Peer Review:
DCPM modelling assumptions

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To: Alexei Mulko and Aproop Bhave
Department of Energy and Climate Change
3 Whitehall Place, London SW1A 2AW
United Kingdom

From: Luca Taschini
London School of Economics and Political Science
The Grantham Research Institute on Climate Change and the Environment
Houghton Street, London WC2A 2AE
United Kingdom
Email: l.taschini1@lse.ac.uk

1 Terms of Reference

DECC is required to update annually the DECC Carbon Price Model (DCPM) to ensure that it stays fit for purpose and that the underlying assumptions and input data are up to date. The DCPM is used to estimate carbon prices over a chosen number of years given annual caps on emissions levels and projections for business as usual emissions in all sectors and countries covered by the EU Emissions Trading System (EU ETS). The DCPM matches demand for abatement (abatement effort that needs to be undertaken to meet the cap) to supply of abatement (given by the marginal costs of technologies that need to be deployed to undertake abatement) and provides the carbon price by equalising supply and demand.

A fundamentals-based model does not take into account market participants' expectations about the future state of the carbon market or the impact of the carbon price on businesses' decisions about abatement. To reconcile DCPM short-term carbon price outputs and market expectations, two parameters are introduced into the DCPM. Different elements of market behaviour, market inertia and speculation, for example, may be captured by these parameters:

- (Limited) foresight – i.e. the number of years into the future over which market participants assess the degree of scarcity in the market and, consequently, their future abatement and carbon trading strategies. Selecting the foresight equal to the planning horizon, the DCPM operates under perfect foresight. Selecting the foresight shorter than the planning horizon, the DCPM operates under limited foresight.

- Risk-adjusted discount rate (RADR) – i.e. the discount rate applied to marginal abatement costs.

The Terms of Reference for this Review relate to provide advice on the length of the foresight and the risk-adjusted discount rate. This document presents initial advice on the key assumptions within the existing methodology and comments on the approach used for deriving the RADR. The document contains also a note on two alternative approaches that could be used for deriving an *implied* foresight (e.g. implied banking value). However, a detailed discussion about these two approaches is not part of the Term of References. This document does not provide advice on DECC's overall methodology for producing carbon values or reviewing the entire DCPM.

2 Sources and Engagement

I have been informed by presentations and discussions at two meetings held at DECC, as well as previously published reports on DCPM methodology and assumptions. I have been provided with a copy of the DCPM model and detailed documentation of the methodology used to process input data and generate output values, carbon prices. I have been provided with a report on the cost-of-carry methodology used to quantify the risk-adjusted discount rate.

My initial focus is upon the selected values of foresight and RADR and the methodology used for quantifying this rate. I presented my initial comments during a meetings held at DECC with DCPM modellers. I shared my initial thoughts on the model parameters via email on different occasions. Below I elaborate on these initial thoughts.

3 Advice on the Key Assumptions

3.1 Background

The EU ETS should ensure reductions of emissions in a cost-effective and economically efficient manner. This is Article 1 of the EU ETS directive. Cost-effectiveness and (dynamic) efficiency relates to the ability of the EU ETS to optimally incentivise short-term abatement efforts and long-term investments in mitigation activities and R&D in low-carbon technologies.

In theory, a cost-optimal pathway should be achievable in systems with long enough commitment periods and appropriate banking and borrowing provisions. Firms have a better view of their own cost-optimal abatement pathway and discount rates than the environmental regulator – the central planner. Hence, by providing scope for banking and borrowing firms can optimise the time at which they reduce emissions. A large surplus in the system could be the result of early abatement in light of scarcity expected in the future, see Ellerman and Montero (2007). Information about current and future emission reductions costs are aggregated and *long-term* price signals would emerge.

Under complete knowledge and full certainty, the carbon price increases at the discount rate.[1] In particular, under full certainty the cost-optimal pathway would correspond to constant carbon abatement volume across all regulated years and constant (discounted) permit price. However, in reality participants in the carbon market do not look far ahead to the future. In particular when planning horizon is far into the future – the planning horizon of the European Commission's Policy Framework is 2030. Businesses often demonstrate a degree of myopia, making abatement investment decisions on the basis of current – less uncertain – information.

Using a combination of RADR and limited foresight, the DCPM generates results that deviate from the theoretical perfect foresight that would look forward to the end of the planning horizon. The foresight affects firms' investment, abatement and carbon trading strategies. Under perfect foresight there is no uncertainty about future emissions, allowance allocation and marginal abatement cost curves. By limiting foresight, firms' expectations of the impact of long-term scarcity on carbon prices change and firms' strategies, including firms' banking and borrowing, differ from those under perfect foresight. In other words, limited foresight make firms resort to discount the expected scarcity of allowances several decades or years away, putting more weight on the current supply-demand balance in the market, thus depressing (respectively, increasing) prices if the market is perceived in over-supply (respectively, under-supply).

3.2 Foresight

The DCPM estimates the annual abatement effort as the difference between Business As Usual (BAU) emissions and the EU ETS cap. The foresight parameter in the DCPM determines how many years ahead are included when assessing the aggregate level of abatement needed to meet the required aggregate cap. Different horizons yields different aggregate costs.[2] When the foresight equals the length of the modelling horizon, approximately 35 years, we have perfect foresight. Under perfect foresight we look at the aggregate balance of supply and demand up to 35 years. There is no uncertainty about future marginal abatement cost curves, future emissions and the EU ETS cap. Firms' abatement and trading strategies are decided under full certainty and the discounted allowance price is, as expected, constant.

[1] This Hotelling-type result is standard in the literature on pollution permit with banking provisions; see Rubin (1996), Kling and Rubin (1997) and Schennach (2000), among others. Prices can never rise faster than the discount rate otherwise traders would attempt to buy low and sell high on an infinite scale.

[2] DCPM relies on the economic argument stating that, in equilibrium, the price for carbon should equal the postulated marginal cost of abatement (MAC).

If the DCPM is used to appraise policies affecting the overall demand of allowances, the BAU, or the overall supply of allowances, the EU ETS cap, than the foresight should be set equal to the planning horizon. First, the cost-optimal price pathway is computed under a foresight equal to the planning horizon. This can be considered the benchmark optimal outcome.[3] Then, the new policies under investigation are introduced and the price pathway is re-computed. The relative difference in modelled carbon prices and their behaviour in time across different polices is what should be used to assess the impact of the policies under investigation.

In the DCPM, only information about abatement costs, Business As Usual emission projections and the EU ETS cap is used to derive carbon prices. Hence, carbon prices produced using the DCPM reflect fundamentals. Short-term market participants' expectations about abatement costs, in particular, and the future state of the carbon market, in general, are not incorporated in the carbon price dynamics. The DCPM is not designed to capture market-wide expectations about the carbon market. However, by changing the foresight and the risk-adjusted discount rate, different elements of market behaviour may be introduced in the DCPM and it can be used for appraisal of policies where short term (absolute) prices are relevant. As such, the identification of an appropriate foresight and an appropriate risk-adjusted discount rate, RADR, is essential. RADR is discussed below.

DECC suggest to proxy foresight using futures trading activity. Carbon futures contracts have a maturity that ranges from 2014 to 2020. The volume of futures transactions decreases rapidly within the nearest years.

My recommendation about the length of the limited foresight is based on the on the following observation. Investment pertains to long-term strategies. Immediate abatement[4] and trading, instead, pertain to short-term strategies. When we think of short-term strategies in the EU ETS we are thinking of the different approaches companies use to match their emissions with their allowances. In some cases, companies do not abate at all and, at the end of the year, they just buy up the shortfall. These firms have one year foresight. Power companies purchase allowances (or related futures instruments or derivatives) in line with the commercial commitments they make to sell power. Power companies have a five to six years foresight.[5] Longer foresight depends on things like: how *sophisticated* are firms; how material is the cost of compliance in the overall P&L, or even whether they have cash available. The lack of a comprehensive

[3] Complete knowledge, perfect certainty and foresight equal to the planning horizon corresponds to perfect foresight. By relaxing the assumption of perfect certainty, the DCPM could be used to appraise policies through long-term carbon price trajectories under uncertainty. Uncertainty might be introduced by perturbing the future emission projections (uncertainty on the demand side) and the future allowances allocation (uncertainty on the supply side).

[4] Examples are investing in renewables and shutting down fossil fuel plants.

[5] Futures with maturity 2020 are traded on the EEX platform.

analysis of the trading practices does not permit to formulate a theory about firms' foresight. As such, the recommendations on the length of the limited foresight in the box below consider power companies as the reference case.[6]

3.3 Risk-adjusted discount rate

DECC calculates the RADR using the cost-of-carry approach. Below I argue that the relation between the RADR and the implied convenience yield deserves careful re-consideration. I suggest to complement the views about RADR using the cost-of-carry approach and identify a (lower bound of) RADR that reflects the firms' costs of financing.

When allowances are considered a factor of production, producers may hold allowances inventories to reduce the costs of adjusting production over time or to avoid stockout. DECC considers allowances a factor of production and calculates the associated cost, so-called cost-of-carry, using spot and futures prices. For a technical description of the arbitrage relationship between spot prices and futures prices we refer to the technical appendix at the end of this document. The cost of storing allowances is negligible, and there is no obvious cost to holding a supply of physical allowances as there is for physical commodities. Yet, the convenience to hold an allowance should reflect existing and potential abatement opportunities too. Following the cost-of-carry rationale, the main difference between a spot and futures carbon allowance is the opportunity cost of money paid for the spot allowance, i.e. spot abatement. That is, the term structure of carbon prices should primarily reflect the term structure of interest rates. However, the data indicates otherwise. In a recent paper, Bredin and Parsons (2014) present evidence of an arbitrage opportunity.[7] The result is puzzling and requires better understating of the arbitrage relationship between the current spot price and the current futures price for carbon allowances. In alternative, I suggest to use the cost of financing abatement investments to identify the DCPM RADR.

In the carbon market context, the RADR is the rate that makes discounted marginal abatement costs equal to the marginal cost of an additional unit of banked emission.[8] In the short term, these abatement costs (and opportunities) are connected to financing costs. A lower bound of the "rate of discount" could

[6] Short note on alternative methods to calibrates the foresight to current market data. Grüll and Kiesel (2012) suggest a possible approach. Given a per year emission rate, the cumulative allowances allocation and the cumulative emissions, it is possible to quantify the time needed to exhaust the amount of allowances currently available; see Definition 4 in Grüll and Kiesel (2012). Grüll and Taschini (2011) suggest a second possible approach. Under the EU ETS, firms submit carbon emission reports for every compliance period. Firms pay a penalty if they do not offset their emissions. They show that futures prices are equivalent to a European-style call option written on the compliance status with strike price equal to the penalty; see section 3 of the Grüll and Taschini (2011).

[7] A suitable strategy would be to borrow at the risk free rate, buy the underlying spot and simultaneously enter into a short futures contract (cash and carry arbitrage).

[8] Economic theory shows that under limited borrowing and perfect foresight, the carbon price increases at the discount rate during the banking period.

be identified by looking at the financing costs. Financing costs could be proxy by repurchase agreements, so-called repo. This was a widespread feature of EU ETS in 2009-2012. This is a *virtual* futures repurchase, since the companies doing this are not often able to join futures exchanges. Instead they have tended to carry out the repo with banks, selling spot and buying forward. If the repo was supposed to be a cheaper way of generating cash than going to the banks for a loan, then surely the implied interest rate would constitute a lower bound for a representative risk-adjusted retail rate.[9]

When the length of the foresight equals the length of the planning horizon, I suggest to use a RADR consistent with the discount rates figures used by the European Commission in the modelling, see EC (2013), Chapter 2, Main Assumptions.

Recommendations on foresight and RADR

- **DCPM is used to appraise policies affecting the overall demand and supply of allowances**
  - Foresight = length of the planning or modelling horizon.
  - RADR = 10% per year.

  Note: The RADR is indicative and should reflect minimum financing costs in the long run. RADR is a nominal discount rate, so an adjustment for inflation expectations should be made for real discount rates. More importantly, RADR will be assumed the same under different policies. As such, it is a constant across all treatments. When comparing carbon prices what matters is the relative price variation across the different policies under investigation.

- **DCPM is used to compute short-term carbon prices and appraise policies**
  - Foresight = 5-7 years.
  - RADR = 5%-6% per year.

  Note: The RADR is indicative and should reflect minimum financing costs. RADR is a nominal discount rate, so an adjustment for inflation expectations should be made for real discount rates.

[9] Data about commercial bank liability forward curves in the U.K. can be found here.

4 Technical appendix

The theory of storage defines an arbitrage relationship between the current spot price and the current futures price for a commodity (see Brennan, 1958). Assume we purchase a commodity at the current spot price, S_t, planning to hold it over a window of time, τ, to period $T = t+\tau$. We pay the current cost of storage $K_t(\tau)$; we earn the current convenience yield $\Psi_t(\tau)$; and we anticipate receiving the spot price S_T at T. The payoff on this investment is:

$$S_T - K_t(\tau) + \Psi_t(\tau) - S_t$$

Assume now that we also sell short one futures contract for the commodity maturing at T, agreeing to pay the difference between the futures price today, $F_t(\tau)$ and the price at maturity, $F_T(0) = S_T$. The payoff on this investment is:

$$-(F_T(0) - F_t(\tau)) = F_t(\tau) - S_T$$

This payoff also varies with the commodity spot price at T, with an exposure exactly opposite to the first payoff. The combined riskless payoff is:

$$F_t(\tau) - S_t - K_t(\tau) + \Psi_t(\tau) = Y_t(\tau)$$

where $Y_t(\tau)$ is the payoff of a riskless bond with maturity τ. Expressing rates as continuously compounded spot rates and rearranging we obtain:

$$F_t(\tau) = S_t \exp\Big((y_t(\tau) - \psi_t(\tau) + \kappa_t(\tau)) \cdot \tau\Big)$$

where we could assume a zero cost of storage, $\kappa_t(\tau) = 0$. The implied continuously compounded spot convenience yield is:

$$\psi_t(\tau) = y_t(\tau) - \frac{1}{T-t} \ln\left(\frac{F_t(\tau)}{S_t}\right)$$

The continuously compounded spot convenience yield from holding a commodity can be regarded as being similar to the continuously compounded dividend obtained from holding a company's stock. It represents the privilege of holding a unit of inventory, for instance, to be able to meet unexpected demand. Permits are fully bankable forward and there is no explicit storage cost, except the foregone interest earned on the money paid for a delivered allowance. The implication is that the carbon basis (the difference between the spot and futures price) should be equal to the interest rate. However, the data indicates otherwise. The figure below displays the time series of implied convenience yields calculated for different futures contracts. Negative yields correspond to a high futures price relative to the spot price.

The Phase 2 results reported in this figure are consistent evidence of a positive convenience yield, up to late 2008. However, this turns to a negative convenience yield for the remainder of Phase 2. This result is consistent with the results reported in Trück et al. (2014) for a sample up to July 2009. The negative convenience yield is persistent, although there is generally a reversion to zero (or on occasions a positive convenience yield) as we approach expiry for each of the individual futures contracts.

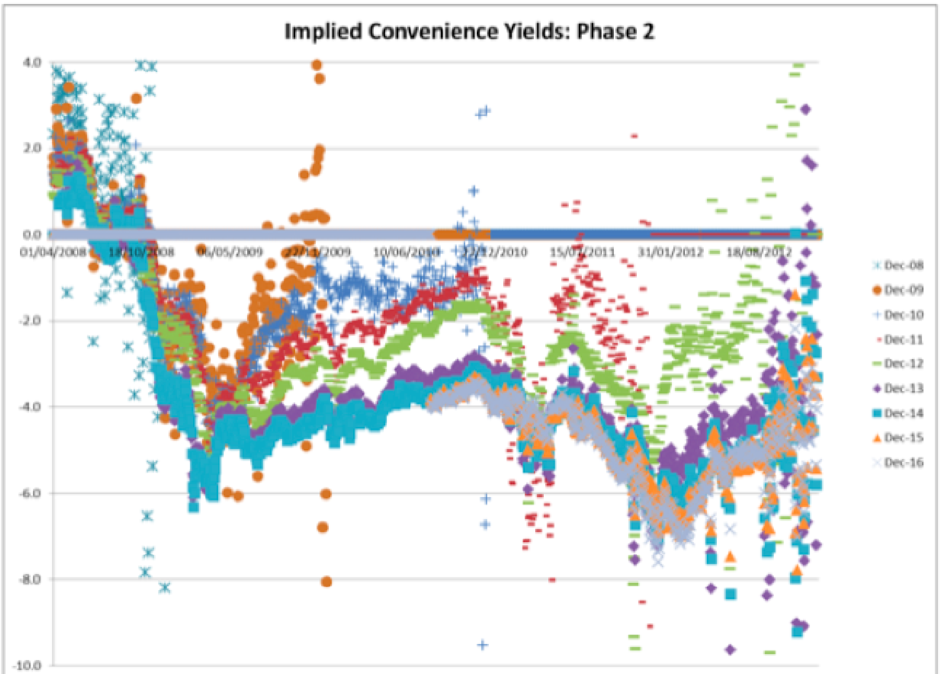

Figure 1: Difference between the implied convenience yield and the treasury yield for Phase 2. Source Bredin and Parsons (2014).

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