Energy Economics 34 (2012) 1143–1152

Contents lists available at SciVerse ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

The impact of power market structure on CO_2 cost pass-through to electricity prices under quantity competition – A theoretical approach

Jos Sijm [a,*], Yihsu Chen [b], Benjamin F. Hobbs [c]

[a] Energy research Centre of the Netherlands (ECN), Amsterdam, the Netherlands, Radarweg 60, 1043 NT, Amsterdam, The Netherlands
[b] School of Social Sciences, Humilities and Arts and School of Engineering, University of California, Merced, 5200 N. Lake Rd., Merced, CA 95343, USA
[c] E^2SHI and DoGEE, The Johns Hopkins University, 3400 N. Charles St., Ames Hall, Baltimore, MD 21218, USA

ARTICLE INFO

Article history:
Received 1 September 2010
Received in revised form 13 July 2011
Accepted 1 October 2011
Available online 8 October 2011

JEL classification:
D40
L11
L94
Q41

Keywords:
Emissions trading
Carbon costs pass-through
Electric power
Market power
Electricity prices
Demand elasticity

ABSTRACT

We present a theoretical analysis of the impact of power market structure on the pass-through rate (PTR) of CO_2 emissions trading (ET) costs on electricity prices. Market structure refers in particular to the number of firms active in the market and the intensity of oligopolistic competition as measured by the conjectural variation, as well as to the functional form of the power demand and supply curves. In addition, we analyse briefly the impact of other power market-related factors on the PTR of carbon costs to electricity prices. These include in particular the impact of ET-induced changes in the merit order of power generation technologies and the impact of pursuing other market strategies besides maximising generator profit, such as maximising market shares or sales revenues of power companies. Each of these factors can have a significant impact on the rate of passing-through carbon costs to electricity prices.

1. Introduction

During the first phase of the EU Emissions Trading Scheme (ETS; 2005–2007), the impact of the scheme on electricity prices became a major political and academic issue (Sijm et al., 2005, 2008). In general, the impact of carbon trading on power prices depends first of all on the price of a CO_2 emission allowance and the carbon intensity of the power sector, especially of the generation technologies setting the electricity price at different levels of power demand. These two factors, i.e., allowance price times carbon intensity, determine the (marginal) carbon costs of power generation.

In addition, however, the impact of emissions trading on electricity prices depends also on the extent to which the CO_2 allowance costs of power generation are passed through to these prices. This so-called '*pass-through rate*' (PTR) is determined largely by the structure of the power market.[1] By structure, we refer in particular to the interaction of the following three elements:

1. The number of firms active in the market (N), indicating the level of *market concentration* or *market competitiveness*. Depending on this number of firms, the market structure is called either monopolistic ($N=1$), duopolistic ($N=2$), oligopolistic ($N=$ small) or competitive ($N=$ large).
2. The shape of the demand curve, notably whether the (inverse) demand curve is linear or iso-elastic.[2]

[1] Another factor that might affect the pass-through rate of emissions trading costs to electricity prices is the method of allocating emission allowances, notably whether free allocations are regularly updated to incumbents and/or new entrants (Sijm et al., 2008).

[2] A linear demand function can be expressed as $Q=r-sP$, and an iso-elastic demand function as $Q=tP^{-\varepsilon}$ ($\varepsilon>0$), where Q is quantity, P is price, s is the slope of the linear demand curve, ε is the constant demand elasticity, while r and t are constants. On the other hand, the so-called *inverse* demand curves can be expressed as $P=w-vQ$ and $P=zQ^{-1/\varepsilon}$, respectively, where w and z are constants, while v ($=1/s$) is the slope of the inverse linear demand curve.

* Corresponding author. Tel.: +31 22456 8255; fax: +31 22456 8339.
E-mail addresses: sijm@ecn.nl (J. Sijm), yihsu.chen@ucmerced.edu (Y. Chen), bhobbs@jhu.edu (B.F. Hobbs).

0140-9883/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.eneco.2011.10.002

3. The shape of the supply (or marginal cost) curve, in particular whether the marginal costs are constant – i.e., a flat, horizontal line of perfectly elastic supply – or variable, i.e., sloping upward in either a linear or iso-elastic way.[3]

The main purpose of this paper is to analyse the impact of power market structure on the pass-through rate of CO_2 emissions trading costs to electricity prices from a theoretical point of view, including graphical illustrations and mathematical proofs. It builds on Section 3 – including the Appendix – of an article by the authors (Chen et al., 2008), making the following additional contributions:

- The results herein are more general in that we distinguish between cases of constant versus non-constant marginal costs and discuss the implications of this distinction for the derivation of the PTR under these cases.
- The implications of ETS-induced changes in the so-called *merit order* of power generation technologies for the PTR of carbon costs to electricity prices are analysed. These changes account for much of the ETS-caused decreases in emissions, but a general analysis of their implications for the PTR of CO_2 costs to power prices has not previously been presented.
- The effects of oligopolistic competition, considering a full range of conjectural variations, including special cases of Bertrand (perfect competition), Allaz–Vila competition, Nash–Cournot competition, and perfect collusion.
- We discuss briefly the implications of other, market-related factors for the pass-through of emissions trading costs to power prices. These factors include in particular the incidence of (i) market regulation, (ii) market imperfections, and (iii) other market strategies besides maximising profits, such as maximising market shares or sales revenues.

In the literature on the electricity sector, several approaches are generally used for modelling competition such as Cournot–Nash models, the 'supply function' approach and the 'auction' approach.[4] In this paper, we predominantly apply the so-called 'conjectural variations' approach, of which the Cournot–Nash model is a special case, to analyse the impact of different market structures on the pass-through of CO_2 emissions trading costs to electricity prices. The basic assumption of this approach is that quantity, i.e., output generated, is the decision variable of rival electricity producers. Whereas the Cournot model is based on the conjecture that rivals will not react to a production change by changing their output, the conjectural variation models are flexible with regard to the conjectures on the response of competitors. By parametrically changing the assumed supply response, different degrees of competitive intensity can be modelled, ranging from pure (Bertrand) competition (infinitely large positive quantity response by rivals to price increases), to oligopolistic Cournot competition (no response), and even collusion (which can be simulated by a negative quantity response to price increases). An intermediate case is Allaz-Vila competition which, under some assumptions, implies that a unit change in output by one firm is believed by that firm to stimulate a 0.5 change in output in the other direction by rival firms (Murphy and Smeers, 2010). Positively sloped conjectured supply functions (CSFs) also represent different degrees of competitive intensity between the Cournot and Bertrand cases (Day et al., 2002; Hansen, 2010).

Recently, Gulli et al. have used an alternative approach – the so-called 'auction' approach – to analyse the impact of market structures on CO_2 cost pass-through to electricity prices (see Bonacina and Gulli, 2007; Chernyavs'ka and Gulli, 2008; and Gulli, 2008). More specifically, by using a dominant firm facing a competitive fringe model, they analyse the short-run impact of CO_2 emissions trading on wholesale electricity spot markets where the pricing mechanism is a uniform, first-price auction. Their main finding is that the impact of carbon trading on power prices significantly depends on the structure of the electricity market. Under perfect competition, electricity prices fully internalise the carbon opportunity costs. Under market power, however, the extent to which these costs is passed through into electricity prices depends on several factors, including (i) the degree of market concentration, (ii) the plant mix operated by either the dominant firm or the competitive fringe, (iii) the carbon price, and (iv) the available capacity in the market, i.e., whether there is excess capacity or not.[5] Our results confirm (i) for the case of Cournot and, more generally, conjectural variation competition.

The remainder of the paper is structured as follows. Sections 2 through 5 discuss the PTR of carbon costs to electricity prices under different power market structures, in particular under different levels of market competitiveness (competitive, Cournot, and monopoly) and different combinations of shapes for power demand and supply (marginal cost) curves. Section 6 generalizes some of these results for oligopolies using conjectural variation competition, while Section 7 discusses two bounding cases of linear demand and supply under competitive markets. Subsequently, Section 8 analyses the implications of ETS-induced changes in the merit order of power generation technologies for the PTR of carbon costs to prices. Next, Section 9 discusses the implications of other, market-related factors for the pass-through of emissions trading costs to power prices, such as the effect of company strategies other than profit maximization. Finally, Section 10 summarizes our major findings.

2. Constant marginal costs and linear demand

Fig. 1 illustrates the pass-through of carbon costs for two polar cases, monopoly ($N=1$) versus full competition ($N=\infty$), both characterised by linear demand and a constant marginal cost curve (i.e., perfectly elastic supply). More generally, under these assumptions and Nash–Cournot competition, the extent to which carbon costs are passed through to power prices, i.e., the pass-through rate (PTR) is given by the formula:

$$\mathrm{PTR} = dP/dMC = N/(N+1) \tag{1}$$

where dP/dMC is the rate of change of price with respect to marginal cost, and N is the number of firms active in the market (the proof is provided in Appendix A.6). Note that under these conditions the change in power price due to emissions trading depends only on the number of firms, but not on the elasticities of power demand or supply.[6]

The implications of this formula are somewhat counterintuitive: a monopoly ($N=1$) passes through only 50% of any increase in carbon costs. However, if a sector is more competitive (i.e., the number of firms increases) and competition is a la Cournot, the pass-through rate rises until it is close to 100%. Hence, under linear demand and

[3] Throughout this paper, we use the term 'supply curve' although in the context of oligopoly models, the more precise term would be 'marginal cost curve', since a unique supply function (as a function of price) does not generally exist for non-competitive markets. The inverse supply curve can be expressed as $MC=a+uQ$ if it is linear, or as $MC=kQ^b$ if it is iso-elastic, where MC is marginal costs, Q is quantity, a is a constant, u is the slope of the linear supply curve, k is a scaling factor, and $1/b$ (>0) is the constant supply elasticity of the (non-inverse) iso-elastic supply curve.

[4] For a discussion of these and other approaches of modeling power market competition – including classifications of various proposed approaches – see, for instance, von der Fehr and Harbord (1998), Stoft (2002) or Hansen (2010).

[5] For more findings and further details, both theoretically and empirically, see Bonacina and Gulli (2007), Chernyavs'ka and Gulli (2008), and Gulli (2008).

[6] The formula is based on the assumption that the companies operating in the market are all affected by the cost change. In the case of the power sector affected by the EU ETS, this is a reasonable assumption as all major companies operating in EU power markets are covered by the scheme (although the cost change varies across these companies as they have different technologies and, hence, different emission rates). However, in the case of significant competition in the form of imports by external companies not covered by the scheme, the formula for the cost PTR becomes $X/(N+1)$, where X is the number of companies affected by the cost change and N the number of companies operating in the market (Oxera, 2004; Sijm et al., 2005; Smale et al., 2006).