Title of the Poster

Can wood pellets save coal? A real options approach to retrofitting coal plants.

Authors Author Affiliation and Contact Information

Sarah Stutzman, Brandon Weiland, Dr. Michael M. Wetzstein, Dr. Paul V. Preckel
Purdue University, Department of Agricultural Economics

Selected Poster prepared for presentation at the
2016 Agricultural & Applied Economics Association Annual Meeting, Boston, MA, July 31- Aug. 2

Can Wood Pellets Save Coal?

A real options approach to retrofitting coal plants

Purdue Agricultural Economics Department

http://api.ning.com/files/C3iwlCcqy-ANXvk3u9AHY*
7OGbpBnJk0PFKvqqUGI5rvPdRkv9sC*YPmNjPbGTCw
OHwNxvt2qHNzzJmvFBOVYwYm8RwVS6x3/OldPowerPlant.jpg

http://thumbs.dreamstime.com/z/wood-pellet-30726554.jpg

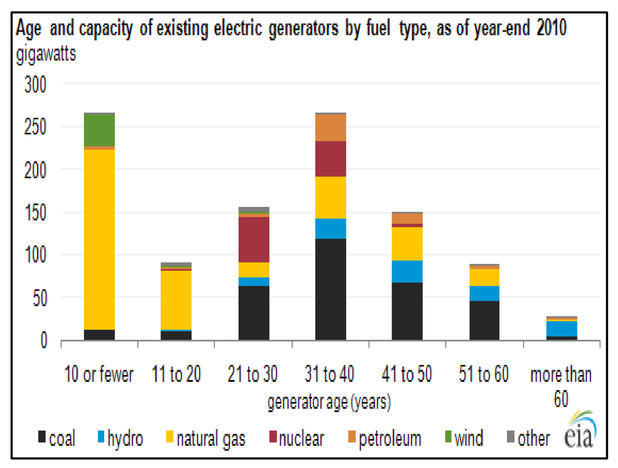
Sarah Stutzman, Brandon Weiland, Michael M. Wetzstein, Paul V. Preckel

Issue

Aging coal power supply:

51% of U.S. power capacity > 30 years old (EIA, 2011a).

73% of coal fired plants > 30 years old (EIA, 2011b).



More stringent emissions standards

Under the Clean Power Plan, states must develop plans to reduce CO_2 emissions from existing fossil-fired electricity units and increase use of renewable energy sources (EIA, 2015).

A Solution: Co-fire coal and wood pellets

Retrofitting with wood pellets is a relatively low-cost option.

Wood pellets are a renewable technology.

Co-firing reduces total carbon and other greenhouse gas emission levels.

Reduces total cost variability (portfolio effect).

Option value of being able to wait as new technology develops before making irreversible replacement decision.

https://img.washingtonpost.com/rf/image_1484w/2010-2019/WashingtonPost/2011/12/17/Editorial-Opinion/Images/Illinois_Coal_Plants_07a2e.jpg?uuid=qBPqlihxEeG0GDqV_7VkWQ

Asset Replacement Literature

Modifications to the initial optimal asset replacement criteria proposed by Faustmann-Samuelson (Faustmann 1968; Samuelson 1937) include increasing operation costs following a Brownian motion process (McLaughlin and Taggart 1992; Mauer and Ott 1995), real options (Dobbs, 2004), nonconstant revenue stream and technological change (Adkins and Paxson, 2011), and asset renewals instead of total replacement (Rindorp and Fu, 2011). In agricultural economics, alterations include allowing for asset rejuvenation under deterministic and stochastic costs (McCelland et al., 1989; Smith et al.,1992).

Our Contribution

We combine the asset rejuvenation problem with real options and increasing stochastic costs. A model is developed for determining the optimal time to retrofit a coal fired plant (virgin stage) to co-fire with wood pellets (rejuvenation stage) and then to replace the plant. Comparative statistics and numerical analysis illustrate how changes in key parameter values impact the length of time spend in each stage and the costs, which trigger rejuvenation and/or replacement.

Model: Deterministic Costs

Operating costs grow at aa constant rate θ_i: $c_{it} = c_{i0}e^{\theta_i T_i}$.

Maximize: $V(T_1^*, T_2^*) = K_1 + \int_0^{T_1} c_{1t}\, e^{-rt}dt + K_2\, e^{-rT_1} + \int_{T_1}^{T_2} c_{2t}\, e^{-rt}\, dt + (V - S)e^{-rT_2}$,

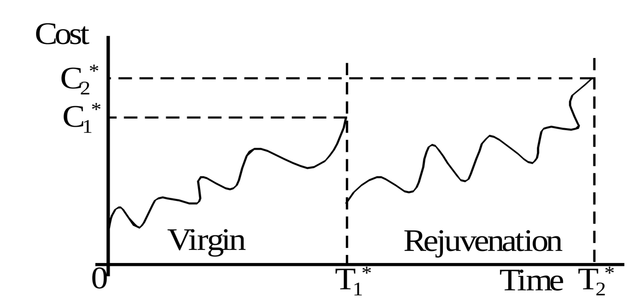
where V represents the present value of power plant costs, i=1 and i=2 refer to the virgin and rejuvenation stages, K_i are the initial virgin and rejuvenation investment costs, c_{it} are the operating costs at time t in each stage, S is the salvage value, r is the discount rate, and T_i are the length of each stage.

Solving the first-order conditions results in estimates for the optimal time spent in each stage (T_1^* and T_2^*) where:

$$T_1^* = \frac{ln\left[\frac{rK_2+c_{20}}{c_{10}}\right]}{\theta_1} \quad \text{and } T_2^* \text{ can be calculated numerically.}$$

Model: Stochastic Costs

Costs grow following Brownian motion: $dc_{it}/c_{it} = \theta_i dt + \sigma_i$, where θ_i is a constant drift rate, σ_i is the rate of volatility, and dz is the increment of a Wiener process.



Maximize simultaneously:

$V_1(c_{1\tau}) = E_\tau(\int_\tau^{T_1(C_1)} c_{1t}\, e^{-r(t-\tau)}dt + W_1(C_1)e^{-r[T_1(C_1)-\tau]}$,

where $W_1(C_1) = K_2 + V_2(C_1)$,

$V_2(C_1,C_2) = E_\tau(\int_{T_1(C_1)}^{T_2(C_1,C_2)} c_{2t}\, e^{-rt}\, dt + W_2(C_2)\, e^{T_2(C_1,C_2)}$,

where $W_2(C_2) = K_1 - S + V_1(c_{10})$.

E_τ is the expectations operator, $c_{1\tau}$ and $c_{2\tau}$ are costs at time τ in the virgin and rejuvenation stages respectfully, $V_1(c_{1\tau})$ is the present value of costs at time τ in the virgin stage ($c_{1\tau}$), C_1 and C_2 are the costs that trigger rejuvenation and replacement respectively, $V_2(C_1,C_2)$ is the present value of costs in the rejuvenation stage, and $W_1(C_1)$ and $W_2(C_2)$ are expected future costs in the subsequent rejuvenation and virgin stages.

We employ Ito's lima and the second order partial differentiation to find a solution that satisfies the value matching and smooth pasting conditions. The following equations when solved simultaneously provide the optimal C_i, $T_1^*(C_1)$, and $T_2^*(C_1,C_2)$:

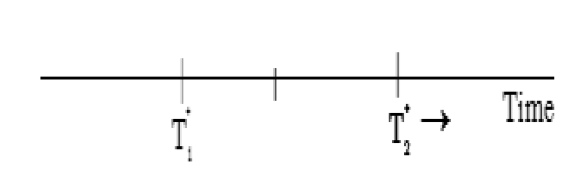
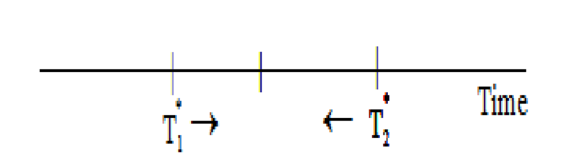
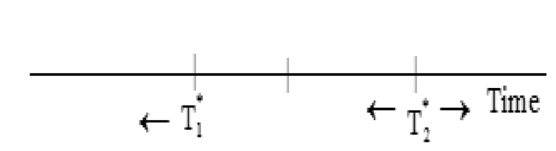
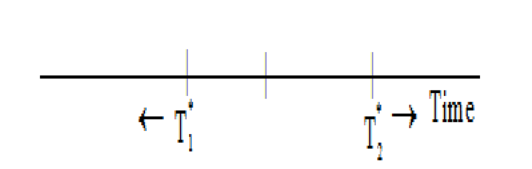
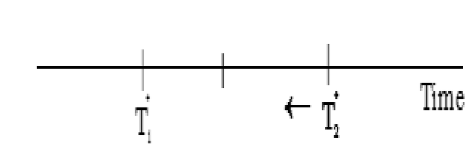
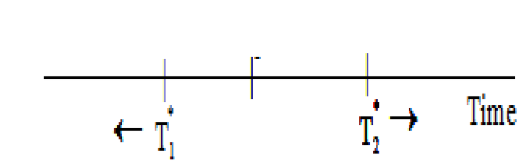
$$\text{I)}\ \frac{C_1}{r-\theta_1} + \frac{C_1}{(r-\theta_2)\lambda_1}\left[\frac{\theta_2-\theta_1}{r-\theta_1} - \left(\frac{C_1}{C_2}\right)^{\lambda_2-1}\right] - K_2 - \frac{C_1}{r-\theta_2} + \frac{C_1}{(r-\theta_2)_{\lambda_2}}\left(\frac{C_1}{C_2}\right)^{\lambda_2-1} = 0,$$

$$\text{II)}\ \frac{C_2}{r-\theta_2} + \frac{-1}{(r-\theta_2)_{\lambda_2\, C_2^{\lambda_2-1}}} C_2^{\lambda_2} - K_1 + S - \frac{c_{10}}{r-\theta_1} - \frac{c_{10}^{\lambda_1}}{(r-\theta_2)\lambda_1 C_1^{\lambda_1-1}}\left[\frac{\theta_2-\theta_1}{r-\theta_1} - \left(\frac{C_1}{C_2}\right)^{\lambda_2-1}\right] = 0.$$

Comparative Statistics

Comparative statistics indicate how the optimal replacement times are impacted by changes in the parameter values. The timelines indicate the comparative statistics shifts in optimal virgin (T_1^*) and total, virgin plus rejuvenation (T_2^*), cycle times given changes parameter values. Movements to the right (left, no movement) of the timeline indicate an increase (decrease, no change) in the optimal time spent in that stage given an increase in the parameter value.

Parameter Impacts on Optimal Cycle Lengths

Parameter		Deterministic Costs	Stochastic Costs
Virgin outlay costs	K_1		
Virgin initial operating costs	c_{10}		
Salvage value	S		

Trucks deliver wood pellets to Virginia City Hybrid Energy Center. Source: Dominion, Virginia City Hybrid Energy Center. http://www.virginiaplaces.org/energy/biomass.html

Numerical Analysis

Numerical analysis is employed to obtain estimates of optimal cycle times and the impact of changes in key parameters on the time spent in each stage. Initial parameter values[1] are chosen and the FOC are solved to determine the optimal time at which to retrofit and/or replace the plant. Elasticity estimates indicate the percent change in the optimal cycle time given a percent increase in the parameter value (ω).

Optimal Times under Stochastic vs. Deterministic Costs

	Deterministic Costs			Stochastic Costs		
	Virgin Period T_1^*	Total Cycle T_2^*	Retrofit Period T_2^*-T_1^*	Virgin Period T_1^*	Total Cycle T_2^*	Retrofit Period T_2^*-T_1^*
Cycle Length (years)	15.70	33.30	50.00	22.49	19.65	42.14

Elasticity Estimates With Respect to Changes in Parameter Values

Parameters (ω)		Stochastic Costs		
		Virgin Period $\varepsilon_{T_1,\omega}$	Total Cycle $\varepsilon_{T_2,\omega}$	Rejuvenation period $\varepsilon_{T_2-Y_1,\omega}$
Rejuvenation Outlay	K_2	-0.008	-0.007	-0.007
Initial rejuvenation operating costs	C_{20}	0	-0.359	-0.780
Rejuvenation operating cost volatility	σ_2	1.260	1.167	1.062

[1] The parameter values are chosen to be as realistic as possible, but do not necessarily represent those of a specific current coal plant specification.

Policy Findings

Not accounting for stochastic costs could lead to underestimates of the time before retrofitting occurs and overestimates of the time the plant is operated after retrofitting and total operation time.

The impacts of changes in key parameters differs when stochastic operating costs are included. After their inclusion, policies that increase the initial fixed investment cost of the coal-only fired plant increase the time before rejuvenation occurs and decrease the time operated after rejuvenation. Increases in the yearly operating costs of the virgin plant, such as carbon emission fees, and increases in the salvage value decrease the time before retrofitting and increase the time the plant is operated after retrofitting.

By calculating elasticity estimates and given stochastic costs the following policy impacts become apparent: mechanisms to reduce retrofitting outlay costs have limited impact on encouraging earlier adoption or extending the operating period of the retrofitted plant, reducing retrofit initial operating costs extends time operated once the technology is installed, but does not quicken the decision to install new technology, and movements to reduce volatility of retrofit costs may reduce time operated once retrofitting occurs.

References

Adkins, R. and D. Paxson. 2011. “Renewing Assets with Uncertain Revenues and Operating Costs,” Journal of Financial and Quantitative Analysis 46(3): 785-813.

Dobbs, I. 2004. “Replacement investment: Optimal economic life under uncertainty,” Journal of Business Finance and Accounting 31:729-757.

EIA, 2015. “Analysis of the Impacts of the Clean Power Plan.” May 22, 2015. http://www.eia.gov/analysis/requests/powerplants/cleanplan/

EIA. 2011a. “Age of electric power generators varies widely,” Today in Energy, U.S. Energy Information Administration, June16, 2011. http://www.eia.gov/todayinenergy/detail.cfm?id=183

EIA. 2011b. “Most coal-fired electric capacity was built before 1980,” Today in Energy, U.S. Energy Information Administration, June 28, 2011. https://www.eia.gov/todayinenergy/detail.cfm?id=1990

Faustmann, M. 1968. “On the determination of the value which forest land and immature stands possess for forestry,” Oxford Institute, paper 42, ed. M. Gane. Oxford, UK.

Mauer, D. and S. Ott. 1995. “Investment under uncertainty: The case of replacement investment,” Journal of Financial and Quantitative Analysis 30:581-605

McClelland, J., M. Wetzstein, and R. Noles. 1989. “Optimal replacement policies for rejuvenated assets,” American Journal of Agricultural Economics 71(1):147-157

McLaughlin, R. and R. Taggart. 1992. “The Reindorp, M. and M. Fu. 2011. “Capital renewal as a real option,” European Journal of Operational Research 214:109-117.

Reindorp, M. and M. Fu. 2011. “Capital renewal as a real option,” European Journal of Operational Research 214:109-117.

Samuelson, P. 1937. “Some aspects of the pure of capital,” Quarterly Journal of Economics 51:469-96.

Smith, G. and M. Wetzstein. 1992. “A stochastic asset replacement model for rejuvenated assets,” American Journal of Agricultural Economics 74(2): 378-87.