Renewable energy implementation and fossil stock development

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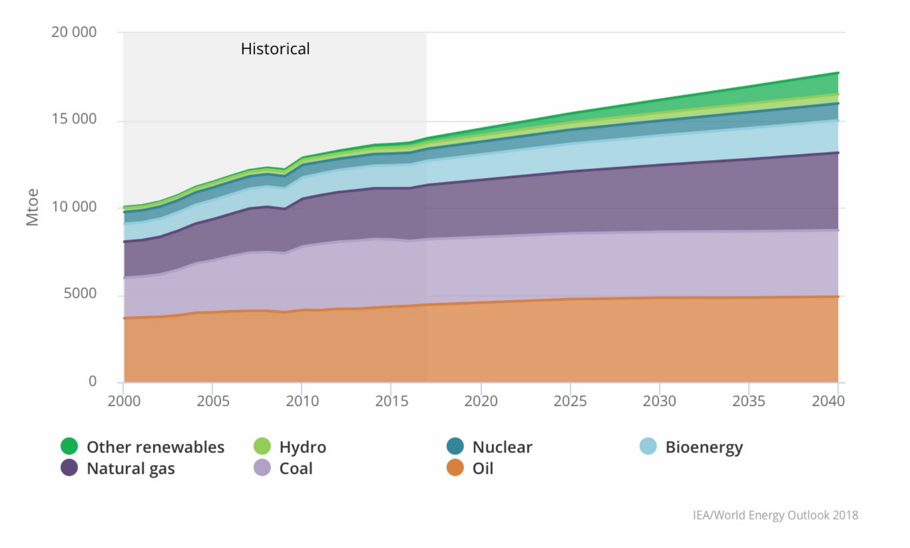
Exeter - June 2019

Introduction

- Economic activity requires a continuous supply of energy
  - Fossil fuels: major source of energy now & foreseeable future
  - Renewables: growing importance in global energy mix
- Secure continuous energy supply requires continued investment in
  - Exploration and development
    - maintains & expands fossil extraction capacity
  - Renewable energy sources
    - expands renewable energy capacity

Introduction; energy demand

Figure: Total primary energy demand (IEA 2018 WEO “New Policies Scenario”)



Introduction; energy demand

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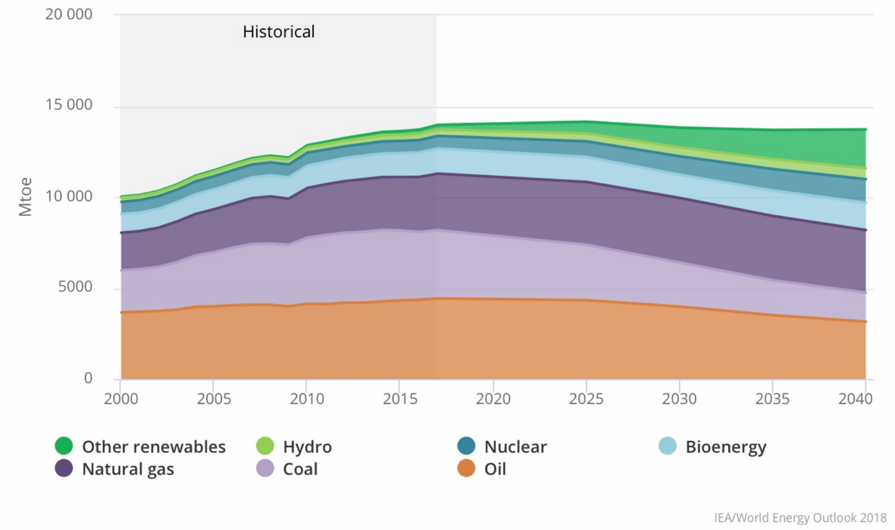

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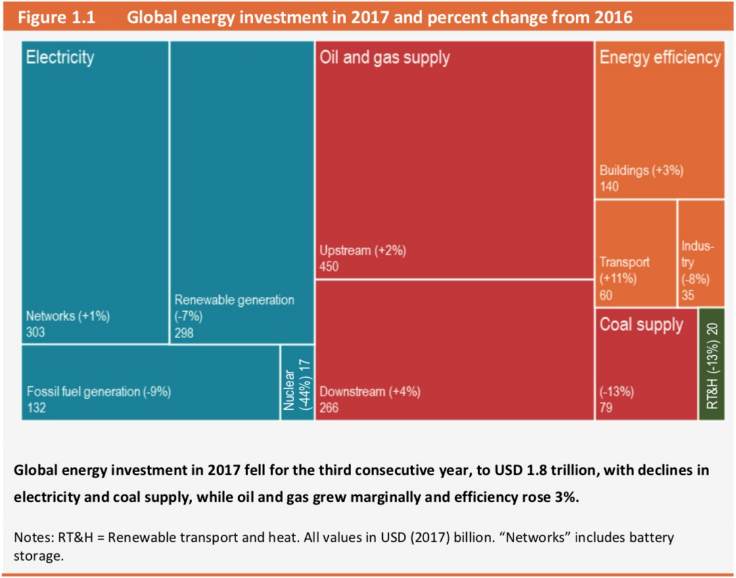
Introduction; energy investment

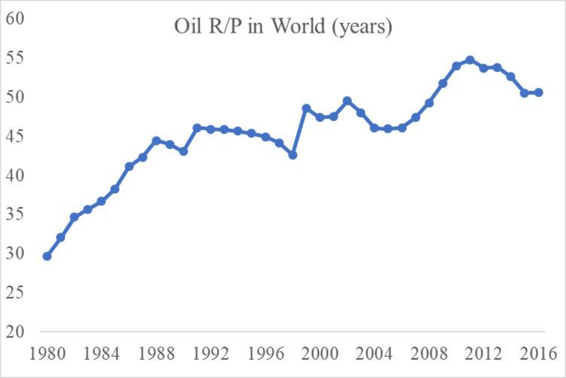
Figure: Global energy investment (IEA 2018 World Energy Investment Report)



Introduction

- Upstream fossil energy investments have lead to
  - large stocks of developed reserves
  - non-declining reserves/production ratio

Figure: Proven global oil reserves to production ratio (BP Statistical Report)



Introduction

- Fossil energy is associated with environmental externalities
- Continued exploration and already accumulated extraction capacities raise concerns about
  - incentives for renewable energy investment
  - cost and possibility of fossil phase-out
    - possible need to abandon developed reserves

This paper

- Consider renewable energy investment against the backdrop of
  - continued (potential) development of new stocks of fossil
  - existing stocks of developed reserves (extraction capacity)
- Assess implications for
  - incentives for renewable energy investment
  - conditions under which a fossil phase-out prevails
    - and developed reserves are abandoned
  - optimal renewable investment policy

Literature

- Exploration and extraction: Pindyck (1978)
  - Timing of opening driven by sunk costs (and partially constrained extraction): Venables (2014)
  - Timing of drilling with constrained extraction: Bai & Okullo (2018), Anderson et al. (2018)
- Renewables expansion and extraction of exhaustible oil reserves
  - Effect of cheaper renewable on fossil extraction: vdrPloeg and Withagen (2012)
  - Resource-saving innovation, expectations: vdrMeijden and Smulders (2017)
- Exploration, extraction, and renewable energy expansion: this project

Output

Concave utility from output $U(Y)$, competitive markets, representative firms.

- Aggregate output production function

$$Y(t) = \min\{E(t), Z\},$$

  - Energy use $E(t)$
  - Other inputs Z (exogenous)
    - Z pins down total energy demand
- Energy needs are satisfied by fossil and renewable sources

$$E(t) = E_F(t) + E_R(t)$$

Setup: fossil energy sector

- Cost of producing fossil energy

$$C_{U,F}\left(E_F\left(t\right)\right)=c_{U,F}E_F(t)$$

  - includes cost of extraction, transformation of resources to energy, and taxes/subsidies
- Developed reserve dynamics

$$\dot{S}\left(t\right)=-E_F\left(t\right)+X\left(t\right)$$

  - $S_0>0$ given
  - exploration cost $C_X\left(X(t)\right)=c_XX(t)$
  - limits on reserve additions; $X\in\left[0,\bar{X}\right]$
- Geological extraction constraint

$$E_F\left(t\right)\leqslant E_F^{cap}\left(t\right)=\kappa S\left(t\right),\ \kappa>0$$

Setup: renewable energy sector

- Renewable energy capacity

$$E_R(t) \leqslant E_R^{cap}(t) = K(t)$$

- Cost of producing renewable energy

$$C_{U,R}\left(E_F\left(t\right)\right) = c_{U,R}E_R(t)$$

  - lower marginal cost from using renewable capacity $c_{U,R} < c_{U,F}$
- Capacity dynamics

$$\dot{K}(t) = I(t) - \delta K(t)$$

  - $\delta > 0$ depreciation, $K_0 \in [0, Z]$ initial capacity
- Convex capacity investment cost $C_I(I(t))$, $C_I' > 0$, $C_I'' > 0$, $C_I'(0) = 0$

Before we move on

We abstract from long-run physical depletion

- Interpretation: energy transition in the medium run
  - Insufficient fossil extraction capacity might lead to immediate scarcity; difficulties in meeting immediate energy needs
    - generates incentives to invest in capacity
  - Abstract from long-run physical depletion
    - energy forecasts: no major concern for the next several decades
    - especially once stringent climate policies are implemented
- Physical depletion would manifest through $c_X \uparrow$ as cumulative exploration $\uparrow$

What do we find? (short run)

1: Larger stocks of developed fossil reserves reduce renewable energy investment

- Aggregate energy demand is Z
- Potential energy supply is $E^{cap}(t) = E_F^{cap}(t) + E_R^{cap}(t) = \kappa S(t) + K(t)$
- If $E^{cap}(t) < Z$
  - $p_E(t)$ is relatively high
  - use both energy sources at full capacity
  - strong incentives for exploration and renewable investment
- If $E^{cap}(t) > Z$
  - $p_E(t)$ is relatively low
  - use renewable at full capacity, fossil for remainder
  - weak incentives for exploration and renewable investment
- If $E^{cap}(t) = Z$
  - use renewable and fossil at full capacity
  - might still observe changes in composition of energy mix

Higher stocks generally imply lower investment incentives.

- exception: if on a trajectory with stock abandonment.

What do we find? (long run)

2: A fossil phase-out occurs if at the margin, the total cost of renewables $<$ total cost of fossil

2 feasible long run equilibria

- simultaneous use of fossil and renewable
- renewable only

Long run marginal costs of energy sources

- Fossil: $c_F = c_{U,F} + \frac{r+\kappa}{\kappa} c_X$
- Renewable: $c_R(K^{ss}) = c_{U,R} + (r+\delta)\, C_I'\,(\delta K^{ss})$
  - with $K^{ss} < Z$ ($= Z$) if simultaneous use (renewable only)

What do we find? (long run)

2: A fossil phase-out occurs if at the margin, the total cost of renewables $<$ total cost of fossil

- Which long run equilibrium will prevail?
  - If $c_R(Z) > c_F$: simultaneous use
  - If $c_R(Z) < c_F$: renewable only

- If renewables only, will developed stock be left in the ground?
  - Marginal cost of extracting previously developed fossil is $c_{U,F} < c_F$
  - Abandon existing developed reserves if $c_R(Z) < c_{U,F}$ (for oil: $c_{U,F} < 2/3 c_F$)
  - Important: distinguishing between exploration (capital) and use costs

- Note: even if we eventually phase-out fossil (and abandon developed stocks)
  - we might observe positive exploration today!
  - relevant if $E^{cap} \ll Z$

What do we find? (policy)

3: (Optimal) renewable subsidies are weakly declining in fossil stocks

- Environmental externality: c_M per unit of extracted fossil
- Assume the policymaker cannot use carbon taxes. Policy strategy: renewable investment subsidy
- The optimal subsidy is

$$g_I(t) = \begin{cases} \frac{1}{r+\delta} c_M e^{-(r+\delta)(t'-t)} & \text{if } E^{cap}(t) < Z \\ \frac{1}{r+\delta} c_M & \text{if } E^{cap}(t) \geqslant Z \end{cases}$$

  with t' such that for all $t < t'$, $E^{cap}(t) < Z$, while for $t \geqslant t'$, $E^{cap}(t) = Z$.
- Intuition: subsidize renewable insofar it crowds out fossil use
  - if $E^{cap} < Z$; renewable will merely increase total energy supply in the short run
  - only if $E^{cap} \geqslant Z$; renewable will immediately crowd out fossil

Wrap-up

- Fossil fuels will continue to be a major source of energy in the foreseeable future
  - We still observe large efforts in exploration and development of new fields
- For the energy transition: relevant to consider the incentives for both exploration and renewable energy investments
- We consider a setting with fossil exploration and development, and renewable investment. Findings:
  - weakly negative relationship between developed fossil and renewable energy investment
  - weakly positive relationship between developed fossil and optimal renewable subsidies
  - thresholds conditions under which fossil phase-outs prevail
    - ★ with/without abandoning developed stock

Thank you