CARBON TRADING AND POWER LAUNDERING:

EVIDENCE FROM THE WESTERN U.S.A.

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Agenda

- Research questions
- Key findings
- Background
- Data description
- Price effects of California's CO_2 cap and trade (C&T) program
- Unintended windfall gains and power laundering

Research questions

- Does the C&T program move the wholesale electricity prices in the Western U.S.A.?
- Is the C&T program effective in reducing the CO_2 emissions in the Western U.S.A.?
- The answers help determine if the C&T program can achieve the state's goal of mitigating global warming, in line with the international commitments of deep de-carbonization made in the 2015 Paris Summit on Climate Change

Why California? A global leader in clean energy development and de-carbonization, the state is the fifth largest economy in the world, with an installed generation capacity of ~80,000 MW in 2015, whose diverse fuel mix includes natural gas (~59%), large hydro (~16%), renewable (~22%), and nuclear (~3%). It is part of the Western Interconnection, a vast electric grid that covers parts of fourteen western states, two Canadian provinces, and one Mexican state.

Why should we care?

- An incomplete pass-through of the CO_2 emissions cost of natural gas generation in wholesale electricity prices indicates the C&T program's ineffectiveness in internalizing the CO_2 emissions' effect on climate change
- The electricity price increases triggered by the program reward solar, wind and hydro generators, thus promoting clean energy development
- These price increases, however, can lead to unintended windfall gains to CO_2-emitting generators and power laundering, *sans* CO_2 emissions reduction in the Western Interconnection

Key findings

- Using a 65-month (01/01/2011 through 05/31/2016) sample of daily market data, we quantify the effect of California's CO_2 C&T program on the wholesale electricity prices of four interconnected market hubs in the Western U.S.A.: North of Path 15 (NP15) and South of Path 15 (SP15) in California, Mid-Columbia (Mid-C) in the hydro-rich Pacific Northwest, and Palo Verde (PV) in the thermal-rich Desert Southwest
- A \$1/metric ton increase in California's CO_2 price is estimated to have respectively increased the electricity prices by \$0.41/MWh (p-value < 0.0001) for NP15, \$0.59/MWh (p-value < 0.0001) for SP15, \$0.41/MWh (p-value = 0.0056) for Mid-C, and \$0.15/MWh (p-value = 0.0925) for PV

Key findings

- These estimates reflect: (a) the NP15 and SP15 sellers' pricing behavior of fully including the CO_2 price in their intra-state transactions; (b) the Mid-C price's 100% pass-through of the CO_2 price in the Pacific Northwest's hydro export to California; and (c) the statutory obligation of paying the CO_2 emissions cost by California's buyers of the electricity imported from the Desert Southwest
- The policy implication is a C&T program that covers all four hubs is necessary to reduce the total CO_2 emissions in the Western U.S.A., while remedying power laundering due to the California program's inadequate geographic coverage

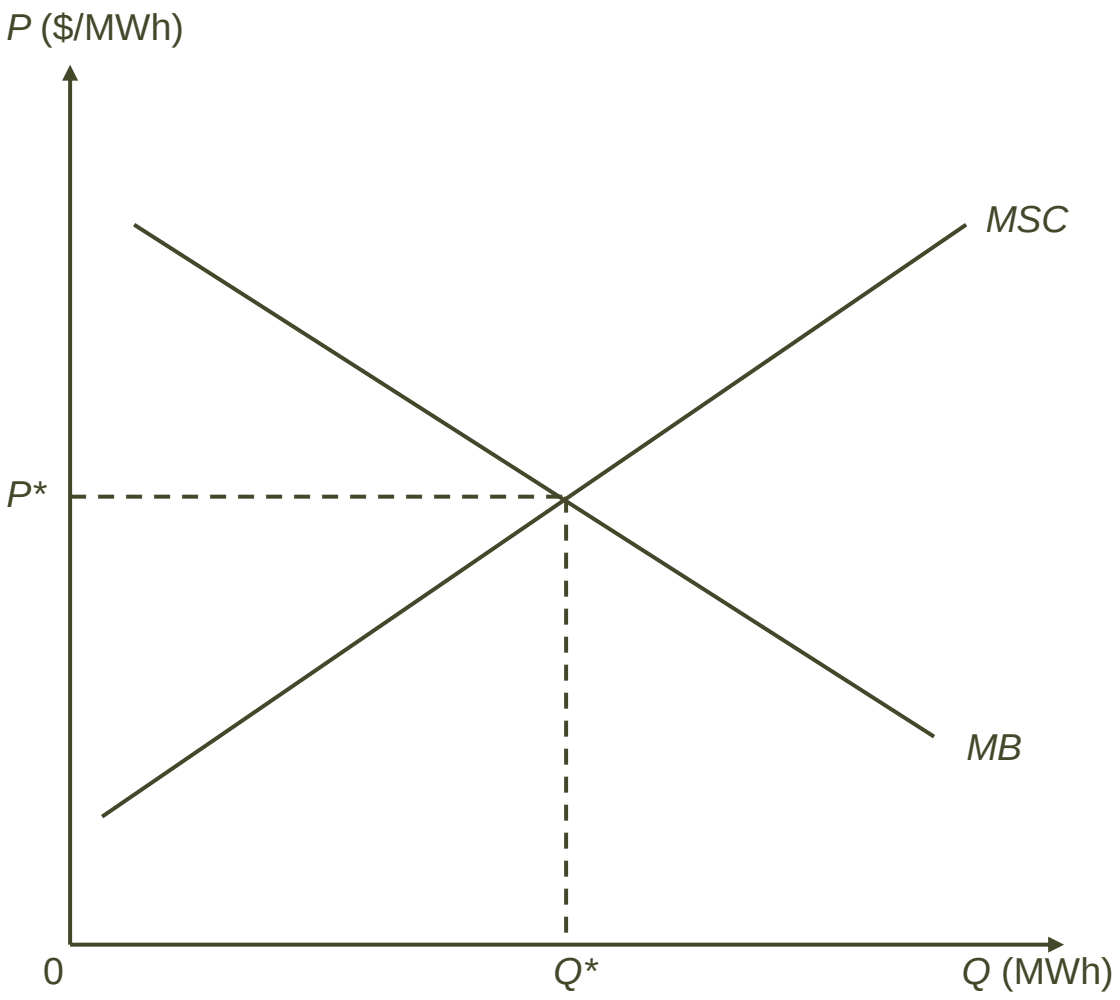
Background

This presentation summarizes the results from the market price analysis partially funded by the Bonneville Power Administration (BPA) and the Education University of Hong Kong:

- Olson, A., C.K. Woo, Y. Chen, J. Moore, N. Schlag, A. Ong, and T. Ho (2017) “Does California’s CO2 price affect wholesale electricity prices in the Western U.S.A.?” revised and resubmitted paper, Energy Policy.
- Olson, A., C.K. Woo, N. Schlag and A. Ong (2016) "What happens in California does not always stay in California: The effect of California's cap-and-trade program on wholesale electricity prices in the Western Interconnection," Electricity Journal, 29(7), 18-22.

Marginal social cost (MSC) pricing of electricity

- The marginal benefit (or demand) curve is *MB*, measuring a consumer's marginal willingness to pay for *Q* MWH of electricity
- *MSC* pricing at *P** is efficient because if *P* > *P** = *MSC*, *Q* < *Q** so that a marginal gain [= (*MB* – *MSC*) > 0] can occur via a price decrease
- *MSC* = marginal cost of CO_2 emissions + marginal costs of other inputs (e.g., fuel and variable O&M)



Marginal cost (*MC*) of CO_2 emissions of natural gas generation

- *MC* = CO_2 price ($/metric ton) × CO_2 content of burning natural gas (0.053 metric ton/MMBtu) × Marginal heat rate (*HR* MMBtu/MWh)
- The change in *MC* due to a $1 increase in the CO_2 price: ΔMC = $1× 0.053 × *HR*
- ΔMC = ~$0.37/MWh if *HR* = ~7 for a combined cycle gas turbine (CCGT)
- ΔMC = ~$0.48/MWh if *HR* = ~9 for a combustion turbine (CT)
- The extent of a wholesale electricity price's pass-through of *MC* is 100% when the effect a $1 increase of the CO_2 price is between $0.37/MWh and $0.48/MWh

California's C&T program

- Established under Assembly Bill (AB) 32 - the California Global Warming Solutions Act of 2006 and administered by the California Air Resources Board, it commenced operation on 01/01/2013 to achieve an overall 15% reduction in the state's GHG emissions to the 1990 levels by 2020
- It covers electricity generators, large industrial facilities and distributors of natural gas and transportation fuels
- The cap for 2013 is ~98% of the emissions level forecast for 2012, with annual decline of ~2% in 2014 and ~3% for 2015 to 2020
- It allocates free allowances to large industrial facilities, with more auctions in later years
- It also gives free allowances to electric and natural gas utilities, which must use the value of these allowances to benefit ratepayers and reduce GHG emissions
- In August 2016, California passed Senate Bill 32 to extend AB32, establishing a new mandate of 40% reductions below the 1990 levels by 2030

Unspecified sources

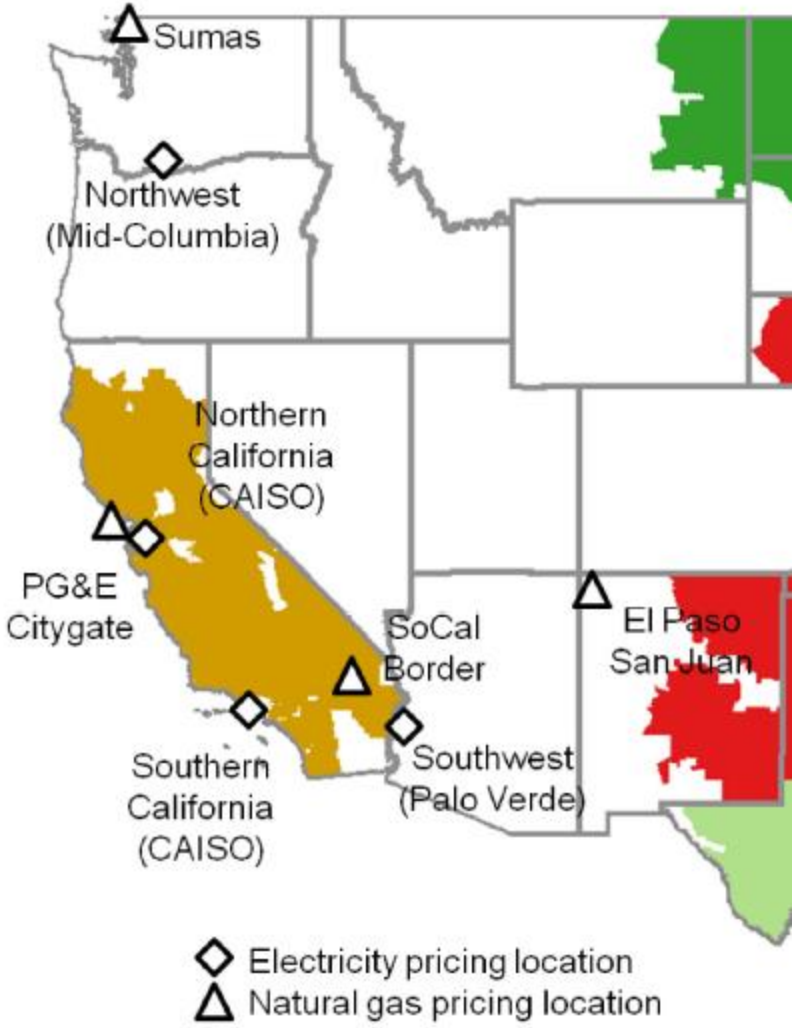
- The California C&T program assigns a default emissions rate of 0.428 metric ton per MWh to imports from “unspecified” generation units in the thermal-rich Desert Southwest and wholesale market purchases whose original source is unknown or mixed
- Since California’s buyers must procure CO_2 allowances for their imports from the unspecified sources, they are unwilling to pay a CO_2 premium in their bilaterally negotiated prices in markets outside of California
- As non-California buyers are not required to procure CO_2 allowances, they are also unwilling to pay a CO2 premium
- Hence, the California C&T program unlikely materially increases the wholesale prices for electricity from the unspecified sources

The Pacific Northwest's hydro export to California

- The California C&T program can affect the wholesale prices for out-of-state renewable generators exporting to California, as well as the Pacific Northwest's generators exporting their surplus hydropower to California
- It assigns a special status to Bonneville Power Administration (BPA) in the Pacific Northwest and BC Hydro in the Canadian province of British Columbia
- The "Asset-Controlling Suppliers" designation reflects BPA and BC Hydro's hydro-dominant resource portfolios, which improves the profitability of BPA and BC Hydro's hydro export to California by eliminating the importers' need to procure CO_2 allowances
- This designation is the reason for the Mid-C price's CO_2 premium and the cause for power laundering in the Western Interconnection

Data description

- Integrated market: four actively traded hubs in the Western Interconnection – Mid-C, NP15, SP15, PV
- Product: Forward contract for next working weekday delivery for the heavy-load-hours (HLH) of 06:00 – 22:00
- Delivery rate: 100% for a flat power block
- Reliability: firm power
- Price determination: Bilateral negotiation among traders



Major pricing locations in the Western Interconnection
(Source: https://www.eia.gov/electricity/monthly/update/wholesale_markets.cfm#tabs_wh_price-3)

Data description

- The HLH prices are highly volatile with large standard deviations and wide ranges. They exhibit contemporaneous correlations, affirming that the four interconnected hubs are integrated to form an aggregate market in the Western Interconnection
- They are postulated to move with their fundamental drivers (effect), which are day-ahead forecasts of the CO_2 price (+), natural gas price (+), system loads (+), solar generation (-), wind generation (-), nuclear capacities available (-), and hydro conditions (-)
- We estimate four market price regressions to explain the HLH price movements due to the changes in the fundamental drivers

Descriptive statistics and price correlations

Table 1. Descriptive statistics for the metric variables in the sample period of 01/01/2011 – 05/31/2016

Variable	Mean	Standard deviation	Minimum	Maximum	Price correlation			
					NP15	SP15	Mid-C	PV
P_{1t}: NP15 HLH price ($/MWh)	38.94	10.78	16.00	175.00	1	0.942	0.820	0.863
P_{2t}: SP15 HLH price ($/MWh)	40.23	11.32	14.50	161.50	0.942	1	0.781	0.869
P_{3t}: Mid-C HLH price ($/MWh)	29.70	13.38	0.50	218.00	0.820	0.781	1	0.799
P_{4t}: PV HLH price ($/MWh)	33.46	10.16	14.86	171.50	0.863	0.869	0.799	1
C_t: California CO_2 price ($/metric ton)	8.05	6.24	0.0	16.39	0.312	0.259	0.189	0.020
X_{1t}: Henry Hub price ($/MMBTU)	3.37	0.90	1.52	8.37	0.687	0.703	0.543	0.716
X_{2t}: PG&E HLH load (average of hourly MWh)	13200.0	1297.0	11054.0	17608.0	0.266	0.306	0.292	0.435
X_{3t}: SCE HLH load (average of hourly MWh)	13347.0	1739.0	10581.0	19498.0	0.278	0.335	0.254	0.422
X_{4t}: California HLH wind (average of hourly MWh)	1190.0	547.12	189.63	2932.0	*0.066*	*0.041*	*0.018*	*0.039*
X_{5t}: California HLH solar (average of hourly MWh)	1275.0	1049.0	-384.47	4410.0	*0.010*	-0.132	-0.069	-0.204
X_{6t}: MW available at the Diablo Canyon nuclear plant	1954.0	389.22	176.56	2264.0	-0.040	-0.086	*0.057*	-0.032
X_{7t}: MW available at the San Onofre nuclear plant	358.57	774.18	0	2139.0	-0.123	-0.120	-0.005	*0.137*
X_{8t}: MW available at Palo Verde nuclear plant	3666.0	558.38	1360.0	4114.0	*0.003*	*0.038*	*0.003*	*0.055*
X_{9t}: Klamath River's HLH discharge (000 ft^3/second)	13.82	14.27	2.78	113.83	-0.378	-0.357	-0.345	-0.356
X_{10t}: Sacramento River's HLH discharge (000 ft^3/second)	17.26	13.36	3.75	84.83	-0.287	-0.233	-0.199	-0.120
X_{11t}: California hydro index (1 = driest, …, 7 = wettest)	3.60	0.66	1.28	5.29	-0.331	-0.236	-0.206	-0.051

Note: For proper chronological matching with the price data, the fundamental drivers' values are day-ahead forecasts produced by PROC FORECAST (SAS, 2004). Since the San Onofre plant was shut down on 01/31/2012, its post-shut-down MW available is zero. Price correlation coefficients in *italic* are contrary to our expecations.

Regression results

- The estimated effect of a $1/metric ton in the CO2 price is $0.41/MWh (p-value < 0.0001) for NP15 and $0.59/MWh (p-value < 0.0001) for SP15, not statistically different from the cost-based benchmark of $0.37/MWh to $0.48/MWh
- The CO_2 price's estimated effect on the Mid-C price is $0.41/MWh (p-value = 0.0056), the same as the NP15 estimate
- The CO_2 price's estimated impact on the PV price is $0.15/MWh and insignificant (p-value = 0.0925), sharply contrasting the highly significant estimates for the Mid-C, NP15 and SP15 prices
- All statistically significant estimates of the remaining drivers' price effects are consistent with our expectations

Regression results

Table 2. ITSUR regression results for the wholesale electricity prices in the four trading hubs in Western U.S.A. for the sample period of 01/01/2011 – 05/31/2016

Variable	Eq. (1): P_{1t} = NP15 HLH price			Eq. (2): P_{2t} = SP15 HLH price			Eq. (5): P_{3t} = Mid-C HLH price			Eq. (6): P_{4t} = PV HLH price		
	Estimate	Standard error	*p*-value	Estimate	Standard error	*p*-value	Estimate	Standard error	*p*-value	Estimate	Standard error	*p*-value
Adjusted R^2	0.8052			0.8508			0.7246			0.7807		
AR(1) parameter	0.4300	0.0181	<.0001	0.5702	0.0191	<.0001	0.7105	0.0211	<.0001	0.5147	0.0187	<.0001
AR(2) parameter	0.1730	0.0174	<.0001	0.0585	0.0180	0.0012	-0.0252	0.0209	0.2290	0.1036	0.0183	<.0001
C_t: California CO_2 price ($/metric ton)	**0.4104**	0.0842	<.0001	**0.5927**	0.0817	<.0001	**0.4126**	0.1486	0.0056	0.1466	0.0871	0.0925
X_{1t}: Henry Hub natural gas price ($/MMBtu)	**7.3862**	0.4012	<.0001	**7.4801**	0.3845	<.0001	**7.4306**	0.6724	<.0001	**6.6582**	0.4096	<.0001
X_{2t}: PG&E HLH load (average of hourly MWh)	**0.0017**	0.0003	<.0001	**0.0009**	0.0003	0.0058	**0.0023**	0.0005	<.0001	**0.0011**	0.0003	0.0011
X_{3t}: SCE HLH load (average of hourly MWh)	**0.0007**	0.0002	0.0028	**0.0011**	0.0002	<.0001	*-0.0004*	0.0004	0.2949	**0.0006**	0.0002	0.0079
X_{4t}: California HLH wind output (average of hourly MWh)	-0.0006	0.0004	0.1248	**-0.0008**	0.0003	0.0128	*0.0007*	0.0005	0.1571	-0.0002	0.0004	0.6411
X_{5t}: California HLH solar output (average of hourly MWh)	-0.0005	0.0005	0.2778	**-0.0026**	0.0004	<.0001	-0.0014	0.0008	0.0767	**-0.0012**	0.0005	0.0132
X_{6t}: MW available at the Diablo Canyon nuclear plant	**-0.0017**	0.0007	0.0104	**-0.0022**	0.0006	0.0007	*0.0003*	0.0011	0.7738	-0.0013	0.0007	0.0551
X_{7t}: MW available at the San Onofre nuclear plant	**-0.0016**	0.0006	0.0088	**-0.0032**	0.0006	<.0001	*0.0001*	0.0011	0.9376	-0.0004	0.0006	0.4714
X_{8t}: MW available at the Palo Verde nuclear plant	-0.0005	0.0005	0.3295	-0.0003	0.0005	0.5760	-0.0011	0.0008	0.1817	-0.0005	0.0005	0.3757
X_{9t}: Klamath River's HLH discharge (000 ft^3/second)	-0.0137	0.0222	0.5370	-0.0381	0.0210	0.0702	-0.0017	0.0345	0.9606	-0.0284	0.0228	0.2126
X_{10t}: Sacramento River's HLH discharge (000 ft^3/second)	-0.0041	0.0284	0.8852	*0.0107*	0.0272	0.6947	*0.0090*	0.0460	0.8446	*0.0151*	0.0292	0.6054
X_{11t}: California hydro index (1 = driest, …, 7 = wettest)	**-2.1255**	0.7022	0.0025	-0.4769	0.6597	0.4699	**-2.8871**	1.0897	0.0082	-0.7916	0.7159	0.2691

Note: Omitted here for brevity are the estimates for the intercept and binary indictors for day-of-week and month-of-year. The coefficient estimates in **bold** for the fundamental drivers' forecasts have the correct sign and are significant at the 5% level; those in *italic* have the wrong sign but are insignificant at the 5% level.

Unintended windfall gains

- The hydro producers in the Pacific Northwest increase their export to California, in response to the higher NP15 and SP15 prices that now include the CO_2 premium
- They also raise the Mid-C prices, matching the opportunity cost of their hydro output
- To enable their hydro export increase, they increase their non-hydro generation or make market purchases delivered at Mid-C
- Non-hydro producers who can sell at Mid-C ask for higher prices, as they know that their deliveries support the hydro export increase to California
- Thus, the California C&T program yields unintended windfall gains to CO_2-emitting generators that can sell at Mid-C

Power laundering

- Suppose the natural gas generation increase in the Pacific Northwest is *A* MWh, enabling a hydro export increase that displaces the marginal natural gas generation in California and the Desert Southwest
- The Pacific Northwest's increase in CO_2 emissions is $Z_1 = A\ C\ X$, where C = natural gas' carbon content and X = marginal heat rate in the Pacific Northwest
- The decrease in CO_2 emissions in California and the Desert Southwest is $Z_2 = (1 - L)\ A\ C\ Y$, where L = marginal transmission loss and Y = marginal heat rate in California and the Desert Southwest

Power laundering

- The change in CO_2 emissions is $(Z_1 - Z_2) = C\,[A\,(X - Y) + L\,A\,Y]$
- Production simulation results indicate $X \approx Y$, $C\,A\,(X - Y) \approx 0$ and $(Z_1 - Z_2) \approx C\,L\,A\,Y > 0$, implying that the California C&T program causes power laundering, *sans* reduction in the Western Interconnection's CO_2 emissions
- The main policy conclusion is that effective de-carbonization requires expanding the C&T program's geographical scope to cover the entire Western Interconnection
- What may happen if Hong Kong imports CO_2-free electricity to displace its local generation?

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