

Table 1. Parameter setting in simulation. Large (β , γ) refers to a severe confounding effect with either β or $\gamma = 0$, indicating no confounding effect.

	α (X-Y association)			note
	no	moderate	high	
$\beta = 0.5, \gamma = 0.5$	0	0.5	1	Strong confounding
$\beta = 0.25, \gamma = 0.25$	0	0.5	1	moderate confounding
$\beta = 0.5, \gamma = 0$	0	0.5	1	no confounding
$\beta = 0, \gamma = 0.5$	0	0.5	1	no confounding

Table 2. List of methods for controlling confounding for ternary exposure X .

Model		Fit
1	unadjusted LR ^{*1}	y on x_1+x_2
2	covariate-adjusted LR	y on $x_1+x_2+ z$'s (sle ^{*4} =0.15)
3	PS-direct adjusted LR	y on $x_1+x_2+PS_1+PS_2$
4	PS-direct adjusted LR	y on $x_1+x_2+PS_1+PS_2+ z$'s (sle=0.05)
5	PS-direct adjusted LR	y on $x_1+x_2+PS_1+PS_2+ z$'s (sle=0.15)
6	PS-matched case-control CLR ^{*2}	Balanced y on x
7	PS-matched cohort CLR	y on balanced x
8	PS-matched cohort CAT ^{*3}	y vs. balanced x

*1 LR: logistic regression,

*2 CLR: conditional logistic regression,

*3 CAT: Cochran-Armitage Test

*4 sle: chosen significance level for entry

Table 3: Type I error rate ($\alpha=0$) comparison under high confounding ($\beta=0.5, \gamma=0.5$).

Trait	Additive		Recessive		Dominant	
	Type I error	STD_T	Type I error	STD_T	Type I error	STD_T
Model 1: unadjusted						
Treatment Contrast	47.70%	0.983	50.10%	0.911	44.40%	0.966
SNP Contrast	28.30%	1.001	30.30%	1.003	29.00%	0.962
Helmert Contrast	42.30%	0.984	43.60%	0.965	44.00%	0.96
Model 2: covariate-adjusted						
Treatment Contrast	35.40%	1.492	34.60%	1.42	36.70%	1.489
SNP Contrast	26.90%	1.283	30.40%	1.282	28.20%	1.278
Helmert Contrast	32.50%	1.224	32.80%	1.254	34.90%	1.248
Model 3: PS-adjusted-0						
Treatment Contrast	13.70%	1.012	14.20%	0.981	11.10%	1.005
SNP Contrast	8.50%	0.967	6.70%	0.941	7.40%	0.921
Helmert Contrast	9.20%	0.916	7.30%	0.919	9.00%	0.942
Model 4: PS-adjusted-0.05						
Treatment Contrast	13.70%	1.014	14.50%	0.987	11.50%	1.019
SNP Contrast	8.40%	0.97	6.90%	0.95	7.50%	0.927
Helmert Contrast	9.20%	0.924	8.00%	0.931	9.20%	0.954
Model 5: PS-adjusted-0.15						
Treatment Contrast	18.50%	1.181	17.60%	1.121	15.20%	1.146
SNP Contrast	14.10%	1.095	12.00%	1.074	12.00%	1.05
Helmert Contrast	13.30%	1.069	13.20%	1.081	15.00%	1.102
Model 6: PS-matched-case-control CLR						
Treatment Contrast	6.50%	0.936	5.60%	0.944	5.00%	0.925
SNP Contrast	1.80%	0.926	1.80%	0.908	1.90%	0.908
Helmert Contrast	3.70%	0.947	2.80%	0.952	3.20%	0.931
Model 7: PS-matched-cohort CLR						
Treatment Contrast	16.50%	0.878	16.10%	0.87	16.40%	0.91
SNP Contrast	15.90%	0.897	17.10%	0.891	16.30%	0.892
Helmert Contrast	22.20%	0.878	25.60%	0.924	22.70%	0.86
Model 8: PS-matched-cohort CAT						
Treatment Contrast	21.20%	-	17.00%	-	14.70%	-
SNP Contrast	21.00%	-	12.50%	-	18.80%	-
Helmert Contrast	30.70%	-	19.70%	-	23.00%	-

Bold: smallest type I error across contrasts.

Table 4: Type I error comparison under moderate confounding ($\beta=0.25$, $\gamma=0.25$)

Trait	Additive		Recessive		Dominant	
	Type I error	STD_T	Type I error	STD_T	Type I error	STD_T
Model 1: unadjusted						
Treatment Contrast	17.50%	0.997	16.20%	0.992	16.20%	0.962
SNP Contrast	14.40%	1.017	14.40%	1.033	14.40%	1.02
Helmert Contrast	15.90%	1.006	17.10%	0.967	17.10%	0.997
Model 2: covariate-adjusted						
Treatment Contrast	17.90%	1.202	19.40%	1.17	18.40%	1.2
SNP Contrast	20.30%	1.163	19.50%	1.187	18.40%	1.172
Helmert Contrast	19.80%	1.16	19.20%	1.145	20.20%	1.144
Model 3: PS-adjusted-0						
Treatment Contrast	10.10%	0.993	10.40%	0.99	10.50%	0.981
SNP Contrast	9.30%	0.99	10.40%	1.027	9.30%	1.024
Helmert Contrast	8.70%	0.982	8.10%	0.971	9.20%	0.963
Model 4: PS-adjusted-0.05						
Treatment Contrast	10.20%	1.007	11.20%	1.008	10.50%	0.996
SNP Contrast	9.60%	1.004	11.10%	1.043	9.50%	1.039
Helmert Contrast	9.50%	1.003	7.90%	0.986	9.90%	0.972
Model 5: PS-adjusted-0.15						
Treatment Contrast	13.40%	1.115	15.70%	1.109	15.00%	1.118
SNP Contrast	12.60%	1.09	15.20%	1.133	15.10%	1.147
Helmert Contrast	12.60%	1.098	11.50%	1.064	13.40%	1.069
Model 6: PS-matched-case-control CLR						
Treatment Contrast	3.30%	0.964	3.60%	0.961	3.10%	0.909
SNP Contrast	2.60%	0.93	2.50%	0.925	3.10%	0.926
Helmert Contrast	3.40%	0.946	2.90%	0.917	2.80%	0.924
Model 7: PS-matched-cohort CLR						
Treatment Contrast	8.10%	0.948	6.90%	0.946	8.50%	0.977
SNP Contrast	6.30%	0.933	6.40%	0.92	6.00%	0.941
Helmert Contrast	7.90%	0.958	6.60%	0.948	7.90%	0.948
Model 8: PS-matched-cohort CAT						
Treatment Contrast	8.10%	-	9.50%	-	7.60%	-
SNP Contrast	8.30%		7.10%		8.70%	
Helmert Contrast	9.20%		9.50%		8.90%	

Bold: smallest type I error across contrasts.

Table 5: Power comparison under high confounding ($\beta=0.5$, $\gamma=0.5$) and moderate X-Y association ($\alpha=0.5$)

Trait	Additive		Recessive		Dominant	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	36.40%	1.014	28.60%	0.982	20.20%	0.951
SNP Contrast	15.60%	0.918	10.00%	0.938	11.20%	0.908
Helmert Contrast	23.30%	0.924	15.30%	0.93	16.90%	0.93
Model 4: PS-adjusted-0.05						
Treatment Contrast	36.50%	1.013	29.10%	0.987	20.50%	0.956
SNP Contrast	15.90%	0.922	10.10%	0.946	11.60%	0.912
Helmert Contrast	23.90%	0.936	15.90%	0.94	17.30%	0.936
Model 5: PS-adjusted-0.15						
Treatment Contrast	38.90%	1.107	30.80%	1.118	22.80%	1.094
SNP Contrast	21.70%	1.031	15.10%	1.042	17.20%	1.033
Helmert Contrast	29.80%	1.07	22.40%	1.06	22.90%	1.048
Model 6: PS-matched-case-control CLR						
Treatment Contrast	15.50%	0.885	8.30%	0.891	7.50%	0.908
SNP Contrast	5.70%	0.837	2.60%	0.885	3.90%	0.877
Helmert Contrast	9.70%	0.824	4.60%	0.898	5.40%	0.897
Model 7: PS-matched-cohort CLR						
Treatment Contrast	52.70%	0.74	34.00%	0.834	34.60%	0.85
SNP Contrast	52.10%	0.753	32.90%	0.833	33.50%	0.834
Helmert Contrast	69.90%	0.717	46.60%	0.837	44.40%	0.814
Model 8: PS-matched-cohort CAT						
Treatment Contrast	60.80%	-	38.20%	-	35.10%	-
SNP Contrast	59.50%	-	33.50%	-	41.60%	-
Helmert Contrast	73.10%	-	44.40%	-	50.50%	-

Bold: largest power across contrasts.

Table 6: Power comparison under moderate confounding ($\beta=0.25$, $\gamma=0.25$) and moderate X-Y association ($\alpha=0.5$)

Trait	Additive		Recessive		Dominant	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	43.00%	10.90%	27.90%	0.966	19.70%	0.968
SNP Contrast	26.00%	0.976	11.90%	0.962	18.10%	0.961
Helmert Contrast	32.70%	0.997	19.00%	0.956	21.40%	1
Model 4: PS-adjusted-0.05						
Treatment Contrast	43.60%	0.904	28.50%	0.975	19.90%	0.98
SNP Contrast	27.00%	0.988	12.50%	0.974	18.10%	0.971
Helmert Contrast	33.10%	1.006	19.40%	0.969	21.80%	1.008
Model 5: PS-adjusted-0.15						
Treatment Contrast	44.60%	0.987	30.00%	1.1	22.30%	1.069
SNP Contrast	32.50%	1.074	16.00%	1.053	23.90%	1.075
Helmert Contrast	36.80%	1.087	22.10%	1.048	23.80%	1.091
Model 6: PS-matched-case-control CLR						
Treatment Contrast	16.20%	0.825	8.90%	0.903	8.70%	0.919
SNP Contrast	10.80%	0.818	4.90%	0.895	6.80%	0.905
Helmert Contrast	14.70%	0.817	6.60%	0.888	6.90%	0.874
Model 7: PS-matched-cohort CLR						
Treatment Contrast	43.10%	0.797	19.30%	0.903	21.20%	0.874
SNP Contrast	43.20%	0.787	21.80%	0.88	21.00%	0.897
Helmert Contrast	48.80%	0.818	27.10%	0.888	26.20%	0.919
Model 8: PS-matched-cohort CAT						
Treatment Contrast	49.20%	-	25.60%	-	24.00%	-
SNP Contrast	47.80%	-	22.30%	-	30.70%	-
Helmert Contrast	58.20%	-	26.60%	-	32.30%	-

Table 7: Power comparison under high confounding ($\beta=0.5$, $\gamma=0.5$) and high X-Y association ($\alpha=1$)

Trait	Additive		Recessive		Dominant	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	65.80%	0.867	48.60%	0.975	30.50%	0.964
SNP Contrast	35.60%	0.845	16.80%	0.948	25.20%	0.927
Helmert Contrast	53.90%	1.5443	30.70%	0.937	32.60%	0.909
Model 4: PS-adjusted-0.05						
Treatment Contrast	65.80%	0.867	49.20%	0.971	30.80%	0.965
SNP Contrast	35.70%	0.848	17.30%	0.954	25.70%	0.93
Helmert Contrast	54.60%	0.923	30.90%	0.938	33.10%	0.914
Model 5: PS-adjusted-0.15						
Treatment Contrast	67.50%	0.934	50.50%	1.053	33.80%	1.048
SNP Contrast	41.00%	0.895	22.00%	1.045	33.00%	1.026
Helmert Contrast	59.60%	0.985	35.10%	1.08	37.00%	0.989
Model 6: PS-matched-case-control CLR						
Treatment Contrast	23.10%	0.692	14.30%	0.846	9.10%	0.834
SNP Contrast	14.30%	0.723	5.30%	0.849	5.80%	0.827
Helmert Contrast	19.90%	0.691	9.10%	0.834	9.10%	0.807
Model 7: PS-matched-cohort CLR						
Treatment Contrast	87.60%	0.542	52.70%	0.788	56.50%	0.767
SNP Contrast	85.20%	0.548	52.90%	0.717	57.10%	0.775
Helmert Contrast	93.90%	0.509	66.50%	0.765	67.30%	0.712
Model 8: PS-matched-cohort CAT						
Treatment Contrast	89.60%	-	62.20%	-	62.30%	-
SNP Contrast	90.00%	-	58.90%	-	65.50%	-
Helmert Contrast	95.00%	-	71.50%	-	76.80%	-

Table 8: Power comparison under moderate confounding ($\beta=0.25$, $\gamma=0.25$) and high X-Y association ($\alpha=1$)

Trait	Additive		Recessive		Dominant	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	79.20%	0.747	58.60%	0.914	38.40%	0.931
SNP Contrast	51.20%	0.817	24.60%	0.921	39.80%	0.99
Helmert Contrast	72.80%	0.916	42.60%	0.973	49.50%	0.943
Model 4: PS-adjusted-0.05						
Treatment Contrast	79.30%	0.751	58.70%	0.92	38.30%	0.938
SNP Contrast	52.20%	0.822	25.20%	0.926	40.40%	0.996
Helmert Contrast	73.10%	0.918	43.60%	0.984	50.50%	0.947
Model 5: PS-adjusted-0.15						
Treatment Contrast	78.90%	0.788	59.40%	1.02	40.80%	1.023
SNP Contrast	57.80%	0.882	30.40%	1.017	45.00%	1.081
Helmert Contrast	74.00%	0.957	47.50%	1.068	55.20%	0.99
Model 6: PS-matched-case-control CLR						
Treatment Contrast	36.90%	0.605	17.70%	0.844	15.60%	0.811
SNP Contrast	27.20%	0.661	12.20%	0.832	11.00%	0.827
Helmert Contrast	32.70%	0.656	13.50%	0.823	14.60%	0.812
Model 7: PS-matched-cohort CLR						
Treatment Contrast	84.00%	0.592	41.60%	0.78	43.00%	0.817
SNP Contrast	83.10%	0.569	43.70%	0.806	43.60%	0.823
Helmert Contrast	87.20%	0.565	50.80%	0.811	52.00%	0.765
Model 8: PS-matched-cohort CAT						
Treatment Contrast	87.90%	-	55.00%	-	57.90%	-
SNP Contrast	87.40%	-	50.50%	-	61.50%	-
Helmert Contrast	92.30%	-	55.80%	-	64.60%	-

Table 9: Power comparison under no confounding ($\beta=0$, $\gamma=0.5$) and high X-Y association ($\alpha=1$)

	Additive Model		Recessive Model		Dominant Model	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	62.10%	0.81	30.60%	0.93	21.90%	0.919
SNP Contrast	37.30%	0.816	13.80%	0.853	25.30%	0.908
Helmert Contrast	54.80%	0.912	23.90%	0.871	30.40%	0.943
Model 4: PS-adjusted-0.05						
Treatment Contrast	62.30%	0.813	31.30%	0.936	22.80%	0.926
SNP Contrast	38.20%	0.819	14.80%	0.863	25.80%	0.913
Helmert Contrast	55.60%	0.919	24.80%	0.88	31.40%	0.949
Model 5: PS-adjusted-0.15						
Treatment Contrast	68.60%	0.825	41.30%	1.031	31.90%	1.021
SNP Contrast	48.20%	0.915	25.30%	1.01	34.70%	1.045
Helmert Contrast	66.30%	0.993	34.40%	1.018	41.40%	1.029
Model 6: PS-matching-case-control						
Treatment Contrast	22.50%	0.729	7.90%	0.879	7.90%	0.891
SNP Contrast	21.70%	0.714	6.90%	0.839	6.60%	0.856
Helmert Contrast	23.20%	0.724	7.70%	0.834	7.80%	0.844
Model 7: PS-matching-cohort						
Treatment Contrast	51.60%	0.757	13.50%	0.893	14.80%	0.884
SNP Contrast	49.80%	0.729	14.70%	0.898	15.10%	0.928
Helmert Contrast	49.60%	0.783	17.40%	0.917	16.60%	0.921
Model 8: PS-matching-CAT						
Treatment Contrast	55.70%	-	22.90%	-	23.70%	-
SNP Contrast	54.80%	-	23.10%	-	25.90%	-
Helmert Contrast	58.60%	-	25.40%	-	24.90%	-

Table 10: Power comparison under no confounding ($\beta=0.5$, $\gamma=0$) and moderate X-Y association ($\alpha=0.5$)

	Additive Model		Recessive Model		Dominant Model	
	Power	STD_T	Power	STD_T	Power	STD_T
Model 3: PS-adjusted-0						
Treatment Contrast	35.60%	0.986	21.90%	1.040	14.60%	1.016
SNP Contrast	24.20%	0.991	11.40%	1.012	13.00%	0.987
Helmert Contrast	30.40%	0.992	17.20%	1.024	18.60%	0.986
Model 4: PS-adjusted-0.05						
Treatment Contrast	36.20%	0.99	22.10%	1.044	15.10%	1.023
SNP Contrast	24.90%	0.997	11.50%	1.016	13.10%	0.99
Helmert Contrast	30.90%	0.997	17.10%	1.031	18.90%	0.992
Model 5: PS-adjusted-0.15						
Treatment Contrast	38.40%	1.048	23.90%	1.099	17.60%	1.082
SNP Contrast	28.80%	1.045	15.20%	1.071	16.60%	1.047
Helmert Contrast	35.20%	1.036	19.60%	1.073	21.40%	1.027
Model 6: PS-matching-case-control						
Treatment Contrast	10.40%	0.833	4.00%	0.917	2.80%	0.889
SNP Contrast	7.40%	0.852	4.10%	0.908	3.30%	0.886
Helmert Contrast	10.30%	0.831	4.00%	0.895	4.40%	0.894
Model 7: PS-matching-cohort						
Treatment Contrast	29.20%	0.891	11.10%	0.937	9.30%	0.931
SNP Contrast	29.80%	0.847	9.90%	0.931	10.50%	0.945
Helmert Contrast	35.00%	0.845	10.90%	0.947	11.90%	0.97
Model 8: PS-matching-CAT						
Treatment Contrast	32.90%	-	14.30%	-	15.90%	-
SNP Contrast	34.00%	-	15.70%	-	17.00%	-
Helmert Contrast	37.30%	-	19.40%	-	18.70%	-