^i)$, represented by utility function

$$U(X_j^i, E_i^i) = \left( \alpha X_j^i \frac{\theta-1}{\theta} + (1 - \alpha) E_i^i \right)^{\frac{\theta}{\theta-1}},$$

with constant elasticity of substitution $0 < \theta < +\infty$
- individuals differ in exogenously given income $Y_j^i$
1. Pure public ecosystem services: model

Individual $j$’s WTP for the environmental good at level $E^i$ in region $i$ depends on income $Y^i$ as follows (Ebert, 2003  [ERE]):

\[ \text{WTP}(Y^i_j) = \kappa^i Y^i_j \eta \quad \text{with} \quad \kappa^i = \frac{1 - \alpha}{\alpha} (P^i E^i)^{1-\eta}, \quad \eta = \frac{1}{\theta}. \]
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Income $Y^i$ is distributed log-normally, with mean $\mu_Y^i$ and coefficient of variation $CV_Y^i = \sigma_Y^i / \mu_Y^i$ of income

- reasonable empirical approximation (e.g. Pinkovskiy and Sala-i-Martin, 2009)
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\]

Income \( Y^i \) is distributed log-normally, with mean \( \mu_Y^i \) and coefficient of variation \( CV_Y^i = \sigma_Y^i / \mu_Y^i \) of income.

\( \Rightarrow \) In each region \( i \), societal mean \textbf{WTP} for a change in \( E^i \) is given by

\[
\overline{\text{WTP}}^i(\mu_Y^i, CV_Y^i) = \kappa^i \mu_Y^i^{\eta} \left( 1 + CV_Y^i 2 \right)^{\frac{\eta(\eta-1)}{2}}
\]
1. Pure public ecosystem services: transfer factors

**from:** study site \((\mu_Y^s, CV_Y^s, E_s^s, P_s^s, \ldots)\)  \hspace{1cm} **to:** policy site \((\mu_Y^p, CV_Y^p, P^p, E^p, \ldots)\)
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from: study site \((\mu_Y^s, CV_Y^s, E^s, P^s, \ldots)\) to: policy site \((\mu_Y^p, CV_Y^p, P^p, E^p, \ldots)\)

Transfer function: \(\overline{WTP}^p = \mathcal{T}(\ldots) \cdot \overline{WTP}^s\)

Corresponding disentangled transfer factors for identical preferences \((\alpha, \eta)\) given by:
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\[
\mathcal{T}_\mu(\mu_Y^p, \mu_Y^s) = \left( \frac{\mu_Y^p}{\mu_Y^s} \right)^\eta
\]

\[
\mathcal{T}_{CV}(CV_Y^p, CV_Y^s) = \left( \frac{1 + CV_Y^p^2}{1 + CV_Y^s^2} \right)^{\eta(\eta-1)/2}
\]

\[
\mathcal{T}_E(E^p, E^s) = \left( \frac{E^p}{E^s} \right)^{\eta-1}
\]

\[
\mathcal{T}_P(P^p, P^s) = \left( \frac{P^p}{P^s} \right)^{\eta-1}
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\mathcal{T}_\mu(\mu_Y^p, \mu_Y^s) = \left(\frac{\mu_Y^p}{\mu_Y^s}\right)^\eta \quad \text{Defra 2007, UBA 2012, OECD 2006}
\]

\[
\mathcal{T}_{CV}(CV_Y^p, CV_Y^s) = \left(\frac{1 + CV_Y^p}{1 + CV_Y^s}\right)^{\frac{\eta(\eta-1)}{2}} \quad \text{new}
\]

\[
\mathcal{T}_E(E^p, E^s) = \left(\frac{E^p}{E^s}\right)^{\eta-1} \quad \text{new}
\]

\[
\mathcal{T}_P(P^p, P^s) = \left(\frac{P^p}{P^s}\right)^{\eta-1} \quad \text{new}
\]
1. Pure public ecosystem services: convergent validity

We test these theory-driven transfer factors using a multi-country contingent valuation study (Ahtiainen et al. 2014 *JEEP*):

- WTP for the same environmental good (nutrient reduction in the Baltic Sea),
- with public good properties (‘open sea areas’),
- elicited with the same survey instrument (contingent valuation),
- across 9 countries with substantially different income distribution.
- Income elasticity for pooled dataset $\tilde{\eta} = 0.28$ (Barbier/Czajkowski/Hanley 2016 *ERE*).
1. Pure public ecosystem services: convergent validity (results)

- Structural benefit transfer reduces transfer errors

| Transfer errors $|TE|$ summary statistics (in percent) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | $|TE|_{unit}$     | $|TE|_{T_E}$     | $|TE|_{T_E,CV_Y}$ | $|TE|_{T_E,\mu_Y}$ | $|TE|_{T_E,\mu_Y,CV_Y}$ |
| mean             | 152.35           | 149.48           | 147.70           | 113.05           | 111.60            |
| median           | 72.88            | 71.86            | 71.82            | 67.21            | 66.04             |
| sd               | 215.57           | 211.56           | 207.26           | 149.24           | 145.96            |

$\Rightarrow$ Mean changes in transfer errors are different from a zero transfer error reduction for all 72 transfers (two-sided t-tests: $p < 0.01$).

$\Rightarrow$ A naive income inequality adjustment with $T'_{CV} = \frac{CV_Y^p}{CV_Y}$ increases transfer errors compared to unadjusted unit transfer and results in mean transfer errors of $|TE|_{T'_CV} = 209.90\%$. 
2. Local public ecosystem services

Many environmental goods vary spatially and local public goods. ⇒ Households differ in their endowment with the environmental good, which might be correlated with income, e.g. due to spatial neighbourhood sorting.

Model:

- There is a single environmental amenity, that households enjoy at different levels.
- The environmental good is distributed log-normally, relative environmental inequality is measured by the coefficient of variation \( \text{CV}_E = \frac{\mu_E}{\sigma_E} \).
- The correlation between income and the environmental local public good is measured with the Pearson correlation coefficient \( \rho \in (-1, 1) \).
2. Local public ecosystem services: transfer factors

**from:** study site \((\mu_Y^s, CV_Y^s, \mu_E^s, CV_E^s, \rho^s...\))  
**to:** policy site \((\mu_Y^p, CV_Y^p, \mu_E^p, CV_E^p, \rho^p...\))

**Transfer function:**
\[
\overline{WTP}^p = \mathcal{T}(...) \cdot \overline{WTP}^s
\]
\[\rho^s, \rho^p \in (-1, 1)\]
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Corresponding disentangled transfer factors for identical preferences \((\alpha, \eta)\) given by:

\[
\mathcal{T}_{\mu_Y}(\mu_Y^p, \mu_Y^s) = \left(\frac{\mu_Y^p}{\mu_Y^s}\right)^\eta
\]

\[
\mathcal{T}_{\mu_E}(\mu_E^p, \mu_E^s) = \left(\frac{\mu_E^p}{\mu_E^s}\right)^{1-\eta}
\]

\[
\mathcal{T}_{CV_Y, CV_E, \rho}(CV_Y^p, CV_E^p, \rho^p, CV_Y^s, CV_E^s, \rho^s) = \left(\frac{1 + CV_Y^p}{1 + CV_Y^s}\right)^{\frac{\eta(\eta-1)}{2}} \cdot \left(\frac{1 + CV_E^p}{1 + CV_E^s}\right)^{\frac{\eta(\eta-1)}{2}}
\]

\[
\cdot \exp \left[ \eta(1 - \eta) \left( \rho^p \sqrt{\ln (1 + CV_Y^p)^2 \ln (1 + CV_E^p)^2} - \rho^s \sqrt{\ln (1 + CV_Y^s)^2 \ln (1 + CV_E^s)^2} \right) \right]
\]

\[\rho^s, \rho^p \in (-1, 1)\]
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from: study site \((\mu_Y^s, CV_Y^s, \mu_E^s, CV_E^s, \rho^s...\)) to: policy site \((\mu_Y^p, CV_Y^p, \mu_E^p, CV_E^p, \rho^p...\))

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\[
\mathcal{T}_{CV_Y}(CV_Y^p, CV_Y^s) = \left(\frac{1 + CV_Y^p^2}{1 + CV_Y^s^2}\right)^{\frac{\eta(\eta-1)}{2}} \\
\mathcal{T}_{CV_E}(CV_E^p, CV_E^s) = \left(\frac{1 + CV_E^p^2}{1 + CV_E^s^2}\right)^{\frac{\eta(\eta-1)}{2}}
\]
3. Natural capital

“There is no way around benefit transfer in natural capital accounting” (Obst, 2018)
⇒ Preferences of households receiving future ecosystem service flows cannot be elicited

Model

- proportional mapping of natural capital to the ecosystem services it provides
  ⇒ suitable for non-use ecosystem services

- income rises exponentially at rate $g_Y$ and ecosystem services decline exp. at rate $g_E$.

- current income is log-normally distributed

- inverse relationship between the elasticity of substitution and the intertemporal elasticity of substitution with respect to the aggregate consumption bundle

- willingness-to-pay measured as a constant payment fraction for a marginal increase in the initial level of ecosystem services

⇒ we derive structural transfer factors for a *dynamic* benefit transfer
3. Natural capital: transfer factors

from: study s.($E^s_0, dE^s, \mu^s_{Y_0}, CV^s_{Y_0}, g^s_Y, g^s_E, \delta^s$) to: policy s.($E^p_0, dE^p, \mu^p_{Y_0}, CV^p_{Y_0}, g^p_Y, g^p_E, \delta^p$)

Transfer function: $\overline{WTP}^p = \mathcal{T}(\ldots) \cdot \overline{WTP}^s$
3. Natural capital: transfer factors

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3. Natural capital: transfer factors

From: study s. \((E_0^s, dE_s, \mu_{Y_0}^s, CV_{Y_0}^s, g_Y^s, g_E^s, \delta^s)\) to: policy s. \((E_0^p, dE_p, \mu_{Y_0}^p, CV_{Y_0}^p, g_Y^p, g_E^p, \delta^p)\)

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\]

\[
\mathcal{T}_{g_E}(g_E^p, g_E^s) = \frac{1 - \rho (1 + g_E^s)^{\eta-1}}{1 - \rho (1 + g_E^p)^{\eta-1}}, \quad \mathcal{T}_E(E_0^p, E_0^s) = \left(\frac{E_0^p}{E_0^s}\right)^{-\eta}, \quad \mathcal{T}_{dE}(dE_p, dE_s) = \frac{dE_p}{dE_s},
\]

\[
\mathcal{T}_{g_Y,\delta}(g_Y^p, \delta^p, g_Y^s, \delta^s) = \frac{1 - \rho (1 + g_Y^p)^{-\eta}}{1 - \rho (1 + g_Y^s)^{-\eta}} \cdot \frac{\sum_{t=0}^{\infty} \delta_p^t (1 + g_Y^p)^t}{\sum_{t=0}^{\infty} \delta_s^t (1 + g_Y^s)^t}
\]
4. Summary and conclusion

- We present recent advances in the economic theory of benefit transfer and provide novel, ready-to-use transfer factors for applications.

- We argue that structural benefit transfer is promising for government agencies, as
  1. grounding benefit transfers in micro-economic theory might increase the accuracy of estimated values,
  2. once developed, transfer factors are easy to apply and thereby meet the time and resource constraints that practitioners typically face.
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- Possible extensions: (i) environmental substitutes; (ii) household mobility; (iii) preference heterogeneity...

- While a convergent validity analysis suggests that structural benefit transfer reduces transfer errors, there is not yet enough evidence to assess (dis-)advantages of structural approaches vis-a-vis meta-analysis & unit transfer (cf. Phaneuf/Requate 2017, Johnston et al. 2018)