Energy transition under irreversibility: a two-sector approach

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Third Annual Conference, GGKP
January 29-30, 2015 – Venice.

Motivation

- Over the recent years, investments in Renewable Energy (RE) sources have been quickly growing : from 63 billion USD in 2006 to 244 billion USD in 2012 (GEA,2013).
- However, fossil fuels are still the main energy source (78.2%) used in the world.
- The transition to renewable energy involves two kinds of environmental concerns :

(i) first, fossil fuels are exhaustible and
(ii) second, their use generates negative externalities through environmental damages.

Motivation(2)

Problems :

- There exist pollution thresholds above which environmental catastrophes are expected to occur (Keller et alii, 2008).

- We have to drastically change the way energy is produced, and
- Also look for energy saving strategies.

- This paper focuses on the issue of energy transition that involves both the decision of RE adoption and that of the investment in energy saving technologies (EST)

Main contributions

- This paper is mainly related to the application in Boucekkine et al. (2013) as it involves both the switching decision to cleaner energy sources and the pollution threshold effect as the main drivers of energy transition.
- A two-sector approach (capital to produce energy, and energy to produce a final good)
- Several studies on RE adoption assume imperfect or perfect substitution between inputs. Alternatively, we consider the case of an economy with rigidities such that oil and RE sources are complementary as in Pelli (2012).

Main contributions(2)

- Moreover, we also assume that capital use and energy are complementary, as in Pindyck and Rotemberg (1983), Boucekkine and Pommeret (2004) or Diaz and Puch (2013).
- Numerical results show that the optimal energy transition path may correspond to a corner regime in which the economy starts using both resources, crosses the pollution threshold by losing a part of its capital and never adopts only renewable energy.
- Investment in energy saving technologies helps to reduce the consumption of energy for the same quality of energy services, and therefore favour energy transition..

Literature review

- Long run depletion of oil reserves (Dasgupta and Heal, 1974, 1979) and polluting feature of oil (Tahvonen, 1996, 1997).
- Climate change as important drivers of transition to clean energy or to clean technologies (Acemoglu et al., 2014 ; Amigues et al., 2013 and Tsur and Zemel, 2003).
- Irreversible damage (Forster, 1975 and Ayong Le Kama et al., 2011), partly reversible (Tsur and Zemel, 1996), or fully reversible (Kollenbach, 2013).
- Damage function : income loss (Tsur and Withagen, 2012), social welfare loss (Van der ploeg and Withagen, 2012), capital loss (Horii and Ikefuji, 2010), or destruction capacity (Golosov et al., 2011).

Literature review(2)

- Complementarity between (i) capital and energy (Pindyck and Rotemberg, 1983 ; Boucekkine and Pommeret, 2004 ; Diaz and Puch, 2013 ;) , and (ii) NRE and RE (Pelli, 2012).

- Boucekkine et al. (2013) provide first order optimality conditions in an optimal regime switching problem with threshold effects : continuity of appropriate co-state and state variables, and that of the Hamiltonian.
- Very few works deal with the adoption of energy saving technologies (Charlier et al., 2011 ; De Groot et al., 2001 and Acemoglu et al., 2012).

Energy sector

- Energy as intermediate goods : oil as a non renewable energy (NRE) E_s and a renewable energy source (RE) E_x.
- Part of the energy E_2 is used as energy services by a representative consumer and the other part E_1 is used as input to produce final goods.
- Extracting oil is costless and the oil stock exhibits : $dS_t = -E_{st}dt$
- Production of RE : $E_x = \varphi K_1 = \varphi \phi K$
- $\Rightarrow E_{st} = E_{1st} + E_{2st}$ and $E_{xt} = E_{1xt} + E_{2xt}$

The pollution threat and final goods

The pollution threat

- Pollution accumulation : $\dot{Z}_t = E_{st}$
- Pollution threshold $\overline{Z}$ above which a part θ of capital is lost (following flooding for instance).

Final goods sector

- $Y = min\{\alpha_2 K_2, \beta_2 E_{1t}\}$ With $E_{1t} = min\{\frac{1}{\xi} E_{1st}, E_{1xt}\}$ and $K_2 = (1 - \phi)K$.

Households

- CRRA utility function : $U = \int_0^{\infty}(\frac{C_t^{1-\delta}}{1-\delta} + \frac{E_{2t}^{1-\delta}}{1-\delta})e^{-\rho t}dt$, where $E_{2t} = min\{\frac{1}{\xi}E_{2st}, E_{2xt}\}$.
- Capital accumulation : $Y_t = C_t + \dot{K}_t$
- Market clearing conditions : $\dot{K}_t = \dot{K}_{1t} + \dot{K}_{2t}$ and $E_{st} + E_{xt} = E_1 + E_2$.

Third and second energy regimes

Third energy regime

$$V_3 = Max \int_{T_2}^{\infty} \left(\frac{C^{1-\delta}}{1-\delta} + \frac{E_2^{1-\delta}}{1-\delta}\right) e^{-\rho(t-T_2)} dt$$

$$\text{st } \dot{K} = \alpha_2 \left(K - \frac{1}{\varphi} E_1 - \frac{1}{\varphi} E_2\right) - C$$

Second energy regime

$$V_2 = Max \int_{T_1}^{T_2} \left(\frac{C^{1-\delta}}{1-\delta} + \frac{E_2^{1-\delta}}{1-\delta}\right) e^{-\rho(t-T_1)} dt + V_3 * e^{-\rho T_2}$$

$$\text{st} \begin{cases} \dot{K} = \alpha_2 (1-\phi) K - C \\ \dot{S} = -\xi (E_1 + E_2) \end{cases}$$

First energy regime and boundary conditions

First energy regime

$$V_1 = Max \int_0^{T_1} [(\frac{C^{1-\delta}}{1-\delta} + \frac{E_2^{1-\delta}}{1-\delta})e^{-\rho t}]dt + V_2^* e^{-\rho T_1}$$

$$\text{st} \begin{cases} \dot{K} = \alpha_2(1-\phi)K - C \\ \dot{Z} = \xi(E_1 + E_2) \end{cases}$$

with $\dot{S} = -\xi(E_1 + E_2) = -\dot{Z}$

Boundary conditions

Continuity of :

- The value of the capital at t= T_1 and at t= T_2,
- The capital at t= T_1 and at t= T_2,
- The Hamiltonian at t= T_1 and at t= T_2.

Corner regimes

- Sole switch to the clean energy ($T_1 = \infty$) : switch from the first regime to the third regime.
- Sole switch above the pollution threshold level ($T_2 = \infty$) : transition from the first to the second regime without the option to switch to the third regime.
- No switch ($T_1 = \infty$ and $T_2 = \infty$) : the economy remains in the first regime forever.
- Starting with RE ($T_1 = \infty$ and $T_2 = 0$) : third regime without the option to switch.

Value function

Energy transition path	**values functions**
General energy transition path	–36.7722
$T_1=\infty$,	-42.4142
$T_2=\infty$	**-17.6568**
$T_1=\infty$ *and* $T_2=\infty$	*-19.2455*
$T_1=\infty$ and $T_2=0$	-50.8961

⇒ The economy starts using both sources of energy. Then, it crosses the pollution threshold and loses a part of its capital. The sole adoption of the RE is never optimal for the economy.

	ρ	θ	S_0	α_2	β_2	$\bar{Z}$
T_1	-	+	small effect	+	+	+

Table 2 : Sensitivity analysis

Introducing investment in Energy Saving Technologies (EST)

The additional investment q_t serves to reduce by $\vartheta(q)$ units the resources that the economy needs in order to get the same energy services.

Investments in EST :

- do not alter the optimal energy transition path.
- increase the time at which the economy may experience the catastrophe and that of the sole adoption of the renewable energy.
- increases the welfare of the society.

Conclusion

- The optimal transition path to clean energy is asymptotic and investments in EST favour this transition.
- Adoption of economic instruments such as taxes on the "dirty" energy, subsidies on the "clean" energy, or incentives for energy saving technologies in order to promote energy transition.
- Also, it is profitable to design economic instruments that jointly target the promotion of "clean" energy and incentives for investment in energy saving technologies.
- But those economic instruments should be designed to meet the long run transition.
- Empiral extension : optimal taxes/subsidies that may favour the adoption of renewable energy and the investments in EST.

Thanks for your attention.