FERC Workshop / Trans-Atlantic Infraday (TAI), Nov 6, 2014

Risk Induced Resource Dependency in Capacity Investments

Janne Kettunen

Assistant Professor in Decision Sciences
The George Washington University, School of Business

Joint work with Derek Bunn (London Business School)

This research is funded by CMC, NRCan, and ISEEE

Background and Motivation

- A capacity acquisition process is **resource dependent** when the existing resources impact the valuation of new resources and hence the investment decision
- Under uncertainties in capacity valuation and when the decision maker is risk averse, the risks of new assets may interact with an existing resource base
- This can result in a source of resource dependency

- Research questions:

1. How significant is the impact of risk induced resource dependency?
2. What strengthens risk induced resource dependency?
3. What are implications of risk induced resource dependency on power generation capacity investments?

Related Literature

- On resource dependency:
  - Diversifying into new markets (Lemelin, 1982)
  - Technology lock-ins, due to increasing returns (Arthur, 1989) and learning (Rosenberg, 1982)
- On capacity investment under uncertainty:
  - Flexibility to delay investment (Dangl, 1999)
  - Including investment and production decisions (Harrison and Van Mieghem, 1999)
  - Importance of accounting for risk aversion (Eppen etl al., 1989; Van Mieghem, 2003)
- In most studies, capacity investments are valued in absence of existing investments
- Also, minimal research on resource dependency due to risk aversion

Structure of Analysis

1. Key theoretical results
   - General properties of resource dependency in capacity acquisition
2. Hypotheses about resource dependency
   - Risk factors strengthening or weakening resource dependency
3. Investigation of resource dependency in power sector investments

Theoretical Results 1/2

- Utility function for risk averse capacity acquisition:

$$U(\zeta_\omega + \zeta_\Omega) = (1-\lambda)\mathbb{E}[\zeta_\omega + \zeta_\Omega] - \lambda R[\zeta_\omega + \zeta_\Omega]$$

- We consider general class of risk measures:

Definition 1

(I) Risk of resources with random values A and B, i.e., $R[A+B]$, is sub-additive (Artzner et al., 1999)

$$R[A+B] \le R[A] + R[B]. \quad (2)$$

(II) $R[A+B]$ is an increasing function of the Pearson correlation among their values, $\rho_{A,B}$. When the correlation is perfect, $\rho_{A,B} = 1$, then (2) *is additive.*

- Externality value of existing resources:

Definition 2 *The value of externality for a resource, ζ_ω, $\omega = 1, \ldots, G$ is $\mathcal{E}[\zeta_\omega|\Omega] = U[\zeta_\omega + \zeta_\Omega] - \left[U[\zeta_\omega] + U[\zeta_\Omega]\right]$.*

Theoretical Results 2/2

- Properties of the externality value:

Proposition 3 *The value of externality due to risk aversion is non-negative, i.e., $\mathcal{E}[\zeta_\omega|\Omega] \ge 0$, $\omega = 1, \ldots, G$.*

Proposition 4 *The value of externality, $\mathcal{E}[\zeta_\omega|\Omega]$, $\omega = 1, \ldots, G$, due to risk aversion, increases in risk aversion factor, λ, and risk of new or existing assets, $R[\zeta_\omega]$ or $R[\zeta_\Omega]$, and decreases in correlation, $\rho_{\zeta_\omega,\zeta_\Omega}$.*

- Resource dependency:

Definition 5 *Capacity acquisition process is resource dependent if $\mathcal{E}[\zeta_\omega|\Omega] \neq \mathcal{E}[\zeta_\omega|\emptyset]$, $\omega = 1, \ldots, G$.*

Theorem 6 *A capacity acquisition process is resource dependent due to risk aversion if there exists a resource, $\omega = 1, \ldots, G$, that is not perfectly correlated with existing resources, $\rho_{\zeta_\omega,\zeta_\Omega} < 1$.*

- Resource lock-in:

Proposition 7 *An increase in risk aversion, λ, deters away from resource lock-in, i.e., $\mathcal{E}[\zeta_{\omega'}|\omega] - \mathcal{E}[\zeta_\omega|\omega]$ $\omega' \neq \omega$, increases.*

Summary of Theoretical Results and Hypotheses Development

1. Practically all capacity acquisition processes are resource dependent (sufficient conditions: uncertainty in resource valuation, risk aversion, values of resources are not perfectly correlated)
2. Risk aversion deters resource lock-in
3. The tendency for resource dependency
   a. increases in decision maker's risk aversion
   b. increases in risk of new and existing assets
   c. decreases in correlation among new and existing asset values

Due to 3b and 3c, differences in the riskiness of the operational environment or firm's circumstances can either increase or decrease the strength of the resource dependency.

Type of factor	Risk increasing factor	Expectation for resource dependency
Tangible	H1: An increase in the scale of existing assets	increase
	H2: A decrease in the scope of existing assets	mixed
Intangible	H3: An increase in existing debt	increase
	H4: A need to re-finance existing debts	increase
Market condition	H5: An increase in operating uncertainties	?
	H6: Dynamic debt rates contingent on firm's performance	?
	H7: A limited flexibility in investment timing	decrease

Case Study: Power Sector Investments

- Decisions:
  - Investment timing and technology selection
    - renewable (e.g., wind, solar, nuclear, hydro)
    - fossil 1 (e.g., coal) w/o CCS
    - fossil 2 (e.g., gas) w/o CCS
  - Operating
    - for new and existing plants
    - for financing and re-financing
- Time horizons:
  - Investment: 10 years (2 years intervals for decision making)
  - Operations: 50 years (10 years intervals for decision making)
- Modelled uncertainties:
  - Carbon price (policy assumed to be effective 10 years later)
  - Interest rate uncertainty

Multistage Stochastic Programming Model to Investigate Resource Dependency

- Investment model:

$$\mathbf{I}: \quad W_{s^\tau} = max_\omega \left\{ U(\zeta_{\omega,s^\tau} + \zeta_{\Omega,s^\tau} | \omega = 1, ..., G), max \left[W_{s^{\tau+1}} | \omega = 0, b(s^{\tau+1}) = s^\tau \right] \right\} \quad 0 \leq \tau < \theta$$

$$W_{s^\theta} = max_\omega \left\{ U(\zeta_{\omega,s^\theta} + \zeta_{\Omega,s^\theta}) \right\}.$$

- Operating model (key components):

$$\mathbf{O}: \quad \min R[\zeta_{\omega,s^\tau} + \zeta_{\Omega,s^\tau}] = \min \left[\alpha + \frac{1}{1-\beta} \sum_{s^T \in S^T} \gamma_{s^T} \right]$$

$$\text{subject to } \gamma_{s^T} \geq p_{s^T} \left[-z_{s^T} - \alpha \right], \qquad \gamma_{s^T} \geq 0$$

$$z_{s^t} = \begin{cases} C\Big(C(\iota, 0, \tau\delta) - u^0 + D_{s^t}, \tau\delta, \Delta\Big) - M_{s^t} + \\ C(I_{s^t}(1, \tau\delta), \tau\delta, \Delta) + I_{s^t}(0, \Delta - \tau\delta) & t = 0 \\ C(z_{b(s^t)} + D_{s^t}, 0, \Delta) - M_{s^t} + I_{s^t}(0, \Delta) & t > 0. \end{cases}$$

$$\sum_{i=0}^{t+1} \sum_{k=t}^{\Gamma} y^k_{b^i(s^t)} = \sum_{j=0}^{\Omega} \frac{\max[0, \eta^j - \Delta t] u^j}{l^j}$$

- Problem size and solution approach:
  - 30 x 115,200 = 3,456,000 scenarios for uncertainties
  - About 33 million decision variables
  - Solution via decomposition (**I** solved conditional on optimal solutions of **O**)

Measuring Strength of Resource Dependency

- Dissimilarity of investment decision with existing resources and investment decision without existing resources:

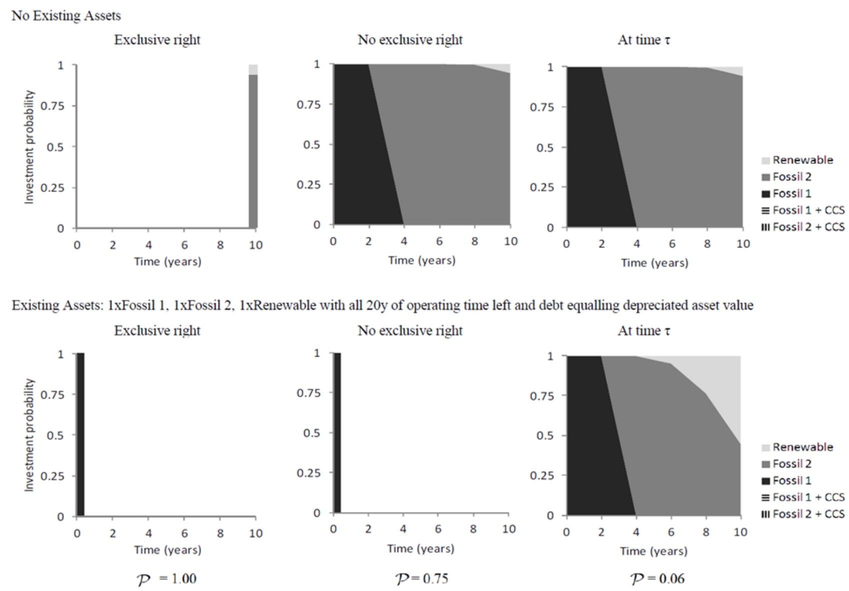
$$\mathcal{P} = \frac{\sum_{\tau=0}^{\theta} \left| \sum_{\omega=1}^{G} \left(\xi_{\omega,\tau} - \phi_{\omega,\tau} \right) \right| + \sum_{\omega=1}^{G} \left| \sum_{\tau=1}^{\theta} \left(\xi_{\omega,\tau} - \phi_{\omega,\tau} \right) \right|}{4}$$

$\mathcal{P} : ([0,1])^{G\theta} \to [0,1]$

If $\mathcal{P} = 0$ then there is no resource dependency

$\omega = 1, ..., G$	Investment alternatives, G>1
$\tau = 0, ..., \theta$	Investment horizon
$\xi_{\omega,\tau}$	Investment probability with existing resources
$\phi_{\omega,\tau}$	Investment probability without existing resources

Results: Significance of Resource Dependency



Results: Testing Hypotheses

Case	Existing assets / adjustment	$\mathcal{P}$ Exclusive right	$\mathcal{P}$ No exclusive right	$\mathcal{P}$ At time τ	Impact on $\mathcal{P}$
Base	1xF1, 1xF2, 1xR	1.00	0.75	0.06	-
H1: Scale	1xF2	0.00	0.00	0.00	increase
	2xF2	**0.76**	**0.41**	0.00	
	3xF2	**1.00**	**0.75**	0.00	
H2: Scope	3xF1	1.00	0.75	**0.08**	mixed among existing resources
	3xF2	1.00	0.75	**0.00**	
	3xR	1.00	0.75	**0.00**	
H3: Debt amount	Base without debt	**0.25**	**0.06**	0.06	decrease
H4: Debt maturity	Base with earlier debt maturity	1.00	0.75	**0.08**	increase
H5: Uncertainty	Base with increased uncertainty	1.00	0.75	**0.10**	increase
H6: Dynamic debt	Base with dynamic debt rate	1.00	0.75	0.06	mixed among existing resources
	No assets, dynamic debt rate	**0.25**	**0.08**	**0.08**	
		H7: Flexibility in investment opportunity			increase

F1: fossil 1 (e.g., coal)
F2: fossil 2 (e.g., gas)
R: renewable (e.g., wind, solar, nuclear, hydro)

Conclusions

- Practically all capacity investment decisions are resource dependent
- Resource dependency can significantly impact investment decisions
- Resource dependency is stronger when:
  i. decision maker is strongly risk averse
  ii. profits are highly uncertain
  iii. substantial scale of existing plants
  iv. existing plants largely funded by debts
  v. existing debts mature earlier than the life time of the assets ends
  vi. there is flexibility in deciding on the investment timing
- Technology subsidies or incentives, provided in a nondiscriminatory way, do not account for resource dependency and may not be as efficient as anticipated
- Without accounting for resource dependency, a misleading view of the evolution of market heterogeneity is obtained
- The developed decomposition approach is useful in solving large-scale capacity expansion problems under uncertainty including both investment and operational decisions