An illiquid market in the desert: estimating the cost of water trade restrictions in northern Chile

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ONLINE APPENDIX

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Energy-Cost Calculations

To calculate energy costs in table 4, we followed the following steps:

1. In a perfect world with no energy losses in pumps and motors, and no other energy losses due to friction, pipe bends, valves, and fittings, you would use 9.81 Joules of energy to lift one litre of water up a height of one meter (CottonInfo, 2015).
2. This means that, to lift one m3 of water up a height of one meter, you would need 9.81 kiloJoules (kJ) of energy.
3. 1 kiloWatt-hour (kWh) of electricity contains 3,600 kiloJoules (kJ) of energy (CottonInfo, 2015).
4. Statements 1 and 3 imply that to lift one m3 of water up a height of one meter, you would need 9.81/3,600 = 0.002725 kwh. This is so in a perfect, no-loss, world.
5. This means that to lift one m3/day up a height of "*x*" meters, the annual energy requirement would be:

$$Annual\ Energy\ Requirement = \frac{0.002725\ x*365}{1{,}000} = \\ = 0.000994625\ x\ (in\ MWH/(\text{m3/day}))$$

6. The above refers only to lifting energy requirements. Additionally, we have considered a "distance cost". We have assumed that the energy required to lift one m3 of water up a height of 1.2 meters is equivalent to the energy required to pump the same m3 of water to a distance of one kilometer (Zhou and Tol, 2005).
7. Statements 5 and 6 imply that the annual energy requirement to pump one m3/day of water up to a height of "*x*" meters, at a distance of "*y*" kilometers, is equal to:

$$Annual\ Energy\ Requirement = \\ = 0{,}000994625\ x + 0{,}00119355\ y\ (in\ MWH/(m3/day))$$

8. Assuming an efficiency factor of 50%, the annual energy requirement can be written as:

$$Annual\ Energy\ Requirement = \\ 0{,}00198925\text{x} + 0{,}0023871\ \text{y}\ (in\ MWH/(\text{m3/day}))$$

9. To this number, we add the desalination-plant annual energy cost, assumed to be equal to 2.4 MWH per m3/day.
10. We assumed an energy cost of 47.6 US dollars per MWH, equal to the average clearing price in 2016 auction to supply regulated-clients energy needs for 20 years starting in 2021.
11. We assumed a discount rate, to get a perpetuity value of water rights, of 6%, equal to the social rate of discount used by the Chilean Ministry of Social Development to evaluate public projects.
12. The above numbers imply an energy cost, in US dollars, per m3/day of water rights (perpetual) equal to:

$$1{,}904 + 1.5781\ x + 1.8938\ y$$

13. Table 4 uses the above formula in all cases, even though some projects involve seawater pumping. This is the case of Algorta Norte, Sierra Gorda, Esperanza and Michilla (partially). Today, common practice pumps desalinated water only.

Desalination Plant Data

Data in table 4 was initially collected from GWI (2012). Data was confirmed/updated using the following sources:

- Escondida/ El Coloso II was renamed "Escondida mega plant" and was **operational** in 2017: 216,000 m3/day capacity source: https://www.desalination.biz/news/0/Escondida-mega-plant-poised-to-produce-water-in-March/8648/; http://www.bechtel.com/projects/escondida-water-supply/
- Algorta Norte is an iodine producer and uses direct seawater; project was updated to **operational** (http://algortanorte.com/en/community/medio-ambiente/)
- Sierra Gorda utilizes seawater and was updated to **operational** (http://kghm.com/en/completion-seawater-pipeline-sierra-gorda-mine)
- Desaladora Sur is on hold but still intended to be built so was removed (http://www3.aguasantofagasta.cl/desalacion.html)

References

CottonInfo (2015) Fundamentals of energy use in water pumping. Fact sheet. Available at https://www.cottoninfo.com.au/sites/default/files/documents/Fundamentals%20EnergyFS_A_3a.pdf.

GWI (2012) Desalination tracker. *Global Water Intelligence* **13**(3), 48–49.

Zhou Y and Tol R (2005) Evaluating the costs of desalination and water transport. *Water Resources Research* **41**(3), W03003.

Table A1. Regression coefficient estimates for figure A2

		Mining		
Year	Coeff.	Const.	SE Coeff.	SE Const.
1995	1.093	3.723	0.822	0.671
1996	1.804	3.799	1.055	0.780
1997	1.874	3.657	0.634	0.560
1998	1.645	4.105	0.428	0.413
1999	0.836	4.735	0.741	0.622
2000	2.437	5.075	1.300	0.871
2001	-3.899	5.343	0.510	0.510
2002	-0.370	6.026	0.295	0.295
2003	0.392	6.496	0.887	0.553
2004	-	5.003	-	0.482
2005	-	6.381	-	1.119
2006	1.350	5.735	0.356	0.356
2007	0.839	6.021	0.251	0.229
2008	0.876	5.880	0.269	0.253
2009	1.816	5.296	0.778	0.754
2010	-	6.668	-	0.310
2011	0.510	6.442	0.943	0.382
2012	0.113	6.643	1.276	0.139
2013	0.261	6.911	0.196	0.141
2014	-	7.055	-	0.075

Notes: This table is created by examining only trades from agriculture to mining and agriculture to agriculture. The log of the price of a per-unit water right is regressed on a dummy indicating a mining buyer, with coefficients allowed to vary for each year: $\ln(P_j) = \alpha_t + \gamma_t I_{mining} + u_j$. Reported standard errors are robust.

Table A2. Results of baseline and sensitivity analyses

Scenario	Pumped water offset (m3/day)	Water transferred from agriculture (m3/day)	Annual cost (million US$)
Baseline	160,500	160,500	52.46
$Q_{ag} = 130K$	112,029	112,029	36.61
$Q_{ag} = 286K$	247,061	247,061	80.75
$\eta = -0.25$	87,017	87,017	25.51
$\eta = -0.90$	166,614	166,614	55.39
E=23.8	171,115	171,115	124.52
E=95.2	142,147	142,147	19.38
$\beta = .45$	371,973	167,388	127.57
$R_0 = 0.8$	95,904	95,904	15.80
$\hat{p}$ CI Low	172,044	172,044	63.21
$\hat{p}$ CI High	139,180	139,180	36.84

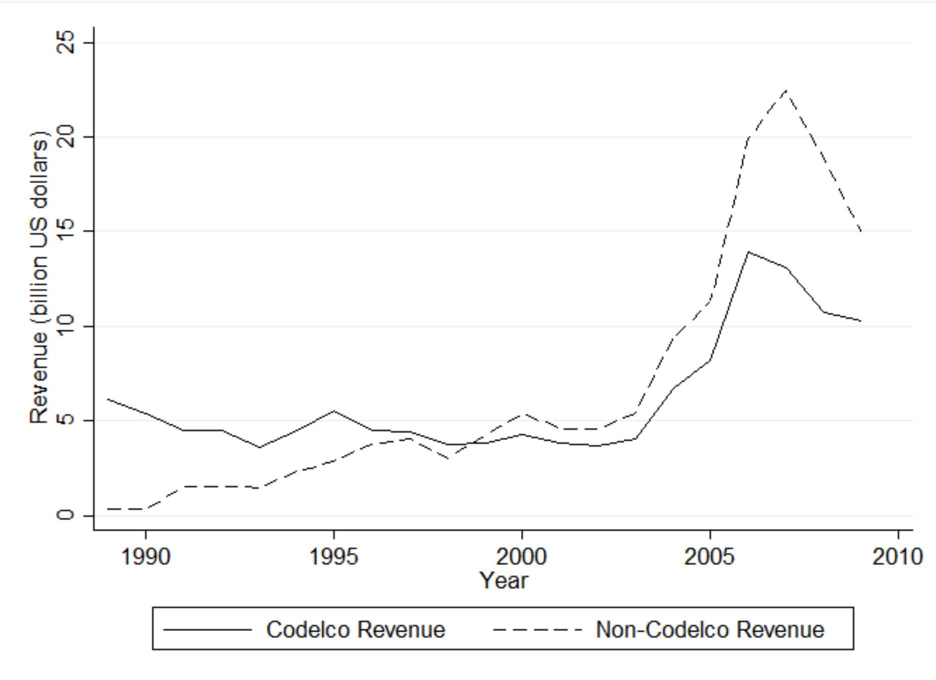

Figure A1. Copper revenues in the Antofagasta Region

Notes: Authors' calculation from Cochilco mine production data. Mines in Region II were designated as Codelco or other, and then production was summed.

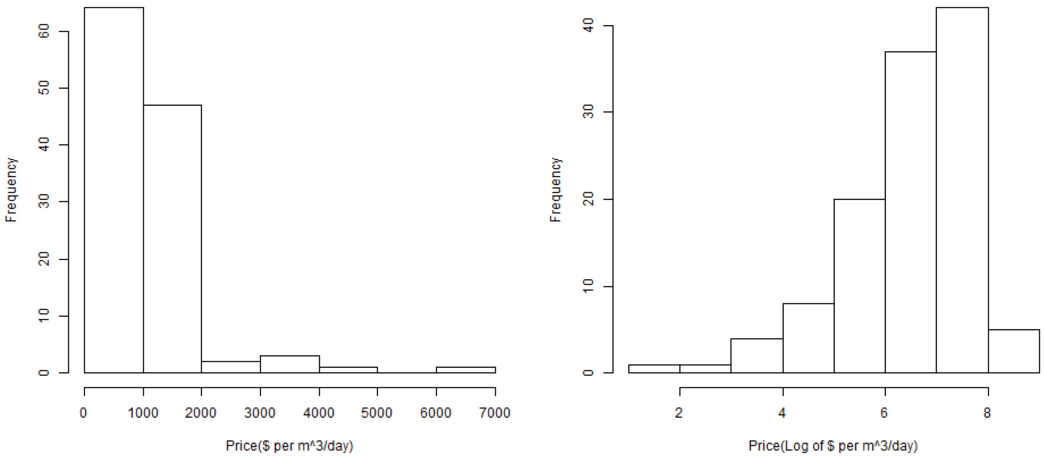

Figure A2. Distribution of prices (left) and log prices (right) of Agriculture-to-Agriculture sales 2004-2014

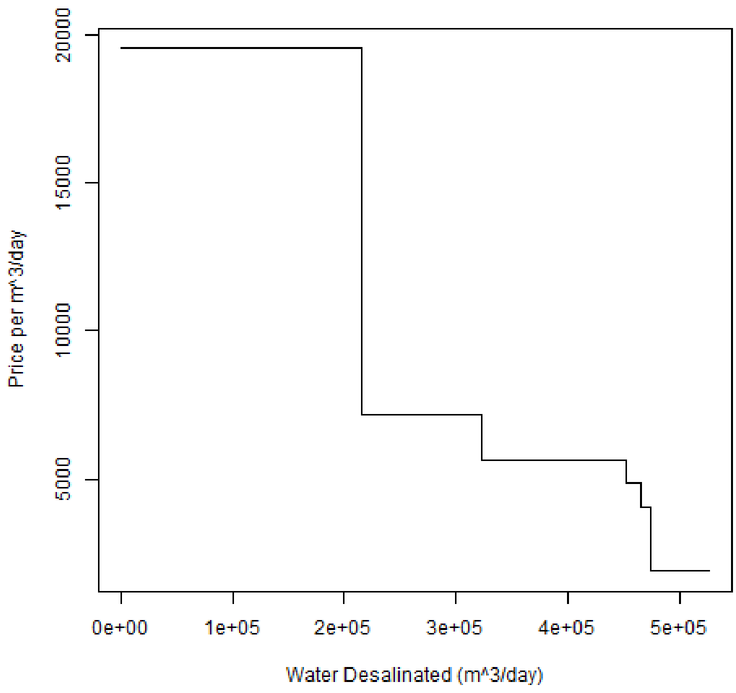

Figure A3. Desalinated water price function