


Coordination of Transmission and Generation Investments

Hung-po Chao and Robert Wilson*

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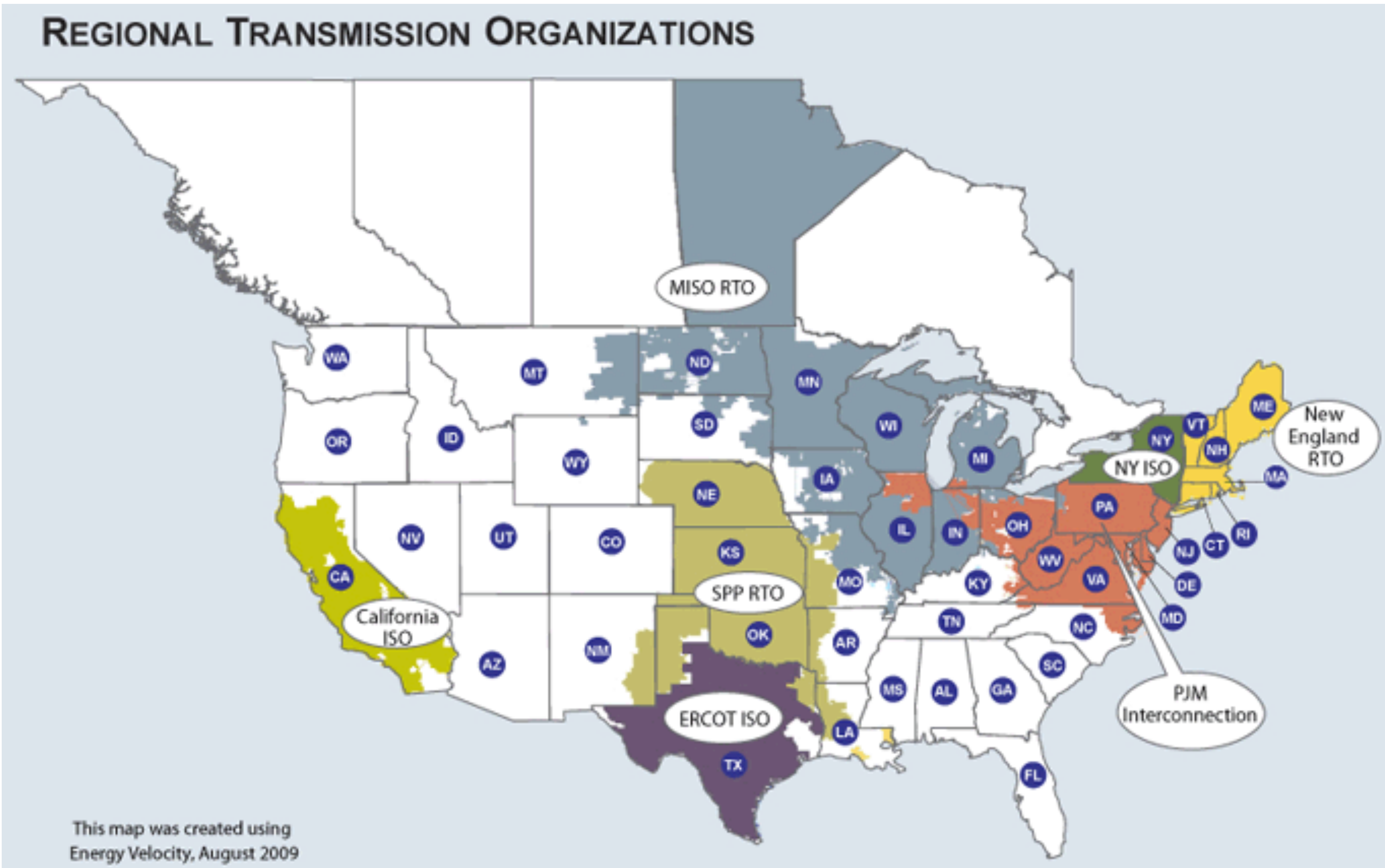
Outline

- The problem
- Economic framework
- Policy scenarios
  - Efficient coordination
  - Merchant investment
  - Sequential coordination
- Concluding remarks

State of the market: modern liberalized markets offer limited means to coordinate investments

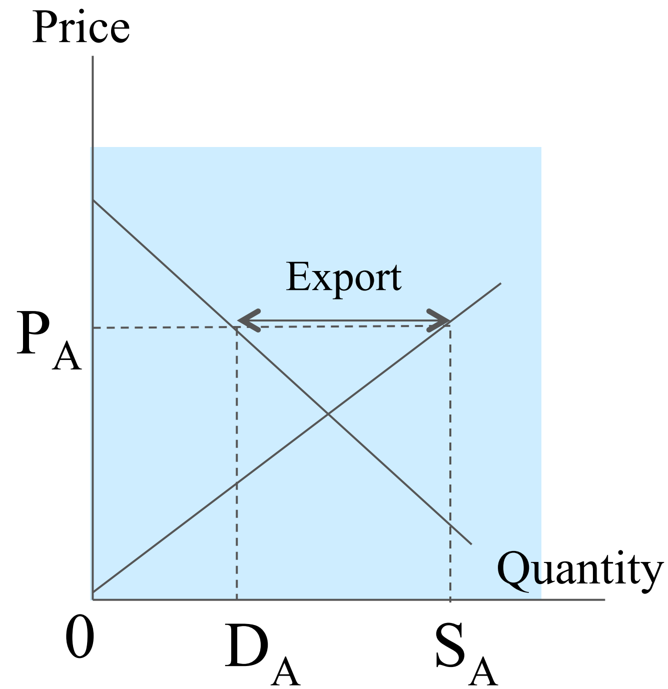


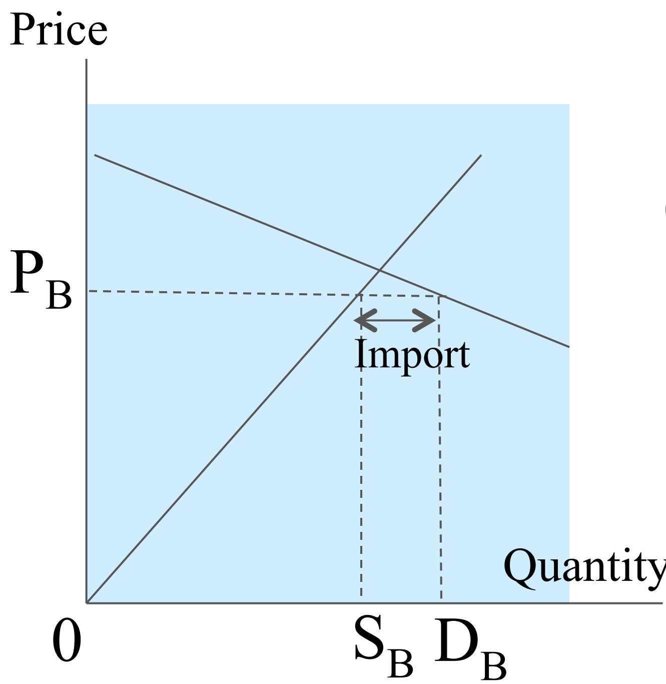
Coordination of generation and transmission planning has been a persistent problem in liberalized systems

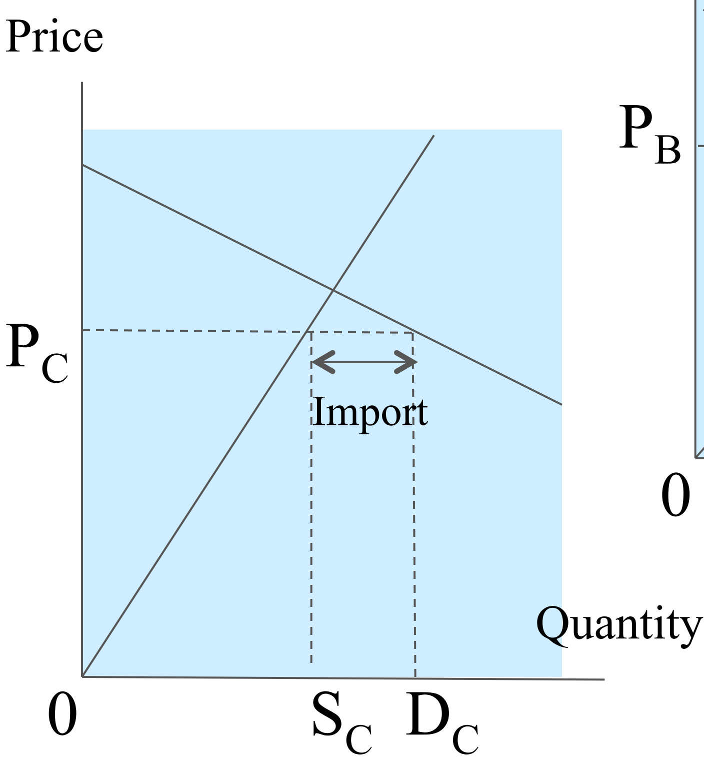
- What are the consequences of an RTO’s possible responses to system changes due to demand growth or retirement of generators?
  - Wait for merchant investors to add new capacity, or
  - Procure new generation capacity or add transmission capacity
- How can an RTO compare merchant investment in transmission with regulated investment?
  - Propose regulated investment only if no merchant investment is offered
  - Propose regulated investment if the welfare impacts of merchant investment are severe
- In planning regulated transmission investment, should an RTO
  - anticipate that subsequent merchant investments in generation capacity will be adapted to the transmission capacity planned, or
  - wait to adapt the transmission expansion plan to the installed generation capacities?

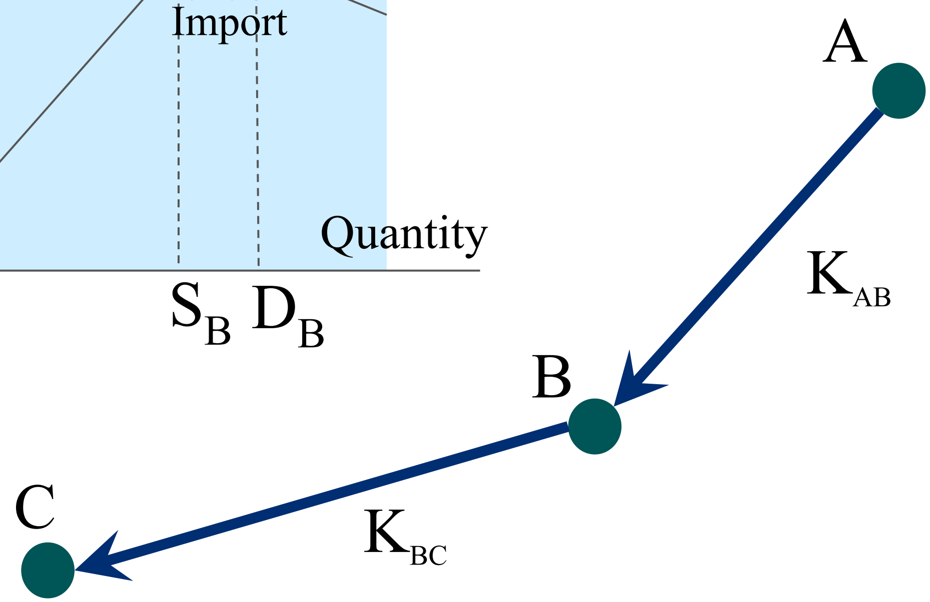
Illustrative energy markets in a tree-structured network

$P_C \geq P_B \geq P_A$









Conundrums of coordinating transmission planning with merchant generation investments

- Which goes first, generation or transmission?
- Which should it be, generation or transmission? and
- How might regulated projects be financed?

An integrated economic framework

- A two-stage sequential decision framework with lumpy transmission investments
- Constrained optimization:
  - Maximizing social welfare and measuring distributional effects on consumers and producers
  - System balancing and competitive equilibrium in energy markets with efficient nodal prices
- Modeling assumptions for illustrative scenarios
  - A three-node tree network
  - Peak and off-peak periods
  - Affine linear transmission investment cost functions $I(K)$:

    $$I(K) = f + v \times K$$
  - Constant demand and supply elasticities

Model parameters

Parameters	Node A	Node B	Node C
Demand scale factor in the peak period	200	400	600
Demand scale factor in the off-peak period	100	200	300
Demand price elasticity	-0.2	-0.2	-0.2
Supply price elasticity	0.5	0.5	0.5
Incremental cost of generation capacity ($/MW)	40	60	80

Parameters	Line A-B	Line B-C
Fixed cost ($Million)	200	200
Variable cost ($/MW)	10	5

Policy scenarios

- **Efficient coordination**
  - Compare with status quo and unconstrained transmission
  - Cost recovery rules
  - Response to system changes
- Merchant investment
- Sequential coordination

Transmission and generation capacity investments

		Status Quo	Efficient Coordination	Uncongested Transmission
Transmission Capacity (MW)	Line A-B	0	66	105
	Line B-C	0	53	76
Generation Capacity (MW)	Node A	106	191	237
	Node B	181	189	183
	Node C	241	242	241
Transmission Investment ($Million)		-	1,324	1,837
Generation Investment ($Million)		-	19,111	19,706
Total Investment ($Million)		-	20,434	21,542

Energy market prices (in $/MWh)

Period	Node	Status Quo	Efficient Coordination	Uncongested Transmission
Peak	A	67	64	68
	B	91	74	68
	C	112	79	68
Off Peak	A	25	27	25
	B	34	27	25
	C	42	27	25

Welfare measures (in $Million)

	Node	Status Quo	Efficient Coordination	Uncongested Transmission
Consumers Surplus	A	17,134	17,183	16,730
	B	29,359	32,653	33,460
	C	37,800	47,722	50,191
	All	84,293	97,559	100,381
Producers Surplus	A	4,725	4,990	5,404
	B	12,068	8,924	7,803
	C	21,429	12,451	10,079
	All	38,221	26,365	23,286
Social surplus	All	122,514	123,923	123,667

Cost recovery rules with efficient coordination

"First best"

- Load sharing: allocation in proportion to peak demand
- Beneficiary pay: allocation in proportion to difference in consumer surplus compared to status quo

Second best

- Boiteux-Ramsey I: recovered from congestion rents under second-best energy prices
- Boiteux-Ramsey II: recovered from injection fees under second-best pricing

Energy market prices (in $/MWh)

Period	Node	Efficient Coordination	Boiteux-Ramsey I	Boiteux-Ramsey II	
				Buyer Price	Injection fee
Peak	A	64	61	65	0.66
	B	74	74	75	0.71
	C	79	82	80	0.59
Off Peak	A	27	26	27	0.28
	B	27	27	27	0.27
	C	27	28	27	0.20

Welfare effects under alternative cost recovery rules (compared to status quo)

	Node	"First best"		Second best	
		Load Sharing	Beneficiary Pay	Boiteux-Ramsey I	Boiteux-Ramsey II
Consumers Surplus	A	48	113	451	65
	B	3,295	3,328	3,560	3,319
	C	9,922	9,825	9,322	9,993
	All	13,265	13,265	13,332	13,377
Producers Surplus	A	266	266	(329)	229
	B	(3,144)	(3,144)	(3,265)	(3,180)
	C	(8,978)	(8,978)	(8,347)	(9,018)
	All	(11,856)	(11,856)	(11,940)	(11,968)
Social Surplus	All	1,409	1,409	1,392	1,409

Welfare effects under alternative cost recovery methods

- The Boiteux-Ramsey I rule yields the lowest social surplus
- The Boiteux-Ramsey II rule yields a social surplus virtually identical to that with efficient coordination, suggesting that it is nearly as efficient as the first-best efficient plan.
- The welfare impacts of both Boiteux-Ramsey rules are more favorable to consumers and less favorable to generators in comparison with the two administrative rules.
- The Boiteux-Ramsey II rule produces patterns of welfare impacts measured in consumers and producers surpluses similar to those with the efficient plan using the beneficiaries-pay cost sharing rule.

Response to Retirement of 9.1 MW Generation at Node B (MW)

	Efficient Plan	Transmission Response	Generation Response	Coordinated Response
Line A-B (MW)	66	73	66	77
Line B-C (MW)	53	53	53	53
Generation at A (MW)	84	84	85	98
Generation at B (MW)	8	8	16	10
Generation at C (MW)	1	1	1	1

Energy Market Prices (in $/MWh) – Generation Retirement at Node B

Period	Node	Efficient Plan	Transmission Response	Generation Response	Coordinated Response
Peak	A	64	69	64	65
	B	74	79	78	75
	C	79	79	79	79
Off Peak	A	27	28	28	27
	B	27	28	28	27
	C	27	28	28	27

Consumers and Producers Surpluses – Generation Retirement at Node B

	Node	Efficient Plan	Transmission Response	Generation Response	Coordinated Response
Consumers Surplus	A	17,183	16,680	17,193	17,105
	B	32,653	31,672	31,976	32,502
	C	47,722	47,437	47,699	47,687
	All	97,559	95,789	96,868	97,294
Producers Surplus	A	4,990	5,829	4,995	5,120
	B	8,924	8,895	8,736	8,239
	C	12,451	12,573	12,493	12,462
	All	26,365	27,297	26,224	25,821
Social surplus	All	123,923	123,086	123,092	123,116

Summary of efficient coordination

- Efficient transmission and generation capacity investments are determined jointly
- The efficient plan eliminates congestion only during the off-peak period and results in a uniform nodal price
- In an efficient plan, the nodal prices vary during the peak period (though less pronounced than the status quo) and the congestion rent covers the variable transmission investment costs
- There are gains and losses among individual participants
  - As a group, consumers gain from greater competition afforded by transmission expansion, but producers tend to lose
  - Transmission expansion tends to lower the price in an import region but raise the price in an export region
- Coordinated response to system changes improves system efficiency to the benefits of consumers

Policy scenarios

- Efficient coordination
- **Merchant investment**
  - Transmission company (TransCo)
  - Alliance between TransCo and Generator A (TG-A)
  - Alliance between TransCo and Utility C (TU-C)
  - Alliance of TransCo, Generator A and Utility C (TGU-AC)
- Sequential coordination

Merchant investment: transmission and generation capacity investments

		Efficient Coordination	TransCo	Merchant TG-A	Merchant TU-C	Merchant TGU-AC
Transmission Capacity (MW)	Line A-B	66	31	37	108	142
	Line B-C	53	25	25	76	96
Generation Capacity (MW)	Node A	191	151	154	240	317
	Node B	189	193	190	181	181
	Node C	242	249	241	241	241
Transmission Investment ($Million)		1,324	838	896	1,862	2,306
Generation Investment ($Million)		19,111	19,176	18,880	19,708	21,240
Total Investment ($Million)		21,034	20,014	19,777	21,570	23,546

Merchant investment: energy market prices ($/MWh)

Period	Node	Efficient Coordination	TransCo	Merchant TG-A	Merchant TU-C	Merchant TGU-AC
Peak	A	64	60	63	68	59
	B	74	76	74	68	59
	C	79	91	96	68	59
Off Peak	A	27	28	28	25	22
	B	27	28	28	25	22
	C	27	30	32	25	22

Merchant investment: welfare measures ($Million)

	Node	Efficient Coordination	TransCo	Merchant TG-A	Merchant TU-C	Merchant TGU-AC
Consumers Surplus	A	17,183	17,553	17,302	17,025	17,478
	B	32,653	32,404	32,668	34,049	34,957
	C	47,722	44,608	43,086	51,074	52,435
	All	97,559	94,564	93,056	102,147	104,870
Producers Surplus	A	4,990	4,531	4,884	5,430	2,711
	B	8,924	9,284	9,034	7,807	6,309
	C	12,451	15,208	16,462	10,103	8,165
	All	26,365	29,023	30,380	23,340	17,185
Congestion revenue		0	79	164	(1,862)	(2,306)
Social surplus	All	123,923	123,665	123,601	123,626	119,749

Summary of merchant investment

- TransCo's investment is less expansive than the efficient plan. This strategy hurts the consumers and benefits the producers in general.
- The alliance of Merchant TG-A is stable because no one would be better off leaving the alliance unilaterally. However, GenCo A is better off under regulated transmission investment with efficient coordination.
- Merchant TU-C exploits the benefits from the complementarities between transmission and generation capacities to such a degree that an uncongested transmission system results
  - The congestion revenue is zero.
  - To sustain the merchant alliance, an internal transfer payment must be made to cover the transmission investment cost incurred by TransCo.
- Merchant TGU-AC is both inefficient and unsustainable.

Policy scenarios

- Efficient coordination
- Merchant investments
- **Sequential coordination**
  - transmission leads generation
  - generation leads transmission

Sequential coordination: transmission and generation capacity investments

		Efficient Coordination	Transmission Leads Generation	Generation Leads Transmission
Transmission Capacity (MW)	Line A-B	66	66	105
	Line B-C	53	53	76
Generation Capacity (MW)	Node A	191	153	237
	Node B	189	193	183
	Node C	242	242	241
Transmission Investment ($Million)		1,324	1,324	1,837
Generation Investment ($Million)		19,111	18,883	19,706
Total Investment ($Million)		20,434	20,206	21,542

Sequential coordination: energy market prices ($/MWh)

Period	Node	Efficient Coordination	Transmission Leads Generation	Generation Leads Transmission
Peak	A	64	79	68
	B	74	79	68
	C	79	79	68
Off Peak	A	27	29	25
	B	27	29	25
	C	27	29	25

Sequential coordination: welfare measures ($Million)

	Node	Efficient Coordination	Transmission Leads Generation	Generation Leads Transmission
Consumers Surplus	A	17,247	16,022	17,046
	B	32,687	31,449	33,590
	C	47,625	46,418	49,745
	All	97,559	93,889	100,381
Producers Surplus	A	4,990	7,088	5,404
	B	8,924	9,932	7,803
	C	12,451	12,692	10,079
	All	26,365	29,712	23,286
Social surplus	All	123,923	123,601	123,667

Summary of sequential coordination

- When transmission leads generation
  - the transmission investment is set at the efficient level, but Cournot competition yields lower generation investments and higher prices than the efficient plan
  - Cournot equilibrium yields zero congestion rents
- When generation leads transmission,
  - unfettered competition within an uncongested transmission network results in greater generation investments and uniform energy prices
- The coordination strategy of generation-leads-transmission yields higher consumers surplus and lower producers surplus than that of transmission-leads-generation

Concluding Remarks

- Efficient coordination requires an integrated economic framework as an adjunct for evaluating transmission and generation capacity expansion plans
  - Distributional effects on benefits, costs and incentives are often larger than the aggregate welfare impacts
  - Injection charge may be considered an effective second-best cost recovery tool based on Boiteux-Ramsey pricing
- Merchant investments based on the complementarities between transmission and generation supplements regulated investments without requiring cost recovery rules
- A sequential coordination strategy of generation-leads-transmission promotes competition and further leverages the complementarities between transmission and generation
  - When transmission leads generation, generators could capture the entire transmission rents in Cournot equilibrium

Thank You
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