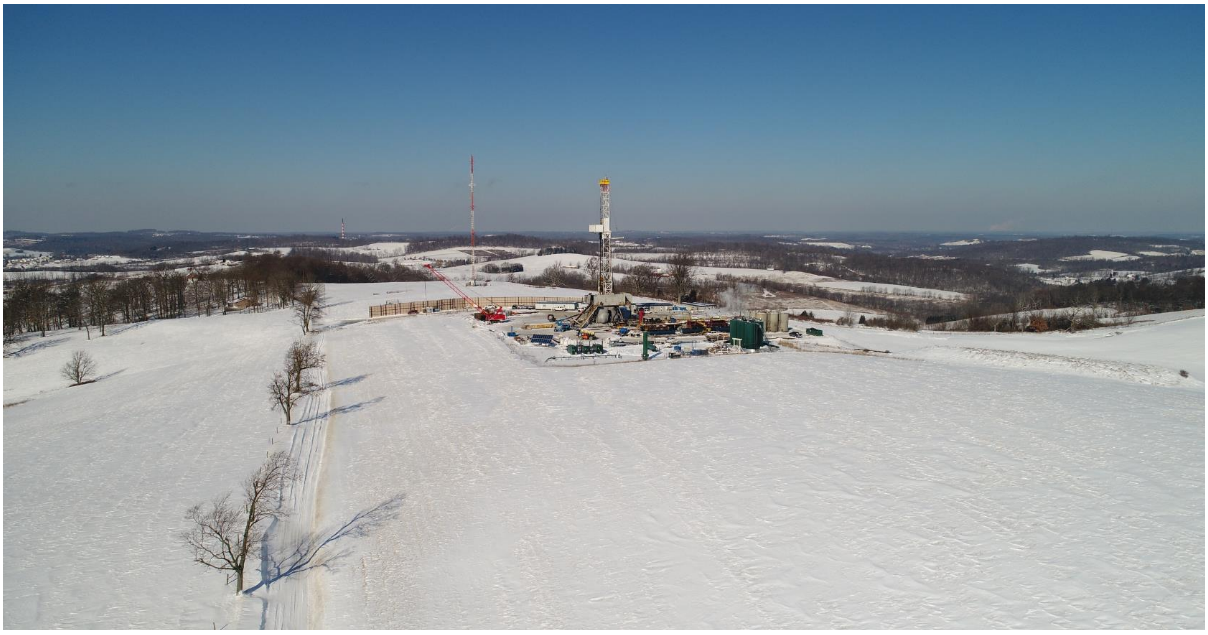
FROM DRY TO WET: SWITCHING OPTIONS FOR RRC[1]   2 Dec 2018



INTRODUCTION

Ral Rherman seeks to advise Range Resources Corporation (RRC) on the value and timing of switching from natural gas (NG) drilling in Appalachia to wet gas (NGL), as and when composite prices for wet gas exceed natural gas enough to justify switching, given the anticipated drilling costs. Range owns approximately 875,000 net acres in Pennsylvania, targeting the Upper Devonian, Marcellus and Utica/UPP shales, "stacked" in that order, allowing for multiple development opportunities. The November 2018 presentation reported that the "resource potential" (not including the proven undeveloped) of Marcellus is around 67 trillion cubic feet equivalent (Tcfe), not including Deep Utica wells or Upper Devonian, which "provide additional wet/dry optionality in the future". There are some 3800 undrilled core wells with #300 wells 40+ Bcfe EUR, #400 wells 30-40, #1400 wells 20-30 and #1400 wells 15-20 (#300 wells not shown). [Multiplying the # wells shown times the EUR results in a total of 82 Tcf.] Note ("SEC") proven reserves disclosed in the 10K 2017 were 15.3 Tcfe, (6.4 proven undeveloped).

[1] © Dean A. Paxson, 2018. Parts of this case are from Valeryie Sherman, AMBS M.Sc. Finance dissertation, RO Projects at AMBS (leader Mauro Zanoletti) and ISEG (leader Alexia Dagorn) 2018, the RRC 2017 10K and November Goldman Sachs Presentation 2018, but the character is fictitious. This case is not intended as an illustration of either good or bad business practices, and mixes hypothetical and actual data and names.

The switching option evaluation considers the opportunity to shift production focus from natural gas, the traditional RRC activity in PA over the last decade, to NGL.

Dry Gas vs. Wet Gas Prices

NGLs are normally priced as a percentage of oil prices and their prices are typically a multiple of dry gas.

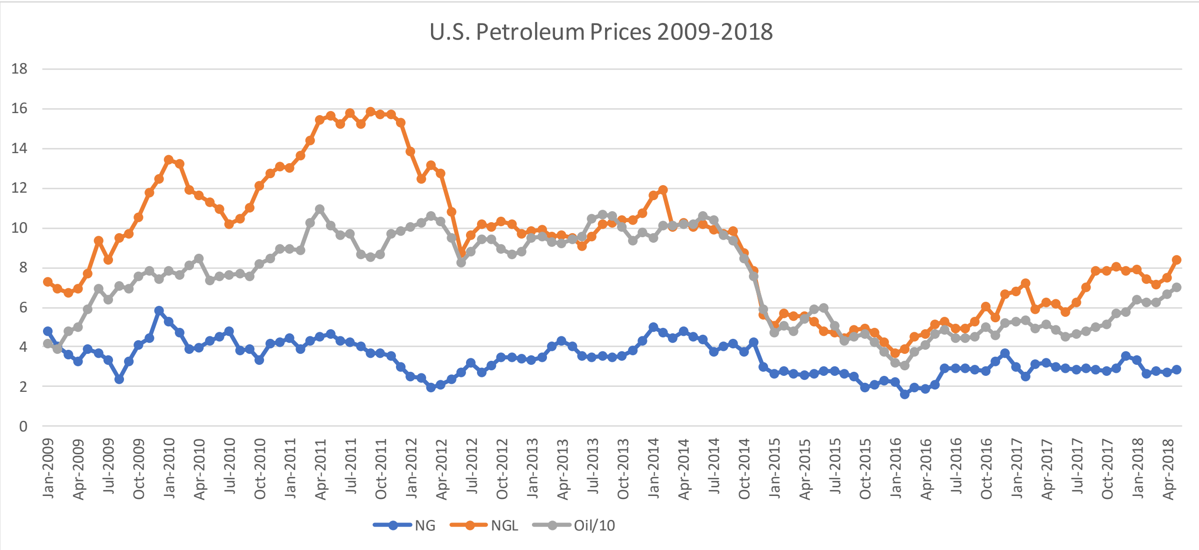


Figure 1. NGL Prices Compared to Natural Gas (E.I.A., 2018)

Switching Model

Dockendorf and Paxson (2013) assume that the prices of the two commodity outputs, *x=NG* and *y=NGL*, are possibly correlated and follow geometrical Brownian motion (gBm) processes:

$$dx = (\mu_x - \delta_x)xdt + \sigma_x x dz_x \quad (1)$$

$$dy = (\mu_y - \delta_y)ydt + \sigma_y y dz_y \quad (2)$$

where μ is the required rate of return on the commodity, δ is the convenience yield, σ stands for the volatility, and dz is the Wiener process. It is possible to switch once between two operating modes, so that the cash flow in each mode equals the output price less operating cost per unit of production, multiplied by the production per year, that is $p_1(x - c_x)$ and $p_2(y - c_y)$ in operating modes '1' and '2' respectively. Suppose the production quantities are equal, and S denotes the per unit cost of switching from operating mode '1' to '2'. Operating costs, interest rates, volatilities, yields and correlations are assumed to be constant, and the production facility perpetual. The company is not restricted in the product mix choice because of selling commitments.

The partial differential equations for the asset values in the two operating modes are as follows:

$$\frac{1}{2}\sigma_x^2 x^2 \frac{\partial^2 V_1}{\partial x^2} + \frac{1}{2}\sigma_y^2 y^2 \frac{\partial^2 V_1}{\partial y^2} + \rho\sigma_x\sigma_y xy \frac{\partial^2 V_1}{\partial x \partial y} + (r-\delta_x)x\frac{\partial V_1}{\partial x} + \left(r-\delta_y\right)y\frac{\partial V_1}{\partial y} - rV_1 + p_1(x-c_x) = 0 \tag{3}$$

$$\frac{1}{2}\sigma_x^2 x^2 \frac{\partial^2 V_2}{\partial x^2} + \frac{1}{2}\sigma_y^2 y^2 \frac{\partial^2 V_2}{\partial y^2} + \rho\sigma_x\sigma_y xy \frac{\partial^2 V_2}{\partial x \partial y} + (r-\delta_x)x\frac{\partial V_2}{\partial x} + \left(r-\delta_y\right)y\frac{\partial V_2}{\partial y} - rV2 + p_2\left(y-c_y\right) = 0 \tag{4}$$

where V_1 and V_2 are the asset values in operating modes ‘1’ and ‘2’ respectively and are equal to the present value of cash streams in the corresponding mode, plus for V_1 the value of the option to switch.

Originally the problem did not have an analytical solution due to its complexity arising from the introduction of switching costs and operating costs. Therefore, the dimension reducing technique as in the McDonald and Siegel (1986) American exchange option model cannot be applied. Dockendorf and Paxson (2013) suggest the methodology of Adkins and Paxson (2011) as a quasi-analytical general solution to this non-homogeneous problem, solving several equations simultaneously.

The value of an RRC dry gas producing facility with the option to switch to wet gas, can be expressed as:

$$V(x,y) = A(x,y)x^{\beta}y^{\eta} + \frac{x}{\delta_x}, \tag{5}$$

with β and η being the roots of equation (6):

$$\tfrac{1}{2}\sigma_x^2\beta(\beta-1) + \tfrac{1}{2}\sigma_y^2\eta(\eta-1) + \rho\sigma_x\sigma_y\beta\eta + (r-\delta_x)\beta + (r-\delta_y)\eta - r = 0, \tag{6}$$

where $r-\delta_x = a_x - \theta_x$, where α is the risk-neutral drift, and θ the production decline rate. Assuming that operating costs are equal, and that $x = \hat{x}, \hat{y}$ is the mode 2 output that justifies immediate switching, the value matching condition is:

$$A\hat{x}^{\beta}\hat{y}^{\eta} + \frac{\hat{x}}{\delta_x} = \frac{\hat{y}}{\delta_y} - S. \tag{7}$$

The smooth pasting conditions are:

$$\beta A\hat{x}^{\beta-1}\hat{y}^{\eta}+\frac{1}{\delta_x}=0, \tag{8}$$

$$\eta A\hat{x}^{\beta}\hat{y}^{\eta-1}-\frac{1}{\delta_y}=0. \tag{9}$$

Thus, we have a system of fours equations to solve: the characteristic root equation (6), the value matching condition (7), and the smooth pasting conditions (8) and (9).

Following Støre et al. (2018), as simplified in Adkins and Paxson (2018), from (8) and (9):

$$-\frac{\hat{x}}{\beta\delta_x}=\frac{\hat{y}}{\eta\delta_y}, \tag{10}$$

so

$$\hat{x}=-\frac{\beta\delta_x\hat{y}}{\eta\delta_y}. \tag{11}$$

From (8):

$$A=-\frac{1}{\beta\delta_x\hat{x}^{\beta-1}\hat{y}^{\eta}}. \tag{12}$$

Substituting (11) and (12) into (7) yields:

$$\hat{x}\frac{1}{\delta_x}\frac{\eta+\beta-1}{\beta}+S=0. \tag{13}$$

Now we have a system of three equations ((6), (11) and (13)) with four unknowns, β, η, $\hat{x}$ and $\hat{y}$. Assuming that the production costs are equal, let

$$C(\hat{x})=1+\frac{\delta_x}{\hat{x}}S. \tag{14}$$

According to Støre et al. (2018), a solution for $\beta(\hat{x})$ is given by:

$$\beta(\hat{x})=\frac{f(\hat{x})}{2g(\hat{x})}-\sqrt{\left(\frac{f(\hat{x})}{2g(\hat{x})}\right)^2+\frac{2(r-a_2)}{g(\hat{x})}}, \tag{15}$$

where $$f(\hat{x})=\sigma_x^2-2(a_x-\theta_x)-2\rho\sigma_x\sigma_y+C(\hat{x})(2a_x+\sigma_y^2) \tag{16}$$

and $$g(\hat{x})=\sigma_x^2+\sigma_y^2C(\hat{x})^2-2\,\rho\sigma_x\sigma_yC(\hat{x}). \tag{17}$$

From (13) and (14):

$$\eta(\hat{x})=1-\beta(\hat{x})C(\hat{x}). \tag{18}$$

By substituting η in (11) and (12) we can obtain the analytical solutions for $\hat{y}(\hat{x})$ and $A(\hat{x})$:

$$\hat{y}(\hat{x})=-\frac{(1-\beta)C(\hat{x})\delta_y\hat{x}}{\beta\delta_x}, \tag{19}$$

$$A(\hat{x}) = -\frac{1}{\beta\delta_x\hat{x}^{\beta-1}\hat{y}^{1-\beta C(\hat{x})}}\,. \tag{20}$$

The value of Range's opportunity to switch from dry gas to wet gas is the LHS of equation (7), where the first part is the value of the real option to switch, and the second part is the current value of producing dry gas.

RRC Application

In order to estimate RRC's real option to switch from drilling a well for dry gas production to drilling a well aimed at producing wet gas instead, given that dry gas and wet gas prices vary over time, it is appropriate to use a single output switching option model.
The calculations for an illustrative single NG well are presented in Table 1:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	**RRC PROVEN UNDEVELOPED RESERVES**																					
2	TIME		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3	HYPERBOLIC	-0.76																				
4	DRY GAS PRICE	3.12																				
5	LOC	1.98																				
6	LOC Fixed	0.10																				
7	DISCOUNT	10%																				
8	YEAR		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
9	PRODUCTION (Mmcf)		4,267	3,552	2,956	2,460	2,048	1,704	1,419	1,181	983	818	681	567	472	393	327	272	226	188	157	131
10	REVENUE	$77,376.00	$13,313	$11,081	$9,223	$7,676	$6,389	$5,318	$4,426	$3,684	$3,066	$2,552	$2,124	$1,768	$1,472	$1,225	$1,019	$849	$706	$588	$489	$407
11	COSTS	$49,106.00	$8,449	$7,032	$5,853	$4,872	$4,055	$3,375	$2,809	$2,338	$1,946	$1,620	$1,348	$1,122	$934	$777	$647	$539	$448	$373	$311	$259
12	FCF	$28,270.00	$4,864	$4,049	$3,370	$2,805	$2,334	$1,943	$1,617	$1,346	$1,120	$932	$776	$646	$538	$447	$372	$310	$258	$215	$179	$149
13	INVESTMENT	$6,500																				
14	PV	$18,103																				
15	NPV	**$11,603**																				
16	EUR	24,800																				
17	TOTAL Mmcf	24,800	0																			
18	SOLVER: C18=0, CHANGE B3																					
19	FCF	-$6,500	$4,864	$4,049	$3,370	$2,805	$2,334	$1,943	$1,617	$1,346	$1,120	$932	$776	$646	$538	$447	$372	$310	$258	$215	$179	$149
20	IRR	58%																				

Table 1. PUD for Dry Natural Gas

The November presentation (S31) reports illustrative dry well economics, estimated cumulative recovery for years 1-2-3-5-10-20, and IRRs for both Strip and $3 NG. The estimated cost to drill and complete one well in the dry gas case is equal to $6.5 million, which is the investment cost in Table 1. The estimated ultimate recovery (EUR) of dry gas is 24.8 Bcf. Additionally, Range discloses dry gas production for the first year equal to 4,267 Mmcf. A hyperbolic rate of -0.76 equates the total production over the 20 years to the estimated ultimate recovery. This means that an approximate production decline rate each year is around 24%.

The reference Henry Hub natural gas prices Range used in the presentation are $3.00/Mcf for the flat pricing case and $2.83/Mcf over 2018 and $2.84/Mcf over 2019-2022 for the strip pricing case as of December 2017. Given the chosen time horizon, the average Henry Hub spot prices for the future is assumed to be $3.12. Fixed and variable lease operating costs were also adjusted to allow the internal rate of return (IRR) to match the IRR of 58% estimated by the company for a dry gas well. Thus, it can be seen that the resulting NPV for dry gas is equal to $11.6 million.

The PV10 calculations for wet gas are given in Table 2 below:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	**RRC PROVEN UNDEVELOPED RESERVES**																					
2	TIME		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3	HYPERBOLIC	-0.81																				
4	NGL PRICE	5.56																				
5	LOC	3.55																				
6	LOC Fixed	0.10																				
7	DISCOUNT	10%																				
8	YEAR		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
9	PRODUCTION (Mmcfe)		3,265	2,961	2,685	2,435	2,209	2,003	1,816	1,647	1,494	1,355	1,229	1,114	1,010	916	831	754	684	620	562	510
10	REVENUE	167356	$18,153	$16,463	$14,930	$13,540	$12,279	$11,136	$10,099	$9,159	$8,306	$7,533	$6,831	$6,195	$5,618	$5,095	$4,621	$4,190	$3,800	$3,446	$3,126	$2,835
11	COSTS	106857	$11,591	$10,512	$9,533	$8,645	$7,840	$7,110	$6,448	$5,848	$5,303	$4,810	$4,362	$3,956	$3,587	$3,253	$2,950	$2,676	$2,427	$2,201	$1,996	$1,810
12	FCF	60499	$6,563	$5,951	$5,397	$4,895	$4,439	$4,026	$3,651	$3,311	$3,003	$2,723	$2,469	$2,240	$2,031	$1,842	$1,670	$1,515	$1,374	$1,246	$1,130	$1,025
13	INVESTMENT	$9,200																				
14	PV	$33,268																				
15	NPV	**$24,068**																				
16	EUR	30,100																				
17	TOTAL Mmcfe	30,100	0																			
18	SOLVER: C18=0, CHANGE B3																					
19	FCF	-$9,200	$6,563	$5,951	$5,397	$4,895	$4,439	$4,026	$3,651	$3,311	$3,003	$2,723	$2,469	$2,240	$2,031	$1,842	$1,670	$1,515	$1,374	$1,246	$1,130	$1,025
20	**IRR**	62%																				

Table 2. PUD for Wet Natural Gas

S27 of the presentation illustrates wet well economics, showing estimated cumulative recovery for years 1-2-3-5-10-20, and IRRs for both Strip and $3 NG. Based on the data for the super-rich area Marcellus well economics, the capital required for the drilling and completion of a well in that location is $9.2 million, which is the investment cost. The estimated ultimate recovery of wet gas is 30.1 Bcfe. Of these 30.1 Bcfe, the recovery of NGLs totals 2.309 million bbls., the gas recovery is 13.734 Bmcf, and condensate (oil) makes up .416 million bbls, which are converted to equivalent Bcfe by multiplying by the energy equivalent. The percentages were used to determine the weighted average price of wet gas, an average price of NGL is $7.01/Mcfe, assuming WTI $63.80 and NGL 42% of WTI. Given the weights of NGLs, natural gas and oil in the total production output, the weighted average price of wet gas is equal to $5.56/Mcfe.

A hyperbolic rate of -0.81 equalises the total production over 20 years and the EUR given by Range Resources. Fixed and variable lease operating costs were obtained by trial and error method so that the IRR from drilling in the super-rich area equals 62%, as disclosed by RRC. The NPV of investing in a "super-rich" well is $24.068 million.

Real Option Model Inputs

The inputs for both cases are summarised in Table 3:

Input Parameter	Notation	Value
Output Dry Gas	x	$1.044MM
Output Wet Gas	y	$1.925MM
Convenience yield of natural gas	δ_x	9%
Convenience yield of wet gas	δ_y	8%
Volatility of dry natural gas	σ_x	44.40%

Volatility of wet gas	σ_y	26.43%
Correlation between dry gas and wet gas	ρ	0.828
Risk-free interest rate	r	10%
Operating cost for natural gas	c_x	0
Operating cost for dry gas	c_y	0
Switching cost from dry gas to wet gas	S_{12}	$1MM

Table 3. Input Parameters Description

In Table 3, the estimated values of output x, i.e. dry gas, and alternative output y, i.e. wet gas, are $1.044 million and $1.925 million respectively, which are the net present values of the two outputs multiplied by their convenience yields, treating the NPV as a perpetual cashflow, net of operating costs. The volatility of dry gas prices, σ_x, are from data on Henry Hub natural gas spot prices for each month from January 2009 to May 2018, extracted from Bloomberg™. In the case of wet gas, the monthly data on WTI spot crude oil prices and U.S. Natural Gas Liquid Composite Prices during 2009-2018 is from the EIA website, using the given weights to find the weighted average monthly returns on wet gas over the period.

Continuous American Perpetual Single Switch Option by Dockendorf and Paxson

Table 4 illustrates the inputs and the resulting outputs of the so-called continuous American perpetual output switch option model when it is only possible to switch once:

	A	B	C	D
1	**Continuous American Perpetual SINGLE SWITCH Option**			
2	ONE WAY SWITCH FROM OUTPUT X TO Y		***$ millions***	Per Well NPV
3	OUTPUT NG	x	1.044	11.603
4	OUTPUT NGL	y	1.925	24.068
5	Convenience yield of natural gas	δx	0.090	
6	Convenience yield of wet gas	δy	0.080	
7	Volatility of dry natural gas	σx	0.444	
8	Volatility of wet gas	σy	0.264	
9	Correlation dry gas with wet gas	ρ	0.828	
10	Risk-free interest rate	r	0.100	
11	Operating cost for natural gas	cx	0.000	
12	Operating cost for dry gas	cy	0.000	
13	Switching cost: dry gas to wet gas	S	1.00	
14				
15	PV of revenues natural gas	X	11.603	
16	PV of revenues ngl	Y	24.068	
17	Switching boundary dry to wet gas	x^	1.044	
18		SOLUTION		ROV
19	Asset value in operating mode '1'	**V1(x,y)**	**23.077**	**11.474**
20	Asset value in operating mode '2'	**V2(x,y)**	24.068	0.000
21		A	3.146	
22	Switching boundary x to y	y^ (x^)	**1.979**	24.742
23	Solution quadrant	β	-0.9559	
24	Solution quadrant	η	2.0382	
25		EQUATIONS		
26	Value matching	EQ 7	0.000	
27	Smooth pasting 1	EQ 8	0.000	
28	Smooth pasting 2	EQ 9	0.000	
29	Solution quadrant 1	EQ 6	0.000	
30	**Solver: C30=0, changing C21:C24.**	Sum	0.000	
31	SPREAD		**0.05**	C22-C4
32	PDE	EQ 3	0.0000	
33	ΔROVx		0.6085	
34	ΔROVy		12.1465	
35	ΓROVx		19.6709	
36	ΓROVy		6.5498	
37	ΓROVx,y		-11.1182	
38	Value matching 1 at y^		23.742	
39	Value matching 2 at y^- S		23.742	

Table 4. Continuous American Perpetual Single Switch Option

The option parameter A is positive; the solution quadrant β of the characteristic root equation (6) is negative, while the other solution quadrant η is positive, which satisfies the requirements of the model that the value of the option to switch from x to y decreases with (increases in) x and increases with y. Moreover, the obtained solutions fully satisfy the system of four equations, that is, the value matching equation (7), the smooth pasting conditions (8) and (9), and the characteristic root equation (6), so the values across cells C26 to C30 are all set to zero.

The real option value is \$11.475 million. The actual value of producing dry gas, $V_1(x,y)$, in the real options framework, consists of the NPV from drilling a dry gas well (the value without switching possibility) plus the value of the real option to switch to producing wet gas, that is \$11.603 + \$11.475 = \$23.078 million. This means that this flexibility in choosing between the two outputs adds more than 98% to the inflexible asset value, so almost half of the asset value in the current mode of drilling a well in the dry gas area is attributable to the opportunity to shift operations to the super-rich area.

Since it is assumed that there is no option to switch back to dry gas once Range starts drilling for wet gas, the asset value in operating mode '2', $V_2(x,y)$, simply equals the NPV resulting from operating in that mode, i.e. \$24.068 million. The real option value in this case will be nil, as the company cannot return to operating mode '1'. The switching boundary denoted by $y_{12}(x)$ represents the optimal level of output y which would justify switching from output x to output y. Here, the value of the switching boundary suggests that for the given output level of dry gas which is \$1.044 million (i.e. the NPV of dry gas times its convenience yield), it would be reasonable to switch to wet gas production once the value of wet gas, y, reaches the level of \$1.979 million, or, equivalently, when the NPV from producing wet gas increases to \$24.742 million. The current value of wet gas, y, given the current estimated wet gas price of \$5.56, is \$1.925 million, so, in order to justify the switching decision, this value has to increase by about \$54 thousand, that is by almost 3%. This is the spread between the switching boundary for wet gas and its current level.

In contrast, the Marshallian rule instructs that switching should take place once the difference between the alternative operating mode and the asset value in the current operating mode without any option value involved exceeds the switching cost (Dockendorf and Paxson, 2013). Since \$24.068 million is almost twice as large as \$12.603 (the NPV of \$11.603 plus the switching cost of \$1) million, managers that follow the conventional Marshallian NPV rule would have decided to switch to wet gas some time ago. Therefore, although the NPV of a wet gas well is much higher than the NPV of a dry gas well, unlike the traditional methods, the real options approach provides a more cautious view on the switching action.

Analytical Solution for Two Factor Output Switching Option

	A	B	C	D	E	F	G
1		Simplified Støre et al. 2018 Analytical Solution Output Switching					
2		INPUTS					
3		x	1.044				
4		y	1.925				
5		δx	0.090				
6		δy	0.080				
7		σx	0.444				
8		σy	0.264				
9		ρ	0.828				
10		r	0.100				
11		cx	0.000				
12		cy	0.000				
13		S	1.00				
14							
15		X	11.603	(C3/C5-C11/C10)			
16		Y	24.068	(C4/C6-C12/C10)			
17		x^	1.044	C3			
18		OUTPUTS					
19	EQ 14	C(x^)	1.086	1+(C5)/(C3)*(C13)			
20	EQ 16	f(x^)	0.102	(C7^2)-(2*(C10-C5))-(2*C9*C7*C8)+(C19*(2*(C10-C6)+(C8^2)))			
21	EQ 17	g(x^)	0.068	(C7^2)+((C8^2)*(C19^2))-(2*C9*C7*C8*C19)			
22	EQ 15	β(x^)	-0.956	(C20/(2*C21))-SQRT(((C20/(2*C21))^2)+(2*((C6)/C21)))			
23	EQ 18	η(x^)	2.038	1-C19*C22			
24	EQ 19	y^	**1.979**	(-(C23/C22)*((C6)/(C5)*C17))			
25	EQ 20	A	3.146	(-(1/C22)*(1/C5)*(1/((C17^(C22-1))*(C24^C23))))			
26	EQ 7	ROV	11.474	C25*(C3^C22)*(C4^C23)			
27	EQ 7	VALUE	**23.077**	C26+C3/(C5)-C11/C10			
28	EQ 3	PDE	0.000				
29		ΔROV1,x	0.608	C22*C25*(C3^(C22-1))*(C4^C23)+1/(C5)			
30		ΔROV1,y	12.147	C23*C25*(C3^C22)*(C4^(C23-1))			
31		ΓROV1, x	19.671	C22*(C22-1)*C25*(C3^(C22-2))*(C4^C23)			
32		ΓROV1,y	6.550	C23*(C23-1)*C25*(C3^C22)*(C4^(C23-2))			
33		ΓROV1,x,y	-11.118	C22*C23*C25*(C3^(C22-1))*(C4^(C23-1))			
34	Value matching 1 at y^		23.742	C25*(C17^C22)*(C24^C23)+C17/C5-C11/C10			
35	Value matching 2 at y^- S		23.742	C24/C6-C12/C10-C13			
36	PDE	0.5*(C7^2)*(C3^2)*C31+0.5*(C8^2)*(C4^2)*C32+C9*C7*C8*C3*C4*C33+(C10-C5)*C3*C29+(C10-C6)*C4*C30-C10*C27+(C3-C11)					

Table 5. Analytical Solution for Two Factor Output Switching Option

Table 5 above demonstrates the same problem but with the application of the analytical solution method proposed by Støre et al. (2018), as adjusted in Adkins and Paxson (2018) which provides the same results to those from the Dockendorf and Paxson (2013) model. The obtained asset value and delta and gamma derivatives in cells C29:C33 solve the partial differential equation (C28). The advantage of this approach is that it provides an analytical solution directly and helps to avoid the computational complexity associated with solving a system of four equations simultaneously. Støre et al. (2018) also claim that their method is suitable for when the threshold value $\hat{x}$ is greater than x.

Ral believes that the net present value method in this case underestimates the value of the flexibility of drilling a facility for producing dry gas, ignoring the existence of the embedded option to switch to wet gas, which, in fact, adds almost 100% to the asset value. Based only on the two NPVs and the switching cost, the NPV rule indicates switch the output much earlier. The real options analysis, in turn, realises the additional value arising from the switching option, and, although the asset value in operating mode '2' is almost equal to the asset value in operating mode '1', ROV takes a more cautious stance on this decision, suggesting that it would be more optimal to wait until the NPV of wet gas increases to $24.742 million. In this way, ROV provides more insight when it comes to decision making in the face of high uncertainty.

PROJECT QUESTIONS

1. **Help Ral update the single well economics from the anticipated Feb 2019 RRC presentation, and at current (mid-March) natural gas and NGL prices. What are the new NPVs for NG and NGL, revising Table 1 and 2?**
2. **What are the recalculated volatilities and NG/NGL correlations, based on your reasonable assumptions?**
3. **What is the value of the opportunity to switch from NG to NGL (or possibly from NGL to NG if propane and ethane continue to decline as in November 2018)?**
4. **Propose a plausible extra valuation to the RRC PV10 as of December 2018 considering the value of this switching option, perhaps that no more than 250 switches could possibly be made each year in the future.**

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