Empirical Natural Resource Economics

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Empirical studies of dynamic natural resource use

- Forestry
  - Provencher, B. 1995. Structural Estimation of the Stochastic Dynamic Decision Problems of Resource Users: An Application to the Timber Harvest Decision. Journal of Environmental Economics and Management 29:321-38.
  - Provencher, B. 1997. Structural versus Reduced-Form Estimation of Optimal Stopping Problems. American Journal of Agricultural Economics 79: 357-68.
  - Berck, P., and W.R. Bentley. 1997. Hotelling's Theory, Enhancement, and the Taking of the Redwood National Park. Am. J. Agr. Econ. 79: 287-98.
- Fisheries
  - Huang, L., and M.D. Smith. 2014. The Dynamic Efficiency Costs of Common-Pool Resource Exploitation. American Economic Review 104(12):4071-4103.
  - Smith, M.D. 2005. State dependence and heterogeneity in fishing location choice. Journal of Environmental Economics and Management 50: 319-340.
  - Provencher, B., and R.C. Bishop. 1997. An Estimable Dynamic Model of Recreation Behavior with an Application to Great Lakes Angling. Journal of Environmental Economics and Management 33(2): 107-127.
- Non-renewable resources
  - Lin, C.-Y. Cynthia and Gernot Wagner. 2007. Steady-state growth in a Hotelling model of resource extraction. Journal of Environmental Economics and Management 54: 68-83.
  - Berck, P., and M. Roberts. 1996. Natural Resource Prices: Will They Ever Turn Up? Journal of Environmental Economics and Management 31(1): 65-78.
  - Lee, J., List, J.A., and M.C. Strazicich. 2006. Non-renewable resource prices: Deterministic or stochastic trends? Journal of Environmental Economics and Management 51: 354-370.
  - Halversen, R., and T.R. Smith. 1991. A Test of the Theory of Exhaustible Resources. Quarterly Journal of Economics 106(1): 123-140.
- Land
  - Plantinga, A.J., Lubowski, R.N., and R.N. Stavins. 2002. The Effects of Potential Land Development on Agricultural Land Prices. *Journal of Urban Economics* 52(3):561-581.
  - Severen, C., Costello, C. and Deschenes, O., 2018. A Forward-Looking Ricardian Approach: Do land markets capitalize climate change forecasts?. *Journal of Environmental Economics and Management*, *89*, pp.235-254.
  - De Pinto, A. and Nelson, G.C., 2009. Land use change with spatially explicit data: a dynamic approach. *Environmental and Resource Economics*, *43*(2), pp.209-229.
- Water (not dynamic)
  - Bigelow, D., Plantinga, A.J., Lewis, D.J., and C. Langpap. 2017. How Does Urbanization Affect Water Withdrawals? Insights from an Econometric-Based Landscape Simulation. Land Economics 93(3):413-436.
  - Olmstead, S.M., and H. Sigman. 2015. Damming the Commons: An Empirical Analysis of International Cooperation and Conflict in Dam Location. Journal of the Association of Environmental and Resource Economists 2(4): 497-526.

Provencher 1995

- Do timber owners behave according to Bellman’s principle?
- Use data on actual harvesting decisions by timber owners to estimate a structural dynamic model of resource use under uncertainty, following Rust (1987).

Theory

$$p_t = \alpha_0 + \alpha_1 p_{t-1} + \varepsilon_t,$$

$$J(p_t, v_t, \theta_t) = \max\{\pi^0(p_t, v_t, \theta_t), \pi^1(p_t, v_t, \theta_t)\},$$

$$\pi^0(\cdot) = \beta E\{J(p_{t+1}, v_{t+1}, \theta_{t+1})\},$$

$$\pi^1(\cdot) = p_t v_t + \gamma + \theta_t,$$

$$v_{t+1} = f(v_t),$$

- Θ is random profit shock observed by the landowner and but not by the econometrician; v is the volume of timber; *γ* is the value of land following harvest

Empirical model

$$\Pr(i_t = 1 | p_t, v_t, \Gamma) = \Pr\left(p_t v_t + \gamma + \theta_t > \beta E\{J(p_{t+1} v_{t+1}, \theta_{t+1} | \Gamma)\}\right)$$

$$= \Pr\left(\theta_t > \beta E\{J(\cdot|\Gamma)\} - p_t v_t - \gamma\right)$$

$$= \int_A^\infty g(\theta)\, d\theta,$$

$$\Gamma = \{\gamma, \alpha_0, \alpha_1, \sigma_\varepsilon, \sigma_\theta, \beta, \psi\}$$

$$A = \beta E\{J(\cdot|\Gamma)\} - p_t v_t - \gamma,$$

$$L(\Gamma) = \prod_{k=1}^{K} \prod_{t=1}^{T} \Pr(i_{kt} | p_t, v_{kt}, \Gamma)$$

$$= \prod_{k=1}^{K} L_k(\Gamma).$$

- i_{kt} is the binary harvest decision on plot k in time t and Ψ is a fixed terminal value in the event of no harvest.

Estimation

- Maximum likelihood search over parameters in Γ. At every iteration, the likelihood value can only be computed after the stochastic DP problem is solved to obtain the expected value function $E\{J(\cdot|\Gamma)\}$
- Model is estimated with quarterly observations of forest plots in southeast Georgia for the period 1982-1987. Attention is limited to plots:
  - Owned by forest industry firms
  - Planted in slash pine
  - Site index 60-70

TABLE II

Estimation Results[a]

Model no.	Model	Parameter β	ψ	α_0	α_1	σ_ε	σ_0	Log like value	Like-ratio test statistic[b]
1.	Unrestricted	1.0201	1.669	−2.040	1.062	.004	.4340	−249.85	—
		(.009)	(.636)	(.509)	(.021)	(.495)	(.132)		
2.	Alternative "best"	.9742	2.057	0.009	1.000	1.689	.0616	−253.76	7.82
		(.0003)	(.234)	(.045)	(.002)	(.266)	(.012)		
3.	$\beta = .96$	.9600[c]	2.401	−9.702	1.209	13.732	.2425	−270.97	42.24
4.	Faustmann	1.0136	1.851	0.0[c]	1.000[c]	0.0[c]	9.0077	−262.66	25.62
5.	"True" price process	1.0140	1.866	9.080[c]	.654[c]	2.099[c]	8.8284	−262.50	25.30

[a] To simplify the presentation, the discount factor is presented in annual terms. So, for instance, a reported discount factor of .99 corresponds to an annual discount rate of 1%. Standard errors for the unrestricted model and the alternative "best" model are in parentheses.

[b] The test statistic is distributed as a chi-square variable with degrees of freedom equal to the number of restrictions. At the .01 significance level the null hypothesis is rejected if the value of the test statistic exceeds the following (degrees of freedom in parentheses): $\chi^2(1) = 6.635$; $\chi^2(2) = 9.210$; $\chi^2(3) = 11.345$; $\chi^2(6) = 16.8$. At the .1 significance level the null hypothesis is rejected if the value of the test statistic exceeds the following: $\chi^2(1) = 2.706$; $\chi^2(2) = 4.605$; $\chi^2(3) = 6.251$; $\chi^2(6) = 10.6$.

[c] Parameter value is not estimated in the model; it represents a restriction.

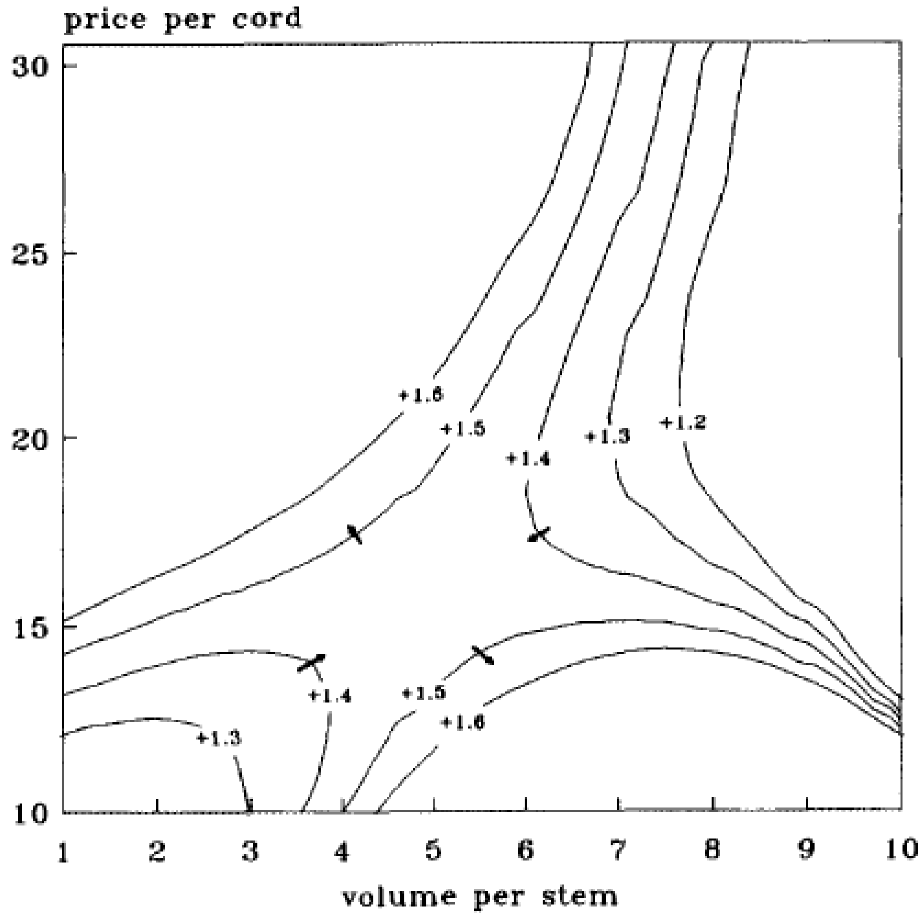

FIG. 1. Profit shock contour mapping of the optimal policy.

- For a given price-volume pair, harvest occurs if the profit shock is larger than the corresponding contour value.

Provencher 1997

- Is structural estimation worth it? How good of an approximation is a reduced-form model? Potential pitfalls include
  - Misspecification
    - For example, a probit model that is linear in the state variables imposes linearity on the value function:

$$(9) \quad \beta_0 + \beta_1 s_{jt} + \beta_2 p_t \equiv -A \equiv p_t v(s_t) + \lambda - \theta E\{V(s_{j,t+1}, p_{t+1})\}$$

  - Misinterpretation of parameters
    - For example, the effect of price on the probability of harvest
  - The Lucas Critique: a reduced-form model may result in faulty predictions of the effects of a policy change because the estimated parameters of the reduced-form model are dependent on the policy in effect during the historical period.
    - For example, consider analyzing the effects of a yield tax.

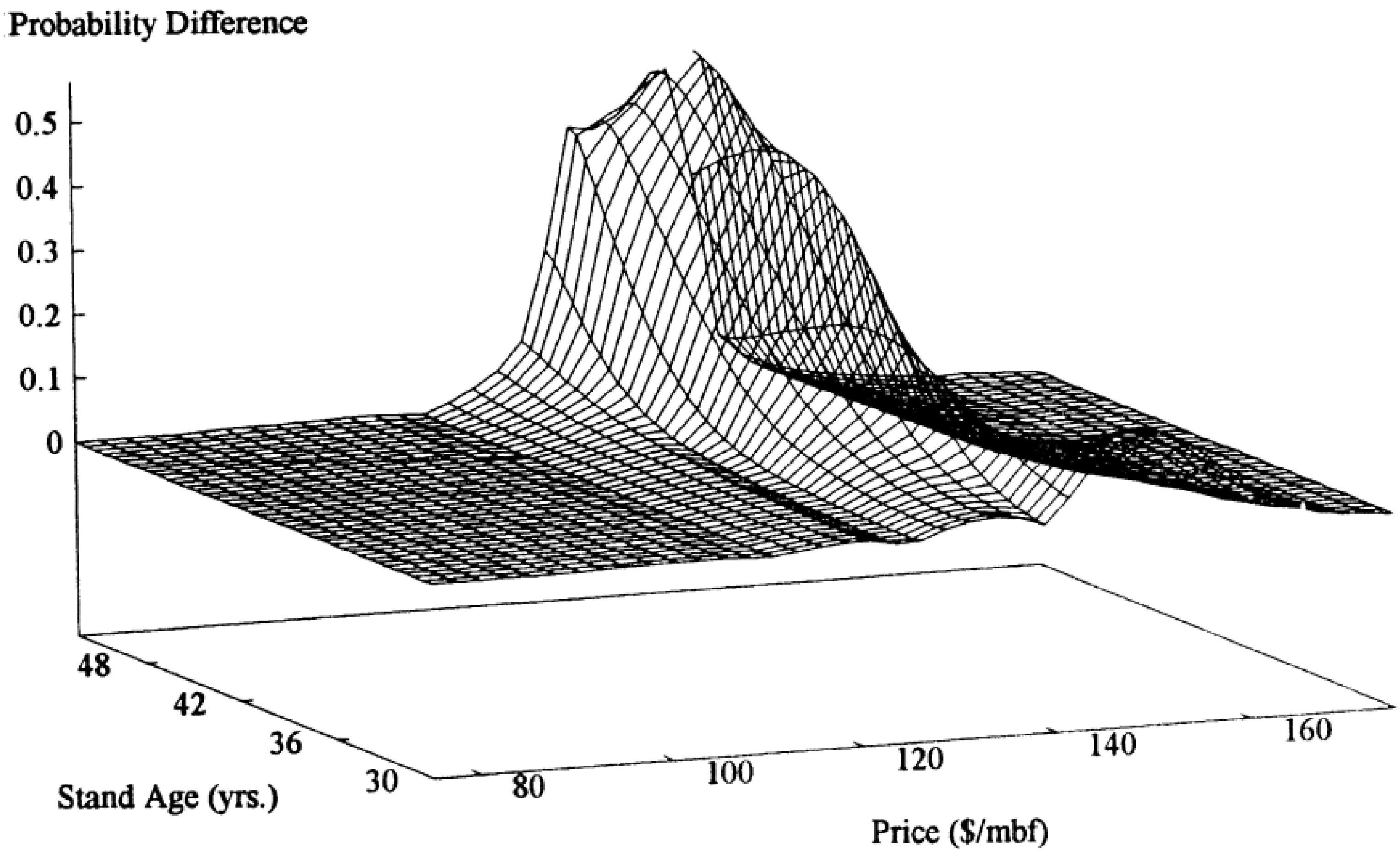

Figure 2. Difference in the probability of harvest: standard probit model versus structural model

Table 2. Actual and Predicted Probabilities of Harvest, With and Without the Addition of a $10/MBF Yield Tax

	Stand Age (yrs.)			
	35	40	45	50
Price ($/mbf)	Probability of Harvest			
130	0.0000	0.0003	0.0004	0.0004
	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0002	0.0003	0.0003
135	0.0000	0.0269	0.0588	0.0986
	0.0000	0.0000	0.0000	0.0000
	0.0066	0.0245	0.0497	0.0798
140	0.0960	0.3264	0.5711	0.7522
	0.0010	0.0023	0.0012	0.0001
	0.1007	0.3123	0.5383	0.7191
145	0.4538	0.8483	0.9728	0.9965
	0.0284	0.0844	0.0934	0.0413
	0.4645	0.8388	0.9672	0.9950
150	0.8583	0.9941	0.9999	1.0000
	0.2327	0.5338	0.6567	0.5902
	0.8643	0.9933	0.9999	1.0000

Note: For each price-age combination, the top number is the actual (structurally derived) probability of harvest with the yield tax, and the bottom number is the actual probability of harvest without the yield tax. The middle number is the probability of harvest with the yield tax predicted by the reduced-form model (see text).

- A yield tax that lowers revenue in every period has little effect on harvest probabilities. In contrast, the predicted effect is large in a reduced-form model where the simulated effect is a drop in only the current price of timber.

Lin and Wagner (2007)

- What explains the fact that market prices for minerals are essentially constant over time?
  - Hotelling's theory predicts that (under certain conditions) market price rise at the rate of interest.
  - Market prices also rise with stock effects (marginal extraction costs rise as the stock is depleted), but at a lower rate than the interest rate.
  - Technological innovation may decrease extraction costs over time, which can cause market prices to decline.
  - Decreasing demand can also cause market prices to decline.
- This paper incorporates stock effects, technological change, and time-varying demand into the Hotelling model and derives conditions under which market prices are constant.
- They then empirically test whether these conditions hold.

Theory

$$\max_{\{E(t)\}} \int_0^\infty (U(E(t),t) - C(X(t),E(t),t))e^{-rt}\,dt$$

$$\text{s.t.}\quad \dot{X}(t) = E(t) : q(t),$$

$$E(t) \geqslant 0,$$

$$X(0) = X_0,$$

X(t) is cumulative extraction

$$U(E(t),t) = \int_0^{E(t)} D^{-1}(x;t)\,dx,$$

- Specific functional forms:

$$C(X,E,t) = \Psi(X)Ee^{-\gamma t},$$

$$\Psi(X) \equiv \Psi_0 X^b,$$

Costs increasing in cumulative extraction

$$D(P,t) = AP^{-\frac{1}{\eta}}e^{\frac{a}{\eta}t},$$

Results

Proposition 1. *With isoelastic decaying costs* (8) *and isoelastic time-varying demand* (11), *the optimal extraction rate is given by*

$$E(t) = gX(t) \longleftarrow \text{Extraction increases over time?} \tag{15}$$

and the growth rate of prices is constant,

$$\frac{\dot{P}(t)}{P(t)} = -\eta g + a, \tag{16}$$

where the growth rate g is given by

$$g = \frac{\gamma + a}{b + \eta}. \tag{17}$$

Proposition 2. *The market price $P(t)$ is constant if the growth rate of extraction is given by*

$$g = \frac{a}{\eta},$$

or, equivalently,

$$\frac{\gamma}{b} = \frac{a}{\eta}.$$

Empirics

Table 2
Tests of the stylized fact that the growth rates of prices equal zero

	BAU	COP	GOL	HC	IRO	LEA	NG	NIC	OIL	PHO	SC	SIL	TIN	ZIN
$\dot{P}(t)/P(t)$ 1970–2004														
Year	−1.04	0.71	−2.05**	−1.50	−0.54	−0.66	0.02	1.19	−0.91	−0.91	−1.50	−1.04	−1.29	−1.17
Constant	0.57	−0.72	1.95*	1.16	0.02	0.38	0.57	−0.58	1.10	0.78	1.16	0.95	0.71	0.93
$\dot{P}(t)/P(t)$ 1974–2004														
Year	−1.07	0.92	−1.00	−1.07	−0.37	−0.50	−0.18	1.20	−0.87	−0.86	−1.07	−0.81	−0.95	−0.30
Constant	0.65	−0.99	0.89	0.75	−0.13	0.24	0.78	−0.45	1.02	0.75	0.75	0.72	0.40	−0.04
$\dot{P}(t)/P(t)$ using Berck–Roberts data														
Year	1.00	0.07	—	—	0.06	0.17	1.53	—	0.31	—	—	1.10	—	−0.55
Constant	−0.98	0.25	—	—	0.23	0.19	−1.27	—	0.03	—	—	−0.96	—	0.98

The table presents *t*-statistics for regressions of the growth rates on year and a constant term.
BAU, bauxite; COP, copper; GOL, gold; HC, hard coal; IRO, iron; LEA, lead; NG, natural gas; NIC, nickel; OIL, oil; PHO, phosphate; SC, brown coal; SIL, silver; TIN, tin; ZIN, zinc. Two stars (**) indicate significance at the 5% level, one star (*) indicates significance at the 10% level. Year in each case is normalized for the first year of the time period to equal 0. Regressions with robust standard errors. The third set of tests uses the entire data series from Berck and Roberts [2]. For BAU the years covered are 1895–1991, for COP 1870–1991, for IRO 1870–1985, for LEA 1870–1988, for OIL 1870–1991, for NG 1880–1991, for SIL 1901–1991, and for ZIN 1870–1991.
Source: Unpublished World Bank data and Berck and Roberts [2].

- Basic series is average real world prices, 1970-2004
- Model is $\frac{\dot{p}}{p} = \beta_0 + \beta_1 t$
- Support found for stylized fact that growth rate in prices are trendless and zero.

Empirics

$$\ln MC = \ln AC = \ln \Psi_0 + b \ln X - \gamma t$$

$$\ln P = \ln A - \eta \ln E + at,$$

where X is cumulative extraction, P is price, E is current extraction. Models estimated with SUR with pooled data and disaggregated with country fixed effects. Also, 3SLS estimates with additional instruments added.

Table 3
Seemingly unrelated regression for demand and supply pooled across all countries

	BAU	COP	GOL	HC	IRO	LEA	NG	NIC	OIL	PHO	SC	SIL	TIN	ZIN
$\ln P =$														
$\ln A$	132.49	62.40	116.99	155.73	70.91	100.34	137.29	51.97	265.48	59.34	30.26	131.69	178.85	66.56
	(6.43)	(4.13)	(12.36)	(7.9)	(5.43)	(3.43)	(9.45)	(4.92)	(4.35)	(1.81)	(2.49)	(5.86)	(6.54)	(4.37)
η	0.83	−0.14	1.74	1.64	0.17	0.30	2.25	0.05	2.60	0.01	−0.53	0.83	0.48	0.16
	(3.14)	(0.71)	(12.16)	(5.28)	(1.27)	(1.32)	(12.23)	(0.69)	(4.67)	(0.03)	(3.35)	(2.47)	(2.06)	(1.10)
a	−0.06	−0.03	−0.04	−0.06	−0.03	−0.04	−0.05	−0.02	−0.10	−0.03	−0.02	−0.06	−0.08	−0.03
	(7.00)	(4.62)	(10.19)	(8.43)	(6.06)	(3.44)	(7.34)	(4.23)	(4.09)	(2.06)	(3.81)	(5.63)	(6.62)	(4.29)
$\ln \mathrm{MC} =$														
$\ln \varphi$	153.91	160.62	123.31	78.91	294.99	51.34	521.06	87.31	535.77	66.87	61.85	157.58	168.97	83.63
	(8.12)	(7.72)	(10.50)	(10.10)	(12.82)	(5.22)	(10.09)	(5.57)	(5.06)	(5.94)	(6.67)	(10.41)	(15.01)	(10.80)
b	0.29	0.07	0.92	0.16	0.94	−0.13	1.32	0.03	1.82	0.04	0.02	0.43	0.46	0.17
	(2.28)	(0.42)	(8.98)	(2.67)	(4.72)	(1.70)	(4.62)	(0.35)	(2.52)	(0.54)	(0.38)	(3.97)	(5.17)	(3.66)
γ	0.08	0.08	0.06	0.04	0.16	0.02	0.27	0.04	0.29	0.03	0.03	0.08	0.08	0.04
	(7.39)	(6.59)	(9.23)	(8.83)	(11.70)	(3.94)	(9.55)	(4.66)	(4.78)	(5.24)	(5.84)	(9.34)	(13.63)	(9.68)

BAU, bauxite; COP, copper; GOL, gold; HC, hard coal; IRO, iron; LEA, lead; NG, natural gas; NIC, nickel; OIL, oil; PHO, phosphate; SC, brown coal; SIL, silver; TIN, tin; ZIN, zinc. Parentheses depict absolute values of t-statistics.

Source: Unpublished World Bank data.

Test of a zero growth rate in prices

Table 7
Test of main result in Proposition 2 using coefficients from SUR with country fixed effects

	BAU	COP	GOL	HC	IRO	LEA	NG	NIC	OIL	PHO	SC	SIL	TIN	ZIN
$H_0 : \frac{\gamma}{b} = \frac{a}{\eta}$														
$\chi^2 =$	4.51	0.45	5.14	0.78	2.10	3.13	0.25	0.31	1.92	5.13	1.09	2.95	8.46	9.04
Prob. $> \chi^2 =$	0.03	0.50	0.02	0.38	0.15	0.08	0.61	0.57	0.17	0.02	0.30	0.09	0.00	0.00

BAU, bauxite; COP, copper; GOL, gold; HC, hard coal; IRO, iron; LEA, lead; NG, natural gas; NIC, nickel; OIL, oil; PHO, phosphate; SC, brown coal; SIL, silver; TIN, tin; ZIN, zinc.
The critical value of χ^2 at the 5% significance level is 3.84. At the 1% significance level, it is 6.63. For values above that value, we reject the null hypothesis. The second row depicts the probability of not rejecting the null hypothesis. For bauxite (BAU), for example, we reject the null hypothesis at the 5% significance level because 0.03 $<$0.05; we do not reject it at the 1% significance level because 0.03 $>$0.01.
Source: Unpublished World Bank data.

Null hypothesis not rejected for nine minerals over the period 1970-2004.

Olmstead and Sigman 2015

- Do countries consider the welfare of other nations that share water resources when they make water development decisions?
  - Are countries more likely to build dams when downstream countries bear some of the costs (reduced quantity, altered temperature, fish passage, etc.)?
- Basic econometric model is:

$$\log(Dams_{ij}) = \beta C_{ij} + \gamma \log X_{ij} + \alpha_i + u_k + \varepsilon_{ij}, \quad (1)$$

where $Dams_{ij}$ is a count of dams in country i, subbasin j, C_{ij} is a measure of international resource sharing (presence and number of countries downstream and proximity to a downstream country), X_{ij} are other covariates.

- Number of dams is increasing in the presence of downstream countries, suggesting a willingness to pass costs on to other countries.