CORRESPONDENCE AND EFFICIENCY IN FORECASTS OF ECOSYSTEM SERVICE BENEFITS

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Introduction

As societies have increasingly realized and identified the benefits that humans experience due to the services of nature, the numerous trade-offs associated with land use changes and consequent ecosystem changes have become an important set of questions. Contributions to human well-being by wetland ecosystems are particularly important due to the role of wetlands in regulating water and due to the extensive conversions of wetlands to uplands, open water, and marine environments.

A result of the difficulty and expense associated with gathering and analyzing data for primary economic valuation studies of ecosystem services, the use of existing valuation data to predict ecosystem service values has gained increased attention. Benefit transfer (BT) is the most common term for the practice of making valuation predictions or forecasts with existing valuation data.

The notion of correspondence has been mentioned a number of times in the ecosystem service valuation literature. Correspondence is relevant to benefit transfers from study sites that have primary data based valuation estimates to policy sites lacking data. Recently in a Land Economics article, Rosenberger and Johnston (2009) theorized that, "Transfer error is often inversely related to the correspondence between a study site and a policy site among various dimensions". We suggest that correspondence relates not only to characteristics of the sites involved, but also to the local population and the valuation method employed.

In a meta-analysis of ecosystem service valuation studies, multiple primary valuation estimates are typically summarized with a statistical approach such as a multiple regression. Meta-analysis benefit transfer (MABT) is where such a statistical summary is used for forecasting ecosystem service values. Because meta-analysts interested in benefit transfer desire high correspondence, an initial census of the literature is often whittled down to a small subset that can be argued to not suffer from extensive transfer errors due to poor correspondence (e.g., Moeltner et al., 2007; Moeltner and Woodward 2009; Smith and Pattanayak 2002).

The alternative to subjectively resampling one's data to enhance correspondence is to estimate a broader model that uses a method that controls for variations in correspondence that might increase transfer error. A sequence of four meta-analyses of wetland ecosystem service valuation studies can be found in the literature that employs this broader modeling approach (Woodward and Wui 2001; Brander, et al., 2006; Ghermandi et al. 2010; and Brander et al. 2013).

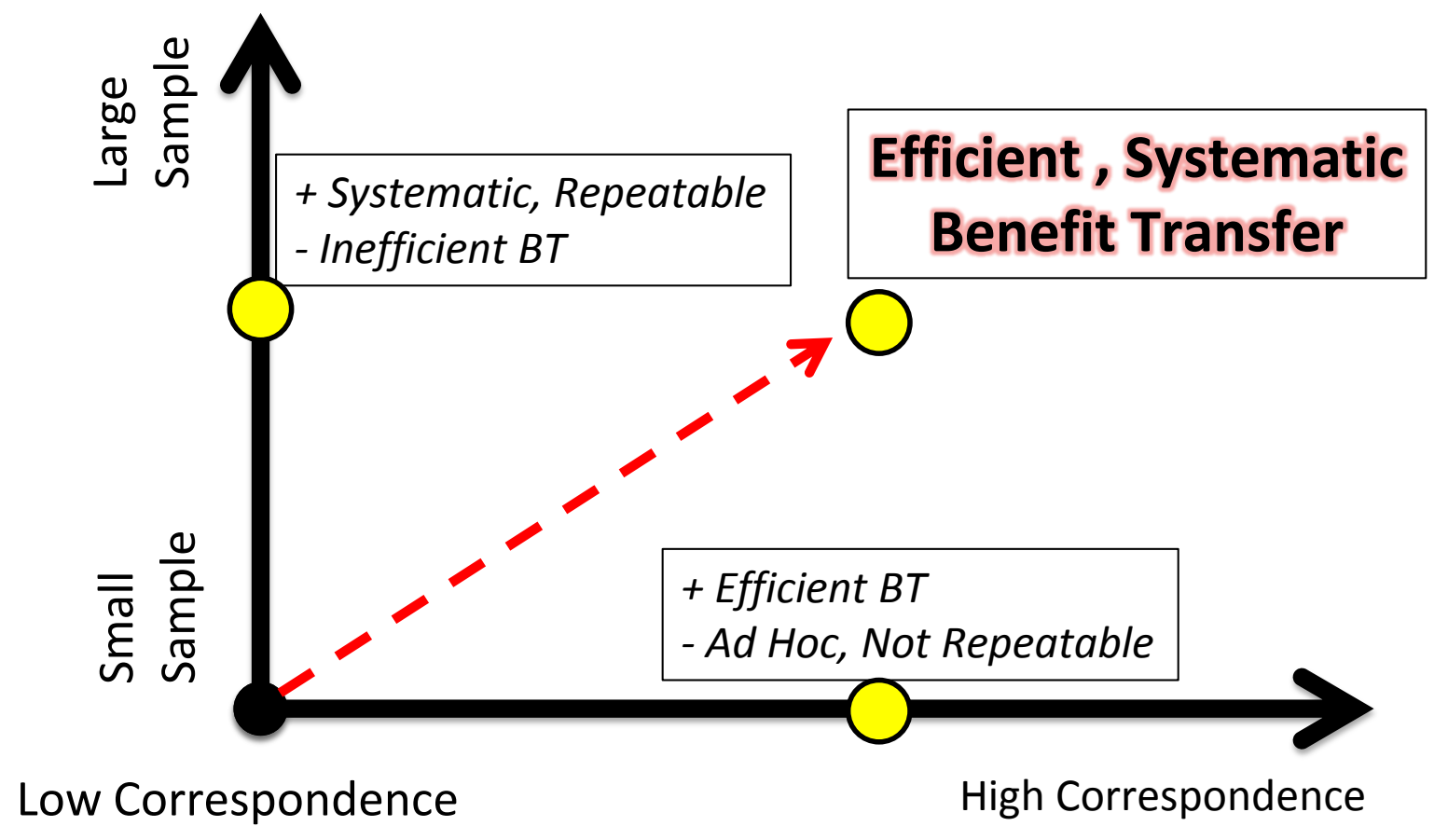

Figure 1 - conceptual relationship between transfer efficiency, correspondence, and a systematic approach

Figure 1 contains a diagram demonstrating the hypothesized benefits of an approach to MABT modeling that attains both efficiency and a systematic approach. Figure 1 can be read as if it represented preferences (a well-intentioned modeler), and the concave lines represent indifferences curves. We expect that movements away from the origin will lead to fewer losses of welfare due to the use of inaccurate BT estimates.

Objectives and Method Overview

In order to better understand the values associated with storm control/flood protection and water quality provisioning services provided by wetlands in US National Wildlife Refuges (NWR), we implement a novel meta-analysis method. Our objective is to develop an estimator that accommodates the desire for reducing the influence of observations that have poor correspondence with a hypothetical valuation study (e.g., a contingent valuation study of a population) of a policy site of interest. without a need for *ad hoc* analyst resampling.

The estimator, dubbed parametric locally weighted least squares (PLWLS), maintains the full sample size while penalizing the influence in an MABT equation of observations that have been identified as having poor correspondence via an estimated correspondence equation. The correspondence equation for one particular study site and one particular policy site takes as its arguments attributes of both sites. The effect of differences in these attributes are moderated by estimated correspondence parameters to yield a correspondence weight between zero and one that is used as a weight in the regression used to forecast a valuation result. Our interpretation of BT is that this result is a forecast of a valuation result from a hypothetical valuation study associated with the policy site. The use of the correspondence equation to specify regression weights leads to a potentially unique regression equation for each policy site despite a single unchanging sample.

We provide Figure 2, a preview of empirical results, as a tool for demonstrating the multivariate concept of correspondence in two dimensions for four NWRs. Each panel of Figure 2 contains a plot of our sample of stated preference and travel cost method studies. The distance in each dimension is the absolute difference in the variable on that dimension between the "centered" policy site (indicated with an open circle) and each study site in the sample; the four smaller dots represent the case study, policy site NWRs. Estimated correspondence parameters serve as a means for scaling the disparate measures of correspondence.

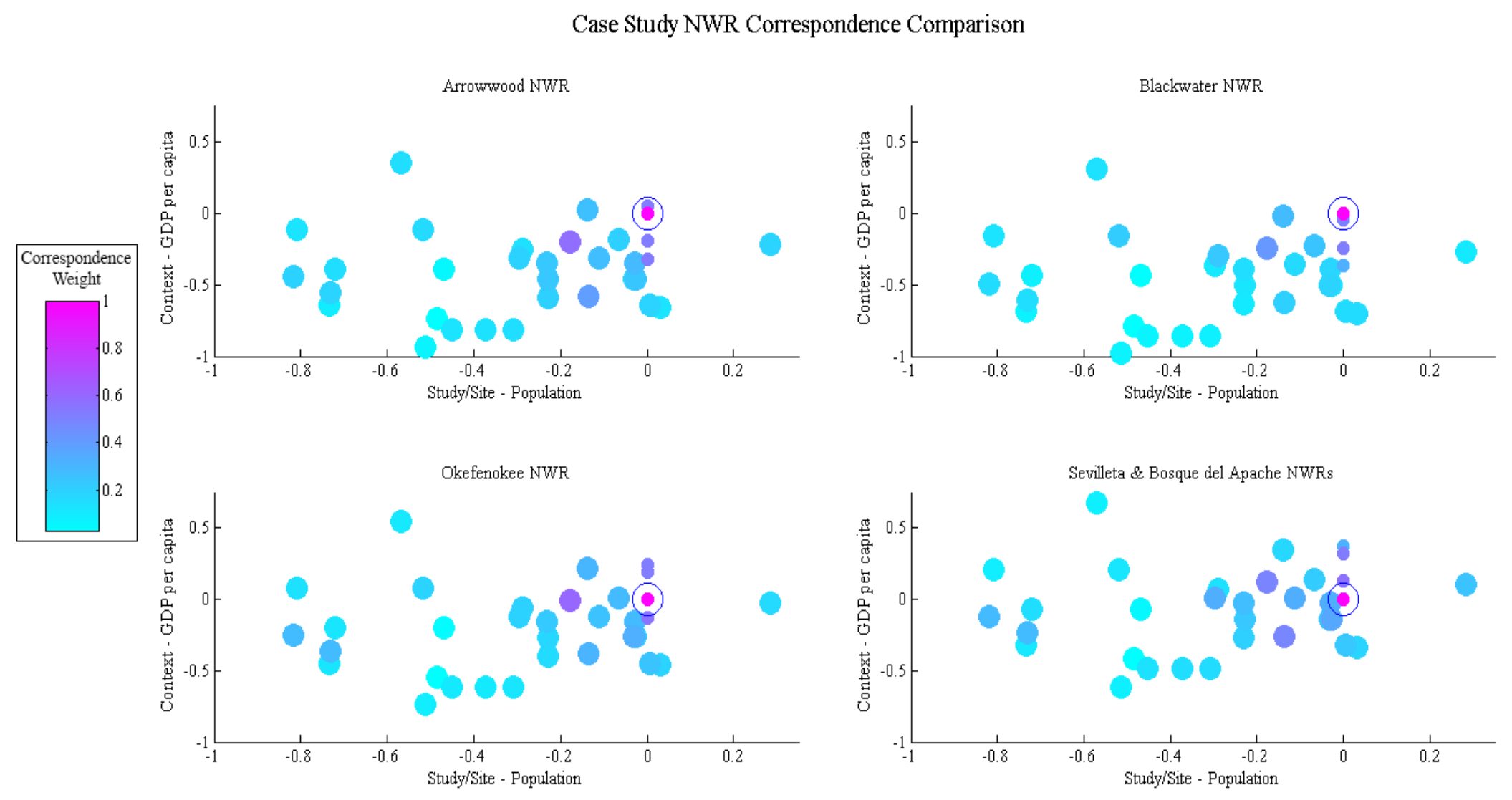

Figure 2- Four plots demonstrating estimated correspondence in two dimensions, GDP per capita and the count of the beneficiaries.

Interestingly in Figure 2, we are able to estimate correspondence distance with the correspondence equation for sites that lack primary valuation data (e.g., the four NWRs). The magenta color indicates greater correspondence while cyan indicates an observation that has relatively poor correspondence with the centered observation and which has been appropriately downweighted to enhance forecast efficiency for the centered policy site.

The alternative employed by earlier MA models either assumes that all points occur in the exact same space or that discarded observations are infinitely far from retained observations. Our approach relaxes this assumption in a systematic manner, offering more robust use of the available information in the sample.

While we lack analytical arguments that our estimator is without bias or that it is consistent, a jackknife simulation is employed to examine the performance of the estimator relative to a conventional OLS estimate that is typically unbiased due to assumed moments.

The Parametric Locally Weighted Least Squares Estimator

In the spirit of Loess regression, the PLWLS estimator employs an optimization routine that takes as its arguments a function of the n^2 errors from n centered regression models, where n is the sample size. Each of the n centered regression models is intended for a particular observation (the centered observation). The source of variation in these regression models is the regression weights that are obtained from the correspondence equation. Below, when we discuss an observation and the regression tailored to that observation, we refer to the observation as being *centered* and we refer to the regression equation for centered observation i as the i^{th} regression equation.

We index observations 1,…,n by both i and j. We define a set of h=1,…,H correspondence attributes for each observation, such that the i^{th} (or the j^{th}) observation has attributes $a_{1i},\ldots,a_{hi},\ldots,a_{Hi}$. that may also be used as regressors. For the i^{th} centered regression equation, we are interested in the ith centered correspondence equation for the jth observation in the sample, which we specify as an exponential function such that,

$$w_{ij} = e^{-\sum_{h=1}^{H}|a_{hi}-a_{hj}|\delta_h} = e^{-(|a_{1i}-a_{1j}|\delta_1+\cdots+|a_{Hi}-a_{Hj}|\delta_H)},$$

where w_{ij} is the weight applied to the jth observation in the centered regression equation for observation i. The non-negative (a restriction we impose during estimation) correspondence parameter, δ_h, scales the seemingly disparate correspondence attributes so they can be meaningfully summed. The exponential function ensures that no observation has a higher weight than the centered observation or a negative weight.

The correspondence equation will equal $1=e^{-0}$ when observation j corresponds perfectly to observation i, that is when all correspondence attributes are equal between those two observations. Our specification ensures the following relationship,

$$\frac{\partial \mathrm{w}_{\mathrm{ij}}}{\partial|\mathrm{a}_{\mathrm{hi}}-\mathrm{a}_{\mathrm{hj}}|} < 0,$$

or that decreased correspondence between observations decreases the information those observations provide about one another due to smaller generalized least squares (GLS) regression weights.

We specify an objective function for estimating the correspondence parameters, $\delta_1,\ldots,\delta_h$, which are the only global parameters or coefficients across all n centered regression equations. This objective function and the specification of the correspondence equation imply that information content between observations is symmetric. For example with the first 2 observations in the data set, the information that observation j=1 provides about observation i=2 in the equation for i=2 is equal to the information that j=2 provides about observation i=1 in the equation for i=1.

The objective function relies on the idea from GLS estimators that the square root of an observation's population error variance could be used to rescale that observation such that the resulting error variance is unity, leading to an estimated regression parameter with a lower variance than can be provided by Ordinary Least Squares (OLS).

The correspondence equation is then specified to be a predictor of the population error variance for observation j in the centered model for observation i. Accordingly, we fit the correspondence equation to the inverse of the sample variance as can be seen in the following equation,

$$\min_{\delta_1,\ldots,\delta_H}\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^2\,(\hat{e}_{ij}^2 - w_{ij}^2),$$

where $\hat{e}_{ij}^2$ is the sample residual for observation j from the GLS regression equation centered on observation i. The GLS weights for each of the j observations in the equation for centered observation i are determined by the correspondence equation, mentioned above. In the present equation, the weight outside the bracket serves as a 2SLS-style weight. We employ this additional weighting based on the idea that we want to preserve more information about the error in the variance prediction when correspondence between observations i and j is high.

Empirical Application

We construct a novel dataset of 26 primary valuation studies that yields 82 georeferenced observations of willingness to pay (WTP). Included valuation methodologies are, the Travel Cost Method, the Contingent Valuation Method, Choice Experiments, Damage Avoidance Methods, and Replacement Cost Methods. Because we are interested in domestic wetlands, all observations are for domestic sites, domestic populations, and all values are attributed by the authors entirely to wetland ecosystems.

We include such a wide variety of valuation studies so that we can examine the magnitude of the parameters estimated for correspondence attributes (i.e., a_{hi}) that indicate which method an observation employed. Ultimately, because no source of error in MABT models has been identified in the literature as dominating all other sources of error, we are agnostic about exclusions beyond the initial requirements for our sample (domestic wetland studies that can be georeferenced).

Results and Discussion

We find that the PLWLS estimator produces fairly comparable value estimates relative to the OLS estimator and an alternative specification of PLWLS that was also considered. Figure 3 contains a comparison of the jackknife simulated forecast efficiency for water quality provisioning and flood control/storm protection supported by wetlands in our four case study NWRs. The vertical axis is estimated WTP/1000people/1000acres and the horizontal axis contains paired observations of water quality then flood control/storm protection for Arrowwood, Blackwater, Okefenokee and Sevilleta/Bosque del Apache NWRs. The central panel demonstrates the approximate sampling variability of OLS. Because the single equation used in OLS models, one can see that each pair of simulated results exhibits the pattern that water quality provisioning is always expected to be more highly valued than flood control/storm protection.

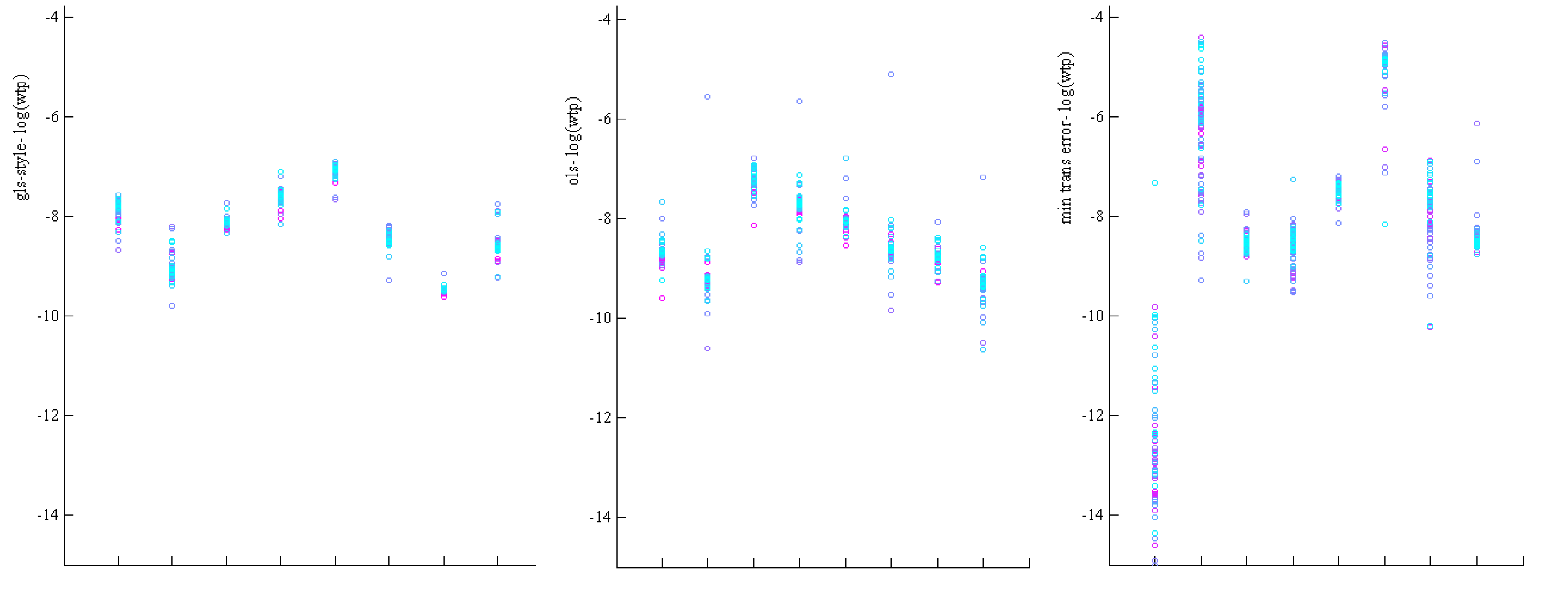

Figure 3 - a graphical comparison of the jackknife simulated forecast efficiency on out of sample observations estimated by PLWLS, OLS, and an alternate specification of PLWLS that minimizes transfer error as the objective function for choosing correspondence parameters, δ_h

The left panel of Figure 3 contains the results of the PLWLS estimator jackknife simulation. In contrast to the OLS model, efficiency is noticeably improved in all cases. Additionally, for the second and fourth pair of transfers, the relative magnitudes of the two services are reversed, demonstrating the flexibility of the PLWLS model.

The right panel of Figure 3 contains an alternative specification of the PLWLS estimator that retains all features less the objective function specified above. For the lef t panel, correspondence parameters were chosen to simply minimize squared transfer error, using one observation from each centered regression model. This intuitively appealing estimator does poorly in this sample. Diagnostics indicate the approach drastically overfits the in sample forecasts.

The PLWLS method appears promising based on our initial analysis. Yet lacking analytical variance formulas or statistics to test this model, some degree of skepticism over formal properties is reasonable. Our results, however indicate that forecast bias is small as is the error variance. Future research is needed to validate the PLWLS approach and develop useful post-estimation strategies for identifying under-studied ecosystem services and situations in which benefit transfers are expected to be especially accurate due to high correspondence in the sample.

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