Incentive Collars for Hinkley Point C[1]

The National Audit Office (2016, 2017) states that the Hinkley Point C Arrangement (HPCA) involves a subsidy to investors in the nuclear facility GEN, the state supported EDF and CGN entities, of a present value of some 30 billion pounds. This is the difference between the feed-in-tariff FiT (92.5 pounds per MWhr as of 2012) offered by the UK government (GOV) on behalf of UK electricity customers and the current UK electricity price as of March 2016. Wow. Newly

[1]©2017. This case was prepared by Dean A. Paxson for purposes of class discussion and student coursework only, and not as an illustration of either good or bad business practices. The model is based on parts of "Risk Sharing with Collar Options in Infrastructure Investments" presented at the Real Options Conference in Boston June 2017, by Roger Adkins and Dean Paxson, and uses as purely illustrative examples material from NAO (2017). Since this paper extracts from that document, and typically simplifies and/or amends the figures, often based on strict assumptions, it should not be used as a representation of that document or NAO opinions, or as the basis for investment decisions. Alliance Manchester Business School, Booth St West, Manchester, M15 6PB, UK. dean.paxson@mbs.ac.uk

elected MP George Little from Manchester wonders whether an alternative arrangement would be polically acceptable, and also in a format that the NAO could hardly quantify.

Professors at the University of Manchester suggest that an alternative collar with a guaranteed minimum electricity price at or below the current UK electricity price could provide equivalent value for the nuclear GEN. A collar backed by the government GOV would guarantee a price floor in the face of adverse circumstances, and simultaneously capture abnormally high returns when the circumstances are sufficiently favorable. A recent analysis of collars by Adkins and Paxson (2017b) (A&P) adopts a real option formulation for the guarantee on the downside and bonus compensation for the government on the upside. Using an American perpetuity model, A&P show that a minimum price guarantee (with a high ceiling) can create a value equivalent to a high feed-in-tariff which is the current arrangement for HPCA.

The HPC arrangement specifies that the GOV (on behalf of electricity customers) may recover some of the construction costs less than the expected amounts, and also obtain a payment from the GEN if the project IRR turns out to be more than 11.4%. The actual Fit is apparently based on an IRR of 9.04%, given the operating costs and reservation for eventual decommissioning costs projected by the GEN.

There is a vast literature on GOV subsidies used to promote certain types of energy facilities, see A&P (2016, 2017a), and Couture and Gagnon (2009), who cite the Spanish “variable premium” on top of the received electricity price by the GEN, that involves a floor and cap. Brandão and Saraiva (2008) suggest a finite collar for Brazilian toll roads, and Shan et al. (2010) also promote the use of European collars in toll PPPs. Adkins et al. (2017) provide an analytical model for finite American collars.

Collar Model

For a firm in a monopolistic situation confronting a sole source of uncertainty due to output price[2] variability, and ignoring operating costs and taxes, the operation of an energy generator depends

[2] This assumption is perhaps more valid for nuclear power, which operates at a constant baseload except for some planned (and also emergency) outages. This model can easily be altered to involve quantity (Q) uncertainty where revenue=R=P*Q. However, in the HPC analysis Q is ignored, but the original construction cost is expressed in terms of unit capacity for Q.

primarily (or solely) on the electricity price evolution, which is specified by the geometric Brownian motion process:

$$\mathrm{d}P = \alpha P \mathrm{d}t + \sigma P \mathrm{d}W \tag{1}$$

where α denotes the expected price risk-neutral drift, σ the price volatility, and $\mathrm{d}W$ an increment of the standard Wiener process. Using contingent claims analysis, the option to operate the project $F(P)$ follows the risk-neutral valuation relationship:

$$\tfrac{1}{2}\sigma^2 P^2 \frac{\partial^2 F}{\partial P^2} + (r-\delta) P \frac{\partial F}{\partial P} - rF = 0 \tag{2}$$

where $r > \alpha$ denotes the risk-free interest rate and $\delta = r - \alpha$ the rate of return shortfall. The generic solution to (2) is:

$$F(P) = A_1 P^{\beta_1} + A_2 P^{\beta_2} \tag{3}$$

where A_1, A_2 are to be determined generic constants for calls and puts, and β_1, β_2 are, respectively, the positive and negative roots of the fundamental equation, which are given by:

$$\beta_1, \beta_2 = \left(\tfrac{1}{2} - \frac{r-\delta}{\sigma^2} \right) \pm \sqrt{\left(\tfrac{1}{2} - \frac{r-\delta}{\sigma^2} \right)^2 + \frac{2r}{\sigma^2}} \tag{4}$$

In (3), if $A_2 = 0$ then F is a continuously increasing function of P and represents an American perpetual call option, Samuelson (1965), while if $A_1 = 0$ then F is a decreasing function and represents a put option, Merton (1973).

1.1 Real Collar Option for an ACTIVE Project

A collar option is designed to confine the output price for an active project to a tailored range, by restricting its value to lie between a floor P_L and a cap P_H. Whenever the price trajectory falls below the floor, the received output price is assigned the value P_L, and whenever it exceeds the cap, it is assigned the value P_H. By restricting the price to this range, the firm benefits from receiving a price that never falls below P_L and obtains protection against adverse price movements, whilst at the same time, it is being forced never to receive a price exceeding P_H to sacrifice the upside potential. Protection against downside losses are mitigated in part by sacrificing upside gains. For an active project, the net revenue accruing to the firm is given by $\pi_C(P) = \min\{\max\{P_L, P\}, P_H\} \times Q$ (assume Q=1, and no operating costs or taxes) and its value V_C is described by the risk-neutral valuation relationship:

$$\tfrac{1}{2}\sigma^2 P^2 \frac{\partial^2 V_C}{\partial P^2} + (r-\delta) P \frac{\partial V_C}{\partial P} - rV_C + \pi_C(P) = 0 . \qquad (5)$$

The valuation of a with-collar active project is conceived over three mutually exclusive exhaustive regimes, I, II and III, specified on the P line, each with its own distinct valuation function. Regimes I, II and III are defined by $P \le P_L$, $P_L < P < P_H$ and $P_H \le P$, respectively. Over Regime I, the firm is granted a more attractive fixed price P_L compared with the variable price P, but also possesses a call-style option to switch to the more favorable Regime II as soon as P exceeds P_L. This switch option increases in value with P and has the generic form AP^{β_1}, where A denotes a to be determined generic coefficient. Over Regime III, the firm is not only obliged to accept the less attractive fixed price P_H instead of P but also has to sell a put-style option to switch to the less favorable Regime II as soon as P falls below P_H. This switch option decreases in value with P and has the generic form AP^{β_2}. Over Regime II, the firm receives the variable price P, possesses a put-style option to switch to the more favorable Regime I as soon as P falls to P_L, but sells a call-style option to switch to the less favorable Regime III as soon as P attains P_H. The various switch options are displayed in Table 1, where A denotes a generic coefficient.

Table 1: The Various Switch Options

From – To	**Option Type**	**Value**	**Sign of A**

I – II	Call	AP^{β_1}	+
II – I	Put	AP^{β_2}	+
II – III	Call	AP^{β_1}	-
III – II	Put	AP^{β_2}	-

If the subscript C denotes the with-collar arrangement, then after paying the investment cost, the valuation function for the firm owning the ACTIVE project is:

$$V_C\left(P\right)=\begin{cases}\frac{P_L}{r}+A_{C11}P^{\beta_1} & \text{for } P\le P_L\\ \frac{P}{\delta}+A_{C21}P^{\beta_1}+A_{C22}P^{\beta_2} & \text{for } P_L<P<P_H\\ \frac{P_H}{r}+A_{C32}P^{\beta_2} & \text{for } P_H\le P.\end{cases} \tag{6}$$

In (6), the first numerical subscript for a coefficient denotes the regime $\{1=I,2=II,3=III\}$, while the second denotes a call if 1 or a put if 2. The coefficients A_{C11}, A_{C22} are expected to be positive because the firm owns the options and a switch is beneficial. In contrast, the A_{C21}, A_{C32} are expected to be negative because the firm is writing the options and is being penalized by the switch. The real collar is composed of a pair of both call and put options. The first pair facilitates switching back and forth between Regime I and II, which results in an advantage for the GEN, while the second pair facilitates switching back and forth between Regime II and III, which results in a disadvantage for the firm. The real collar design differs from the typical European collar, which only involves buying and selling two distinct options.

A novel expression for the option coefficients is:

$$A_{C11} = \left[\frac{P_H}{P_H^{\beta_1}} - \frac{P_L}{P_L^{\beta_1}} \right] \times \frac{\left(r\beta_2 - r - \delta\beta_2 \right)}{\left(\beta_1 - \beta_2 \right) r\delta} > 0,\ A_{C21} = \frac{P_H \left(r\beta_2 - r - \delta\beta_2 \right)}{P_H^{\beta_1} \left(\beta_1 - \beta_2 \right) r\delta} < 0,$$
$$A_{C22} = \frac{-P_L \left(r\beta_1 - r - \delta\beta_1 \right)}{P_L^{\beta_2} \left(\beta_1 - \beta_2 \right) r\delta} > 0,\ A_{C32} = \left[\frac{P_H}{P_H^{\beta_2}} - \frac{P_L}{P_L^{\beta_2}} \right] \times \frac{\left(r\beta_1 - r - \delta\beta_1 \right)}{\left(\beta_1 - \beta_2 \right) r\delta} < 0. \tag{7}$$

The signs of the four option coefficients comply with expectations. Other findings can also be derived. The coefficient A_{C22} for the option to switch from Regime II to I, which depends on only P_L and not on P_H, increases in size with P_L. This switch option becomes more valuable to the firm as the floor level increases. Similarly, the coefficient A_{C21} for the option to switch from Regime II to III, which depends on only P_H and not on P_L, decreases in magnitude with P_H. This switch option becomes less valuable to the government as the cap level increases. The coefficients A_{C11} and A_{C32} for the switch option from Regime I to II and from Regime III to II, respectively, depend on both P_L and P_H.

1.2 Floor and Cap Options

The analogous results for the floor only and the cap only are shown below.

Price Floor Model

We use the additional subscript f to indicate a model with only a floor. From (6) the active project valuation function becomes:

$$V_{Cf}\left(P\right) = \begin{cases} \dfrac{P_L}{r} + A_{Cf11} P^{\beta_1} & \text{for } P \le P_L \\ \dfrac{P}{\delta} + A_{Cf22} P^{\beta_2} & \text{for } P_L < P, \end{cases} \tag{8}$$

with:

$$A_{Cf11} = \frac{-P_L \left(r\beta_2 - r - \delta\beta_2 \right)}{P_L^{\beta_1} \left(\beta_1 - \beta_2 \right) r\delta} \ge 0,\ A_{Cf22} = \frac{-P_L \left(r\beta_1 - r - \delta\beta_1 \right)}{P_L^{\beta_2} \left(\beta_1 - \beta_2 \right) r\delta} \ge 0. \tag{9}$$

A feasible floor for an active asset yields both a more valuable investment opportunity and one that is exercisable at an earlier time. Consequently, a floor represents a government granted subsidy, Armada et al. (2012).

Price Cap Model

The additional subscript c indicates a model with only a cap. From (6) the active project valuation function becomes:

$$V_{Cc}\left(P\right)=\begin{cases}\dfrac{P}{\delta}+A_{Cc21}P^{\beta_1} & \text{for } P<P_H\\ \dfrac{P_H}{r}+A_{Cc32}P^{\beta_2} & \text{for } P_H\le P,\end{cases} \tag{10}$$

with: $$A_{Cc21}=\frac{P_H}{P_H^{\beta_1}}\frac{(r\beta_2-r-\delta\beta_2)}{\left(\beta_1-\beta_2\right)r\delta}\le 0,\quad A_{Cc32}=\frac{P_H}{P_H^{\beta_2}}\frac{(r\beta_1-r-\delta\beta_1)}{\left(\beta_1-\beta_2\right)r\delta}\le 0\,. \tag{11}$$

A ceiling is less desirable for the GEN than an operation without a cap, and consequently it is imposed by, for example, a government intent on offering a subsidy but shielding electricity customers against escalating prices.

3 Collar Partial Derivatives

The more traditional deltas (partial derivatives of the option coefficients and value of the floor or ceiling), and gammas (second derivative of the option coefficients and value of the floor or ceiling) are used to show that indeed the original ODE (5) is solved, see Table 2.

The first derivatives of the ACTIVE option coefficients with respect to changes in P are as follows:

$$\Delta V_C\left(P\right)=\begin{cases}\beta_1 A_{C11}P^{\beta_1-1} & \text{for } P\le P_L\\ \dfrac{1}{\delta}+\beta_1 A_{C21}P^{\beta_1-1}+\beta_2 A_{C22}P^{\beta_2-1} & \text{for } P_L<P<P_H\\ \beta_2 A_{C32}P^{\beta_2-1} & \text{for } P_H\le P.\end{cases} \tag{12}$$

Numerical Illustrations

Suppose the current net revenue is 6 with a volatility of 25%, no operating costs, instantaneous construction cost is 100, and r=δ=4%. If the government guarantees in perpetuity a P_L=4, with a cap of P_H=10, the ROV of operating such a perpetual activity is (6), while the present value is P/δ =150. With a collar, the ROV=150-41.61 call plus 29.98 put=138.37. These results are very sensitive to changes in most of the parameter values.

	A	B	C	D
1			**ACTIVE GEN WITH COLLAR**	
2	**INPUT**			EQ
3	P	6.00		
4	K	100.00		
5	σ	0.25		
6	r	0.04		
7	δ	0.04		
8	P_L	**4**		
9	P_H	**10**		
10	**OUTPUT**			
11	VC	**138.3688**		6
12	VC PV	**150.0000**	**IF(B3<B8,B8/B6,IF(B3>B9,B9/B6,B3/B7))**	6
13	P/δ	150.0000	B3/B7	
14	β_1	1.7369	0.5-(B6-B7)/(B5^2)+SQRT(((B6-B7)/(B5^2)-0.5)^2 + 2*B6/(B5^2))	4
15	β2	-0.7369	0.5-(B6-B7)/(B5^2)-SQRT(((B6-B7)/(B5^2)-0.5)^2 + 2*B6/(B5^2))	4
16	AC11*P^β1	**40.1361**	**B21*(B3^B14)**	6
17	AC21*P^β1	**-41.6129**	**B22*(B3^B14)**	6
18	AC22*P^β2	**29.9818**	**B23*(B3^B15)**	6
19	AC32*P^β2	**-117.2670**	**B24*(B3^B15)**	6
20	VC	138.3688	B12+B17+B18	
21	AC11	1.7862	(B9/(B9^B14)-B8/(B8^B14))*(B25/B27)	11
22	AC21	-1.8520	(B9/(B9^B14))*(B25/B27)	11
23	AC22	112.2797	(-B8/(B8^B15))*(B26/B27)	11
24	AC32	-439.16	(B9/(B9^B15)-B8/(B8^B15))*(B26/B27)	11
25	[ ]	-0.0400	(B6*B15-B6-B7*B15)	11
26	( )	-0.0400	(B6*B14-B6-B7*B14)	11
27	{ }	0.0040	(B14-B15)*B6*B7	11
28	VC	IF(B3<B8,B8/B6+B21*(B3^B14),IF(B3>B9,B9/B6+B24*(B3^B15),B3/B7+B22*(B3^B14)+B23*(B3^B15)))		
29	ODE	0.0000	0.5*(B5^2)*(B3^2)*B31+(B6-B7)*B3*B30-B6*B11+MIN(MAX(B8,B3),B9)	5
30	VC Δ	9.2711	IF(B3<B8,B14*B21*(B3^(B14-1)),IF(B3>B9,B15*B24*(B3^(B15-1)),1/B7+B14*B22*(B3^(B14-1))+B15*B23*(B3^(B15-1))))	16
31	VC Γ	-0.4136	IF(B3<B8,B14*(B14-1)*B21*(B3^(B14-2)),IF(B3>B9,B15*(B15-1)*B24*(B3^(B15-2)),B14*(B14-1)*B22*(B3^(B14-2))+B15*(B15-1)*B23*(B3^(B15-2))))	
32	Floor Deltas			
33	ΔAC11*P^β1	-0.6703	-((1-B14)*(B8^(-B14))*(B25/B27))	17
34	ΔAC22*P^β2	48.7556	-(1-B15)*B8^(-B15)*(B26/B27)	17
35	ΔAC32*P^β2	48.7556	-(1-B15)*B8^(-B15)*(B26/B27)	17
36	Ceiling Deltas			
37	ΔAC11*P^β1	0.1365	(1-B14)*B9^(-B14)*(B25/B27)	18
38	ΔAC21*P^β1	0.1365	(1-B14)*(B9^(-B14)*(B25/B27))	18
39	ΔAC32*P^β2	-95.7809	(1-B15)*(B9^(-B15)*(B26/B27))	18

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Not all of these authors investigate the incentives for the concessionaire, for instance to control construction costs, or operate just short of the level that triggers the upside option, or reduce the project volatility by hedging or issuing risk sharing debt instruments. According to Shaoul et al. (2012), UK transportation PPPs are expensive and have failed to deliver value for public money.

Various National Audit Commission (2016, 2017) reports have not provided contrary evidence, or periodic valuations of the UK government options in the various PPP arrangements.

HPC Case Questions:

1. What is the gross (and also net) present value in 2017 of the apparent HPC project, stating your reasonable assumptions, including a 2% yearly CPI inflation adjustment for the FiT, with a termination in 35 years , with both a net asset yield and discount rate of 5%? Note the NAO (2017) report on HPC operating costs, and perhaps assume operating costs and decommissioning funding costs equal to 13% of gross revenue, with the facility operating 95% of the time. It is convenient to use net revenue per unit (87% of gross) in translating the HPC NCF sheet to the collar sheet, with a similar adjustment for the floor and ceiling.
2. What is the real option value (government liability) of the apparent HPC arrangement compared to a collar (net floor of 35 and ceiling of 250, or your other designs) with a price volatility of 20%?
3. How sensitive are your answers to (1) and (2) to increase/decrease in the CPI or Electricity Prices +3% or -3% p.a., and also to increases/decreases in the price volatility to 40% or 0.
4. What are the costs and benefits of a Collar, or alternatively a Floor only, arrangement for the GEN and for the GOV, and advantages/disadvantages of the perpetual real option method compared to net present values?

GUIDE TO HPC EXCELS

1	HPC
2	ACT COLLARS 4 EQS
3	ACT COLLARS & D
4	ACT FLOOR/CEIL
5	Armada et al. (2012)
6	Case A Shaoul et al. (2012)
7	Prices