Supplementary Materials for "Improved Generalized Raking Estimators to Address Dependent Covariate and Failure-Time Outcome Error"

Eric J. Oh*[1], Bryan E. Shepherd[2], Thomas Lumley[3], Pamela A. Shaw[1]

[1]University of Pennsylvania, Perelman School of Medicine
Department of Biostatistics, Epidemiology, and Informatics

[2]Vanderbilt University School of Medicine
Department of Biostatistics

[3]University of Auckland
Department of Statistics

Appendix A: Properties of the proposed raking estimators

Regularity conditions for asymptotic normality

The following conditions are required for $\sqrt{N}(\hat{\beta} - \beta_0)$ to be asymptotically normal, where $\hat{\beta}$ represent the proposed raking estimators. Note that here we only give intuitive statements of the conditions for simplicity; the fully technical statements of the conditions can be found in Saegusa and Wellner (2013).

1. The auxiliary variables A are not concentrated at 0 and has bounded support
2. g is a strictly increasing continuously differentiable function that is bounded above and below by constants
3. $\dot{g}$, the derivative of g, exists and is bounded below by 0 and above by a constant
4. $\mathrm{E}(A^{\otimes 2})$ is finite and positive definite
5. The solution to the raking estimating equation (2) is consistent for β_0
6. For β in a neighborhood of β_0, the partial score equations are contained in a Donsker class, which has an integrable envelope
7. The random map association with the raking estimation equation (2) has a continuously invertible Fréchet derivative

*Corresponding author: ericoh@pennmedicine.upenn.edu

Conditions (1) and (4) are satisfied for our estimators by our selection of the auxiliary variables as influence functions. Conditions (2) and (3) are satisfied for $g_i = \exp\left(\hat{\lambda}' A_i\right)$, see Deville and Särndal (1992) for details. Condition (5) is shown to be satisfied in the Supplementary Materials of Saegusa and Wellner (2013). Conditions (6) and (7) are shown to be satisfied for the Cox proportional hazards model in Van der Vaart (2000), Section 25.12.

Lack of bias from imputing auxiliary variables

Assume that the outcome model is correctly specified so that under the model,

$$\mathrm{E}\left[\psi(\beta_0)\right] = 0 \quad \text{and} \quad \mathrm{E}\left[\frac{R}{\pi}\psi(\beta_0)\right] = 0.$$

Consider a calibration procedure using the auxiliary variables $A(\alpha)$, where $\alpha = (\eta, \omega, \theta)$ are the parameters of the phase one working models, with estimators $\hat{\alpha}$ and limiting value $\alpha^{\star}$. For the purpose of demonstrating the lack of bias utilizing $\hat{\alpha}$ in calibration, it is sufficient to consider linear calibration which is known to be asymptotically equivalent to generalized raking.

Define the estimating equation

$$\bar{\psi}(\beta; \alpha, \gamma) = \sum_{i=1}^{N} \frac{R_i}{\pi_i} \left(\psi_i(\beta) - \gamma A_i(\alpha)\right) + \sum_{i=1}^{N} \left(1 - \frac{R_i}{\pi_i}\right) \gamma A_i(\alpha).$$

The linear calibration estimator is identical to the estimator obtained by solving

$$\bar{\psi}(\beta; \hat{\alpha}, \hat{\gamma}) = 0$$

where $\hat{\gamma}$ is obtained by the design-weighted regression of ψ_i on A_i. For any *fixed* α and γ, $\gamma A(\alpha)$ does not depend on phase two data, and it is easy to see that

$$\mathrm{E}\left[\bar{\psi}(\beta; \alpha, \gamma)\right] = 0$$

Now consider the linear calibration estimator with nuisance parameter estimates $\hat{\alpha}$ and $\hat{\gamma}$. Theorem 5.31 in Van der Vaart (2000) shows that the limiting distribution of $\hat{\beta}$ from solving such an estimating equation depends on $\hat{\alpha}$ and $\hat{\gamma}$ through the so-called 'drift term'. Specifically, the 'drift term' in this setting is $\sqrt{n}\mathrm{E}\left[\bar{\psi}(\beta; \hat{\alpha}, \hat{\gamma})\right]$ and we want to show it is $o_p(1)$. To do so, we can expand around α^* and γ^* to obtain:

$$\mathrm{E}\left[\bar{\psi}(\beta; \hat{\alpha}, \hat{\gamma})\right] = (\hat{\alpha} - \alpha^*) \frac{\partial}{\partial \alpha} E\left[\bar{\psi}(\beta_0; \alpha, \gamma^*)\right]\Big|_{\alpha = \alpha^\dagger} + (\hat{\gamma} - \gamma^*) \frac{\partial}{\partial \gamma} E\left[\bar{\psi}(\beta_0; \alpha^*, \gamma)\right]\Big|_{\gamma = \gamma^\dagger}$$

where $\alpha^\dagger$ is between α and $\hat{\alpha}$ and $\gamma^\dagger$ is between γ and $\hat{\gamma}$. The two derivatives are identically zero, so the drift term is zero. Thus, as long as $(\hat{\alpha}, \hat{\gamma}) \xrightarrow{p} (\alpha^*, \gamma^*)$ the limiting distribution of $\hat{\beta}$ depends only on (α^*, γ^*). For our proposed estimators, we fit standard regression models to obtain $\hat{\alpha}$ and $\hat{\gamma}$, which are consistent for $\alpha^\star$ and $\gamma^\star$ and therefore satisfy the conditions to yield no bias when used for calibration or raking.

Appendix B: Misclassification metrics for simulations

Table 1: The sensitivity (Sens), specificity (Spec), positive predictive value (PPV), and negative predictive value (NPV) for the event indicator generated for error scenarios 1, 2, and 3 in the simple random sampling simulations.

β_z	% Cens	β_x	Sens	Spec	PPV	NPV
$\log(0.5)$	50	log(1.5)	0.465	0.947	0.878	0.684
		log(3)	0.479	0.948	0.893	0.669
	75	log(1.5)	0.672	0.905	0.693	0.897
		log(3)	0.705	0.889	0.659	0.908
	90	log(1.5)	0.822	0.820	0.330	0.977
		log(3)	0.819	0.796	0.294	0.977

Table 2: Misclassification generation process for the sampling design comparison simulations. The sensitivity (Sens), specificity (Spec), positive predictive value (PPV), and negative predictive value (NPV) for the event indicator are presented.

β_z	% Cens	β_x	$\Delta^\star$	Sens	Spec	PPV	NPV
$\log(0.5)$	90	log(1.5)	Bernoulli$(\text{expit}(-1 + 4 * \Delta + 0.5 * X - 0.5 * U - 0.5 * Z))$	0.718	0.961	0.665	0.969
		log(3)	Bernoulli$(\text{expit}(-1.5 + 4 * \Delta + 0.5 * X - 0.5 * U - 0.5 * Z))$	0.715	0.970	0.710	0.971

Appendix C: Multiple Imputation Details

We explicate the multiple imputation implementation details below for imputation models without interaction terms. Define

- $V_i = (1_i, \Delta_i^\star, X_i^\star, U_i^\star, Z_i)'$
- $V_{-U,i} = (1_i, \Delta_i^\star, X_i^\star, Z_i)'$
- $V_{\Delta,i}^{(l)} = (1_i, \Delta_i^\star, \hat{X}_i^{(l-1)}, \hat{U}_i^{(l-1)}, Z_i)$
- $V_{X,i}^{(l)} = (1_i, \hat{\Delta}_i^{(l)}, X_i^\star, \hat{U}_i^{(l-1)}, Z_i)$
- $V_{U,i}^{(l)} = (1_i, \hat{\Delta}_i^{(l)}, \hat{X}_i^{(l)}, Z_i)$,

and let the lower case versions denote their observed counterparts. MI with interaction terms follows exactly the same except the terms defined above contain all possible interaction terms.

Multiple imputation for Δ only

1. Fit the logistic regression model $\text{logit}(P(\Delta_i = 1)|V_i = v_i) = v_i'\eta$ using the validation subset to obtain $\hat{\eta}$. This corresponds to characterizing a posterior distribution for η given the phase two data under a non-informative prior distribution.
2. For $m = 1, \ldots, M$ iterations:
3. Generate $\eta_\star^{(m)} \sim \text{N}(\hat{\eta}, \tau_{\Delta,\star}^2 (V'V)^{-1})$, where $\tau_{\Delta,\star}^2 \sim \hat{\tau}_\Delta^2 \frac{n-p_\eta}{\chi_{n-p_\eta}^2}$, $\hat{\tau}_\Delta^2$ is the squared sum of the working residuals from the logistic regression model, and p_η is the dimension of η.
4. Sample and impute $\hat{\Delta}_i^{(m)} \sim \text{Bernoulli}(\text{expit}(v_i'\eta_\star^{(m)}))$ for all phase one subjects.
5. Stop after M iterations

Fully conditional specification multiple imputation

1. Fit the logistic regression model $\text{logit}(P(\Delta_i = 1)|V_i = v_i) = v_i'\eta_V$ and linear regression models $\text{E}(X_i|V_i = v_i) = v_i'\theta_V$ and $\text{E}(W_i|V_{-U,i} = v_{-U,i}) = v_{-U,i}'\omega_V$ using the validation subset to obtain $\hat{\eta}_V$, $\hat{\theta}_V$, and $\hat{\omega}_V$.
2. For $m = 1, \ldots, M$ iterations:
3. Generate $\eta_\star^{(0)} \sim \text{N}(\hat{\eta}_V, \tau_{\Delta,V,\star}^2 (V'V)^{-1})$, $\theta_\star^{(0)} \sim \text{N}(\hat{\theta}_V, \tau_{X,V,\star}^2 (V'V)^{-1})$, and $\omega_\star^{(0)} \sim \text{N}(\hat{\omega}_V, \tau_{U,V,\star}^2 (V_{-U}'V_{-U})^{-1})$ where $\tau_{\Delta,V,\star}^2 \sim \hat{\tau}_{\Delta,V}^2 \frac{n-p_{\eta_V}}{\chi_{n-p_{\eta_V}}^2}$, $\tau_{X,V,\star}^2 \sim \hat{\tau}_{X,V}^2 \frac{n-p_{\theta_V}}{\chi_{n-p_{\theta_V}}^2}$, $\tau_{U,V,\star}^2 \sim \hat{\tau}_{U,V}^2 \frac{n-p_{\omega_V}}{\chi_{n-p_{\omega_V}}^2}$, $\hat{\tau}_{\Delta,V}^2$, $\hat{\tau}_{X,V}^2$, and $\hat{\tau}_{U,V}^2$ are the squared sum of working residuals/residual sum of squares from their respective regression models, and p_{η_V}, p_{θ_V}, and p_{ω_V} are the dimensions of their respective parameters.
4. Sample and impute $\hat{\Delta}_i^{(0)} \sim \text{Bernoulli}(\text{expit}(v_i'\eta_\star^{(0)}))$ and $\hat{X}_i^{(0)} \sim \text{N}(v_i'\theta_\star^{(0)}, \tau_{X,V,\star}^2)$ for all phase one subjects. Sample $\hat{W}_i^{(0)} \sim \text{N}(v_{-U,i}'\omega_\star^{(0)}, \tau_{U,V,\star}^2)$ and impute $\hat{U}_i^{(0)} = U_i^\star - \hat{W}_i^{(0)}$ for all phase one subjects.
5. For $l = 1, \ldots, L$ iterations:
6. Fit the logistic regression model $\text{logit}(P(\Delta_i = 1)|V_{\Delta,i}^{(l)} = v_{\Delta,i}^{(l)}) = v_{\Delta,i}'^{(l)}\eta$ on the validation subset to obtain $\hat{\eta}^{(l)}$.
7. Generate $\eta_\star^{(l)} \sim \text{N}(\hat{\eta}^{(l)}, \tau_{\Delta,\star}^2 (V_\Delta^{(l)'} V_\Delta^{(l)})^{-1})$ where $\tau_{\Delta,\star}^2 \sim \hat{\tau}_\Delta^2 \frac{n-p_\eta}{\chi_{n-p_\eta}^2}$.
8. Sample and impute $\hat{\Delta}_i^{(l)} \sim \text{Bernoulli}(\text{expit}(v_{\Delta,i}^{(l)'}\eta_\star^{(l)}))$ for all phase one subjects.
9. Fit the linear regression model $\text{E}(X_i|V_{X,i}^{(l)} = v_{X,i}^{(l)}) = v_{X,i}'^{(l)}\theta$ on the validation subset to obtain $\hat{\theta}^{(l)}$.
10. Generate $\theta_\star^{(l)} \sim \text{N}(\hat{\theta}^{(l)}, \tau_{X,\star}^2 (V_X^{(l)'} V_X^{(l)})^{-1})$ where $\tau_{X,\star}^2 \sim \hat{\tau}_X^2 \frac{n-p_\theta}{\chi_{n-p_\theta}^2}$.
11. Sample and impute $\hat{X}_i^{(l)} \sim \text{N}(v_{X,i}^{(l)'}\theta_\star^{(l)}, \tau_{X,\star}^2)$ for all phase one subjects.
12. Fit the linear regression model $\text{E}(W_i|V_{U,i}^{(l)} = v_{U,i}^{(l)}) = v_{U,i}'^{(l)}\omega$ on the validation subset to obtain $\hat{\omega}^{(l)}$.

13. Generate $\omega_{\star}^{(l)} \sim \mathrm{N}(\hat{\omega}^{(l)}, \tau_{U,\star}^2 (V_U^{(l)'} V_U^{(l)})^{-1})$ where $\tau_{U,\star}^2 \sim \hat{\tau}_U^2 \frac{n-p_\omega}{\chi_{n-p_\omega}^2}$.

14. Sample $\hat{W}_i^{(l)} \sim \mathrm{N}(v_{U,i}^{(l)'} \omega_{\star}^{(l)}, \tau_{U,\star}^2)$ and impute $\hat{U}_i^{(l)} = U_i^{\star} - \hat{W}_i^{(l)}$ for all phase one subjects.

15. Stop after L iterations

16. Stop after M iterations

Appendix D: Error scenario 2 - data imputation results

Table 3: Simulation results for estimating β_x using the data imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 2000$, $n = 400$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	0.077	0.040	2.322	0.039	0.002	0.950
			HT	0.863	0.092	1.000	0.088	0.008	0.937
			GRN	0.859	0.076	1.209	0.073	0.006	0.946
			GRMIS	1.032	0.064	1.433	0.064	0.004	0.948
			GRMIC	0.855	0.065	1.424	0.063	0.004	0.948
			GRFCSMIS	0.853	0.063	1.454	0.064	0.004	0.950
			GRFCSMIC	0.876	0.065	1.421	0.063	0.004	0.947
		log(3)	True	−0.008	0.042	2.366	0.044	0.002	0.951
			HT	0.449	0.099	1.000	0.098	0.010	0.942
			GRN	0.211	0.081	1.214	0.080	0.007	0.944
			GRMIS	0.018	0.071	1.393	0.070	0.005	0.944
			GRMIC	0.055	0.070	1.399	0.070	0.005	0.946
			GRFCSMIS	0.097	0.068	1.449	0.070	0.005	0.948
			GRFCSMIC	−0.039	0.070	1.416	0.069	0.005	0.944
	75	log(1.5)	True	−0.112	0.051	2.511	0.053	0.003	0.946
			HT	1.593	0.127	1.000	0.119	0.016	0.938
			GRN	0.405	0.099	1.282	0.097	0.010	0.946
			GRMIS	0.156	0.091	1.395	0.092	0.008	0.941
			GRMIC	−0.601	0.093	1.362	0.091	0.009	0.945
			GRFCSMIS	−0.270	0.092	1.388	0.092	0.008	0.942
			GRFCSMIC	−0.940	0.091	1.399	0.091	0.008	0.945
		log(3)	True	−0.018	0.058	2.372	0.059	0.003	0.948
			HT	0.564	0.138	1.000	0.132	0.019	0.938
			GRN	0.513	0.123	1.121	0.114	0.015	0.938
			GRMIS	0.130	0.111	1.240	0.104	0.012	0.946
			GRMIC	−0.183	0.110	1.246	0.103	0.012	0.941
			GRFCSMIS	−0.005	0.109	1.259	0.104	0.012	0.942
			GRFCSMIC	−0.311	0.110	1.255	0.103	0.012	0.939
	90	log(1.5)	True	0.014	0.084	2.232	0.083	0.007	0.947
			HT	1.893	0.188	1.000	0.184	0.036	0.944
			GRN	0.748	0.168	1.123	0.166	0.028	0.940
			GRMIS	0.393	0.161	1.171	0.159	0.026	0.929
			GRMIC	0.502	0.163	1.157	0.157	0.027	0.928
			GRFCSMIS	0.250	0.161	1.170	0.160	0.026	0.933
			GRFCSMIC	0.861	0.163	1.154	0.157	0.027	0.930
		log(3)	True	−0.047	0.089	2.287	0.089	0.008	0.950
			HT	1.421	0.202	1.000	0.199	0.041	0.944
			GRN	1.283	0.189	1.073	0.189	0.036	0.946
			GRMIS	0.120	0.177	1.143	0.176	0.031	0.944
			GRMIC	−0.272	0.176	1.153	0.174	0.031	0.938
			GRFCSMIS	0.852	0.178	1.138	0.177	0.032	0.945
			GRFCSMIC	−0.019	0.176	1.147	0.173	0.031	0.935

Appendix E: Large cohort simulation results

Table 4: Simulation results for estimating β_x using the data imputation approach for error scenario 1 (error only in event indicator) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	0.055	0.017	2.362	0.018	0.000	0.951
			HT	−0.027	0.041	1.000	0.039	0.002	0.958
			GRN	−0.171	0.032	1.270	0.032	0.001	0.946
			GRMIS	0.119	0.028	1.447	0.028	0.001	0.952
			GRMIC	0.171	0.028	1.440	0.028	0.001	0.950
		log(3)	True	−0.052	0.020	2.155	0.020	0.000	0.942
			HT	−0.061	0.044	1.000	0.044	0.002	0.946
			GRN	−0.099	0.039	1.143	0.036	0.001	0.945
			GRMIS	−0.081	0.031	1.413	0.031	0.001	0.946
			GRMIC	−0.133	0.031	1.429	0.031	0.001	0.948
	75	log(1.5)	True	−0.346	0.024	2.239	0.024	0.001	0.956
			HT	−0.295	0.053	1.000	0.053	0.003	0.944
			GRN	−0.239	0.043	1.235	0.043	0.002	0.943
			GRMIS	−0.307	0.042	1.263	0.041	0.002	0.954
			GRMIC	−0.111	0.043	1.224	0.041	0.002	0.949
		log(3)	True	−0.035	0.027	2.086	0.026	0.001	0.942
			HT	0.007	0.057	1.000	0.059	0.003	0.948
			GRN	−0.030	0.052	1.080	0.051	0.003	0.948
			GRMIS	−0.149	0.046	1.231	0.045	0.002	0.950
			GRMIC	−0.171	0.045	1.246	0.045	0.002	0.948
	90	log(1.5)	True	0.300	0.038	2.190	0.037	0.001	0.946
			HT	−0.279	0.084	1.000	0.083	0.007	0.950
			GRN	−0.150	0.076	1.101	0.074	0.006	0.951
			GRMIS	−0.125	0.073	1.148	0.071	0.005	0.946
			GRMIC	0.115	0.073	1.155	0.071	0.005	0.946
		log(3)	True	−0.108	0.040	2.205	0.040	0.002	0.948
			HT	−0.033	0.088	1.000	0.089	0.008	0.952
			GRN	−0.063	0.085	1.033	0.083	0.007	0.953
			GRMIS	−0.054	0.077	1.147	0.074	0.006	0.954
			GRMIC	−0.130	0.076	1.161	0.075	0.006	0.948

Table 5: Simulation results for estimating β_x using the data imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	−0.191	0.018	2.303	0.018	0.000	0.948
			HT	0.566	0.041	1.000	0.039	0.002	0.949
			GRN	−0.000	0.033	1.224	0.033	0.001	0.958
			GRMIS	−0.100	0.029	1.411	0.028	0.001	0.952
			GRMIC	0.058	0.028	1.434	0.028	0.001	0.950
			GRFCSMIS	−0.160	0.029	1.420	0.028	0.001	0.954
			GRFCSMIC	−0.095	0.029	1.409	0.028	0.001	0.953
		log(3)	True	0.007	0.020	2.217	0.020	0.000	0.954
			HT	0.141	0.045	1.000	0.044	0.002	0.958
			GRN	0.120	0.037	1.198	0.036	0.001	0.953
			GRMIS	−0.006	0.033	1.368	0.031	0.001	0.950
			GRMIC	0.003	0.032	1.374	0.031	0.001	0.954
			GRFCSMIS	−0.103	0.031	1.434	0.031	0.001	0.958
			GRFCSMIC	0.022	0.032	1.399	0.031	0.001	0.950
	75	log(1.5)	True	0.014	0.025	2.117	0.024	0.001	0.949
			HT	0.244	0.053	1.000	0.053	0.003	0.951
			GRN	0.107	0.044	1.217	0.043	0.002	0.951
			GRMIS	0.342	0.043	1.242	0.041	0.002	0.946
			GRMIC	0.264	0.042	1.264	0.041	0.002	0.944
			GRFCSMIS	0.311	0.043	1.222	0.041	0.002	0.948
			GRFCSMIC	0.286	0.042	1.248	0.041	0.002	0.944
		log(3)	True	−0.057	0.028	2.082	0.026	0.001	0.946
			HT	0.080	0.059	1.000	0.059	0.003	0.958
			GRN	−0.017	0.051	1.148	0.051	0.003	0.954
			GRMIS	−0.104	0.047	1.238	0.046	0.002	0.950
			GRMIC	−0.099	0.048	1.228	0.046	0.002	0.954
			GRFCSMIS	−0.134	0.046	1.260	0.046	0.002	0.954
			GRFCSMIC	−0.115	0.047	1.254	0.046	0.002	0.950
	90	log(1.5)	True	0.300	0.038	2.093	0.037	0.001	0.946
			HT	0.614	0.080	1.000	0.083	0.006	0.944
			GRN	0.517	0.076	1.061	0.075	0.006	0.947
			GRMIS	0.190	0.072	1.119	0.072	0.005	0.941
			GRMIC	0.411	0.072	1.123	0.071	0.005	0.942
			GRFCSMIS	0.540	0.070	1.145	0.072	0.005	0.942
			GRFCSMIC	0.643	0.070	1.147	0.071	0.005	0.942
		log(3)	True	−0.108	0.040	2.110	0.040	0.002	0.948
			HT	0.207	0.084	1.000	0.089	0.007	0.949
			GRN	0.115	0.079	1.064	0.084	0.006	0.942
			GRMIS	−0.150	0.077	1.091	0.078	0.006	0.948
			GRMIC	−0.225	0.076	1.116	0.078	0.006	0.948
			GRFCSMIS	−0.148	0.075	1.122	0.078	0.006	0.948
			GRFCSMIC	−0.291	0.075	1.127	0.078	0.006	0.946

Table 6: Simulation results for estimating β_x using the data imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	−0.191	0.018	2.306	0.018	0.000	0.948
			HT	−0.388	0.041	1.000	0.039	0.002	0.947
			GRN	−0.065	0.040	1.009	0.039	0.002	0.949
			GRMIS	−0.407	0.040	1.012	0.039	0.002	0.943
			GRMIC	−0.423	0.040	1.013	0.039	0.002	0.944
			GRFCSMIS	−0.194	0.032	1.253	0.033	0.001	0.953
			GRFCSMIC	−0.208	0.033	1.230	0.033	0.001	0.950
		log(3)	True	0.007	0.020	2.176	0.020	0.000	0.954
			HT	0.153	0.044	1.000	0.044	0.002	0.944
			GRN	0.183	0.044	1.000	0.044	0.002	0.938
			GRMIS	0.140	0.043	1.010	0.044	0.002	0.944
			GRMIC	0.131	0.043	1.011	0.044	0.002	0.945
			GRFCSMIS	0.084	0.039	1.108	0.039	0.002	0.946
			GRFCSMIC	0.082	0.040	1.095	0.039	0.002	0.944
	75	log(1.5)	True	0.014	0.025	2.070	0.024	0.001	0.949
			HT	−0.427	0.052	1.000	0.053	0.003	0.953
			GRN	−0.089	0.050	1.028	0.052	0.003	0.952
			GRMIS	−0.192	0.052	1.002	0.053	0.003	0.950
			GRMIC	−0.142	0.052	0.998	0.053	0.003	0.950
			GRFCSMIS	−0.198	0.046	1.122	0.046	0.002	0.946
			GRFCSMIC	0.056	0.046	1.128	0.046	0.002	0.942
		log(3)	True	−0.057	0.028	2.161	0.026	0.001	0.946
			HT	0.257	0.061	1.000	0.059	0.004	0.940
			GRN	0.304	0.061	1.002	0.058	0.004	0.939
			GRMIS	0.304	0.062	0.983	0.059	0.004	0.937
			GRMIC	0.279	0.062	0.984	0.059	0.004	0.938
			GRFCSMIS	0.247	0.055	1.099	0.054	0.003	0.947
			GRFCSMIC	0.162	0.054	1.115	0.054	0.003	0.942
	90	log(1.5)	True	0.300	0.038	2.135	0.037	0.001	0.946
			HT	−0.134	0.082	1.000	0.083	0.007	0.944
			GRN	0.403	0.081	1.010	0.080	0.007	0.949
			GRMIS	0.539	0.081	1.011	0.080	0.007	0.948
			GRMIC	0.397	0.081	1.011	0.080	0.007	0.949
			GRFCSMIS	0.114	0.078	1.049	0.077	0.006	0.948
			GRFCSMIC	0.325	0.077	1.066	0.076	0.006	0.947
		log(3)	True	−0.108	0.040	2.366	0.040	0.002	0.948
			HT	0.106	0.095	1.000	0.089	0.009	0.944
			GRN	0.368	0.091	1.045	0.087	0.008	0.946
			GRMIS	0.398	0.089	1.059	0.086	0.008	0.944
			GRMIC	0.384	0.091	1.036	0.086	0.008	0.944
			GRFCSMIS	0.205	0.088	1.079	0.085	0.008	0.943
			GRFCSMIC	0.161	0.090	1.051	0.085	0.008	0.946

Appendix F: Type 1 error results

Table 7: Type 1 error results for $\beta_x = 0$ using the data imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with $N = 10000$, $n = 2000$, and simple random sampling. The absolute bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error (MSE), and type 1 error are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	Bias	ESE	RE	ASE	MSE	Type 1 error
log(0.5)	50	0	True	0.001	0.044	2.193	0.043	0.002	0.052
			HT	0.002	0.097	1.000	0.096	0.009	0.052
			GRN	0.003	0.094	1.038	0.093	0.009	0.052
			GRMIS	0.006	0.094	1.038	0.093	0.009	0.052
			GRMIC	0.006	0.092	1.051	0.093	0.009	0.055
			GRFCSMIS	0.004	0.090	1.084	0.090	0.008	0.052
			GRFCSMIC	0.005	0.090	1.075	0.090	0.008	0.056
	75	0	True	−0.003	0.064	2.423	0.067	0.004	0.044
			HT	−0.004	0.156	1.000	0.146	0.024	0.057
			GRN	0.001	0.154	1.014	0.145	0.024	0.060
			GRMIS	−0.000	0.152	1.027	0.144	0.023	0.060
			GRMIC	−0.002	0.155	1.009	0.144	0.024	0.064
			GRFCSMIS	−0.004	0.154	1.015	0.144	0.024	0.057
			GRFCSMIC	−0.000	0.148	1.053	0.143	0.022	0.059
	90	0	True	0.001	0.113	2.250	0.111	0.013	0.057
			HT	0.002	0.254	1.000	0.238	0.065	0.066
			GRN	−0.001	0.254	0.999	0.237	0.065	0.069
			GRMIS	0.002	0.257	0.988	0.237	0.066	0.068
			GRMIC	−0.001	0.262	0.971	0.236	0.068	0.070
			GRFCSMIS	0.002	0.250	1.016	0.236	0.063	0.071
			GRFCSMIC	−0.005	0.244	1.042	0.234	0.059	0.072

Appendix G: Influence function imputation results

Table 8: Simulation results for estimating β_x using the IF imputation approach for error scenario 1 (error only in event indicator) with $N = 2000$, $n = 400$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	–0.036	0.040	2.289	0.039	0.002	0.956
			HT	1.229	0.091	1.000	0.088	0.008	0.949
			GRN	1.407	0.074	1.226	0.073	0.006	0.950
			GRMIS	–0.902	0.065	1.397	0.065	0.004	0.946
			GRMIC	–1.011	0.065	1.394	0.064	0.004	0.950
		log(3)	True	0.041	0.042	2.454	0.044	0.002	0.948
			HT	0.631	0.102	1.000	0.098	0.010	0.939
			GRN	0.282	0.083	1.236	0.080	0.007	0.942
			GRMIS	–0.226	0.075	1.365	0.071	0.006	0.952
			GRMIC	–0.228	0.074	1.384	0.071	0.005	0.954
	75	log(1.5)	True	0.119	0.052	2.266	0.053	0.003	0.954
			HT	0.781	0.117	1.000	0.119	0.014	0.952
			GRN	0.917	0.097	1.203	0.097	0.009	0.945
			GRMIS	–0.965	0.095	1.237	0.091	0.009	0.940
			GRMIC	–0.552	0.096	1.224	0.091	0.009	0.940
		log(3)	True	–0.013	0.061	2.241	0.059	0.004	0.949
			HT	1.035	0.136	1.000	0.131	0.019	0.938
			GRN	0.386	0.119	1.144	0.114	0.014	0.934
			GRMIS	–0.249	0.104	1.310	0.102	0.011	0.945
			GRMIC	–0.116	0.102	1.336	0.102	0.010	0.942
	90	log(1.5)	True	0.014	0.084	2.223	0.083	0.007	0.947
			HT	1.805	0.188	1.000	0.184	0.035	0.943
			GRN	0.309	0.167	1.122	0.166	0.028	0.940
			GRMIS	–2.531	0.161	1.166	0.155	0.026	0.942
			GRMIC	–1.376	0.162	1.160	0.153	0.026	0.933
		log(3)	True	–0.047	0.089	2.316	0.089	0.008	0.950
			HT	1.161	0.205	1.000	0.198	0.042	0.938
			GRN	0.945	0.194	1.055	0.187	0.038	0.941
			GRMIS	–1.027	0.183	1.122	0.165	0.034	0.931
			GRMIC	–0.949	0.179	1.147	0.163	0.032	0.924

Table 9: Simulation results for estimating β_x using the IF imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 2000$, $n = 400$, and simple random sampling. The % bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	−0.036	0.040	2.259	0.039	0.002	0.956
			HT	1.193	0.090	1.000	0.088	0.008	0.944
			GRN	0.369	0.074	1.214	0.073	0.005	0.940
			GRMIS	−0.669	0.068	1.321	0.064	0.005	0.950
			GRMIC	−1.174	0.067	1.327	0.064	0.005	0.947
			GRFCSMIS	−0.689	0.066	1.350	0.064	0.004	0.948
			GRFCSMIC	−1.045	0.067	1.338	0.064	0.004	0.948
		log(3)	True	0.041	0.042	2.388	0.044	0.002	0.948
			HT	0.159	0.099	1.000	0.098	0.010	0.942
			GRN	−0.058	0.084	1.187	0.081	0.007	0.940
			GRMIS	−0.339	0.074	1.335	0.072	0.006	0.942
			GRMIC	−0.339	0.075	1.332	0.072	0.006	0.942
			GRFCSMIS	−0.331	0.074	1.337	0.072	0.006	0.940
			GRFCSMIC	−0.418	0.072	1.371	0.071	0.005	0.941
	75	log(1.5)	True	0.119	0.052	2.277	0.053	0.003	0.954
			HT	0.106	0.118	1.000	0.119	0.014	0.946
			GRN	0.074	0.099	1.185	0.097	0.010	0.938
			GRMIS	−1.397	0.096	1.231	0.091	0.009	0.934
			GRMIC	−2.023	0.098	1.199	0.090	0.010	0.928
			GRFCSMIS	−1.135	0.096	1.231	0.091	0.009	0.938
			GRFCSMIC	−1.805	0.096	1.220	0.091	0.009	0.929
		log(3)	True	−0.013	0.061	2.183	0.059	0.004	0.949
			HT	0.359	0.133	1.000	0.132	0.018	0.946
			GRN	−0.089	0.115	1.151	0.114	0.013	0.939
			GRMIS	−1.048	0.102	1.305	0.103	0.011	0.944
			GRMIC	−1.143	0.104	1.280	0.103	0.011	0.948
			GRFCSMIS	−1.180	0.101	1.316	0.103	0.010	0.943
			GRFCSMIC	−1.161	0.102	1.308	0.102	0.010	0.944
	90	log(1.5)	True	0.014	0.084	2.241	0.083	0.007	0.947
			HT	−0.122	0.189	1.000	0.185	0.036	0.940
			GRN	−0.472	0.168	1.126	0.166	0.028	0.937
			GRMIS	−4.908	0.166	1.141	0.156	0.028	0.925
			GRMIC	−3.431	0.167	1.134	0.153	0.028	0.923
			GRFCSMIS	−4.209	0.162	1.166	0.154	0.027	0.931
			GRFCSMIC	−2.697	0.166	1.136	0.152	0.028	0.927
		log(3)	True	−0.047	0.089	2.308	0.089	0.008	0.950
			HT	1.213	0.204	1.000	0.200	0.042	0.946
			GRN	1.110	0.195	1.046	0.188	0.038	0.942
			GRMIS	−1.140	0.177	1.153	0.171	0.032	0.929
			GRMIC	−1.084	0.180	1.137	0.169	0.032	0.923
			GRFCSMIS	−1.557	0.172	1.187	0.169	0.030	0.928
			GRFCSMIC	−0.900	0.177	1.155	0.166	0.031	0.926

Table 10: Simulation results for estimating β_x using the IF imputation approach for error scenario 1 (error only in event indicator) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	0.055	0.017	2.362	0.018	0.000	0.951
			HT	–0.027	0.041	1.000	0.039	0.002	0.958
			GRN	–0.171	0.032	1.270	0.032	0.001	0.946
			GRMIS	0.100	0.030	1.374	0.029	0.001	0.949
			GRMIC	0.089	0.029	1.387	0.029	0.001	0.950
		log(3)	True	–0.052	0.020	2.155	0.020	0.000	0.942
			HT	–0.061	0.044	1.000	0.044	0.002	0.946
			GRN	–0.099	0.039	1.143	0.036	0.001	0.945
			GRMIS	–0.091	0.033	1.353	0.032	0.001	0.952
			GRMIC	–0.067	0.033	1.338	0.032	0.001	0.950
	75	log(1.5)	True	–0.346	0.024	2.239	0.024	0.001	0.956
			HT	–0.295	0.053	1.000	0.053	0.003	0.944
			GRN	–0.239	0.043	1.235	0.043	0.002	0.943
			GRMIS	–0.325	0.044	1.213	0.042	0.002	0.950
			GRMIC	–0.468	0.044	1.205	0.042	0.002	0.948
		log(3)	True	–0.035	0.027	2.086	0.026	0.001	0.942
			HT	0.007	0.057	1.000	0.059	0.003	0.948
			GRN	–0.030	0.052	1.080	0.051	0.003	0.948
			GRMIS	–0.288	0.047	1.198	0.046	0.002	0.948
			GRMIC	–0.237	0.047	1.212	0.046	0.002	0.948
	90	log(1.5)	True	0.300	0.038	2.190	0.037	0.001	0.946
			HT	–0.279	0.084	1.000	0.083	0.007	0.950
			GRN	–0.150	0.076	1.101	0.074	0.006	0.951
			GRMIS	–0.382	0.076	1.108	0.073	0.006	0.947
			GRMIC	–0.479	0.075	1.124	0.072	0.006	0.946
		log(3)	True	–0.108	0.040	2.205	0.040	0.002	0.948
			HT	–0.033	0.088	1.000	0.089	0.008	0.952
			GRN	–0.063	0.085	1.033	0.083	0.007	0.953
			GRMIS	–0.181	0.079	1.120	0.075	0.006	0.947
			GRMIC	–0.137	0.078	1.128	0.075	0.006	0.948

Table 11: Simulation results for estimating β_x using the IF imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	0.055	0.017	2.348	0.018	0.000	0.951
			HT	0.440	0.041	1.000	0.039	0.002	0.953
			GRN	−0.059	0.034	1.204	0.033	0.001	0.955
			GRMIS	0.002	0.030	1.344	0.029	0.001	0.953
			GRMIC	0.040	0.031	1.325	0.029	0.001	0.951
			GRFCSMIS	0.029	0.031	1.320	0.029	0.001	0.955
			GRFCSMIC	0.001	0.031	1.320	0.029	0.001	0.956
		log(3)	True	−0.052	0.020	2.161	0.020	0.000	0.942
			HT	0.062	0.044	1.000	0.044	0.002	0.951
			GRN	−0.140	0.036	1.247	0.036	0.001	0.950
			GRMIS	−0.171	0.032	1.391	0.033	0.001	0.950
			GRMIC	−0.208	0.032	1.385	0.033	0.001	0.950
			GRFCSMIS	−0.268	0.032	1.391	0.032	0.001	0.945
			GRFCSMIC	−0.244	0.032	1.397	0.032	0.001	0.946
	75	log(1.5)	True	−0.346	0.024	2.313	0.024	0.001	0.956
			HT	0.621	0.055	1.000	0.053	0.003	0.949
			GRN	−0.174	0.044	1.257	0.043	0.002	0.943
			GRMIS	−0.272	0.041	1.328	0.042	0.002	0.950
			GRMIC	−0.330	0.040	1.357	0.042	0.002	0.949
			GRFCSMIS	−0.238	0.042	1.323	0.042	0.002	0.952
			GRFCSMIC	−0.353	0.041	1.350	0.042	0.002	0.951
		log(3)	True	−0.035	0.027	2.136	0.026	0.001	0.942
			HT	0.174	0.058	1.000	0.059	0.003	0.948
			GRN	0.102	0.051	1.139	0.051	0.003	0.936
			GRMIS	−0.266	0.046	1.257	0.047	0.002	0.949
			GRMIC	−0.239	0.046	1.254	0.047	0.002	0.952
			GRFCSMIS	−0.390	0.047	1.242	0.047	0.002	0.946
			GRFCSMIC	−0.430	0.047	1.245	0.047	0.002	0.950
	90	log(1.5)	True	0.300	0.038	2.138	0.037	0.001	0.946
			HT	0.682	0.082	1.000	0.083	0.007	0.945
			GRN	−0.030	0.075	1.090	0.075	0.006	0.942
			GRMIS	−0.519	0.073	1.126	0.073	0.005	0.948
			GRMIC	−0.534	0.074	1.115	0.073	0.005	0.948
			GRFCSMIS	−0.573	0.073	1.128	0.073	0.005	0.950
			GRFCSMIC	−0.720	0.074	1.114	0.072	0.005	0.948
		log(3)	True	−0.108	0.040	2.220	0.040	0.002	0.948
			HT	0.172	0.089	1.000	0.089	0.008	0.946
			GRN	−0.003	0.083	1.076	0.084	0.007	0.940
			GRMIS	−0.576	0.079	1.131	0.078	0.006	0.945
			GRMIC	−0.629	0.077	1.151	0.078	0.006	0.945
			GRFCSMIS	−0.689	0.077	1.151	0.077	0.006	0.942
			GRFCSMIC	−0.721	0.079	1.122	0.077	0.006	0.941

Table 12: Simulation results for estimating β_x using the IF imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with $N = 10000$, $n = 2000$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	0.055	0.017	2.283	0.018	0.000	0.951
			HT	–0.010	0.039	1.000	0.039	0.002	0.952
			GRN	0.521	0.039	1.005	0.039	0.002	0.950
			GRMIS	–0.232	0.040	0.990	0.038	0.002	0.939
			GRMIC	–0.350	0.040	0.998	0.038	0.002	0.938
			GRFCSMIS	0.158	0.034	1.147	0.033	0.001	0.944
			GRFCSMIC	0.042	0.034	1.171	0.033	0.001	0.940
		log(3)	True	–0.052	0.020	2.194	0.020	0.000	0.942
			HT	0.033	0.045	1.000	0.044	0.002	0.950
			GRN	0.105	0.045	1.001	0.044	0.002	0.953
			GRMIS	0.104	0.043	1.037	0.042	0.002	0.946
			GRMIC	0.102	0.044	1.033	0.042	0.002	0.946
			GRFCSMIS	–0.084	0.041	1.090	0.040	0.002	0.948
			GRFCSMIC	–0.091	0.041	1.093	0.040	0.002	0.945
	75	log(1.5)	True	–0.346	0.024	2.224	0.024	0.001	0.956
			HT	–0.145	0.053	1.000	0.053	0.003	0.952
			GRN	0.489	0.052	1.006	0.052	0.003	0.950
			GRMIS	1.163	0.052	1.023	0.050	0.003	0.948
			GRMIC	1.205	0.052	1.010	0.050	0.003	0.946
			GRFCSMIS	0.014	0.044	1.191	0.046	0.002	0.955
			GRFCSMIC	–0.060	0.044	1.200	0.046	0.002	0.954
		log(3)	True	–0.035	0.027	2.195	0.026	0.001	0.942
			HT	0.210	0.059	1.000	0.059	0.004	0.955
			GRN	0.343	0.058	1.024	0.058	0.003	0.952
			GRMIS	0.179	0.054	1.094	0.055	0.003	0.948
			GRMIC	0.179	0.055	1.074	0.055	0.003	0.944
			GRFCSMIS	0.119	0.054	1.106	0.054	0.003	0.947
			GRFCSMIC	0.083	0.054	1.092	0.054	0.003	0.944
	90	log(1.5)	True	0.300	0.038	2.273	0.037	0.001	0.946
			HT	0.094	0.087	1.000	0.083	0.008	0.950
			GRN	0.391	0.084	1.038	0.080	0.007	0.950
			GRMIS	1.613	0.083	1.047	0.077	0.007	0.940
			GRMIC	1.605	0.083	1.050	0.077	0.007	0.938
			GRFCSMIS	1.233	0.078	1.112	0.077	0.006	0.946
			GRFCSMIC	0.715	0.080	1.090	0.077	0.006	0.944
		log(3)	True	–0.108	0.040	2.177	0.040	0.002	0.948
			HT	–0.213	0.087	1.000	0.089	0.008	0.956
			GRN	–0.021	0.086	1.009	0.087	0.007	0.954
			GRMIS	0.446	0.087	0.996	0.085	0.008	0.948
			GRMIC	0.345	0.088	0.985	0.085	0.008	0.948
			GRFCSMIS	–0.187	0.087	1.006	0.084	0.008	0.952
			GRFCSMIC	–0.126	0.087	0.996	0.083	0.008	0.945

Appendix H: Sampling design comparison results

Table 13: Simulation results for estimating β_x using the data imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 4000$, $n = 800$ comparing simple random sampling (SRS), case-control sampling (CC), and stratified case-control sampling (SCC). The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Design	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	90	log(1.5)	SRS	True	−0.196	0.057	2.316	0.059	0.003	0.953
				HT	−0.097	0.132	1.000	0.131	0.017	0.946
				GRN	−0.219	0.105	1.258	0.105	0.011	0.948
				GRMIS	−0.459	0.105	1.249	0.104	0.011	0.946
				GRMIC	−0.096	0.105	1.255	0.103	0.011	0.940
				GRFCSMIS	−0.283	0.105	1.256	0.104	0.011	0.946
				GRFCSMIC	0.057	0.106	1.236	0.103	0.011	0.944
			CC	True	−0.196	0.057	2.173	0.059	0.003	0.953
				HT	1.443	0.123	1.000	0.120	0.015	0.936
				GRN	1.055	0.108	1.140	0.106	0.012	0.934
				GRMIS	−0.305	0.110	1.122	0.106	0.012	0.935
				GRMIC	1.013	0.107	1.152	0.106	0.012	0.928
				GRFCSMIS	0.351	0.108	1.146	0.106	0.012	0.939
				GRFCSMIC	−0.051	0.110	1.122	0.106	0.012	0.930
			SCC	True	−0.196	0.057	2.025	0.059	0.003	0.953
				HT	1.542	0.115	1.000	0.109	0.013	0.942
				GRN	1.334	0.104	1.108	0.100	0.011	0.934
				GRMIS	1.348	0.105	1.100	0.100	0.011	0.936
				GRMIC	1.120	0.105	1.098	0.100	0.011	0.935
				GRFCSMIS	1.454	0.106	1.089	0.100	0.011	0.939
				GRFCSMIC	0.827	0.104	1.105	0.100	0.011	0.934
		log(3)	SRS	True	0.129	0.065	2.199	0.063	0.004	0.954
				HT	0.164	0.143	1.000	0.140	0.020	0.946
				GRN	0.046	0.120	1.187	0.115	0.014	0.943
				GRMIS	−0.339	0.117	1.223	0.114	0.014	0.951
				GRMIC	−0.361	0.118	1.210	0.113	0.014	0.941
				GRFCSMIS	−0.353	0.117	1.215	0.113	0.014	0.946
				GRFCSMIC	−0.291	0.118	1.212	0.113	0.014	0.945
			CC	True	0.129	0.065	2.035	0.063	0.004	0.954
				HT	0.864	0.132	1.000	0.130	0.018	0.930
				GRN	0.906	0.118	1.115	0.113	0.014	0.930
				GRMIS	0.355	0.116	1.136	0.113	0.014	0.934
				GRMIC	0.490	0.116	1.139	0.113	0.013	0.930
				GRFCSMIS	0.276	0.116	1.138	0.112	0.013	0.931
				GRFCSMIC	0.282	0.117	1.128	0.112	0.014	0.930
			SCC	True	0.129	0.065	1.918	0.063	0.004	0.954
				HT	0.744	0.124	1.000	0.120	0.016	0.938
				GRN	0.857	0.112	1.112	0.109	0.013	0.940
				GRMIS	0.448	0.110	1.130	0.109	0.012	0.944
				GRMIC	0.590	0.111	1.120	0.109	0.012	0.944
				GRFCSMIS	0.530	0.110	1.132	0.109	0.012	0.942
				GRFCSMIC	0.279	0.111	1.125	0.108	0.012	0.940

Table 14: Simulation results for estimating β_x using the IF imputation approach for error scenario 2 (errors in event indicator and failure time) with $N = 4000$, $n = 800$ comparing simple random sampling (SRS), case-control sampling (CC), and stratified case-control sampling (SCC). The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Design	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	90	log(1.5)	SRS	True	0.013	0.059	2.258	0.059	0.004	0.951
				HT	0.591	0.134	1.000	0.131	0.018	0.940
				GRN	0.764	0.109	1.228	0.104	0.012	0.940
				GRMIS	−1.380	0.109	1.230	0.103	0.012	0.930
				GRMIC	−1.163	0.110	1.222	0.102	0.012	0.924
				GRFCSMIS	−1.433	0.110	1.217	0.103	0.012	0.929
				GRFCSMIC	−0.970	0.112	1.195	0.102	0.013	0.926
			CC	True	0.013	0.059	2.086	0.059	0.004	0.951
				HT	3.006	0.124	1.000	0.121	0.015	0.940
				GRN	2.412	0.112	1.106	0.107	0.013	0.934
				GRMIS	−0.878	0.114	1.083	0.107	0.013	0.935
				GRMIC	−0.092	0.120	1.032	0.107	0.014	0.922
				GRFCSMIS	−1.993	0.112	1.102	0.107	0.013	0.931
				GRFCSMIC	−0.974	0.117	1.060	0.106	0.014	0.916
			SCC	True	0.013	0.059	1.909	0.059	0.004	0.951
				HT	0.351	0.113	1.000	0.110	0.013	0.946
				GRN	0.059	0.103	1.104	0.100	0.011	0.945
				GRMIS	−2.497	0.104	1.089	0.100	0.011	0.934
				GRMIC	−2.394	0.103	1.105	0.099	0.011	0.931
				GRFCSMIS	−2.944	0.103	1.103	0.099	0.011	0.937
				GRFCSMIC	−2.923	0.104	1.087	0.099	0.011	0.933
		log(3)	SRS	True	0.090	0.065	2.228	0.063	0.004	0.948
				HT	0.988	0.145	1.000	0.141	0.021	0.942
				GRN	0.463	0.114	1.273	0.115	0.013	0.947
				GRMIS	−0.886	0.113	1.284	0.113	0.013	0.940
				GRMIC	−1.009	0.116	1.250	0.112	0.014	0.933
				GRFCSMIS	−1.295	0.113	1.292	0.111	0.013	0.940
				GRFCSMIC	−1.211	0.114	1.280	0.110	0.013	0.936
			CC	True	0.090	0.065	2.179	0.063	0.004	0.948
				HT	1.522	0.142	1.000	0.130	0.021	0.918
				GRN	1.019	0.122	1.170	0.113	0.015	0.922
				GRMIS	−0.356	0.126	1.132	0.111	0.016	0.911
				GRMIC	0.024	0.129	1.101	0.111	0.017	0.907
				GRFCSMIS	−0.509	0.121	1.178	0.110	0.015	0.919
				GRFCSMIC	−0.130	0.128	1.110	0.109	0.016	0.898
			SCC	True	0.090	0.065	2.037	0.063	0.004	0.948
				HT	0.601	0.133	1.000	0.119	0.018	0.934
				GRN	0.595	0.115	1.153	0.108	0.013	0.938
				GRMIS	−0.588	0.113	1.180	0.106	0.013	0.942
				GRMIC	−0.447	0.116	1.150	0.107	0.013	0.935
				GRFCSMIS	−0.970	0.113	1.174	0.106	0.013	0.934
				GRFCSMIC	−0.874	0.111	1.201	0.105	0.012	0.927

Table 15: Simulation results for estimating β_x using the IF imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with $N = 4000$, $n = 800$ comparing simple random sampling (SRS), case-control sampling (CC), and stratified case-control sampling (SCC). The % bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Design	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	90	log(1.5)	SRS	True	0.013	0.059	2.334	0.059	0.004	0.951
				HT	0.645	0.139	1.000	0.130	0.019	0.948
				GRN	1.081	0.125	1.106	0.120	0.016	0.951
				GRMIS	3.094	0.126	1.098	0.115	0.016	0.928
				GRMIC	2.869	0.125	1.111	0.115	0.016	0.926
				GRFCSMIS	0.402	0.119	1.162	0.112	0.014	0.940
				GRFCSMIC	0.595	0.121	1.147	0.111	0.015	0.939
			CC	True	0.013	0.059	2.113	0.059	0.004	0.951
				HT	1.422	0.125	1.000	0.121	0.016	0.944
				GRN	1.617	0.125	1.007	0.120	0.016	0.942
				GRMIS	2.025	0.126	0.999	0.116	0.016	0.926
				GRMIC	2.742	0.130	0.965	0.115	0.017	0.919
				GRFCSMIS	−0.489	0.115	1.092	0.111	0.013	0.936
				GRFCSMIC	−0.440	0.122	1.031	0.111	0.015	0.930
			SCC	True	0.013	0.059	1.850	0.059	0.004	0.951
				HT	0.545	0.110	1.000	0.110	0.012	0.944
				GRN	1.085	0.110	0.996	0.110	0.012	0.946
				GRMIS	1.545	0.113	0.974	0.108	0.013	0.930
				GRMIC	1.326	0.114	0.963	0.108	0.013	0.930
				GRFCSMIS	−1.441	0.105	1.042	0.104	0.011	0.947
				GRFCSMIC	−0.427	0.108	1.018	0.104	0.012	0.940
		log(3)	SRS	True	0.090	0.065	2.211	0.063	0.004	0.948
				HT	0.407	0.144	1.000	0.141	0.021	0.940
				GRN	0.385	0.137	1.054	0.130	0.019	0.942
				GRMIS	1.244	0.139	1.041	0.127	0.019	0.930
				GRMIC	1.307	0.140	1.029	0.127	0.020	0.930
				GRFCSMIS	−0.738	0.135	1.067	0.122	0.018	0.934
				GRFCSMIC	−0.662	0.136	1.065	0.122	0.018	0.925
			CC	True	0.090	0.065	2.015	0.063	0.004	0.948
				HT	1.265	0.132	1.000	0.130	0.018	0.935
				GRN	1.185	0.135	0.978	0.129	0.018	0.932
				GRMIS	1.728	0.134	0.979	0.127	0.018	0.924
				GRMIC	1.827	0.137	0.962	0.126	0.019	0.919
				GRFCSMIS	−0.358	0.132	0.997	0.121	0.017	0.921
				GRFCSMIC	0.105	0.130	1.015	0.120	0.017	0.915
			SCC	True	0.090	0.065	1.901	0.063	0.004	0.948
				HT	1.200	0.124	1.000	0.123	0.016	0.934
				GRN	1.282	0.123	1.013	0.122	0.015	0.934
				GRMIS	1.169	0.125	0.991	0.121	0.016	0.932
				GRMIC	1.349	0.124	1.001	0.120	0.016	0.928
				GRFCSMIS	−0.738	0.123	1.013	0.117	0.015	0.930
				GRFCSMIC	−0.361	0.126	0.988	0.116	0.016	0.928

Appendix I: Complex misclassification results

Table 16: Misclassification generation process for the simulations testing misclassification generation with interactions. The sensitivity (Sens), specificity (Spec), positive predictive value (PPV), and negative predictive value (NPV) for the event indicator are presented.

$\Delta^\star$	% Cens	β_x	β_z	Sens	Spec	PPV	NPV
Bernoulli(expit$(-1.1 + 0.5 * \Delta - 0.25 * X - 0.1 * U + 0.2 * Z + 0.85 * \Delta * X + 0.2 * \Delta * U + 0.8 * \Delta * z))$	50	log(1.5)	log(0.5)	0.833	0.889	0.860	0.867
		log(3)	log(0.5)	0.874	0.892	0.880	0.887
	75	log(1.5)	log(0.5)	0.768	0.818	0.573	0.917
		log(3)	log(0.5)	0.826	0.797	0.553	0.938
	90	log(1.5)	log(0.5)	0.709	0.734	0.224	0.959
		log(3)	log(0.5)	0.797	0.717	0.226	0.972

Table 17: Simulation results for estimating β_x using the data imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with interaction terms in the misclassification generation, $N = 2000$, $n = 400$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	–0.036	0.040	2.358	0.039	0.002	0.956
			HT	0.969	0.093	1.000	0.088	0.009	0.944
			GRN	2.066	0.093	1.003	0.088	0.009	0.942
			GRMIS	2.038	0.093	1.007	0.088	0.009	0.944
			GRMIC	2.069	0.092	1.011	0.088	0.009	0.942
			GRFCSMIS	1.111	0.070	1.339	0.071	0.005	0.954
			GRFCSMIC	0.807	0.070	1.338	0.069	0.005	0.947
		log(3)	True	0.041	0.042	2.491	0.044	0.002	0.948
			HT	0.313	0.104	1.000	0.098	0.011	0.942
			GRN	0.534	0.105	0.990	0.098	0.011	0.946
			GRMIS	0.451	0.105	0.983	0.098	0.011	0.945
			GRMIC	0.525	0.105	0.988	0.098	0.011	0.947
			GRFCSMIS	0.289	0.089	1.165	0.086	0.008	0.943
			GRFCSMIC	0.232	0.088	1.177	0.085	0.008	0.938
	75	log(1.5)	True	0.119	0.052	2.317	0.053	0.003	0.954
			HT	1.004	0.120	1.000	0.119	0.014	0.948
			GRN	1.895	0.119	1.003	0.117	0.014	0.949
			GRMIS	2.028	0.121	0.993	0.118	0.015	0.950
			GRMIC	2.267	0.121	0.987	0.117	0.015	0.949
			GRFCSMIS	0.288	0.100	1.203	0.104	0.010	0.952
			GRFCSMIC	0.812	0.099	1.209	0.102	0.010	0.946
		log(3)	True	–0.013	0.061	2.250	0.059	0.004	0.949
			HT	0.836	0.137	1.000	0.131	0.019	0.952
			GRN	1.165	0.134	1.020	0.130	0.018	0.950
			GRMIS	1.065	0.137	1.002	0.131	0.019	0.950
			GRMIC	1.028	0.136	1.007	0.131	0.019	0.952
			GRFCSMIS	0.640	0.124	1.108	0.122	0.015	0.949
			GRFCSMIC	0.475	0.122	1.126	0.121	0.015	0.944
	90	log(1.5)	True	0.014	0.084	2.252	0.083	0.007	0.947
			HT	1.898	0.190	1.000	0.183	0.036	0.940
			GRN	1.972	0.189	1.003	0.180	0.036	0.940
			GRMIS	2.311	0.190	1.001	0.180	0.036	0.948
			GRMIC	2.802	0.187	1.017	0.178	0.035	0.940
			GRFCSMIS	–0.059	0.185	1.029	0.174	0.034	0.940
			GRFCSMIC	–0.060	0.184	1.032	0.172	0.034	0.934
		log(3)	True	–0.047	0.089	2.349	0.089	0.008	0.950
			HT	0.929	0.208	1.000	0.197	0.043	0.939
			GRN	0.856	0.205	1.015	0.194	0.042	0.938
			GRMIS	1.024	0.206	1.012	0.193	0.042	0.939
			GRMIC	1.051	0.203	1.023	0.191	0.041	0.937
			GRFCSMIS	0.820	0.201	1.033	0.191	0.041	0.933
			GRFCSMIC	0.472	0.198	1.050	0.189	0.039	0.935

Table 18: Simulation results for estimating β_x using the IF imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with interaction terms in the misclassification generation, $N = 2000$, $n = 400$, and simple random sampling. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	−0.036	0.040	2.358	0.039	0.002	0.956
			HT	0.969	0.093	1.000	0.088	0.009	0.944
			GRN	2.066	0.093	1.003	0.088	0.009	0.942
			GRMIS	1.470	0.094	0.996	0.082	0.009	0.914
			GRMIC	0.961	0.093	1.004	0.082	0.009	0.920
			GRFCSMIS	−0.018	0.070	1.332	0.069	0.005	0.944
			GRFCSMIC	−0.278	0.070	1.341	0.069	0.005	0.942
		log(3)	True	0.041	0.042	2.491	0.044	0.002	0.948
			HT	0.313	0.104	1.000	0.098	0.011	0.942
			GRN	0.534	0.105	0.990	0.098	0.011	0.946
			GRMIS	1.800	0.104	0.999	0.092	0.011	0.927
			GRMIC	1.777	0.103	1.009	0.092	0.011	0.925
			GRFCSMIS	−0.134	0.096	1.082	0.084	0.009	0.934
			GRFCSMIC	−0.288	0.095	1.095	0.084	0.009	0.932
	75	log(1.5)	True	0.119	0.052	2.317	0.053	0.003	0.954
			HT	1.004	0.120	1.000	0.119	0.014	0.948
			GRN	1.895	0.119	1.003	0.117	0.014	0.949
			GRMIS	3.458	0.120	0.996	0.107	0.015	0.926
			GRMIC	3.698	0.120	0.999	0.106	0.015	0.924
			GRFCSMIS	0.701	0.105	1.146	0.101	0.011	0.947
			GRFCSMIC	0.954	0.104	1.155	0.100	0.011	0.943
		log(3)	True	−0.013	0.061	2.250	0.059	0.004	0.949
			HT	0.836	0.137	1.000	0.131	0.019	0.952
			GRN	1.165	0.134	1.020	0.130	0.018	0.950
			GRMIS	1.141	0.134	1.026	0.121	0.018	0.931
			GRMIC	1.082	0.135	1.017	0.121	0.018	0.933
			GRFCSMIS	−0.384	0.127	1.074	0.117	0.016	0.934
			GRFCSMIC	−0.253	0.125	1.095	0.117	0.016	0.930
	90	log(1.5)	True	0.014	0.084	2.252	0.083	0.007	0.947
			HT	1.898	0.190	1.000	0.183	0.036	0.940
			GRN	1.972	0.189	1.003	0.180	0.036	0.940
			GRMIS	8.575	0.208	0.915	0.168	0.044	0.902
			GRMIC	8.465	0.199	0.953	0.165	0.041	0.892
			GRFCSMIS	4.651	0.183	1.036	0.165	0.034	0.925
			GRFCSMIC	4.944	0.182	1.043	0.162	0.034	0.910
		log(3)	True	−0.047	0.089	2.349	0.089	0.008	0.950
			HT	0.929	0.208	1.000	0.197	0.043	0.939
			GRN	0.856	0.205	1.015	0.194	0.042	0.938
			GRMIS	4.226	0.205	1.016	0.184	0.044	0.916
			GRMIC	4.046	0.206	1.010	0.182	0.044	0.915
			GRFCSMIS	1.593	0.196	1.063	0.179	0.039	0.911
			GRFCSMIC	1.238	0.202	1.031	0.177	0.041	0.908

Appendix J: Misspecified imputation model results

Table 19: Simulation results for estimating β_x using the IF imputation approach for error scenario 3 (errors in event indicator, failure time, and X) with misspecified imputation models, $N = 2000$, $n = 400$, and simple random sampling. $\Delta^{\star}$ was generated as Bernoulli(expit$(3 \times \Delta - (0.75 \times \sin(\pi \times X)) - \exp(0.2 \times U) + (0.5 \times Z)^5)$) and $X^{\star}$ was generated as $0.2 + X^3 + (2 \times (1 - Z))^4 - 0.4 \times \Delta - (0.25 \times \sin(\pi \times U)) + \epsilon$. The $\%$ bias, empirical standard error (ESE), relative efficiency (RE), average standard error (ASE), mean squared error, and coverage probabilities (CP) are presented for 2000 simulated datasets.

β_z	% Cens	β_x	Method	% Bias	ESE	RE	ASE	MSE	CP
log(0.5)	50	log(1.5)	True	–0.036	0.040	2.174	0.039	0.002	0.956
			HT	1.949	0.086	1.000	0.088	0.007	0.951
			GRN	1.847	0.088	0.984	0.088	0.008	0.950
			GRMIS	1.693	0.086	1.006	0.088	0.007	0.949
			GRMIC	1.589	0.086	0.999	0.088	0.007	0.951
			GRFCSMIS	1.615	0.087	0.990	0.088	0.008	0.949
			GRFCSMIC	1.179	0.088	0.982	0.087	0.008	0.946
		log(3)	True	0.041	0.042	2.323	0.044	0.002	0.948
			HT	0.384	0.097	1.000	0.098	0.009	0.952
			GRN	0.363	0.098	0.988	0.098	0.010	0.952
			GRMIS	0.338	0.098	0.988	0.098	0.010	0.953
			GRMIC	0.379	0.097	0.992	0.098	0.010	0.952
			GRFCSMIS	0.442	0.098	0.986	0.097	0.010	0.954
			GRFCSMIC	–0.285	0.095	1.012	0.097	0.009	0.947
	75	log(1.5)	True	0.119	0.052	2.376	0.053	0.003	0.955
			HT	0.207	0.123	1.000	0.119	0.015	0.951
			GRN	0.636	0.121	1.015	0.119	0.015	0.952
			GRMIS	0.224	0.121	1.014	0.119	0.015	0.950
			GRMIC	0.352	0.122	1.003	0.119	0.015	0.951
			GRFCSMIS	0.333	0.121	1.017	0.118	0.015	0.950
			GRFCSMIC	0.315	0.121	1.013	0.118	0.015	0.950
		log(3)	True	–0.013	0.061	2.328	0.059	0.004	0.949
			HT	0.778	0.142	1.000	0.132	0.020	0.952
			GRN	0.870	0.142	1.001	0.131	0.020	0.953
			GRMIS	0.899	0.140	1.012	0.132	0.020	0.950
			GRMIC	0.916	0.142	1.002	0.131	0.020	0.951
			GRFCSMIS	0.880	0.141	1.006	0.131	0.020	0.952
			GRFCSMIC	0.576	0.141	1.003	0.131	0.020	0.953
	90	log(1.5)	True	0.014	0.084	2.243	0.083	0.007	0.947
			HT	1.454	0.189	1.000	0.183	0.036	0.942
			GRN	1.117	0.187	1.010	0.184	0.035	0.944
			GRMIS	1.068	0.188	1.006	0.183	0.035	0.942
			GRMIC	0.997	0.188	1.007	0.184	0.035	0.940
			GRFCSMIS	0.528	0.188	1.007	0.183	0.035	0.942
			GRFCSMIC	0.956	0.184	1.028	0.183	0.034	0.938
		log(3)	True	–0.047	0.089	2.365	0.089	0.008	0.951
			HT	0.755	0.209	1.000	0.198	0.044	0.941
			GRN	0.743	0.210	0.996	0.197	0.044	0.936
			GRMIS	0.664	0.209	1.004	0.198	0.044	0.935
			GRMIC	0.621	0.211	0.995	0.198	0.044	0.936
			GRFCSMIS	0.636	0.209	1.004	0.197	0.044	0.939
			GRFCSMIC	0.563	0.207	1.013	0.198	0.043	0.937

Appendix K: VCCC analysis details

For this study, we analyzed data on 4797 HIV-positive patients that had been fully validated and applied some common inclusion/exclusion criteria used in HIV studies to obtain the final analysis dataset. Specifically, any patients that had an indeterminate ART start date, no CD4 count measurement between 180 days before or 30 days after starting ART, no follow-up visits in the clinic after starting ART, an ADE before starting ART, or an indeterminate ADE date were excluded. In addition, patients must have been at least 18 years of age at ART start and not started ART prior to enrollment. Lastly, any ADE within 6 months of starting ART were not considered a true failure due to the time required for ART to be efficacious. After application of these criteria, the unvalidated and validated data contained 1995 and 1595 patients, respectively. The 1595 patients that met the criteria in the validated dataset were used for the analysis of the ADE outcome.

The censoring rate among the 1595 patients was very high at 93.8%, suggesting that an outcome-dependent sampling design that oversamples cases would be necessary. Of the 1595 patients, 11% had a misclassified ADE; specifically, 161 were incorrectly classified as having an ADE and 12 were incorrectly classified as having been censored. For the failure times, 34.5% were incorrect, with the errors having mean and standard deviation of -0.75 and 2.89 years, respectively. There were errors in the CD4 count at ART start for only 6.7% of the patients; however, the errors were right skewed, having mean and standard deviation of 10 and 154 cell$/\text{mm}^3$, respectively. In addition, the errors in the failure times and CD4 count at ART start had a correlation of -0.10.

Table 20: The median hazard ratios (HR) and their corresponding 95% confidence interval widths calculated using the IF imputation method from 100 different sampled validation subsets for a 100 cell/mm^3 increase in CD4 count at ART initiation and 10-year increase in age at CD4 count measurement.

Subset size	Sampling	Method	CD4 HR	CD4 CI width	Age HR	Age CI width
340	CC	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.677	0.323	0.805	0.576
		GRN	0.68	0.284	0.821	0.477
		GRMIS	0.704	0.323	0.807	0.526
		GRMIC	0.695	0.296	0.804	0.492
		GRFCSMIS	0.69	0.307	0.813	0.488
		GRFCSMIC	0.684	0.299	0.813	0.463
	SCCB	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.682	0.283	0.855	0.571
		GRN	0.682	0.278	0.835	0.497
		GRMIS	0.691	0.284	0.851	0.515
		GRMIC	0.691	0.277	0.861	0.499
		GRFCSMIS	0.7	0.289	0.846	0.506
		GRFCSMIC	0.702	0.282	0.848	0.490
	SCCN	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.694	0.310	0.829	0.702
		GRN	0.69	0.304	0.813	0.609
		GRMIS	0.711	0.303	0.820	0.583
		GRMIC	0.715	0.298	0.824	0.570
		GRFCSMIS	0.708	0.301	0.838	0.566
		GRFCSMIC	0.723	0.298	0.826	0.561
680	CC	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.691	0.237	0.839	0.411
		GRN	0.69	0.227	0.830	0.386
		GRMIS	0.696	0.234	0.829	0.391
		GRMIC	0.7	0.232	0.834	0.385
		GRFCSMIS	0.696	0.232	0.832	0.388
		GRFCSMIC	0.702	0.230	0.830	0.386
	SCCB	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.688	0.228	0.828	0.413
		GRN	0.69	0.227	0.821	0.387
		GRMIS	0.694	0.230	0.831	0.398
		GRMIC	0.697	0.229	0.830	0.390
		GRFCSMIS	0.698	0.230	0.826	0.393
		GRFCSMIC	0.7	0.231	0.824	0.388
	SCCN	True	0.693	0.190	0.829	0.361
		Naive	0.91	0.125	1.087	0.275
		HT	0.688	0.231	0.832	0.438
		GRN	0.687	0.231	0.832	0.409
		GRMIS	0.693	0.232	0.825	0.407
		GRMIC	0.694	0.231	0.825	0.402
		GRFCSMIS	0.694	0.233	0.823	0.402
		GRFCSMIC	0.698	0.233	0.828	0.400

References

Deville, J. C. and Särndal, C. E. (1992). Calibration estimators in survey sampling. *Journal of the American Statistical Association* **87,** 376–382.

Saegusa, T. and Wellner, J. A. (2013). Weighted likelihood estimation under two-phase sampling. *Annals of Statistics* **41,** 269–295.

Van der Vaart, A. W. (2000). *Asymptotic Statistics*, volume 3. Cambridge university press.