Supplemental Appendix for: The Value of Heterogeneous Property Rights and the Costs of Water Volatility

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A Bayesian Model Averaging

Table A.1: Bayesian Model Averaging

	Posterior Mean	Posterior Std. Dev.	PIP
Acres	-0.0097	0.0011	1.00
Acres^2	0.0000	0.0000	1.00
Improvements	0.0001	0.0000	1.00
Orchard_1	0.2318	0.0430	1.00
Acres^3	-0.0000	0.0000	1.00
Residential	0.1869	0.0401	1.00
Kittitas	0.6034	0.1396	0.99
Reservation	-0.3612	0.1073	0.97
Improvements^2	-0.0000	0.0000	0.96
Time	0.0035	0.0009	0.95
Benton	0.1653	0.0708	0.90
Developed_1	0.1422	0.0930	0.76
Slope	-0.0042	0.0050	0.48
Dist Stream^2	0.0175	0.0236	0.46
Dist Stream^3	-0.0028	0.0037	0.43
Dist Stream	0.0127	0.0328	0.40
Slope - ID 20NN	0.0107	0.0152	0.38
$\text{Soil Productivity}^3$	0.0000	0.0000	0.32
Rolling Avg Price	1.3339	3.8025	0.29
Slope^2	-0.0001	0.0003	0.28
Rolling Avg^2	-0.0121	0.3813	0.27
Dist City	0.0016	0.0061	0.26
Rolling Avg TWSA	0.0201	0.0370	0.26
Rolling Avg^3	-0.0048	0.0164	0.25
$\text{Soil Productivity}^2$	-0.0000	0.0002	0.19
Improvements^3	0.0000	0.0000	0.16
Soil Productivity	0.0013	0.0125	0.14
Slope^3	0.0000	0.0000	0.13
Orchard_2	0.0126	0.0394	0.11
Dist City^2	0.0001	0.0004	0.10
Groundwater	0.0113	0.0391	0.09
Residential - ID 20NN	-0.0547	0.2038	0.09
Dist UGA^3	0.0000	0.0001	0.08
Improvements - ID 20NN	0.0000	0.0000	0.08
Pasture_2	-0.0077	0.0291	0.08
Time^3	-0.0000	0.0000	0.07
Dist UGA^2	0.0002	0.0011	0.06
Time^2	0.0000	0.0000	0.06
Deviation TWSA	-0.0023	0.0111	0.06
Dist City^3	-0.0000	0.0000	0.06
Soil Class 3	-0.0056	0.0262	0.06
Dist River	0.0019	0.0099	0.05
Grains_2	0.0038	0.0197	0.05
Pasture_1	0.0031	0.0174	0.04
Dist River^3	-0.0000	0.0000	0.03
Dist River^2	-0.0001	0.0008	0.03
Grains_1	0.0025	0.0175	0.03
Dist UGA	0.0001	0.0038	0.02
Sr	-0.0011	0.0264	0.02
Acres - ID 20NN	-0.0000	0.0003	0.01
Soil Class 2	0.0003	0.0063	0.01
Hay_1	0.0003	0.0061	0.01
Sr Percent	0.0013	0.0325	0.01
Other Crops_2	-0.0003	0.0088	0.01
Developed_2	0.0001	0.0031	0.01
Other Crops_1	0.0005	0.0123	0.01
Hay_2	0.0001	0.0046	0.01
Observations	2392		
Candidate Regressors	57		
R^2	0.287		

Note: Coefficients are weighted by the posterior odds probability and are zero when covariates do not appear in a model. Posterior means and standard deviations are the based on 200,000 draws were taken with 50,000 burn-ins. PIP is the posterior inclusion probability.

B Regression Tables

Table A.2: Bayesian Regression - Senior Dummy

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.04907	0.04167	-0.03241	0.12990
Groundwater	0.13428	0.05470	0.02635	0.24012
Residential	0.18998	0.03918	0.11307	0.26673
Reservation	-0.13875	0.08211	-0.30058	0.02240
Benton	0.23245	0.05893	0.11712	0.34967
Kittitas	0.65255	0.11996	0.41867	0.88721
Acres	-0.00991	0.00102	-0.01191	-0.00790
Acres^2	0.00004	0.00001	0.00003	0.00005
Acres^3	-0.00000	0.00000	-0.00000	-0.00000
Improvements	0.00006	0.00001	0.00004	0.00007
Improvements^2	-0.00000	0.00000	-0.00000	-0.00000
Rolling Avg TWSA	0.05247	0.03981	-0.02536	0.13047
Deviation TWSA	-0.03665	0.02303	-0.08185	0.00829
Time	0.00181	0.00323	-0.00454	0.00818
Time^2	0.00002	0.00003	-0.00004	0.00007
Time^3	-0.00000	0.00000	-0.00000	0.00000
Rolling Avg	27.51228	76.38455	-122.29040	177.98048
Rolling Avg^2	-2.77727	8.93140	-20.40450	14.70444
Rolling Avg^3	0.09155	0.34769	-0.58819	0.77638
Soil Productivity	0.20688	0.06981	0.06950	0.34259
$\text{Soil Productivity}^2$	-0.00293	0.00098	-0.00484	-0.00101
$\text{Soil Productivity}^3$	0.00001	0.00000	0.00000	0.00002
Slope	0.01215	0.01068	-0.00878	0.03315
Slope^2	-0.00188	0.00068	-0.00322	-0.00054
Slope^3	0.00003	0.00001	0.00001	0.00005
Dist Stream	-0.13322	0.06578	-0.26235	-0.00396
Dist Stream^2	0.10020	0.02966	0.04200	0.15856
Dist Stream^3	-0.01323	0.00356	-0.02023	-0.00624
Dist City	0.00984	0.00237	0.00526	0.01455
Residential - ID 20NN	-0.23068	0.23215	-0.68378	0.22584
Improvements - ID 20NN	0.00005	0.00002	0.00002	0.00009
Slope - ID 20NN	0.04023	0.00806	0.02456	0.05604
Orchard_1	0.22052	0.04000	0.14128	0.29868
Developed_1	0.19055	0.05267	0.08632	0.29301
σ^2	0.48023	0.01404	0.45313	0.50817
Observations	2392			
R^2	0.302			

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.3: Bayesian Regression - Senior Percent

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Sr Percent	0.08360	0.05291	-0.02000	0.18620
Groundwater	0.13652	0.05469	0.02858	0.24231
Residential	0.18856	0.03919	0.11159	0.26532
Reservation	-0.16500	0.07228	-0.30777	-0.02352
Benton	0.23318	0.05856	0.11867	0.34968
Kittitas	0.64849	0.11961	0.41487	0.88300
Acres	-0.00986	0.00102	-0.01186	-0.00786
Acres^2	0.00004	0.00001	0.00003	0.00005
Acres^3	-0.00000	0.00000	-0.00000	-0.00000
Improvements	0.00006	0.00001	0.00004	0.00007
Improvements^2	-0.00000	0.00000	-0.00000	-0.00000
Rolling Avg TWSA	0.05268	0.03980	-0.02518	0.13059
Deviation TWSA	-0.03731	0.02303	-0.08250	0.00767
Time	0.00182	0.00323	-0.00452	0.00818
Time^2	0.00002	0.00003	-0.00004	0.00007
Time^3	-0.00000	0.00000	-0.00000	0.00000
Rolling Avg	26.59571	76.37159	-123.18735	177.03884
Rolling Avg^2	-2.67275	8.92985	-20.30037	14.80960
Rolling Avg^3	0.08759	0.34763	-0.59214	0.77226
Soil Productivity	0.20721	0.06977	0.07018	0.34298
$\text{Soil Productivity}^2$	-0.00294	0.00098	-0.00484	-0.00101
$\text{Soil Productivity}^3$	0.00001	0.00000	0.00000	0.00002
Slope	0.01336	0.01073	-0.00768	0.03441
Slope^2	-0.00194	0.00069	-0.00329	-0.00060
Slope^3	0.00003	0.00001	0.00001	0.00005
Dist Stream	-0.13280	0.06577	-0.26193	-0.00363
Dist Stream^2	0.10047	0.02963	0.04226	0.15880
Dist Stream^3	-0.01325	0.00356	-0.02026	-0.00627
Dist City	0.01006	0.00238	0.00546	0.01480
Residential - ID 20NN	-0.24182	0.23162	-0.69397	0.21334
Improvements - ID 20NN	0.00006	0.00002	0.00002	0.00009
Slope - ID 20NN	0.04050	0.00806	0.02484	0.05629
Orchard_1	0.22156	0.04000	0.14236	0.29978
Developed_1	0.19028	0.05264	0.08611	0.29272
σ^2	0.48001	0.01404	0.45292	0.50793
Observations	2392			
R^2	0.303			

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.4: Senior Dummy and Time Interaction

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.09113	0.07933	-0.06449	0.24680
Sr*Time	-0.00029	0.00046	-0.00120	0.00061

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient and an interaction with a linear time trend with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.5: Senior Dummy and Time Interaction (Quadratic)

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.05039	0.12117	-0.18642	0.28821
Sr*Time	0.00052	0.00186	-0.00312	0.00415
Sr*Time^2	-0.00000	0.00001	-0.00002	0.00001

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient and an interaction with a linear and quadratic time trend with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.6: Percentage of Orchards by Senior and Groundwater Rights

Comparison	Mean without Right	Mean with Right	t-statistic	p-value
% Orchard by Senior	17.1	24.7	-4.506	0.000
% Orchard by Groundwater	19.4	30.9	-3.324	0.001
% Orchard by Groundwater (Senior Only)	24.6	26.5	-0.344	0.732
% Orchard by Groundwater (Junior Only)	15.5	33.3	-4.071	0.000

Note: The rows represent comparisons of the percentage of parcels that have orchard as the primary crop by senior and groundwater rights. The last two rows compare groundwater rights isolating the senior and junior sample. The sample percentage of orchards is 20%.

Table A.7: Robustness for Aggregate Senior Premium - 90% HPD

	(1) Base	(2) No Developed	(3) No Residential	(4) Price	(5) Acres	(6) Year	(7) County*Time	(8) County*Roll
Senior	0.049	0.059	0.045	0.042	0.051	0.039	0.023	0.021
	[-0.02, 0.12]	[-0.01, 0.13]	[-0.04, 0.13]	[-0.01, 0.1]	[-0.02, 0.12]	[-0.03, 0.11]	[-0.04, 0.09]	[-0.05, 0.09]
Groundwater	0.134	0.157	0.182	0.067	0.19	0.125	0.099	0.111
	[0.04, 0.22]	[0.06, 0.25]	[0.07, 0.29]	[-0.01, 0.14]	[0.09, 0.29]	[0.03, 0.21]	[0.01, 0.19]	[0.02, 0.2]
Observations	2392	2168	1621	1912	1911	2392	2392	2392

Note: The rows display estimates of the posterior means with the 90% HPD interval underneath.The columns represent different regression models.

Table A.8: Heterogeneity In Senior Premium - 90% HPD

	(1) Base	(2) Right	(3) Orchard	(4) Right & Orchard
Senior	0.049	0.066	0.08	0.096
	[-0.02, 0.118]	[-0.005, 0.137]	[0.005, 0.152]	[0.022, 0.174]
Groundwater	0.134	0.2	0.128	0.193
	[0.042, 0.223]	[0.088, 0.312]	[0.043, 0.225]	[0.083, 0.308]
Orchard	0.22	0.22	0.295	0.292
	[0.153, 0.286]	[0.156, 0.288]	[0.203, 0.387]	[0.199, 0.381]
Sr*Groundwater		-0.183		-0.176
		[-0.369, -0.001]		[-0.353, 0.011]
Sr*Orchard			-0.141	-0.137
			[-0.259, -0.016]	[-0.261, -0.019]
Observations	2392	2392	2392	2392

Note: The rows display estimates of the posterior means with the 90% HPD interval underneath.The columns represent different regression models.

C MCMC Convergence Diagnostics

The Gibbs sampler is an MCMC procedure where arbitrary initial values may bias the results. There are several diagnostic tools used to assess the convergence of the Gibbs sampler to the true joint posterior distribution, ensuring that the effect of the starting values has worn off. We employ three tools that all indicate that the Gibbs sampler reached convergence. The dependence factor, also known as the I-statistic, is the ratio of the number of draws required for given accuracy level to the number of draws necessary if the chain was i.i.d., developed by Raftery and Lewis (1992). Table A.9 shows that for an accuracy level of 0.5% the I-statistic for all parameters is around 1, which is the recommended level and safely below the recommended threshold of 5. Next I use the Geweke diagnostics Geweke (1992) which tests the equality in means for two regions of the Gibbs sampler. I use the first 20% and the last 50% of the MCMC draws. If the Gibbs sampler reached convergence then any subset should represent the true joint posterior and there should be no difference in parameter means for different regions. Table A.10 shows z-statistics and the associated p-values for the χ^2 test for the null of equal means. Almost every parameter has p-values well above the 10% level. Another set of diagnostics is the Heidelberger-Welch test for stationarity and the halfwidth test. These tests assess if the length of MCMC draws is sufficient for the distribution to be deemed stationary. Table A.11 shows that all parameters are determined to come from a stationary distribution and the halfwidth test shows that most are below the conventional halfwidth/mean ratio threshold of 0.1. Lastly I assess the autocorrelation of draws in the parameter chain, which is another metric to determine if the Gibbs sampler is drawing from the true distribution. The low level of serial correlation in the Gibbs draws as shown in Table A.12 provides evidence that the draws represent and independent sample. These diagnostics tool suggest that the Gibbs sampler has reached convergence; not a surprise given that running 40,000 draws with 100,000 burn-in draws is extremely circumspect.

Table A.9: Raftery-Lewis MCMC Diagnostics

	Burn-in (M)	Total (N)	Lower bound (Nmin)	Dependence factor (I)
Interpect	2	3710	3746	0.99
Senior	2	3730	3746	1.00
Groundwater	2	3781	3746	1.01
Residential	2	3720	3746	0.99
Reservation	2	3680	3746	0.98
Benton	2	3844	3746	1.03
Kittitas	2	3730	3746	1.00
Acres	2	3781	3746	1.01
$Acres^2$	2	3649	3746	0.97
$Acres^3$	2	3649	3746	0.97
Improvements	2	3730	3746	1.00
$Improvements^2$	2	3802	3746	1.01
Rolling Avg TWSA	2	3761	3746	1.00
Deviation TWSA	2	3771	3746	1.01
Time	2	3730	3746	1.00
$Time^2$	2	3761	3746	1.00
$Time^3$	2	3792	3746	1.01
Rolling Avg	2	3771	3746	1.01
$Rolling\ Avg^2$	2	3720	3746	0.99
$Rolling\ Avg^3$	2	3761	3746	1.00
Soil Productivity	1	3750	3746	1.00
$Soil\ Productivity^2$	2	3761	3746	1.00
$Soil\ Productivity^3$	2	3730	3746	1.00
Slope	2	3740	3746	1.00
$Slope^2$	2	3740	3746	1.00
$Slope^3$	2	3771	3746	1.01
Dist Stream	2	3680	3746	0.98
$Dist\ Stream^2$	2	3710	3746	0.99
$Dist\ Stream^3$	2	3740	3746	1.00
Dist City	2	3690	3746	0.98
Residential - ID 20NN	1	3750	3746	1.00
Improvements - ID 20NN	2	3844	3746	1.03
Slope - ID 20NN	2	3771	3746	1.01
$Orchard_1$	2	3771	3746	1.01
$Developed_1$	2	3700	3746	0.99
σ^2	2	3710	3746	0.99

Table A.10: Geweke MCMC Diagnostics

	Z-statistic	p-value
Interpect	-1.208	0.227
Senior	-0.752	0.452
Groundwater	-0.356	0.722
Residential	0.226	0.821
Reservation	-1.525	0.127
Benton	-0.208	0.835
Kittitas	-0.155	0.877
Acres	-1.361	0.174
Acres^2	1.679	0.093
Improvements	0.898	0.369
Rolling Avg TWSA	-1.318	0.188
Deviation TWSA	0.574	0.566
Time	0.360	0.719
Time^2	-0.504	0.614
Time^3	0.526	0.599
Rolling Avg	1.178	0.239
Rolling Avg^2	-1.155	0.248
Rolling Avg^3	1.134	0.257
Soil Productivity	1.015	0.310
$\text{Soil Productivity}^2$	-0.970	0.332
$\text{Soil Productivity}^3$	0.939	0.348
Slope	1.177	0.239
Slope^2	-1.802	0.072
Slope^3	1.902	0.057
Dist Stream	1.739	0.082
Dist Stream^2	-1.196	0.232
Dist Stream^3	0.702	0.483
Dist City	-0.108	0.914
Residential - ID 20NN	0.347	0.729
Improvements - ID 20NN	0.964	0.335
Slope - ID 20NN	-0.549	0.583
Orchard_1	-1.850	0.064
Developed_1	-1.135	0.256
σ^2	1.484	0.138

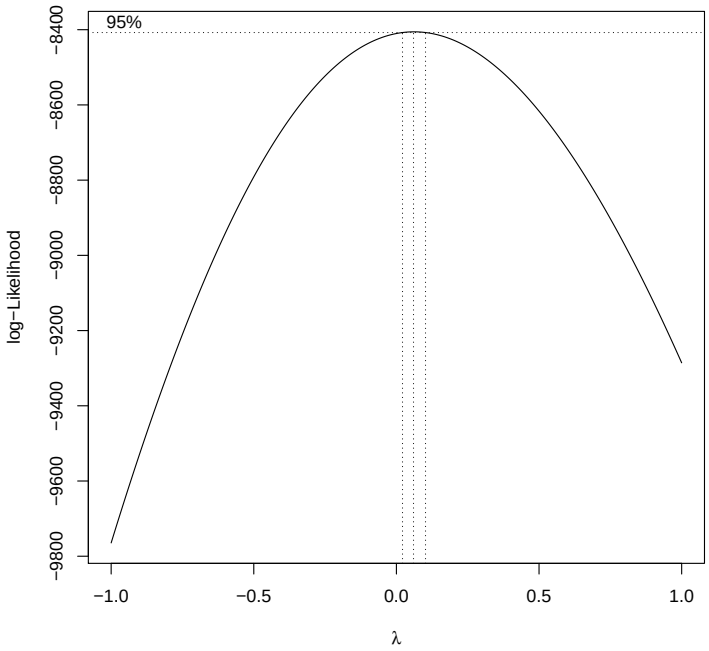
Table A.11: Heidelberger-Welch MCMC Diagnostics

	Stationarity Test p-value	Mean	Halfwidth	Ratio
Interpect	0.176	-87.156	2.461	-0.028
Senior	0.644	0.049	0.000	0.010
Groundwater	0.972	0.134	0.001	0.005
Residential	0.516	0.190	0.000	0.002
Reservation	0.268	-0.139	0.001	-0.007
Benton	0.915	0.232	0.001	0.003
Kittitas	0.702	0.653	0.001	0.002
Acres	0.088	-0.010	0.000	-0.001
Acres^2	0.053	0.000	0.000	0.002
Improvements	0.482	0.000	0.000	0.002
Rolling Avg TWSA	0.101	0.052	0.000	0.009
Deviation TWSA	0.657	-0.037	0.000	-0.007
Time	0.219	0.002	0.000	0.020
Time^2	0.234	0.000	0.000	0.021
Time^3	0.291	-0.000	0.000	-0.023
Rolling Avg	0.189	27.512	0.864	0.031
Rolling Avg^2	0.199	-2.777	0.101	-0.036
Rolling Avg^3	0.209	0.092	0.004	0.043
Soil Productivity	0.259	0.207	0.001	0.004
$\text{Soil Productivity}^2$	0.236	-0.003	0.000	-0.004
$\text{Soil Productivity}^3$	0.219	0.000	0.000	0.004
Slope	0.329	0.012	0.000	0.010
Slope^2	0.111	-0.002	0.000	-0.004
Slope^3	0.090	0.000	0.000	0.004
Dist Stream	0.207	-0.133	0.001	-0.006
Dist Stream^2	0.508	0.100	0.000	0.003
Dist Stream^3	0.525	-0.013	0.000	-0.003
Dist City	0.598	0.010	0.000	0.003
Residential - ID 20NN	0.849	-0.231	0.003	-0.011
Improvements - ID 20NN	0.213	0.000	0.000	0.004
Slope - ID 20NN	0.917	0.040	0.000	0.002
Orchard_1	0.155	0.221	0.000	0.002
Developed_1	0.632	0.191	0.001	0.003
σ^2	0.354	0.480	0.000	0.000

Table A.12: Autocorrelation of MCMC draws

	Lag 0	Lag 1	Lag 5	Lag 10	Lag 50
Interpect	1	-0.004	0.010	0.005	0.012
Senior	1	-0.010	0.003	-0.004	-0.004
Groundwater	1	0.009	0.001	0.003	-0.005
Residential	1	-0.004	0.011	-0.007	-0.007
Reservation	1	0.002	0.003	0.007	0.000
Benton	1	0.002	-0.004	0.000	0.005
Kittitas	1	0.001	-0.008	0.004	0.007
Acres	1	0.002	0.000	-0.002	0.006
Acres^2	1	0.005	-0.002	0.000	0.005
Acres^3	1	0.006	-0.001	0.002	0.007
Improvements	1	-0.004	0.001	0.008	-0.005
Improvements^2	1	-0.003	-0.000	0.007	-0.002
Rolling Avg TWSA	1	-0.000	0.000	0.000	0.007
Deviation TWSA	1	0.004	-0.003	-0.000	0.001
Time	1	-0.004	-0.005	0.008	0.006
Time^2	1	-0.003	-0.003	0.008	0.006
Time^3	1	-0.003	-0.002	0.008	0.006
Rolling Avg	1	-0.004	0.010	0.005	0.012
Rolling Avg^2	1	-0.004	0.010	0.005	0.012
Rolling Avg^3	1	-0.004	0.010	0.005	0.012
Soil Productivity	1	0.003	0.004	0.001	0.002
$\text{Soil Productivity}^2$	1	0.002	0.005	0.002	0.002
$\text{Soil Productivity}^3$	1	0.002	0.005	0.002	0.002
Slope	1	0.004	0.000	-0.010	-0.012
Slope^2	1	0.008	-0.005	-0.008	-0.009
Slope^3	1	0.010	-0.006	-0.004	-0.007
Dist Stream	1	0.007	-0.006	-0.001	0.005
Dist Stream^2	1	0.010	-0.002	-0.001	0.006
Dist Stream^3	1	0.011	-0.001	-0.004	0.006
Dist City	1	-0.001	0.005	0.006	-0.004
Residential - ID 20NN	1	0.007	-0.007	0.004	0.010
Improvements - ID 20NN	1	0.002	0.002	-0.003	0.002
Slope - ID 20NN	1	0.009	0.005	0.006	-0.004
Orchard_1	1	-0.002	-0.007	0.001	-0.005
Developed_1	1	0.003	-0.001	0.007	-0.008
σ^2	1	0.010	-0.004	-0.004	-0.012

Figures



Note: This is the a Box-Cox test for model specification in the base regression. Values of λ range from -1 to 1 in increments of 0.01. The preferred value of λ is 0.06, and the 95% confidence interval barely excludes zero.

Figure A.1: Box Cost Test

References

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