A SCHEME FOR INCENTIVIZING INVESTMENT IN TRANSMISSION ENHANCEMENTS

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• Planning in the competitive environment
• Centralized and decentralized transmission investment formulations
• Investment incentives in decentralized planning: the investment game
• Illustrative case study
• Concluding remarks
• Future work
OBJECTIVES

• Incentive mechanism design for transmission network investment
• Cooperative game theory framework (Shapley value) to allocate payments to investors
• Payments based on added social welfare
• Compare decentralized and centralized transmission investment settings
THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE

- Customers
- IPP
- Generation
- Transmission
- Distribution
- Customer Service
- Self-generation
VERTICALLY INTEGRATED UTILITY STRUCTURE IS DISINTEGRATING
PLANNING UNDER COMPETITION

• Major shift in the planning paradigm
  – cessation of the centralized integrated planning of the past
  – role of regional planning under the independent grid operator
  – unclear responsibility for implementation under the ownership/control separation
  – role of decentralized decision making
PLANNING UNDER COMPETITION

• Planning, to the extent it is performed in the new environment, is an asset management problem
  – investment under uncertainty
  – critical importance of effective risk management
  – subject to regulations in a continuous state of flux
CENTRALIZED TRANSMISSION INVESTMENT FORMULATION

• Maximize:
  – aggregate social welfare – investment costs

  subject to:
  – power flow balance equations
  – line flow equations
  – generator and demand limits
  – line flow limits
  – budget constraints to build lines
CENTRALIZED TRANSMISSION INVESTMENT FORMULATION

$/MWh

consumer surplus

$\rho_B$

congestion rents

$\rho_S$

producer surplus

MWh/h

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CENTRALIZED TRANSMISSION INVESTMENT FORMULATION

The solution of the problem determines:

- social welfare
- amounts sold and bought by the pool players
- new lines to be built
- cost of investment in new lines
DECENTRALIZED TRANSMISSION INVESTMENT FORMULATION

• Maximize:
  – aggregate social welfare

  subject to:
  – power flow balance equations
  – line flow equations
  – generator and demand limits
  – line flow limits
  – budget constraints to pay investors
DECENTRALIZED TRANSMISSION INVESTMENT FORMULATION

The solution of the problem determines:

• social welfare

• amounts sold and bought by the pool players

• new lines to be built

• payments to the line investors
DECENTRALIZED INVESTMENT INCENTIVES : THE INVESTMENT GAME

• The transmission planner (TP) needs to send incentives to the investors so that they maximize social welfare

• Value of a transmission asset for the system : increase in social welfare that the asset produces

• Bargaining process between the planner and the investors :
  – TP objective : increase social welfare
  – Investors’ objective : specific Rate of Return (RoR)
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

• The TP uses the Shapley value to calculate the individual investor contribution to the increase in social welfare

• Cooperative bargaining game:
  – TP: offers payments to investors based on social welfare increase calculated by the Shapley value
  – Players: investors accept / reject the offer compared to their RoR
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

• Investment game defined by a pair \((Y, \Delta SW)\):
  
  – \(Y\) = set of all the investors
  
  – \(\Delta SW\) = increase in social welfare
  
  – Shapley value allocation per investor
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

• Shapley value: SV
  – It is one “fair” way to distribute the total gains to the players, assuming that they form coalitions
  – IF the coalition being formed one player at a time, with each player demanding their contribution as a fair compensation
  – THEN the SV is the average over the possible different permutations in which the coalition can be formed
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

• Shapley value axioms:
  – The set of players receives all the resources available
  – A player that does not add value receives nothing
  – The value assigned to a player does not depend on the position in the set of players of a coalition
  – The SV is an additive function
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

Start

TP selects best initial candidates for investment meeting budget constraint of the decentralized investment model.

\[ i = 1 \]

Investment candidates selection

TP creates all combinations of investors

TP calculates increases in social welfare for all combinations of investors

TP calculates how much is allocated to investors using Shapley values

Are all the required payments smaller than Shapley value allocations?

Yes

End

No

Dissatisfied investors withdraw

\[ i = i + 1 \]
DECENTRALIZED INVESTMENT INCENTIVES: THE INVESTMENT GAME

• Step 1: The transmission planner (TP) selects the initial set of investors.

• Step 2: The TP calculates the increase in social welfare ($\Delta SW$) per combination and makes payment offers to investors.

• Step 3: The TP verifies the investors that accept the offers.

• Step 4: The game ends if there are no new investors willing to build more transmission assets.
CASE STUDY : GARVER’S 6-BUS NETWORK

• Garver 6-bus system

• 3 generators and 5 loads

• 25 years of operating life

• 10% interest rate and 5% rate of return

• 3 parallel lines can be built per corridor

• Marginal offers and bids
CASE STUDY: GARVER’S 6-BUS NETWORK
OFFER PARAMETERS

\[ a_i \]

\[ b_i \]

Generator offer

\[ $/MWh \]

\[ MW \]
BID PARAMETERS

$/MWh

c_j

d_j

demand bid

MW
EQUIVALENCE BETWEEN CENTRALIZED AND DECENTRALIZED FORMULATIONS

• The centralized and decentralized solutions are equivalent in terms of social welfare if:
  – The payments are equal to the actual costs
  – The decentralized budget limit is equal to the optimal investment cost of the centralized problem
DISCUSSION OF THE RESULTS

• Decentralized investment models with no budget constraints produce more candidate lines
• Higher rates of return reduce the number of candidate lines
• Allowing more investors produces more competitive results
• Cost-based budget constraints in decentralized models produce similar results to centralized investment models
CONCLUDING REMARKS

• Scheme for the incentivizing of transmission asset investments
• Two models of investment, centralized and decentralized, are compared
• Incentives based on Shapley value allocation
• Effects of rate of return and budget constraints
• Equivalence between the two models
FUTURE WORK

• Combination of generation and transmission investments

• Modeling of uncertainty:
  – Change in load patterns
  – Change in bidding patterns
  – Entrance or exit of market players
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