HBS: GREEN NEIGHBOURS IN CAMBRIDGE Dec 2015

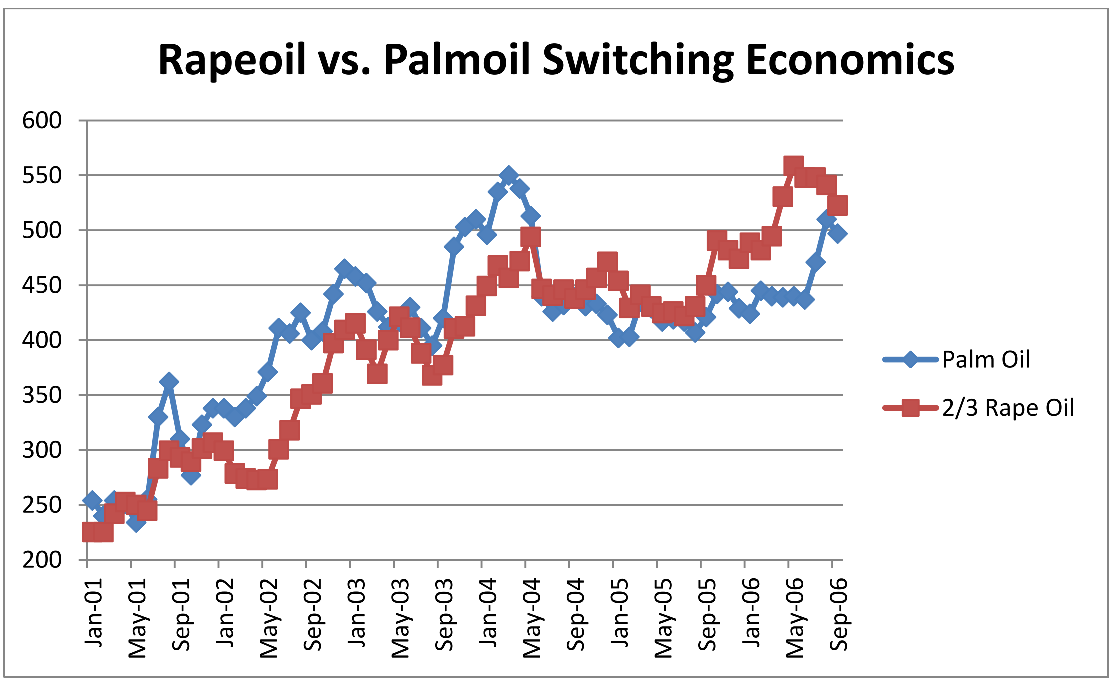
"In February 2004, Harvard University in Cambridge, Massachusetts, announced that it had begun to use B20 in all of its diesel vehicles and equipment, including shuttle buses, mail trucks and solid waste and recycling trucks. Although a number of alternative fuels were studied, biodiesel was finally selected because it provided the greatest health and environmental benefits in the most cost-effective way, according to David Harris Jr., general manager of transportation services at Harvard. But there were other reasons for the switch as well. 'Harvard is not a stand-alone campus,' Harris said. 'Our shuttle buses drive down the streets of Cambridge, past houses and other schools. We feel a responsibility to be a good neighbour and be as environmentally friendly as possible. Biodiesel helps us accomplish that using the vehicles we already have'." (Pahl, pp. 278-279) World Energy Alternatives LLC (of Massachusetts) supplied the biodiesel. Pahl believes their success and stability is partly due to "feedstock flexibility". (Pahl, p. 224).

George Gamble graduated from Harvard Business School in September 2006, and believed he could make a worthwhile contribution to his alma mater and to his own modest wealth by constructing and operating a flexible biodiesel plant in Cambridge to supply World Energy (and Harvard) with a sustainable, renewable, environmentally friendly transportation fuel, using a flexible production plant. George founded Harvard Biodiesel Sustainable (HBS).

He believes World Energy might guarantee a fixed price of $1000 per ton for the biodiesel output. George believes a new venture scale plant might produce 100 tons yearly. He plans to import canola (rape) oil from Canada, or palm oil from Malaysia, for use in a plant, capable of switching between rape oil and palm oil. The equivalent (2/3 canola=one unit of palm oil) cost of both canola oil and palm oil is currently around $400 per ton, efficiency is assumed to be 100%, there are no other operating costs apart from feedstock, and switching costs are about $1000 per ton for switching once from canola to palm oil. HBS is registered as a charity, and so pays no tax.

George wonders whether the facility to switch basic feedstock inputs is critical, after examining the relative prices over the last five years as shown in Figure 1.

Figure 1



Seemans A.G. has offered to supply a flexible plant for an investment cost of $3500 per ton of production, with an infinite life, or alternatively a plant capable of using only rape oil for an investment cost of $500 per ton less.

A little rusty on switching options, George turned to some classical finance teachers, Professor Marshall at the University of Cambridge and Professor Jevons at the University of Manchester. Use net present values ("deterministic"), said Professor Marshall, because that is a trusted and established method.

"Wait", said an up and coming American finance Professor Brash. "Marshall assumes certainty in feedstock prices. As you know both palm oil and rape seed oil prices are variable, and cultivation geographically distance, so use the new Adkins and Paxson (2011) approach ("stochastic x and y")."

What a palaver, thought George, that these academics cannot agree. What difference does it make anyhow?

Here is Professor Brash's story.

Consider a flexible facility which can use one of two different inputs by switching between operating modes. Assume the prices of the two inputs x and y, are stochastic and correlated and follow a geometric Brownian motion process:

$$dx = (\mu_x - \delta_x) x\,dt + \sigma_x\, x\,dz_x \tag{1}$$

$$dy = (\mu_y - \delta_y) y\,dt + \sigma_y\, y\,dz_y \tag{2}$$

with the notations:

μ Required return on the input, δ Convenience yield of the input

σ Volatility of the input, dz Wiener process (stochastic element)

ρ Correlation between the two input prices: $dz_x\, dz_y / dt$

The instantaneous cash flow in each operating mode is the unit output price less the respective price of the input, assuming production of one (equivalent) unit per annum, (p-x) in operating mode '1' and (p-y) in operating mode '2'. A switching cost of S_{12} is incurred when switching from operating mode '1' to '2'. The appropriate discount rate is r for non- stochastic elements, such as constant output prices. For convenience and simplicity, assume that the appropriate discount rate for stochastic variables is δ which is equal to μ-r. Further assumptions are that the output price is constant, the lifetime of the asset is infinite, and the company is not restricted in the input mix choice because of quality requirements or operating efficiency. Moreover, the typical assumptions of real options theory apply, with interest rates, convenience yields, volatilities and correlation constant over.

The asset value with a perpetual opportunity to switch once between the two operating modes is given by the present value of perpetual cash flows in the current operating mode plus the option to switch to the alternative mode. Let V_1 be the asset value in operating mode '1', using input x, and V_2 the asset value in operating mode '2', using input y accordingly. The switching option depends on the two correlated stochastic variables x and y, and so do the asset value functions which are defined by the following partial differential equation, allowing for different output prices using the different inputs: (3)

$$\frac{1}{2}\sigma_x^2 x^2 \frac{\partial^2 V_1}{\partial x^2} + \frac{1}{2}\sigma_y^2 y^2 \frac{\partial^2 V_1}{\partial y^2} + \rho\sigma_x\sigma_y xy \frac{\partial^2 V_1}{\partial x \partial y} + \left(r - \delta_x\right) x \frac{\partial V_1}{\partial x} + \left(r - \delta_y\right) y \frac{\partial V_1}{\partial y} - rV_1 + \left(p_x - x\right) = 0$$

(4)

$$\frac{1}{2}\sigma_x^2 x^2 \frac{\partial^2 V_2}{\partial x^2} + \frac{1}{2}\sigma_y^2 y^2 \frac{\partial^2 V_2}{\partial y^2} + \rho\sigma_x\sigma_y xy \frac{\partial^2 V_2}{\partial x \partial y} + \left(r - \delta_x\right) x \frac{\partial V_2}{\partial x} + \left(r - \delta_y\right) y \frac{\partial V_2}{\partial y} - rV_2 + \left(p_y - y\right) = 0$$

Assuming one starts with input[1] x, the American perpetual option to switch from x to y can be determined. A switch is justified if V_1 (switching option value plus operating value) is less than V_2 (operating value) less the switching cost. The value matching condition is:

$$A x_{12}^{\beta_{11}} y_{12}^{\beta_{12}} + \frac{p_x}{r} - \frac{x_{12}}{\delta_x} = \frac{p_y}{r} - \frac{y_{12}}{\delta_y} - S_{12} \tag{5}$$

Furthermore, smooth pasting conditions hold at the boundaries:

$$\beta_{11} A x_{12}^{\beta_{11}-1} y_{12}^{\beta_{12}} - \frac{1}{\delta_x} = 0 \tag{6}$$

$$\beta_{12} A x_{12}^{\beta_{11}} y_{12}^{\beta_{12}-1} + \frac{1}{\delta_y} = 0 \tag{7}$$

[1] Adkins and Paxson (2011) allowed starting either with x or y, depending on whether V_1 is greater than V_2 (in which case, starting with x is logical, if feasible).

where β_{11} and β_{12} satisfy the characteristic root equation

$$\tfrac{1}{2}\sigma_x^2\beta_{11}(\beta_{11}-1)+\tfrac{1}{2}\sigma_y^2\beta_{12}(\beta_{12}-1)+\rho\sigma_x\sigma_y\beta_{11}\beta_{12}+\beta_{11}(r-\delta_x)+\beta_{12}(r-\delta_y)-r=0 \quad (8)$$

The characteristic root equation (8) together with value matching condition (5) and smooth pasting conditions (6) and (7) represents the system of 4 equations, while there are 5 unknowns, β_{11}, β_{12}, A, x_{12}, y_{12}. So assuming one starts with x= x_{12}, it is easy to derive the other values by solving simultaneously the four equations, where y_{12} is the second possible input level that justifies making the single switch.

Numerical Illustration Table

	A	B	C	D	E	F	G	H
1	**Continuous American Perpetual SINGLE SWITCH Option**							
2	ONE WAY SWITCH FROM INPUT x TO y		**TEMPLATE**					
3	INPUT x	x	40					
4	INPUT y	y	40					
5	Convenience yield of x	δ_x	0.05					
6	Convenience yield of y	δ_y	0.03					
7	Volatility of x	σ_x	0.20					
8	Volatility of y	σ_y	0.25					
9	Correlation x with y	ρ	0.50					
10	Risk-free interest rate	r	0.07					
11	Output price for x	p_x	80					
12	Output price for y	p_y	80					
13	Switching cost from x to y	S_{12}	120					
14								
15	PV of revenues using x	X	343					
16	PV of revenues using y	Y	-190					
17	Switching boundary x to y	x_{12}	40					
18								
19		SOLUTION		OPTION VALUE				
20	Asset value in operating mode '1'	**V_1(x,y)**	**436.93**	**94.08**				
21	Asset value in operating mode '2'	**V_2(x,y)**	**-190.48**					
22		A	0.66					
23	Switching boundary x to y	y_{12} (x)	**9.89**					
24	Solution quadrant	β_{11}	2.2834	*must be positive*				
25	Solution quadrant	β_{12}	-0.9409	*must be negative*				
26		EQUATIONS						
27	Value matching	EQ 5	0.000					
28	Smooth pasting	EQ 6	0.000					
29	Smooth pasting	EQ 7	0.000					
30	Q function	EQ 8	0.000					
31		Sum	0.000					
32		SOLVER: SET C31=0, CHANGING C22:C25						
33	EQ 5	C22*C17^C24*C23^C25-C17/C5+C11/C10+C23/C6-C12/C10+C13						
34	EQ 6	C24*C22*C17^(C24-1)*C23^C25-1/C5						
35	EQ 7	C25*C22*C17^C24*C23^(C25-1)+1/C6						
36	EQ 8	0.5*C7^2*C24*(C24-1)+0.5*C8^2*C25*(C25-1)+C9*C7*C8*C24*C25+C24*(C10-C5)+C25*(C10-C6)-C10						
37	SPREAD		**30.11**					
38	V_1(x,y)	-C3/C5+C11/C10+C22*C3^C24*C4^C25						
39	V_2(x,y)	-C4/C6+C12/C10						
40	Asset value in operating mode '2'	**V_2(x12,y12)**	**813.21**					
41	Asset value in operating mode '1'	**V_1(x12,y12)**	**693.21**					
42	**V_2(x12,y12)-V_1(x12,y12)**		**120.00**					

Here are illustrative results for the single input switch model, assuming current operating costs are half of current gross revenue for each output. When switching is only possible from x to y but not vice versa, the switching trigger is y_{12}. The asset value before the switch is V_1, and after the switch the asset value is equal to the PV of revenues less the PV of the input y, that is V_2. Starting with x, the once off switch to y should be made when $y_{12}<9.89$ if x is still 40. The initial facility value is 437, with an option value to switch once of 94. Note that if y remains at 9.89, the facility would be worth 813, even without an option to switch back.

References

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Kulatilaka, N. (1993). The value of flexibility: the case of a dual-fuel industrial steam boiler. Financial Management, 22, 271-280.

Pahl, G. (2008). Biodiesel: Growing a New Energy Economy. Chelsea Green Publishing, White River Junction, VT.

www.worldenergy.net www.theice.com Canola Futures

www.palmoilhq.com BMD Crude Palm Oil Futures

HBS GREEN CASE QUESTIONS:

1. What are the initial assumptions, advantages and disadvantages of the reciprocal energy switching model?
2. Some of the data in the Table are from the wild imagination of Professor Brash. Using "real data" for volatilities and correlation for rape oil and palm oil, which plant should George buy, and why? When should George switch inputs?
3. What are the primary environmental concerns that alter any (all?) of these decisions?
4. Suppose George can raise half of the plant investment cost by issuing 50% of HBS equity for around $200,000. He plans modestly to buy a plant with capacity for 100 tons for a total investment cost of $350,000 if he decides on the flexible plant. Would you invest in the equity in this venture?