Ex-post investigation of cost pass-through in the EU ETS

An analysis for six sectors

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Contact: Ismo ULVILA

E-mail: *ismo.ulvila@ec.europa.eu*

European Commission
B-1049 Brussels

Abstracts

Abstract

In the discussion on the potential risk of carbon leakage related to the EU ETS and the effect of safeguard measures, the scope for passing through carbon costs in final product prices is deemed a key issue. This study investigates whether and to what extent ETS-related carbon costs have indeed been passed through into product prices by EU industry. It further analyses the factors that may have influenced such pass-through. The study approaches cost pass-through from different angles: (i) a detailed literature review (theoretical, ex-ante modelling and ex-post empirical studies); (ii) econometric estimates for a number of products in six sectors in different countries, and (iii) a qualitative and quantitative analysis of potential factors explaining ability or inability to pass through carbon costs. In line with the literature, our econometric results show that significant cost pass-through could be observed for a number of products, in particular in the cement, iron & steel and refineries sectors, with the actual rates of pass-through diverging. Market power both within the EU and in international markets, including bargaining power, and exposure to international competition seem to be among the main driving forces of both price formation processes and the ability to pass through carbon costs.

Résumé

Dans la discussion du risque potentiel de fuite de carbone liée au SEQE-UE et de l'effet de mesures de sauvegarde, la possibilité de répercuter le coût du carbone sur les prix de produits finis est considérée comme un aspect important. Cette étude examine la question de savoir si et dans quelle mesure le coût du carbone lié au SEQE a été répercuté sur les prix de produits au sein des industries de l'UE. Elle analyse en outre les facteurs susceptibles d'avoir influencé la répercussion observée du coût. L'étude aborde la question de la répercussion du coût de trois points de vue: (i) une analyse de la documentation (études théoriques, de modélisation ex-ante et études empiriques ex-post); (ii) des évaluations économétriques de plusieurs produits dans six secteurs au sein de plusieurs pays, et (iii) une analyse qualitative et quantitative quant aux facteurs potentiels expliquant la capacité ou l'incapacité à répercuter le coût du carbone. Conformément à la documentation, nos résultats économétriques démontrent qu'une répercussion considérable du coût a pu être observée pour plusieurs produits, particulièrement dans les secteurs du ciment, de la sidérurgie et des raffineries, avec des taux réels variables de répercussion du coût. La position sur le marché aussi bien au sein de l'UE qu'au niveau international, y compris le pouvoir de négociation et l'exposition à la concurrence internationale semblent figurer parmi les principales forces motrices du processus de formation des prix et de la capacité à répercuter le coût du carbone.

Executive summary (English)

Since the inception of the EU Emissions Trading Scheme there has been a debate as to what extent ETS participants have been able to pass through their carbon costs in final product prices. This degree of pass-through is one of the main factors determining the potential impact of the ETS on companies' competitiveness. The ETS Directive states that any analysis of whether sectors or subsectors are likely to be subject to a risk of carbon leakage should be "*based on an assessment of the inability of industries to pass on the cost of required allowances in product prices without significant loss of market share to installations outside the Community which do not take comparable action to reduce their emissions*."

Two carbon leakage indicators, carbon costs and trade intensity, have been developed for regulatory purposes to approximate such competitiveness effects. Threshold values in these indicators determine whether sectors should receive a high share of free allowances to address the risk of negative competitive impacts from the EU ETS. Negative distortive impacts may emerge both in the short run, through a loss of market share, and in the long run, through a reduction in investments. However, if companies qualify for the two carbon leakage indicators but are nonetheless able to pass through carbon costs, free allowances imply a financial transfer from consumers (or client industries) to energy-intensive industries, which would give rise to what is often referred to as 'windfall profits'. These considerations make a good understanding of the degree of carbon cost pass-through across major EU ETS sectors relevant both for the political debate and also as an element to be potentially used for regulatory purposes.

The aim of the present study is to determine the extent to which ETS-related carbon costs have been passed through in the product prices of industries covered by the EU ETS and to investigate the factors that may have influenced the observed cost pass-through. The study approaches these questions from three angles:

1. A literature review (theoretical and empirical studies).
2. An empirical assessment for six sectors, using statistical techniques (econometrics).
3. Additional qualitative and quantitative analysis of potential factors explaining the degree of carbon-cost pass-through.

1. Literature review (theoretical and empirical studies)

The literature on cost pass-through can be classified into theoretical, ex-ante modelling and ex-post econometric studies. The neoclassical economic literature shows that cost pass-through is likely for profit-maximising firms. According to theory, when facing a trade-off between cost pass-through (to retain profits) and a loss in market share, firms will maximise profits rather than market shares and therefore pass through carbon costs. This result holds, in economic theory, regardless of whether the emission allowances are (partly) auctioned or given away at zero cost, since at the margin carbon costs are the same for auctioned and free allowances.

The theoretical literature further defines a number of factors that cost pass-through rates may depend on, including market power, elasticities of demand, the elasticity of domestic supply and elasticities of foreign supply (so-called Armington elasticities). These factors have proven difficult to estimate in empirical work and have therefore been approximated by a range of measurable drivers that are linked to these stylised factors. These drivers include trade intensity, transport costs, tariff barriers and product substitutability (underlying the Armington elasticities), as well as indicators of market concentration and pricing power (underlying the market structure). However, it is infeasible to assess whether firms will be induced to pass through the carbon costs of participation in the EU ETS based on theoretical literature alone.

Despite ten years of operation of the EU ETS, the literature offering empirical estimates of the pass-through of carbon costs for industrial products remains relatively scarce. The literature review in this study identifies eight original studies estimating cost pass-through for a range of industrial products. Three of these studies are based on ex-ante modelling exercises and five use ex-post econometric techniques. All studies show that costs have been passed through in the majority of sectors investigated. However, when comparing the results of these studies in more detail, it becomes apparent that the quantified cost pass-through rates vary substantially across studies. Clearly, the exact extent to which costs are estimated to be passed through is highly dependent on the methods chosen and the data used.

2. Empirical assessment of cost pass-through in six sectors using statistical techniques (econometrics)

Following a discussion of the methods applied in the literature and potential variations in and extensions of these methods, a so-called cost-price model is applied to estimate the share of carbon costs in final product prices. Using this model, the shares of various input costs in final product prices are estimated. Input costs considered include raw-material, labour and capital costs as well as energy and carbon costs. Although this method is relatively data-intensive, as it requires time-series data of sufficient length for both the prices of outputs and all inputs considered, it has the advantage that it is relatively straightforward and that fewer assumptions are required compared with other models.

The cost-price model is then applied to a number of products in six ETS sectors. These sectors were selected ex-ante on the basis of magnitude of emissions, (direct) carbon costs and data availability, and include (in NACE Rev. 2):

- iron and steel (NACE 2410);
- refineries (NACE 1920);
- cement (NACE 2351);
- organic basic chemicals (NACE 2014);
- fertiliser (NACE 2015);
- glass (NACE 231).

For each of these sectors, monthly and/or weekly data were gathered on the output prices of a number of products, as well as on the input prices of labour, capital, materials, energy and carbon. For each sector, the relationship between input and output prices is estimated for 2-3 products in 2-3 countries. In total, more than 50 unique product price series were investigated in this study, using individual time-series regressions for each product/country combination.

An estimation strategy framework was developed and applied to each product/country combination. Based on statistical tests of the data series and robustness indicators of the regression at hand, the estimation strategy follows a clear rule-based path to arrive at the most appropriate method in each case. The only pre-selection criterion implemented before applying the framework was the decision on which time frame to consider for each product. While data were available for the time frame 2005-2014, the analysis was often limited to include only EU ETS Phase 2 and 3 owing to a change of scope (petrochemical and fertiliser industries) and the fact that Phase 1 is widely regarded as a ‘learning phase’ during which the carbon price was nearly zero for an extended period of time.

The regression equations are formulated in such a way as to test the hypothesis of ‘no cost pass-through’. This implies a standardised ‘cautious approach’ by presuming there is no relationship between marginal carbon costs and product prices unless this is explicitly revealed by statistical tests. Table 1 summarises the results of these empirical estimates. For every product included in the regression analysis, the table provides information by country on the cases where prices of the product were significantly influenced by carbon costs, indicating that carbon costs have been passed through. Our econometric results show that this was the case for about 60% of the product prices investigated. Significant proof of cost pass-through was more often found for products in the cement, iron and steel, refineries and fertiliser sectors than for products in the petrochemical and glass sectors (compare columns 3 and 4).

Despite these uncertainties, the indicative values show that there may well be differences between sectors in the rates of cost pass-through observed. In the cement sector they seem to be lowest and range, in general, between 20-40% (with the exception of Portland cement in Poland). This is consistent with earlier results in the literature that have identified about 30% cost pass-through in the cement sector. Indicative cost pass-through rates in the iron and steel sector range, in general, between 55-85% (except for hot rolled coil in Southern Europe, for which a higher cost pass-through rate was found). This result also confirms earlier ex-ante estimates in the literature. For refineries, we find signs of higher indicative cost pass-through rates, ranging from 80-100% for petrol and at, or over, 100% for diesel and gasoil. Such high indicative cost pass-through rates were also found in the fertiliser and petrochemical sectors, for those products where estimated coefficients were significant. The glass sector, finally, shows somewhat lower indicative cost pass-through rates of between 40-100%.

Table 1 Overview of main empirical results of this study

Sector	Product	Cost pass-through not significant*	Cost pass-through significant*	Indicative cost pass-through rates if significant^
Cement	Clinker	UK, CZ	FR, DE, PL	35-40%
	Total cement	UK, IT	FR, DE	20-40%
	Portland cement		CZ,PL	90-100%
Petrochemicals	Ethylene		NWE, MED	>100%
	Mono ethylene glycol	MED		NA
	Propylene oxide		NWE	~100%
	Propylene glycol ether**	NWE	NWE	>100%
	Methanol, Butadiene, Propylene	NWE, MED		NA
Iron and steel	Flat steel HRC		NE, SE	75->100%
	Flat steel CRC		NE, SE	55-85%
Fertiliser	Ammonia	NWE		NA
	Ammonium nitrate	FR	UK	>100%
	Calcium ammonium nitrate		DE	>100%
	Urea ammonium nitrate		FR	>100%
	Urea	NL	NWE	100%
Refineries	Diesel	DE	BE, FR, GR, IT, PL	>100%
	Gasoil	GR, PL, IT	BE, DE, FR	>100%
	Petrol	GR, PL	BE, DE, FR, IT	80-95%
Glass	Hollow glass	DE, ES	FR, IT	40->100%
	Fibre glass	DE		NA

Notes:

* BE=Belgium, CZ=Czech Republic, DE=Germany, ES=Spain, FR=France, GR=Greece, IT=Italy, NE=Northern Europe, NL=Netherlands, NWE=North-Western Europe, MED=Mediterranean countries (Southern Europe), PL=Poland, SE=Southern Europe, UK=United Kingdom. Decision on whether CO_2 cost coefficient was significant made on the basis of a 10% critical threshold level (based on one-sided T-statistics).[1]

** For propylene glycol ether we use three different spot prices for NWE. Estimates show that in the regression employing one price series, CO_2 prices were found to be significant, whilst not for the other two.

^ Conjectured average estimate of the percentage of carbon costs passed through in product prices for the cases where cost pass-through was significant.

3. Additional qualitative and quantitative analysis of potential factors explaining the ability or inability to pass through carbon costs

To improve understanding of price formation in the respective industries, interviews were conducted with client industries and market experts regarding their experience with price formation in supplier industries and their view on main price determinants. The sample differed by industry and also by size, bargaining power and product portfolio of the client industry in question. Energy prices were perceived to play a major role in product price formation. Transportation costs, on the other hand – even though considerable in some industries – only seem to play a role in price variation if

[1] One-sided confidence levels are more appropriate because we are testing whether the opportunity cost of freely obtained allowances are not passed through in product prices. Since it makes no sense to assume that a negative opportunity-cost value is passed through in the product price, a one-sided confidence level seems appropriate.

transportation capacity becomes scarce and expensive (such as in the pre-crisis year 2008) or if goods are difficult to transport in the first place (e.g. fragile glass or hazardous chemicals).

In addition to these interviews, this study presents quantitative evidence on other factors potentially influencing the process of price formation such as utilisation rates, market power and trade intensity, which could broadly estimate the degree of carbon-cost pass-through.

Utilisation rates may in some sectors be a driver explaining differences in cost pass-through – with higher capacity utilisation generally being associated with higher cost pass-through rates. The lowest utilisation rates were found in the cement sector (substantial overcapacity), somewhat higher rates in the iron and steel sector, with the highest rates in the fertiliser industry, where installations run at high capacity. This study finds corresponding differences in cost pass-through rates between these sectors. This finding also confirms the theoretical literature on the subject.

Market power, both of the EU in global markets and the concentration of power within EU markets, also seem to be important variables. Generally, a higher market concentration seems to be associated with a higher ability to pass through costs. However, lack of empirical data prevents clear estimation of this relationship.

Finally, a weak correlation between trade intensity and cost pass-through can be observed for the product/country pairs investigated in this study. Products for which no cost pass-through was found tend to have higher trade intensities than products for which cost pass-through could be revealed. However, this link is not statistically significant when comparing the two groups and more research – in particular on more products – would be needed before conclusions can be drawn about the relative strength of the trade-intensity criterion as an indicator of cost pass-through. Moreover, the ability to pass through costs is not a one-to-one indicator of whether or not a risk of carbon leakage exists, as other factors such as maintaining market shares (or not) also come into play.

4. Discussion

This study indicates that, in practice, industry often passes through a substantial share of the opportunity cost of freely obtained allowances. It is important to note that evidence of carbon cost pass-through is not in itself an indicator of carbon leakage risk. We have not further investigated the extent to which cost pass-through has resulted in a loss in market share or has (negatively or positively) impacted on the profitability of firms. This can be investigated further in future work. We note, however, that empirical evidence, at present, has not documented carbon leakage for EU industries.

The findings in this study are not inconsistent with the observation that the majority of firms claim - in surveys or public statements - that they do not pass through carbon costs. In a market where the price is determined by the costs of the marginal producer (and the marginal producer is short of allowances or calculates with opportunity cost concepts), the market price would already contain CO_2 cost-components to which all other producers adjusted without knowing that they are (implicitly) passing through carbon costs. Only price-setters can make a formal decision to pass through carbon costs explicitly. Price takers "automatically" pass through carbon costs without ever taking a formal decision about the role of carbon costs in price formation by the sales department.

Finally, the results show that econometrics can be a valuable method to determine whether or not product prices contain carbon cost components for products with a relatively high carbon content. Econometrics can thus provide information additional to the existing work that has surveyed companies participating in the EU ETS. However, the question as to how much of these costs are exactly passed through in product prices (i.e. the magnitude of cost pass-through rates) is more difficult to answer. The literature review has shown that estimation results of cost pass-through rates depend - to a large extent - on the models and data used in the process. Therefore, results from econometric studies can, for the time being, be especially useful for determining the relevance of indicators approximating cost pass-through. Given the high relevance of empirical carbon cost pass through for devising a well-targeted carbon leakage and free allocation policy it is recommended to continue and intensify efforts to derive more solid estimates and indicators. In addition to trade intensity, this study has pointed to the potential importance of other indicators, such as utilisation rates and market power, to explain cost pass-through, both of which also deserve further investigation.

Résumé (français)

Depuis sa mise en œuvre, le SEQE-UE a engendré un débat considérable sur la question de savoir dans quelle mesure les participants au système ont été capables de répercuter les coûts du carbone sur les prix de leurs produits finis. Le niveau de répercussion du coût du carbone est l'un des principaux facteurs déterminant l'impact potentiel du SEQE sur la compétitivité des entreprises. La Directive SEQE affirme que l'analyse quant à la question de savoir s'il est probable que les secteurs et les sous-secteurs soient soumis à un risque de fuite de carbone devrait être basée sur l'évaluation de *l'incapacité des industries à répercuter le coût des quotas nécessaires sur les prix des produits sans subir de perte importante de parts de marchés en faveur d'installations établies hors de la Communauté qui ne prennent pas de mesures comparables pour réduire leurs émissions*.

Deux indicateurs de fuite de carbone, le coût du carbone et l'intensité des échanges ont été conçus à des fins de réglementation pour se rapprocher d'un tel impact sur la compétitivité. Les valeurs seuils au sein de ces indicateurs déterminent l'obtention par les secteurs d'une plus grande quantité de quotas gratuits, afin d'éviter les effets négatifs de distorsion de la concurrence du SEQE-UE. Des effets de distorsion négatifs peuvent apparaître à court terme, par une perte de parts de marché et à long terme, par une réduction des investissements. Toutefois, si les sociétés répondent aux critères des deux indicateurs de fuite de carbone, tout en étant cependant capables de répercuter le coût du carbone, les quotas gratuits impliquent un transfert financier des consommateurs (ou de la clientèle industrielle) vers les industries énergivores, ce qui engendrerait des bénéfices supplémentaires. Ces considérations rendent utile une bonne compréhension du niveau de répercussion du coût du carbone à travers les principaux secteurs SEQE-UE, aussi bien pour le débat politique que comme élément potentiel utilisé à des fins de réglementation.

L'objectif de la présente étude est de déterminer dans quelle mesure le coût du carbone lié au SEQE a été répercuté sur les prix des produits au sein d'industries couvertes par le SEQE-UE et d'examiner les facteurs susceptibles d'avoir influencé la répercussion observée sur les coûts. L'étude aborde ces questions de trois points de vue :

1. Une analyse de la documentation (études théoriques et empiriques).
2. Une estimation empirique pour six secteurs au moyen de techniques statistiques (économétrie).
3. Des analyses qualitatives et quantitatives supplémentaires quant aux facteurs potentiels expliquant le niveau de répercussion du coût du carbone.

1. Analyse de la documentation (études théoriques et empiriques)

Les ouvrages concernant la répercussion du coût se classent en études théoriques, de modélisation ex-ante et en études économétriques ex-post. La documentation économique néoclassique indique que la répercussion du coût est probable pour les sociétés qui cherchent à maximiser leurs profits. Selon la théorie, si elles sont confrontées à un compromis - entre une répercussion - des coûts (pour maintenir ses profits) et une perte de parts de marché, les sociétés maximiseraient les profits plutôt que les parts de marché et répercuteraient, par conséquent, le coût du carbone.
Ce résultat se maintient, dans la théorie économique, que les quotas d'émissions soient (partiellement) mis aux enchères ou donnés gratuitement ou pas, car à la marge, le coût du carbone est équivalent pour les quotas mis aux enchères et les quotas gratuits.

La documentation théorique définit en outre plusieurs facteurs dont les taux de répercussion peuvent dépendre, y compris la position sur le marché, les élasticités de la demande, l'élasticité de l'offre nationale et les élasticités de l'offre étrangère (ce qu'on appelle - les élasticités d'Armington). Comme ces facteurs se sont avérés difficiles à évaluer dans les travaux empiriques, une correspondance approximative a été établie avec une série de moteurs mesurables liés à ces facteurs. Citons parmi ces moteurs l'intensité des échanges, les coûts du transport, les barrières tarifaires et la substituabilité des produits (qui sous-tend les élasticités d'Armington), ainsi que les indicateurs de concentration de marché et de pouvoir de fixation des prix (sous-tendant la structure du marché). Toutefois, il est impossible d'évaluer si les sociétés seront incitées à répercuter le coût du carbone résultant de la participation au SEQE-UE en s'appuyant uniquement sur la documentation théorique.

Malgré la décennie de fonctionnement du SEQE-UE, les ouvrages offrant des évaluations empiriques de la répercussion du coût du carbone pour les produits industriels demeurent relativement rares. L'analyse de la documentation de cette étude identifie huit études d'origine évaluant la répercussion du coût pour une série de produits industriels. Parmi ces études, trois s'appuient sur des exercices de modélisation ex-ante et cinq d'entre elles utilisent des techniques économétriques ex-post. Toutes les études démontrent que les coûts ont été répercutés dans la majorité des secteurs examinés. Toutefois, une comparaison plus détaillée des résultats de ces études laisse apparaître que les taux exacts de répercussion du coût varient considérablement d'une étude à l'autre. Il est clair que la question de l'évaluation quantifiée du coût dont estime qu'il est répercuté dépend fortement des méthodes choisies et des données utilisées.

2. Estimation empirique pour six secteurs au moyen de techniques statistiques (économétrie)

Suite à une discussion des méthodes appliquées dans la documentation et les variations et extensions possibles de ces méthodes, un modèle dit du prix de revient a été appliqué, afin d'évaluer la part des coûts du carbone contenue dans les prix des produits finis. Au moyen de ce modèle, on évalue les parts d'une série de prix d'intrants intégrés aux prix des produits finis. Citons parmi les prix d'intrants les matières premières, la main-d'œuvre et les coûts d'investissement, ainsi que les coûts énergétiques et du carbone. Bien que cette méthode demande un volume relativement important de données, car elle nécessite des données en série chronologique de longueur suffisante autant pour les prix des extrants que pour tous les intrants considérés, elle offre l'avantage d'être relativement simple et d'exiger moins d'hypothèses comparée aux autres modèles.

Le modèle du prix coûtant est alors appliqué à une série de produits dans six secteurs SEQE. Parmi ces secteurs, sélectionnés ex-ante sur la base de l'ampleur des émissions, sur les coûts (directs) du carbone et sur la disponibilité de données, citons les suivants (dans NACE Rev.2):

- sidérurgie (NACE 2410);
- raffineries (NACE 1920);
- ciment (NACE 2351);
- produits chimiques organiques de base (NACE 2014);
- engrais (NACE 2015);
- verre (NACE 231).

Pour chacun de ces secteurs, des données mensuelles et/ou hebdomadaires ont été recueillies sur les prix des extrants de plusieurs produits finis, ainsi que sur les prix des intrants de la main-d'œuvre, des capitaux, des matériaux, de l'énergie et du carbone. La relation entre les prix des extrants et des intrants est évaluée pour deux ou trois produits dans deux ou trois pays de chaque secteur. Au total, plus de 50 séries uniques de prix de produits ont été examinées dans cette étude au moyen de régressions individuelles en série chronologique pour chaque combinaison de produits/ pays.

Un cadre stratégique d'évaluation a été développé et appliqué à chaque combinaison de produit / pays. En s'appuyant sur les tests statistiques des séries de données et en ayant à portée de main les indicateurs de robustesse de la régression, la stratégie d'évaluation suit un parcours clair basé sur des règles - pour parvenir à la méthode la plus adaptée dans chaque cas. Les seuls critères antérieurs à la sélection mis en œuvre avant d'appliquer le cadre ont été la décision de la période à prendre en compte pour chaque produit. Alors des données étaient généralement disponibles pour la période 2005-2014, l'analyse était souvent limitée pour inclure les Phases 2 et 3 du SEQE-UE uniquement, en raison de modifications de la portée (industries pétrochimiques et des engrais) et du fait que la Phase 1 est largement considérée comme une « phase d'apprentissage » au cours de laquelle le prix du carbone était proche de zéro pendant un laps de temps prolongé.

Les équations de régression ont été formulées de manière à tester l'hypothèse « pas de répercussion du coût ». Ceci implique une « approche prudente » normalisée en supposant qu'il n'existe aucune relation entre les coûts marginaux du carbone et les prix des produits, sauf si les tests statistiques l'indiquent explicitement.

Tableau 2 résume les résultats de ces évaluations empiriques. Pour chaque produit inclus dans l'analyse de régression, le tableau fournit des informations par pays sur les cas où les prix du produit concerné ont été considérablement influencés par le coût du carbone, ce qui indique que ces derniers ont été répercutés. Nos résultats économétriques démontrent que c'est le cas dans 60% environ des prix de produits examinés. Des preuves significatives de répercussion du coût ont été trouvées plus souvent pour les produits des secteurs du ciment, de la sidérurgie, des raffineries et des engrais que pour les produits issus des secteurs pétrochimique et du verre (comparez les colonnes 3 et 4).

Le coefficient de carbone résultant de l'évaluation économétrique donne la fraction moyenne des coûts du carbone par rapport au total des coûts du produit. Cette fraction a servi à calculer le taux de répercussion comme pourcentage de coûts du carbone répercutés sur les prix des produits. Toutefois, le calcul exact de ce taux de répercussion se caractérise par une incertitude plus importante que la conclusion quant à la question de savoir si oui ou non des coûts du carbone ont été répercutés. Par conséquent, les taux de répercussion présentés dans le Tableau 2 doivent être interprétés comme des « valeurs indicatives ».

Tableau 2 Bilan des principaux résultats empiriques de cette étude

Secteur	Produit	Répercussion des coûts pas significative*	Répercussion des coûts si significative*	Coûts indicatifs taux de répercussion si significative
Ciment	Clinker	UK, CZ	FR, DE, PL	35-40%
	Ciment total	UK, IT	FR, DE	20-40%
	Ciment Portland		CZ,PL	90-100%
Produits pétrochimiques	Éthylène		NWE, MED	>100%
	Mono-éthylène glycol	MED		
	Oxyde de propylène		NWE	~100%
	Éther de propylène glycol**	NWE	NWE	>100%
	Méthanol, butadiène, propylène	NWE, MED		NA
Sidérurgie	Acier plat HRC		NE, SE	75->100%
	Acier plat CRC		NE, SE	55-85%
Engrais	Ammoniaque	NWE		
	Nitrate d'ammonium	FR	UK	>100%
	Nitrate d'ammonium et de calcium		DE	>100%
	Nitrate d'ammonium et d'urée		FR	>100%
	Urée	NL	NWE	->100%
Raffineries	Diesel	DE	BE, FR, GR, IT, PL	>100%
	Gasoil	GR, PL, IT	BE, DE, FR	>100%
	Essence	GR, PL	BE, DE, FR, IT	80-95%
Verre	Verre creux	DE, ES	FR, IT	40->100%
	Fibre de verre	DE		

Remarques :

* BE=Belgique, CZ=République tchèque, DE=Allemagne, ES=Espagne, FR=France, GR=Grèce, IT=Italie, NE=Europe du Nord, NL=Pays-Bas, NWE= Nord-ouest de l'Europe, MED= Pays méditerranéens (Europe du Sud), PL=Pologne, SE=Sud de l'Europe, UK=Royaume-Uni. Décision quant à la question de savoir si le coefficient du coût du CO_2 était significatif prise sur la base d'un taux de seuil critique de 10% (basés sur des statistiques T unilatérales).[2]

** Pour l'éther de propylène glycol, nous utilisons trois prix au comptant différents pour la région NWE. Les évaluations démontrent que dans la régression utilisant une série de prix, les prix du CO_2 se sont avérés significatifs, ce qui n'était pas le cas pour les deux autres.

^ Moyenne estimée du pourcentage de coûts du carbone répercutés sur les prix des produits dans les cas où la répercussion des coûts était significative.

Malgré ces incertitudes, les valeurs indicatives démontrent que la présence d'écarts entre les secteurs est fort possible au niveau des taux observés de répercussion du coût. Ces taux semblent être au plus bas dans le secteur du ciment et varier, généralement, entre 20 et 40% (sauf pour le ciment Portland en Pologne).
Ceci concorde avec les résultats précédents issus de la documentation identifiant une

[2] Des taux de confiance unilatéraux sont plus appropriés car nous testons si le coût de substitution de quotas obtenus gratuitement n'est pas répercuté sur les prix de produits. Comme cela n'a pas de sens de supposer qu'une valeur négative du coût de substitution soit répercutée sur le prix du produit, un taux de confiance unilatéral semble approprié.

répercussion du coût dans le secteur du ciment de 30% environ. Les taux indicatifs de répercussion du coût de l'industrie sidérurgique varient, en général, entre 55 et 85% (sauf pour les rouleaux laminés à chaud dans le Sud de l'Europe pour lesquels un taux de répercussion du coût plus élevé a été repéré). Ce résultat confirme également des estimations ex-ante antérieures présentes dans la documentation. Pour les raffineries, nous trouvons des indications de taux indicatifs de répercussion du coût plus élevés, variant de 80 à 100% pour l'essence et atteignant ou dépassant 100% pour le diesel et le gasoil. De tels taux indicatifs de répercussion du coût élevés ont également été constatés dans le secteur des engrais et des produits pétrochimiques, pour les produits dont les coefficients évalués étaient significatifs. Enfin, le secteur du verre présente des taux indicatifs de répercussion du coût quelque peu moins élevés situés entre 40 et 100%.

3. Analyses qualitatives et quantitatives supplémentaires quant aux facteurs potentiels expliquant le niveau de répercussion du coût du carbone

Pour mieux comprendre la formation des prix dans les secteurs respectifs, des interviews ont été menés avec la clientèle industrielle et des experts du marché concernant leur expérience en matière de formation des prix dans les industries en amont et leur point de vue sur les principaux déterminants des prix. L'échantillon différait en fonction du secteur ainsi que de la taille, du pouvoir de négociation et du portefeuille de produits de la clientèle industrielle en question. Les prix de l'énergie ont été perçus comme jouant un rôle majeur dans la formation des prix de produits. D'un autre côté, les coûts du transport, même s'ils sont considérables dans certains secteurs, semblent jouer un rôle dans la variation des prix uniquement si la capacité de transport devient rare ou coûteuse (comme en 2008, l'année ayant précédé la crise) ou si les marchandises sont difficiles à transporter dès le départ (verre fragile, par exemple, ou produits chimiques dangereux).

Outre ces interviews, la présente étude apporte plusieurs preuves quantitatives sur les facteurs potentiels qui influencent le processus de formation des prix et pourraient expliquer le niveau de répercussion du coût du carbone, comme les taux d'utilisation, la position sur le marché et l'intensité des échanges.

Dans certains secteurs, les taux d'utilisation peuvent constituer un moteur expliquant les différences en termes de répercussion du coût, les taux d'utilisation plus élevés étant généralement associés aux taux de répercussion du coût plus importants. Les taux d'utilisation les plus faibles figuraient dans le secteur du ciment (surcapacité importante), des taux un peu plus élevés dans le secteur sidérurgique et les taux les plus élevés dans le secteur des engrais où les installations fonctionnent à haute capacité. Cette étude présente des différences correspondantes en termes de niveau de répercussion du coût entre ces deux secteurs. Ce résultat confirme la documentation théorique sur ce sujet.

La position sur le marché, de l'UE au sein des marchés mondiaux et la concentration des positions au sein des marchés de l'UE semblent également constituer des variables importantes. Généralement, une concentration plus importante du marché semble s'associer à une plus grande capacité à répercuter les coûts. Cependant, le manque de données empiriques ne permet pas d'évaluer clairement cette relation.

Enfin, une faible coïncidence entre l'intensité des échanges et la répercussion du coût s'observe pour les paires de produits/pays examinées dans cette étude. Les produits pour lesquels aucune répercussion du coût - n'a été repérée ont tendance à présenter des intensités d'échanges plus élevées que les produits pour lesquels une répercussion du coût a pu être démontrée. Toutefois, ce lien n'est pas significatif statistiquement comparé aux groupes et il faudrait davantage d'études – particulièrement sur plus de produits – avant de tirer des conclusions sur la force relative du critère de l'intensité des échanges comme indicateur de la répercussion du coût. De plus, la capacité à répercuter les coûts n'est pas un indicateur direct de la présence ou pas d'un risque de fuite de carbone, car d'autres facteurs comme le maintien (ou pas) des parts de marché entrent également en jeu.

4. Discussion

Cette étude indique que dans la pratique, l'industrie répercute souvent une part considérable du coût d'opportunité de quotas obtenus gratuitement. Il est important de remarquer que la preuve de la répercussion du coût du carbone ne constitue pas un indicateur du risque de fuite du carbone. Si les producteurs marginaux ont répercuté le coût du carbone sur leurs prix de produits, l'industrie dans son intégralité a observé une augmentation du niveau des prix ce qui peut avoir eu des répercussions négatives sur la compétitivité internationale entraînant une perte de parts du marché sur les marchés nationaux et internationaux. Nous n'avons pas examiné de plus près dans quelle mesure la répercussion du coût a engendré une perte de parts de marché ou a affecté la rentabilité des sociétés. Ces questions peuvent faire peuvent être examinée de plus près à l'avenir. Nous remarquons, toutefois, que les preuves empiriques, à l'heure actuelle, ne font pas état de fuites de carbone pour les industries de l'UE.

Les résultats de cette étude concordent avec l'observation que la majorité des sociétés affirme – dans des enquêtes ou des déclarations publiques – ne pas répercuter le coût du carbone. Les mécanismes examinés dans cette étude peuvent impliquer que les sociétés ne sont pas nécessairement conscientes de répercuter le coût du carbone. Si seul le producteur marginal répercutait ses coûts du carbone, les prix du marché contiendraient les composants de coût du CO_2 auxquels tous les autres producteurs s'adapteraient sans savoir qu'ils répercutent (implicitement) le coût du carbone. Seuls les fixeurs de prix peuvent prendre une décision formelle de répercuter explicitement le coût du carbone. Les preneurs de prix répercutent « automatiquement » le coût du carbone implicitement sans jamais prendre de décision formelle quant au rôle du coût du carbone dans la formation des prix par le service de vente.

Enfin, les résultats montrent que l'économétrie peut constituer une méthode précieuse pour déterminer si les prix de produits contiennent ou pas des composants de coût du carbone pour les produits ayant un contenu de carbone relativement important. L'économétrie peut ainsi apporter des informations supplémentaires sur les études existantes qui ont examiné les sociétés participant au SEQE-UE. Il est toutefois plus difficile de connaître le montant exact des coûts répercutés sur les prix de produits (c'est-à-dire l'ampleur des taux de répercussion du coût -). L'analyse de la documentation a démontré que les résultats d'évaluation des taux de répercussion du coût dépendent - largement - des modèles et des données utilisées dans le processus. Par conséquent, il semble impossible de baser la décision d'inscrire ou pas un secteur ou un produit sur la liste de fuite de carbone uniquement sur une analyse économétrique. Par conséquent, les résultats d'études économétriques peuvent, pour l'instant, s'avérer surtout utiles pour déterminer la pertinence d'indicateurs évaluant approximativement la répercussion du coût. Outre l'intensité des échanges, cette étude a mis en évidence l'importance potentielle d'autres indicateurs comme les taux d'utilisation et la position sur le marché pour expliquer la répercussion du coût ; ces deux indicateurs méritent également d'être étudiés de plus près.

0 Content

1 Introduction

1.1 Background

Emission trading schemes, like the EU ETS, belong to the most efficient and effective policy options to achieve a given emission reduction target. In an emission trading system, each emission allowance gives the 'right' to emit one unit of pollution. By reducing the amount of allowances issued, the system can achieve emission reductions among its participants. By making the allowances tradable, the market assures that these reductions are achieved at the least possible cost for participants and society.

In theory, the efficiency of the system is achieved regardless of the initial allocation method. Allocation methods most often considered are auctioning and free allocation (the latter either based on historical emissions or on product specific benchmarks like in the EU ETS). Because free allocation has a smaller impact on the cost burden for companies, it is sometimes considered to be a better system in the context of unilateral climate policies. Through free allocation, the differences in (average) production costs between installations inside and outside the scope of the system would be minimised. Free allocation would therefore limit the distortive impacts of the EU ETS on the competitiveness of EU industries.

Distortive competitiveness impacts of unilateral climate policies have may result in 'carbon leakage'. Carbon leakage can be defined as the offsetting emission reductions within a certain jurisdiction by a growth of emissions outside this jurisdiction through relocation of economic activities because of climate costs. In any emission trading scheme with an absolute cap, a relocation of production to countries not covered by CO_2 targets implies an increase in global CO_2 emissions. Carbon leakage in the context of the EU ETS thus refers to the (potential) increase in carbon emissions outside the countries participating in the EU ETS because of a relocation of economic activities that fall under the EU ETS. In general, carbon leakage can occur through various channels, but the most debated channels in the political arena are the impacts on market shares and trade (short-term competitiveness issues) and the impacts on profits margins and medium-term relocation of investments. However, these short- and medium-term impacts are largely intertwined. If companies in the EU would lose market shares because of climate-oriented policies, also their investments can be expected to be negatively affected.

The possibility to pass through the carbon costs into product prices is an important element in the discussion about carbon leakage and allocation methods. The ETS Directive states that any analysis of whether sectors or subsectors are likely to be subject to a risk of carbon leakage should be 'based on an assessment of the inability of industries to pass on the cost of required allowances in product prices without significant loss of market share to installations outside the Community which do not take comparable action to reduce their emissions.'

However, the precise impacts of cost pass-through on carbon leakage are subject to debate. On the one hand, there is the popular belief that the inability to pass through carbon costs would justify free allocation. Empirical evidence (Sijm et al., 2005 and 2006) has shown that electricity producers had passed through the opportunity value of their freely obtained allowances into the electricity prices in the first two trading periods of the ETS, which has resulted in windfall profits. The general belief was that electricity producers were capable of doing this because they do not face severe competition from non-ETS countries because of the limited interconnection capacity between EU and non-EU countries. Therefore, electricity producers could pass through the costs without a loss in market share - an important reason why electricity producers have been placed under an auctioning regime since the start of Phase 3.

On the other hand, however, it could be the case that cost pass-through is more related to pricing strategies at the firm level rather than foreign competition. According to economic theory, companies are profit-maximising institutions that prefer profitability on invested capital over maintaining market shares. If passing through the opportunity costs into product prices can enhance their profitability, they will do so even if this would bring them some harm in terms of loss in market shares, as long as the additional profits outweigh the additional costs. This means they would have an impetus to pass through their costs independent of whether allowances were allocated for free or auctioned. To what extent firms are able to pass through costs depends on a range of factors, including market structure and the elasticity of demand and supply.

A few recent empirical studies have indeed indicated that not only electricity producers but also energy intensive industries have passed through the opportunity costs of their freely obtained allowances into the product prices. However, these studies have shown a wide variety in methodological approaches, data used and results. The studies are also heavily contested by industry. As stated in the Impact Assessment of the 2030 framework (EC, 2014), energy intensive industries argue that cost pass-through does not occur in their industries by arguing that the stylised world of economic science assumed in the studies does not represent their day-to-day business operations. In their view it is more rational for firms in the medium to long run to pursue a strategy of maximising market share rather than profits.

In light of this debate it is important to gather more information on cost pass-through and determine to what extent this has played a role in the EU ETS and what factors determine the occurrence and extent of potential pass-through of carbon costs. This is not only important to better understand carbon leakage and the competitive position of energy intensive industries, but also for the evaluation of the competitive position of so-called client industries. Client industries are industries buying products from the energy intensive industries that also compete on international markets. If energy intensive industries would raise their prices, client industries would potentially have a cost increase and associated loss in competitive position compared to non-EU producers Therefore, the whole cost distribution of the EU ETS matters not only for the competitive position of the energy intensive industries, but also for wider range of industrial products and services – although it has to be noted that the total impact for client industries would be lower due to the higher value of products in these industries.

1.2 Objectives and study framework

The objective of the present study is to determine the extent to which ETS-related carbon costs are or can be passed through in the pricing of products produced by the energy intensive industries in the EU ETS and provide insights into and explanations of the factors that may have influenced the occurrence and extent of cost pass-through.

The study uses the following framework:

- The study is conducted using both a literature review and an empirical analysis using econometric methods;
- The literature review has been undertaken to include literature published up until June 2015;

- The empirical estimation is conducted for six sectors (defined at NACE Rev. 2 4-digit level) representing a substantial share of industrial emissions in the EU ETS;
- For each sector 2-3 products are chosen and situations in 2-3 countries investigated;
- In a final step, additional qualitative and quantitative analysis into potential factors explaining the ability or inability to pass through carbon costs is carried out.

1.3 Empirical analysis for six sectors

The empirical analysis in this study is conducted for a number of products in six sectors, which were chosen beforehand. The selection of sectors was based on three considerations:

A. Share of overall ETS emissions. The sectors chosen should represent a considerable amount of emissions in the EU ETS. The distribution of emissions over sectors is rather skewed; with the ten most carbon intensive sectors emitting more than 80% of industrial CO_2 emissions. It was decided that the sectors should at least be chosen from the top-12 industrial sectors with respect to emissions.
B. A reasonable share of carbon costs in production. Low carbon costs may hamper the econometric analysis as it would test whether the carbon costs (as a percentage of the product price) is significantly different from zero. Cost pass-through of carbon costs representing only a small share of the final product price are therefore more difficult to discern than cost pass-through of substantial carbon cost shares. Given the fact that the carbon price has been low, it is important to select sectors with relatively high carbon emissions per unit of sold output.
C. Data availability. There should be ample data available (either through public services such as Eurostat or obtained through data warehouses such as ICIS, Platts and Argus) for the sectors chosen, thus allowing for sufficient product or country combinations.

Table 3 gives the average emissions for twelve NACE 4-digit sectors and presents a very rough indicator of the expected cost share of CO_2 emissions by comparing the direct costs over value added used for the determination of the carbon leakage list 2015-2019. From Table 3 it was concluded that iron and steel, refineries, cement and organic basic chemicals should be included because of their share in ETS emissions. Together, these sectors make up for almost 68% of industrial ETS emissions. On the basis of cost shares it was furthermore decided to exclude paper because of the low direct cost share.[3] Fertiliser was included because of the high cost share and substantial emissions. As a sixth sector the entire glass sector was included (including both hollow glass, flat glass and glass fibres). Together this sector is important both regarding its ETS emissions and its carbon costs. This effectively implied that the data

3 The share of direct CO_2 costs to production costs was estimated to be below 1% in the paper sector. The relatively high share of electricity costs in paper production would represent another challenge in the econometric estimation as carbon costs have been passed through in power prices (Sijm et al., 2005, 2006).

collection of the glass sector took place at the NACE 3-digit level (231). Therefore the final list of sectors that were chosen was as follows:

- iron and steel (NACE 2410);
- refineries (NACE 1920);
- cement (NACE 2351);
- organic basic chemicals (NACE 2014);
- fertiliser (NACE 2015);
- glass (NACE 231).

In total these sectors make up almost three-quarters of the industrial ETS emissions.

Table 3 Share of emissions (average 2008-14) of sectors and their costs relative to value added

NACE	Name	Share emissions in industrial ETS*	Direct costs/GVA**	Total costs/GVA**
24.10	Iron and steel	22.5%	17.1%	22.2%
19.20	Refineries	19.7%	16.4%	17.9%
23.51	Cement	18.1%	42.0%	46.7%
20.14	Organic basic chemicals	7.5%	8.3%	10.4%
17.12	Paper	3.9%	4.3%	11.5%
20.15	Fertiliser	2.6%	29.4%	31.8%
23.13	Hollow glass	1.5%	4.8%	8.3%
10.81	Sugar	1.2%	5.9%	6.1%
20.13	Inorganic basic chemicals	1.1%	3.4%	7.7%
24.42	Aluminium	1.0%	4.5%	12.0%
23.32	Bricks, tiles	1.0%	9.5%	11.4%
19.10	Cokes	0.9%	33.3%	33.9%
23.11	Flat glass	0.9%	8.2%	10.0%

* Own calculations based on EUTL.

** Information taken from the tables presented as "Results of carbon leakage assessments for 2015-19 list (based on NACE Rev.2) as sent to the Climate Change Committee on 5 May 2014" and calculated with a hypothetical EUA price of € 30/tCO_2.

1.4 Content and concepts

1.4.1 Content of this report

Chapter 2 of this report contains an overview of the existing literature on cost pass-through (in theory and empirical estimation) and summarises the cost pass-through rates estimated in the literature. Chapter 3 is a methodological chapter that identifies the challenges when estimating cost pass-through in econometric work. Models and estimation routines are reviewed and formulated, as well as the data collection process described and potential issues regarding the collected data discussed. Following on from these theoretical foundations, Chapter 4 presents results from our own empirical work and gives extensive additional explanations and material for the sectors refineries, cement, iron and steel, fertiliser, petrochemicals and glass. The findings from our own econometric estimation will be compared with the literature and with interviews held with market analysts and client industry experts in order to investigate potential factors that could explain the found cost pass-through rates. Chapter 5 compares the findings from the sectors and investigates to what extent a cross-sectoral view would yield additional information on the potential to pass through the costs and important drivers. Chapter 6 sums up and concludes.

1.4.2 Two important cost concepts

While we do not want to give an extensive account of all concepts that are being used in this report, a few concepts are important to discuss at this stage since they will be repeated in specific parts of this report without further explanation.

Expenditures versus opportunity costs

One important misunderstanding in the cost pass-through debate relates to the difficulty to understand the difference between expenditures and opportunity costs. Expenditures are what the firm pays to obtain the possession over a resource. For example, if a firm buys natural gas through a year-ahead contract, the expenditure is equivalent to the cost of buying the natural gas as specified in the contract. Now suppose that natural gas prices increased substantially over the year and that at the moment of delivery the firm does not need the natural gas.

It will then not sell the gas at the price of the expenditure, but rather at the value of the natural gas at the market at that particular moment. This value is called 'the opportunity costs'. Opportunity costs are thus not related to what a resource has cost, but rather to the value of the resource.

This difference plays an important role in the context of freely obtained allowances. These allowances have zero expenditure costs but could be sold at the market at the carbon price at that moment. Therefore, they do have positive opportunity costs. The implications of this difference will be discussed from a theoretical perspective in Chapter 2.

Average versus marginal costs

Much of the confusion in the literature about carbon leakage and cost pass-through can be attributed to the difference in the perception of average versus marginal costs. Average costs are represented by the total costs divided by the number of units of production. Average labour costs for a firm are, for example, the sum of paid salaries and hired labour (services) divided by the number of product units sold.

Marginal costs, on the other hand, are the additional costs of producing one additional unit. If a firm expands its production, this can firstly be done using the existing amount of capital. The marginal costs are then equivalent to the variable costs. However, if capital is fully utilised, new investments must be made in machinery and buildings and marginal costs sharply increase. According to economic theory marginal costs determine, in the end, the supply curve of a firm. A firm will expand production up to the point that the marginal costs equal the market price. Therefore, in conventional economics, the market price is equivalent to the marginal costs.

2 Literature review on cost pass-through

2.1 Introduction

In this chapter we aim to give an account of the academic and other literature on the hypothesis of passing through carbon costs. The literature can conveniently be classified into theoretical studies, ex-ante empirical studies using specific models and ex-post empirical studies using econometrics and other statistical techniques. In this chapter we will categorise and review the literature. We consider studies on cost pass-through of EU based energy intensive industries, as well as comparative studies. The literature review provides background information in a systematic manner by presenting the main focus, sector and country coverage, data used, methodological set-up as well as main results of each study.

First, in Section 2.2 we will categorise the literature and define concepts. In Section 2.3 we will investigate the theoretical literature. Following on from these theoretical foundations, Section 2.4 will review ex-ante modelling studies, whilst Section 2.5 presents ex-post empirical work. Section 2.6 summarises the range of cost pass-through rates estimated in the literature and concludes.

2.2 Categorisation of literature

The literature review in this chapter is focussed on cost pass-through under the EU ETS, with a special emphasis on cost pass-through in industrial sectors. The existing literature can be categorised into three main areas:

1. Theoretical studies on cost pass-through;
2. Ex-ante empirical studies on cost pass-through;
3. Ex-post empirical studies on cost pass-through.

Most of these studies deal with estimating the cost pass-through rate. The cost pass-through rate can generally be described as the change in output price in response to a change in input costs. In the literature it often serves as a means to assess competitiveness effects and potential output or carbon leakage. Cost pass-through influences two main elements of competitiveness: profit margins and market shares (Reinaud, 2008).

The **theoretical studies** often deal with the conditions under which firms can pass-through their costs and the impact of a change in these conditions on the cost pass-through rates. In Section 2.3 we elaborate on cost pass-through from a theoretical perspective.

Empirical assessments for cost pass-through have been attempted from different angles:

- ex-ante research, which employs calibrated partial or general equilibrium models to simulate the impact of hypothetical carbon pricing;
- ex-post studies, which use econometrics and other tools, including industry surveys, to assess historical cost pass-through.

Ex-ante modelling studies aim to assess the future effect of unilateral climate policies and mostly have the advantage to account for (global) economic interaction (in case of whole economy models) or include detailed technology choices to meet a given demand (partial models). Unless they are macro-econometric models they require data for one base year only and are based on a number of specific assumptions relating to producer and consumer behaviour (supply and demand elasticities) and production technologies (input substitution, technological progress) which in themselves influence the outcome of the modelling exercise. In Section 2.4 we will elaborate in more detail on the ex-ante cost pass-through studies.

In contrast, ex-post studies have the benefit of using historical data to assess real-world phenomena. Ex-post studies would either require an econometric approach to reveal the cost pass-through ratio based on collected data or use surveys. Both of these methods have their pros and cons. Econometric approaches tend to be precise but require a sufficiently large set of either time series or cross-sectional data and a careful specification of the model equations. Moreover, econometric analysis is oriented on hypothesis testing which may limit interpretations. Most of the econometric analysis is based on testing the null hypothesis of no cost pass-through. If this hypothesis is rejected, it is clear that there is evidence of cost pass-through. However, if this hypothesis is not rejected it does not represent direct evidence that the costs are not passed through, as it may also be the case that with the given data and model one is unable to fully examine the issue.

The alternative would be applying qualitative methods such as surveys and interviews. These are capable of capturing key trends or developments that are often more difficult to obtain via the use of simplified indicators. However, depending upon the research question, the advantage of qualitative approaches can also be a limitation as it is difficult to make assumptions beyond the opinions captured for a specific group of participants. Moreover, strategic behaviour in responding and adverse selection is among the two most important problems that plague studies based on surveys.
In Section 2.5 we elaborate in more detail the ex-post cost pass-through studies.

2.3 Theoretical perspectives on cost pass-through

2.3.1 Cost pass-through as a concept in economic theory

Cost pass-through of unilateral policy costs is essentially described in the economic literature as literature on ‘tax incidence’. This literature in essence investigates who, in the end, bears the cost of taxation. The key finding in this literature is that the tax burden does not depend on where the revenue is collected, but rather on the price elasticity of demand and supply, along with the market structure in place. The question who bears the cost of taxation therefore crucially depends on the extent to which the firm can pass-through these costs to others (e.g. to end consumers, but also to industry by the suppliers of labour, capital, energy and materials).

This theory has been applied by, for example, Sijm and Chen (2009) in their treatment of sheltered theoretical cost pass-through of companies operating in the EU ETS and Smale et al. (2006) and CE Delft (2010b) for companies facing international competition. These analyses show that the extent to which carbon costs can be passed through depends mainly on four factors:

- The elasticity of demand in the EU market. The more inelastic demand, the larger the share of cost pass-through. This is intuitively logical. If consumers do not react to price increases by reducing their demand, opportunities for cost pass-through are increased.
- The marginal costs of supply of EU manufacturers. The more elastic the supply curve is, the more costs are passed through. If the marginal costs of supply are constant with respect to output (perfectly elastic supply curve such as in

perfect competition), the shape of the demand curve solely determines the extent to which costs can be passed through. However, if marginal costs are dependent on production output, and if demand is elastic, lower production levels will lower marginal costs. Since price equals marginal costs in perfect competition, the final price increase is also lower and hence limiting the cost pass-through.

- The marginal costs price differences between EU and non-EU manufacturers and the shape of the supply curve of non-EU manufacturers exporting to the EU market. If due to the EU ETS, marginal costs of non-EU manufacturers are lower than those of the EU manufacturers, and if their marginal cost curve is perfectly elastic, they will increase their exports which will lower the price increase in the EU market and therefore limit the ability of EU manufacturers to pass through costs. It is important to realise that not only the marginal cost price differential matters but also the shape of the marginal cost curve of non-EU producers. If non-EU manufacturers would already run at full capacity and face high marginal costs when increasing their output, they will not be able to expand their production. The extent to which EU production can be substituted by non-EU production is quantified using so-called Armington elasticities (Armington, 1969). Reinaud (2008) argues that it is also dependent on transport costs and market tightness of non-EU manufacturers. If foreign production capacity is tight domestic cost pass-through might be possible without affecting the market share of European producers.
- The number of firms operating in a given market (EU and non-EU). The more firms operate in a market (and the more competitive the market is), the higher the cost pass-through. This finding is at first sight counterintuitive. However, it can be explained by the fact that under a monopoly prices would never equal marginal costs because the monopolist can maximise their profits by limiting output. The additional cost price increase at the margin due to an ETS is thus partly absorbed by the monopolist themselves. Sijm and Chen (2009) show that the cost pass-through of the monopolist could be about half of that of a firm under perfect competition but would typically depend on the underlying cost structure of the monopolist. For oligopolies, cost pass-through rates would lie somewhere between a competitive and a monopolistic market and ultimately depend on the type of price setting and competition in the market (see e.g. Smale et al., 2006).

The extent to which carbon costs can be passed through is defined by Sijm and Chen (2009) as the cost pass-through rate: the increase in the final price of the product divided by the additional (opportunity) carbon costs in production. Using linear demand and supply curves (as in standard economics), cost pass-through rates can vary between 0 to 100%, depending on the influence of the above variables.
With non-linear demand functions (e.g. iso-elastic demand), cost pass-through rates can also be higher than 100%. The same applies to the supply curve due to merit-order effects. If due to the EU ETS a different firm than before becomes the firm with the highest marginal costs (which sets the price in a given market), the *average* cost pass-through rate observed on the market may be well above 100%.

This standard economic theory is important in the debate about cost pass-through because it relates the ability to pass through carbon costs to additional factors, rather than the popular ‘foreign competition’ argument alone. It shows that cost pass-through can be expected even if allowances are issued for free. The extent to which costs can be passed through depends on the shape of the domestic demand and supply curve, the shape of foreign supply curves and the market structure.

It also shows that cost pass-through is expected to be higher in perfectly competitive markets than in monopolistic markets. Moreover, it shows that not the average cost price differences between EU and non-EU manufacturers matter for cost pass-through, but rather the marginal cost price differences along with the shape of the foreign supply curve. These are important observations to be applied in the present study, which also have implications for political debates on the subject.

2.3.2 Pricing strategies at the company level

The economic theory on cost pass-through as outlined above has been incorporated by the economic models that have been employed to analyse the impacts of EU climate policies (e.g. GEM-E3, E3MLab). In such models costs are in general assumed to be passed though dependent on the elasticities of demand and supply and the Armington elasticities. However, as stated in the Impact Assessment of the 2030 framework (EC, 2014), energy intensive industries argue that cost pass-through does not occur in their industries. They assert that the stylised world of economic science does not represent their day-to-day business operations. In their view it is more rational for firms to pursue a strategy of maximising market share rather than profits. This would limit the possibilities of cost pass-through.

According to economic theory, firms aim to maximise profits – or more precisely, to maximise the sum of present and future returns on their investments. It is hardly disputed that international investors seek to maximise the return on their investments. Most energy intensive industrial firms operating in the EU ETS are privately owned. However, Smale et al. (2006) rightly state that managers may have a different interest than investors. Their study cites US-based research indicating that the salary of managers is influenced by sales rather than by profits. If a firm would be capable of price manipulation because it would operate in oligopolistic or monopolistic environments, sales maximisation is therefore not an unreliable assumption. But this is completely congruent with the standard economic theory, as identified in Section 2.3.1. The question is therefore: do firms in the EU ETS operate in oligopolistic market structures so that they could pursue a strategy of maximising sales?

In CE Delft (2010b) it is investigated under which conditions oligopolistic firms would not pass-through the carbon costs in product prices. The study lists three conditions that are crucial for carbon costs not to be passed through into final product prices (see Section 1.4.2 for an explanation of terms):

1. Firms would base their pricing on the expenditures for allowances rather than the opportunity costs of allowances.
2. Firms would engage in average cost pricing rather than marginal cost pricing.
3. Firms are price takers instead of price setters.

Only in the case that firms would base their pricing on expenditures instead of (opportunity) costs, if firms would be engaged in average cost pricing and firms are price setters, it can be expected that firms do not pass through the value of allowances in the product prices. All of these three conditions must be met so that the price of products does not contain carbon costs. It is clear that this will rarely be the case. But these conditions also explain *why* companies claim that they do not pass through the carbon costs: within any sector one of these conditions are violated for one or more companies. This will be investigated in more detail below.

Expenditures versus opportunity costs

If firms would base their pricing strategies on expenditures rather than opportunity costs, they could decide not to pass-through the freely obtained allowances into product prices. According to economic theory, however, firm decisions are based on opportunity costs. Every business entrepreneur must make a decision how to make the most money from the assets that are available. Investors, governors and creditors prefer to know the market values of a firm's assets - rather than their historical expenditures - because the current values give them better information to make decisions. In fact, a company that is not taking into account opportunity costs in decision making may be outcompeted on costs by firms that have an opportunity cost focus.[4]

In a survey-research, Warwick & Ng (2012) conclude that practices with respect to valuation of freely obtained allowances vary among EU firms. Firms participating in the EU ETS do not have definitive guidelines as to how to account for carbon emission allowances. In the absence of authoritative accounting guidance, freely obtained allowances are accounted for as intangible assets, inventory, whilst in a third of the firms the accounting method is not disclosed. More importantly, about 40% of firms value the freely granted allowances at nil value, while a quarter of firms did not disclose a method of valuation. Purchased allowances, on the other hand, are recorded at market value by the majority of firms.

This shows that opportunity cost pricing, at least at the level of financial accounts, is not a generalised rule for EU business. However, it should be noted that if a few firms engaged in opportunity cost pricing, and if these firms were price setters, the price of products would still include the opportunity costs of freely obtained allowances (see also below). Therefore, the mere knowledge that some firms do not value freely obtained allowances as opportunity assets is not relevant for the final price formation.

Average versus marginal costs

The research by Warwick & NG (2012) revealed another important element in this context: firms seem to value the purchase of carbon allowances in their cost structure. This is important because it shows that carbon prices matter for business. If firms would base the pricing of their products on marginal costs, product prices would still contain carbon cost components.

The question if firms are engaged in marginal or average cost pricing is difficult to discern. Surveys in general show that managers do not very well understand the concept of *marginal* costs (Smale et al., 2006). Managers tend to believe they are engaged in average cost pricing since they understand the concept much more intuitively than marginal costs. Smale et al. indicate that further research is needed, but that it appears that both marginal and average cost pricing strategies exist among firms.

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4 However, in the context of the EU ETS, the situation may be slightly more complex because firms do not really 'own' the freely obtained allowances since closure rules in the EU ETS impede the valuation of the freely obtained allowances as assets on which banks can grant loans. If the firm would go bankrupt, banks cannot materialise the future stream of freely obtained allowances since they will not be distributed to the owners of the firm's debts.

If all firms are engaged in average cost pricing, the price of products will be influenced by average costs. But if some firms are engaged in marginal cost pricing, the market price of products may still reflect marginal cost components. Again, the majority is not important in this context, but rather what happens at the margin.

Intentional versus unintentional cost pass-through

In a previous study, CE Delft (2010b) has analysed the argument that firms do not pass through carbon costs and concluded that in many markets, companies may indeed not intentionally pass through carbon costs. Companies are rarely price setters and often price takers. Companies would not want to fix a price by giving a mark-up on their costs, but investigate what price they can ask in a given market. Therefore there is indeed not a strategy to deliberately pass through CO_2 costs. However, if the process of price formation on a market would include CO_2 costs components, each company would gain additional profits from the EU ETS even though the CO_2 costs were never intentionally passed through.

For relatively homogenous products, the process of price formation is such that there is one marginal producer that 'sets' the price. The marginal producer is the producer that sells the product against a price that is barely covering their costs, i.e. not making a (substantial) profit. Other producers, who operate at lower costs, are also selling their products at these prices while making a profit. Therefore, the decision about cost pass-through is - in the end - a decision of a producer becoming the marginal producer because they include carbon costs in their pricing strategy. Other producers will then follow as they can get a better price for their products, without *knowing* that their prices now contain carbon costs. Therefore, the question is not whether industry on average passes through carbon costs, but whether the marginal producer in the EU ETS passes through carbon costs.

As identified above, there may be two reasons why this marginal producer would pass-through carbon costs. First, the marginal producer may be allocated allowances in excess of their emissions but may regard the allowances as an asset which could be sold if not used. In this case, the producer would put forward the opportunity costs of freely obtained allowances in their prices. Second, the producer may be short of allowances and in that case forced to include CO_2 costs in the price of their products in order to cover costs if they are engaged in marginal cost pricing.[5]

In both cases, the market price would contain CO_2 cost components to which all other producers (the price takers) adhere. So while it can be perfectly true that the vast majority of companies does not pass through carbon costs into product prices, they still would gain an additional profit from higher product prices. Therefore, the discussion about cost pass-through should not be devoted to the question of whether or not companies deliberately pass through opportunity costs of freely obtained allowances in order to reap windfall profits, but to what extent product prices contain CO_2 cost components.

5 One should note in this respect that many more companies are short of allowances in Phase 3 of the ETS due to the existence of benchmarks and the cross-sectoral correction factor than was the case in the first to phases. Furthermore, since the marginal producer in a given market is likely to be less efficient than their competitors, they are therefore more likely to be short on allowances.

2.3.3 Impacts of cost pass-through on carbon leakage

Cost pass-through is also an important element in the context of carbon leakage since the question whether costs are passed through into product prices determines the direction of carbon leakage. In order to sketch this, we would hypothesise that firms would have real, tangible costs related to unilateral climate policies. Firms now have two choices: either to pass through these costs to consumers and maintain profitability whilst potentially losing market shares; or not to pass through these costs and maintain market shares whilst losing profitability.

If costs are not passed through, firms need to bear the additional costs and their profits will potentially fall affecting investment decisions and competitiveness in the longer term. If, in turn, costs are passed through and result in higher product prices, this may affect production and competitiveness (market shares) as follows:

1. Domestic demand may be lost as consumers may decide to buy alternative and less expensive domestic substitutes or imported products (only the latter effect is associated with carbon leakage).
2. Export shares may be lost to countries that are not subject to comparable policies (Graichen et al., 2008).

Therefore, the decision of whether or not to pass through costs is highly related to carbon leakage. If costs are passed through there is potential leakage through the trade channel, and if costs are not passed through there is potential leakage through the investment channel.

The arguments do not change fundamentally if we would take into account cost pass-through of freely obtained allowances. If the opportunity costs were passed through, shareholder value of companies may be increased which, potentially, could attract investments or prevent the closure of facilities in challenging times for business, e.g. because of stagnating demand in the European Union. However, this may come at the expense of a loss in market shares. If costs are not passed through, market shares would be maintained but profitability of EU industries would not be stimulated.

2.3.4 Additional drivers of cost pass-through

The standard economic model described above identifies four factors that determine whether companies pass through costs:

1. Market structure, in particular whether firms operate in a competitive, oligopolistic or monopolistic environment.
2. The elasticity of demand within the EU.
3. Marginal costs of domestic supply.
4. Marginal costs of foreign supply.

These stylised factors have proven difficult to estimate in empirical work and have therefore been approximated by a range of measurable drivers, which are linked to these stylised factors. Reinaud (2008), CE Delft (2010b) and Varma et al. (2012) investigate some of these factors influencing whether, and to which extent, costs may be passed-through:

- Capacity utilisation rates (CE Delft, 2010b). If capacity is fully utilised, full cost pass-through is more likely. Full capacity is for most sectors capacity that is near the 90-95%. In that case cost pass-through is more likely since a firm's marginal costs of additional production increase steeply. It is also conceivable that price increases are not immediately passed through to the customers, but price decreases of inputs are then used as a balancing mechanism (Conforti, 2004).
- Exposure to international trade may also influence the ability of a firm to pass through additional CO_2 costs (Varma et al., 2012). For example, if the exposure of a firm to international trade is low, higher product prices due to passing through additional costs may not impact the competitiveness of the firm. However, the trade exposure might actually differ within the EU, as for production located in the centre of the EU demand might exclusively be within the EU while for production located at the periphery competition with less expensive production units outside the EU is much stronger.
- Market power, both of the EU in global markets and the concentration of power within EU markets. Generally, a higher market concentration can be expected to be associated with a higher ability to pass through costs.
- Product differentiation (Reinaud, 2008). It has been argued that industries operating in highly differentiated markets may have more possibilities to pass through carbon costs. If products are homogenous, then demand will react highly sensitive to any change in price whereas in the case of specialty products, higher prices may not divert demand.
- Border and domestic policies. Trade policies such as import tariffs and quotas affect spatial price transmission directly but also domestic policies affecting price formation such as taxes and subsidies may have an influence on the process of market integration.

2.4 Overview of ex-ante empirical studies for the EU ETS

The majority of ex-ante studies on cost pass-through in the context of the EU ETS tend to focus on the economic effects of unilateral climate policy, in particular on impacts on regulated industrial sectors (e.g. iron and steel, cement and aluminium). Ex-ante top-down modelling analyses were used as part of the Impact Assessment for the Energy and Climate Package (2008) in order to assess effects on GDP, value added, employment, economic structure and trade in response to a more stringent cap on ETS emissions. Bottom-up modelling was used to derive industry specific results on the future energy mix, technology choice and sectoral production.

Modelling exercises are also devoted to assessing the risk of output or carbon leakage with the estimates showing a substantial range depending upon the modelling approach adopted, the underlying assumptions applied (i.e. with respect to trade elasticities or future carbon prices) and the specific design of the policy scenario (e.g. emission reduction target, inclusion of preventative measures). Examples include Kuik and Hofkes (2010); Carbon Trust (2010); Ponssard and Walker (2008); Demailly and Quirion (2006); Demailly and Quirion (2008); Summerton et al. (2010).

2.4.1 Summary of main ex-ante studies

Not many ex-ante studies have been devoted to explicitly assessing cost pass-through rates in response to unilateral carbon pricing. Most studies look into competitiveness and subsequent potential carbon leakage and only indirectly touch the issue of cost pass-through by either assuming specific pass-through rates or taking assumptions on elasticities of demand, supply and trade and on market structure. Most recently, Vivid Economics (2014), however, provided an estimation of cost pass-through rates based upon an ex-ante analysis using a bottom-up partial equilibrium modelling approach.

Ex-ante studies outside the EU tend to develop scenarios for climate policies and their impact on specific sectors, such as Bassi and Yudken (2009) for the chemicals sector in the US or Morgenstern et al. (2007) for the manufacturing sector in the US.

To keep the focus of this literature review explicitly on cost pass-through rates we only highlight the approaches and results from those ex-ante studies that provide explicit estimates of cost pass-through although we are aware that the literature on carbon leakage rates is closely linked. There are two studies that have provided empirical estimates of cost pass-through rates among a variety of sectors: McKinsey (2006) and Vivid Economics (2014). In addition, Smale et al. (2006) have estimated ex-ante cost pass-through rates for the iron and steel sector.

2.4.2 Estimated cost pass-through rates in ex-ante studies

An initial assessment of cost pass-through rates was provided by McKinsey (2006) in a study that was meant to provide input for the design of Phase 2 of the EU ETS.
In McKinsey (2006) a change of the international competitiveness is taken as a change in operating margin approximated by the percentage cost increases of end products. Assuming a competitive power market with full pass-through of CO_2 costs into electricity prices and assuming that 95% of the required allowances are grandfathered, McKinsey investigate to what extent the additional carbon costs could be passed through into product prices. Without providing full information about their estimation strategy and how they arrived at their conclusions, they present a range of cost pass-through rates for a number of sectors as indicated below.

Steel:

- BOF: 6% of the additional cost can be passed through to customers;
- EAF: 66% of the additional cost can be passed through to customers.

Pulp & paper production:

- 50% of the additional cost can be passed through to customers in chemical pulping;
- 0 to 20% for paper from integrated processes can be passed-through to customers.

Cement from dry process:

- 0 to 15% of the additional cost can be passed through to customers.

Refining:

- 25 to 75% of the additional cost can be passed through to customers.

Aluminium:

- 0% of the additional cost can be passed through to customers.

Independently of the McKinsey study, Smale et al. (2006) provide estimates of cost pass-through among a number of EU and UK industries. Their paper, however, does not list the extent to which costs have been passed through except for the steel sector where they explicitly stated that the cost pass-through was estimated to be 65% at the EU level. The Smale et al. (2006) study is based on the economic framework depicted in Section 2.3.1, defining demand and supply functions in order to estimate the extent of costs pass-through.

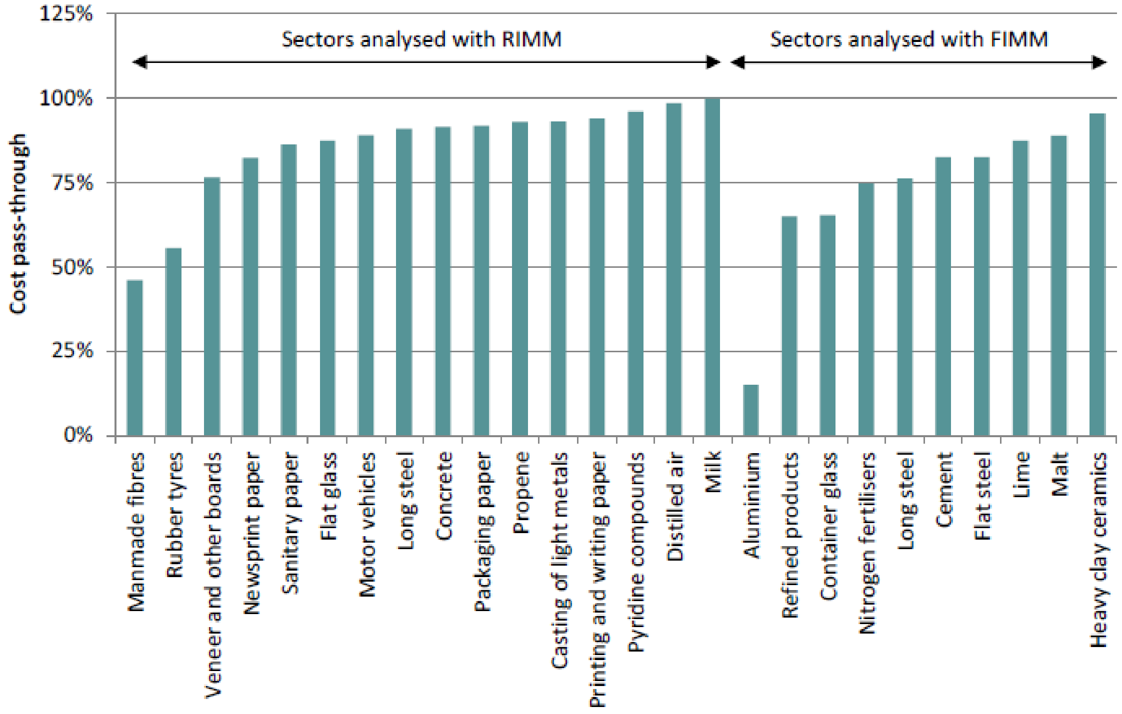
A more recent and more comprehensive study estimating cost pass-through, output and production leakage rates has been conducted by Vivid Economics (2014) based upon an ex-ante analysis using bottom-up models. They analyse 24 sectors (ten of which in detail) and specifically model cost pass-through as a function of the inside market share (that is, market share of firms affected by the cost change). They further introduce an indicator for market structure ('inverse competitiveness') which yields higher cost pass-through as the market becomes perfectly competitive and which reduces pass-through as the market becomes first oligopolistic and then collusive. They conclude that cost pass-through rates vary significantly by sector. Specifically, 'the rate of cost pass-through is one if there are no outside firms and the market is perfectly competitive. As inside firms are introduced, the cost pass-through rate falls. If margins are high for the number of firms present, the cost pass-through rate falls further. Less than perfect competition occurs in most markets, and may reflect a concentration of ownership of firms (many firms having the same owner, that is, being associated firms), product differentiation, or a small number of firms' (Vivid Economics, 2014).

In particular, they find that the aluminium sector is associated with low levels of cost pass-through (absorbing more than 80% of the cost increase) due to the fact that the commodity is:

1. Traded on a global market.
2. Has a very low weight to value ratio.
3. There is sufficient global capacity.

In contrast, the malt sector is identified as being able to fully pass-through their carbon costs as a consequence of the absence of non-EU competition. As shown in Figure 1, the majority of the other sectors considered in the study were estimated to have cost pass-through rates above 75%. However it is noted within the study that high cost pass-through rates do not necessarily prevent firms from experiencing cost shocks that impact upon their competitiveness. In addition, simplified assumptions within the modelling (i.e. all firms treated the same regardless of geographical location) means that in reality cost pass-through rates may be lower for firms located on the coast or nearer to non-EU borders. The authors stress that their results represent upper bound estimates.

Figure 1 Cost pass-through rates derived by Vivid Economics (2014) in sectors investigated in reduced and full detail (2020, € 15/tCO_2)



Source: Vivid Economics

Note: RIMM refers to their Reduced Industrial Market Model while FIMM refers to their Full Industrial Market Model.

2.4.3 Drivers of cost pass-through

Several studies have investigated potential drivers of cost pass-through (e.g. Reinaud 2005, 2008; OECD, 2015) without providing direct estimations on the cost pass-through rates.

The literature also shows that actual cost pass-through rates – even within sectors - may greatly vary from product to product and country to country. Based on the literature review it can be concluded that the following factors are considered important drivers of the extent of cost pass-through:

- Market conditions, such as the amount of competition in the markets, trade intensities of the sectors that operate in these markets, price differentials in input costs between EU and non-EU companies (e.g. energy costs) and/or price differentials in output prices.
- Demand elasticities, referring to the degree to which supply or demand of a product responds to a change in price. If the demand elasticity of a product is zero (i.e. rigid demand) then additional CO_2 costs can be passed through with no risk of a firm losing market share.
- Exposure to international trade also influences the ability of a firm to pass through additional CO_2 costs.

- Product characteristics, such as transport costs or transportability of these products.
- Capacity utilisation rates, e.g. expressed as utilisation rates (actual production over maximum production).

2.5 Overview of ex-post empirical studies for the EU ETS

Given the relatively short time period that the EU ETS has been in operation, the amount of empirical data remains limited but is growing and recently published articles have attempted to verify the findings of ex-ante modelling. Based upon different sources of empirical data (i.e. trade data, employment data, qualitative data) and different ex-post analysis techniques (i.e. econometric analysis, surveys) several authors have assessed the impact of the EU ETS on various aspects of competitiveness (i.e. trade, employment, innovation) and leakage, also considering cost pass-through. The following sections provide a summary of the main studies, including a presentation of their results and a detailed discussion of the data and method applied for deriving the results. The data and method section is particularly important in the context of the current study as it provides relevant information for subsequent sections.

As the focus of our study is on cost pass-through in industrial sectors and subsectors, the following overview focusses primarily on studies devoted to these sectors.
The vast share of the literature on cost pass-through, however, is devoted to the electricity sector. However, an analysis of cost pass-through for the electricity sector differs substantially from other industrial sectors, e.g. in terms of trade exposure, input structure (inputs are mainly limited to energy resources), data availability (data on prices for energy inputs are easily accessible). Thus, the learning experience from taking a deeper look at studies on the electricity sector for our exercise would be small.

2.5.1 Summary of main ex-post studies

Based upon empirical data from the first two phases of the EU ETS attempts have been made in the literature (Alexeeva-Talebi, 2010; Oberndorfer et al., 2010; CE Delft, 2010; Walker, 2008) to estimate the extent to which costs have been passed through into product prices. These studies either look into the correlation of industry-specific input costs and prices (cost-price approach) or into the correlation of industry-specific prices in the EU versus countries outside of the EU (e.g. USA) and carbon prices (market equilibrium approach).[6] While prices of outputs are usually available on a monthly or even weekly basis, input costs for specific industries are more challenging to obtain.

Applying the cost-price approach, Alexeeva-Talebi (2010) finds that producers of cement, lime & plaster are capable of passing through the majority of additional costs and also identify a wide range of cost pass-through rates that exist across the different sectors (i.e. between 0 and 75%), see also Table 4. In another study, Alexeeva-Talebi (2011) estimates that EU refineries fully passed through the price of EUAs into petrol prices between 2005 and 2007. Using the same approach, Oberndorfer et al. (2010) show for the UK that industries passed through additional costs in a wide range from 0% (container glass) up to 100% (LPDE) and more

[6] For more details see Section 3.3.

(ceramic goods), using weekly data for 2005-2006 for refineries and monthly data for the period 2001-2007 for other sectors. A pass-through rate of more than 100% might result from certain market characteristics (see also Section 2.3) and can be interpreted as a complete pass-through of policy induced carbon costs.

The studies by Alexeeva-Talebi (2010) and Oberndorfer et al. (2010) calculate different cost pass-through rates for hollow glass, which reflects the use of different data, different lengths of their time series and/or different specification of their estimated equations (i.e. which input costs the authors consider in their estimation on the one hand and which commodity prices (retail, consumer) are to be explained). Walker (2008) also employs the cost-price approach to look into cost pass-through for the cement sector in various EU Member States. He finds that cost pass-through is lowest in countries on the periphery Portugal (0%), Italy (<10%) and Greece (<11%) and higher in more centrally located countries as well as UK. These studies and their results are summarised in
Table 4.

Employing the market equilibrium approach and monthly price data from 2001 until 2009 CE Delft (2010) find that energy-intensive industries such as iron and steel, refining and chemicals actually passed-through a large fraction of the EUA price to product prices, compare Table 4.

Other ex-post econometric studies do not specifically tackle cost pass-through rates but estimate the impact of the EU ETS on employment, output or revenue using panel or cross-sectional data (e.g. Abrell et al. 2011; Commins et al., 2011; Anger and Oberndorfer, 2008), and are not further investigated in this review.

Another strand of literature employs survey or interview techniques with individual firms to assess the effects of the EU ETS. These surveys or interviews usually cover a wide range of questions related to the EU ETS ranging from abatement activities, implementation, and organisational set-up to shifts in production or capacity utilisation, effects on profit, production location or carbon leakage. Explicit questions on cost pass-through were not addressed or answered. A comprehensive summary of these studies can be found in Dechezlepêtre et al. (2014).

2.5.2 Estimated cost pass-through rates in ex-post studies

Table 4 Estimate of cost pass-through rates from ex-post econometric studies

Study	Study scope	Method	Regression	Dependent variable	Explanatory variable	Country	Time Period	Sector	Sector/ Product	Cost pass-through
Alexeeva-Talebi (2010)	Cost pass-through in energy intensive industries	Econometric analysis	Cost approach: domestic producer price as function of foreign producer prices and domestic costs (labour, material, electricity - carbon price not included	Domestic producer price index	– Import producer price index CIF (4-digit level) – Labour costs: gross wages indexed (2-digit level) – Energy: electricity producer price index – Material cost index	DE	Monthly data from January 1995 to December 2008	Paper	Paper and Paperboard	0%
									Household and toilet paper	>38%
								Chemicals	Dyes and pigments	37%
									Other basic inorganic chemicals	10%
									Fertiliser and nitrogen compounds	16%
									Plastic in primary form	42%
									Perfumes and toilet preparations	0%
									Other rubber products	75%
								Glass	Hollow glass	>60%
									Glass Fibres	27%
									Other glass	24%
								Cement	Cement Lime, Plaster	73%
Alexeeva-Talebi (2011)	Cost pass-through in EU petroleum markets	Econometric analysis	Cost approach: output price as function of EUA, oil price, exchange rate	domestic output price: Euro-95-unleaded petrol	Input prices: – EUA – Crude oil price (Brent) – Exchange rate	AT, BE, CZ, DK, FR, DE, GR, HU, IT, LT, NL, PT, ES, SE	For weekly data: Phase 1: Sep 2005 to March 2007;Phase 2: Jan 2008 to Sep 2010	Refineries	EU-95 unleaded petrol	Likely full (100%)
CE Delft (2010)	Cost pass-through in energy intensive industries	Econometric analysis	Market approach: assumes that price of inputs and output are globally linked through trade flows, thus prices in different regions depend on each other	Output price EU	Output price USA, long-term market equilibrium, CO_2 price, exchange rate, crude oil price, DOW Jones and AEX stock indices	EU	Weekly (monthly for steel) data from 2001 to 2009 (Chemicals from 2005 to 2009); CO_2 price second quarter 2005	Refineries	Gasoline	500%
									Diesel	350%
								Chemicals	Polyethylene (PE)	100%
									Polystyrene (PS)	33%
									Polyvinylchloride(PVC)	100%
								Steel	Hot rolled coil	120%
									Cold rolled coil	110%

Study	Study scope	Method	Regression	Dependent variable	Explanatory variable	Country	Time Period	Sector	Sector/ Product	Cost pass-through
							to 2009			
Walker (2008)	Cost pass-through in cement	Econometric analysis	Cost approach	Output price	Input prices	France	Annual 1995-2004	Cement		<30%
						Germany				<30%
						Italy				<10%
						UK				<31%
						Greece				<11%
						Portugal				0%
						Spain				<37%
Oberndorfer (2010)	Cost pass-through in energy intensive industries	Econometric analysis	Cost approach: for products other than diesel and gasoline carbon price not included (cost shock on other input costs)	Output price	Input prices/costs (see column data and data sources)	UK; EU for chemicals	Weekly data on gasoline and diesel for 2005-2006; glass and ceramics; chemicals monthly data 2001-2007	Refineries	Diesel	50%
									Gasoline	75%
								Chemicals	LPDE	100%
									Ammonium	50%
								Glass	Hollow glass	20-25%
									Container glass	0%
								Ceramics	Ceramic goods	>100%
									Ceramic bricks	30-40%

2.5.3 Data and methods

An overview of the data and data sources used in some of the main studies estimating cost pass-through rates is given in Table 5. Lack of data or data frequency provided a challenge in all studies and was circumvented by using proxies or constructed time series based on data with lower frequency. The experience and insights on data sources and methods from other studies provide valuable information to the approach taken in this study.

Table 5 Data and sources used in the literature estimating cost pass-through

Study	Data and data sources
Alexeeva-Talebi (2010)	Time series data. Input and output price indices from the German Federal Statistical Office. Wages from Eurostat (for labour costs wages on two-digit level are used).
Alexeeva-Talebi (2011)	Time series data. Output price: net-of-taxes nominal retail price for Euro-95 unleaded petrol at EU country level (Eurostat Oil Bulletin). Input prices: EUA Point Carbon spot Index, crude oil (Brent), exchange rate (Oil Bulletin, for US$ from DataStream). Estimations in local currencies, all time series in logarithms.
CE Delft (2010)	Time series data. Weekly data, except for I&S monthly from Steel Business, ICIS (chemicals), Oil bulletin EIA, DOW Jones, and AEX stock price index.
Walker (2008)	Time series data. Output price: Exane BNP Paribas annual price data 1995-2004. Input price: Coal, petroleum coke import from Eurostat 1994-2005, Quarry gate crushed limestone price tax dummy in UK for 2002; Post cartel dummy to distinguish data before and after the start of the 2002-2003 price war.
Oberndorfer et al. (2010)	Time series data. **Weekly data** (refineries). Output data weekly: OPAL UK Diesel and Gasoline (taxes excluded) from DataStream (Thomson Financial). Input data weekly: Interest rate (i.e. capital cost) UK interbank overnight middle rate from DataStream (Thomson Financial). Exchange rate from DataStream (Thomson Financial). Brent Crude Oil UK Close from DataStream. 1-month forward natural gas (ICE London) from DataStream. EUA price until 31 Dec 2006 (2007 and 2008 dropped from estimation). **Monthly data** (glass and ceramics). Output data monthly: Output price indices, except container glass measured as revenue per ton relative to 2001 average monthly price. From BERR (now BIS) Input data monthly: Interest rate (i.e. capital cost) UK interbank overnight middle rate from DataStream (Thomson Financial). Exchange rate from DataStream (Thomson Financial). Brent Crude Oil UK Close from DataStream. UK large consumer gas price index from BERR; UK Energy Stats. APX Power UK Spot Base Load Index (account for shocks from electricity market). **Monthly data** (chemicals) Output data: UK chemical industries association (CIA) Input: Euro overnight index average (Eocia, offered rate) from DataStream for interest rate, i.e. capital shocks. Exchange rate from DataStream.

Study	Data and data sources
	Brent Crude Oil UK Close from DataStream, for LPDE instead Naphtha price from CIA (€/2kg). West European gas price index from CIA. APX Power UK Spot Base Load Index (account for shocks from electricity market). Data on energy intensity: Energy purchase and turnover from Eurostat.

In terms of methodological approach, the empirical literature on measuring cost pass-through in product prices of energy intensive sectors in the EU ETS can roughly be demarcated by whether a cost-price approach is used or whether a market equilibrium approach is used. Examples of the former are Alexeeva-Talebi (2011, 2010); Oberndorfer (2010) and Walker (2006). Examples of the latter are CE Delft (2010a, b). For both approaches, a measure of the elasticity of the price of an output in an energy intensive sector with respect to the price of CO_2 is estimated using econometric techniques on ex-post data. To obtain an indicator for the extent of cost pass-through, this elasticity then is compared to a measure for the CO_2 intensity of production. The indicator for the extent of pass-through of CO_2 costs into product prices can be calculated as the ratio of the estimated elasticity divided by the CO_2 intensity in production. In Section 3.2, a detailed account of the methods used in other studies is given and related to the approach employed in this study.

2.6 Conclusions

Cost pass-through is a generalised economic concept that stems from the theory of tax incidence. This economic theory states that the tax burden does not depend on where the revenue is collected, but rather on the price elasticity of demand and supply, as well as the market structure in place. The question of who bears the cost of taxation therefore crucially depends on the extent to which the firm can pass-through these costs to others (e.g. to consumers but also to other industries by the suppliers of labour, capital, energy and materials).

While cost pass-through is a generally accepted concept in economic theory, it has been heavily debated in the context of unilateral climate policies, such as the EU ETS. Within this context, cost pass-through has been analysed from a theoretical, ex-ante and ex-post perspective.

From a theoretical perspective it has been established that cost pass-through is likely for profit maximising firms. The theoretical literature shows that the cost pass-through rate may depend on:

- The market structure in the sense that more competition generally means more cost pass-through;
- The elasticity of demand in the sense that less elastic demand generally implies more cost pass-through;
- The marginal cost curve of domestic industries implying that more elastic marginal cost curves generally imply more cost pass-through;
- The marginal cost curves of foreign competitors represented by Armington elasticities implying that lower elasticities generally imply more cost pass-through.

Cost pass-through according to theory would normally range between 0 and 100%. However, using iso-elastic demand curves or merit-order impacts in supply curves, one can show that cost pass-through rates above the 100% would also be possible – even in theory.

Only in the case that firms would maximise market shares rather than profits, cost pass-through may be questioned from a theoretical basis. The analysis in this chapter shows that this would imply that three conditions would have to be met simultaneously: (i) firms would frame their decisions on expenditures rather than opportunity costs; (ii) firms would base their decisions on average costs rather than marginal costs; (iii) this would hold for every firm that could become the price setter in the market if it would pass-through carbon costs. The evidence obtained through surveys for the first two conditions is mixed. Therefore it is unlikely that this would hold for every firm that falls under the EU ETS.

Nevertheless, the fact that various firms do frame decisions on expenditures rather than opportunity costs and that there are firms that do take into account average costs rather than marginal costs, explains why there is disbelief among industrial organisations that they would pass through the costs. This chapter adds to this the insight that indeed most companies need not pass through carbon costs deliberately for them to show up in the market price. However, if the marginal firm passes through carbon costs, others will implicitly follow by maximising revenues from their sales against observed market prices.

Evidence on cost pass-through cannot be obtained through theoretical exercises alone. Therefore, empirical work is important. The bulk of empirical work has been devoted to cost pass-through of carbon costs into electricity prices. Eight studies have tried to estimate empirically cost pass-through of carbon costs into product prices for industrial products. Three of them are ex-ante in nature and use modelling techniques, whilst five are ex-post using econometric techniques. Overall, the studies show that an analysis aimed at singling out the effect of CO_2 on product prices is challenging with regards to the availability of data of adequate quality, frequency and length – as well as with regards to the definition of the adequate estimation approach.

Taking into account all studies reviewed, we find evidence that costs have been passed through in the majority of sectors examined with the exact pass-through rates showing a rather large variation across studies. Table 6 gives a weighted average of cost pass-through rates from the ex-ante literature, the ex-post literature and the preliminary estimations from the on-going research. The minimum and maximum values are weighted averages from the literature.

Table 6 Overview of the range of average expected cost pass-through in selected sectors from the literature

Sector	Product	Minimum*	Maximum*	# of studies	Estimated in:
Iron and steel	Flat products	60%	100%	4	McKinsey(2006); Vivid Economics (2014); CE Delft (2010); Smale et al. (2006)
	Long products	66%	80%	3	McKinsey(2006); Vivid Economics (2014); Smale et al. (2006)

Sector	Product	Minimum*	Maximum*	# of studies	Estimated in:
Cement	Portland cement, white cement	30%	50%	4	McKinsey (2006); Vivid Economics (2014); Walker (2008); Alexeevi-Talebi (2010)
Glass	Container glass	20%	50%	2	Vivid Economics (2014); Oberndorfer (2010)
	Hollow and other glass	30%	60%	3	Vivid Economics (2014); Oberndorfer (2010); Alexeevi-Talebi (2010)
Refineries	Petrol	50%	>100%	5	McKinsey(2006); Vivid Economics (2014); CE Delft (2010); Alexeevi-Talebi (2011); Oberndorfer (2010)
	Diesel	40%	>100%	3	McKinsey (2006); Vivid Economics (2014); CE Delft (2010); Oberndorfer (2010)
Petrochemicals	Plastics, PE, PVC, PS	25%	80%	3	CE Delft (2010); Alexeevi-Talebi (2010), Oberndorfer (2010)
Fertilisers	Fertiliser and nitrogen compounds	15%	75%	3	Alexeevi-Talebi (2010), Oberndorfer (2010); Vivid Economics (2014).

* Minimum and maximum values have been determined as the average of minimum and maximum values found in the cited studies weighted by the number of products listed in the studies and our own interpretation of the quality of the estimated and assessment of the potential range.

The values from Table 6 must be interpreted with care. They provide a range of average expected cost pass rates through based on a review of the literature. In this literature both ex-ante and ex-post estimates have been treated as a single observation from which an average has been calculated. No attempt has been made to correct for the number of regression estimates in the literature. Nevertheless, the study shows that actual cost pass-through varies quite considerably. The most obvious reason is that data and methods vary substantially between studies and that these tend to influence the results. Therefore, Chapter 3 will look more carefully at the methods that have been employed in ex-post research on cost pass-through, as well as the data used by these studies. The insights will be used to arrive at an adequate estimation method and identify useful data sources for the econometric analysis carried out in this study.

3 Technical background

3.1 Introduction

In this chapter we will give a more elaborated technical background on the methods that have been used to estimate cost pass-through. In this technical background we have a sole focus on studies that have estimated cost pass-through ex-post.
The literature review will serve as a background for our own model formulation.

First, in Section 3.2 we review the existing literature with respect to cost pass-through of carbon costs in the ETS from the perspective of general approaches that have been used. Then, in Section 3.3 we will elaborate on the methodological choices that have been made in order to investigate cost pass-through in the industrial ETS sectors empirically. Finally in Section 3.4 we will elaborate on the more practical details of estimating cost pass-through such as the data availability and choice of sectors.

While this chapter is important for framing the methodological aspects of this study, the descriptions and treatment of the literature may be fairly technical and therefore of less interest to general readers. They may just read the recommendations and conclusions in Section 3.5 to be informed on the practicalities we have considered and decisions taken for data collection, model formulation and estimation routines.

3.2 Approaches used to estimate cost pass-through in the literature

Hereafter, we discuss the studies mentioned above grouped by their approach.
Then, we discuss how they obtain a measure for the extent of cost pass-through.
The section is closed by discussing the literature on cost pass-through in other domains. The lessons that we draw from these discussions are summarised in Section 3.5.

3.2.1 Cost-price approach

Studies that use a cost-price approach typically explain the price of an output by the prices of its inputs components added with a price of CO_2 emissions. The typical form of the cost-price approach is to estimate the following equation:

$$P_t^j = \alpha^j + \gamma_1 P_t^C + \gamma_2 P_t^L + \sum_n \gamma_{3n} P_{n,t}^E + \sum_q \gamma_{4q} P_{t,q}^M + \gamma_5 P_t^K + \epsilon_t^j \qquad (1)$$

Where P refers to the prices, and the suffix j refers to a product, and the suffixes C, L, E, M and K refer respectively to the inputs of Carbon, Labour, Energy, Materials and Capital. Therefore, this model in essence investigates the relationship between the price of inputs and the price of outputs. The main variable of interest would then be γ_1 that determines the extent to which CO_2 costs have been passed through.

Adaptations of model (1) have been used by Oberndorfer (2010); Walker (2008) and Alexeevi-Talebi (2010 and 2011). Alexeeva-Talebi (2011) analyses whether companies in the European refinery sector have been able to pass-through the costs of EUA's in fourteen EU countries The model used explains unleaded petrol retail prices (in the local currency) at country level by the price of crude oil (in Dollars), the price of an EUA and the exchange rate between the $ and the local currency. Her model is a Vector Error Correction Model (VECM) that allows for cointegration between all variables[7]. Extensive tests for unit roots in the separate series are applied using the PP-test as a standard. In case of inconclusive results she applies the KPSS-test. The latter has a null hypothesis of stationarity, as opposed to the PP-test which has a null hypothesis of non-stationarity.

Alexeeva-Talebi (2010) analyses whether cost pass-through of CO_2 prices has taken place in three German industrial sectors. In the model, the price of outputs is explained by the price of inputs (labour, material, and energy), the foreign price and some market characteristics. The two latter variables indicate for a flexible mark-up that depends on the market structure and the connectedness with foreign markets. Her estimation strategy is a VECM. She estimates cost pass-through as a weighted average of the ability of companies in the sector to pass-through the costs of domestic input prices (labour, material, energy). Hence no direct measure of the pass-through of CO_2 prices is obtained. She again applies extensive tests for stationarity of the different series.

Oberndorfer (2010) studies cost pass-through of CO_2 prices in the UK for the sectors Diesel and Gasoline, hollow glass and ceramic goods, and low density polyethylene film and ammonium nitrate. The model is an Autoregressive Distributed Lags (ARDL) model that is estimated in first differences (hence it gives a weaker indication of the long-run relationship). Compared with the Alexeeva-Talebi models, it has the innovation that it allows for asymmetric price transmissions: the impact of input prices on the price of output may differ according to whether input prices are rising or falling. Furthermore, heteroscedasticity and autocorrelation consistent standard errors (HAC se's) are calculated.[8]

Walker (2006) studies cost pass-through in ETS of the Portland cement industry. He explains cement prices by energy costs, using a variety of models (OLS, ARDL, panel-data models with fixed effects) for a set of 7 European countries. As in Alexeeva-Talebi (2010), no direct measure of CO_2 prices is included in the regressions; hence no direct measure of CO_2 cost pass-through is obtained. Also no tests for stationarity of series and/or possible cointegration are applied. The study stands out for its analysis of the relevant frequency of data in the time series. It argues that the relevant frequency of price changes in the cement sector is monthly. Factors to take into consideration are: whether prices are published, whether there is a single market clearing price (regional differences, vertical integration), whether there are possibilities to stock the output products, whether there are technical constraints on switching inputs.

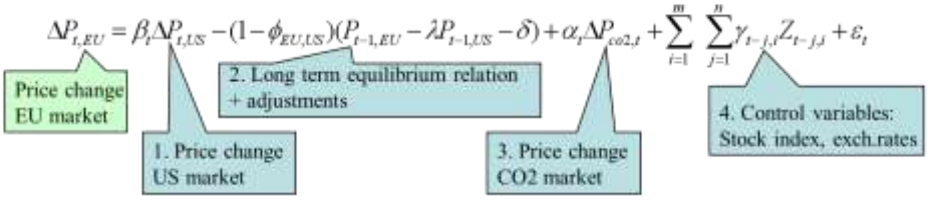
3.2.2 Market equilibrium approach

There is one study (CE Delft 2010) that has uses a different approach – a market equilibrium approach. This approach builds on the assumption that markets are internationally integrated to the extent that a (long-run) equilibrium relation exists

7 The use a VECM implies that all variables in the cointegration relationship are endogenous. So technically, the explanatory variable consists of more variables, i.e. the price of crude oil, the price of EUAa and the exchange rate. Considering variables are observed at country level, this multi-causal system seems appropriate.

8 The calculation of HAC se's is possible in an ARDL context. However, there is not yet a method to do this in a VECM context in mainstream econometrics software. One should nevertheless notice that even without HAC se's a VECM is still consistent (albeit not efficient).

between domestic and foreign prices. The model employed typically explains the domestic price (EU-price) of an output by the US price, the CO_2 price and the exchange rate. One model formulation can be as follows:



Where the price change in the EU market is made dependent on:

A. The price change in the US market.
B. The long-term equilibrium between EU and US markets taking into account fixed factors like the state of production, transport costs, etc.
C. The CO_2 price in the EU ETS.
D. Exchange rates and a variable describing the general state of the economy in both countries, which can be GDP or the stock markets indexes.

CE Delft (2010a) analyses the question whether energy intensive sectors have been able to obtain windfall profits through the introduction of the EU ETS. It analyses this question by measuring whether companies in these sectors have been able to pass-through the (opportunity) costs of freely obtained CO_2 emission allowances in their product prices. The model employed explains the domestic price (EU price) by the US price, the CO_2 price and the exchange rate. The US price and EU price are in the cointegration relation, if tests reveal this is appropriate, and then a VECM is estimated. Otherwise, (if tests reveal no cointegration), then a Vector Autoregressive (VAR) model with variables in first differences is estimated if Granger Causality is present, otherwise the model in first differences is estimated by Ordinary Least Squares (OLS).

The advantage of this approach is that it is less data-intensive than the cost-price approach. A disadvantage is that the model contains more assumptions regarding price adjustments and market integration.[9]

3.2.3 Measuring the extent of cost pass-through

To obtain a measure of the extent of cost pass-through, Alexeeva-Talebi (2010 and 2011) compares the estimated long-run elasticity of product prices with respect to the price of CO_2 with the cost share of CO_2 allowances needed to cover the emissions (e.g. costs of CO_2/turnover of product). The use of cost shares as a comparison differs from the CE Delft (2010b) study that compares with the physical share of CO_2 in production (emission rates, e.g. tonnes CO_2/tons of output). The difference is explained by the fact that Alexeeva-Talebi uses variables in log-form, while the CE Delft study uses plain variables.

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[9] Formally the model assumes that the CO_2 costs price increase in the EU market in the end spreads over to the US market, as well as that US prices go up (due to higher demand) and EU prices go down. This is because the CO_2 price itself is not part of the cointegration relationship (because it does not contain a unit root) and is thus only used as an adjustment mechanism.

Another feature to point out is that Alexeeva-Talebi (2010) derives a formal t-statistic to test whether cost pass-through of individual inputs differs significantly from 100%. This statistic is calculated as: t=(X-u)/s, where X is the estimated coefficient for CO_2 in the cointegration relationship, u is the cost share of the input for the industry, and s is the estimated standard deviation.

3.2.4 Cost pass-through in the electricity sector

Jouvet & Soulier (2013); Mandal et al. (2012); Mirza & Bergland (2012) and Zachman & Hirschhausen (2008) focus on cost pass-through of CO_2 into electricity prices in the ETS. In many cases this more recent work extends the original work done in this area by Sijm et al. (2005, 2006). Jouvet & Soulier and Mirza & Bergland use a cost-price approach, while Mandal et al. use a Philips curve approach to explain pass-through into wages. The latter is not relevant to our analysis of cost pass-through into product prices because the Philips curve model is specific to the labour market. Jouvet & Soulier (2013) estimates, following initial studies by Sijm et al. (2005, 2006) the effect of CO_2 prices on the spread between electricity prices and fuel prices. This model can be regarded as a restricted version of the cost-price model presented above, as well as of model (1) that we aim to estimate in the current project. Restrictions arise because the pass-through of fuel input prices is assumed to be fixed while our model allowa for different rates of pass-through of input prices. Furthermore, the models suffer from incorrect treatment of the order of integration of the variables.

Mirza & Bergland (2012) develop an indicator for the extent of market power by analysing asymmetric cost pass-through in the Norwegian electricity sector. The retail electricity price is regressed on several input prices in an ARDL model. No account of possible endogeneity is given. Series are tested for stationarity with a PP-test, and are found to be stationary. Zachman & Hirschhausen (2008) focusses on asymmetric pass-through as well. They use two models: an ECM that allows for asymmetric adjustments in the short run, and an ARDL (in first differences) that allows for asymmetric adjustments.

3.2.5 Examples of approaches used in other policy domains

The issue of whether costs of governmental policies can be put forward in prices has played a role in other areas, such as VAT differences between countries, or the differences in profit taxes affecting competitive position of companies. As part of our literature review we have briefly investigated this body of literature and looked if relevant methods have been employed.

Carbonnier (2005, 2006) and Delipalla & O'Donnell (2001) assess the extent to which excise duties and/or VAT are passed on to consumers or cut into profit margins. We should note that the studies on VAT cost pass-through are only partly relevant for our study on cost pass-through in the ETS because VAT applies to both domestic and imported goods. The relevance comes from the notion that with the VAT, comparable to carbon costs, firms distribute the costs among absorption in profit margins or pass-through to consumers. These studies follow a cost-price approach. Delipalla & O'Donnell (2001) focus on deriving a measure for market power, indicated by the extent to which taxes are under or over shifted to consumers in the electricity sector in different EU countries. The model explains cigarette prices by tax rates, labour costs, GDP, CPI, and the exchange rate. It adopts a panel data approach, grouping countries with similar pass-through coefficients based on separate time series analysis to obtain significant coefficients in spite of a rather short time span. Turning to the Carbonnier studies, these explain consumer prices of products in a number of sectors by VAT rates and a number of controls for input prices. All variables are expressed in growth rates, so no account of cointegration is given. The 2005 study allows for asymmetric adjustment.

Fuest et al. (2012) and Clausing (2013) focus on cost pass-through of corporate taxes. These are more comparable to the ETS in the sense that it is a unilateral tax. However, cost pass-through is usually analysed not in a downstream direction (e.g. in consumer prices), but in an upstream direction (e.g. into wages). Both studies estimate a wage equation that is not related to the cost-price approach that we adopt. Finally, we mention a study on cost pass-through of exchange rate fluctuations into prices of exports (Ceglowski, 2010). This study adopts a market equilibrium approach, with a number of controls that are consistent with a cost-price approach. The dependent variable is the export price index of a number of Japanese products. The independent variables are the competitor price on the relevant export market in the foreign currency, input costs and economic activity in the export market. For the different products, time series estimation in first differences is performed. Hence no account of possible cointegration is given.

3.3 Model formulation and estimation routine

3.3.1 Model formulation

For the empirical estimation we have used a cost-price model, similar in fashion to Alexeeva-Talebi (2011). In this model we estimate the logarithm of the price of a product as the dependent variable and regress it on the logarithm of the price of inputs. Relevant inputs include: prices of labour, capital, energy, materials and CO_2 allowances.

This model can be directly derived from the accounting identity that the costs of production equal costs of all inputs in production.

$$Y_t * P_{y,t} \stackrel{\text{def}}{=} \Sigma X_t * P_{x,t} + CO2_t * P_{co2,t}$$

where Y denotes the volume of output, P_y its price, X the volume of non-CO_2 inputs (e.g. labour, materials, energy) and P_x their respective prices, $CO2$ the volume of CO_2 allowances used in production and P_{co2}its price. The index t denotes time.

This identity translates into the regression equation estimated in CE Delft (2010a,b):

$$lnP_{y,t} = \beta_0 + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} lnP_{co2,t} + \frac{X_t * P_{x,t}}{Y_t * P_{y,t}} lnP_{x,t}$$

If we rewrite the identity in growth rates and integrate, we obtain an equation that translates into the cost-price models that are generally estimated (e.g. Alexeva Talebi, 2011)[10].

$$lnP_{y,t} = \beta_0 + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} lnP_{co2,t} + \frac{X_t * P_{x,t}}{Y_t * P_{y,t}} lnP_{x,t} + \varepsilon_t$$

10 See Annex J for a derivation.

Which translates into the regression equation:

$$lnP_{y,t} = \beta_0 + \beta_1 lnP_{co2,t} + \sum_x \beta_x lnP_{x,t} + \varepsilon_t \qquad \text{(M1)}$$

In this case, the β_x's can be interpreted as (time constant) shares of the costs of inputs in the costs of production for x production factors. Specific interest here is the coefficient β_1 that determines the share of cost of CO_2 in the cost of production.

If we estimate the regression equation in VECM form, we estimate the following VECM-model:

$$\Delta \boldsymbol{P}_t = \Pi \boldsymbol{P}_{t-1} + \sum_{k=1}^{p-1} \Gamma_k \Delta \boldsymbol{P}_{t-k} + \varepsilon_t$$

Where $\boldsymbol{P}_t$ represents a vector of non-stationary endogenous price variables for $t = 1, \dots, n$ with: $\boldsymbol{P}_t = (P_t^j, P_t^C, P_t^L, P_t^E, P_t^M, P_t^K)$

The matrix Π contains information about the long-run relationships among the price of the product and the prices of its inputs. To facilitate further explanation, for the single-term co-integration case, we write the term

$\Pi \boldsymbol{P}_{t-1}$ as:

$$\phi(P_{t-1}^j - \alpha^j - \beta_1 P_{t-1}^C - \beta_2 P_{t-1}^L - \sum_n \beta_{3n} P_{n,t-1}^E - \sum_q \beta_{4q} P_{q,t-1}^M - \beta_5 P_{t-1}^K) \text{ (M1*)}$$

When expressed in logs, the long-run coefficients β will be representative of the cost share of the specific production factor in the total end product. The main variable of interest here is the coefficient β_1 on the share of CO_2 costs contained in the final product price.

3.3.2 Null hypothesis and main interpretation

The model M1* will be formulated in such way that the null hypothesis is that the opportunity costs of CO_2 have not been passed through. This null hypothesis will only be rejected if the coefficient β_1 in the model (M1*) is significantly different from zero. In that case there is evidence that (some amount) of costs have been passed through.

Since the model will be estimated in logarithms, the coefficient β_1 can be interpreted as the share of the sales price that is explained by the CO_2 costs. It can thus be interpreted as the CO_2 cost share.

The formal test in our econometric study is therefore if this β_1 coefficient is statistically significantly different from zero. If carbon costs are reasonably high (e.g. above 5% of total costs), it is clear that this is a good test. However, if carbon costs are very small (e.g. 1% of total costs), or if not all costs have been passed through into product prices, it becomes more difficult to discern whether this variable is statistically significantly from zero given the typical noise in the data.

This problem may be aggravated due to two likely causes:

A. Divergence between costs and prices. Model M1* assumes that costs explain price. However, if there is only a loose connection between price of products and their underlying costs (e.g. markets where the intensiveness of competition varies over time), it may be more difficult to discern if small cost shares are statistically significantly different from zero.

B. Data problems: both prices and cost shares are observed through various statistical sources (see also Section 3.4). They are collected through a combination of surveys, customs data, top-down calculations (like in the national accounts) and a system of checks and balances. In the process of data construction, a substantial amount of noise may enter the data that make them less reliable than required for a precise econometric estimation. Another issue is that we have used a mixed dataset where price data from commercial vendors on materials and products have been combined with statistical data on the costs of labour, capital and energy (see also Section 3.4).

In our tests of significance of β_1, we have used one-sided confidence intervals. We only allow for positive values of β_1, for a negative value would imply a negative cost share as well as that product prices would decrease with the CO_2 costs. This does not make sense. A result where the coefficient β_1 is not statistically significantly different from zero can therefore not be regarded as evidence that no costs have been passed through. It can only serve as evidence that, with the available data, we could not prove that CO_2 costs have been passed through in the product prices.

If, on the other hand, the coefficient $\beta_1$turns out to be statistically significant from zero, we consider the hypothesis of no cost pass-through to be rejected. If the null hypothesis of no cost pass-through is rejected, this provides evidence that (some part of) the carbon costs have been put forward in the product prices. A significant coefficient $\beta_1$implies therefore that the data reveal that the probability that carbon costs have not been forwarded in the product prices, is low - in our case below 10%.

It should be reiterated that when $\beta_1$is not significant, this does not imply that carbon costs have not been passed through. It implies that, based on the combination of the logarithmic model and the data, the probability that costs have not been passed through is higher than 10%.It also implies that a different model may be more accurate to describe the actual process of cost pass-through that generates the data. Especially if many firms pass through carbon costs in different moments in time, the price impact of carbon may get diluted and the statistical tests may not reveal cost pass-through.

3.3.3 Estimation of the cost pass-through rate

The advantage of model M1* is that the coefficient $\beta_1$has a specific meaning as being the CO_2 cost share. The coefficient thus gives the share of CO_2 costs in the total product price. In principle, this observed cost share can be compared with the expected value of CO_2 costs that would appear if all the opportunity costs of CO_2 allowances were put forward in the product price. This gives information about the extent to which opportunity costs have been put forward in the product price.

We define the % cost pass-through rate as a measure of the size of the estimated coefficient in relation to the size of cost pass-through that would be consistent with a one-to-one cost pass-through of the CO_2 cost (expressed as opportunity costs) as an average over the time-span of analysis. It is calculated as the ratio of the estimated coefficient β_1 over the hypothetical CO_2 cost share if all opportunity costs would have been passed through. Or in formula:

$$\% \, Cpt \, rate = \frac{Estimated \, coefficient \, \beta_1}{(Emissions * CO2 \, price)/Value \, product \, sales} \qquad \text{(c1)}$$

In this way the estimated coefficient β_1 would be compared to the expected value of CO_2 emissions relative to the turnover of the company. It is important here to emphasise as well that the expected value of cost pass-through is calculated irrespective of whether these costs are actually paid (because the sector was short in allowances) or not.

This expected value of cost pass-through can, in principle, be derived statistically at NACE 4-digit level by calculating for each year the emissions multiplied by the EUA price and divide this by the sectoral turnover from Eurostat. This gives an approximation of the specific CO_2 costs in the sector. This may be a reliable estimate if all of the CO_2 emissions in the product may occur within the sector and if the sector only produces the product under scrutiny[11]. It is clear that this will be rarely the case. At NACE 4-digit level cement may classify for this if all of the clinker was to be produced within the EU.

If the denominator in equation (c1) is not correctly established because sectoral turnover would contain activities that are not listed in the price series or activities that do not fall under the EU ETS, the denominator in (c1) will be underestimated due to problems in establishing the correct statistical boundaries. This typically would result in an *overestimation* of the cost pass-through rate. An alternative route would therefore be a technical approach (in contrast to the statistical route above). Using the technical approach would imply rewriting (c1) by dividing the ratio in the denominator with the quantity of products sold, so that the following expression remains:

$$\% \, Cpt \, ratio = \frac{Estimated \, coefficient \, \beta_1}{\{\frac{Emission \, factor * CO2 \, price}{Product \, price}\}} \qquad \text{(c2)}$$

In this way, one could determine the emission factor for producing one unit of product from, e.g., Life-cycle analysis (LCA), multiply this with the average EUA price and compare it to the particular price of the product. This may be more accurate if the sector produces more than one product and/or substantial CO_2 emissions occur upstream in the value chain with substantive import- and export flows. However, uncertainty about the emission factor can result in biased estimates on the cost pass-through rate.

A more fundamental issue here is that the ratios, as defined above, determine the *average* cost pass-through of a sector. The average cost pass-through rate assumes that the sector adheres to *average cost pricing* in the sense that the average costs determine the cost price increase. As we have discussed in Section 2.3 this will rarely be the case.

If the companies that settle the price at the margin are less efficient than average (which is a likely assumption, see CE Delft (2010b), it is likely that a larger share of costs are passed through in product prices than the sectoral average. In that case the somewhat startling result can emerge that cost pass-through rates are substantially above 100%. The study on benchmarks (Ecofys, 2009) shows that emission factors

[11] An additional assumption is here that average costs determine the costs passed through and not the marginal costs.

diverge substantially among EU installations. If e.g. the marginal installation is only half as efficient as the sectoral average, and if this installation has the highest marginal costs in a sector (and thus sets the price), a 100% cost pass-through rate for this installation would imply an average cost pass-through rate of 200% for the whole sector.

1. It should thus be clear that the average cost pass-through rate is not precise and must be perceived as an indicative value (or conjectured estimate) for three distinct reasons: The value of β_1 is a statistical approximation. The value lies within confidence bounds that can sometimes be quite substantial. Such confidence bounds could lie between (e.g.) 0.5-3 which implies that the estimated cost pass-through would lie between the 50-300%.
2. The denominator in c2 is difficult to determine precisely because of data issues. Furthermore, emission factors from LCAs cannot be determined precisely either.
3. Marginal inefficient installations may be price setters in the product markets that have higher than average carbon costs.

Therefore, the main statistical information we derive from estimating model M1* is the fact of whether or not cost pass-through has occurred. The magnitude of cost pass-through (measured in percentage terms) is inherently much more uncertain and will only be given as a conjectured estimate (or indicative value).

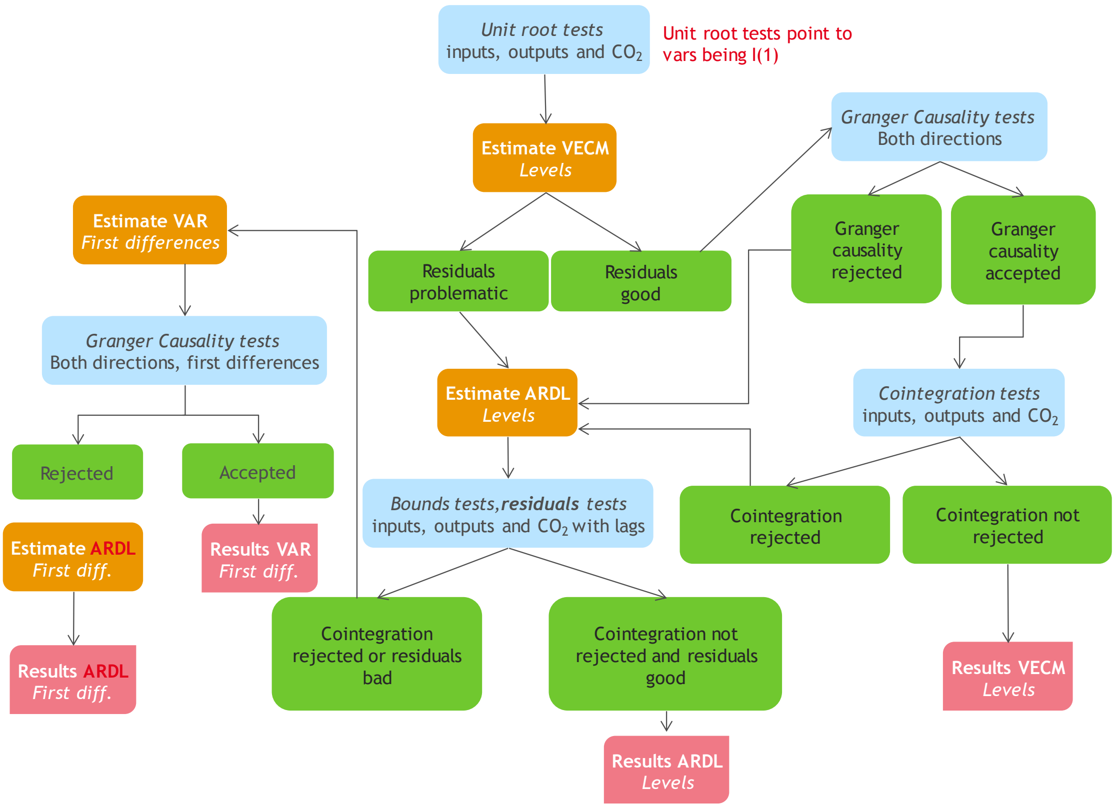
3.3.4 Estimation procedure

Our preferred estimation method would be the VECM type that allows for cointegration similar to Alexeeva-Talebi (2011) and CE Delft (2010a). However, a VECM can only be estimated if:

- The residuals are free of autocorrelation so that the estimated coefficients and test statistics are consistent;
- There is two-direction Granger causality between the input and output prices indicating that a system of estimations is the most efficient way forward;
- There is cointegration among the prices of inputs and outputs.

While the last condition is normally explicitly addressed in the literature, the two former conditions are equally important and have played an important role in our estimation procedure. Figure 2 gives the generalised estimation procedure in this research.

Figure 2 Estimation procedure followed in this research



Note: Text in light blue refers to statistical tests, text in orange to an estimation model, text in green to possible outcomes of the estimation and text in red to the selected estimation model for which results are reported.

First, we have transferred all variables to Euros using Eurostat (daily/weekly/monthly) exchange rates (where necessary) and transformed into logarithms so that model (M1*) is estimated and its estimates can be interpreted as cost shares. Subsequently the variables are tested for unit roots[12]. A unit root test is a test on whether a variable has a (stochastic) trend. If variables in a model do have a trend, then one should test for cointegration between these variables in a VECM approach[13]. Thus, in a third step, a VECM was estimated of Model (M1*) and the results were analysed with respect to the behaviour of the residuals. If the residuals showed that they were free of higher order autocorrelation, we classified the VECM as appropriate for further testing. This constituted of undertaking Granger Causality tests to investigate whether the variables are part of an endogenous system which would justify estimation of a VECM. If the Granger causality was accepted, cointegration tests were executed to investigate whether (and under which model) the series of input and output prices

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12 In this study we use two different unit root tests, notably the ADF-test (with a constant, without trend) and the PP-test (with constant, without trend). We also ran a third test, the KPSS-test (not reported, results available on request), which we use when the combined result from the ADF and PP-tests are inconclusive. The critical value for the unit root tests was 5%.

13 In some cases, unit root variables have been included in first differences as exogenous control variables.

were cointegrated. If the null of no cointegration was not rejected, a VECM model was estimated and the results were reported.

If the residuals were not free of autocorrelation, Granger causality was rejected or there was no cointegration among the inputs and outputs, an ARDL was set up and tested. There are specific reasons why an ARDL may perform better in this case. The VECM method compares current prices of outputs (e.g. price of petrol) with current prices of inputs (e.g. labour, capital, crude oil and CO_2). However these prices may constitute costs to the company in different moments in time. The price of a product is usually recorded at the moment of sale of the product. However, costs may have been incurred months earlier. This is clearly the case for capital and labour costs which in the short run at least can be regarded as fixed costs. But also CO_2 costs may be passed through with a lag into product prices. Such delays cannot be appropriately modelled in a VECM context, because the reversed causality is theoretically flawed as this would imply future values causing passed values. Given that ARDL's display less autocorrelation in the residuals, we interpret the excess autocorrelation in the VECM as arising from incomplete models for the reversed causality and inadequate modelling of the time lags of cost pass-through. Therefore, if cointegration is not present in the VECM, we continue investigating an ARDL including lagged prices of the input variables in the cointegration relationship.

A specific issue when an ARDL may be preferred over a VECM approach is when the unit root tests indicate that some variables contain a unit root and others not. The traditional approach would be to exclude the variables that do not contain a unit root from the cointegration equation in the VECM approach and include them as exogenous variables. However, an ARDL approach is less stringent in this case for it has developed proper test routines (e.g. Bounds tests, see below) in case variables are integrated with a different order. In that case – as will be for the iron and steel sector- we have estimated the variables in an ARDL as well.

The ARDL is then properly tested using Bounds test for cointegration[14]. If either the residuals or the Bounds test reject the appropriateness of ARDL estimation with a cointegration term, we would turn to an estimation of cost pass-through using first differences in either a VAR or ARDL context.

The optimal lag-length of the variables was determined by minimising the Akaike information criterion (AIC). Variables were included with lag-length of maximum five months. The adequate delay of the CO_2 price (and other explanatory variables) was found by estimating different models and then choosing the one that minimises the Schwarz information criterion (SIC) (after ensuring that no autocorrelation was present in the residuals).

[14] The advantage of the ARDL is that it allows for setting up a Bounds test that provides for testing for cointegration when both I(1) and I(0) variables are present in the cointegration term. This combination is quite common in the sample that we estimated and with the inclusion of the Bounds tests we have a valid test whereas the standard Johansen test is not giving the right critical values when I(1) and I(0) variables are included in the estimation.

3.3.5 Differences between Phase 1 and Phase 2/3

There may be econometrical and technical problems in analysing cost pass-through over the entire time frame 2005-2014 because Phase 1 of the EU ETS is quite different from the other two phases under investigation. First, Phase 1 can be regarded as a trial-phase in which companies and regulators have gained some first experience with the working of an ETS. Behaviour of companies may therefore be different than in subsequent phases. In addition, during a substantial period of time the CO_2 prices were near zero which has certain statistical implications[15].

We solved this by estimating the equations both for the full subset of CO_2 prices and a limited price set for Phase 2/3 only. Often the latter proved to explain the data much better than the former.

3.4 Choice of sectors, data and practical issues

3.4.1 Choice of sectors and products

As explained in Section 1.4, the empirical analysis in this study has been confined to six industrial sectors: refineries, iron and steel, cement, fertiliser, petrochemicals and glass. In order to analyse cost pass-through in these sectors, respective products had to be formulated and chosen that would allow estimation.

Estimation of model M1* is quite data intensive. For every product/country combination, data must be collected for prices of products and prices of inputs (labour, capital, energy, material inputs), preferably over a time-span of 2005-2014 but with a minimum of time-span of 2008-2013. Therefore the amount of products and countries had to be limited to make execution of the estimations feasible. For every sector we decided to estimate the data for 4-15 product/country combinations. This could hence be one product (e.g. petrol) in multiple countries, or one country with multiple products. The main driver here was data availability, both with respect to inputs as with respect to outputs.

Table 7 gives an overview of the product/country combinations we have selected for analysis in the six sectors.

Table 7 Overview of products and country/region considered in this study

Sector	Products	Countries*
Cement	Clinker	CZ, DE, FR, PL, UK
	Total cement	DE, FR, IT, UK
	Portland cement	CZ, PL
Petrochemicals	Ethylene	NWE, MED
	Mono ethylene glycol	MED
	Propylene oxide	NWE
	Propylene glycol ether	NWE
	Methanol, Butadiene, Propylene	NWE, MED
Iron and steel	Flat steel HRC	NE, SE
	Flat steel CRC	NE, SE

15 We also observe that including Phase 1 in the VECM model framework may imply that CO_2 is not cointegrated with the other price variables, as in CE Delft (2010a). In this light we also observe that it is very rare for a prices of derivatives (as in the case of CO_2) to be not integrated.

Sector	Products	Countries*
Fertiliser	Ammonia	NWE
	Ammonia nitrate	FR, UK
	Calcium ammonium nitrate	DE
	Urea ammonium nitrate	FR
	Urea	NL, NWE
Refineries	Petrol	BE, DE, FR, GR, IT, PL
	Diesel	BE, DE, FR, GR, IT, PL
	Gasoil	BE, DE, FR, GR, IT, PL
Glass	Hollow glass	DE, FR, ES, IT
	Fibre glass	DE

* BE = Belgium, CZ = Czech Republic, DE = Germany, ES = Spain, FR = France, GR = Greece, IT = Italy, NE = Northern Europe, NWE = North-Western Europe, MED = Mediterranean countries (Southern Europe), PL = Poland, SE = Southern Europe, UK = United Kingdom.

3.4.2 Data collection

In order to estimate model M1*, the following data are required:

- Data on the price of the end product (e.g. tonnes produced steel);
- Data on the price of labour input (wages paid in e.g. steel manufacturing);
- Data on the price of energy (energy used in steel, or cokes prices);
- Data on the price of material input (e.g. pig iron);
- Probably data on price of capital input (e.g. commercial loans with interest rate);
- Data on the price of CO_2 allowances.

In addition, control variables may be required to present an estimation of the impact of market conditions on the price formation in markets. It is well recognised, for example that a booming market may exhibit different pricing behaviour than a stagnating or declining market. To control for these factors we have added data on stock market behaviour or the volume of sectoral output.

We have classified the data in three Tiers:

- Tier 1: Actual price data from client industry and market quotations. There are many industry data providers (e.g. ICIS, Thomson Reuters, and Argus) that sell commercial data to traders of these products. These data are not publicly available and have been purchased by the team executing this research for licensed use in this project only.
- Tier 2: Producer price indices. These data will be used in the absence of actual price data. Producer price indices are either available from national statistical offices or Eurostat or from the commercial platform DataStream. Producer prices indices are usually available at a monthly timescale and geographical availability depends on the product at hand[16].
- Tier 3: Implied prices derived from Prodcom/Comext ratios. In this case data have been calculated by taking the ratios of volume and value from Prodcom (production or trade) or Comext if data on producer price indices is also not

16 For the manufacture of cement (C2351), for example, Eurostat provides an index for five individual countries (Germany, Spain, France, Italy and the UK), as well as a composite index for the whole EU.

available for certain industrial products. If we had to revert to Comext data we would calculate a weighted average of implicit import and export prices.

In general we would consider Tier 1 data as more reliable than Tier 2 and Tier 2 data more reliable than Tier 3. For the selection of data, we refer to the sectoral analysis in Chapter 4. More detailed information on data can be found in Annex A.

3.4.3 Time frame of analysis

The time frame for analysis is set at January 2005 to February 2015 (or alternatively as far as data is available). To investigate delayed impacts of costs passed through into product prices, we started collecting data from January 2002 onwards.

The data were collected on a monthly for all sectors. For refineries, fertilisers and petrochemicals, weekly data have been collected as well. Data availability on output prices proved to be the most critical factor for the number of empirical estimations conducted.

3.4.4 Types of price data and their impact on estimations

Commodity price data (Tier 1) is normally classified to the type of contracts for which price information is gathered – also called 'delivery terms'. Table 8 gives the abbreviations for the type of contracts that have been used throughout this research project. CIF, FOB and FCA are most frequently used. In general, FCA is cheaper than FOB and FOB is cheaper than CIF.

Table 8 Main delivery terms used in the international price series. Lower placed in the table implies in general costs

Abbreviation	Title	Meaning
EXW	Ex works	The goods are made available at the seller's premises (for example: works, factory, warehouse, etc.) and the buyer bears all the costs (loading, transport, etc.) from that point on.
DDU or DDP or DEL	Delivered Domicile (fully delivered)	The seller delivers the goods to a named place in the country of arrival (for example: the buyer's premises or a particular warehouse) and is responsible for all costs involved in doing so. DDP would imply including costs of duties, DDU would be without duty costs.
CIF	Cost, insurance and freight to the port of arrival	The seller pays all the costs and freight charges and insurance necessary to get the goods to a port or airport in the EU. The buyer is responsible for the charges associated with domestic transport from the port or airport.
CFR (or C&F)	Cost and freight	Similar to CIF excluding the insurance costs.
FOB	Free on board at the port of departure	The seller bears the cost of transporting the goods to the vessel/aircraft of the (air)port in the country of exportation.
FCA	Free Carrier	The seller bears the costs of transporting the goods to the port in the country of exportation. It has no obligation to deliver the goods on the vessel/aircraft.

Note: Prices ordered according to general costs (high to low).

The details of these prices are not so important for conclusions of our research. The changes in prices (and the impact of CO_2 costs on these changes) could be measured regardless of the type of delivery terms that are being used. However, it is important to realise that the price series differ with respect to the moment of price quotation. Prices are thus recorded at a certain moment, mostly at the moment of international trade of the product. For example: a price quoted as 'Free on Board' (FOB), implies that the moment of price recording is when the product is loaded onto a vessel or aircraft. However, such prices may have been agreed upon earlier. The product may be produced several weeks or months ahead of the moment that the product is delivered at a port or airport and prices may have been agreed at the moment of production. Prices may also have been negotiated on the basis of a contract settled months ahead.

Such differences between the moment of recording and price formation can be exaggerated by the role of intermediate traders – as is the case with refined products for example. Traders may buy products and deliver them later depending on the differential margins at the port of delivery. If prices are quoted at the moment of delivery, there may be several weeks/months of price formation going on before the final price is recorded.

Therefore, the prices may contain some past traces of production decisions. This implies that we would, a-priori, expect that an ARDL would be a better estimation method than a VECM. This is explicitly taken account for in the estimation procedure set up in Section 3.3.

3.4.5 Reliability of data

Empirical estimations of cost pass-through are made on the basis of analysing price data, where the price of outputs (products) is tested for the significance of the price of inputs (including CO_2) used in production. As CO_2 costs are relatively small, the results are very sensitive against the quality of the data, especially regarding the price of outputs.

In this research we have taken great care in gathering appropriate and high quality data and were actually able to do so for quite a number of sectors. Data have subsequently been plotted in order to investigate outliers and/or unusual behaviour. By doing this, we observed that Tier 3 data, which have been used in the cement and glass sectors, proved to be relatively poor with some unexpected and unexplained variations in the data. After initial regression analysis for these two sectors we have decided to smooth these series by taking either moving averages or by substituting the outlier for a specific country with the price development in another country. This in general improved the estimations. Nevertheless, in the end, as could have been expected ex-ante, the cement and glass sectors remained as the two sectors where data quality could be judged to be lowest and this may have impacted on the results (see Chapter 4).

3.5 Conclusions

Studies that use a cost-price approach typically explain the price of an output by the prices of its input components and add the price of CO_2 emissions. The typical form of the cost-price approach is to estimate the following equation:

$$P_t^j = \alpha^j + \beta_1 P_t^C + \gamma_2 P_t^L + \sum_n \gamma_{3n} P_{n,t}^E + \sum_q \gamma_{4q} P_{t,q}^M + \gamma_5 P_t^K + \epsilon_t^j \qquad \text{(M1)}$$

Where P refers to the prices, the suffix j refers to a specific product, and the suffixes C, L, E, M and K refer respectively to the inputs of Carbon, Labour, Energy, Materials and Capital. Therefore, this model in essence investigates the relationship between the price of inputs and the price of outputs. The main variable of interest would then be β_1 that determines the extent to which CO_2 costs have been passed through.

Estimation of model (M1) is carried out under the null hypothesis is that the opportunity costs of CO_2 have not been passed through. This null hypothesis will only be rejected if the coefficient β_1 is significantly different from zero. In that case there is evidence that (some amount) of costs have been passed through. Therefore, the estimation procedure is set up in such a way that the assumption is that costs are not being passed through. This assures an unbiased estimation where conclusions are less affected by e.g. data issues.

The econometric estimation in essence estimates whether or not costs are passed through. However, politically, it is also interesting to investigate to what extent costs are passed through. When rewritten in logs, model M1 estimates cost shares of the various input factors. To get an estimate of the magnitude of cost pass-through, we compare the estimated cost share of CO_2 (β_1) with the hypothetical cost share of CO_2 that would arise if all CO_2 costs embodied in production (including opportunity costs) were passed through into the product price. This gives the average cost pass-through ratio.

We have argued that the cost pass-through rate cannot be determined precisely in such models due to different reasons. First, there are confidence bounds associated with econometric estimations.[17] Second, there are various data issues arising when determining the hypothetical cost share if all costs were passed through. Third, the estimator of the cost pass-through rate compares the marginal cost price increase with the average expected cost price increase. If marginal and average costs diverge, cost pass-through rates may be calculated at well above the 100%, which is difficult to explain politically. We will, however, explore the extent to which the hypothetical cost share can be determined for the marginal firm, which is expected to set the price (see Chapter 4).

Therefore, we would state that the estimated cost pass-through rate in this research is only giving an indicative value and can by no means be interpreted as 'absolute truth'. It provides a conjectured estimate of the amount of costs that seem to be passed through in the product prices. It is by definition true that this amount is larger than 0%, but the exact amount of costs passed through is difficult to discern precisely. This also implies that it is difficult to base a decision regarding carbon leakage risk and the free allocation of emission allowances on estimated cost pass-through rates alone.

[17] The confidence bounds would, for example, indicate that costs are passed through between 40 to 120%.

4 Econometric results

4.1 Introduction

Using the data and routines described in Chapter 3, over 50 product prices have been analysed for their potential of cost pass-through. More than 300 price series of inputs have been employed as explanatory variables and substantial additional research work has been carried out including interviews with traders or client industries.

The null hypothesis of no cost pass-through was tested for several product outputs in the selected sectors for a range of countries or regions. In order to investigate the null hypothesis of no-cost pass-through a sophisticated estimation procedure was set up, which has been summarised in Chapter 3 The crucial element is here to obtain an estimation that is unbiased and efficient in which the t-statistics can be interpreted without problem.

This chapter gives account of the methods, results and explanation of price formation and cost pass-through in the six selected sectors. The order is as follows:

- Section 4.2: Refineries
- Section 4.3: Iron and Steel
- Section 4.4: Fertiliser
- Section 4.5: Cement
- Section 4.6: Petrochemicals
- Section 4.7: Glass

Section 4.8 concludes by giving a cross-sectoral overview of results and indicative values of the cost pass-through rates and discusses a first indication with regards to the underlying drivers, which is further elaborated on in the following Chapter 5.

4.2 Refineries

4.2.1 Introduction

The refineries sector produces refined petroleum products from crude oil. Typically, these products are used as transport or heating fuels or as inputs to the petrochemical industry (notably naphtha). The refining process varies in complexity (IEA, 2005b) but all techniques do follow a similar production pattern. The process can be split into three parts (McKinsey, 2006):

1. Separation. The crude oil is broken up into its components, for example, via distillation.
2. Conversion. Depending on the end products required, several intermediate streams can be converted, typically by further breaking up molecules.
3. Finishing. It means that different intermediate streams are blended to achieve the desired qualities, and impurities are removed.

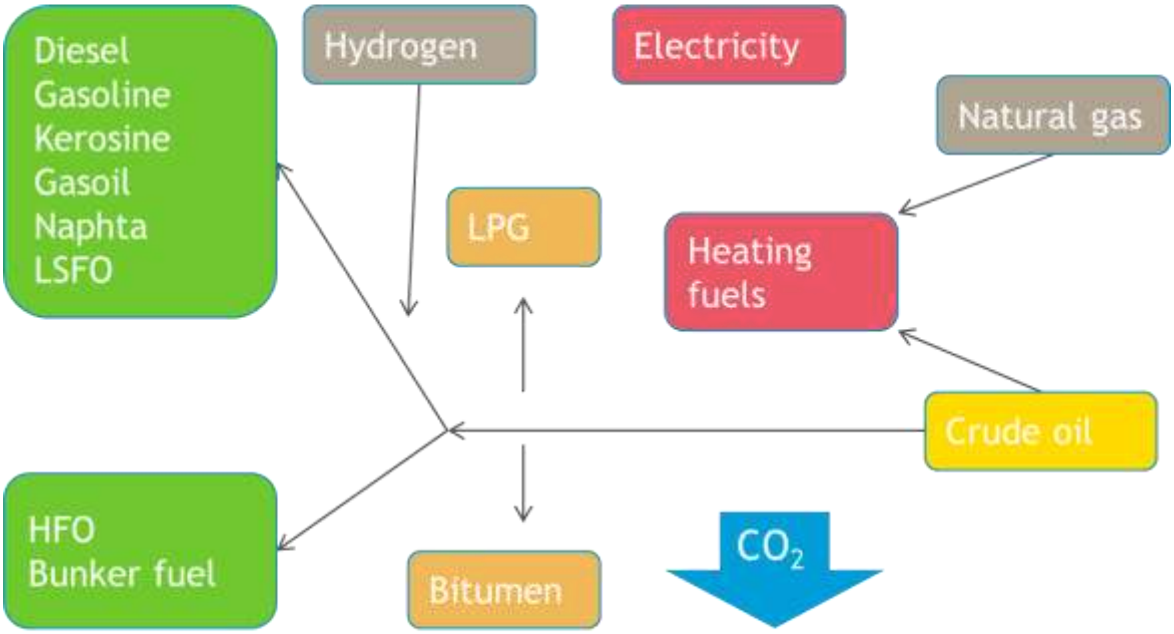
In addition to these traditional steps, specialised effort must be undertaken to desulphurise the oil to meet environmental regulation (and to reduce corrosive capacities of the fuel). CO_2 emissions occur during separation and conversion (e.g., process heaters and boilers).

In addition to these combustion-related sources there are certain processes, such as fluid catalytic cracking units (FCCU), hydrogen production units, and sulphur recovery plants, which have significant process emissions of CO_2 (EPA, 2010).

Refining of crude oil into petrol, diesel and gas oil requires heating the oil, which causes CO_2 emissions. These are regulated under the EU ETS. In addition, carbon is of course included in the products from the refineries sectors. These are not regulated.

We have focussed our analysis of cost pass-through on the production of petrol, diesel and gasoil. The stylised production route is depicted in Figure 3.

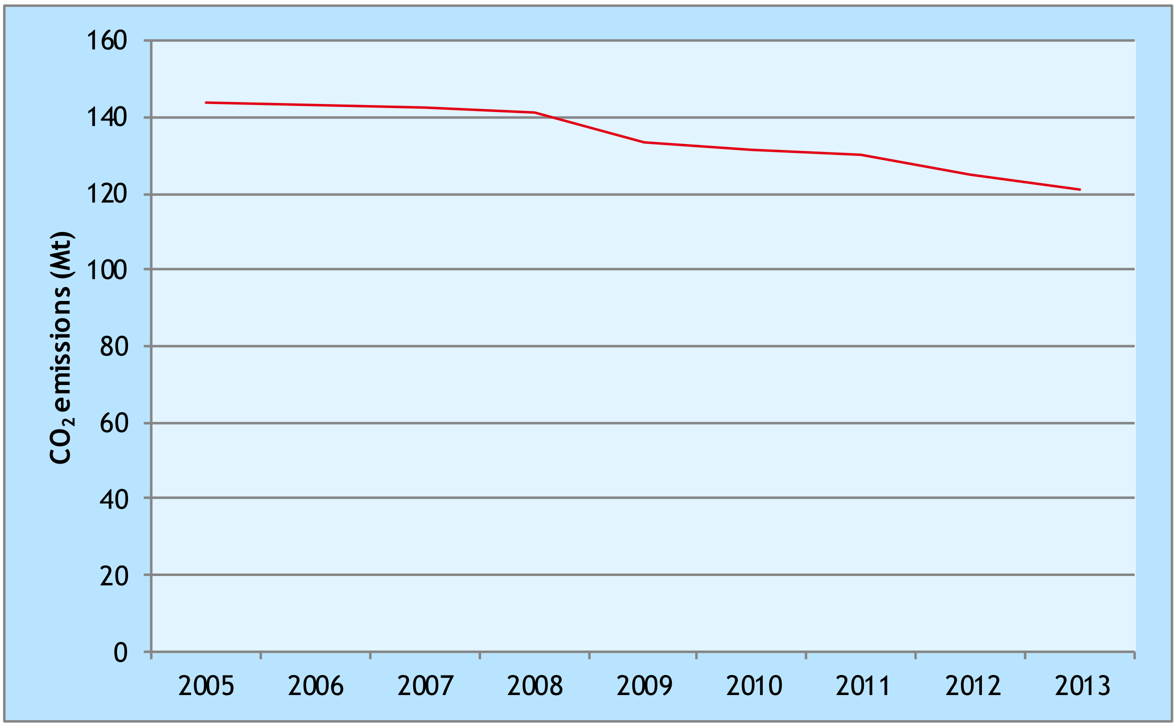
Figure 3 Production process of petrol, diesel and gasoil



4.2.2 ETS emissions

The refineries sector GHG emissions were part of the ETS since its start in 2005. However, Bulgaria, Norway and Romania only joined in at the start of Phase 2 in 2008. The sector accounts for some 7% of total emissions recorded under the ETS, which is equivalent to about 21% of industrial emissions. For the sector remained stable, the number of emissions declined somewhat from around 150 million ton before the crisis to 123 million ton in 2013, see Figure 4.

Figure 4 Total verified CO_2 emissions (Mt) for the sector refineries (excl. Bulgaria, Romania, Norway and Croatia)



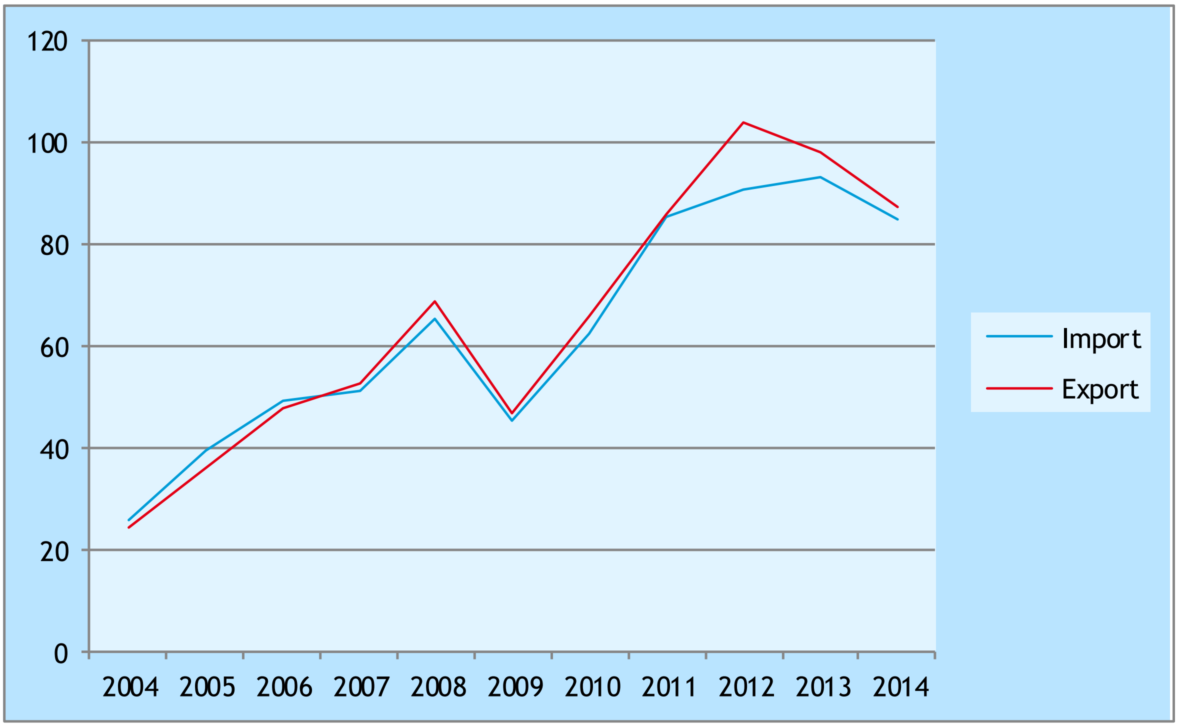
Source: EUTL, own calculations.

4.2.3 Market conditions

European refineries are mostly part of large multinational companies that operate worldwide. The global market for refined products is a regional market where trade flows exist between major trading blocs where prices are to some degree integrated. Refining capacity is dominated by the Middle East, Eastern Europe and North America, which together account for nearly two thirds of global refineries (IEA, 2005b).

Trade data on refined products show that imports and exports of the refined petroleum products are very much in balance and have been growing substantially over the last decade. Since 2007 the EU refinery sector has been a net exporter of refined petroleum products (when expressed in value) which may show its relatively good competitive position. However, when compared to major trading blocks, the EU refinery sector falls a bit behind in trade performance to its most important competitors (EC, 2014).

Figure 5 Extra EU27 imports and exports in €bn from the refinery sector (NACE 192)



Source: Eurostat international trade statistics.

Between 2005-2010 there was a shortage of refining capacity in the world market caused by the strong demand in the rapidly growing regions with insufficient refining capacity, such as in Asia (especially China) and North America. Moreover, strict European standards concerning e.g. Sulphur content of petrol, gasoil and kerosene have formed a barrier to competition from imports (McKinsey, 2006; IEA, 2005b). Both advantages are slowly disappearing according to the sector and literature. Worldwide substantial new refinery capacity is realised (especially in the Middle East and Russia) which aims to serve export demand and thus will compete with the EU refineries (CIEP, 2014). EU refineries have experienced a decline in capacity utilisation starting from 2005, due to fuel substitution in industry and buildings and energy efficiency improvements in transport[18]. The crisis in 2008 extended and accelerated this trend. Since 2011, the sector has recovered a bit, but capacity utilisation rates are still well below pre-crisis levels. This limits the sector's ability to maintain profit margins.

Price regimes in the refinery sector differ from fuel to fuel. There is an on-going debate to what extent the refinery sector is capable of influencing the market price by using its oligopolistic power. The top five EU refining companies hold over fifty percent of the market share (McKinsey, 2006). Refineries are often part of a vertically integrated chain that consists of oil fields and gas stations. In Germany, some heavily contested evidence of an oligopolistic market structure manipulating prices has been

18 http://www.enerdata.net/enerdatauk/press-and-publication/energy-news-001/middle-east-oil-refined-consumption-increase_30188.html

shown in the markets for gasoline and diesel. (Bundeskartellamt, 2011)[19]. However, in other countries such a pattern could not be found (see OECD, 2013 for an overview). Therefore it is difficult to generalise this. A substantial part of the EU's retail sector is in the hands of the self-employed who are not part of the refining business and refineries compete with importers to supply to them.

This is most obvious in the case of lubricants where the vast majority of products are imported (CEPS, 2008).

4.2.4 Data

In this research it was decided to investigate the impact of the EU ETS on prices of diesel, petrol and gasoil. Diesel and petrol are primarily used in the transport sector and constitute together over 50% of production output of the refineries sector. Gasoil is mainly used as heating oil and constitutes a smaller amount of output from the EU refineries (around 10%).

Prices of diesel and gasoline are available on a weekly and monthly basis. While such data are available for many EU27 countries, the choice of countries was, in the end, based on Eurostat data-availability of additional data for the sector refineries (NACE 1920) on labour input, capital costs and turnover. This resulted in collecting price data for 6 countries: Belgium, Germany, France, Greece, Italy and Poland. Prices have all been collected excluding taxes.

Next to these, crude oil price data has been collected using different series. For the weekly data, the Brent Index from PLATTS was used. Descriptive statistics of the data and data sources can be found in Annex A.

4.2.5 Price formation

Prices of crude oil in international markets are considered to be the main driver of petrol and diesel prices for road use. However, gasoline pump price changes and volatility are not only the result of variations in crude oil prices, but also of changes in other factors (OECD, 2014). International benchmark prices or quotations of refined products serve as reference to ex-refinery prices of petrol and diesel which will be reflected in retail gasoline prices. Exchange rates also influence retail gasoline prices. Increasing demand for gasoline, higher prices of ethanol and loss of refinery capacity or situations of refinery outages and political turmoil may all have an influence on price formation.

Fuels are heavily taxed in the EU countries. While we estimate the impacts of the EU ETS on pre-tax prices, the tax system may introduce distortions in the relative price of gasoline and diesel and influence demand and thereby indirectly influence the pre-tax price.

[19] Such behaviour may even be true in more competitive markets through the eventual use of distorted (or manipulated) price industry benchmarks (see also below).

Although a large number of firms are vertically integrated, there is an open and transparent market for the sub products that form the chain between crude oil and end products sold to the transport sector. We use these open markets to observe wholesale prices for Diesel, Petrol and Gas Oil.

Prices at the retail market are formed through a combination of contracts and spot prices. We distinguish here three types of clients in the wholesale market that may influence the price formation:

A. Supply & Trading clients, like large fuel distributers with there own storage or traders. Trading takes place in batches of products of 2.500 tonnes at a minimum. Prices can be either spot or based on contracts for no longer than 12 months.
B. Commercial & Industrial clients like industry, haulage companies, agricultural companies, supermarkets and general resellers. Trading volumes vary from a few thousand litres to large annually contracted amounts. Prices are spot and based on contracts for no longer than 12 months.
C. Retail clients, like company retail sites and contracted dealers. Prices are usually based on contracts for a 5 year term.

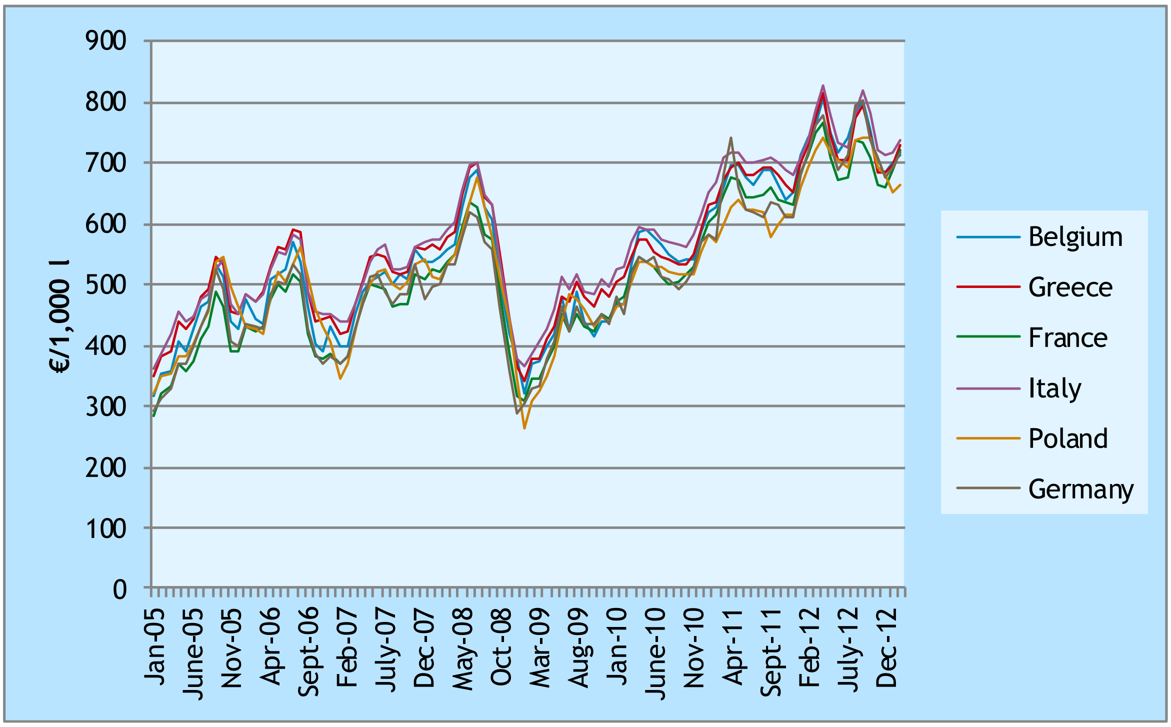
If prices are based on contracts, these contracts are typically based on a PLATTS plus tariff. The PLATTS part will float as per the daily published market price. The plus quotient will be fixed containing any costs, like credit, compulsory stock, duty, VAT, delivery or additives, plus a profit margin (source: anonymous interview).

Price competition between customers may be limited by the use of service cards or loyalty cards. These cards are issued to business consumers and may limit competition. In the case of diesel they account for almost 40% of the total sales volumes in Germany (Bundeskartellamt, 2011). They are noticeably less significant in petrol sales and are used to a larger extent at motorway petrol stations than at off-motorway petrol station.

Price formation for petrol and diesel may be influenced by the use of price industry benchmarks. The prices assessed and published by Price Reporting Agencies serve as benchmarks for trade in the physical and financial derivative markets. Prices for many contracts, i.e. long-term contracts and contracts for financial products (derivatives) that influence the price formation are based on these price benchmarks (of physical spot trades). There are several price reporting agencies in the oil market, of which PLATTS is the benchmark for contracts. Competing agencies are Argus and ICIS. There are concerns (OECD, 2013) that the price benchmarks are based on too low a number of bids and offers, making them prone to manipulation. In Europe, for instance, the quotations for refined products published on a daily basis by Platts for transactions carried out with refineries in North Western Europe (NWE) or in the Mediterranean (MED).

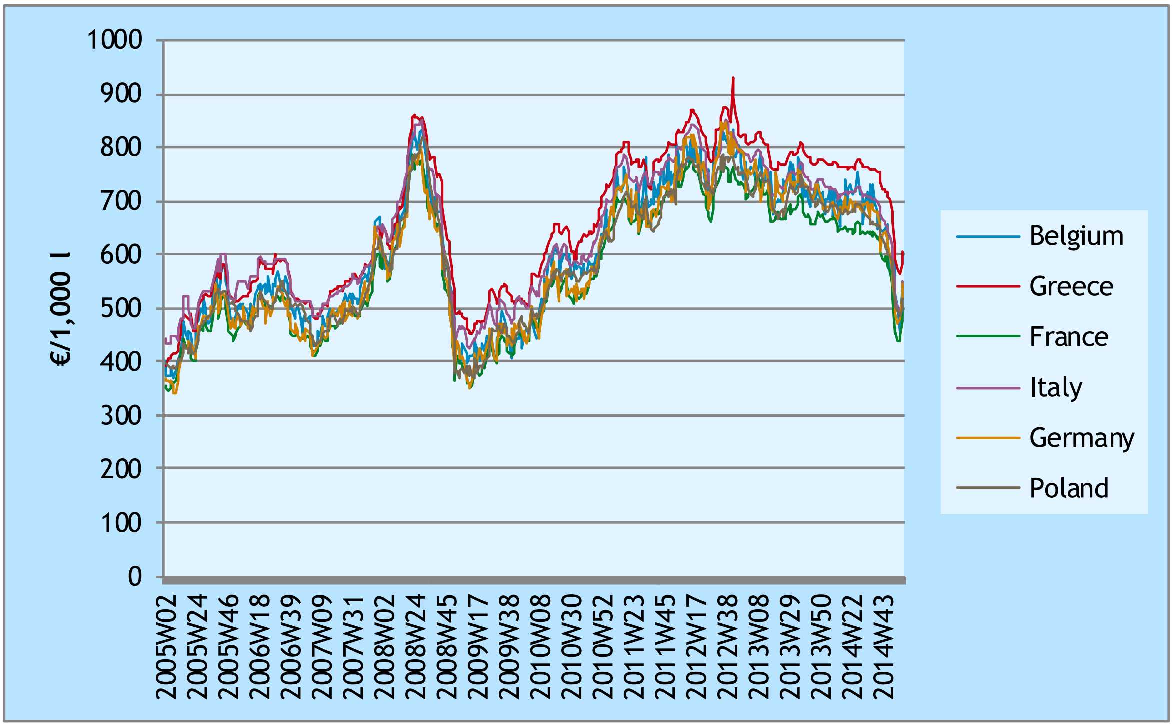
Prices of the products chosen are given in Figure 6/Figure 7/Figure 8. As the prices of the three products chosen are largely driven by crude oil prices, they exhibit a similar pattern. The spikes and throughs of the output prices follow the spikes and throughs of the crude oil price quite consistently, with peaks just before the crisis, a sharp drop in 2008 and a recovery as we move towards the end of the timespan observed.

Figure 6 Nominal prices of petrol before taxes for the countries analysed



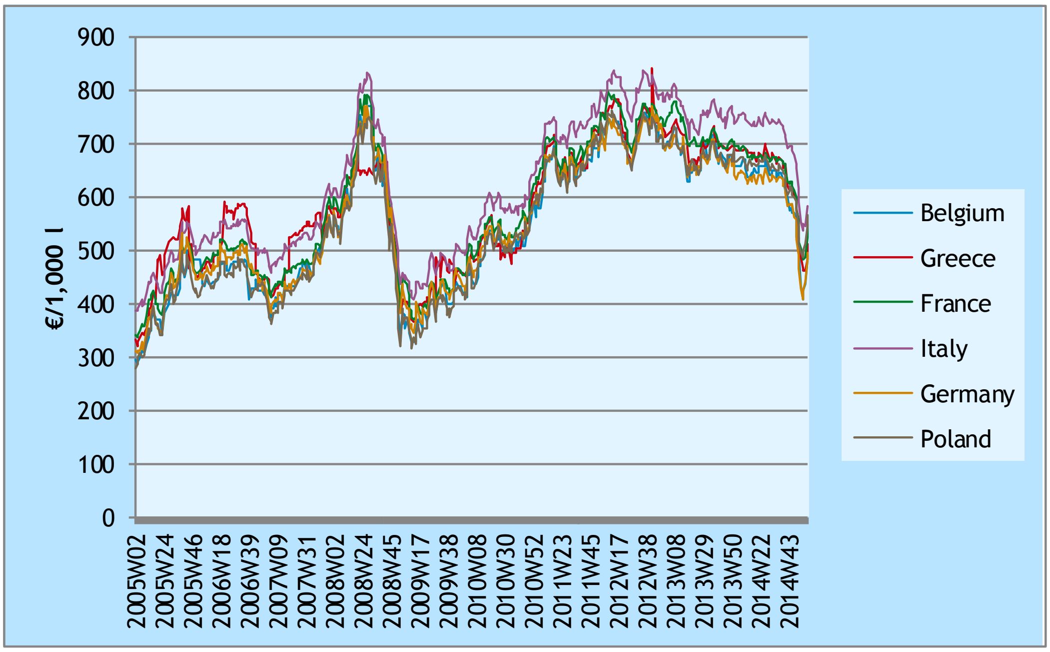
Source: Oil Bulletin.

Figure 7 Nominal prices of diesel before taxes for the countries analysed



Source: Oil Bulletin.

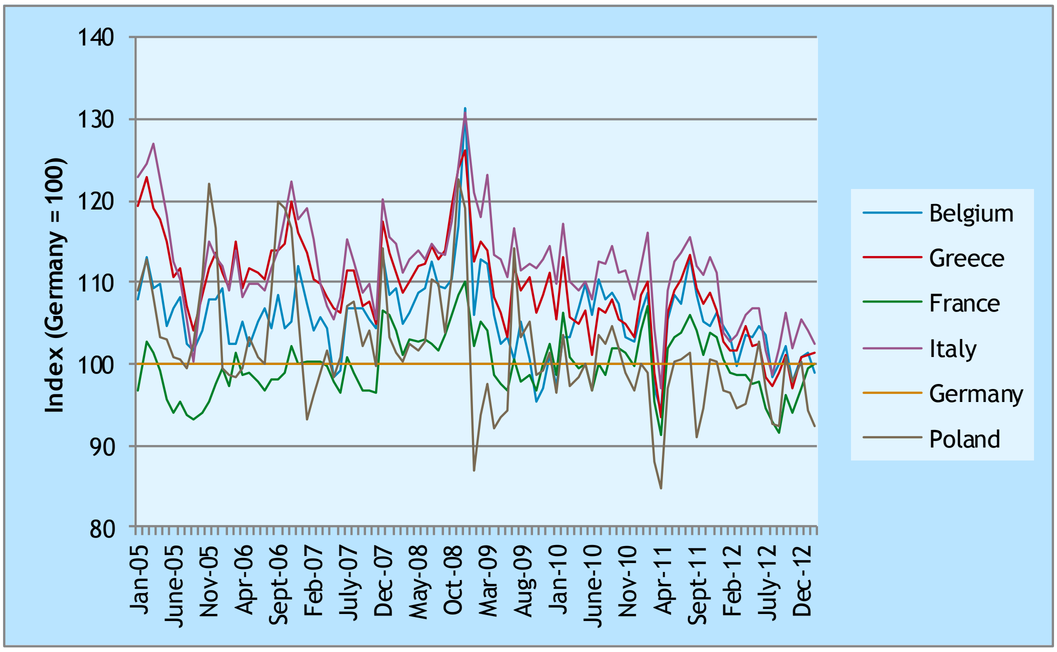
Figure 8 Nominal prices of gasoil before taxes fort he countries analysed



Source: Oil Bulletin.

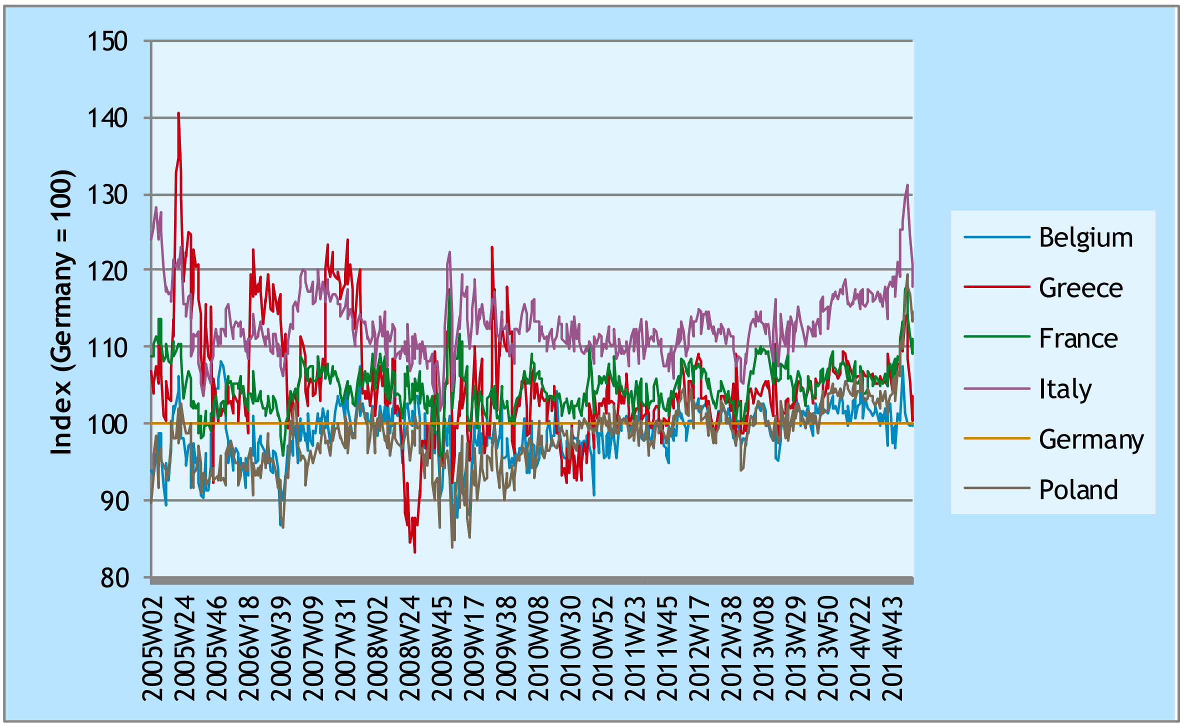
We further observe that prices in different countries have to some extent a similar pattern, which points to integrated markets between these countries. However, over time it can be shown that the prices are not consistently integrated over the time period. Figure 9 and Figure 10 depict the price of petrol and gasoil in various countries relative to Germany. What is remarkable is that it seems that there is a pattern in the deviations in petrol prices relative to Germany. Moreover, over time, these deviations tend to become smaller. With gasoil a less clear picture emerges.

Figure 9 Prices of petrol before taxes relative to Germany



Source: Oil Bulletin.

Figure 10 Prices of gasoil before taxes relative to Germany



Source: Oil Bulletin.

4.2.6 Estimation procedure

In order to test the influence of the EUA price on the price formation of diesel, petrol and gasoil, we have followed the estimation procedure described in Chapter 3. First, all variables have been transformed to logs to facilitate estimation of the model. Second, unit root tests have been applied to investigate whether the variables contain unit roots. In the appendix, unit root tests are reported for these variables. The outcome of the unit root tests is that all price variables contain a unit root. Subsequently, we have tested for cointegration.

This showed that cointegration was present especially between crude oil prices, product prices and CO_2 prices for diesel and gasoil for weekly prices.[20] For petrol often no cointegration could be found for weekly prices and the data seemed to be highly correlated when included in an adapted form in an ARDL or VECM. Therefore, we decided to augment the data for petrol to include other observations (on energy, labour and capital costs) in a monthly format.

[20] The output prices are explained by their main input: crude oil. Next to this we add a variable for the price of CO_2 EUA's, and a number of variables that indicate other costs, such as wages, the interest rate and the exchange rate as well as controls for the general economic climate such as a stock market index and an indicator for the production volume in the sector. All variables are entered in logs. The control variables are entered in first differences except for petrol where the exchange rate was introduced in levels.

We have run models for the six countries Belgium, Germany, France, Greece, Italy and Poland, using the weekly (diesel, gasoil) or monthly (petrol) data and trying to explain the prices of the three products mentioned above. The procedure followed was as described in Chapter 3. Using a VECM approach, we obtained the following insights:

A. The results are highly sensitive to the amount of lagged first differences included. This includes sensitivity of the outcome of cointegration tests, signs and significance of coefficients of CO_2 costs and of the adjustment coefficient.
B. Tests for residual autocorrelation (e.g. the Q-statistic, the LM-statistic or the simple t-test) indicate that residual autocorrelation is present for lags that are below or near the last lagged difference that is included in the equation. This would lead to inconsistent results.
C. Granger causality tests show that granger causality is rejected for output prices of refineries industry causing the input prices.

The results on the VECM point to the appropriateness of using an ARDL. As explained in Chapter 3, we consider an ARDL appropriate if statistical tests cannot reject the hypothesis of no granger causality, or if we are stuck with inconsistent models due to excess autocorrelation in the residuals. Given that ARDL's display less autocorrelation in the residuals, we interpret the excess autocorrelation in the VECM as arising from incomplete models for the reversed causality.

An added benefit of using an ARDL is that we can explicitly consider potential delays in the cost pass-through. A delay in cost pass-through happens if e.g. CO_2 prices are not transferred directly into product prices, but rather with a delay of e.g. 1 or 2 weeks/months. As explained in Chapter 3, such delays cannot be appropriately modelled in a VECM context. The interpretation of found delays is multifaceted: it may stem from the definition of price variables, containing a mix of prices of long-term contracts, futures and/or spot prices, or it may stem from actual behaviour of market parties.

The ARDL models were estimated for a sample including all potential observations and a sample where the observations were limited to Phase 2 and Phase 3. In general the ARDL models behaved reasonably well for the refineries sector, especially for the estimations that were limited to Phase 2 and Phase 3. We were able to select models with well behaved residuals according to the simple AC and PAC tests as well as the LM and Q-tests. These models have consistent estimates where all variables have the expected signs. In these cases, the Bounds-test indicated a cointegration relationship for most countries and significant cost pass-through of CO_2 was found for the analysis of Phase 2 and 3, while the estimate for the cost share of Crude Oil seemed reasonable.

4.2.7 Estimation results

Table 9, Table 10 and Table 11 display the results for models that explain the price of diesel, petrol and gasoil respectively for the ETS Phases 2 and 3. As indicated in Chapter 3, models explaining price behaviour in the ETS Phases 2 and 3 were more consistent and with more explanatory power than models explaining price behaviour for the entire ETS period. [21]

[21] Results including Phase 1, 2 and 3 can be found in the Annex and contained less clear results.

With respect to diesel, our estimated model shows significant cost pass-through of crude oil and CO_2 (for all six countries except Germany).

Table 9 Summary of estimation results: Diesel, Phase 2 and 3

Country	Belgium	Germany	France	Greece	Italy	Poland
CO_2_delay	2	0	0	0	0	0
CRUDE OIL_delay	0	0	0	0	0	0
Maxlags	4	3	1	3	5	3
CRUDE OIL_coef	**0.886**	**0.876**	**0.852**	**0.772**	**0.822**	**0.849**
CRUDE OIL_t_stat	12.789	14.597	35.718	15.800	17.231	26.425
CRUDE OIL_pval	0.000	0.000	0.000	0.000	0.000	0.000
CO_2_coef	**0.047**	0.012	**0.037**	**0.028**	**0.053**	**0.040**
CO_2_t_stat	1.545	0.453	3.362	1.322	2.605	2.733
CO_2_pval	0.062	0.325	0.000	0.094	0.005	0.003
adj. coef	**-0.122**	**-0.116**	**-0.194**	**-0.062**	**-0.065**	**-0.137**
t_adj. coef	-4.048	-3.915	-10.426	-4.480	-4.136	-6.770
p_adj. coef	0.000	0.000	0.000	0.000	0.000	0.000
SIC	-5.497	-5.852	-6.595	-7.633	-7.599	-6.737
Bounds F-statistic	**6.561**	**6.018**	**40.220**	**8.618**	**7.228**	**17.765**

Figures in bold indicate statistical significance of at least 10%.

The appropriate delay for crude oil as well as CO_2 is 0, except for Belgium where the delay for CO_2 is two weeks.[22] Crude oil has a cost share that ranges from 77 to 89%, which we consider plausible. The bounds tests point to cointegration between the diesel price, CO_2 price and crude oil price – which form the long-run equilibrium relationship. Adjustment coefficients are negative and significant indicating a long-term tendency within the market for diesel to revert to the equilibrium relationship.

The coefficient for CO_2 indicates that the price of diesel contains CO_2 costs equivalent from 2.8% in Greece to 5.3% in Italy. These costs are quite high - and higher than one would expect on the basis of LCA (see also Section 4.2.8).

For **petrol**, the results from the weekly series did not produce any satisfactory results that were free of higher order autocorrelation. Therefore, additional variables have been added for the costs of labour. This improved the estimates and the results for Phase 2 and 3 can be found in Table 10. For Poland, this model performs not satisfactory in terms of residual behaviour and Bounds tests. For the remaining countries, the crude oil cost component is significant with estimated cost shares slightly below that of diesel. The CO_2 costs are significant for Belgium, Germany, France and Italy and only insignificant in the case of Greece.

[22] Maximum lag length of included first differences of the long-term relationships varies between countries from 1 to 5.

Table 10 Summary of estimation results: Petrol, Phase 2 and 3

Country	Belgium	Germany	France	Greece	Italy	*Poland**
CRUDE OIL_delay	0	0	0	0	0	*2*
CO_2_delay	3	0	0	3	0	*1*
Maxlags	3	3	2	3	2	*1*
CRUDE OIL_coef	**0.746**	**0.769**	**0.801**	**0.656**	**0.646**	***0.287***
CRUDE OIL_t_stat	33.393	25.713	29.044	26.155	34.061	*0.338*
CRUDE OIL_pval	0.000	0.000	0.000	0.000	0.000	*0.368*
CO_2_coef	**0.015**	**0.013**	**0.016**	0.006	**0.013**	*0.017*
CO_2_t_stat	2.239	1.315	1.730	0.987	2.057	*0.139*
CO_2_pval	0.014	0.096	0.043	0.163	0.021	*0.445*
adj. coef	**-0.649**	**-0.468**	**-0.442**	**-0.516**	**-0.464**	*-0.068*
t_adj. coef	-7.259	-6.022	-5.503	-6.288	-6.374	*-0.604*
p_adj. coef	0.000	0.000	0.000	0.000	0.000	*0.274*
SIC	-4.647	-4.648	-4.913	-5.264	-5.577	*-3.846*
Bounds F-statistic	**17.497**	**12.205**	**9.809**	**13.468**	**13.423**	*0.639*

Notes: Results from estimating with monthly data, Jan 2008-febr 2013. Figures in bold indicate statistical significance of at least 10%.

* This model does not satisfy our criteria on residual behaviour and the Bounds test negate the possibility of an ARDL structure for Poland. Results are presented here only for reference.

The delay by which CO_2 prices influence the price of petrol varies between 0 and 3 months, while that of the crude oil price is 0 months. Adjustment coefficients are negative and significant, while the Bounds test statistic points to a cointegration relationship between the Petrol price, the crude oil price and the CO_2 price in all countries except Poland.

For **gasoil** Table 11 the results of our estimates. The model performed reasonably well for all countries. In half of the countries, notably Belgium, Germany and France, significant cost pass-through of CO_2 was found in the period covered by these ETS phases.
Cost shares in Belgium and France are around 2% and three times higher in Germany. There are some reasons to believe that this latter cost share is too high (see also the discussion in Section 4.3.8).

Table 11 Summary of estimation results: Gasoil, Phase 2 and 3

Country	Belgium	Germany	France	Greece	Italy	Poland
CO_2_delay	0	1	0	1	0	1
CRUDE OIL_delay	0	0	0	0	0	1
Maxlags	1	5	1	4	1	3
CRUDE OIL_coef	**0.871**	**0.929**	**0.844**	**0.814**	**0.803**	**0.887**
CRUDE OIL_t_stat	33.826	16.378	21.983	15.843	25.255	13.062
CRUDE OIL_pval	0.000	0.000	0.000	0.000	0.000	0.000
CO_2_coef	**0.019**	**0.071**	**0.023**	0.001	0.008	0.018
CO_2_t_stat	1.633	2.998	1.326	0.059	0.598	0.556
CO_2_pval	0.052	0.001	0.093	0.477	0.275	0.289
adj. coef	**-0.240**	**-0.114**	**-0.114**	**-0.118**	**-0.109**	**-0.094**
t_adj. coef	-9.917	-4.870	-7.285	-4.785	-7.931	-3.466
p_adj. coef	0.000	0.000	0.000	0.000	0.000	0.000
SIC	-5.995	-6.310	-6.808	-6.205	-7.313	-5.928
Bounds F-statistic	**35.064**	**11.905**	**21.679**	**9.583**	**26.875**	**4.491**

Notes: Results from estimating weekly data, January2008 to Ferbruary 2015. Figures in bold indicate statistical significance of at least 10%.

The cost share of crude oil that is implied by our estimations ranges from 80% to 93%. Adjustment coefficients are negatively significant, cointegration cannot be rejected according to the Bounds test.

4.2.8 Indicative cost pass-through rates

The coefficients from the estimations above represent the cost share of the opportunity costs of CO_2 in the product prices. They show that the null hypothesis of no cost pass-through was rejected in more than half of the investigated price series indicating that in the majority of cases cost pass-through seems likely in the refineries sector.

As stated in Chapter 3, it is not always straightforward to interpret the coefficient in terms of *cost pass-through* rate in order to determine *how much* of the carbon costs seemed to be passed through. This depends on the specific emissions that are allocated to the product by the company and on emissions that occur prior in the production chain. In addition, there is a divergence between *marginal* cost pass-through rates and *average cost* pass-through rates where average cost pass-through rates typically are higher than the marginal cost pass-through rates.

In a very extensive study, COWI et al. (2015) have given average values of carbon intensity in refineries for a number of products and countries in the EU. Their data show that the average EU CO_2 coefficients for petrol and diesel from well to tank are 18.2 and 17.4 grCO_2eq./MJ of product respectively. This is equivalent to 801 and 743 gCO_2/litre of product. These emissions do not only include emissions at the refinery plant but also emissions upstream. However, since also oil and gas exploration falls under the EU ETS, we think one should use the abovementioned figures in order to produce an indicative value of cost pass-through rates.[23]

If we multiply these emission factors with the average price of CO_2 over the estimation period, one obtains the insight that, on average, the cost share of petrol would be 1.6% and the cost share for diesel 1.3%. For gasoil the same value as for diesel can be chosen. In order to calculate an indicative value of cost pass-through rates, these cost shares can be compared to the estimator for the CO_2 cost share from Table 9 to Table 11. This would yield the insight that for petrol the indicative cost pass-through rates vary between the 80% for Germany and Italy to nearly 100% in Belgium and France. These results are reasonable and in line with what one would expect a-priori.

For diesel and gasoil we find evidence of indicative cost pass-through rates higher than 100% - ranging between the 200-400%. While this seems implausible high at first sight, three explanations can be offered that would potentially justify such results:

A. As explained in Chapter 3, cost pass-through rates are defined at the margin rather than at the average. The report by COWI shows that there are substantial differences in efficiency between EU MS, where Romania and

[23] If only emissions at the refineries plant would have been taken into account, the average EU CO_2 coefficients for petrol and diesel are 8.2 and 7.6 grCO_2eq./MJ of product respectively. The specific emission factors have been calculated with E3MLab's PRIMES refinery model by measuring of the variation of emissions after the marginal change of the demand for a specific fuel. Marginal content refers to the additional emissions generated from one additional unit of production of the specific product, which depends on refinery configuration that varies in the EU countries.

Croatia are on average 2-3 times less efficient than the EU average.[24] If the marginal inefficient installation for diesel determines the price and passes through 100% of their marginal carbon costs, average cost pass-through rates of 200-300% for the entire refineries sector can be expected.

B. Demand for diesel is different than demand for gasoline where diesel has been identified in the literature (see also below) as less price elastic than the demand for gasoline. The lower price elasticity would justify a higher cost pass-through rate than for petrol. In addition, under iso-elastic demand curves, cost pass-through rates higher than 100% could emerge (Sijm and Chen, 2009) if the refineries sector would not be characterised by perfect competition. OECD (2013) gives an overview of studies that have argued that price manipulation in especially the diesel market seems to be quite common. This could open the floor for specific pricing strategies from refineries in cost pass-through for diesel, such as deterministic cost allocation[25] or asymmetric price formation[26] that could explain cost pass-through rates higher than 100% as well.

C. The cost share estimates themselves are the outcome of regression analysis. These estimates are shielded by a confidence interval. The confidence interval gives an interpretation of the robustness of the estimate and consists of a range of values (interval) that act as good estimates of the unknown cost pass-through parameter. We have tested the confidence bounds and conclude that for diesel, France, Italy and Poland have cost pass-through higher than 100%, while 100% is within the confidence interval of cost pass-through rates for Belgium and Greece. For gasoil, Germany's cost pass-through rate is above 100%, while Belgium and France have cost pass-through rates with 100% within their respective confidence intervals.

Therefore, one should not conclude that indicative cost pass-through rates exceeding 100% would necessarily invalidate our results. Our estimates for the average cost pass-through rates are given in in Table 12.

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24 This implies that the total efficiency is 30-50% of the EU average. It should be noted here that the emission profiles are partly related to the refinery complexity and partly due to crude specifications. For example, for the relatively high capacity of vacuum distillation (47%), catalytic cracking (~20%) and coking (~9%) contribute most to emissions in Romania. The relatively high capacity of catalytic cracking along with the presence of hydrocracking and coking units are responsible for the higher carbon intensities of fuels in Croatia. Similarly, the low emissions in Denmark are due to the very low vacuum distillation capacity and the absence of main emitting processes (catalytic cracking and coking).

25 Deterministic cost allocation: refineries produce a couple of products and have CO_2 emissions not clearly allocated to each product. Petrol, diesel and gasoil typically make up for 50-60% of total products produced. If all CO_2 costs would be attributed to these products, cost pass-through ratios above the 100% could be expected.

26 Over the period 2008-2015 the CO_2 price has gradually been fallen. There has been quite some substantial literature on the asymmetric price formation in the refineries markets where refineries tend to pass-through price increases more directly than price decreases (Conforti, 2004). If this would have applied to CO_2 costs, it may be the case that in the end, the price rise would be entirely passed through in the product but the price fall only partially.

Table 12 % cost pass-through ratio's for cost pass-through of CO_2 in ETS Phase 2 and 3

Product	Country	CO_2 coeff.	P-value	% cpt ratio*	Statistically different from 100% cpt?**
Diesel	Belgium	**0.047**	**0.062**	**>100%**	**No**
Diesel	Germany	0.012	0.325		
Diesel	France	**0.037**	**0.000**	**>100%**	**Yes**
Diesel	Greece	**0.028**	**0.094**	**>100%**	**No**
Diesel	Italy	**0.053**	**0.005**	**>100%**	**Yes**
Diesel	Poland	**0.040**	**0.003**	**>100%**	**Yes**
Petrol	Belgium	**0.015**	**0.014**	**95%**	
Petrol	Germany	**0.013**	**0.096**	**80%**	
Petrol	France	**0.016**	**0.043**	**100%**	
Petrol	Greece	0.006	0.163		
Petrol	Italy	**0.013**	**0.021**	**80%**	
Petrol	Poland*	0.017	0.445		
Gasoil	Belgium	**0.019**	**0.052**	**>100%**	**No**
Gasoil	Germany	**0.071**	**0.001**	**>100%**	**Yes**
Gasoil	France	**0.023**	**0.093**	**>100%**	**No**
Gasoil	Greece	0.001	0.477		
Gasoil	Italy	0.008	0.275		
Gasoil	Poland	0.018	0.289		

* The % cost pass-through ratio has been calculated only in case of significant CO_2 cost coefficient. Explanations for cost pass-through rates above the 100% have been provided in the text above this table.

** Indicates whether or not significantly different from 100% cost pass-through at 10% level. This variable indicates whether 100% cost-pass-through rate lays within the confidence bounds of the CO_2 coefficient in the estimates. If the price variable is listed with "yes" in this table, it implies that we cannot say, on statistical grounds, that the found coefficient of cost pass-through is staisticially significant higher than 100%.

4.2.9 Discussion and interpretation

Our results show that in 2/3 of the estimated cases we find evidence of cost pass-through in the refinery sector. Indicative cost pass-through rates range between 80-100% for petrol and 100% (or above) for diesel and gasoline. This would imply that refineries seem to be able to pass-through the majority of the costs of carbon allowances.

The cost pass-through possibilities in the refinery sector should not be confused with the general economic situation. The EU refinery sector is generally believed to be in a more difficult situation than a decade ago. Demand for their products has been falling as a result of the economic crisis and climate policies. Since 2009 utilisation rates in the refineries sector declined towards around the 70% and a substantial share of production capacity has been closed between 2011 and 2013. In 2014 capacity utilisation rates have been increasing again to around 85%.[27] Our analysis does not

[27] Although the capacity utilisation rate can in theory differ between the 0 and 100%, capacity utilisation rates above the 90-95% are considered as suboptimal (refineries must be closed for maintenance and process switches) so that 95% can be regarded as operating under full capacity (Inkpen en Moffet, 2011).

find evidence that the lower capacity utilisation has limited the refineries in passing through the carbon costs in product prices.

Another noteworthy feature of the estimation results in the refinery sector is that we find a difference with respect to the magnitude of cost pass-through in petrol and diesel prices. Taking the indicative cost pass-through rates at face value shows that these rates for diesel are, on average, a factor 2 larger than for petrol. Moreover, the nature of cost pass-through was slightly different between diesel and petrol since we had to estimate two different models for these products. The fact that petrol and diesel prices may be diverging is a fact well noted in the literature (Bundeskartellamt, 2009). Firstly, petrol and diesel are not substitutable from a purchaser's point of view once he has taken a decision in favour of a particular engine technology. Petrol is more often sold at highway stations where different price regimes may prevail than in off-highway stations. Petrol is also more often sold through fuel and service cards to business consumers. In Germany these cards absorb 40% of the petrol market (Bundeskartellamt, 2011) and profit margins are larger for diesel than for petrol.[28] This may also be relevant for other countries. OECD (2013), for example, quotes Polish research that has shown that in Poland operating margins of diesel fuel are much larger than for petrol. Therefore these markets do not compete with each other and competitive conditions between these markets may diverge. Secondly, the potential use of price markers in both markets may be different. Petrol and gasoline prices are quoted at the London Stock Exchange. However, petrol is quoted on the New York Mercantile Exchange (NYMEX).[29]

Therefore one may conclude that the process of price formation between petrol and petrol diverges according to the literature and our results confirm this observation. Both markets may be oligopolistic in nature but operating margins are higher in the diesel market which may indicate that the market structure is less competitive in the diesel market than in the petrol market which gives more opportunities to maximise profits. Our econometric analysis on cost pass-through reinforces the literature on this subject.

4.3 Iron and Steel

4.3.1 Introduction

Steel is an internationally traded commodity that is used as an intermediate product in many industries, in particular in the automotive and construction materials industries. Steel can be produced either via the more carbon intensive primary steel production route (Blast Furnace/Basic Oxygen Furnace process –BF/BOF) primarily based on iron ore and coke or via the less emission intensive secondary EAF route primarily based on steel scrap and electricity (Figure 11).

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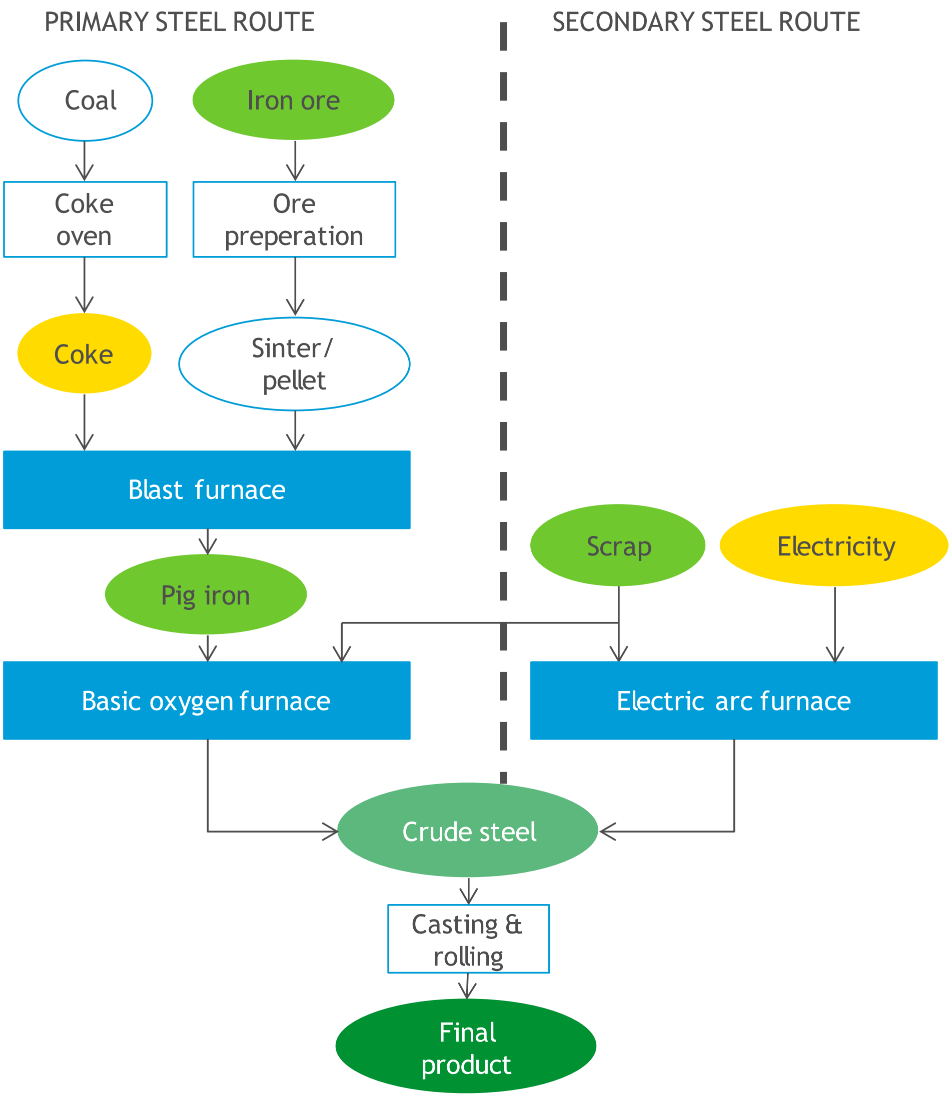
28 A possible explanation for the higher gross retail margin in the case of diesel may lie in the lower price elasticity in the demand for diesel because of the use of cards where purchasers of the fuel do not bear the costs themselves directly.

29 Another reason may be that weekly data are not entirely reliable. The OECD (2013), in giving account of the fuel price situation in OECD countries, quotes findings from the German literature showing that the price level of diesel and petrol was lower at the beginning of the week and increased, at easily identifiable points in time, over the course of the week until the most expensive day of the week, which was Friday.

Figure 11 Production process of iron and steel

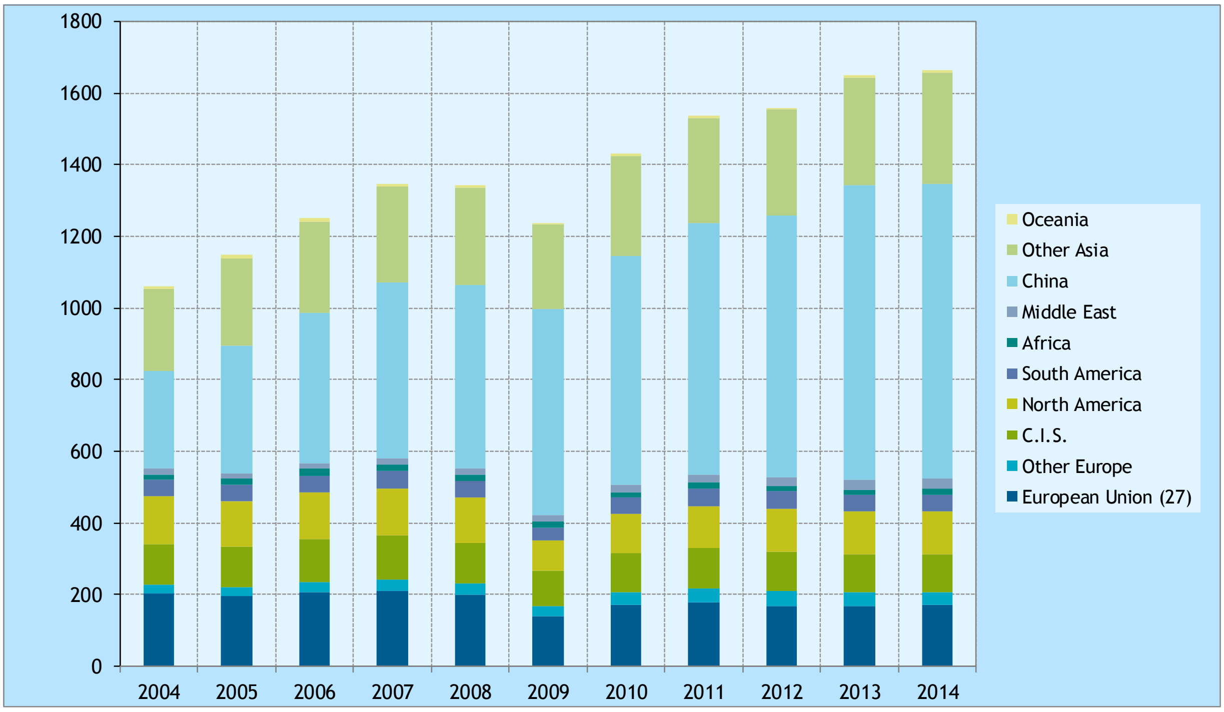


Global steel production amounted to about 1.665 million tons in 2014. It is concentrated in a few countries with China supplying about 50% of global production, followed by other Asian countries (e.g. India, South Korea, together 20%), the European Union (10%), North America (7%) and Russia (CIS, 6%)[30] (Figure 12). Market dynamics have substantially changed over the last decade with significant capacity increases in China.

30 CIS stands for Commonwealth of Independent States, an organisation representing the successor states of the Soviet Union. The abbreviation CIS is often used for the group of successor states, somewhat regardless of their actual member status in the association. Technically, CIS comprises of Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, and Uzbekistan. When grouping the countries for statistics, usually 'participating states' (Turkmenistan, Ukraine) and former member states (Georgia) are included in the calculations. This is also the case in Worldsteel data. The main steel producing 'CIS' countries under this definition are Russia and Ukraine, followed at a distance by Kazakhstan and Belarus.

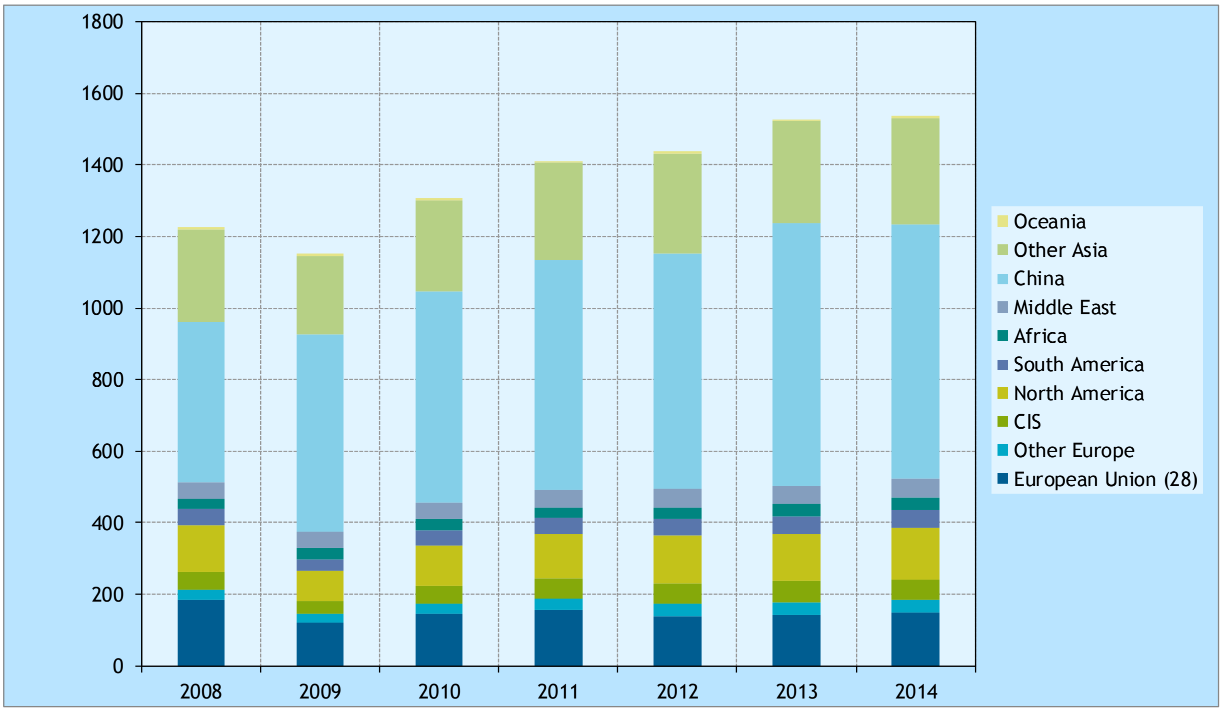
Steel consumption shows a similar picture (Figure 13). Consumption in China accounts currently for more than 50% of global steel demand and has been growing in recent years. The effects of the economic crisis can clearly be seen in 2009 for both consumption and production. However, it hardly affected Asian countries.

Figure 12 Crude steel production, by region, over time (million tons)



Source: World Steel Association, Steel Statistical Yearbook 2015 and World Steel in Figures 15.

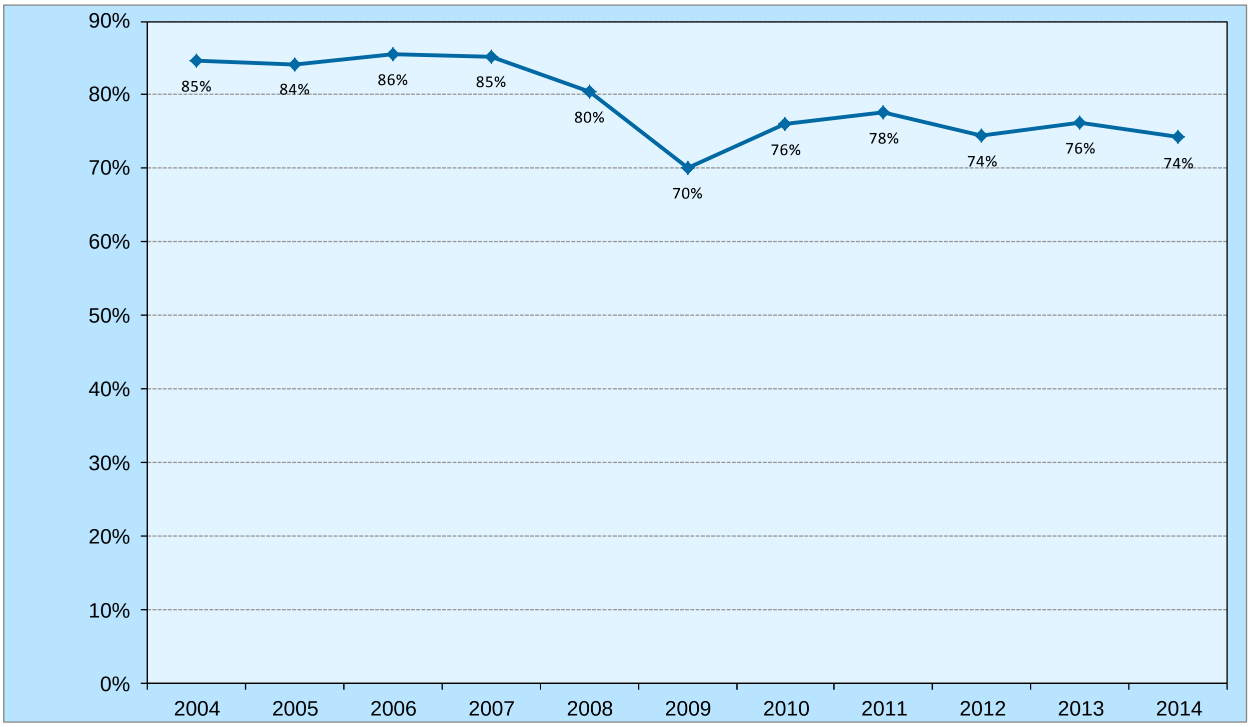
Figure 13 Apparent steel consumption, by region, over time (million tons)



Source: World Steel Association, Steel Statistical Yearbook 2014 and World Steel Figures 2015.

Capacity utilisation was very high in the pre-economic crisis years where many installations would be constantly deployed.[31] Capacity dropped considerably during the economic crisis and only slight recovered thereafter. While the prior crisis years were marked by international shortage of capacity, the build up of substantial production capacity in China in recent years - which is not mirrored by similar increases in demand- has resulted in excess capacity. This trend is expected to continue as other regions intend to expand their capacity as well (e.g. Middle East, CIS and Latin America, which have lower cost in processing steel and access to raw materials such as energy and iron ore). Also, the shale gas exploitation in the US might revive their steel industry with plans to use technologies (DRI process) based on natural gas rather than coke (Dröge, 2013). Capacity utilisation rates do not seem to differ much across major steel producing countries (e.g. US at 72% in 2015, China at 72% in 2013, EU 71% in 2013, CIS 74%).[32]

Figure 14 Capacity utilisation ratio global (production versus capacity in %)



Source: www.oecd.org/sti/ind/steelcapacity.htm

In 2014, on average 61% of crude steel in the European Union (EU28) was produced via the primary basic oxygen process, with Austria and the Netherlands almost exclusively producing via this route, while Bulgaria, Croatia, Greece, Luxembourg, Portugal and Slovenia exclusively employing the EAF route (Worldsteel Association, 2015). Within the EU, these shares have been rather stable over time. The picture looks different in other world regions: The share of primary steel production is

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31 Due to plant maintenance and down-time, plants cannot be used to 100%, a utilisation rate of 85% can be considered close to full capacity utilisation.

32 http://www.census.gov/manufacturing/capacity/; http://www.reuters.com/article/2014/05/08/us-china-steel-closures-idUSBREA4706D20140508; OECD (2015) Excess Capacity In The Global Steel Industry And The Implications Of New Investment Projects.

substantially lower, for example, in North America (around 40%) with a decreasing trend over time, whereas in China steel is primarily and increasingly produced via the more carbon and capital intensive conventional route (85% BOF steel production in 2004 and 94% in 2014, Worldsteel Association, 2015).

Products within the steel sector are either flat, e.g. slabs and hot/cold rolled coil, or long products, e.g. rod and bar. Flat products tend to be produced via the BOF route, while long products are primarily produced via the EAF route. Long products are generally of lower quality. They are primarily used for construction purposes. Flat products are of higher quality and are often tailored to reflect consumer specificities. They tend to have a higher value per ton of output and are therefore more profitable to transport and are more widely traded (Dröge, 2013).

4.3.2 ETS emissions

Steel production is an emissions intensive process. In particular the conventional integrated steel production process (BF/BOF) based on iron ore and coke is highly emission intensive. As shown in Table 13, emissions in integrated steel mills are on general 4-5 times higher than EAF emissions. For the EAF process, emissions are dependent on the fuel mix used for electricity generation.

Table 13 Specific emissions from production routes in the steel industry

Production route	Range of emissions
Integrated steel production (BF/BOF)	1.5-2.5 tCO_2/t crude steel
EAF using scrap	0.4 tCO_2/t crude steel

Source: Wooders et al. (2009).

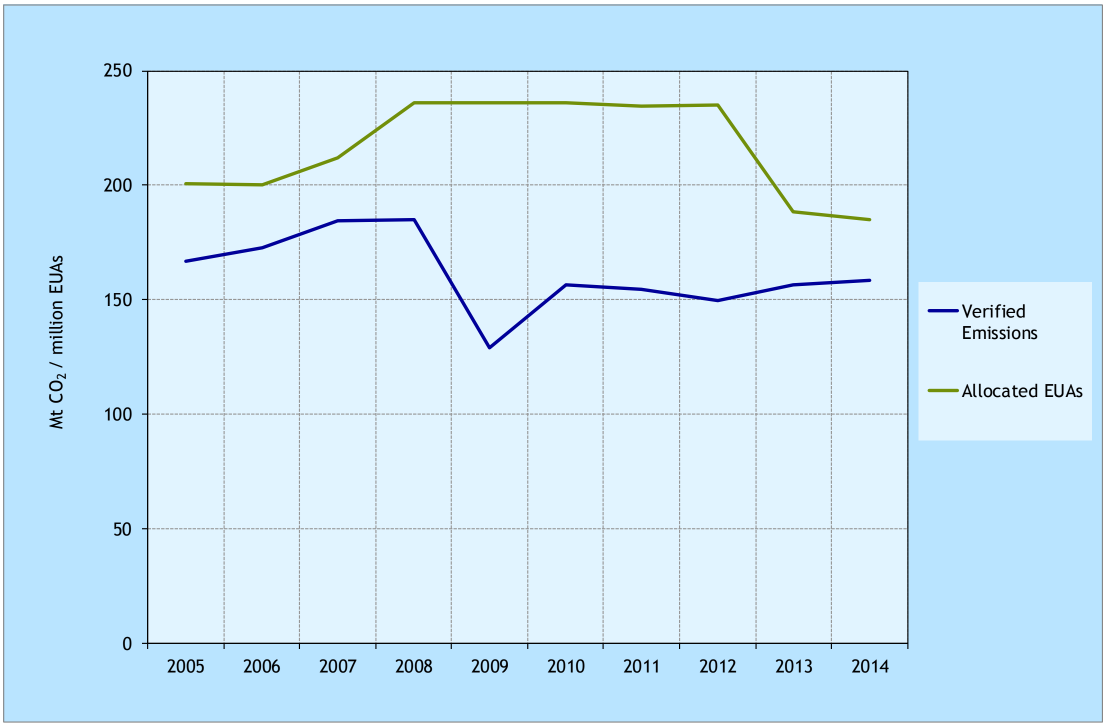
For our assessment of cost pass-through, we will be investigating only flat products, in particular hot rolled coil and cold rolled coil, which are produced via the conventional BOF/BF route, as these are much more carbon intensive and carbon costs are more substantial for this route.[33] Total direct emissions from iron and steel production within the EU are almost solely due to the BOF/BF route and are given in Table 123.

In 2014, installations with NACE code 24.10 account for roughly 9% of total EU ETS emissions and 18% of industrial emissions. Allocation of EUAs to the iron and steel sector has exceeded verified emissions continuously since the start of the EU ETS in 2005 – which partly has to do with coverage for the use of waste gases for electricity production and partly with the reduction in production due to the economic crisis.[34]

[33] For the long products (EAF), indirect costs due to higher electricity prices may be an issue.

[34] Emissions from blast furnace waste gases are recorded in the EUTL as emissions from the electricity sector. In some cases, authorities have granted iron and steel factories additional EUAs which were then transferred to the electricity producers to cover for the higher CO_2 content of these waste gasses.

Figure 15 Verified emissions and allocation of EUAs in the EU iron and steel sector (NACE code 24.10)

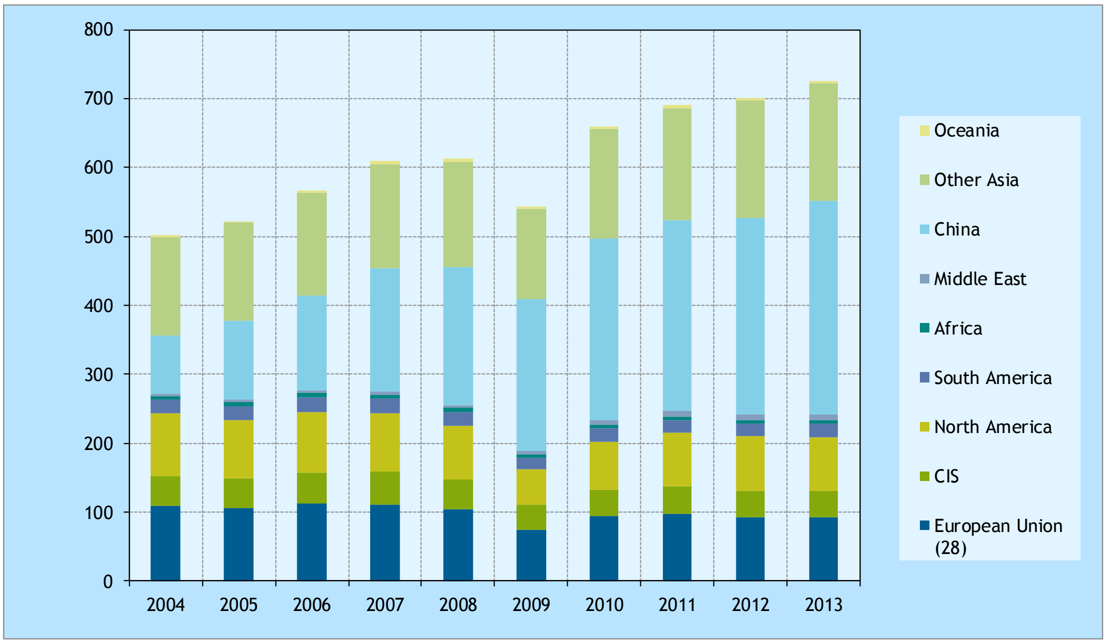


Source: Based on EUTL and NACE matching (EC, 2014a).

4.3.3 Market conditions

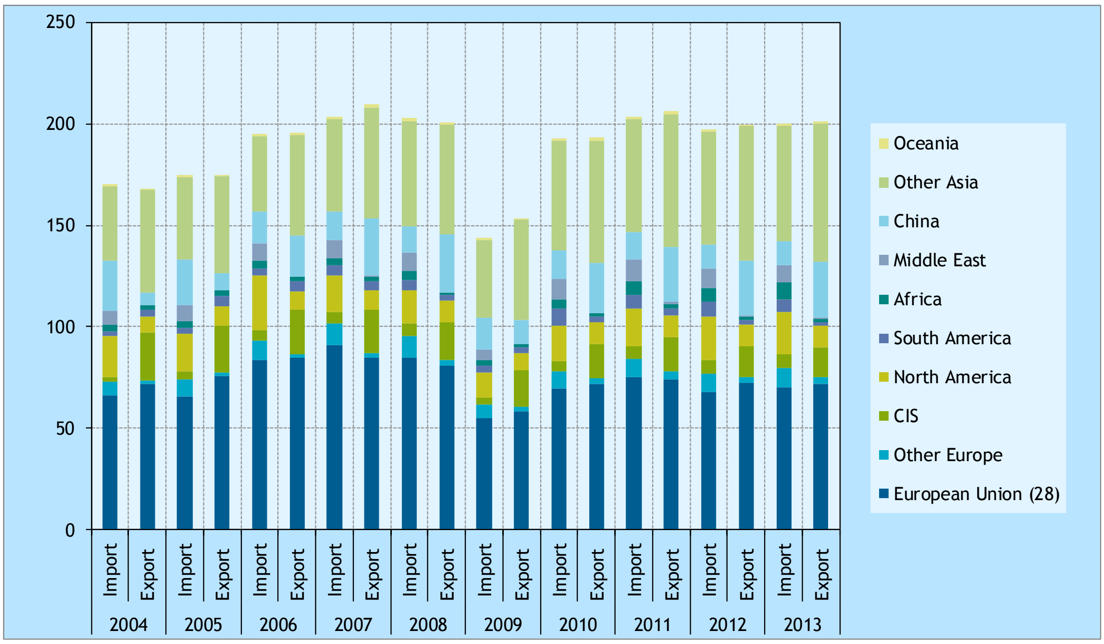
Taking a deeper look at flat steel products which are in the focus of our assessment, it can be noted that production of high quality flat steel products has increased in the last decade (Figure 16) – a growth that can be entirely attributed to the increased production in China which rose from 17% of global production in 2004 to 43% in 2013. Other Asian countries witnessed an increase in production as well, whereas the EU and North-America showed declining production levels.

Figure 16 Production of hot rolled flat products, by region, over time (million tons)[35]



Source: Worldsteel Association (2014).

Figure 17 Imports and exports of hot rolled flat products, by region, over time (million tons)



Source: Worldsteel Association (2014).

35 Data is only given for hot rolled flat products. The World Steel Association notes 'Hot rolled (hr) products (hr long products, hr flat products, seamless tubes) are products of first transformation. These products may be further worked to produce cold rolled-, coated-, and tubular products (except seamless tubes)' (Worldsteel Association, 2014, p.121).

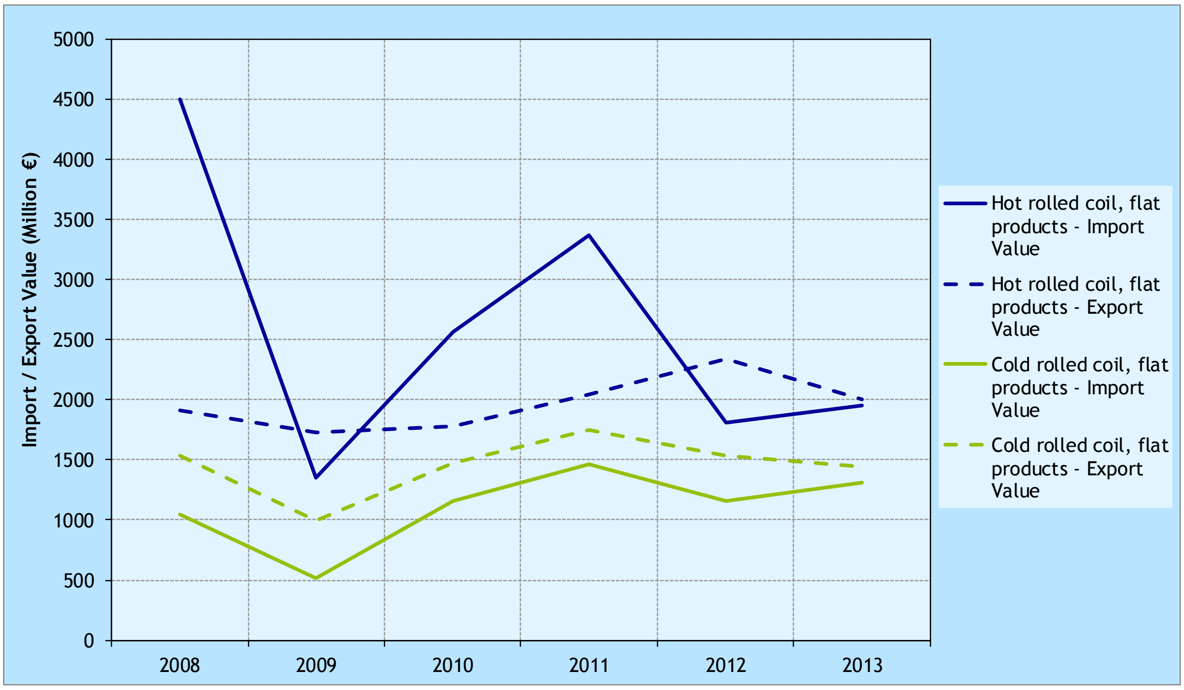
Interestingly, in terms of trade volumes the EU remained the largest importer and exporter of hot rolled flat products throughout the last decade. In most years, exports have surpassed imports in the EU, with the exception of the two pre-crisis years 2007 and 2008 when capacity utilisation and steel production was very high.

The European steel sector is a modern industry with its main customer base found within its home markets, particularly in the high-end segments.

The main competitive strength is based on high quality products, product innovation and technological development, efficiency and skilled manpower.

Trade plays a key role in European steel production. To derive a clearer picture of European trade, we look at trade patterns between the EU and countries outside of the EU for the two high quality products, hot rolled and cold rolled coil flat products that are subject to investigation in our study (Figure 18). The import value for hot rolled coil has been consistently higher than the import value for cold rolled coil. However, in recent years the difference has declined.[36] Import values of hot rolled coil are more volatile over time and show a much more pronounced response to the economic crisis compared to cold rolled coil. Whereas the import value of hot rolled coil is in most years higher than the export value, the picture is reversed for cold rolled coil where export values are consistently above import values in all years.

Figure 18 Imports and exports of hot and cold rolled coil to and from EU (values)



Source: Prodcom, whole EU: imports from extra-EU, exports to extra-EU, consistent scope only possible from 2008 onwards.

[36] It needs to be noted that import quantities for cold rolled coil are relatively lower (than those of hot rolled coil steel), thus cold rolled coil shows a higher value to weight ratio. The value to weight ratio can be considered an implicit import price.

4.3.4 Market concentration and price formation

Over the last decade, the steel market has increasingly been dominated by Chinese steel producers with a vast capacity expansion. This is also shown in Table 14 which provides an overview of the global top-10 steel producing companies. In 2014, out of the top-10, top-20 and even top-50 producers of crude steel more than half of the production originates from companies with headquarters in China.

Within the European Union, headquarter companies are Arcelor Mittal, which holds the largest global production followed by ThyssenKrupp AG, Germany (production of 16 million tons crude steel in 2014), SSAB, Sweden, Voestalpine Group, Austria and RIVA, Luxembourg (all around 8 million tons crude steel production in 2014).

Table 14 Top-10 producers of crude steel (million tons)

Companies	HQ	2011	2012	2013	2014
ArcelorMittal	Luxembourg	97	94	96	98
Nippon Steel and Sumitomo Metal Corporation	Japan	33	48	50	49
Hebei Steel Group	China	44	43	46	47
Baosteel Group	China	43	43	44	43
POSCO	South Korea	39	40	38	41
Shagang Group	China	32	32	35	35
Ansteel Group	China	30	30	34	34
Wuhan Steel Group	China	38	36	39	33
JFE Steel Corporation	Japan	30	30	31	31
Shougang Group	China	30	31	32	31
Others		1,120	1,132	1,204	1,219

Source: Worldsteel Association (2014).

The question is, however, to what extent this market concentration has influenced price formation and the competitive position of EU industries. After all, final steel products are quite heterogeneous. There are variations in steel grades and qualities to satisfy a wide range of applications, including the construction, automotive, packaging and manufacturing industries. These differences may constitute a kind of protection barrier for EU companies against competition from the global market, especially for flat products demanded by the automotive industry and for cans. In the EU, products and production methods are generally advanced compared to other regions. Nevertheless, such an advantage may vanish in the medium-term as technology quickly spreads (Hatch Beddows, 2007).

For products in the construction segment, the situation is different as products of a more uniform quality are required, which other regions can also supply. Subsequently, Europe might face more international competition, in particular in this segment.

European steel producers are being increasingly confronted with new competitors on the world market (China, Brazil, India and the Commonwealth of Independent States (CIS) countries). Some literature has identified substantial differences in operating costs observed throughout the world.[37] The average BOF Western EU plant has 40% higher operating costs than Brazil and Russia. This gap falls to around 20% for India

37 Although at the moment, due to the economic crisis, steel is dumped on EU markets by countries like Russia and the Ukraine which have overcapacity.

and China (Hourcade et al., 2007)[38]. This might indicate that the European steel market seems to be somewhat protected from foreign imports through trade barriers.

Interviews with anonymous client industries revealed that price formation for high quality products (e.g. flat products) differs from lower quality products. Integration of suppliers and client industries is more pronounced for higher quality products. This is particular true for specialty steels. Also, demand for steel is primarily driven by activities further down the value chain, in particular by the economic situation/activity in the client industry. Prices thus respond to the economic climate and downstream pro-cyclical changes in demand (Dröge, 2013). At the same time, steel demand is less responsive to an exogenous change in steel prices due to, for example, higher input costs including CO_2 related costs. This might provide an indication that cost pass-through is possible in the steel sector without compromising the market share. However, this point was not stated or affirmed by the interviewees (client industries).

Moreover, price formation also differs by type of client industry. Smaller clients, such as steel traders for retail with small storage capacities, reported to purchase flat steel products on spot markets with prices fluctuating according to demand and supply, economic development and input prices (in particular energy and raw materials as well as scrap). Capacity utilisation was considered an important driver of prices.

Large client industries, such as the automobile industry or large manufacturers of steel products (Siemens, Bombardier) were more hesitant to respond to interviews.
A search through newspaper articles and some statements revealed that price formation processes seem to differ for these client industries. Large client industries seem to directly arrange for long-term contracts with the steel industry which then apply to all interim steel processing companies (e.g. for coating) down to the large client. In this sense, these arrangements reduce the risk of price fluctuation that would otherwise be passed through by the interim processing companies which might not have the same bargaining power. Furthermore, prices for different kinds of steel seem to be negotiated individually.

Transport costs were considered an essential part, but not a significant driver of changes in steel product prices. Except for a short period of time before the economic crises, when large vessels imposed a capacity constrained and transport costs spiked, transport costs have decreased over time and have not provided a constraint.
Thus steel traders and client industries purchase products in all regions of the world. Anti-dumping regulations were considered important by small client industries to keep prices in bound.

4.3.5 Data

A few institutes gather price data for products from the iron and steel industries. Price information can be obtained on hot and cold rolled products such as coil, sheet, wire, rods, bars, tubes, etc. For this research we used price information for hot rolled coils and for cold rolled coil. Price data for these products seem to be representative for the majority of the steel products according to data vendors (CE Delft, 2010).

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38 Concerning the EAF plants, operating costs vary much less among regions (Hourcade et al., 2007), so low trade intensities are not striking as far as cost differences are concerned.

There are no weekly data available for the steel market. Therefore we have used monthly price data for the econometric estimation of cost pass-through for the two carbon steel flat products under investigation (hot rolled and cold rolled coil). Prices of these products are influenced by the prices of the production factors. With respect to material inputs, we have collected data on price developments of iron ore, scrap and coke. Other data that have been included related to other inputs such as electricity prices, wages, interest rate, the euro/dollar exchange rate as well as controls for the general economic climate, such as a stock market index and an indicator for the production volume in the sector. These are used alongside the price of EUAs as the prime variable of interest in our estimations. Table 15 gives an overview of data series used.

Table 15 Description of data series used in the steel sector

	Type	Characteristics	EU-countries	Frequency	Source
Output					
Carbon Steel, Flat products, hot rolled coil	Commodity prices	Domestic ex-work, import (CFR main port)	Northern Europe, Southern Europe	Monthly, (09/2003-12/2014)	Metal Bulletin
Carbon Steel, Flat products, cold rolled coil	Commodity prices	Domestic ex-work, import (CFR main port)	Northern Europe, Southern Europe	Monthly, (09/2003-12/2014)	Metal Bulletin
Main inputs					
Iron Ore (ore_br)	Commodity prices	Import (FOB plus transport cost)	From BR to NL	Monthly (2002-2014)	Steelonthenet
Iron Ore 62% FE (ore_cn)	Commodity prices	CFR Tianjin port	China import	Monthly (1980–2014)	IMF
Ferrous Scrap (shredded)	Commodity prices	FOB Rotterdam	Export NL	Monthly (2002-2014)	Metal Bulletin
Combined ore and scrap	Commodity prices	Import EU	EU	Monthly (1996-2014)	DataStream
Pig Iron	Commodity prices	Import cfr	Western Europe	Monthly (09/2003-12/2014)	Metal Bulletin
Energy sources*					
Coke (coke_EE)	Implied commodity Prices	Export FOB shipped from Poland and Czech Republic (volume weighted)	European destinations	Monthly (2002-2014)	Steelonthenet
Coke (coke_br)	Commodity Prices	Export FOB shipped from China (incl. Transport costs)	NL	Monthly (2002-2014)	Steelonthenet
Capital and labour cost					
Wages	Implied wages			Monthly	Eurostat, see Annex
Interest rate	Government bond yields			Weekly	Eurostat, see Annex
Other controls					
Exchange rate	USD/EUR			Weekly	Eurostat, see Annex
Production index				Monthly	Eurostat, see Annex

	Type	Characteristics	EU-countries	Frequency	Source
Stock market index				Weekly	Eurostat, see Annex

* Natural gas and electricity not included in regression due to dominant share of cokes in energy supply.

For both products, we have collected data for Northern Europe (NE) and Southern Europe SE.[39] Output prices for hot and cold rolled coil for Southern Europe are shown in Figure 19 and for Northern Europe in Figure 20.

We collected prices for European production (domestic, ex-works) and imports to European ports. They follow the same pattern with cold rolled coil prices continuously being higher than hot rolled coil prices. Prices in Northern and Southern Europe are very similar with differences mostly in recent years with Southern European prices staying slightly above Northern European prices for both products.

The price spike in 2008 stands out. It was due to capacity constraints caused by high demand for steel products in booming economies around the world. At the same time, transport capacities were short and transport costs spiked. This extreme situation was instantly reversed the year after with the economic recession setting in. Following a slight recovery in the latter part of 2010 and in 2011, overcapacity of steel plants (compare Figure 19) has driven prices down.

Due to the apparent break in the data series, for the purpose of estimation, we use the data series starting in August 2008 – the first observation after the break.

39 For input/control variables, such as interest rates, wages, production index that were available on a country level only, we have used data for Germany as an indication for price development in NWE and data for Spain as a proxy for SE.

Figure 19 Southern European steel prices for carbon steel, flat products, hot and cold rolled coil in €/t

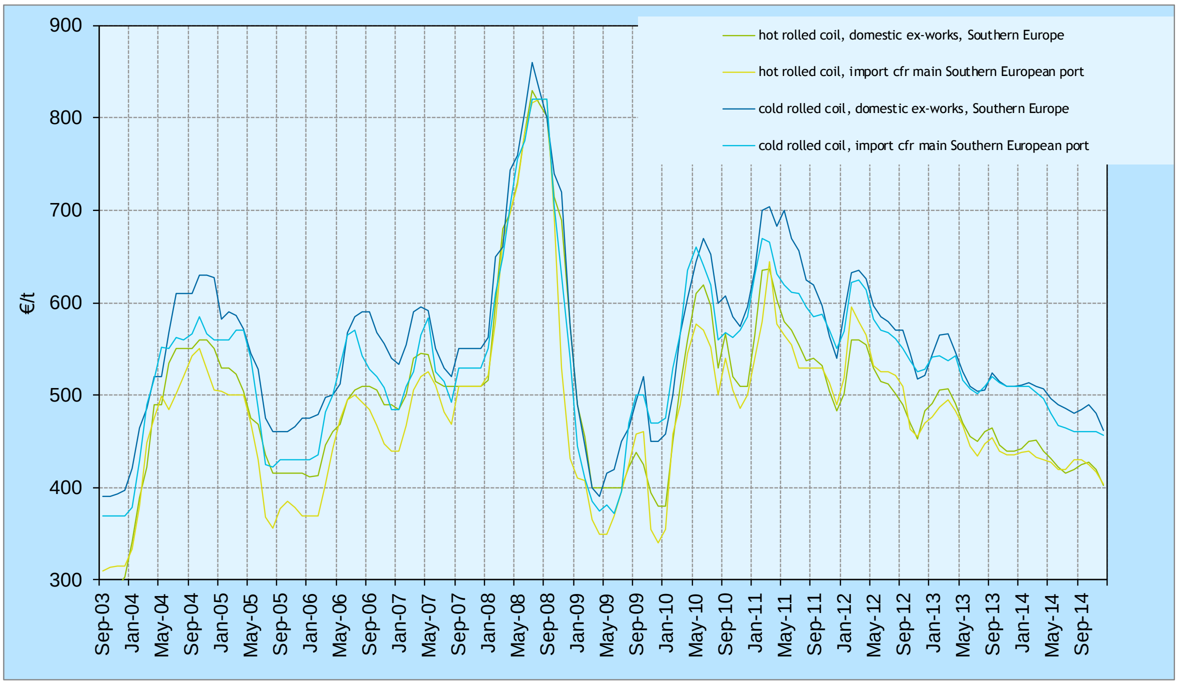
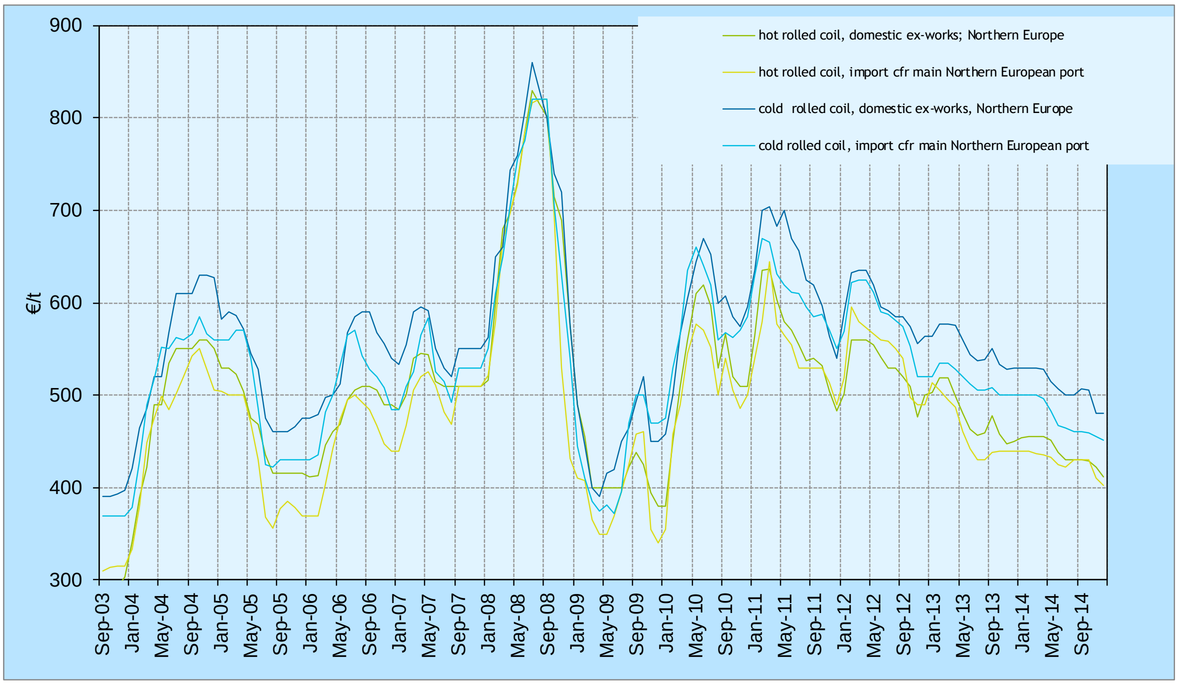


Figure 20 Northern European steel prices for carbon steel, flat products, hot and cold rolled coil in €/t



Conforming to the procedures outlined in Chapter 3, all variables have first been converted to Euros (if needed) and taken as the natural logarithm. Then, unit root tests were applied (see Annex A). These tests showed that the prices of steel products (both hot rolled coil as well as cold rolled coil) do not contain a unit root – a result that was earlier reported in CE Delft (2010). For input prices we get mixed results but most often find a unit root. In some cases the evidence differs in conclusiveness. The CO_2 price contains a unit root in both time samples, with quite strong evidence.

The control variables show mixed evidence as well. Usually no unit root can be found in first differences, with the exception of the wage time series, which shows a unit root even in first difference. Due to the poor performance of the wage time series, we did not include wage data into the final specification of our model.

4.3.6 Estimation procedure

The fact that the output prices do not contain a unit root in the time series used for the estimation implies that we cannot estimate a VECM with the output price included in the endogenous relationship, since cointegration in this framework is only possible between endogenous variables where all contain a unit root. Therefore, we turn directly to the estimation of an ARDL in levels, which can reconcile the inclusion of both I(1) and I(0) variables in the dynamic relationship.

The ARDL may not only be supported from a technical perspective but also from the perspective of price formation in the steel sector: If prices are passed through in the long run with a delay, e.g. the output price needs some time to adjust to changes in the input price, it may be more appropriate to model the long-run relationship between the output prices and its main inputs allowing for delays in the input prices.

Different specifications for the ARDL model were tested, starting from a model that included all candidates in the dynamic relationship, i.e. output price, iron ore, coke, scrap, wages and CO_2, as well as the interest rate, stock market index and the exchange rate. It was generally found that a parsimonious specification that included only the output price, prices for iron ore, coke, scrap and CO_2 in a dynamic relationship led to results that were plausible in terms of magnitude of the coefficients and good in terms of residual behaviour. For hot rolled steel, prices for scrap and iron ore interacted in a way that including both in the dynamic relationship led to implausible results. A reason for this might be that they are partial substitutes. Therefore, ore prices were included as fixed variable for hot rolled steel. Including the monthly exchange rate or stock index turned out to be mostly insignificant in the dynamic relationship.

Residual and bounds tests were generally satisfactory and significant, indicating a long run relationship between the variables in levels. However, it turned out that the price hike up to mid-2008 (see Figure 19 and Figure 20) was highly influencing the results. Therefore, it was finally decided that we tested the hypothesis of cost pass-through on the data after August 2008 when the overheated market had cooled down.

4.3.7 Estimation results

Table 16 summarises the results for the investigated steel sector products in Northern and Southern Europe. All estimates for the endogenous variables are significant; the results for CO_2 are shown below and the full estimation output can be found in Annex C. The ARDL allows us to include delays of the explanatory variables, which may be important if price shocks are not directly passed through to the output prices.
The selected models (using the Schwarz Information Criterion (SIC), see Chapter 46) contained the CO_2 price variable with a delay of 1-3 months, indicating that changes in CO_2 prices are passed through with a delay of 1-3 months.

The (significant) long-run estimators imply that a 1% rise in the price of CO_2 leads to a rise of 0.03–0.08% in the output price. This indicates that it is likely that the iron and steel sector is capable of passing through, at least some of the (opportunity) costs of CO_2 allowances into the product prices.

Table 16 Results of estimations for products in the steel sector

Product	Region	Frequency	Data range	Final model choice	Included variables	Estimator long-run	T-stat	Delay in months
Flat steel, hot rolled coil	Northern Europe	Monthly	08/2008-12/2014	ARDL	Dynamic: Scrap, Coke (CN), CO_2 Fixed: Ore (BR), interest rate, stoxx	0.041	2.042	3
Flat steel, cold rolled coil	Northern Europe	Monthly	08/2008-12/2014	ARDL	Dynamic: Scrap, Ore (CN), Coke (CN), CO_2 Fixed: interest rate, stoxx	0.047	2.663	2
Flat steel, hot rolled coil	Southern Europe	Monthly	08/2008-12/2014	ARDL	Dynamic: Scrap, Coke (CN), CO_2 Fixed: Ore (BR), interest rate, stoxx	0.084	4.108	3
Flat steel, cold rolled coil	Southern Europe	Monthly	08/2008-12/2014	ARDL	Dynamic: Scrap, Ore (BR), Coke (CN), CO_2 Fixed: interest rate, stoxx	0.031	1.561	1

4.3.8 Indicative cost pass-through rates

In order to determine what this implies in terms of indicative cost pass-through rates of CO_2 prices, the estimated coefficients can be compared to the expected value of CO_2 costs in steel production.

Cost information for the steel sector is available from Steelonthenet for integrated steel making resulting in liquid steel (see also Annex C). The price information for inputs used by Steelonthenet (for 2015) corresponds largely to the price series used in the regression analysis[40]. We convert their values to Euros using a March 2015 average exchange rate and add CO_2 related costs using the average CO_2 price over the time span 08/2008-12/2014 of 10.31 €/t CO_2 and a CO_2 intensity of steel production of 2 t CO_2/t crude steel. This yields an average CO_2 cost share of about 5.5% if all allowances for the production of steel had to be bought (or were auctioned). This average cost share thus gives the average cost share of the opportunity costs of CO_2 in production (Table 17).

Table 17 Estimating cost shares including CO_2 costs for crude steel production via the BF/BOF process

	Total costs (incl. CO_2 related costs)*	Cost shares
	€/t crude steel	%
Iron ore	124.07	34.2%
Iron ore transport	9.38	2.6%
Coking coal	85.54	23.6%
Coking coal transport	6.23	1.7%
Steel scrap	36.07	9.9%
Scrap delivery	0.69	0.2%
Industrial gasses	20.76	5.7%
Ferroalloys	11.65	3.2%
Fluxes	19.83	5.5%
Refractories	7.26	2.0%
Other costs	18.03	5.0%
By product credits	-13.62	-3.8%
Thermal energy, net	-67.45	-18.6%
Electricity	20.79	5.7%
Labour	14.75	4.1%
Capital charges	48.89	13.5%
CO_2	**20**	**5.5%**
Total	362.9	100.0%

Source: Steelonthenet, Annex C.
Note: Based on the average CO_2 price over the time span 08/2008-12/2014 of 10.31 €/t CO_2 and a CO_2 intensity of steel production of 2 t CO_2/t crude steel.

Comparing the estimated cost share of 5.5% to the share of CO_2 prices embodied in output prices estimated at 3.1 to 8.4% (Table 17), implies that indicative CO_2 cost pass-through rates in North Europe range from 75% for hot rolled coil to 85% for cold rolled coil. In Southern Europe a larger differential can be found where the cost pass-through of hot rolled coil would surpass 100% and for cold rolled coil would equate to 55%. Such estimates are in line with what was found in the ex-ante literature by Smale et al. (2006) that predicted that cost pass-through of EU steelmakers would be around 65% - an estimate that is lying well in range of our estimates.

[40] Unfortunately, no information was available for further processing into the two specific products we investigate. However, Steelonthenet says that 'the steel plant is assumed to make commodity grade carbon steel for flat products with average labour productivity' which can be assumed to be in line with our products.

4.3.9 Discussion and interpretation

Overall, the estimations show that the majority of CO_2 opportunity costs have been put forward in the product prices at rates between 55% and 100% depending on the product and region investigated. Results further show that this pass-through is likely to have taken place with a delay of 1-3 months (compare the last column in Table 156 indicating the appropriate delay of the CO_2 price variable in the models).

Such results have earlier been reported in the literature. For example, IEA (2005a) calculated that the transport costs for HRC steel are high enough to avoid import penetration as long as CO_2 prices are under 28 €/t CO_2, thereby indicating that full pass-through is possible under low carbon prices. It should be noted in this respect that the industry itself claims that there is only a very limited, close to zero, scope of CO_2 cost pass-through (CEPS, 2008). The analysis here refutes the hypothesis that costs have not been passed through in product prices and confirms, albeit with a different methodology, earlier results by CE Delft (2010).

Steel production is mainly driven by demand. After a boom in demand before the economic crisis in 2009, demand has dropped profoundly during the crisis and has not picked up on its previous strong growth since. Together with a substantial capacity expansion in Asia in recent, this has led to a situation of continued low capacity utilisation. Consequently, product prices have decreased as have most of the input prices (iron ore, coke, and scrap). In such a situation, remaining competitive becomes an even more important issue for companies. They aim to sustain their market share by keeping prices competitive and simultaneously recover at least their fixed costs. Additional (unilateral) costs, e.g. CO_2-related costs, might not be fully recoverable and can thus not fully be passed-through.

At the same time, however, producer-client relationships in the steel sector are close and prices are often negotiated individually for specific products, which often are specialty products. Large clients negotiate with steel producers and agree to some extent on long-term contracts, smaller clients seem to purchase products through traders more on spot markets. Both of these provide a basis for cost pass-through. Together with the above mentioned trade-off between imports and transportation costs, these aspects explain the varying degrees of cost pass-through for specific products.

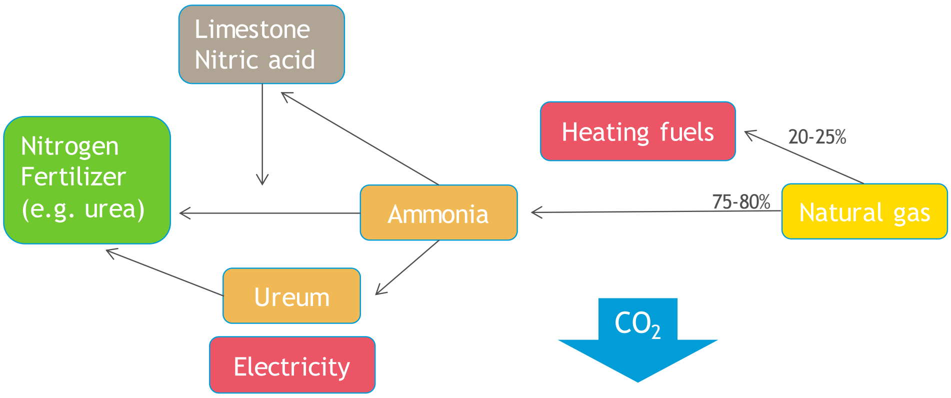
4.4 Fertiliser

4.4.1 Introduction

The fertiliser industry (NACE code 20.15) is a collection of industrial activities that produce various types of fertilisers – most of which are used in agricultural applications. There are in total three types of fertilisers based on the main macronutrients: nitrogen (N), phosphorus (P), potassium (K). From these fertilisers, nitrogen fertilisers are by far the most CO_2 intensive. Most of the installations that fall under the EU ETS are producers of nitrogen fertilisers and we therefore focus on these types of fertilisers.

Nitrogen fertilisers are made from natural gas. Ammonia is used as a feedstock for all nitrogen fertilisers, such as urea. The ammonia is produced by the Haber-Bosch process. In this energy-intensive process, natural gas (CH_4) supplies the hydrogen and the nitrogen (N_2) is derived from the air. Figure 21 depicts the production process of ammonia and nitrogen fertiliser schematically.

Figure 21 Production process of ammonia and nitrogen fertilisers

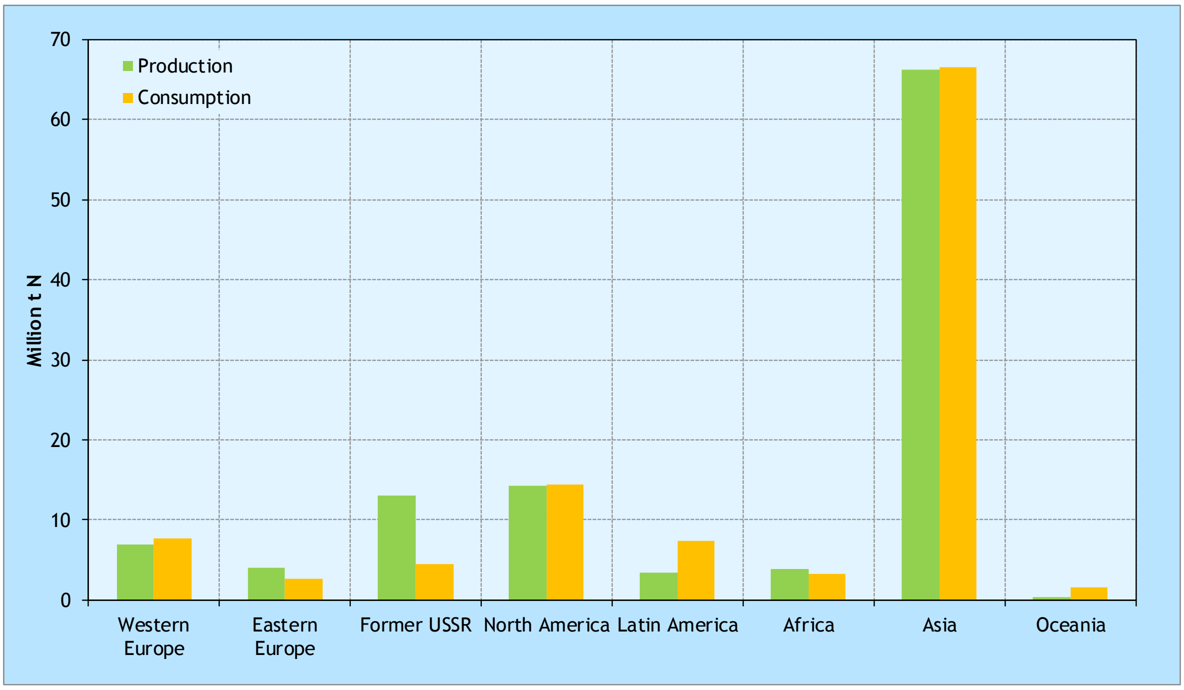


Source: Own illustration.

Because of the higher CO_2 content we will pay special attention to products from the ammonia-based route in the fertiliser sector, namely Ammonia, urea, ammonium nitrate (AN), Calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN). All of these products use natural gas as their raw material input.

Global demand for fertilisers has been increasing, due to an increase in population and changed eating habits towards diets including more animal products and meat (Yara, 2014). Fertiliser is consumed and produced in all world regions (Figure 22). Asia is by far the largest producer as well as the largest consumer. Whilst production and consumption are more or less on par in Western Europe, countries of the former USSR produce more fertiliser than they consume, partly because they have access to relatively cheap natural gas (see also below).

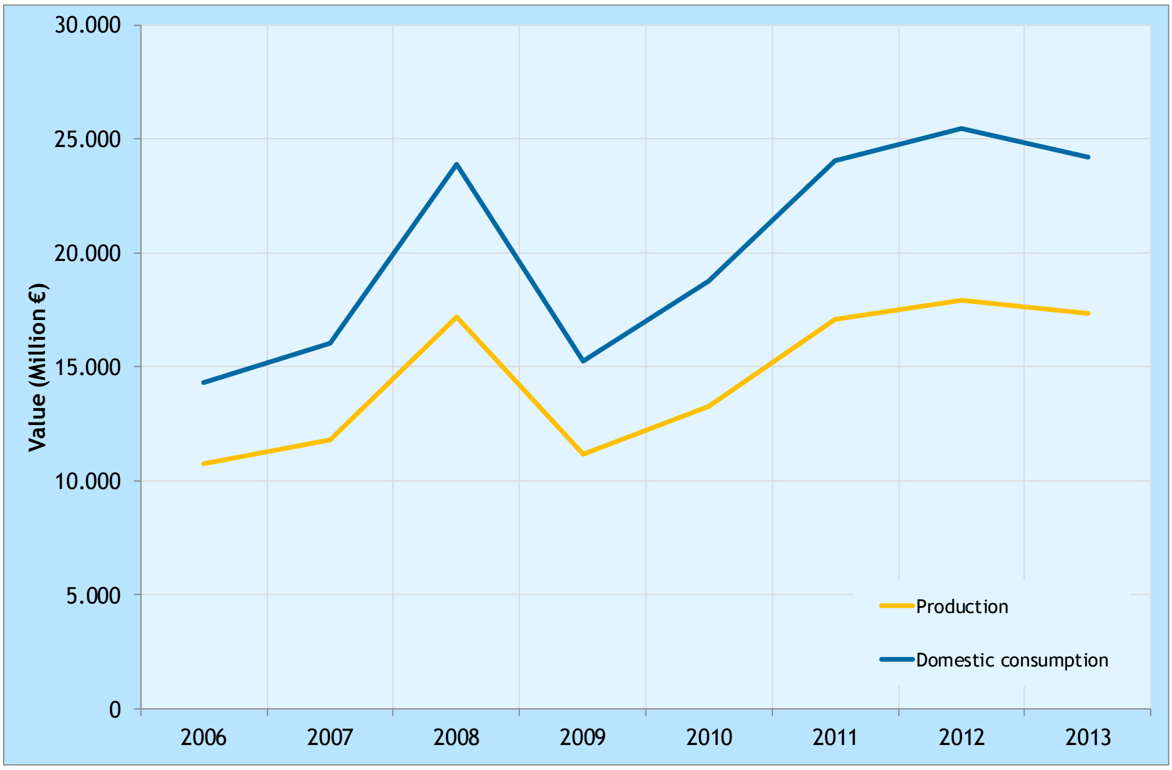
Figure 22 Nitrogen fertiliser production and consumption in 2011-2012



Source: Own illustration based on Industrieverband Agrar (2013).

Figure 23 shows the value of production and domestic consumption of fertiliser within the EU. Consumption was 11 to 17% above domestic production between 2006 and 2013, making the EU a net importer of fertiliser products. In 2008, domestic production value was approximately € 17.2 bn.; however this declined after the recession. Production value and demand have risen again and levelled off at approximately 2008 values. In all other years, production value was between € 10.7 bn and € 13.3 bn.

Figure 23 Development of the value of production and consumption between 2006-2013 for activities covered under the NACE 4-digit code 2015 in the EU



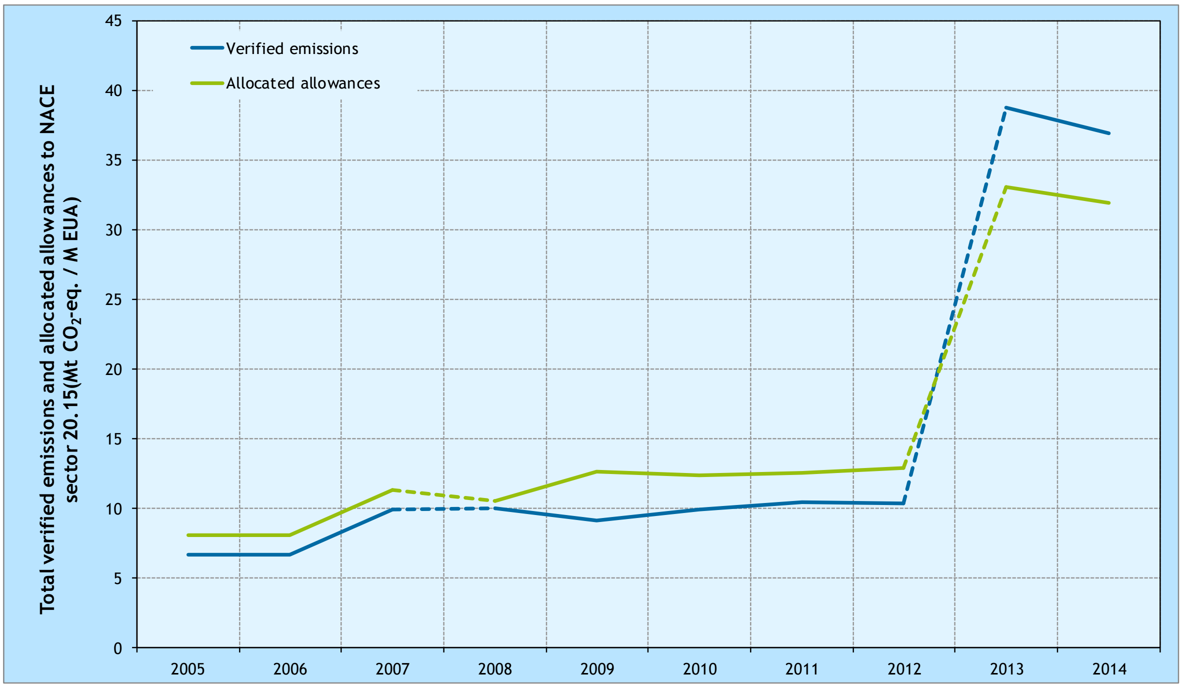
Source: Own illustration based on Prodcom (2015).

4.4.2 ETS emissions

Figure 24 displays verified emissions and allocated allowances to installations with NACE sector 20.15 covered by the EU ETS. It demonstrates the rising share of emissions in these sectors that are covered by the EU ETS since 2013. In most countries, installations in these sectors entered the EU ETS in 2013. Some countries, however, opted-in N_2O emitting installations already during the second trading period, notably the Netherlands and Norway (2008), Austria (2010) and Italy and the UK (2011). In 2014, the share of installations with NACE code 20.15 in overall emissions amounts to 2%. The share in industrial emissions (defined as all those emissions from installations with NACE codes other than 35.00/starting with 35.1) amounts to 4%.

Until 2012, the NACE sector 20.15 received excess allowances as compared to its emissions, from 2013 onwards verified emissions are higher than allocated allowances in the installations belonging to this sector. One reason is that this sector contains CCGT plants, which until 2012, were allocated allowances based on a double benchmark for electricity and heat, whilst from 2013 onwards, in general, allowances to electricity production are auctioned under the EU ETS.

Figure 24 Verified emissions and allocated allowances of installations in NACE sector 20.15



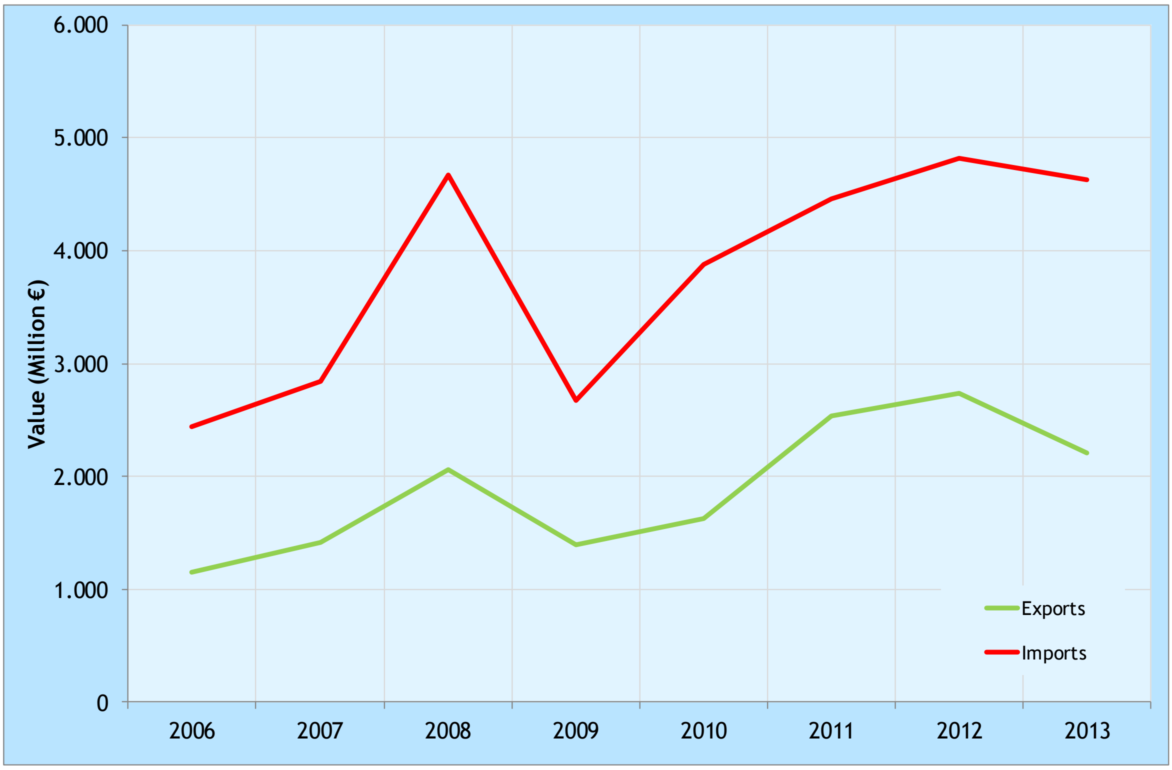
Source: Own illustration based on EUTL and NACE matching (EC, 2014a).

CO_2 allowances are surrendered for those emissions stemming from the production process, i.e. CO_2 from ammonia production and N_2O from nitric acid production. CO_2 and N_2O emissions that are released after application of the fertiliser in, for example, agriculture, are not covered by the EU ETS.

4.4.3 Market conditions

As noted above, the EU is a net importer of nitrogen fertiliser products and in fact, has been a net importer for the past two decades (Copenhagen Economics, 2015).
In 2008, imports peaked at € 4.7bn. and after the recession even rose to € 4.8bn. in 2012. The highest exports took place in the year 2012 with an export value of € 2.7 bn.

Figure 25 Development of the value of imports and exports 2006-2013 for activities covered under the NACE 4-digit code 20.15 in the EU



Source: Own illustration based on Prodcom (2015).

Russia represents the largest exporter of fertiliser products into the EU. Russian fertiliser producers have a significant competitive advantage over European producers, mainly due to their access to domestic natural gas which is sold at a fraction of the world market price. In 2014, domestic customers in Russia paid about a fifth of the prices charged from European importers.[41] Since 1995 anti dumping protection against Russian producers has been in place in the EU. It was renewed in 2014 charging up to 47 €/t of product in anti dumping charges for Russian producers importing into the EU (EC, 2014b). This regulation is explicitly set to protect producers in France, Lithuania, Poland and the UK.

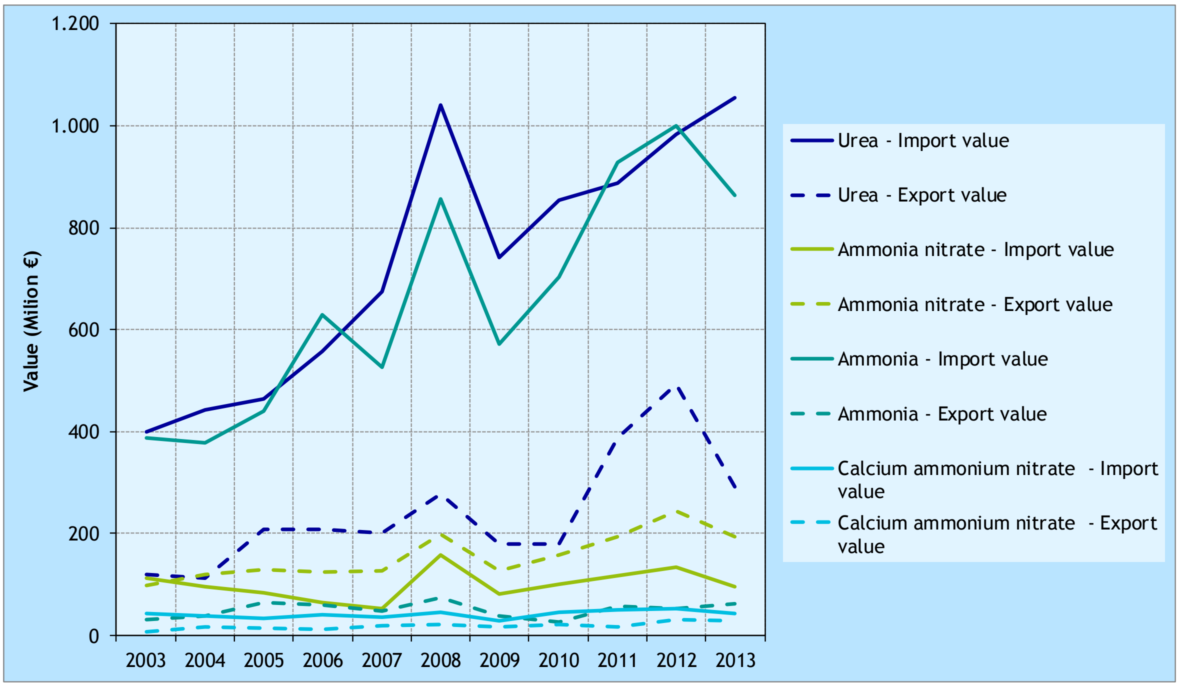
Despite differences in energy costs, the EU continues to export fertiliser products to a range of markets (i.e. three of the largest markets in 2013 included Brazil, Turkey and the United States). Looking at import and export patterns for individual products (Figure 26), a more differentiated picture emerges. The import value for urea and ammonia is similar and much higher than the import value for ammonium nitrate and calcium ammonium nitrate. The higher export value for urea makes it the most traded among the four fertiliser products considered.

In the case of ammonium nitrate, the EU even emerges as a net exporter.
This indicates that the two finished products of ammonium nitrate and calcium ammonium nitrate are produced within the EU, partially using imported ammonia.

41 The Moscow Times (2014); Tarr and Thomson (2004).

Fertiliser products based on ammonium nitrate, such as AN, UAN and CAN have limited transportability due to hazardous characteristics, such as being combustible, decomposing under high temperature and explosive, all associated with the release of hazardous gases (EFMA, 2004). Also the transport of pure ammonia has not always been taken for granted. However, the reality is that these products are already traded internationally and increasingly so (Copenhagen Economics, 2015).

Figure 26 Development of the value of imports and exports 2003-2013 fir different products in the fertiliser sector



Source: Own illustration based on Comext (2015).
Note: Imports from and exports to extra-EU from EU28.
The aggregate values shown in this graph are slightly lower than in the figure using Prodcom data as the NACE sector 20.15 contains additional products in comparison to the ones shown here.

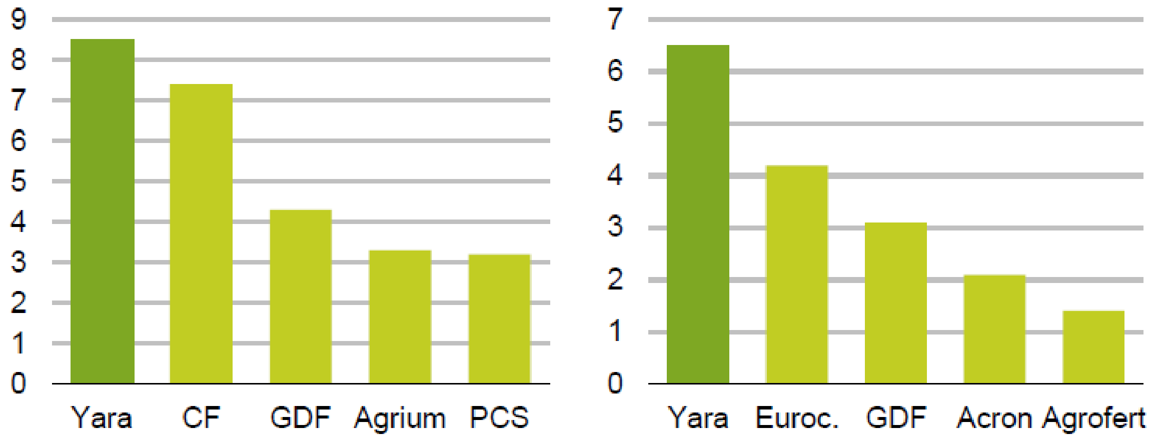
Although transportation costs (relative to product prices) are therefore higher for nitrogen fertiliser products than for example steel or refined products (Copenhagen Economics, 2015), European fertiliser products do compete on an increasingly global market.

Additional capacity additions until the end of the decade are mostly expected in countries that have access to low-cost raw material, in particular in the Middle East (Yara, 2014), but significant additions are also expected in the US (The Western Producer, 2015). Whilst expected capacity additions are expected to be in line with historical consumption growth (Yara, 2014), some experts believe that at higher capacity and lower utilisation rates, prices are likely to fall, at least in those countries that cease to be a net importer of nitrogen fertilisers, such as the U.S. (The Western Producer, 2015).

4.4.4 Market concentration and price formation

The market for fertiliser products is dominated by a number of very large companies. Yara is the largest producer of both ammonia and nitrates. They are an international fertiliser producer with headquarters in Oslo, Norway, employing about 12,000 people with production sites concentrated in Europe, Latin America and Asia.[42] CF Industries is a fertiliser company headquartered in the US, which also mainly produces there, but is also involved in joint ventures in Europe and elsewhere. CF employs 2,800 people worldwide and was ranked #4 in international value creation according to the Boston Consulting Group (2012).[43] Group DF conducts its fertiliser business mainly in the Ukraine, where it employs nearly 50,000 people.[44] Eurochem is a global fertiliser producer headquartered in Switzerland, with production sites in Europe, Asia and Mexico.[45]

Figure 27 Production capacity in Mio t of the largest companies in the markets for ammonia (left) nitrates (right)



Source: Yara (2014).
Note: Compared to total global production of nitrogen fertilisers of 112 Mio.t in 2011-12 (Industrieverband Agrar, 2013).

Fertiliser products are bought and sold both through contracts and spot markets. [46] In Europe most products are bought under contract – with volumes normally agreed at the start of the contract period and then tonnes delivered regularly. However, there is also an active spot market. Contracts can have different durations (e.g. monthly, quarterly, etc.) There are differing lead times for fixing these contracts ranging from one month to several months. If new capacity is coming on line, it may be fixed even further in advance.

A contract is made between a supplier and buyer for a certain amount of product over a certain period. There are usually minimum quantities involved, so that both sides are protected. If a buyer needs more product than under the contract then they ask for extra volumes from the supplier, or buy from the spot market if that is not possible. Conversely if a supplier doesn't have sufficient volumes for a customer they might source product spot from another supplier to cover that commitment.

42 http://yara.com/about/what_we_do/
43 www.cfindustries.com/profile_overview.html
44 https://groupdf.com/en/press-center/press-kit/fertiliser-business/
45 http://eurochemagro.com/
46 Information in this paragraph is based on interview with industry expert.

Contract prices usually follow spot prices, but partners will also take into account (expected) levels of demand (related to seasonal crop cycles and inventory stock) and supply and moving futures. Raw material costs are a big contributor to fertiliser prices, in particular, natural gas.

Other costs also play a role, such as costs for energy and labour – and potentially CO_2 (which will be tested in the following). In general, the higher the cost of these inputs, the higher the prices for fertiliser products that use them as an input. In this context, considerations about cost pass-through and carbon leakage come into play when there are differentiated price increases for producers situated in different countries or regions. This may be related to the access to raw materials (in this case: natural gas) or regulatory costs, such as CO_2 prices.

If output prices are too low to cover production costs (at a reasonable margin) then producers can stop production. As about 90% of costs are variable (Yara, 2014) in the fertiliser industry, this is a relevant option for producers. However, there may be situations also where producers sell below break-even costs to maintain market share, which is in turn related to the current and (expected) future market tightness.

4.4.5 Data

The estimation period for fertiliser corresponds to the period in which the products have been covered by the EU ETS, i.e. since 2013 for most countries or during the second trading period, if countries decided to opt-in these installations. Therefore, the estimation period if quite short in most instances and we decided to use weekly rather than monthly data (if available) to ensure we have enough observations for a meaningful estimation.

We have weekly price data for a number of products of the fertiliser sector, notably: Ammonia, urea prilled and granular bulk, Ammonium nitrate (AN), Calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN). We are therefore using both intermediate products (i.e. ammonia)[47] and final products that contain ammonia. In principle, cost pass-through could be observed in both intermediate and final products, since the production of ammonia itself represents the emissions intensive step. We will test this further below.

As noted above, prices in the market for fertiliser products are both expressed in contractual agreements, as well as on the spot market. The weekly price series we use from ICIS Pricing is based on their market research regarding both types of prices and they give a range of prices for a given week, usually the spread is in the range of 10–20 US$/ton (ICIS Pricing, 2014). In this project, we use the upper price range for our estimations, since for example for ammonium nitrate UK, which is given as an FCA price (see Chapter 3), the lower end of the range usually represents the price of imported material and the upper end of AN produced in the UK.[48]

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[47] Ammonia is in some cases also used directly as a fertiliser.

[48] In fact, most time series considered reflect prices of both local and imported product. Only for ammonium nitrate DEL France and calcium ammonium nitrate CIF bulk Germany, the price reflects only local production.

These product prices are used as dependent variables in our estimation and are explained by the prices of inputs in the production process. The main input in the fertiliser sector is natural gas. As other inputs to production, we add prices of energy[49], wages, the interest rate and the euro/dollar exchange rate as well as controls for the general economic climate such as a stock market index and an indicator for the production volume in the sector (although the indicator for the production volume in the sector turned out to not be useful). We also add our main variable of interest: the price of EUAs. See Annex A for more information on the variables used.

Depending on the product, we have data for North West Europe (NWE), France (FR), Germany (DE), the Netherlands (NL) and the UK (see Table 18). For NWE output prices, input prices for DE are used as an approximation. All data series are of weekly frequency – except for the data series for NL, which is a monthly price index (see Table 18).

Table 18 Description of data series used in the fertiliser sector

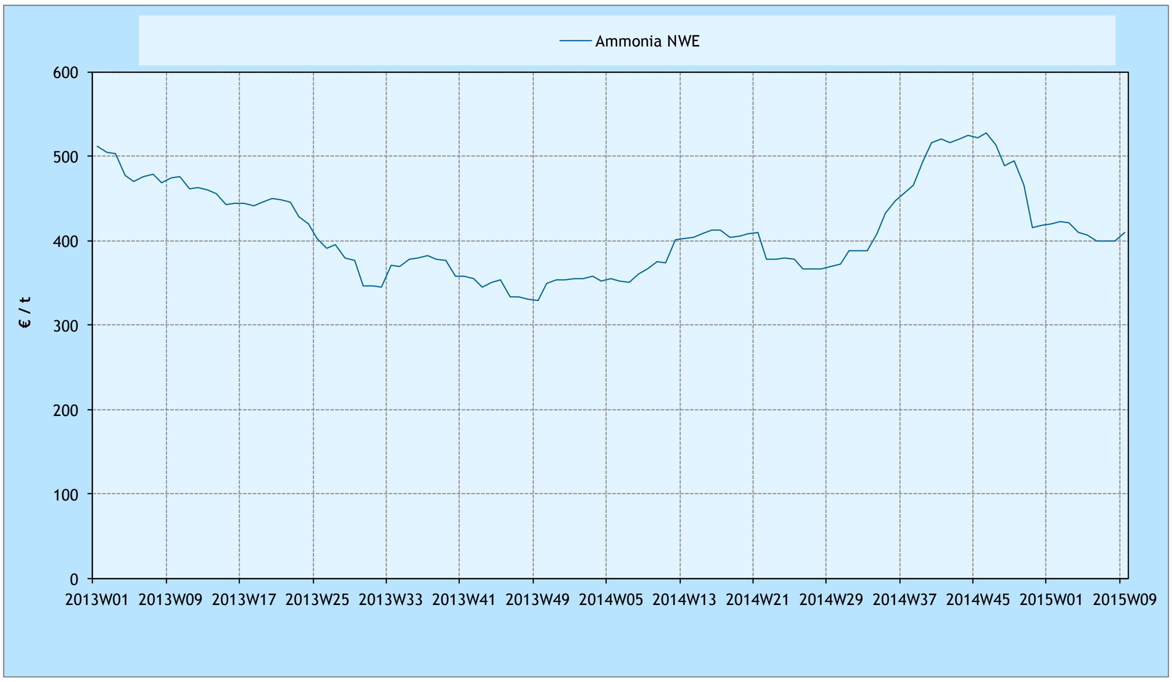
	Type	Characteristics	EU-countries	Frequency	Source	Data manipulation
Output						
Ammonia	Commodity prices	CFR (local + import)	NWE	Weekly (01/2002 – 02/2015)	ICIS Pricing	Upper end of price range used for NWE, FR, DE, UK prices
Urea prilled bulk	Commodity prices	FCA (local + import)	NWE	Weekly (03/2006 – 02/2015)	ICIS Pricing	
Urea granular bulk	Commodity prices	FCA (local + import)	NWE	Weekly (06/2009 – 02/2015)	ICIS Pricing	
Ammonium nitrate	Commodity prices	FCA (local + import)	UK	Weekly (12/2007 – 02/2015)	ICIS Pricing	
Ammonium nitrate	Commodity prices	DEL (local product)	FR	Weekly (03/2006 – 02/2015)	ICIS Pricing	
Calcium ammonium nitrate	Commodity prices	CIF bulk (local product)	DE	Weekly (03/2006 – 02/2015)	ICIS Pricing	
Urea ammonium nitrate	Commodity prices	FCA (local + import)	FR	Weekly (01/2002 – 02/2015)	ICIS Pricing	
Urea	PPI		NL	Monthly (01/2005 – 10/2014)	Dutch Stat. Office	
Main input						
Natural gas spot	Commodity prices	TTF	many	Daily	EEX	
Energy sources						
Heavy fuel oil	Commodity Prices		EU average	Weekly	EC Bulletin	
Electricity	Commodity		many	Weekly	ICIS Pricing	

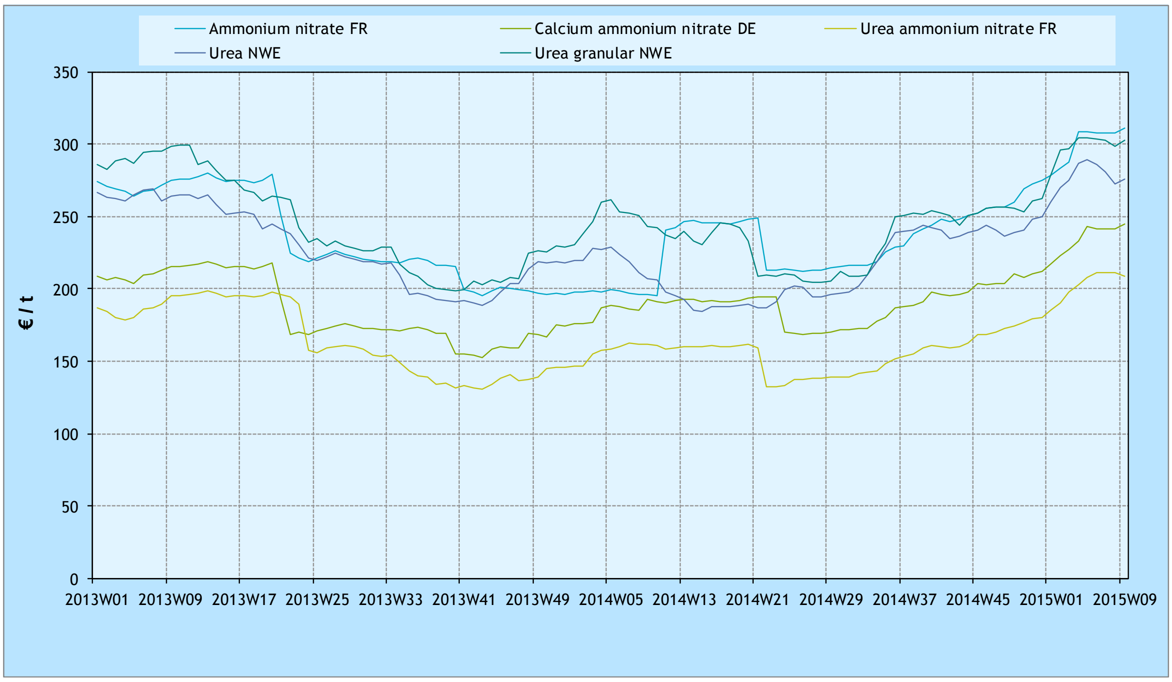
49 In this weekly setting, we use fuel oil/electricity prices directly instead of energy price index (cf. Annex A.3), because of the higher frequency data used.

	Type	Characteristics	EU-countries	Frequency	Source	Data manipulation
Y+1	Prices					
Energy price index	Based on commodity prices		Benelux	Monthly	See Annex A.3	Used for PPI urea (NL) only
Capital and labour cost						
Wages	Implied wages			Monthly	Eurostat, see Annexes	
Interest rate	Government bond yields			Weekly	ECB, see Annexes	
Other controls						
Exchange rate	USD/EUR			Weekly	Eurostat, see Annexes	
Production index				Monthly	Eurostat, see Annexes	
Stock market index				Weekly	Eurostoxx, see Annexes	

For countries that did not opt in N_2O emitting installations during the second trading period of the EU ETS, we run a model using data starting in 2013 (Figure 28). Following a drop that lasted until the fourth quarter of 2013, prices recovered, before dropping again in the second/third quarter of 2014 (to varying degrees). By the first quarter of 2015, all prices had recovered to their levels observed at the beginning of 2013 and even surpassed these values. These variations may represent changes in demand and inventory stock, but also changes in the prices for inputs. We will investigate the importance of different inputs in the regression analysis below.

Figure 28 Fertiliser prices in non opt-in countries €/t, Jan 2013-Feb 2015



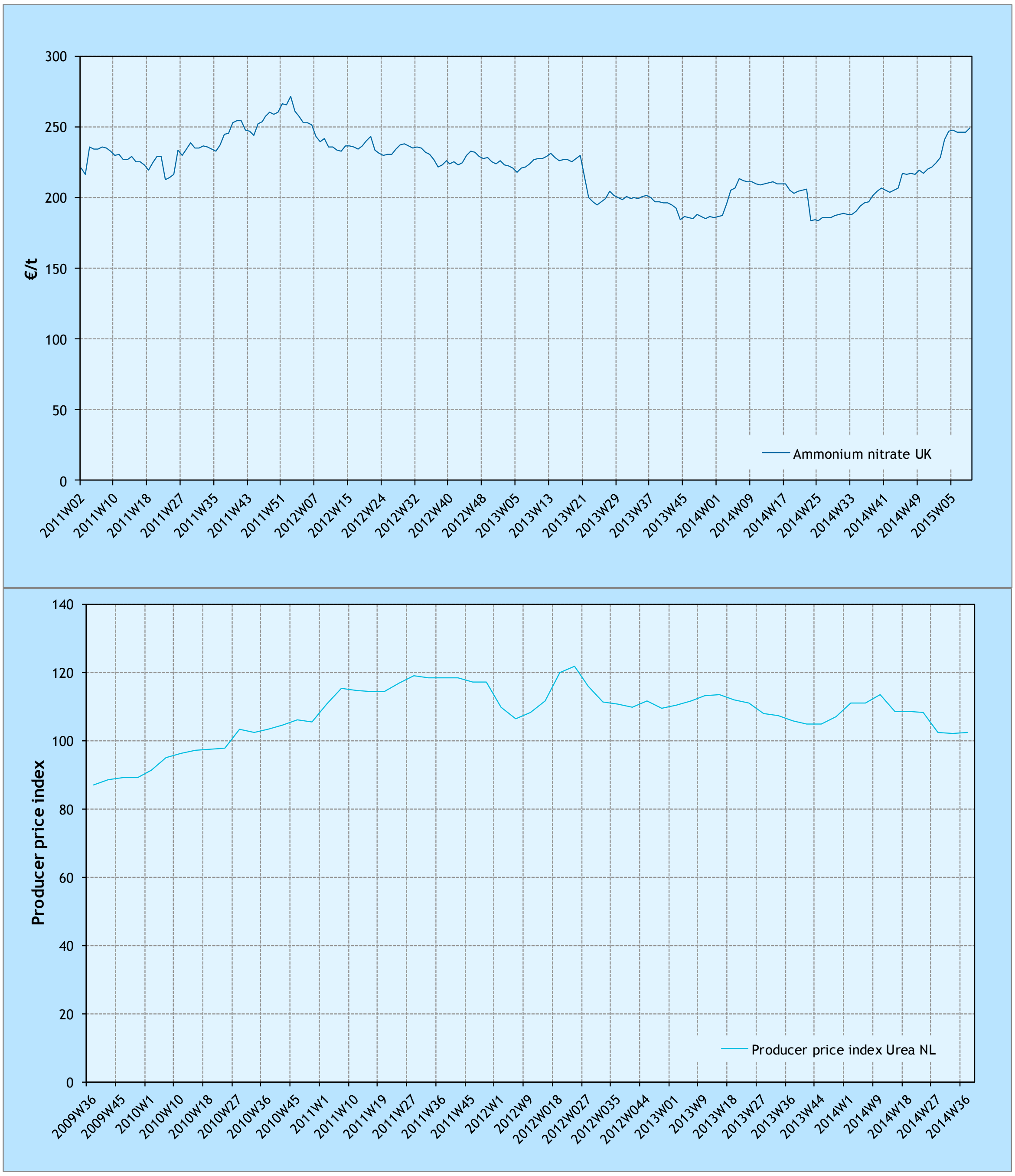


Source: ICIS Pricing.
Note: Ammonia price series shown separately due to the differential in price.

Since the Netherlands and the UK opted in N_2O emitting installations, the estimation starts at an earlier point in time (Figure 29). The UK opted in N_2O emitting installations in 2011, prices for AN had risen until the second/third quarter of 2011 and then began a descent that lasted until February 2015, with a couple of interim peaks in between.

In the time series for the Dutch PPI of urea, the effect of the financial and economic crisis in 2008 and 2009 was apparent. We therefore decided to start the estimation in September 2009, which has been identified as a break in the data series.

Figure 29 Fertiliser prices in opt-in countries $/t (AN UK) and PPI (Urea NL)



Sources: ICIS Pricing; Statistics Netherlands.

All prices are used in/converted to Euro values and converted to their natural logarithm. In a first step, unit root tests have been applied to all of the time series used. All weekly time series used in the regressions for those products shown in Figure 29 in the period January 2013 to February 2015 contain a unit root (Annex D.1). Similarly, most of the variables used in the estimation of AN UK contain a unit root.

One exception is the exchange rate, which has consequences for the way in which it will be used in the estimation (see below). Finally, most monthly time series used in the estimation of the PPI of urea contain a unit root. However, the fact that the natural gas price does not contain a unit root when used in monthly frequency for this longer period implies that the use of a number of estimation techniques is precluded (see below).

4.4.6 Estimation procedure

We follow the procedure explained in Chapter 3. As a first step, we estimate a VECM, where the endogenous variables enter in levels, whilst the exogenous variables that contain a unit root enter in first differences and the exogenous variables that do not contain a unit root enter in levels as well (i.e. the exchange rate in the estimation of AN UK). The fact that the price for the most important input to production, i.e. natural gas, did not contain a unit root in the time series used for the estimation of the Dutch PPI of urea, implies that for this product, we cannot estimate a VECM in levels, since cointegration in this framework is only possible between endogenous variables where *all* contain a unit root. Therefore, for the Dutch PPI of urea, we turn directly to the estimation of an ARDL in levels, which can reconcile the inclusion of both I(1) and I(0) variables in the dynamic relationship.

For all products where the estimation of a VECM in levels was possible, i.e. all series except the Dutch PPI or urea, we were able to identify specifications where the behaviour of residuals indicated that tests could be interpreted as normal. The tests - i.e. Granger causality tests and (Johansen) cointegration tests – indicated that the estimation of a VECM is not appropriate for these data series. The Johansen tests consistently indicated that no cointegration exists between the fertiliser prices and their main inputs. This was confirmed by the fact that no Granger causality could be detected running from the prices of fertiliser products towards the price of natural gas, wages, the energy price index or the price of CO_2.

Therefore we turn to the estimation of an ARDL in levels[50]. Different specifications for the ARDL model were tested, starting from a model that included all candidates in the dynamic relationship, i.e. output price, natural gas, cost of energy and labour and CO_2, as well as the stock market index and the exchange rate. It was generally found that a parsimonious specification that included only the output price, the gas and CO_2 price in a dynamic relationship led to results that were plausible in terms of magnitude of the coefficients and good in terms of residual behaviour. Including (monthly) data on wages led to implausibly high coefficients on the price of labour, whilst energy prices, the stock market index and exchange rate turned out to be mostly insignificant in the dynamic relationship. However, Bounds tests were generally not or only marginally significant, indicating that a long run relationship between the variables in levels could not be detected beyond reasonable doubt. Furthermore, the sum of all coefficients in the long-run relationship often exceeded 1 which is another sign of misspecification as the total share of costs should not exceed unity (or substantial losses are made by the sector).

50 The ARDL may not only be supported from a technical perspective but also when one considers pricing behaviour in the fertiliser sector: If prices are passed through in the long run with a delay, e.g. the output price needs a few weeks to adjust to changes in the input price, it may be more appropriate to model the long-run relationship between the output prices of fertilisers and its main inputs allowing for delays in the input prices. This may be particularly relevant in the context of using weekly data.

One exception is the ARDL in levels run for the Dutch PPI of urea, where residuals behaved well and Bounds tests indeed indicated the existence of a long-run relationship between the urea price (index), the price of natural gas, the price of labour and the price of CO_2.

For all other product prices, i.e. all weekly time series, we turned to the estimation of models in first differences (FD). First a VAR in FD was run and the residuals checked for autocorrelation. Generally, as could have been expected, all models run in FD did not exhibit problematic behaviour of residuals. For two product prices, i.e. ammonia (NWE) and ammonium nitrate (France), Granger causality tests indicated that estimation of a VAR was the right way forward, since causality running from output prices to input prices could not be rejected. For all other product/country pairs, an ARDL in FD was estimated.

4.4.7 Estimation results

Table 19 summarises results for all product/country pairs investigated in the fertiliser sector. Most of the models (with the exception of the Dutch PPI for urea) are estimated in first differences, as no cointegration relationship could be found between the variables.[51] In all of the models in first differences, the output price, the price of natural gas and the price of CO_2 enter the endogenous/dynamic relationship, whilst the prices of energy, labour, the exchange rate and the stock market index serve as exogenous/fixed variables.

Whilst both the price of natural gas and the CO_2 price are insignificant in the VARs in first differences (see also Table 48 in Annex D), they are significant (at any common level) in all of the ARDLs in first differences. This is likely connected to the fact that the ARDL exhibits a more sophisticated lag structure than the VAR, where all variables are included with the same lag length. Moreover, the ARDL allows us to include delays of the explanatory variables, which may be important if price shocks are not directly passed through to the output prices. The adequate delay of the CO_2 price (and other explanatory variables) was found by estimating different models and then choosing the one that minimises the Schwarz information criterion (SIC) (after ensuring that no autocorrelation was present in the residuals). The models minimising the SIC contained the CO_2 price with a delay of 6-11 weeks, indicating that CO_2 prices are passed through with a delay of approximately two months. This observation is confirmed by the choice of CO_2 price delay in the ARDL in levels for the Dutch PPI of urea, where the SIC again chooses a model with a 2-month delay of the CO_2 price.

The (significant) long-run estimators imply that a 1% rise in the price of CO_2 leads to a rise of 0.09–0.24% (only significant coefficients used) in the output price. In order to determine what this implies in terms of cost pass-through of CO_2 prices, the literature generally compares these results to the actual cost share of CO_2 in fertiliser production.

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[51] Although estimating the model in first differences gives a somewhat less strong indication of the long-run effect, the accumulated effect of the first difference can still indicate whether there is cost pass-through or not and its magnitude can be interpreted and compared to cost shares in order to estimate the rate of cost pass-through.

Table 19 Results of estimations for products in the fertiliser sector

Product	Region	Frequ.	Data range	Final model choice	Included variables	Estimator long-run	T-stat	Delay
Ammonia	NWE	Weekly	01/01/2013-26/02/2015	VAR in FD	Endogenous: Gas, CO_2 Exogenous: Fuel oil, electricity, wage, xrate, stoxx	-0.04	-0.73	-
Ammonium nitrate	FR	Weekly	01/01/2013-26/02/2015	VAR in FD	Endogenous: Gas, CO_2 Exogenous: Fuel oil, electricity, wage, xrate, stoxx	0.005	0.04	-
Ammonium nitrate	UK	Weekly	01/01/2011-26/02/2015	ARDL in FD	Dynamic: Gas, CO_2 Fixed: Fuel oil, electricity, wage, xrate, stoxx	0.12	3.68	6
Calcium ammonium nitrate	DE	Weekly	01/01/2013-26/02/2015	ARDL in FD	Dynamic: Gas, CO_2 Fixed: Fuel oil, electricity, wage, xrate, stoxx	0.13	3.32	11
Urea ammonium nitrate	FR	Weekly	01/01/2013-26/02/2015	ARDL in FD	Dynamic: Gas, CO_2 Fixed: Fuel oil, electricity, wage, xrate, stoxx	0.24	4.28	8
Urea granular	NWE	Weekly	01/01/2013-26/02/2015	ARDL in FD	Dynamic: Gas, CO_2 Fixed: Fuel oil, electricity, wage, xrate, stoxx	0.10	2.38	8
Urea prilled bulk	NWE	Weekly	01/01/2013-26/02/2015	ARDL in FD	Dynamic: Gas, CO_2 Fixed: Fuel oil, electricity, wage, xrate, stoxx	0.09	2.18	8
Urea	NL	**Monthly**	Sep 2009-Dec 2014	ARDL in Levels	Dynamic: Gas, CO_2, wage Fixed: energy index, xrate, stoxx	0.04	0.80	2 (months)

Please refer to Table 48, Table 49, and Table 50 in Annex D for detailed regression results.

4.4.8 Indicative cost pass-through rates

Using prices for a range of fertiliser products and countries, we do find some indication of cost pass-through in our regression analysis. As explained in Section 3.3, it is not straightforward to translate the coefficients of CO_2 cost shares into an estimation of cost pass-through rates. There are a number of ways in which the cost share of CO_2 in the price of output can be determined. In the case of fertiliser, we tried an approach, whereby the total emissions in this sector (by NACE code) are multiplied with average CO_2 prices in a respective year and divided by production value in the same sector (from Eurostat). However, one caveat of this approach is that production values from Eurostat are only available until 2012, whereas the estimation for most products starts in 2013.

Therefore, we decided to turn to information from the process of determining benchmarks for free allocation to the fertiliser sector. As all of the fertiliser products considered here are based on ammonia, we use the benchmarking curve leading to the ammonia benchmark of 1.619 tCO_2/t product (EC, 2011). Since this benchmarking value is based on the average rather than the marginal plant, which can be expected to be price setting, we use a value of 2.5 tCO_2/t product (see Figure 7 in Ecofys et al., 2009) and adjust for the different products based on their price differential to ammonia.

We then multiply this benchmark with (1) the average price of CO_2 between 01/01/2013 and 26/02/2015 of 5.31 €/ t CO_2 and (2) and a price of 10 €/t CO_2 to be consistent with the one employed for the other sectors. Depending on the CO_2 price chosen, the estimated CO_2 cost share ranges between 3 and 6% (Table 20). This is in line with a CO_2 cost share of 17–18% for nitrogen fertilisers at CO_2 prices of 30 €/tCO_2 estimated in a recent study (Copenhagen Economics, 2015).

Table 20 Estimating CO_2 cost shares in fertiliser products

	Avg product price 01/01/2013 - 26/02/2015	Avg CO_2 cost	Avg CO_2 cost share	Avg CO_2 cost	Avg CO_2 cost share
	€/t	10 €/tCO_2	%	5.31 €/tCO_2	%
Ammonia (NWE)	412.2	25.0	6.1%	13.3	3.2%
Ammonium nitrate (FR)	237.8	14.4	6.1%	7.7	3.2%
Ammonium nitrate (UK)	207.5	12.6	6.1%	6.7	3.2%
Calcium ammonium nitrate (DE)	190.4	11.5	6.1%	6.1	3.2%
Urea ammonium nitrate (FR)	163.2	9.9	6.1%	5.3	3.2%
Urea granular (NWE)	245.1	14.9	6.1%	7.9	3.2%
Urea prilled bulk (NWE)	225.8	13.7	6.1%	7.3	3.2%

Source: Own calculations based on ICIS Pricing, EEX, EC (2011), Ecofys et al. (2009).

At an assumed CO_2 price of 10 €/t, the cost share of CO_2 in the production of ammonia based fertilisers is therefore equal to 6%. Combining these with the results of the regression analysis above, implies that full cost pass-through, potentially even surpassing 100% may have taken place in the fertiliser sector; keeping in mind the limitations to the estimation of cost pass-through rates discussed in Chapter 3.

4.4.9 Discussion and interpretation

Most installations in the fertiliser sector are relatively new to the EU ETS, since in most countries they have been covered only since 2013. Although European producers face an increasing amount of competitors in particular from countries with access to cheap natural gas, the rising global demand has to date ensured that European production levels have remained fairly stable, with the EU itself presenting an important domestic market.

Results indicate that cost pass-through into prices of European fertiliser products were possible for a number of products and countries. Estimated cost pass-through rates imply full cost pass-through of the (opportunity) cost of CO_2. This result is higher than the ones estimated in the literature to date, ranging between 15% (Alexeeva-Talebi, 2010), 50% (Oberndorfer et al., 2010) and 75% (Vivid Economics, 2014). These differences may be due to the different methods employed (ex-post vs. ex-ante; including the price of CO_2 or other proxies for cost pass-through). One also has to keep in mind the difficulties involved in determining the extent of cost pass-through discussed in Chapter 3.

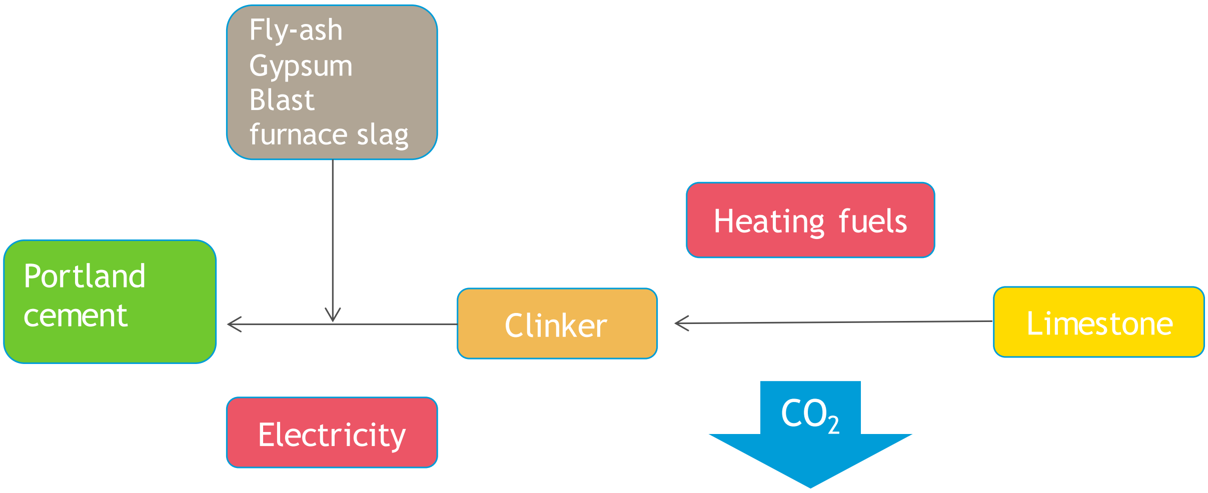
Potential drivers of the relatively high rates observed likely are the growing international demand for fertiliser products and limitations to the transportability of some of the fertiliser products investigated. It has to be noted, however, that with additional capacity coming online in countries with access to cheap raw material, i.e. gas, European producers may face enhanced international competition in the future.

Whilst our estimation procedure fails to find significant evidence of cost pass through for pure ammonia, we do find significant pass through for ammonium nitrates, as well as urea. However, this difference should not be overstated, as our estimation framework led us to use a different model for the estimation of pure ammonia and ammonium nitrate (France), i.e. a VAR in first differences, whereas for the remaining output prices an ARDL model was applied. The fact that the ARDL model exhibits a more sophisticated lag structure than the VAR as well as allowing for the inclusion of delays of the explanatory variables, may drive the difference in results.

4.5 Cement

4.5.1 Introduction

Cement production is a highly CO_2 intensive activity. Portland cement is by far the most common type of cement and is made by heating limestone (calcium carbonate) with small quantities of other materials to 1,450°C in a kiln whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called ‘clinker’, is then ground with a small amount of gypsum, fly-ash or slag into a powder to make Portland Cement.

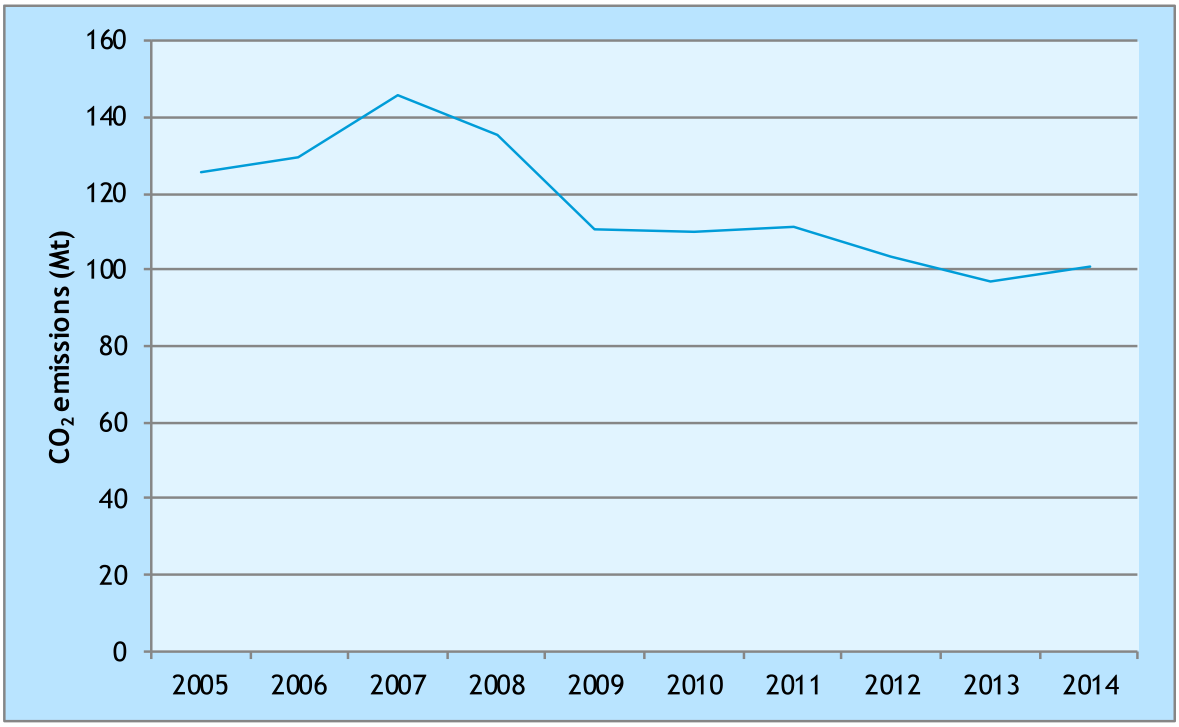


The making of clinker is therefore the most energy intensive process.

4.5.2 ETS emissions

Cement has been included in the EU ETS since 2005. By counting the number of companies operating under the EU ETS with the statistical information from Eurostat on the number of companies operating in the cement sector (NACE 2351), one can argue that all of the cement companies in the EU fall under the EU ETS.

Figure 30 Development of Cement emissions 2005-2014



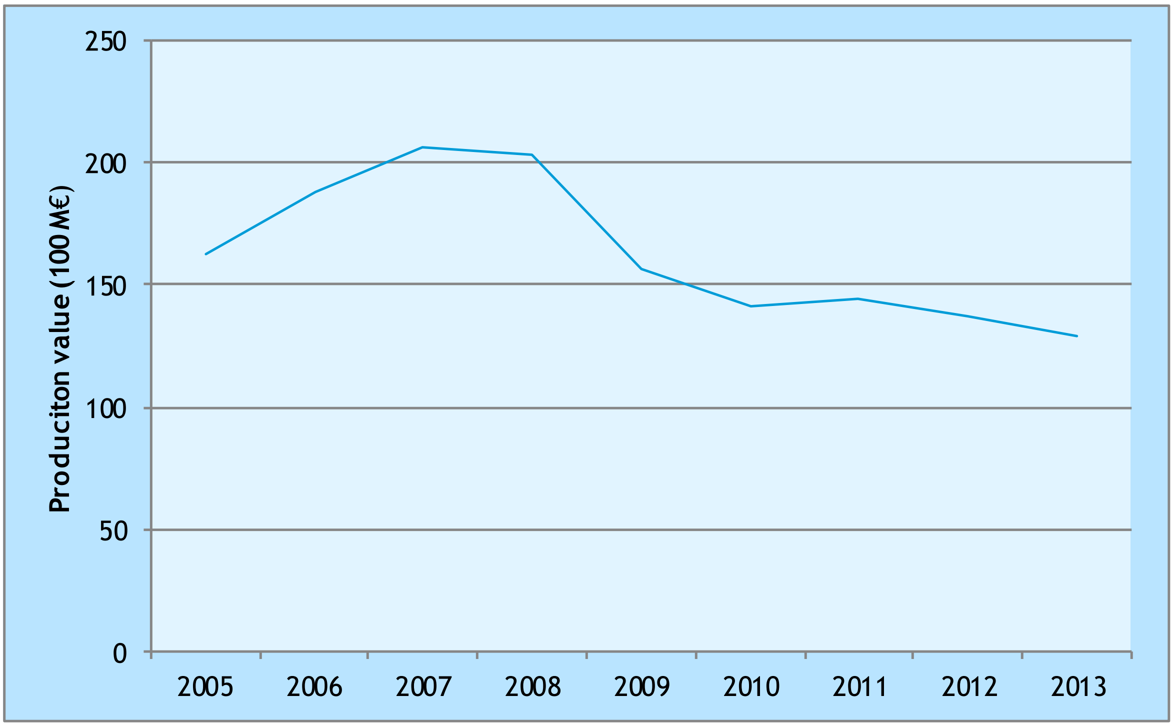
Source: EUTL, own calculations.

4.5.3 Market characteristics

Cement is globally produced and used. Production facilities are in virtually all countries since cement is an important construction material and the raw material (limestone) needed for cement production is geographically abundant (IEA, 2005). Moreover, relatively high transport costs to low value make trade limited in cement products. Multinational companies in the cement market exist where companies typically have various production facilities in many countries. The largest companies operating on the EU market are Lafarge (based in France), Holcim (Switzerland), Heidelberg (Germany), Italcementi & Buzzi (Italy) and Cemex (Mexico). Firms in the market are vertically integrated. The major cement producers consume a significant proportion of the cement they produce in their own downstream ready-mix concrete production.

The demand for cement products is highly cyclical and fluctuates with activities in the sectors construction and civil engineering. Output in the sector has peaked at the height of the construction boom, and has fallen by some 50% in the aftermath of the crisis.

Figure 31 The value of production in the EU27 for the sector cement (NACE 2351)

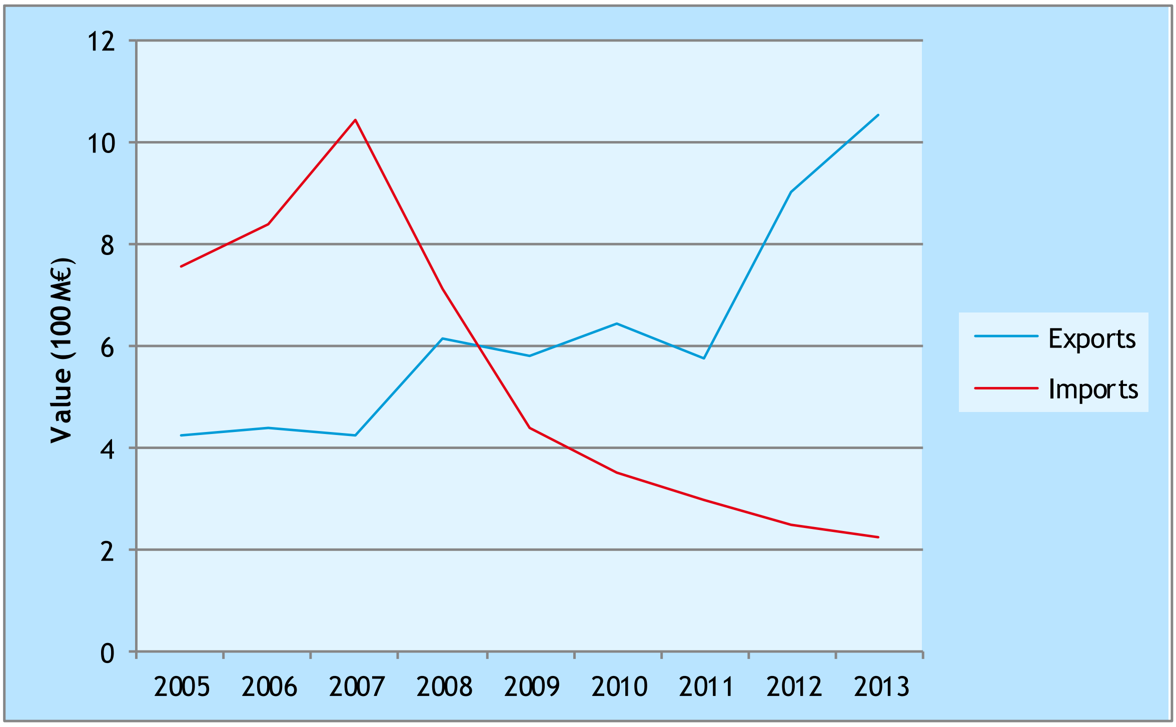


Source: EU Prodcom trade statistics.

While demand contracted after the economic crisis, the production capacity in the EU27 kept growing due to already planned investments. This resulted in a sharp decline in capacity utilisation and a reduced ability to raise prices, which squeezed profit margins (Boyer & Ponssard, 2013).

Trade in cement products is limited, because cement is a high-density product with a relatively low selling price. These characteristics make transport costs dominant for trade. Compared to the total value of production, exports and imports make up only a limited fraction. The value of imports fell from 5% to 2% of total production in the last decade, while the value of exports rose from 3% to 8%. Total exports currently equal over 1 billion Euros (see Figure 32).

Figure 32 The value of extra EU imports and exports in the EU27 for the sector cement (NACE 2351)



Source: EU Prodcom trade statistics.

The EU exports mainly to the US and imports come mainly from East Asian countries like China, Thailand, and the Philippines[52].

As imports are limited and the EC market is dominated by some large companies, there have been questions to what extent the cement market is competitive enough or should be regarded as highly oligopolistic. The reduced profitability, as noted by Boyer and Ponssard (2013), would negate the possibility of an oligopoly. Nevertheless, the EC is currently carrying out an investigation on whether the EU cement companies participated in colluding behaviour, in particular import/export restrictions, market sharing and price coordination in cement and materials markets (EC, 2014).
This investigation is still ongoing. Among the factors that inspired this research, are the characteristics that the EU market is dominated by a small number of vertically integrated large producers. These EU producers now own almost 60% of US production capacity, limiting competition from overseas (EC, 2015). The sector is characterised by high capital investments, involving the mining concession and the capacity of plant. These inhibit new market entry. The cost of laying down a cement

52 See e.g. http://ec.europa.eu/growth/sectors/raw-materials/industries/non-metals/cement-lime/index_en.htm, accessed 9 June 2015.

production installation is estimated to be equivalent to around three years' turnover (EC, 2010).[53]

4.5.4 Data

There are no institutes that record independently prices of cement, which would qualify as Tier 1 in our analysis.[54] Therefore prices series have been constructed on the basis of a combination of monthly Eurostat production data (ppi indexes, Tier 2 in our data framework in Chapter 3) and trade statistics (Tier 3). The general routine that has been followed was to use Eurostat production data first, and to use the trade statistics to fill in data gaps.

For Germany, Spain, France and Italy, price information on total cement was taken from Eurostat using Ppi indices. For Poland and Czech Republic, price series were constructed from the COMEX trade data as an average of import and export prices.

As production of clinker is the most carbon intensive product in the cement sector, additional data on clinker prices were extracted from the COMEXT trade statistics for the same countries as listed here above.

The literature and Interviewees indicated that power and fuel cost account for about one third of the price of cement, raw materials such as limestone making op 30 to 40% and transport costs about 20% (Marketrealist, 2014). The remaining part is maid up of labour costs including costs of repair and maintenance charges. Given the relative importance of logistics, cement frequently originates from local sources or at least surrounding countries (max. about 155 miles). Therefore, in addition to the cement prices, we would ideally include data on energy, limestone and labour. While we were capable of producing series on labour and energy (see Annex A), Tier 1 or 2 limestone prices could not be found and would show strange unexplained patterns when constructed from the trade statistics (Tier 3). As most cement companies are vertically integrated price information on lime-stone through trade statistics may also be less relevant in this case. Therefore, it was decided to leave this out in the regressions (see also below).

4.5.5 Price development

Large producers of cement products like concrete mortar and high grade prefab, used to conclude contracts with fixed cement dealers to guarantee the continuity and quality of the material. Contracts were typically on a yearly basis, or attached to a certain infrastructural project. Indexes are used to mitigate price risks related to transport and fuels. However, a substantial share of the market is taken by smaller vendors which may adhere more to a type of spot-market prices.

The used price statistics (see Annex A) contain an average of delivered prices as observed by the cement manufacturers (in the case of ppi) or customs (in the case of

[53] It should be noted though, that recent decline in sea transport prices in combination with overcapacity in countries such as China and Turkey, might pose some import pressure.

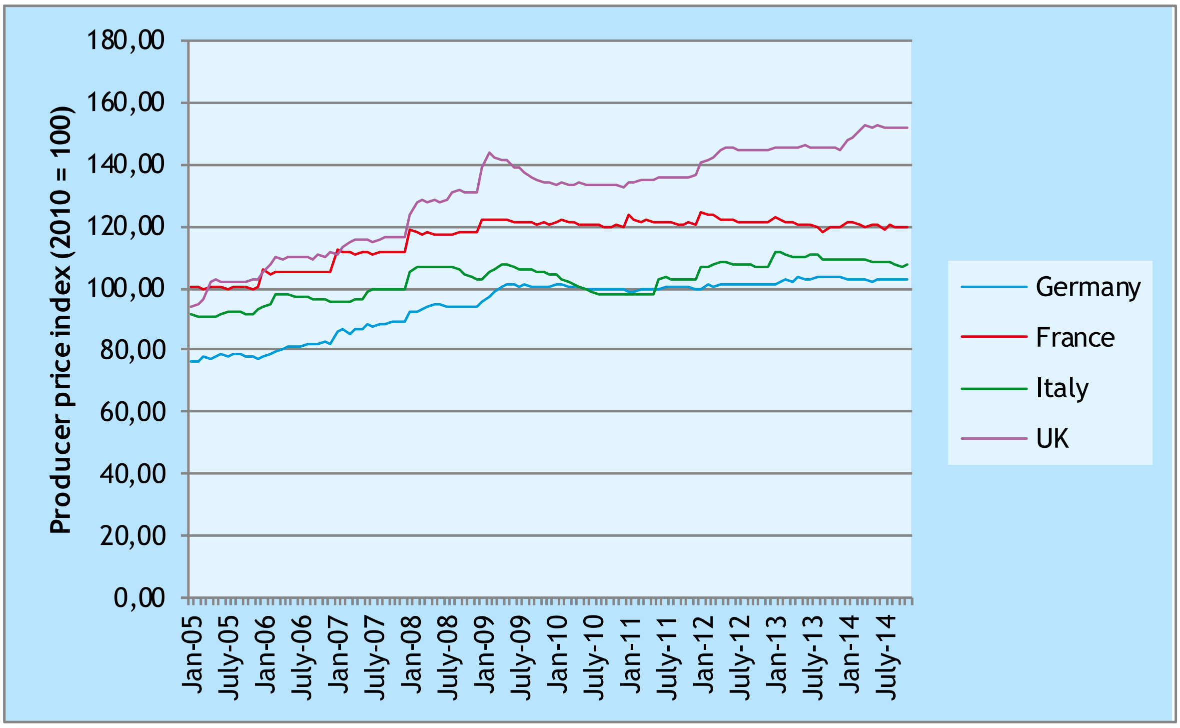
[54] While organisations like CEMWEEK advertises with cement prices, the coverage and quality of the data proved to be too poor for our analysis here.

Comext based series of clinker and Portland cement). Therefore we regard these prices as a typical average mixture of spot and contract prices.

Figure 33 gives the nominal prices of cement products for the countries analysed in our study. We observe that prices have been rising steadily since the beginning of 2005 until mid 2009. Initially, these prices may have been pushed up by fuel costs and stricter labour regulations (Trout, 2015[55]). In 2006 prices of building materials rose in general, but those of energy intensive products like cement with a higher margin. In 2007 prices kept rising, which caused concern about possible cartel formation. These concerns have eventually led to the earlier mentioned investigation by the European Commission, which is still ongoing.

Among these concerns is the practice of pre-announced 1 January price hikes, which are visible as the stepwise developments in Figure 33. Prices kept rising until 2009, when declining volumes lead to a stabilisation of prices, and for some countries even a small fall in prices. Price formation became more market driven instead of cost price driven since then.

Figure 33 PPI based on nominal prices of total cement products for the countries analysed in our study

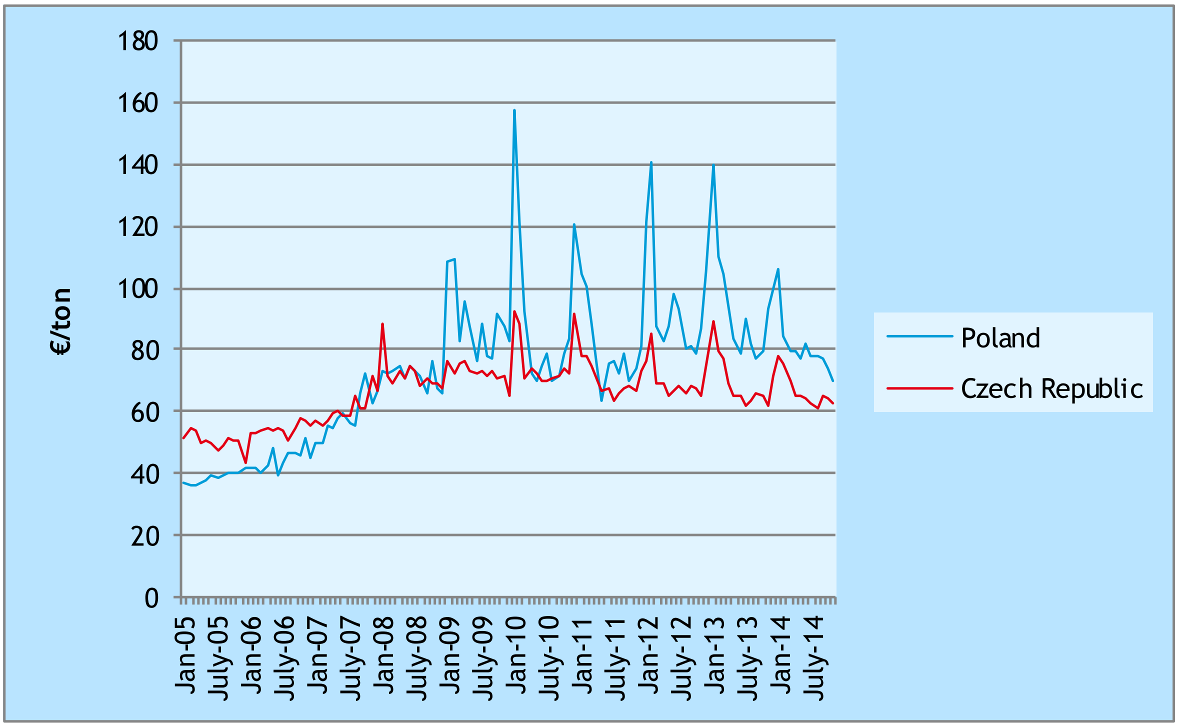


Source: Eurostat SBS and CEM Week; PPI with 2010 = 100 for Germany and Italy; 2005 = 100 for France and UK.

In addition to the overall prices of cement, additional information was obtained for Poland and the Czech Republic for the price of Portland cement. Especially the prices in Poland show substantial price hikes – often during winter months when relatively little cement is being traded.

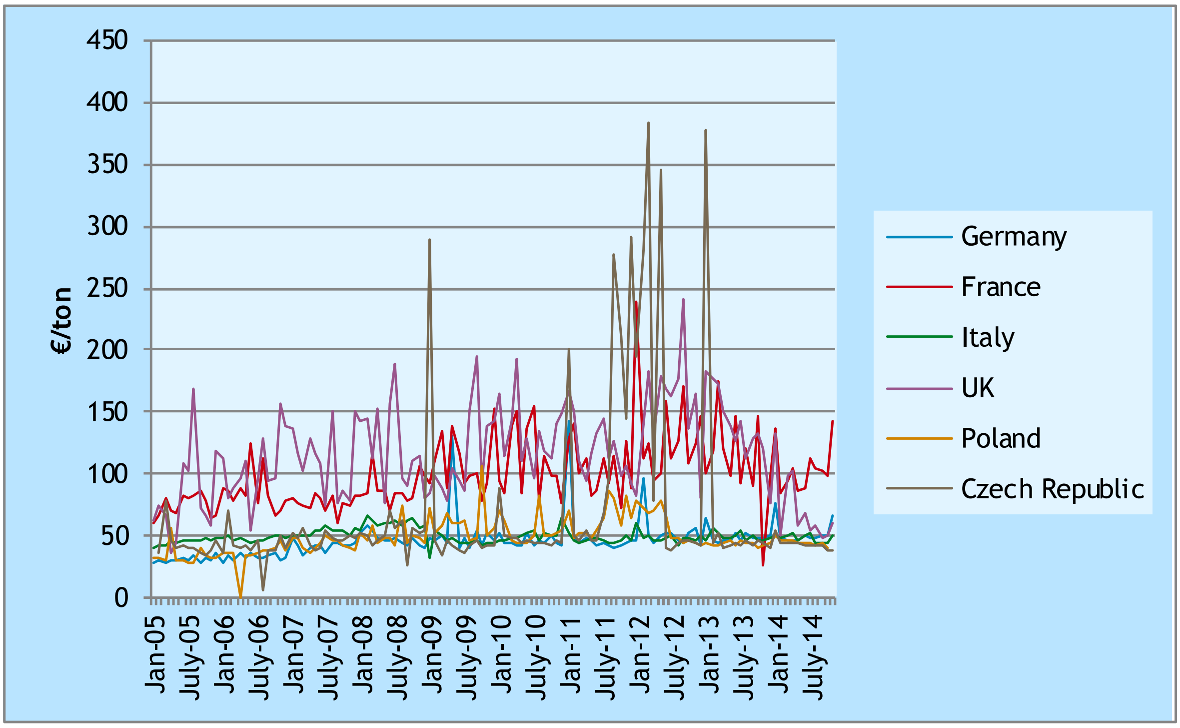
55 This account is for UK cement, but we see similar price developments in other countries.

Figure 34 Nominal Prices of Portland cement for the countries analysed in our study



Source: Comext trade data and own calculations.

Figure 35 Nominal Prices of cement clinker for the countries analysed in our study



Source: Comext trade data and own calculations.

Prices of cement clinker display less of a trend than the prices of Portland and total cement, but show a lot more seasonal variation.

4.5.6 Estimation procedure

For the cement sector, we run models that explain the price for three products: Total cement, Portland cement and cement clinker. The prices are explained by the main inputs of these products, notably limestone and energy. Next to this we add a variable for the price of CO_2 EUA's, and a number of variables that indicate other costs, such as wages the interest rate and the exchange rate as well as controls for the general economic climate such as a stock market index and an indicator for the production volume in the sector.

In order to test the influence of the EUA price on the price formation in the cement sector, we have followed the estimation procedure described in Chapter 3. First, all variables have been transformed to logs to facilitate estimation of the model. Second, unit root tests have been applied to investigate whether the variables contain unit roots. In the appendix, unit root tests are reported for these variables. The outcome of the unit root tests is that all cement price variables contain a unit root. Tests also strongly conclude that energy prices have a unit root, while CO_2 prices (both the combined price for Phase 1, 2 and 3 and the price for Phase 2 and 3) also contain a unit root[56]. All series in first differences (including the control variables) do not contain a unit root.

We subsequently tested for cointegration among the variables cement price, energy price and CO_2 price. These tests generally favoured the existence of a cointegration relationship.

Using a VECM approach, we obtained the following insights.

A. The results are highly sensitive to the amount of lagged first differences included. That counts for the outcome of cointegration tests, signs and significance of coefficients of CO_2 costs and of the adjustment coefficient.
B. Tests for residual autocorrelation (e.g. the Q-statistic, the LM-statistic or the simple t-test) indicates that residual autocorrelation is present for lags that fall within the range lags of first differences or are close to that range.
C. Granger causality tests show that granger causality is rejected for output prices of cement industry causing the input prices.

The results on the VECM point to the appropriateness of using an ARDL. Given that ARDL's display less autocorrelation in the residuals, we interpret the excess autocorrelation in the VECM as arising from incomplete models for the reversed causality. Considering the results with the ARDL, they led us to drop the Limestone price from our models. Limestone was discarded as an explanatory variable because the estimation results implied that its share in costs was implausibly high, with estimated shares often above 1. Because of the poor data quality of the limestone series (from trade statistics) and the limited importance of limestone prices for vertically integrated companies we decided to drop this variable from the estimations.

[56] We did not include limestone in this table, because we discarded limestone as an explanatory variable for reasons mentioned above.

4.5.7 Estimation results

Model M1* (Chapter 3) was estimated for two time-intervals:

1. Over the entire sample 2005-2014 – so including Phase 1, 2 and 3.
2. Limiting CO_2 cost pass-through to Phase 2 and 3 (2008-2014).[57]

In general the ARDL models behaved reasonable well for both the price of total cement and the price of cement clinker for both time-intervals. However, the first interval (entire sample) resulted in very large estimates for the price of energy explaining sometimes over 100% of the cost-price. Closer visual inspection of the data made us to conclude that although the price of energy must have played a role in the increase of prices in Phase 1, the price increases seemed to be more the result of shortage on the market which was not sufficiently dampened by including the stock market index as control variable. Therefore we have decided to restrict our sample to only include Phase 2 and 3 for more reliable results (The results of the entire sample can still be found section E.4 – and in this case also cost pass-through of CO_2 prices was found).

We were able to select models with well behaved residuals according to the simple AC and PAC tests as well as the LM and Q-tests. These models have consistent estimates. In these cases, the Bounds-test indicated a cointegration relationship for most countries and significant cost pass-through of CO_2 was found, while the estimate for the cost share of energy seemed reasonable.

Total cement

Table 21 displays the estimation results of models where the total cement price is explained by the price of energy input and the price of CO_2 EUA's in Phase 2/3 (January 2008 to December 2014). The null hypothesis that no carbon costs were passed through in product prices was rejected in 2 out of 4 countries: Germany and France. Cost shares of CO_2 were around the 2% and seemed to be passed through with a delay of 1 month. Energy typically accounts for between 20 to 30% of total cement costs and seems to be passed through with a delay of three months presumably because of contracts in the purchase of energy. For the UK, no cointegration between the input prices and the price of total cement was found. For France, the evidence on cointegration is inconclusive indicated by the relatively low value of the Bounds test. For Italy, no models satisfy our criteria of positive cost pass-through.

Table 21 Estimations results, total cement (PPI), 2008-2014

Country	Germany	France	Italy*	UK
PE_delay	3	3		2
CO_2_delay	1	1		1
PE_coef	**0.231305**	**0.21904**		**0.380734**
PE_t_stat	7.81558	6.680681		3.39244
PE_pval	0	0		0.00045
CO_2_coef	**0.02584**	**0.020546**		0.032794
CO_2_t_stat	3.848569	2.340368		0.974432

[57] Latest data point was the first week of March 2015.

Country	Germany	France	Italy*	UK
CO_2_pval	0.0001	0.0104		0.16585
adj. coef	**-0.10307**	**-0.12184**		**-0.03049**
t_adj. coef	-5.41501	-3.50093		-1.93322
p_adj. coef	0	0.0003		0.0277
SIC	-8.42118	-7.755		-7.79704
Bounds F-statistic	**13.24344**	3.264381**		1.695197

* All selected models generated negative coefficients; no p-value reported.
** This value lies between the I0 and I1 bound for the 10% significance level.
Figures in bold indicate statistical significance of at least 10%.

Portland cement

Table 22 presents the results for models that explain the price of Portland cement over the time span covered by Phase 2 and 3 (January 2008 to November 2014) for the countries for which no price information on total cement was available (Poland and Czech Republic). We observe that cost pass-through of CO_2 is found for both countries, with CO_2 cost shares of 7% to 10%. Energy in Czech is estimated to account for about 25% of the costs of Portland cement, while this value is much higher in Poland (85%). As in the case of total cement, costs of energy are typically passed through with a delay of three months, while those of CO_2 are passed through with a delay of 1 month.

Table 22 Estimations results, Portland cement (Tier 3 data), 2008-2014

Country	Poland	Czech
PE_delay	3	3
CO_2_delay	1	1
PE_coef	**0.868633**	**0.26632**
PE_t_stat	4.209453	5.201963
PE_pval	0.00005	0
CO_2_coef	**0.106692**	**0.067368**
CO_2_t_stat	2.507253	4.704611
CO_2_pval	0.0068	0
adj. coef	**-0.34412**	**-0.65375**
t_adj. coef	-5.23889	-7.99203
p_adj. coef	0	0
SIC	-2.58738	-3.49864
Bounds F-statistic	**9.016469**	**16.89335**

Figures in bold indicate statistical significance of at least 10%.

Cement clinker

Table 23 covers the results for models in which the price of Cement Clinker is explained by the price of energy and the price of CO_2 allowances in Phase 2 and 3 (January 2008 to October/November 2014). The delays by which the inputs enter in the model vary from country to country from 0 to 3 months. We find evidence for cost pass-through of CO_2 in Germany, France and Poland[58]. CO_2 accounts for 7 to 9% of cement clinker prices for these countries. Energy accounts for about 40 to 65% of cement clinker prices.

58 The adjustment coefficient for Germany and France is high with a value of around 1.

For Italy none of the models estimated satisfy the residual criteria. For UK and Czech, no significant cost pass-through is found.

Table 23 Estimations results, cement clinker (Tier 3), 2008-2014

Country	Germany	France	Italy	UK	Poland	Czech
PE_delay	0	0	*	**	3	3
CO_2_delay	2	3			3	3
PE_coef	**0.455019**	**0.38067**			**0.623836**	**0.687248**
PE_t_stat	6.547484	4.656219			2.869051	1.809216
PE_pval	0	0			0.00245	0.0364
CO_2_coef	**0.082512**	**0.069063**			**0.088797**	0.038266
CO_2_t_stat	4.657283	3.285673			1.95418	0.353901
CO_2_pval	0	0.00065			0.02655	0.362
adj. coef	**-1.01707**	**-1.10535**			**-0.52037**	**-0.49016**
t_adj. coef	-11.975	-13.0361			-6.36255	-5.16887
p_adj. coef	0	0			0	0
SIC	-1.9671	-1.46			-1.72274	-0.05994
Bounds F-statistic	**47.82366**	**55.36851**			**13.09179**	**8.847856**

* For Italy, no models satisfy the criteria on the behaviour of the residuals.
** The VECM results point to estimating the equation in a VAR in first differences, which points to cost pass-through of CO_2 being insignificant (results available on request).
Figures in bold indicate statistical significance of at least 10%.

4.5.8 Indicative cost pass-through ratios

The values found for CO_2 cost shares in the Tables above, can be compared with the expected CO_2 costs if all opportunity costs were passed through in the product prices. In the EU all cement manufacturers fall under the EU ETS.[59] For cement manufacturing, the total turnover (taken from Eurostat) can therefore be used to determine the sales from cement. In this way, it can be calculated that the indicative cost pass-through of total cement diverges from 20% in France to 40% in Germany. In the Czech Republic and Poland, indicative cost pass-through rates (of Portland cement) would be higher and in the range of 90-100%.

For cost pass-through of cement clinker, we have to investigate the benchmark studies. The average specific emission of the cement industry in the EU was 865 kg CO_2 per tonne of clinker in 2008.[60] The average price of clinker over the period was around € 50/t. Therefore, the expected cost share of CO_2 costs in clinker production would be equivalent to 20%. The found coefficients show that cost pass-through for clinker production in France, Germany and Poland would be equivalent to 35-40%.

59 Result obtained from on-going project on impact of benchmarks for DG Clima.

60 www.cembureau.be/newsroom/article/eu-ets-%E2%80%93-clinker-benchmark

4.5.9 Discussion and interpretation

Cement is a relatively shielded sector that has limited competition from non-EU countries where carbon has no price. A-priori one would therefore expect more room to pass-through carbon costs, but the here discovered indicative cost pass-through rates are well below the 50% (except for Portland cement in the Czech Republic and Poland). This result is consistent with Walker (2006). It raises the question why cost pass-through possibilities are lower than expected. There are three explanations possible:

A. The price variables contain an average of contract and spot prices and the impact of CO_2 prices may occur in different moments in time.
The interviewees indicated that a considerable amount of cement may be pre-fixed in price by cement traders and contracts may well be established a year in advance. In our estimation procedures we discarded cost pass-through later than five months delay. The price variables are 'delivery' prices and these may contain a mix of spot and contract prices. If the spot market would, for example, constitute 30% of cement sales, it could be the case that cost pass-through for the spot market was 100%, which would translate as a 30% estimate in our model since the CO_2 cost pass-through in the remaining 70% was established before in long term contracts.
B. The cement sector is engaged in a specific type of oligopoly that aims to lower prices in order to increase profitability. Sijm et al. (2009) have argued that on oligopolistic markets the ability to pass-through the costs will depend on the pricing strategy and the utilisation rates. If capacity is fully utilised, full cost pass-through is likely. However, if capacity is not fully utilised, companies may decide not to pass-through the entire share of (opportunity) carbon costs in order to regain market share and recover the fixed costs. Since the demand for cement was lacking behind production, it may be the case that this has played a role in the cement sector.
C. Finally, for Phase 3, specific entry and exit rules have been formulated in the ETS. If production would be below the 50, 25 and 10% of the historic activity level (HAL), companies would receive less free allowances. As indicated by Branger et al. (2014) this provision may have formed an impetus for cement manufacturers to keep production at 51% level of individual installations. Given the substantial oversupply in European cement manufacturing it is therefore not unlikely that companies may have opted to pass-through less carbon allowances in order to maintain market shares so that free allowances would not be jeopardised. This implies that for individual cement manufacturers there tend to be opportunity benefits from additional production equivalent to (or in excess of) the opportunity costs of using the CO_2 credits. This implies that companies will not price in CO_2, at least not fully.

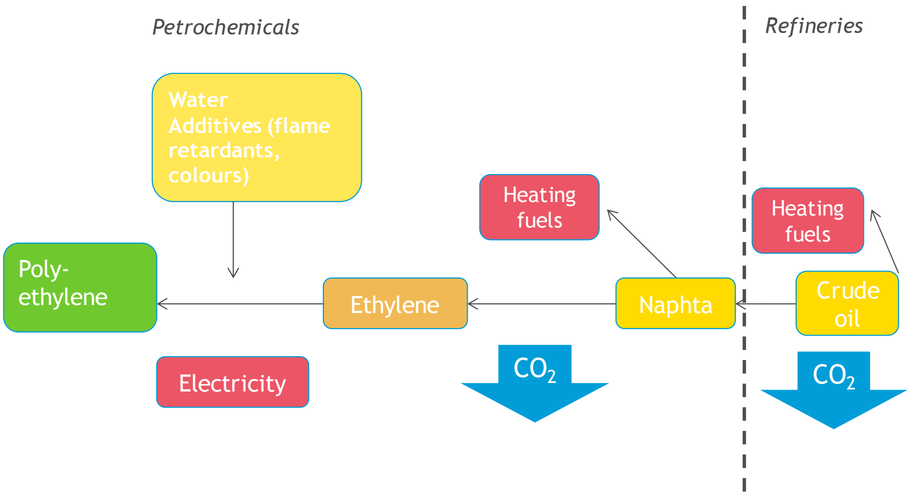
Each of these explanations would justify the findings for the cement sector.

4.6 Petrochemicals

4.6.1 Introduction

The Petrochemical sector deals with the production of organic chemical compounds. Petrochemicals are chemical products derived from petroleum. Some chemical compounds made from petroleum can also be obtained from other fossil fuels or renewable sources (biomass). Often used petrochemical products include: polyethylene (PE), polystyrene (PS), poly-urethane (PUR), polypropylene (PP), polyvinylchloride (PVC). Although the production step for each of these petrochemicals, and their inputs, is slightly different for each product, there is a common production route in which crude oil is being cracked as naphtha and subsequently naphtha is cracked into a monomer as precursor of the end products. This monomer is then subsequently transformed in a last step in the polymer end-product.

For poly-ethylene, the production step thus can be simplified in the following diagram.



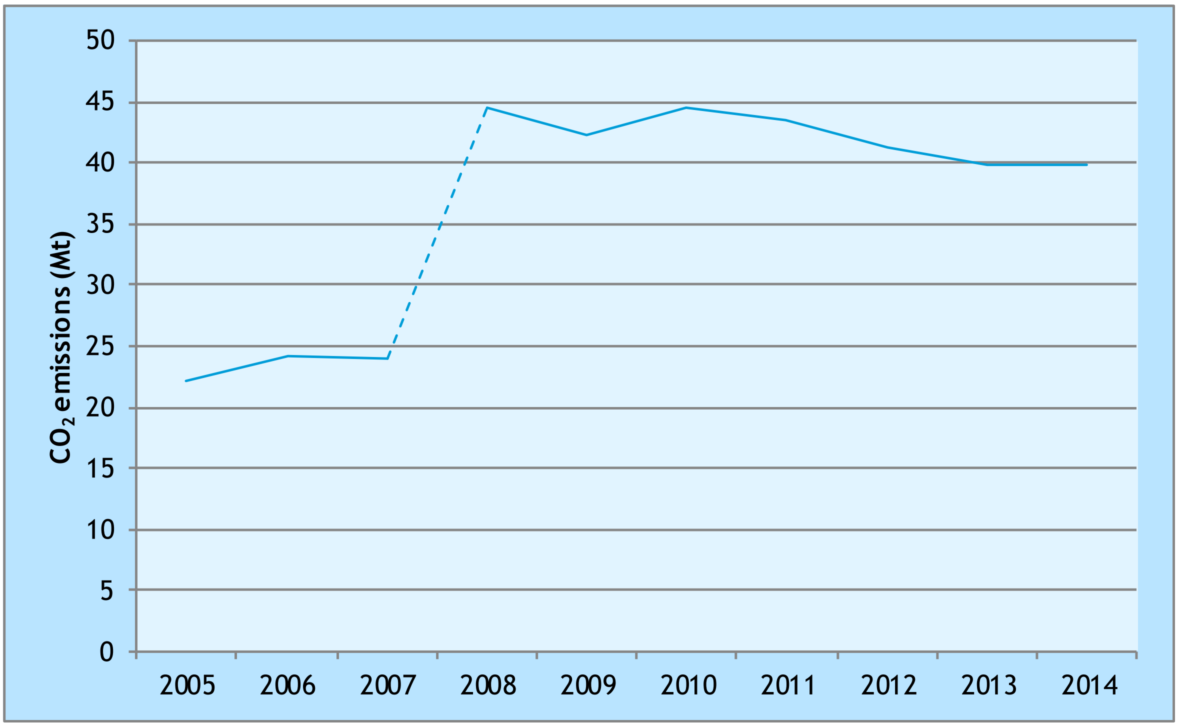
The most significant source of CO_2 emissions is thus the transformation of naphtha into the monomer ethylene through steam cracking. Therefore the input price would be naphtha and the output price preferably ethylene. If ethylene has not been investigated, one could also take poly-ethylene as an output variable, but then one has to take into account that electricity costs will be forwarded in the price, so an additional analysis has to be made. One potential problem, however, is that naphtha is an output of a sector that is also included in the ETS. If the refinery sector passes through the costs of freely obtained allowances, but the petrochemical industry does not, the econometric model may suffer from some multicollinearity problems as naphtha and CO_2 prices seems to be highly dependent. We cannot state at the outset how serious this problem is, but it may be the case that our models pick up some cost pass-through which in fact is related to the cost pass-through of naphtha.

Another problem is that the chemical industry is highly vertically integrated in which only a (small) portion of total volumes are openly traded in markets. It may therefore the case that the cost pass-through of the petrochemical sector in the end is directly passed through to the production of chemical products. Since the costs of ethylene in chemical products may only consist of a small portion of total costs, the cost pass-through is diluted and may not be properly measured anymore.

4.6.2 ETS emissions

Figure 36 gives the ETS emissions in the petrochemical sector (NACE code 2014).

Figure 36 Development of GHG emissions in the petrochemical industry under the ETS



Note: Emissions determined via NACE code 2014, not EUTL activity levels.

The data in this figure clearly show the scope changes in Phase 2 which implied that emissions in the petrochemical sector were almost doubled. Since 2010 emissions have been steadily declining. This also implies that estimation of cost pass-through over the entire time period may not be very fruitful since the carbon costs have changed in 2008. Therefore it was decided a-priori to limit the sample to only include observations in Phase 2 and 3.

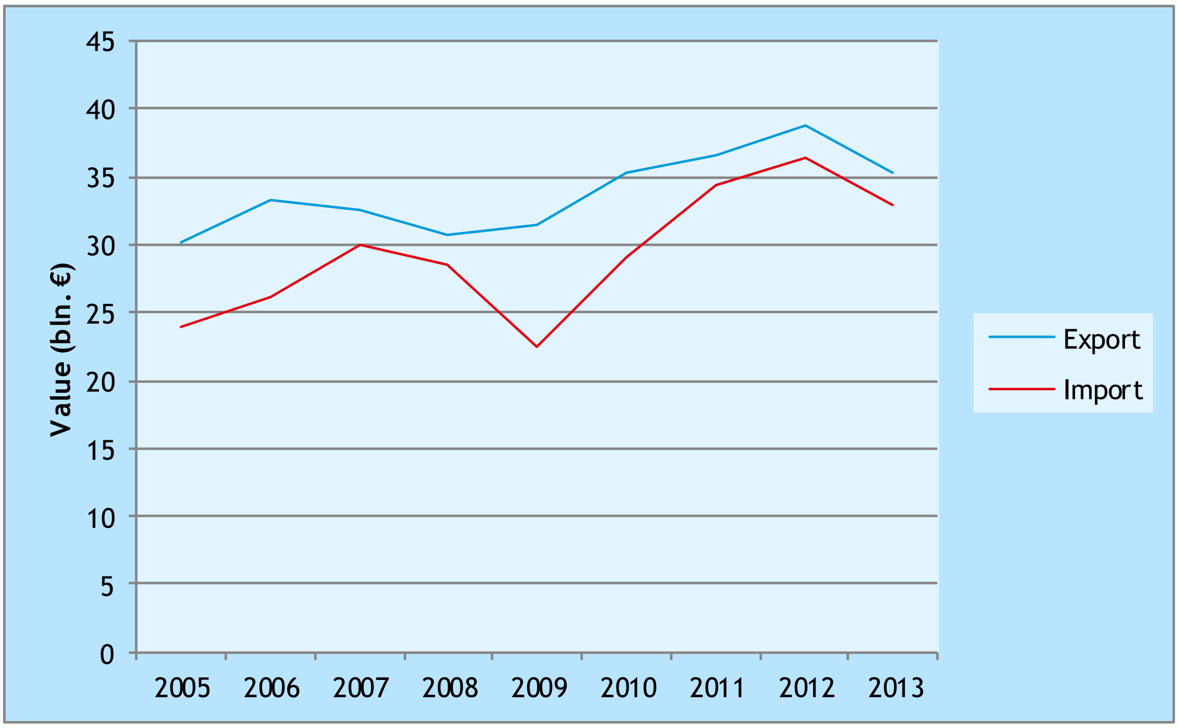
4.6.3 Market conditions

The EU petrochemicals industry (Nace code 2014) is a major industry in Europe, with a yearly sales of around € 110 billion euro's. Petrochemicals is a complex sector that comprises of 20 sub sectors with various types of production processes and outputs. Worldwide, EU27 is the largest production region of chemicals. In 2007, 12 of the 30 leading chemical companies in the world were headquartered in Europe, representing 10 percent of world chemical sales (KPMG, 2015[61]). The EU basic chemical production is, however, dominated by a few countries. Germany is on top, followed by, France, UK, the Netherlands, Belgium and Ireland (NERI et al., 2007a). In terms of turnover, the petrochemical industry is the most important sub sector.

[61] www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Lists/Expired/The-Future-of-the-European-Chemical-Industry.pdf

Looking at EU27 imports and exports values, we see that exports have been somewhat higher than imports over the years. This is an indication that the EU petrochemicals industry is competitive at world scale. This competitive edge especially is present in high-value specialities (Boston Consulting Group, 2012). EU industry can be regarded as world-leading in this area (ECF, 2013). Exports are a share of 30-35% of the value of total production, while imports make up 29%.

Figure 37 EU27 import and exports of Petrochemical (NACE 2014) products (nominal)



Source: EU Prodcom trade statistics.

Despite the strong competitive positions, there have been worries in the business regarding the future perspective. The share of the EU chemicals sector in the world market, has been declining since the 1990's. It dropped from 32% in 1993 to 17% in 2013 (CEFIC, 2014). Some specific causes for the decline in competitiveness relate firstly to the US-shale gas boom that has resulted in a cost-advantage for both feedstock and energy for US companies and associated investments for the production of Ethane and Propane. These investments will expand US production capacity of ethane with 43% and world capacity with 7% (Deloitte, 2013). Another important factor cited by companies as affecting competitiveness is the growing cumulative costs of implementing European legislation in the chemical sector (CEFIC, 2014). This has led to under-utilisation of capacity which is expected to continue in the future, in spite of recent increases in custom tariffs for petrochemical products from the Gulf nations.[62]

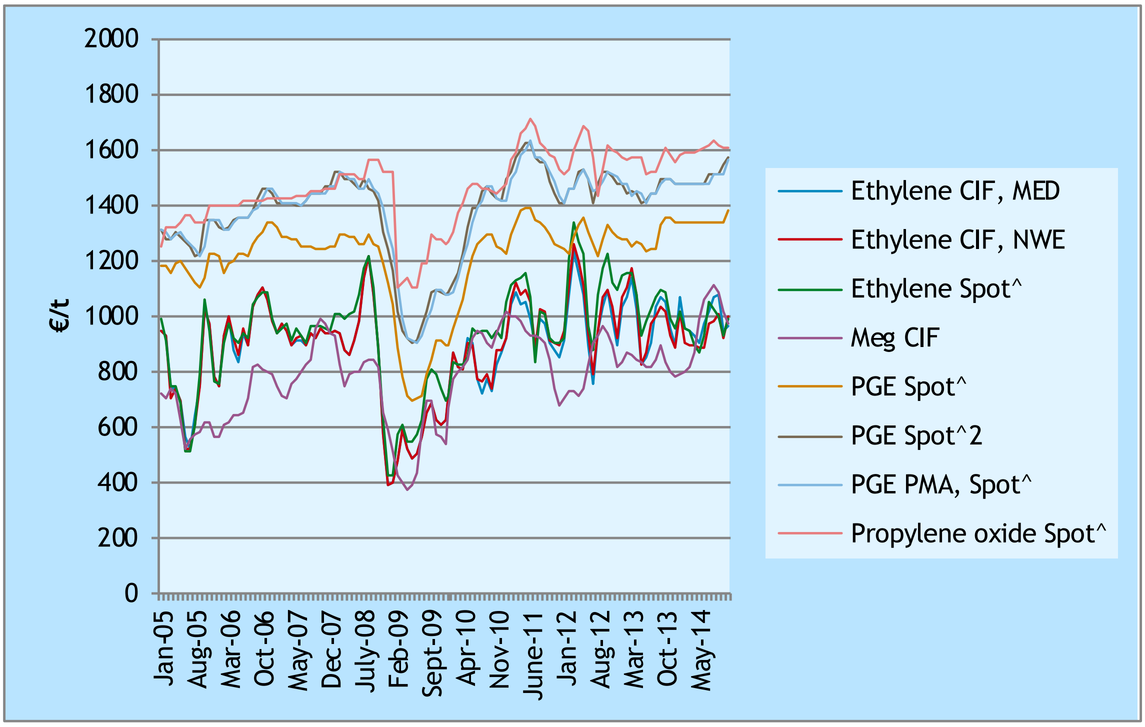
[62] http://www.platts.com/news-feature/2014/petrochemicals/europe-2014-outlook/polyethylene

4.6.4 Price information

Prices of petrochemical products are predominantly based on prices of feedstocks (such as Naphtha) and energy. Petrochemicals are typically traded by volume contracts with about a month ahead delivery time. These contracts can be both fixed price or agreed as a mark up on a spot market price as indicated by interviews with traders.

Figure 38 depicts the prices of some typical products for the petrochemicals sector.

Figure 38 Nominal prices of petrochemical products (€/mt)

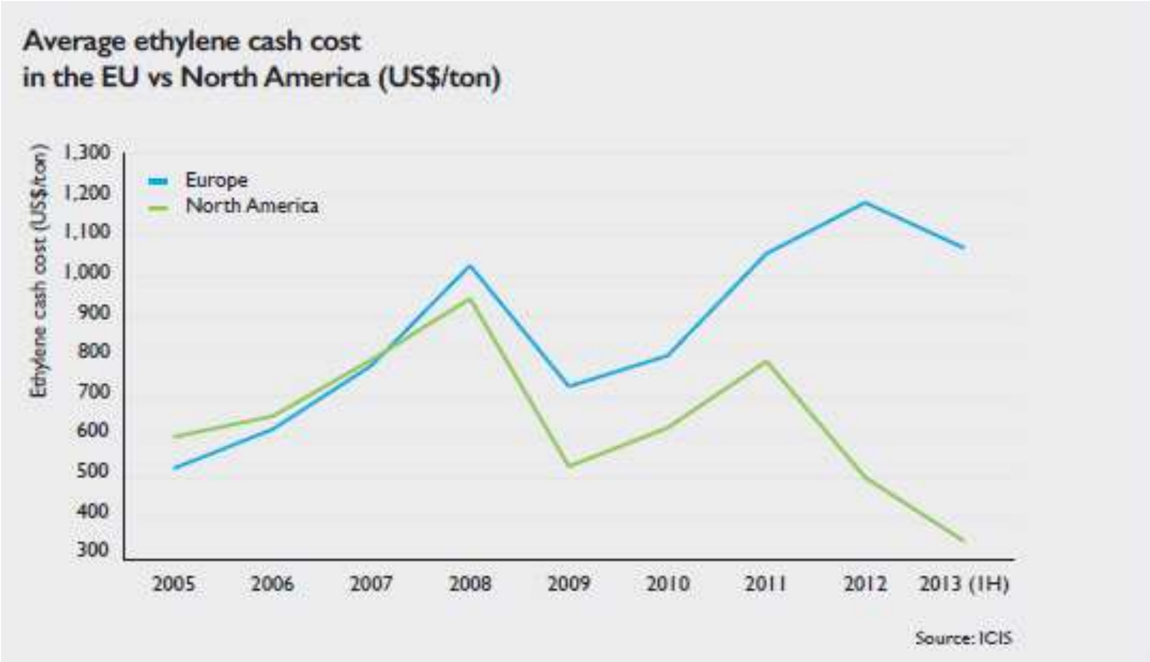


Source: Thomson Reuters DataStream.
Notes: ^ Spot relates here to spot, free delivered.
Abbreviations: MEG = Mono Ethylene Glycol; PGE = Propylene glycol ether, methanol based; PGE PMA= Propylene Glycol Ether, Propylene Glycol Methyl Ether Acetate based; NWE = North-West Europe. MED = Mediterranean. CIF = costs insurance and freight.

The price data show a small rising trend in prices up to the crisis in 2008, followed by a sharp drop till the second half of 2008. Over the years 2009–2011 prices recover to their pre-crisis values.

Figure 39 shows that the pattern of prices follows the pattern of costs. Costs of producing ethylene have declined since 2008 because of the falling prices of Crude Oil and Naphtha. These are the major cost components of petrochemical products, with a share of 50–90% depending on the type of product.

Figure 39 Costs of producing Ethylene



Product prices restored to normal values in 2011, as did the costs of production. Another thing to note in the figure is a widening gap between US production costs and EU production costs, caused by the shale gas revolution in the US. This gap was identified before as a driver for the EU loosing market share on the world market, although the EU maintains a positive trade balance for refinery products.

4.6.5 Data

We have collected data for seven products of the petrochemicals sector, notably: Butadiene, Ethylene, Methanol, Mono Ethylene Glycol, Propylene, Propylene Glycol Ether and Propylene Oxide. These products were approximated by various data series including spot and contract prices, and prices FOB (free on board) or CIF (including insurance and freight costs). We have data for two European regions: North West Europe (NWE) and the Mediterranean countries (MED). The used variables are listed in Table 24.

Table 24 Prices of Petrochemical products used in our models

Product	Market
Ethylene, Cost Insurance and Freight	North-west Europe
Ethylene, Cost Insurance and Freight	Mediterranean Europe
Ethylene, Spot Free Delivered	North-west Europe
Mono Ethylene Glycol, Cost Insurance and Freight	North-west Europe
Mono Ethylene Glycol, Cost Insurance and Freight	Mediterranean Europe
Propylene Glycol Ether, methanol based; Spot Free Delivered	North-west Europe

Product	Market
Propylene Glycol Ether, propylene glycol methyl ether acetate based; Spot Free Delivered	North-west Europe
Propylene Oxyde, Spot Free Delivered	North-west Europe

These products are explained by the price of the main input in the sector: Naphtha. Next to this we add a variable for the price of EUA's, and a number of variables that indicate other costs, such as energy prices, wages, the interest rate, the stock exchange, an indicator for the production in the sector and the euro/dollar exchange rate. All variables are entered in logs and converted to euro values. The control variables are entered in first differences.

For Energy, wages and the interest rate, we use German data as a proxy for the NWE-values and Italian data as a proxy for the MED values. Data are on a monthly frequency. See Annex F for more information on data sources and descriptive statistics of the variables.

Unit root test

In Annex F, we report unit root tests for these variables. A unit root test is a test on whether a variable has a (stochastic) trend. If variables in a model do have a trend, then one should test for cointegration between these variables. If cointegration is not present, estimating a model with these variables will lead to spurious results. If, on the other hand, cointegration is present, then the estimation results are more reliable when compared to an estimation with variables without a unit root[63].
The results of the tests are that all price variables have unit root, except the price of mono ethylene glycol (CIF) over the time span associated with Phase 2 and 3 of the ETS[64]. CO_2 and naphtha prices have a unit root.

4.6.6 Estimation procedure

We have run models for the nine products, using the monthly data and limiting the sample to Phase 2 and 3. The procedure followed was as in Chapter 3. Using a VECM approach, we obtained the following results.

A. The results are highly sensitive to the amount of lagged first differences included. That counts for the outcome of cointegration tests, signs and significance of coefficients of CO_2 costs and of the adjustment coefficient.
B. Tests for residual autocorrelation (e.g. the Q-statistic, the LM-statistic or the simple t-test) indicates that residual autocorrelation is present for lags that fall within the range lags of first differences or are close to that range.
C. Granger causality tests show that granger causality is rejected for output prices of petrochemical industry causing the input prices.

63 In technical terms: the estimation results then are superconsistent.

64 Note that our cointegration test (the ARDL bounds test) allows for a mix of variables with and without a unit root. Thus, the finding that one of prices of Petrochemical products does not have a unit has no consequences for the validity of this test.

The results on the VECM point to the appropriateness of using an ARDL. We consider an ARDL appropriate if statistical tests cannot reject the hypothesis of no granger causality, or if we are stuck with inconsistent models due to excess autocorrelation in the residuals. Given that ARDL's display less autocorrelation in the residuals, we interpret the excess autocorrelation in the VECM as arising from incomplete models for the reversed causality.

An added benefit of using an ARDL is that we can model delays in cost pass-through explicitly. A delay in cost pass-through happens if e.g. CO_2 prices are not transferred directly into product prices, but rather with a delay of e.g. one or two months. Such delays cannot be appropriately modelled in a VECM context, because the reversed causality is theoretically flawed as this would imply future values causing passed values. The interpretation of found delays is multifaceted: it may stem from the definition of price variables, containing a mix of prices of long term contracts, futures and/or spot prices, or it may stem from actual behaviour of market parties.

In general the ARDL models behaved reasonable well for a number of products in the petrochemicals sector. We were able to select models with well behaved residuals according to the simple AC and PAC tests as well as the LM and Q-tests. These models have consistent estimates. In these cases, the Bounds-test indicated a cointegration relationship for most countries and significant cost pass-through of CO_2 was found, while the estimate for the cost share of energy seemed reasonable.

However, in six prices series our models behaved poorly. In these cases, the models we estimated did not solve the issue of higher order auto correlation and the ARDL selection did not pick any model as reliable. This was the case for butadiene, propylene and methanol. Therefore, in these cases we could not estimate the potential cost pass-through for these products in the petrochemical industries.

4.6.7 Estimation results

The table below displays the results of models that explain prices of different products of the petrochemical industry, by the price of Naphtha and the price of CO_2 EUA's in Phase 2 and 3. In seven out of nine models, we find cost pass-through of CO_2 ranging from 2 to 18% depending on market and product, with a cointegration relationship between the price of the output, the price of Naphtha and the CO_2 price. Naphtha is the main constituent of product prices in the petrochemical sector, with its share ranging from 40% (Propylene oxide) to 86% (Ethylene ife both in the NWE and MED markets). Adjustment coefficients are all negative, but somewhat large for Ethylene. For the other products, they have more moderate values. Only in the models that explain Meg isf (NWE, MED) and PGE SFD we do not find cost pass-through of CO_2. For MEG isf there is no cointegration relation.

Table 25 Summary of estimation results, Petrochemical products, Phase 2 and 3

Product	Ethylene CIF	Ethylene CIF	Ethylene Spot^	Meg CIF	Meg CIF	PGE Spot^	PGE Spot^	PGE PMA spot^	Propylene oxide Spot^
Market	NWE	MED	NWE	NWE*, **	MED*	NWE	NWE	NWE	NWE
Naphtha delay	1	0	1	3	3	2	0	1	2
CO_2 delay	2	0	0	3	3	1	0	0	0
Maxlags	2	2	1	2	2	2	3	3	1
Naphtha_coef	**0.859**	**0.858**	**0.804**	**0.654**	**0.581**	**0.706**	**0.632**	**0.642**	**0.399**
Naphtha_t_stat	24.198	23.798	13.356	4.430	3.686	9.865	10.685	13.140	15.400
Naphtha_pval	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO_2_coef	**0.027**	***0.120****	**0.055**	***0.182****	0.030	0.043	**0.062**	**0.068**	**0.021**
CO_2_t	1.434	3.843	1.797	2.307	0.203	1.262	2.253	2.968	1.676
CO_2_pval	0.078	0.000	0.038	0.012	0.420	0.106	0.014	0.002	0.049
Adj. coef	**-0.960**	**-0.858**	**-0.534**	**-0.883**	**-0.236**	**-0.194**	**-0.205**	**-0.240**	**-0.611**
t_adj. coef	-10.073	-8.560	-4.990	-7.279	-3.947	-4.599	-5.160	-5.649	-7.940
p_ads. coef	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SIC	-3.743	-3.859	-3.790	-4.487	-3.748	-5.673	-5.957	-6.035	-5.451125
Bounds F-stat	**12.498**	**26.034**	**8.163**		**5.505**	**7.203**	**9.516**	**11.173**	**25.96181**

Notes: Results from estimating with monthly data, Jan 2008-dec 2014. Figures in bold indicate statistical significance of at least 10%. Figures in bold indicate statistical significance of at least 10%.

Abbreviations: MEG = Mono Ethylene Glycol; PGE = Propylene glycol ether, methanol based; PGE PMA= Propylene Glycol Ether, Propylene Glycol Methyl Ether Acetate based; NWE = North-West Europe. MED = Mediterranean. CIF = costs insurance and freight.

^ Spot relates here to spot, free delivered.

* The price for MEG CIF is an EU price. In the NWE model, explanatory variables come from NWE countries (Germany), in the MED model, explanatory variables are for MED countries (Italy).

** The VECM results point to estimating this model as a VAR in first differences. The VAR in first differences did not satisfy criteria for residuals, subsequent estimates for an ARDL in first differences reported here.

*** Cost pass-through estimates in these two products may point at potential problems in model formulation as they seem to be too high (see also Section 4.6.8 below).

4.6.8 Indicative cost pass-through rates

In order to interpret the estimated CO_2 costs in product prices as indicative cost pass-through rates, we have to investigate in more detail the specific emissions from producing petrochemicals. The vast majority of emissions in the petrochemical industry stem from steam cracking. Figure 40 illustrates the mass balance and energy balance of a modern naphtha processing steam cracker which can be regarded as the bulk of EU steam cracker feed. As illustrated, approximately 60% of the feed is converted into directly utilisable high value components (ethylene, propylene, C4-cut), while approximately another 14-15% of HVC's can be recovered in the shape of aromatics from the PyGas and PyOil. At the same time 7.6–8.7 GJ of fuel gas per tonne of naphtha is produced, representing an associated CO_2 emission of 510–580 kg CO_2 when assuming a specific emission factor of 66.7 kg CO_2/GJ[65]. Dividing the 510–580 kg CO_2/tonne naphtha by a mass fraction of approximately 75% of HVC gives a specific average emission factor of 670–770 kg CO_2 per tonne product. In their study for the benchmarking project, Ecofys (2009) calculates that the average value of EU industry is about 800 kg CO_2 per tonne product. Therefore these numbers seem to be quite reliable.

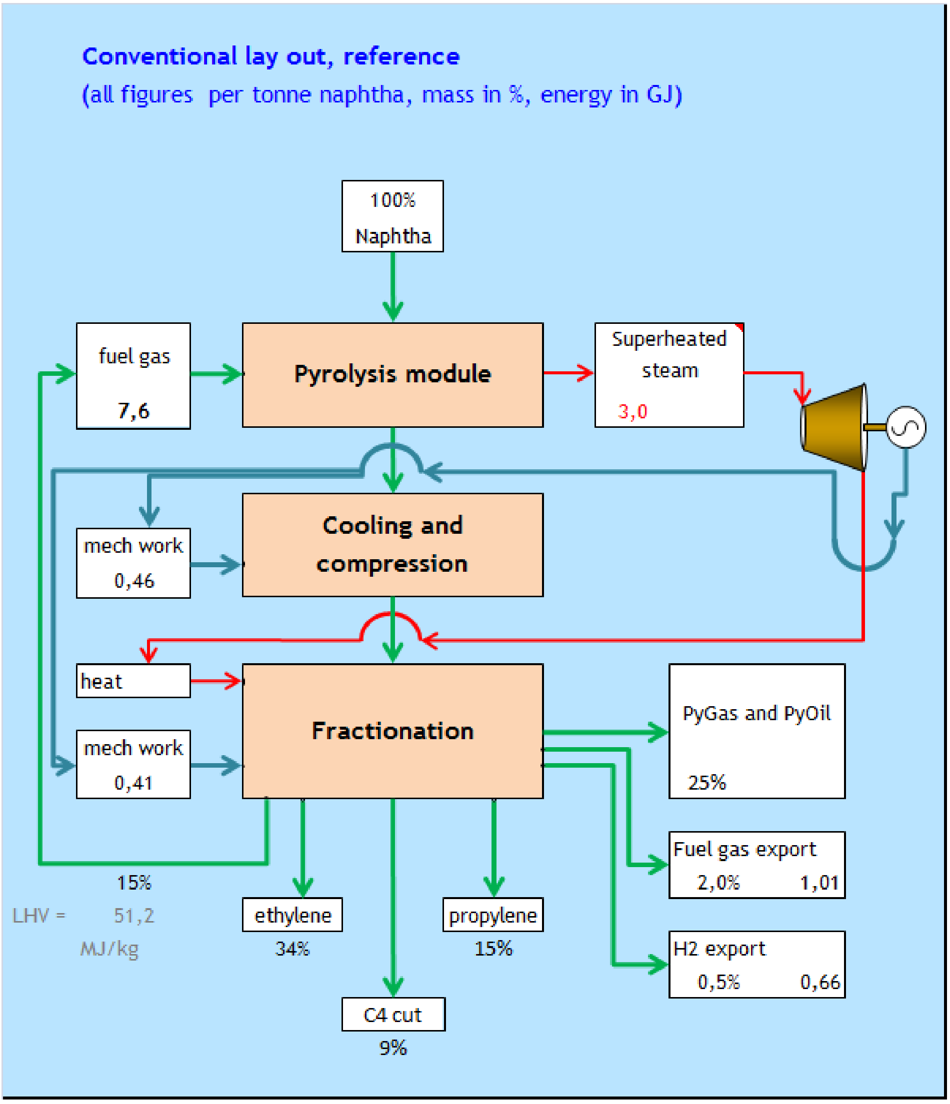
65 This factor is taken from the Dutch chemical industry (see Agentschap NL, 2012).

Subsequent conversion processes for conversion of HVC's into other platform chemicals may result in some additional CO_2 emissions but these are very low compared to the steam cracking process and can be ignored for the bulk products we investigated in our study. If one would take the value of 800 kg CO_2 per tonne product, one would have expected a cost share of nearly 1%. This is well below our estimated CO_2 cost shares indicating an average cost pass-through rate of above the 100%. Three explanations can be given to this:

A. The estimates are surrounded by confidence bounds. If we apply the confidence bounds to the estimators presented in the Table above, one would conclude that for all estimates the cost shares could be equivalent to 100% average cost
pass-through except for ethylene prices (CIF) in the Mediterranean and MEG prices (CIF) in North-West Europe.
B. The chemical industry uses naphtha as input – a product from the refineries sector. We have seen in Section 4.2 that there is ample evidence that refineries have put forward carbon costs into their product prices. Therefore it seems likely that if they would have done this on naphtha prices, the end products of the chemical industries would also include carbon cost components from the refineries sector. Naphtha is a light liquid output from the refineries sector, like kerosene. COWI (2015) estimated the well to tank emission factor of kerosene to be 15 grCO_2e/MJ, or about 650 kg CO_2/tonne product. Including refinery emissions, the CO_2 cost share increases to around 1.6%.
C. Average cost pass-through rates can be above the 100% since the marginal producer may set the price. From Ecofys (2009) it can be concluded that there is substantial increase in marginal CO_2 emissions for the 10% of installations that are least carbon efficient. If such installations would be price setter, the average cost pass-through will be higher than 100%.

Therefore, the indicative average cost pass-through rates can be in line with the 100% estimate except for the Mono ethylene glycol prices (CIF) in Northern Western Europe and Ethylene prices (CIF) in the Mediterranean which may invalidate their plausibility. Therefore we would say that, from the estimates in Table 25 5 out of 9 cases show a positive sign of cost pass-through in the petrochemical industries.

Figure 40 Overview of energy use in the petrochemical industry



4.6.9 Discussion and interpretation

The results show that some evidence of cost pass-through was obtained in the petrochemical sector, especially for ethylene and mono-ethylene glycol. However, the evidence is not overwhelming for two different reasons:

A. Our models seemed to suit the data not very well. In total seven different products were estimated of which three could not be approached by the models and estimation methods we applied in this research and we had to refute inclusion of them on statistical grounds. This was the case for for butadiene, propylene and methanol. For ethylene, mono ethylene glycol, propylene oxide and propylene glycol ether, our models did produce results that would satisfy statistical hypothesis testing on autocorrelation and heteroscedasticity.
B. Of the four products that were included in our estimations, 9 price series were investigated. Our estimates showed significant plausible cost pass-through in 7 out of 9 price series.
C. The estimated cost shares are high – especially since the average CO_2 costs in the petrochemical industries can be expected to be quite low. We have

investigated three causes that could explain such higher cost pass-through rates (confidence bounds, carbon costs upstream and inefficient marginal producers) and they show that cost pass-through for ethylene and propylene glycol ether in North-Western Europe can be expected to be around 100%, but for ethylene in Southern Europe and Mono Ethylene Glycol, the results cannot be explained and seem to be too high.

Therefore we regard the evidence of cost pass-through quite mixed in the petrochemical sector using our models and approaches. Without further analysis it is difficult to discern to what extent costs may have been passed through in the chemical sector.

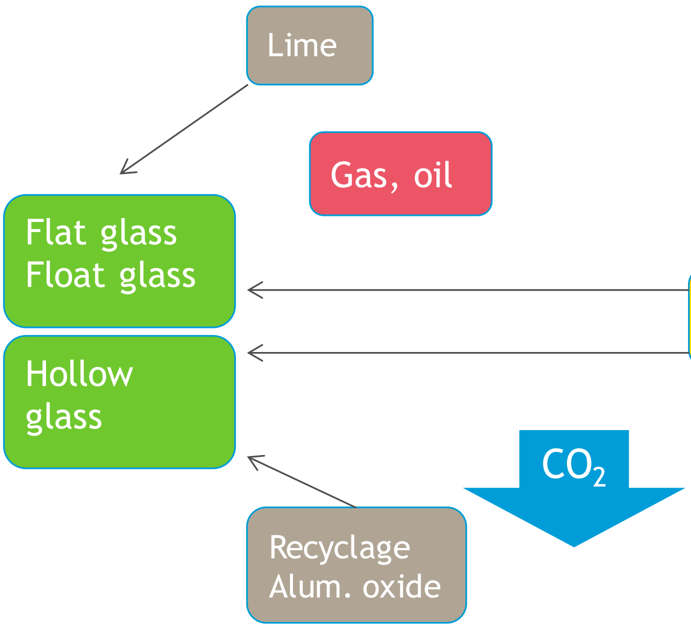
4.7 Glass

4.7.1 Introduction

There are different types of glass but the most common glass is made out of silica (SiO_2), soda ash, lime and recycled glass (Figure 41, CEPS, 2014). Glass manufacturing takes place using two different production techniques: one technique for flat glass (e.g. windows) and a different technique for hollow glass (e.g. cans and jars). Although the techniques differ, both are relatively energy intensive and need high temperatures for melting of materials. The main fuel is natural gas followed by oil products and electricity.

Within the glass sector, container or hollow glass accounts for about 50-60% of European glass production followed by flat glass (Figure 42). Worldwide, Europe is the largest producer of hollow glass (JRC, 2013).

Figure 41 Production process of glass



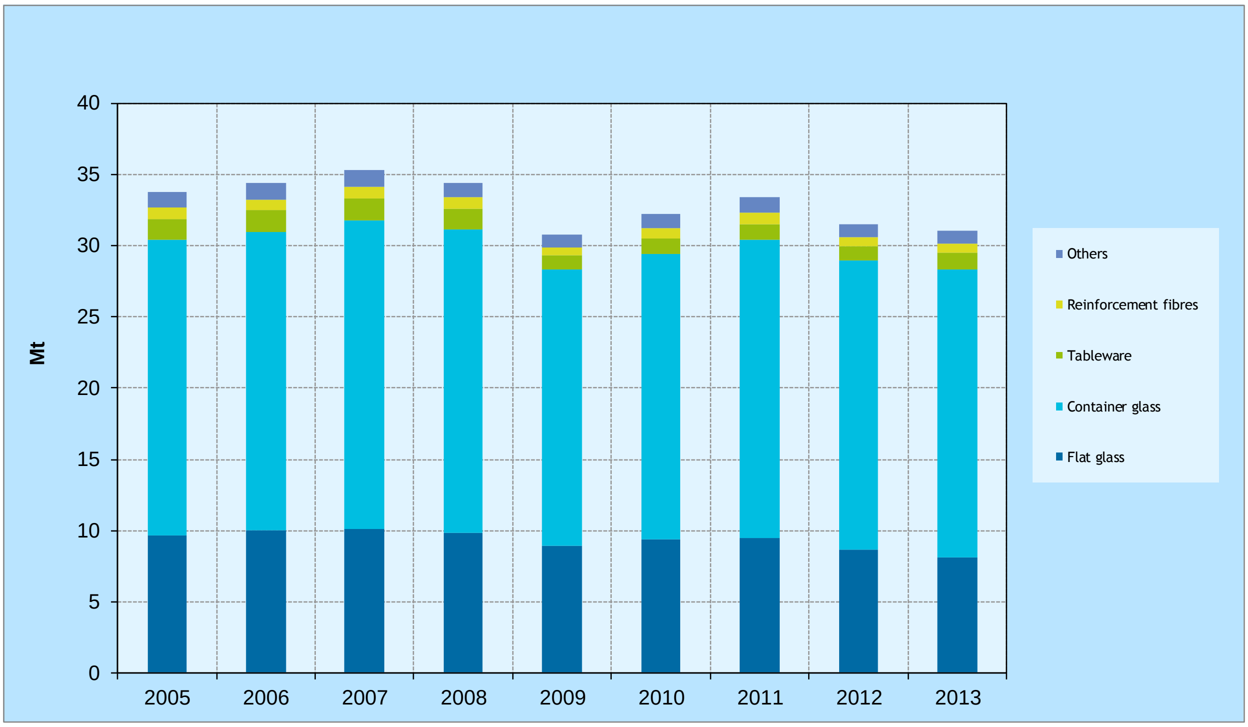
The sector hollow/container glass includes several sorts of bottles, drinking glasses, jars and glass containers that can be coloured or not. Hollow glass is mainly supplied to the food industry. Furthermore, hollow glass is also needed for the bottling of cosmetics, perfumes and pharmaceuticals as well as for technical products. Wine, beer, soft drink and other beverage bottles are of lower value.

Flat glass consists mainly of two different products: float glass and rolled glass. The majority of flat glass is float glass used in the building and automotive industry. Rolled glass only accounts for about 3.5% of the EU's glass production with a decreasing trend and is mainly used for decorative purposes, in light applications, in some greenhouses and for photovoltaic panels (CEPS, 2014).

Glass fibres provide a high value to volume product. They include threads, filaments, mats, voiles, etc. and are used to produce composite materials with a wide range of industrial applications. The glass fibre sector also includes the manufacture of glass wool, which is used for building insulation. Finally, the glass sector also includes the production of special glass products such as laboratory glassware, optical glass, and extra-thin glass for use in electronic applications (Ecorys et al., 2013).

Thus, the glass sectors includes a mix of final goods (commodities) that can be directly used by households and other sectors, while other products serve as intermediate products to client industries. Because of the structure of their client industries (in particular the automotive and building industry), the glass sector is considered highly dependent on economic trends (CEPS, 2014).

Figure 42 EU glass production

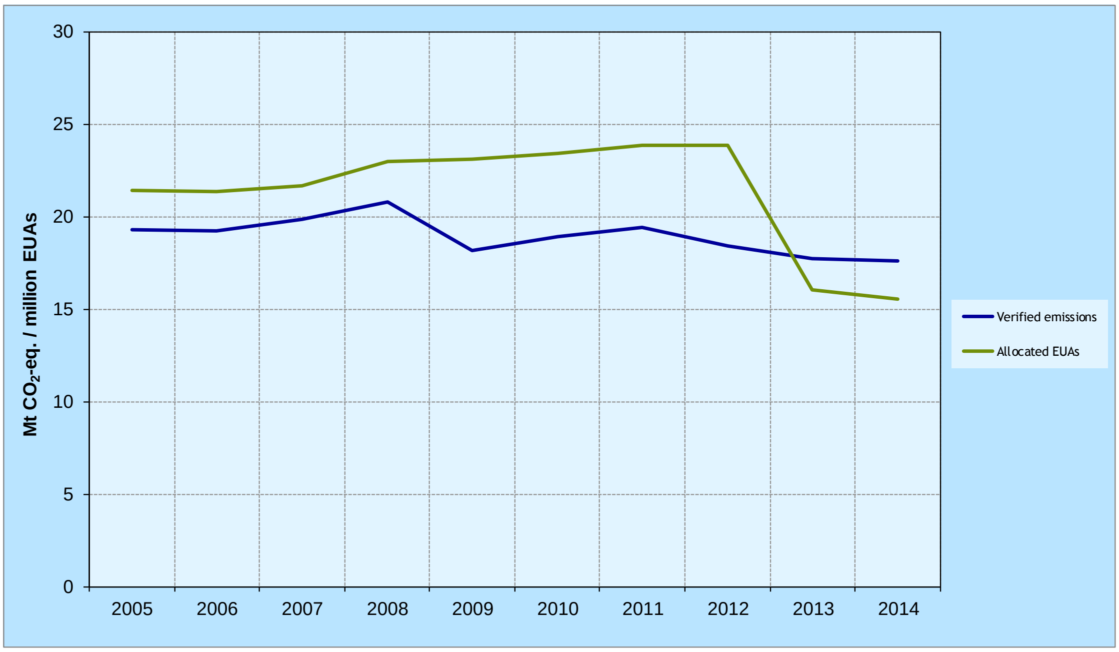


Source: Glass Alliance Europe.

4.7.2 ETS emissions

In 2014, manufacture of glass represented 1% of overall ETS emissions and 2% of industrial ETS emissions (defined as all those emissions from installations with NACE codes other than 35.00/starting with 35.1). Allocated EUAs exceeded emissions in the first and second trading period (2005-2012), whereas starting in the third period allocation has been below verified emissions providing incentives for mitigation activities. Float glass production (a sub product of flat glass) is more energy/carbon intensive than the production of bottles, jars and coloured glass (sub products of hollow glass), as can been derived for example from the benchmarks used in the EU ETS since 2013 (EC, 2011).

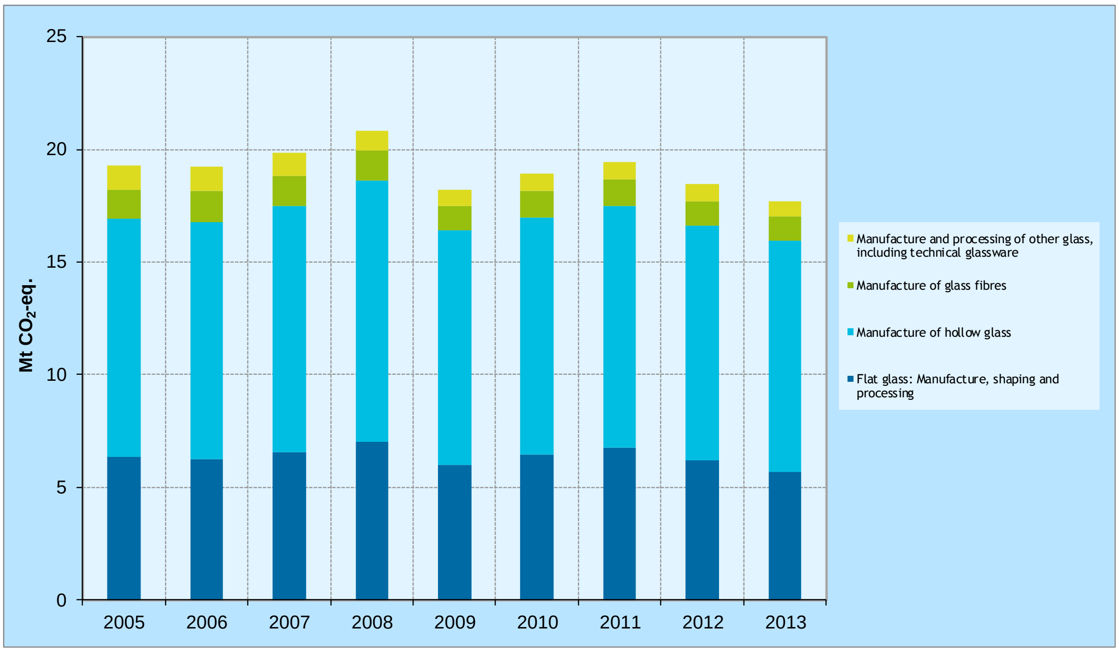
Figure 43 Verified emissions and allocation of EUAs in the EU glass sector (NACE code 23.11-23.19)



Source: Based on EUTL and NACE matching (EC, 2014a).

Total emissions differ by product. As hollow glass holds the largest production share, so do hollow glass emissions (Figure 44).

Figure 44 Emissions by different types of glass



Source: Based on EUTL and NACE matching (EC, 2014a).

4.7.3 Market conditions

Across Member States, Germany held the largest share of EU glass production, accounting for about 20% of production in 2010, followed by France and Italy, Spain and the UK. Together they accounted for about 70% of EU production (Ecorys et al., 2013).

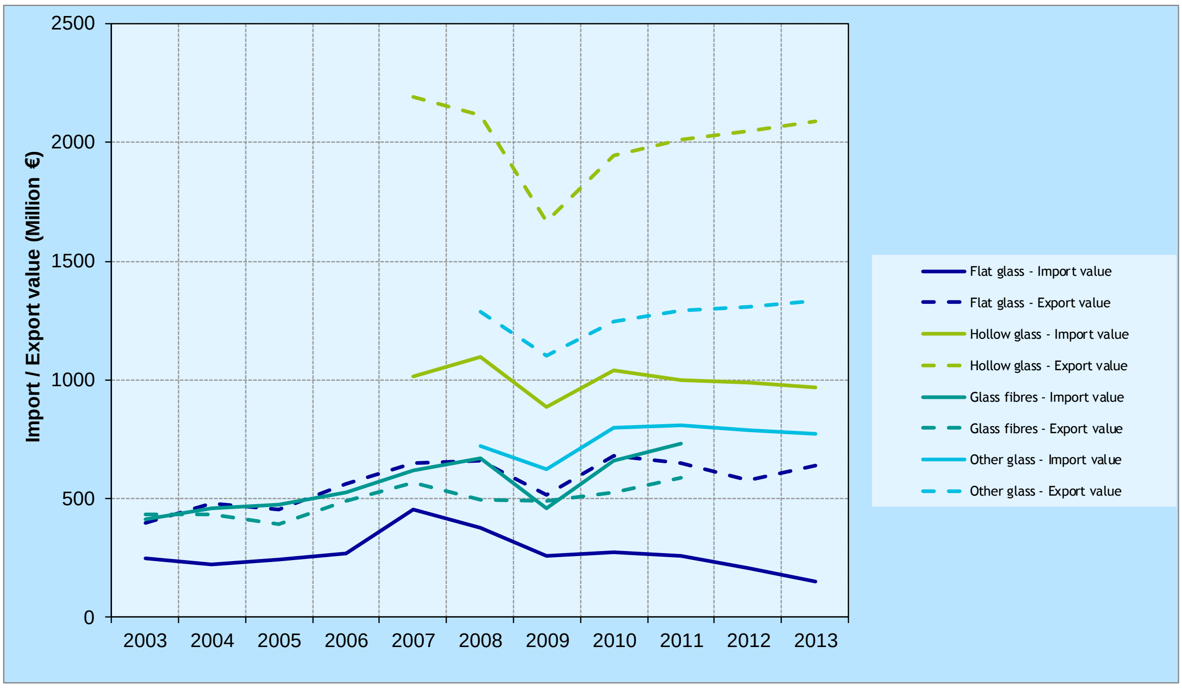
Trade plays a substantial role in the glass sector. However, the majority of EU glass products are traded within the EU so that they go towards EU-domestic consumption.[66]

Trade flows with extra-EU countries are dominated by exports of glass products (Figure 45). Extra-EU exports are highest for hollow glass followed by other glass, flat glass and glass fibres. Imports from outside the EU are substantially lower than exports for all products except glass fibres. In particular flat glass, which is a high value added product, is not imported very much. Glass products, in particular flat glass cannot easily and economically be transported on land. It is fragile and relatively high weight. Transportation via sea by floatlines is easier. The most feasible import origins include Algeria, Egypt, and Ukraine.[67]

[66] http://ec.europa.eu/growth/sectors/raw-materials/industries/non-metals/glass/index_en.htm

[67] http://www.glassforeurope.com/en/industry/facts-and-figures.php

Figure 45 Imports and exports of glass products to and from EU (values)



Source: Prodcom, EU28: imports from extra-EU, exports to extra-EU, only years with consistent data coverage.

4.7.4 Market concentration and price information

The glass industry in Europe is characterised by several large EU-based companies that compete on global markets. Because of the capital intensity of the process small size producers do exist but are not so common according to the industry.[68]

Glass producers are confronted with powerful suppliers and customers. Many client industries, such as automotive, engineering or retailing, are dominated by large multinational companies. Simultaneously, upstream suppliers of raw materials are often large and integrated and operate in some cases in an oligopolistic market. This implies that glass producers have little or no bargaining power (Ecorys et al., 2013).

According to Ecorys et al. (2013) "the production of soda ash and other compounds in Europe, for example, is dominated by just a handful of (global) suppliers (Solvay, Tata Chemicals, Ciech, Novacarb, Soda Sanayii (Sisecam). In some cases, such as where producers of domestic glass sell to smaller specialist retailers (dedicated glass specialists as opposed to department stores or other general retailers) the glass producer may have more bargaining power, but must pick up more of the distribution/ searching costs, which are typically around 15% of total costs. Along with the heavy reliance of some subsectors on a few industries, this means firms in all parts of the glass sector have historically struggled to repel supplier cost increases or pass on cost increases to the customer (p.58)."

68 www.glassonweb.com/articles/utils/print.php?id=575

A number of interviews with client industries were conducted within this project to improve understanding of the price formation process. While large client industries were not available for interviews, medium to smaller clients by and large confirmed the insights from the Ecorys study. A fibre glass client pointed out that many clients in his range directly purchase fibre glass products from the manufacturer without a need for a wholesaler. The purchase is usually based on a one year fixed contract with no flexibility to account for cost changes. Contracts are normally tendered with product quality, price, availability and supply chain playing the main roles. The price is determined by signals of energy prices and duties, and differs by product.
The interviewee also experienced cases where prices increased for other reasons with the impression that producers might reduce supply in order to stabilise prices.

Interviews with hollow glass clients, large and medium sized breweries and beverage companies, revealed that the hollow glass value chain involves and intermediate wholesaler who can store large quantities of different glass products to cater for the demands of a range of end users. Larger end users are more likely to arrange for fixed contracts, smaller end users reported to mainly buy on spot markets. Many end users only buy one specific products. It was pointed out that a production line must run continuously for a number of days in order to be profitable (operation for three days constantly producing between 500 and 800 bottles a minute – to be financially viable). Again, energy prices are perceived as the biggest driver of prices.

All in all, given the supply chain with its strong suppliers and customers in a constrained market structure (limited competitiveness in a market with low shares of trade), the bargaining power of glass producers is reduced. Most client industries perceived energy prices to be the main price driver. At the same time, however the energy cost share is rather small compared to the labour or raw material one. Thus, it seems to be used as a signal to price formation with limited actual impact on costs.

4.7.5 Data

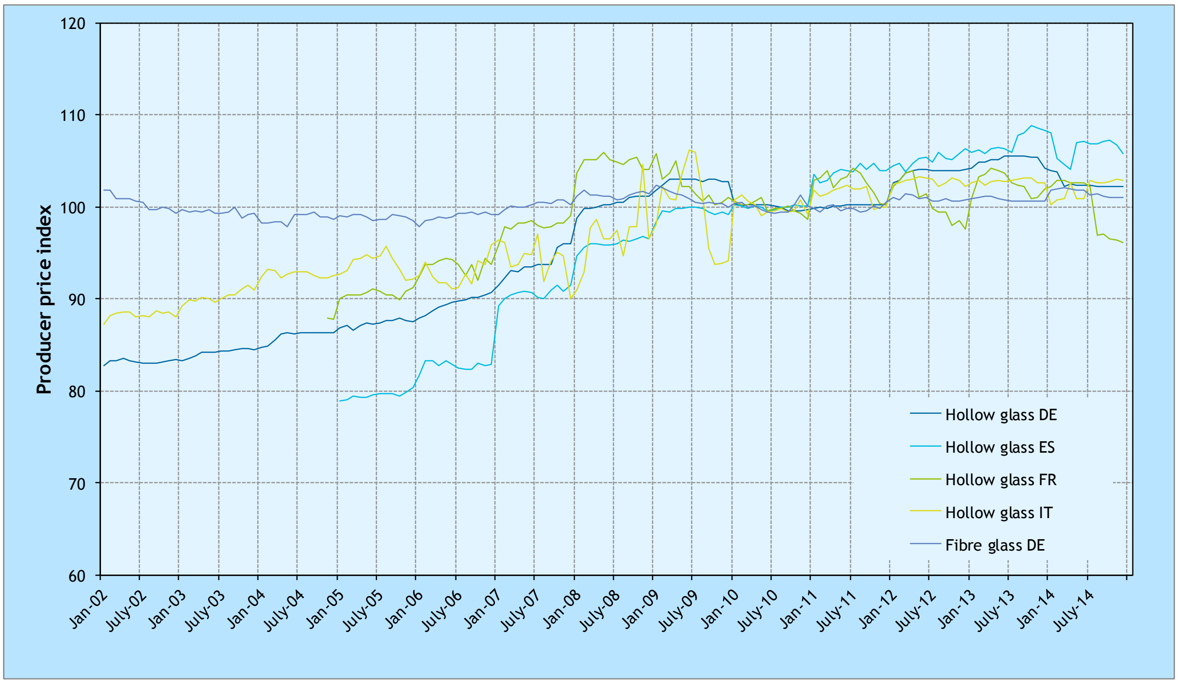
In the glass sector, the data situation is generally challenging. No consistent data base exists that provides market based price data for glass products for a range of time. For this reason, we had to refer to our Tier 2 approach which relies on output price indices from Eurostat (available for a number of countries). On the input side, price data was even more challenging to find. We revert to our Tier 3 approach and derive implied prices based on trade statistics (Eurostat Comext); using a weighted average of all imports and exports (intra and extra EU). These implied price series were corrected for a few spikes which occurred because of missing data. Using these approaches, price series for hollow glass could be derived for Germany, Spain, France and Italy, whilst data series for glass fibres could be derived for Germany only.
All data series are of monthly frequency and available for the whole period 2005-2014 in most cases (Table 53). Unfortunately, flat glass and other glass needed to be excluded due to lack of consistent and reliable data. However, with hollow glass accounting for the largest share in international trade, we cover the most important ‘exposed’ product.

Table 26 Description of data series used in the glass sector

	Type	Characteristics	EU-countries	Frequency	Source	Data manipulation
Output						
Manufacture of hollow glass	Total output price index		DE, ES, FR, IT	Monthly (at least 01/2005 – 12/2014)	Eurostat	
Manufacture of glass fibres	Total output price index		DE	Monthly (01/2002 – 12/2014)	Eurostat	
Main inputs						
Silica sands and quartz sands, whether or not coloured (2505.10)	Implied price by Comext	Weighted average of all import and export (intra EU-28 and extra EU-28)	DE, ES, FR, IT	Monthly (01/2002 – 12/2014)	Eurostat	Linear interpolation if missing values
Silicon dioxide (2811.22)	Implied price by Comext	Weighted average of all import and export (intra EU-28 and extra EU-28)	DE, ES, FR, IT	Monthly (01/2002 – 12/2014)	Eurostat	Linear interpolation if missing values
Disodium carbonate = Soda ash (28362000)	Implied price by Comext	Weighted average of all import and export (intra EU-28 and extra EU-28)	DE, ES, FR, IT	Monthly (01/2002 – 12/2014)	Eurostat	Linear interpolation if missing values
Aluminium oxide (2818.20)	Implied price by Comext	Weighted average of all import and export (intra EU-28 and extra EU-28)	DE, ES, FR, IT	Monthly (01/2002 – 12/2014)	Eurostat	Linear interpolation if missing values
Energy source						
Energy price index	Based on commodity prices		DE, ES, FR, IT	Monthly	see Annex A.3	
Capital and labour cost						
Wages	Implied price		DE,ES, FR, IT	Monthly	see Annexes	Linear interpolation if missing values
Interest rate	Government bond yields			Weekly	ECB, see Annexes	
Additional controls						
Exchange rate		USD/EUR			Eurostat, see Annexes	
Production index					Eurostat, see Annexes	
Stock market index					Eurostoxx, see Annexes	

The output price series indices for hollow glass and fibre glass are shown in Figure 46. For hollow glass the series for France and Italy show more pronounced short-term spikes in either direction than those for Germany and Spain. Similarly, the series for fibre glass is fairly flat for Germany.

Figure 46 Hollow glass PPI



Source: Eurostat.

The data series generally show a unit root for output prices and no unit root for input material prices (see Annex G). Therefore, input materials are generally used as exogenous or fixed variables, while energy and labour are included as endogenous or dynamic variables.

4.7.6 Estimation procedure

We follow the procedure set out in Chapter 3. As a first step, we estimate a VECM, where the endogenous variables enter in levels, whilst the exogenous variables that contain a unit root enter in first differences and the exogenous variables that do not contain a unit root enter in levels as well (which is, for example, the case for most input material series derived from Comext).

For hollow glass, either a VECM or ARDL in levels was estimated. Depending on the country and period investigated, the behaviour of residuals and the results of the cointegration tests led us to choose different models. In terms of the variables included in the cointegration relationship (VECM) or dynamic specification (ARDL), different specifications were tested. We started from a model that included all candidates in this relationship, i.e. output price, input prices, cost of energy and labour and CO_2, as well as the stock market index and the exchange rate. It was generally found that a more parsimonious model, where only a subset of these explanatory variables was included in the long-run relationship (whilst the others enter as exogenous explanatory variables) led to results that were plausible in terms of magnitude of coefficients and good in terms of residual behaviour.

For the German and Spanish price series in hollow glass, residuals exhibited persistent autocorrelation within the VECM framework, which may indicate that changes in input prices are passed through with a delay, which would lead to autocorrelation in the residuals. Therefore, an ARDL in levels was estimated, which allows for the inclusion of delays in the explanatory variables. On the one hand, this makes economic sense if one thinks that changes in input prices or other explanatory variables do not show up instantaneously in the output price. On the other hand, residuals from the ARDL estimation in levels generally exhibited less autocorrelation. Bounds tests do not reject a long-run relationship in Germany between the output price, the energy price index and the CO_2 price. Whilst for Spain, a long-run relationship between the output price and its input variables is rejected for the period 2005-2014, whereas for 2008-2014, a long-run relationship was indicated to exist between the output price, the price of labour, energy and CO_2.

For France, a VECM specification in levels led to well-behaved residuals and was also favoured on the grounds of Granger causality and Johansen cointegration tests. However, the setup of the cointegration relationship differs between 2005-2014 and 2008-2014. In the former, wage, CO_2 and the exchange rate enter along with the output price; whilst for the latter it is energy and CO_2. For Italy, results are somewhat mixed. Whilst the VECM produces plausible results and well-behaved residuals, Granger causality tests are ambiguous, which is why we also report results for an ARDL model in levels in Table 27.

Due to data limitations, for fibre glass, we only carried out estimations for the German price series. Since Granger causality tests rejected a two-way relationship between the variables, an ARDL was estimated.

4.7.7 Estimation results

Table 27 summarises results for the CO_2 coefficient in the estimations for all product/country pairs investigated, whilst full estimation results can be found in Annex G. Note that within the VECM framework a negative coefficient indicates a positive long-run relationship between the CO_2 price and the output price (due to the negative cointegration coefficient), whilst for the ARDL specification, it is the other way around.

For the VECMs estimated for hollow glass in France and Italy, results point to a significant effect of the CO_2 price on the output price in the range of 0.004–0.006, indicating that a 1% rise in the price of CO_2 would increase output prices by 0.004–0.006%. The ARDL specification for Italy, similarly points to an effect of the CO_2 price on the output price of 0.013%.

Whilst the coefficients for the ARDL estimation for hollow glass in France show a similar order of magnitude, they are not significant for either of the periods considered. In the estimation for hollow glass in Germany, the energy price which also enters the dynamic relationship has a significant and positive effect of a plausible order of magnitude, but the CO_2 price coefficient is either insignificant or negative.

In the ARDL estimation for the fibre glass price series in Germany again a very small and insignificant coefficient on the CO_2 price is estimated.

To sum up, in the glass sector, for three out of five country/product pairs we find some indication of cost pass-through at relatively low rates. This low rate show the limitation of an econometric modelling approach since the formal test is whether the cost share is signficiantly different from zero. Therefore, with low carbon cost shares, data quality becomes very crucial in order to be able to test whether the found coefficients are statistically significantly different from zero.

Related to the data quality, the fact that we had to resort to Tier 2 (producer price indices for outputs) and Tier 3 (implied prices for material inputs) data sources means that necessarily some of the information that would be embodied in commodity prices is lost and the models may therefore struggle to relate output to input prices and additional control variables.

Related to the point about low CO_2 cost shares in the glass sector (also see next paragraph) it has to be noted that in our model setup, we test whether the coefficient on the CO_2 price is statistically different from 0. If the cost share is very close to 0 itself, econometric models would find it difficult to discern to what extent the estimates are significantly different from 0.

Table 27 Results for CO_2 coefficients in estimations for products in the glass sector

Product	Region	Frequ.	Data range	Final model choice	Included variables	Estimator long-run P1-P2/3	T-stat	Delay	Estimator long-run P2/3	T-stats	Delay
Hollow glass	DE	Monthly	Jan 2005 - Oct 2014	ARDL in Levels	Dynamic: Energy index, CO_2 Fixed: Wage, silica sand, silicon dioxide, aluminium oxide, stoxx, xrate	-0.025	0.081	0	-0.031	-3.144	1
Hollow glass	ES	Monthly	Jan 2005 - Oct 2014	ARDL in Levels	Dynamic: Wage, energy index, CO_2 Fixed: Silica sand, silicon dioxide, aluminium oxide, stoxx, xrate	0.010	0.987	0	0.002	0.172	1
Hollow glass	FR	Monthly	Jan 2005 - Oct 2014	VECM in Levels	**2005-14:** Endogenous: Wage, CO_2 , xrate Exogenous: Energy index, silica sand, silicon dioxide, aluminium oxide, stoxx **2008-14:** Endogenous: Energy index, CO_2 Exogenous: wage, silica sand, silicon dioxide, aluminium oxide, stoxx, xrate	**-0.006**	-1.395	-	-0.006	-0.608	-
Hollow glass	IT	Monthly	Jan 2005 - Oct 2014	VECM in Levels	Endogenous: Wage, CO_2 Exogenous: Energy index, silica sand, silicon dioxide, aluminium oxide, stoxx, xrate	**-0.004**	-1.334	-	0.016	1.297	-
Hollow glass	IT	Monthly	Jan 2005 - Oct 2014	ARDL in Levels	Dynamic: Wage, energy index, CO_2, stoxx Fixed: Silica sand, silicon dioxide, aluminium oxide, xrate	**0.013**	4.678	6	**0.013**	1.978	6
Fibre glass	DE	Monthly	Dec 2004 - Oct 2014	ARDL in Levels	Dynamic: Wage, energy index, CO_2 Fixed: Silica sand, silicon dioxide, stoxx, xrate	-0.002	-2.253	6	0.0003	0.062	2

Note: In the VECM specifications, a negative coefficient implies a positive relationship between the variable in question and the dependent variable, whilst in the ARDL specifications it is the other way around.

4.7.8 Indicative cost pass-through rates

We estimate CO_2 cost shares in glass production using the following two approaches:

- Multiplying the total of verified emissions (average 2008-2014) for the respective glass product with a carbon price of 11.15 €/tCO_2[69], and dividing this value by the value of production for the respective product (2008-2010 values used).
- Using benchmarks for allocation in the third trading period (EC, 2011) multiplying them with the price for CO_2 and comparing to overall output price.

Using the second approach, we obtain cost shares for hollow glass and glass fibres in the range of 0.2 to 0.3%. This cost share of CO_2 applies to the 10% most efficient firms. For the sector as a whole, we expect higher cost ratios of CO_2.

This line of reasoning is confirmed by the second approach (Table 28). We find cost shares of CO_2 of around 1% for both hollow and flat glass products.

Table 28 Expected CO_2 cost shares in glass production, based on Carbon cost of 11.15 €/tCO_2)

Nace 2	Product	Production value (M€)	Share in ETS	CO_2 emissions (Mton)	Cost share of CO_2 (2008-2010)
23.13	Hollow glass	12,258	1.5%	10.56	1.0%
23.11	Flat glass	6,626	0.9%	6.26	1.1%

Source: Own estimations based on Eurostat, EUTL and EEX.

The significant coefficients for hollow glass in France and Italy in the range of 0.4-0.6% (VECM specification) and 1.3% (ARDL specification) can then be compared to the 1.0% CO_2 cost shares estimated for this sector and are, in most cases, below them. By dividing the first (CO_2 cost share embodied in price of final product) by the second (estimated CO_2 cost share in the production process), an indicator of the cost pass-through rate can be derived.

Doing this division points to indicative cost pass-through rates of between 40% for hollow glass in France and 60% in Italy (using results from the VECM) and above the 100% for hollow glass in Italy, when the ARDL model is used. The insignificant estimates for the remaining product/country pairs do not necessarily indicate that no cost pass-through took place, but may rather be a result of the limitations related to available data in the glass sector and the fact that the methods employed may struggle in particular with results for sectors with very low CO_2 cost shares (cf. Chapter 3).

4.7.9 Discussion and interpretation

Glass producers operate on markets which are marked by strong and powerful suppliers and customers. Major raw materials (e.g. soda ash) are supplied by a limited number of companies in oligopolistic markets. Client industries are dominated by large

[69] Representing the average CO_2 price since the start of the EU ETS. The average price since the start of the second trading period is only marginally lower (EEX).

multinational companies. This reduces the bargaining power of glass producers. Most of the glass produced within the EU is also consumed or used for further production steps within the EU. However, despite its transportation challenge, glass is also traded on global markets.

Exports to extra-EU countries play a role in particular for hollow glass products while imports are relatively low. Competing with other countries on these export markets and given the structure of strong and integrated supply and demand markets, the ability of glass producers to pass-through additional (unilateral) costs without a potential loss in market share might be limited. At the same time, however, the CO_2 cost share is very small, and so are the additional costs that glass producers face.

The estimation of cost pass-through in the glass sector, however, is a challenge due to the fact that data on output and input prices is hard to obtain – we use producer price indices for the output prices and derived prices from Comext for material inputs. Furthermore, the low CO_2 cost share in glass manufacturing (around 1% for hollow glass) makes it hard to estimate coefficients that are significantly different from zero simply because of this low share. In two cases (the French and Italian price series for hollow glass) we do estimate a significant effect of changes in the CO_2 price on output prices. Translating the estimated coefficients into approximate pass-through rates using CO_2 cost shares indicates incomplete CO_2 cost pass-through of around 50% (whereas one model specification estimates higher rates). However, this result cannot be confirmed for all country/product pairs.

4.8 Overall conclusions

This chapter has investigated cost pass-through in the EU ETS in six carbon intensive sectors for price series in a range of products and countries. The null hypothesis of no cost pass-through was tested for a number of different products in the selected sectors and for a range of countries or regions. In order to investigate the null hypothesis of no cost pass-through, a sophisticated estimation procedure was set up, which has been summarised in Chapter 3. The crucial element regarding estimation procedure and results is to obtain coefficient estimates that are unbiased and efficient of which the t-statistics can be interpreted in terms of significance without problems.

Table 29 gives a summary overview of results on cost pass-through and presents our conjectured estimate of the indicative cost pass-through rates.

Table 29 Overview of main empirical results of this study

Sector	Products	Cost pass-through not significant	Cost pass-through significant*	Average cost share	Indicative cost pass through rates^	Remarks
Cement	Clinker	UK, CZ	FR, DE, PL	0.07 to 0.09	35-40%	Primarily valid for Phase 2/3
	Total cement	UK, IT	FR, DE	0.02	20-40%	Primarily valid for Phase 2/3
	Portland cement		CZ,PL	0.06-0.1	90-100%	Primarily valid for Phase 2/3
Petrochemicals	Ethylene		NWE, MED	0.03-0.12	>100%	Only valid for Phase 2/3
	Mono ethylene glycol	MED		NA	Not sign.	
	Propylene oxide		NWE	0.021	~100%	Only valid for Phase 2/3
	Propylene glycol ether**	NWE	NWE	0.06	>100%	Only valid for Phase 2/3
	Methanol, Butadiene, Propylene	NWE,MED		NA	NA	No relevant models found
Iron and steel	Flat steel HRC		NE, SE	0.04-0.08	75->100%	Only valid for Phase 2/3
	Flat steel CRC		NE, SE	0.03-0.05	55-85%	Only valid for Phase 2/3
Fertiliser	Ammonia	NWE		NA	Not sign	Only valid for Phase 3
	Ammonium nitrate	FR	UK	0.12	>100%	Only valid for Phase 2/3
	Calcium ammonium nitrate		DE	0.13	>100%	Only valid for Phase 3
	Urea ammonium nitrate		FR	0.24	>100%	Only valid for Phase 3
	Urea	NL	NWE	0.09-0.1	Not sign ->100%	Only valid for Phase 2/3
Refineries	Diesel	DE	BE, FR, GR, IT, PL	0.03 to 0.05	>100%	Only valid for Phase 2/3
	Gasoil	GR,PL.IT	BE, DE,FR	0.02-0.07	>100%	Only valid for Phase 2/3
	Petrol	GR,PL	BE,DE,FR,IT	0.01	80-95%	Only valid for Phase 2/3
Glass	Hollow glass	DE, ES	FR, IT	0.004-0.01	40->100%	Valid for Phase 1/2/3
	Fibre glass	DE		NA	Not sign.	Valid for Phase 1/2/3

Notes:

* BE=Belgium, CZ=Czech Republic, DE=Germany, ES=Spain, FR=France, GR=Greece, IT=Italy, NE=Northern Europe, NWE=North-Western Europe, MED=Mediteranean countries (Southern-Europe), PL=Poland, SE=Southern Europe. Decision whether CO_2 cost coefficient was significant made on the basis of a 10% critical threshold level (based on one-sided T-statistics).[70]

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[70] One-sided confidence levels are more appropriate because we are testing here whether the opportunity costs of freely obtained allowances are not passed through in the product prices. Since it does not make sense to assume that a negative value of opportunity costs is passed through in the product prices, a one-sided confidence level seems appropriate.

** For one propylene glycol ether we used three different spot prices for NWE. All in all, our estimates show that in one price series, CO_2 prices were significant for the two other not.

^ Conjectured estimate of the percentage of costs passed through into product prices

Overall, this table shows that the null hypothesis of no cost pass-through was rejected in over half of the cases when we focussed only on observations in Phase 2 and 3 (from 2008 onwards). Based on these results, cost pass-through seems to be more common in the cement, iron and steel and refineries sector than in the petrochemical and glass sector.

In the cement sector evidence was found for cost pass-through in Germany, France and Poland for both clinker and cement and in the Czech Republic for cement alone. The indicative cost pass-through rates seem to be below the 50% with the exception of Portland cement in Poland. This is consistent with earlier results in the literature as in Walker (2006).

Also in the iron and steel sector we find evidence of cost pass-through of freely obtained allowances, with a slightly longer delay of about three months. Indicative cost pass-through rates would generally range between 55-85% except for hot rolled coil in Southern Europe for which a higher indicative cost pass-through rate surpassing 100% was found. It should be noted that these results are in line with ex-ante calculations by Smale et al. (2006).

In the refineries sector we also found evidence of cost pass-through in all products investigated – albeit more for diesel and petrol than for gasoil. The indicative cost pass-through rate for petrol was between the 80-100%. For diesel and gasoil our estimates hinted at even higher cost pass-through rates although this cannot be stated with certainty.

For fertiliser, petrochemicals and the glass sector the evidence on cost pass-through was rather mixed. For fertiliser some cost pass-through was found especially in Phase 3 when, due to scope changes, more activities were included under the EU ETS. Moreover, the fertiliser sector seems to be short of allowances since Phase 3.
Our results indicate that at least for some products the full (opportunity) costs of carbon seem to be passed through in the price of products.

For the glass sector cost pass-through could also be found in some cases (but not in many other cases). The CO_2 costs are in general quite low in the glass sector making it difficult with econometrics to discern whether they are significantly different from zero. In addition, the data situation in the glass sector was rather challenging as no direct price information could be obtained, but implied prices had to be calculated from Eurostat data. Indicative cost pass-through rates suggest that only some part of the opportunity carbon costs have been put forward in the product prices.

For the petrochemical industries, finally, cost pass-through was more difficult to discern. Our estimated models would not fit the data well in three out of seven investigated products. For the other half, about ¾ of the products showed signs of cost pass-through in the product prices. Indicative cost pass-through ranges were at or above the 100%.

While we do find some evidence of cost pass-through in the econometric estimation, we also observe that, especially with monthly data, the number of observations in the time series is relatively limited. While formally this does not necessarily have to be a problem if the models estimated describe reality very well, the stochastic nature of price data (e.g. influence of market power, speculation, etc.), means that this is hampering the use of our models. Often we encountered the situation that we have a model that seems to describe the data well but that fails under residual testing (e.g. for autocorrelation). We then had to refute such a model on statistical grounds.[71] If CO_2 prices increase in the future and longer data series are available due to the extended time horizon under which the EU ETS applies, the opportunities for modelling cost pass-through of (freely obtained) allowances using econometric methods would also increase.

The following caveats must be made with respect to these results:

- The results evidenced cost pass-through in most cases only when we limited the sample to Phase 2/3. If also Phase 1 was taken into account our econometric models performed more poorly and it was more difficult to find significant pass-through of carbon costs.
- The potential to pass-through carbon costs cannot unequivocally be interpreted in terms of carbon leakage. It may have been the case that costs were passed through but that market shares were lost (cf. Section 2.3). Recent research (Ecorys et al., 2014) has concluded that it is unlikely that EU industries have suffered from carbon leakage. Therefore, we have not further investigated this in the present study – but this should be investigated in more detail in the future.
- Finally, we consider the data situation for econometrically estimating cost pass-through as far from ideal. In general, price data showed much unexplained variation and models did not always behave very well.
  Labour costs were insignificant in most of the cases which is unlikely and most likely caused by the problems in transforming annual labour statistics into monthly series (see also the Annexes).

With respect to potential factors that could explain cost pass-through, we cannot depict generalised rules here. Insights from interviews with market experts and clients industry differed by industry and also by size, bargaining power and product portfolio of the client industry in question. Energy prices were perceived to play a major role in product price formation. Transportation costs on the other hand – even though considerable in some industries – only seem to play a role in price variation if transportation capacity becomes scarce and expensive (such as in the pre-crisis year 2008) or if goods are difficult to transport in the first place (e.g. fragile glass or hazardous chemicals). Utilisation rates may in some sectors be a driver explaining differences in cost pass-through – with higher capacity utilisation generally being associated with higher cost pass-through rates. The lowest utilisation rates were found in the cement sector (substantial overcapacity), somewhat higher rates in the iron and steel sector and the highest in the fertiliser industry where installations run at high capacity and we have found corresponding differences in cost pass-through rates. This finding also confirms the theoretical literature on this subject.

[71] To our opinion there has been a lack of transparency in the existing literature regarding these potential problems.

5 Drivers of cost pass-through

5.1 Introduction

Chapter 4 has shown that some evidence of cost pass-through was found in every sector investigated. In the cement, iron and steel and refinery sectors, the majority of investigated cases evidenced cost pass-through of the opportunity costs of carbon allowances in the product prices. Also in the glass, petrochemical and fertiliser sector various cases were identified where the econometric estimations negated the null hypothesis of no cost pass-through.

While the sectoral chapters already aimed to find some explanation for cost pass-through in terms of market power, price formation and utilisation rates, we have not tried to present a cross-sectoral overview there. Therefore, in this chapter, we aim to investigate cost pass-through from the perspective of a sectoral comparison in order to explore the extent to which common drivers explaining cost pass-through can be found. The following explanations will be discussed:

- Trade intensity. To what extent can the relative openness of the sector explain the extent to which costs can be passed through in product prices? (Section 5.2);
- EU market share. To what extent can the share of the value of EU products on the global market explain the ability of cost pass-through (Section 5.3)?;
- Market concentration within the EU market. To what extent can the market structure in the EU market explain potential cost pass-through (Section 5.4)?;
- Transport costs and tariff barriers. To what extent can transport costs and tariff barriers play a role in explaining the cost pass-through? (Section 5.5).

5.2 Trade intensity

5.2.1 Introduction, definition and rationale

Trade intensity is an indicator that reflects the openness of a sector to international competition. Within the EU ETS, trade intensity has been used as an indicator to assess the risk of carbon leakage. The higher the trade intensity the more challenging it might be for the EU to pass-through the cost of carbon without potentially losing a significant market share. Therefore, trade intensity may be a relevant indicator for price formation. It should be noted in this respect that the trade intensity indicator and the applied threshold have been contested as a good measure for exposure to international competition and cost pass-through potential (Dröge et al., 2010; Carbon Trust (2010)). Moreover, the amount of countries that are installing carbon markets is growing steadily which would imply that trade with non-EU countries cannot be necessarily equated with trade with partners without carbon constraints (CE Delft, 2013). We will abstain from these important discussions and investigate here only to what extent the trade intensity may explain the differences in cost pass-through between sectors.

5.2.2 Data and results

Trade intensity is defined as the value of trade (import and export) divided by the domestic availability of the product (value of domestic production plus imports).

$$Trade\ Intensity = \frac{(Import\ value + Export\ value)}{(Import\ value + Production\ value)}$$

Trade intensities have been calculated for all relevant products and countries investigated in this study (Table 30).

Production data was taken from Prodcom (DS-056120), Export and Import trade data with extra EU-28 was taken from Comext (DS-045409) for all products except for refined petroleum products. For refined petroleum products other data sources had to be used because Prodcom does not survey the petroleum and energy products (communication with Eurostat helpdesk on September 2nd, 2015 confirmed this). Only aggregated data was found for these products: Production data was gained from Eurostat's structural business statistics (SBS), trade data was used from the Eurostat database DS-057009.

Production and trade data were given on a much more detailed level in the databases than needed for the purpose of the analysis of the products investigated in this study. Therefore, for each product, several Prodcom codes (for production) as well as several HS-8 codes (for trade) were aggregated. The HS-8 codes were again more detailed than the Prodcom codes. To avoid inconsistencies, trade data was only taken into account for those HS-codes for which also production data was available for the corresponding Prodcom codes. Trade refers to extra-EU trade.

Trade Intensities were calculated for all years between 2008 and 2014 to the extent data availability allowed it. In a next step, average values were calculated for the trading period that was analysed for the product, see Table 30. The given average trade intensity does not give an indication whether trade intensities are available for all years in the trading period or not. However, if no value at all is provided for trade intensity of a product and country, this indicates that data was not available for any year in the respective trading period.

Table 30 Trade intensity for investigated products and trading periods

Sector	Products	Cost pass-through significant*	Cost pass-through not significant*	EU Total	Trade Intensity (Phase 2 and 3; 2008-2014)
Cement	Clinker	FR			81%
		DE			5%
		PL			3%
			UK		-
			CZ		-
				EU28	49%
	Total cement	FR			3%
		DE			4%
			UK		2%
			IT		5%
				EU28	8%
	Portland cement	CZ			0%
		PL			1%
				EU28	5%
Petrochemicals	Ethylene	NWE			10%
		MED			-

Sector	Products	Cost pass-through significant*	Cost pass-through not significant*	EU Total	Trade Intensity (Phase 2 and 3; 2008-2014)
				EU28	5%
	Mono ethylene glycol		MED		71%
				EU28	46%
	Propylene oxide	NWE			-
				EU28	4%
	Propylene glycol ether	NWE	NWE		57%
				EU28	35%
	Methanol, Butadiene,		NWE		7%
	Propylene		MED		88%
				EU28	21%
Iron and steel	Flat steel HRC	NWE			13%
		MED			40%
				EU28	25%
	Flat steel CRC	NWE			9%
		MED			30%
				EU28	26%
Fertiliser	Ammonia		NWE		20%
				EU28	35%
	Ammonia nitrate	UK			0%
			FR		55%
				EU28	15%
	Calcium ammonium	DE			-
	nitrate			EU28	55%
Refineries	Refined Petroleum	BE(3)			30%
	Products	FR(3)			29%
		GR(1)	GR(2)		47%
		IT(2)	IT(1)		33%
		PL(2)	PL(1)		8%
		DE(1)	DE(2)		-
				EU28	28%
Glass	Hollow glass	FR			22%
		IT			16%
			DE		23%
			ES		11%
				EU28	24%
	Fibre glass		DE		23%
				EU28	26%

Of the investigated products trade intensities are highest for clinker in France, some petrochemical and some fertiliser products. They are lowest for cement and ethylene and are in a medium range (about 15 to below 30%) for almost all other products.

Although it is very difficult to generalise, one can conclude on the basis of this information that for the group of products that do show cost pass-through, trade intensities are on average about 9% lower than for the group where no cost pass-through could be discerned[72]. This implies that for the energy intensive industries investigated in our study openness to international trade may have had some influence on the ability to pass through costs.

[72] In this calculation we have used the information on trade intensities as leading for defining an individual case. This implies that the refineries sector has been defined as six cases (for each country one case), and not differentiating between petrol, diesel and gasoline.

When we investigate the influence of the indicative cost pass-through rate, the results seem no longer to hold. The indicative cost pass-through rate and trade intensities seem to correlate positively in the case of glass and cement, where both trade intensity and cost pass-through is low. Therefore, we cannot generalise the above conclusion to explain differences in cost pass-through between countries within sectors[73].

Not only the value of trade intensity but also the volatility over time deserves consideration in the context of cost pass-through and the risk of carbon leakage.
In the EC Directive, only a snapshot of trade intensity (an average over three recent years) is used as an indicator. Higher trade intensities seem, to some extent, indeed to coincide with a limited ability to pass-through costs. However, the volatility in trade intensities may also indicate relevant information. If trade intensity is rather volatile over time, then competition on international markets might be even more pronounced due to stronger reactions to economic drivers. On the other hand, if trade intensity is high but rather stable over time indicating a robustness to economic forces, then EU companies seem to have a more settled role in international markets and are more robust in terms of competitiveness.

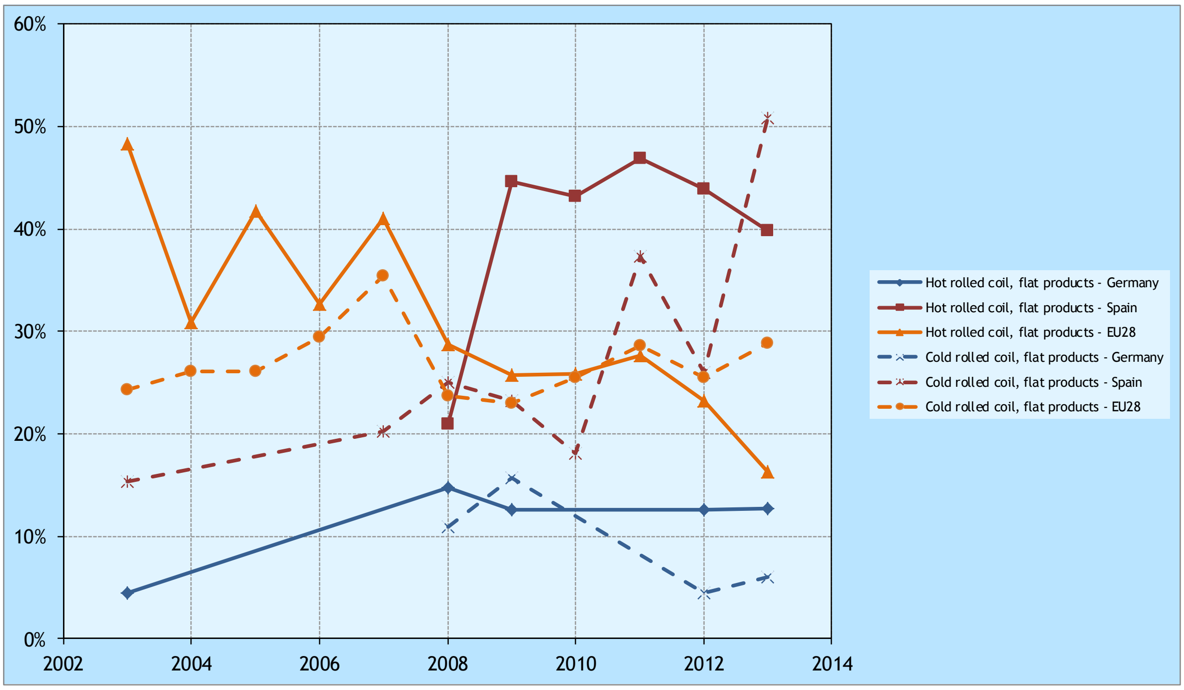
When we apply this to the investigated sectors, we see however that the products with more pronounced trade intensity show rather stable trade intensities over time (clinker, fertiliser, petrochemicals). Within the iron and steel sector, for example, it is not clear that the differences in cost pass-through can be explained by reference to the volatility of the trade intensities over time (see Figure 47). Figures for the other sectors can be found in Annex K.

5.2.3 Conclusions

For our range of products in the investigated energy intensive industries, we do find some evidence that higher trade intensities seem, to some extent, to coincide with a limited ability to pass-through costs. Lower trade intensity might thus enable cost pass-through. While we can generalise this finding on the evidence of cost pass-through – at least for the sectors under consideration, which are also subject to significant carbon costs - we cannot precisely determine the influence of the trade intensities on the indicative level of cost-pass through. Some products with higher cost pass-through rates (petrochemicals, refineries, steel, and fertiliser) show quite mixed trade intensities. Moreover, trade intensities seem to fluctuate over time quite substantially for some products, potentially indicating higher exposure to international competition and lower ability to pass through costs. However, no conclusive relationship could be found from the analysis.

[73] We have to be a bit careful here, since glass and cement are arguably those sectors with the most problematic data situation.

Figure 47 Trade intensities within the steel sector



5.3 EU market share

5.3.1 Introduction, definition and rationale

In addition to trade intensities, another relevant variable relates to the market power of EU industries. One could argue that the EU constitutes a significant part of the world economy in many sectors. Therefore not only the relative openness of an industry might determine whether or not (opportunity) costs can be passed through in product prices, but additionally (or rather) the extent to which the EU is price setter in the global market. To understand the position of EU producers in the global market, we look at the production share of the EU28 in global production. The higher the market share the more likely it is that the EU is substantially engaged in setting prices in global markets.

5.3.2 Data and results

The market share is defined as production in a certain region divided by total global production. Data on global production or on market shares is not readily available on a product level from any data source. For this analysis, we therefore collected production data from international data sources and calculated markets shares for some products (hot rolled flat steel, fertilisers and refineries) while for other products (cement, crude steel and glass) we screened the literature and conducted a web-based information search. Recent market shares and underlying data sources are given in Table 31. Market shares might change over time for various reasons, the most significant one being the economic boom in China with soaring demand and capacity expansion over the last decade. Market shares also changed because of demand reduction in a number of countries in response to the economic crisis. Additionally, over time, satiated markets in industrialised countries with rather steady levels of demand lead to potential losses in global market share unless exports pick up in a balancing way.

We used the UNSD Industrial Database, to derive production quantities for the EU28 and for the world. As aggregates are not provided in the database and the number of countries that data points are reported for vary, we summed up production quantities of the available EU member states and divided these by the sum of all available states. This may lead to slight inaccuracies when data for countries are missing.
In order to minimise inaccuracies, we checked that all important countries (esp. China) are included in the list. For refineries, for example, data is available for more than 100 countries whereas for fertilisers, data is reported for 22 countries only.
The most recent year data is available for from the UNSD database was 2012. Market shares for cement, steel and glass were extracted from the respective sources for the most recent year, 2014. For petrochemical products, information was only found for the year 2010.

Table 31 EU28 market shares for investigated products in 2012[74]

Sector	Products	Market share of EU28 in 2012/2014	Source
Cement (without clinker)		4%	http://www.cembureau.be/about-cement/key-facts-figures
Petrochemicals		14% (in 2010)	https://www.rolandberger.com/media/pdf/Roland_Berger_Global_Petrochemicals_20121113.pdf
Iron and steel	Flat steel HRC	13%	World Steel Association (2015)
	Flat steel CRC	20%	UNSD Industrial Database
Fertiliser		17%	UNSD Industrial Database
Refineries	Diesel	20%	UNSD Industrial Database
	Gasoil		
	Petrol	13%	UNSD Industrial Database
Glass		appr. 33%	http://www.glassallianceeurope.eu/en/industries; http://ec.europa.eu/growth/sectors/raw-materials/industries/non-metals/glass/index_en.htm

The table shows that market shares for glass products (in particular hollow glass) are highest among all the investigated products, with the EU holding about one third of global production. Market shares between 10 and 20% are found for all remaining products, except for cement in which the EU accounts for only 4% of global production. Annex K gives in more detail the EU market share in global production and compares this with other important producers in these markets.

From this table we cannot conclude that EU market shares are a dominant factor explaining cost pass-through. The average market shares for products for which we found cost pass-through is about the same as the average market share for products for which no cost pass-through can be found. However, it seems that the market share is somehow correlated to the height of the indicative cost pass-through rate that we found. Relating the indicative cost pass-through rates to current market shares ,we find that within our investigation low market shares occur in fact together with low

74 It should be noted that market shares have changed over time, in particular over the last ten years with China becoming an important player in global production for almost all of the investigated products. The market shares provided above thus represent lower ends within the time span that we estimate cost pass-through rates for.

cost pass-through rates, for example in the cement sector. Conversely, the glass sector has a high market share and also shows pronounced cost pass-through. A similar picture can be detected for fertiliser products and refineries which have substantial EU market shares and high cost pass-through rate. For petrochemicals, the picture is more mixed.

5.3.3 Conclusions

Within the context of cost pass-through the assumption prevails that companies pass through carbon induced costs to the extent that they do not compromise their market share, at least not for the reasons of cost pass-through. If EU producers constitute a significant share of the global market, they might be considered price setters and thus are able to pass-through their carbon costs without compromising their market share.

While we do not find evidence that the market share influences the likeliness of cost pass-through we find some evidence that the indicative rates of cost pass-through coincide with the EU market share. However, without any in-depth statistical analysis, we cannot establish a statistical significant relationship between market shares and cost pass-through rates.

5.4 Internal market concentration

5.4.1 Introduction, definition and rationale

Another line of thinking would be that not so much the international market relations determine the extent to which costs can be passed through in the product prices, but rather the internal market concentration. The general belief is that industries operating in more concentrated markets may have more opportunities to pass through the costs. In less competitive markets, firms may have more impetus to pass through the costs since they know that competitors will not break the (implicit or explicit) price agreements in order to maintain profitability. However, as was indicated in Section 2.3.1, this is not in line with standard economic thinking which would rather argue that cost pass-through is lower in oligopolistic and monopolistic markets (Sijm and Chen, 2009). Therefore, the impact of market concentration on cost pass-through is not clear a-priori.

Market concentration is normally measured by indices, such as the Herfindahl-Hirschman index (HHI). This is the sum of the squares of the market shares of all firms in the market. It can also be computed as the squares of market shares of a number of largest firms in the market, as is done in Bruegel (2014) for the four largest companies within a sector.

The HHI can differ from approximately zero in a case of a large number of firms with relatively equal size, to a maximum of 1 in the case of one firm with 100% market share.[75]. As the number of firms in an industry decreases, the HHI increases. Also, as the disparity in size between firms increases, the HHI increases (US Department of Justice, 2015). The HHI is often used to judge potential collision threats from mergers. US agencies consider markets with a HHI higher than 0.25 as highly concentrated and

75 Market share is expressed as either production in physical units or turnover. In some cases, not percentiles of market shares have been taken, but rather absolute numbers. In case market share is presented in numbers, the HHI is between 0 and 10,000.

transactions that increase the HHI by more than 0.02 are presumed to enhance market power (US Department of Justice, 2015)[76].

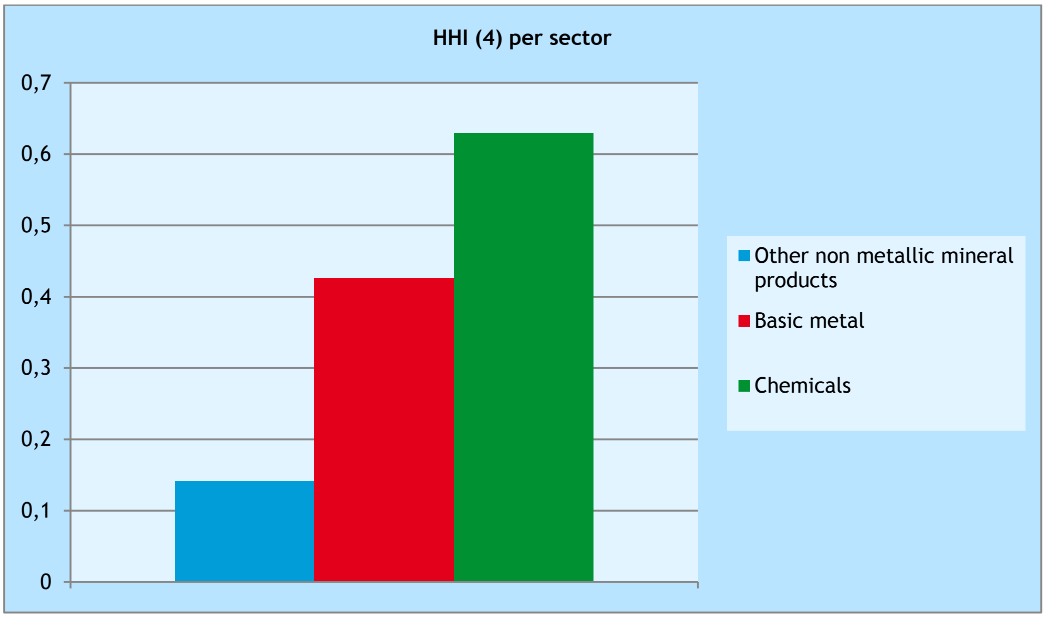
It is important to note that the influence of market concentration on cost pass-through is not uniformly defined in the literature. Sijm et al. (2009) have argued that cost pass-through in oligopolistic markets may be less than in perfectly competitive markets because in oligopolistic markets (and in particular Bertrand-type of oligopolies) prices may be kept lower in order to obtain maximum profits.
Others (e.g. Fitz Gerald and Scott, 2007; Reinaud, 2008) have argued that market concentration, as a sign of market power, may increase the possibilities of cost pass-through. This latter position corresponds more closely to the intuitive perception that market power would raise the possibilities of cost pass-through, even though this is in conflict with standardised economic theory (Reinaud, 2008).

5.4.2 Data and results

European wide data on the HHI for several sectors do not exist at present and Eurostat does not have data that allow calculation of the HHI. Using commercial data, Breugel (2014) reports several indicators for five European countries in the period 2000-2011, including the HHI for the 4 largest firms within a sector (HHI4).
The sectors are here defined as NACE 2 and some specification for subsectors is shown in the results. Figure 48 shows the HHI(4) in the EU28 for three sectors that also are included in the analysis in this chapter. In this figure, the chemical sector has a higher market concentration compared to iron and steel and cement. From this perspective, it is interesting to notice that the ranking of these industries matches the ranking in the indicative cost pass-through ranges with lowest indicative cost pass-through rates for cement and highest for chemicals (fertiliser and petrochemicals) with iron and steel in the middle. However, we cannot really conclude this relationship because there is not enough data that would allow a firm conclusion here.

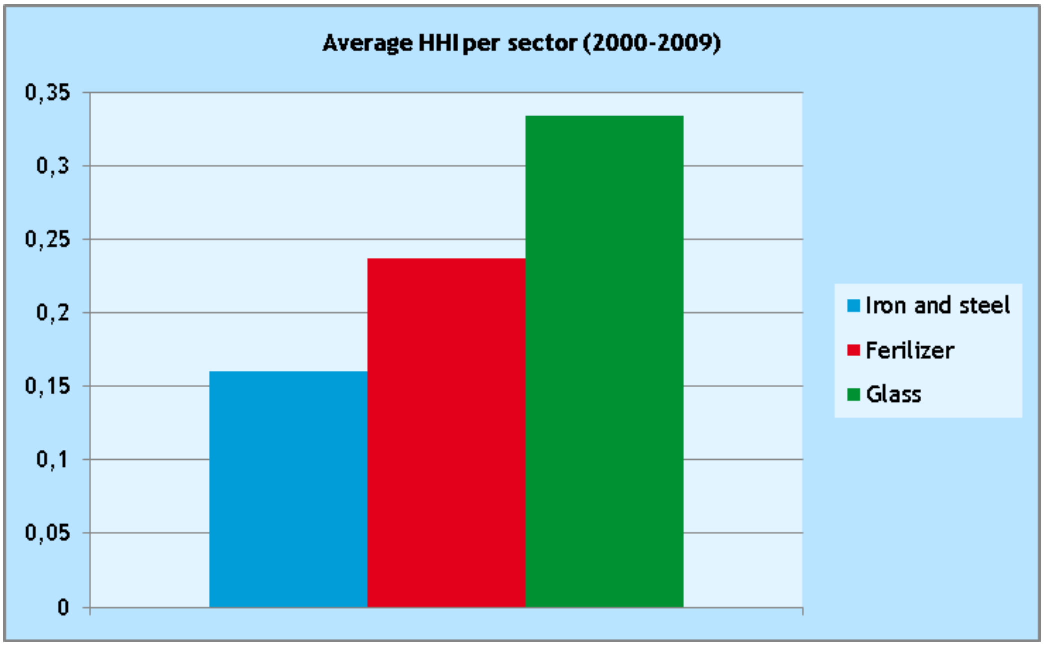
[76] An industry is regarded as strongly concentrated when the average HHI of an industry belongs to the highest tertile of the distribution of the average HHI across all industries (Cheung et al., 2011).

Figure 48 Herfindahl-Hirschman index (HHI) of the four largest firms in the EU28 (2000-2011) for some sectors



At the level of individual MS some additional studies have been undertaken. The most extensive is probably the Agora MMS project (Eyckman et al, 2011), which provides a database on concentration rates and HHI for several sectors in Belgium for the period 2000-2009. Using this data to compare the HHI gives an overview presented in Figure 49. This shows that among these sectors, the glass sector is the most concentrated sector and the iron and steel sector is the least concentrated.

Figure 49 Average Herfindahl-Hirschman Index for Belgium given as percentiles (Eyckman et al., 2011)



5.4.3 Conclusions

At present there are no good data giving an overview of market power in EU industries. Therefore, it is difficult to estimate the influence of market power on the ability to pass through the costs. It would be an interesting feature to investigate this in more detail in future research.

5.5 Transport costs

Transportation is an important issue for all products that are traded on international markets. As shown above in Section 5.2, most of the investigated products are well traded, with the exception of cement. There are several product characteristics that impact on transportation costs and therefore decisions made with regards to how (widely) a product should be traded.

The value-to-weight ratio of a product plays an important role for trade decision making. The heavier a product and the lower its value the higher will be the share of transportation costs in total costs. Transporting these products across long distances puts a burden on costs which cannot economically be retrieved. Thus, for these products production and demand locations are usually in close proximity.

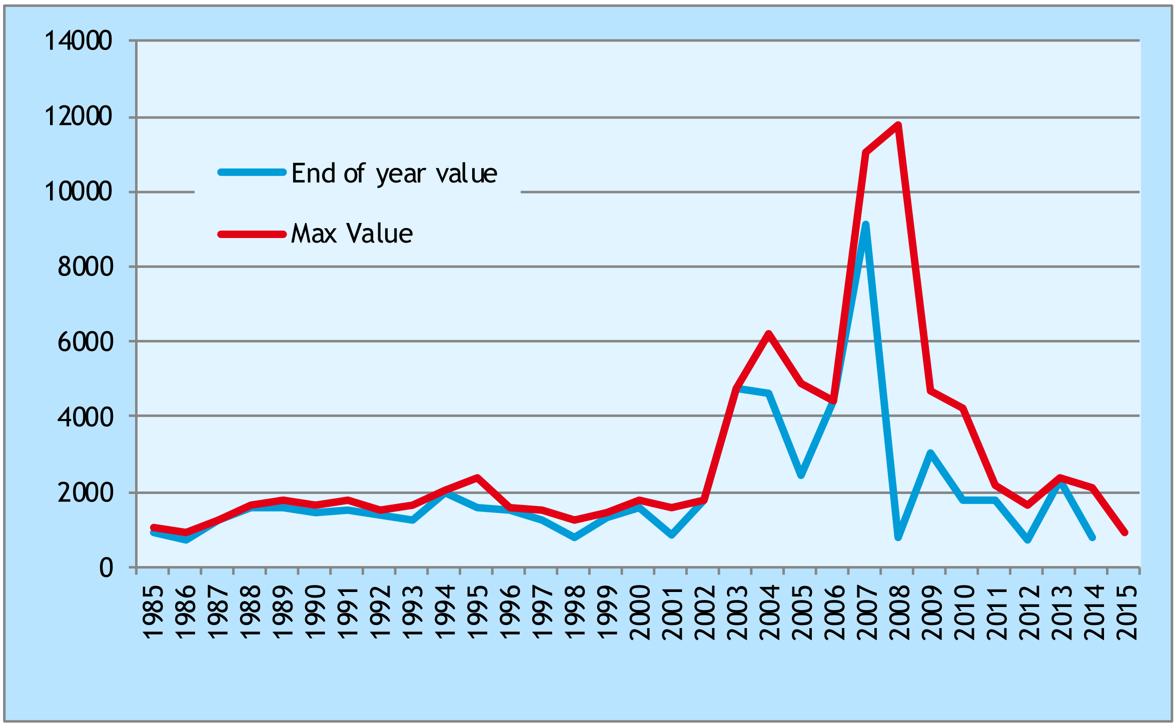
For products with a higher value-to-weight ratio, and in particular for products with high value added, transport costs are often not an important decision factor regarding both pricing and trading strategies (see also Section 4.3 for steel). Other product characteristics also play a role regarding their transportability. For example, if they are hazardous to transport and additional (costly) precautionary measures are necessary (e.g. this applies to a number of products in the fertiliser sector).

One reason why transportation costs may not be that important is that the development of transportation costs typically follows the demand for transportation (i.e. trade activity) rather than the other way round. In years of economic boom (e.g. right before the economic recession in 2008) demand for shipping soared and so did costs as shipping capacities were getting tight.

This can be seen in Figure 50 for the Baltic Dry Index, an index of the average price to ship raw bulk materials (e.g. cement, steel coils, ores etc.) on global markets.
With the onset of the economic recession, prices plummeted back to previous levels and have remained low ever since.

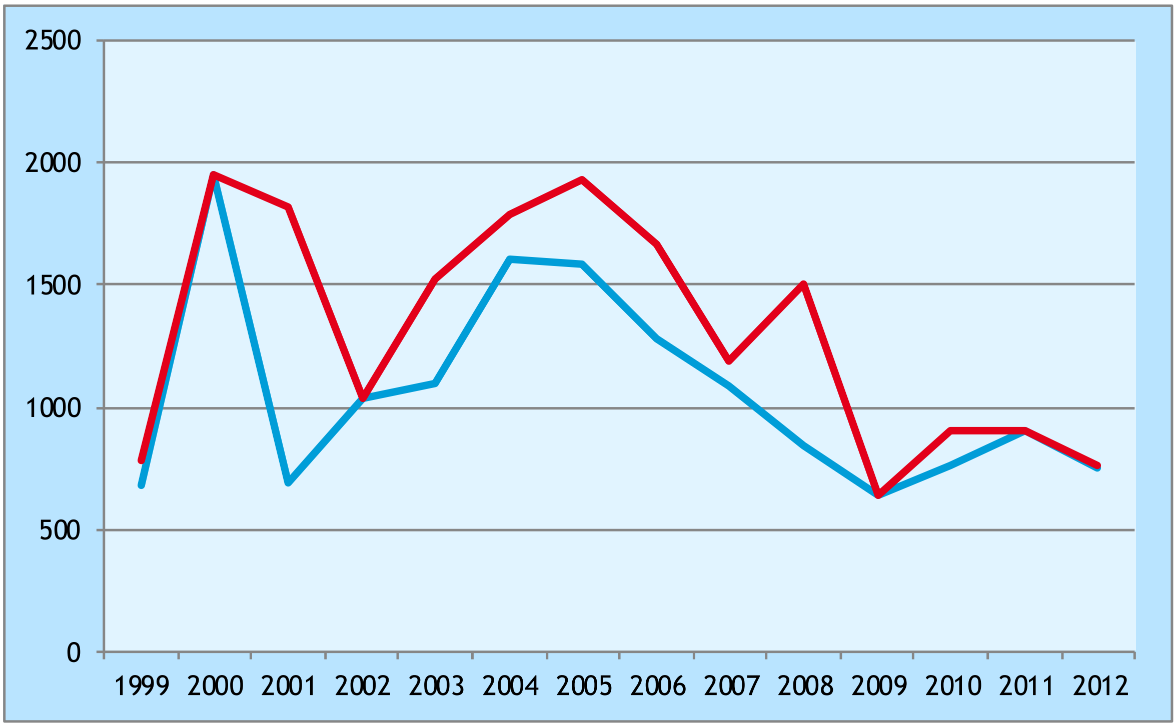
Figure 51 to Figure 53 show transportation cost indices for other investigated products, e.g. liquid products, such as refinery products and crude oil, and container goods (e.g. hollow glass) respectively. Compared to the Baltic Dry Index they do not show an extensive peak in the pre-crisis years, but show volatile patterns over time. All indices indicate decreasing costs in recent year.

Figure 50 Baltic Dry Index; shipping costs of dry bulk products on global markets



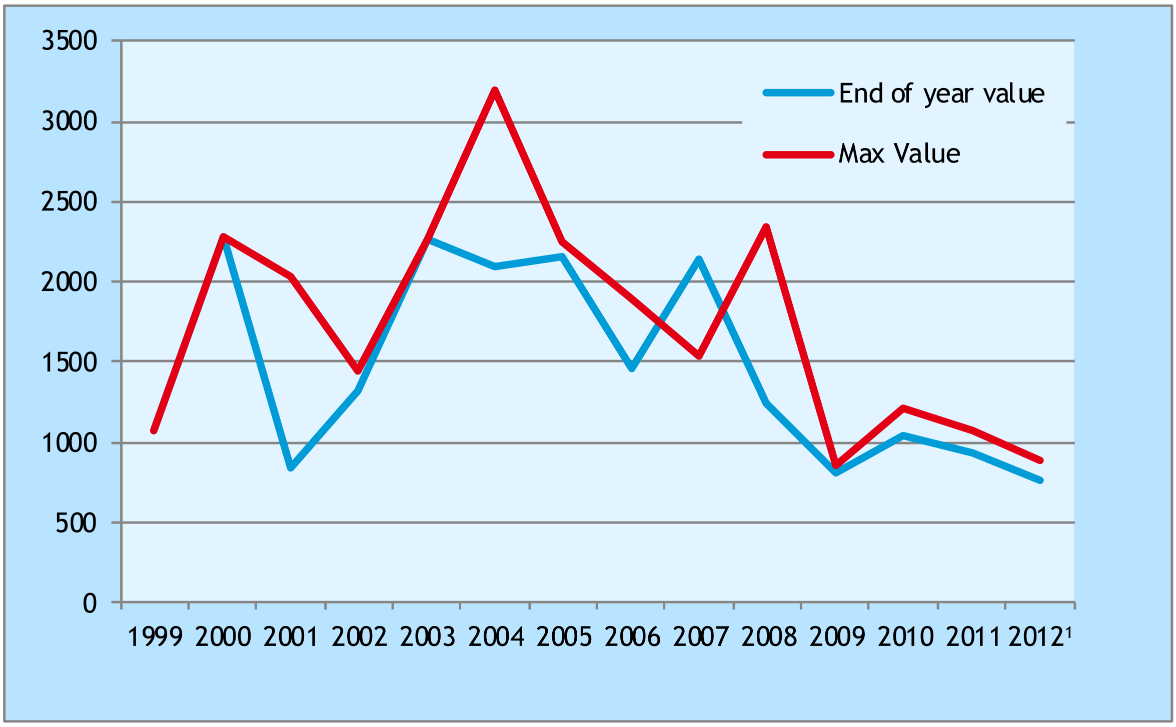
Sources: https://de.wikipedia.org/wiki/Baltic_Dry_Index; https://www.quandl.com/data/LLOYDS/BDI-Baltic-Dry-Index

Figure 51 Baltic Clean Tanker Index (BCTI); shipping costs of refinery products on standard routes



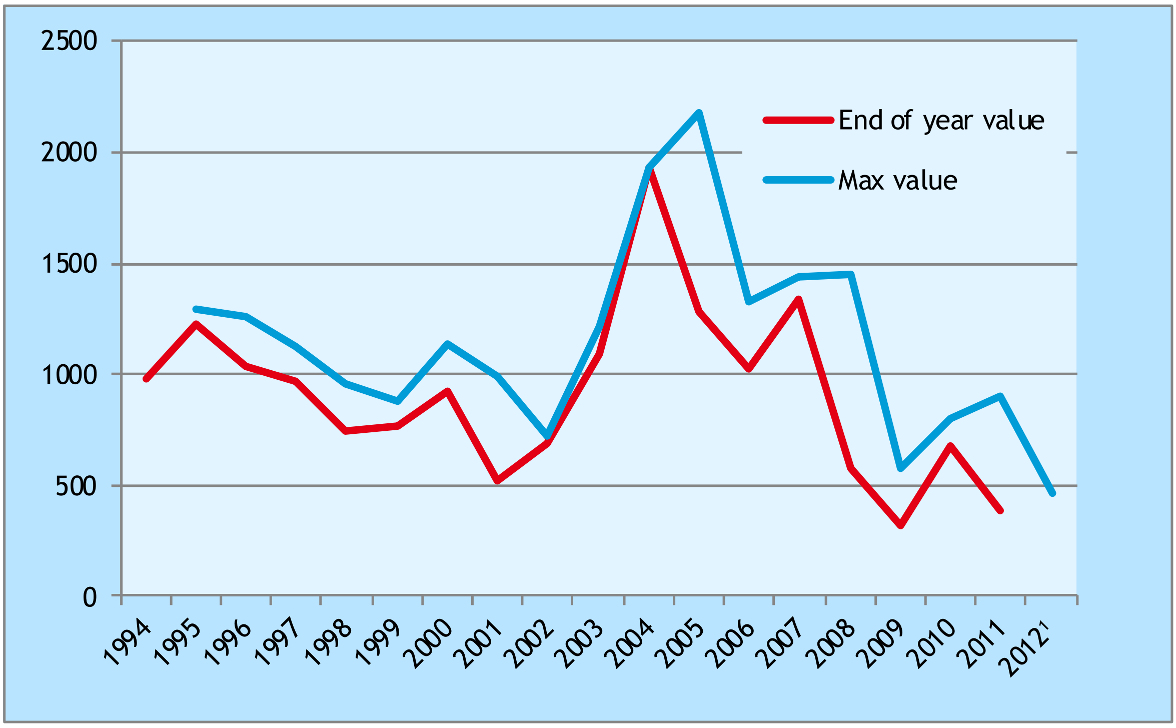
Source: https://de.wikipedia.org/wiki/Baltic_Clean_Tanker_Index

Figure 52 Baltic Dirty Tanker Index (BDTI); shipping costs of crude oil on standard routes



Source: https://de.wikipedia.org/wiki/Baltic_Dirty_Tanker_Index

Figure 53 HARPEX (Harper Petersen Charter rate Index); shipping costs in containers



Source: https://de.wikipedia.org/wiki/HARPEX

Companies regularly face a trade-off between potentially lower production costs in other regions and higher transportation costs to supply the respective markets. For some sectors, this trade-off leads to (regional) limitations of trade (e.g. cement because of its weight, some fertiliser products because they are explosive). For other sectors, this trade-off matters less and transportation costs seem to not be the main concern in company's strategic decisions.

In relation to cost pass-through of carbon costs, we would expect low value-to-weight ratio products or hazardous products with their limited suitability for international trade to be better 'candidates' for cost pass-through than products that can easily and economically be transported. However, as can be seen in the case of cement with its low transportability but still low pass-through rates or refineries with good transportability and nonetheless high pass-through rates, other market characteristics potentially play a larger role in decisions on cost pass-through than transport costs. This supports the insights from the sector chapters and the interviews that transportation costs are not in the foreground of product price formation and can therefore not be regarded as a good proxy for explaining cost pass-through.

5.6 Conclusions

In this chapter, we have investigated some additional factors potentially explaining differences in capabilities of sectors to pass through carbon costs. We have seen that there is some evidence that trade intensity explains the potential of carbon cost pass-through. The trade intensity of products for which cost pass-through was found, is in general lower than the trade intensity of products for which no cost pass-through could be found.[77] However, the potential relation between the indicative cost pass-through rate and trade intensity is less clear. Obviously, the exposure to international competition which might explain cost pass-through is affected not only by the activity of trade (trade intensity) but also by the reactivity of foreign demand to price changes (elasticity of demand, compare 2.3.1), which are again influenced by factors such as market power, product characteristics, capacity utilisation, etc. Therefore it cannot be concluded that trade intensity alone would be a good criterion for the amount of costs that can be passed through.

The EU market share in global markets may influence the ability to pass through costs. If EU industries would be world price setter, they have a higher chance of passing through the carbon costs. In general the EU market share did not explain the ability to pass through costs, although there was a weak correlation between the indicative cost pass-through rates and EU market shares. A higher EU market share would then imply that more costs could be passed through. However, the data are very sketchy here indicating that this argument could be investigated in more detail in future work.

In addition to the EU market share in global production, we have investigated the internal market concentration. Data is here even more difficult to gather. Therefore it is difficult to estimate the influence of market power on the ability to pass through the costs. The existing examples show again that the amount of costs passed through could be higher for sectors that are more concentrated. This could be an interesting

[77] It needs to be noted that this applies to our range of products in the investigated energy intensive industries – which are also subject to significant carbon costs. It can not be concluded that this is true for all sectors on the carbon leakage list.

topic for future research that would try to establish an EU-wide database of market power (e.g. through Horizon 2020 research).

Transportation costs widely vary over time with the Baltic Dry Index showing sea transport costs in 2008 about 3-4 times higher than at present. There is in general not much evidence that points in the direction that these costs are important for cost pass-through.

6 Summary and conclusions

This study has investigated the extent to which ETS-related carbon costs have been passed through into product prices of industries covered by the EU ETS. Moreover, it has investigated the factors that may have influenced the observed cost pass-through. These questions have been approached from three angles:

1. A literature review (theoretical, ex-ante modelling and ex-post empirical studies).
2. An empirical assessment of cost pass-through in six sectors using statistical techniques (econometrics).
3. Additional qualitative and quantitative analysis of potential factors explaining the ability or inability to pass through carbon costs.

6.1 Literature review

The literature on cost pass-through can be classified into theoretical and empirical contributions. The empirical literature can further be classified into ex-ante modelling and ex-post econometric studies.

The theoretical literature argues that cost pass-through is likely for profit maximising firms. According to neoclassical economic theory, if facing a trade-off between cost pass-through (to retain profits) and a loss in market share, firms would maximise profits rather than market shares and therefore pass through carbon costs. This result holds, in economic theory, regardless of whether the emission allowances would be (partly) auctioned or given away at no costs since at the margin carbon costs are equal for auctioned and free allowances.

According to the theoretical literature, the exact amount of costs passed through can be expected to range between 0 and 100%. However, under certain assumptions regarding the shape of demand curves and substantial differences in carbon intensity between marginal and average producers, it may lie well above 100%. The precise cost pass-through rate depends, according to the theoretical literature, on a number of stylised factors:

- The market structure in the sense that more competition generally implies more cost pass-through;
- The elasticities of demand in the sense that less elastic demand generally implies more cost pass-through;
- The marginal cost curve of domestic industries in the sense that more elastic marginal cost curves generally imply more cost pass-through;
- The marginal cost curves of foreign competitors (represented by Armington elasticities) in the sense that lower elasticities generally imply more cost pass-through.

These stylised factors have proven difficult to estimate in empirical work and have therefore been approximated by a range of measurable drivers, which are linked to these stylised factors. These drivers include trade intensity, transport costs, tariff barriers and product substitutability (underlying the Armington elasticities), as well as indicators of market concentration and pricing power (underlying the market structure). However, it is infeasible to assess whether firms will be induced to pass through the carbon costs of participation in the EU ETS based on theoretical literature alone.

Despite ten years of operation of the EU ETS, the literature offering empirical estimates of the pass-through of carbon costs for industrial products remains relatively scarce. The literature review in this study identifies eight original studies estimating cost pass-through for a range of industrial products. Three of these studies are based on ex-ante modelling exercises and five use ex-post econometric techniques. All studies show that costs have been passed through in the majority of sectors investigated. Table 632 gives a weighted average of cost pass-through rates from both ex-ante and ex-post literature. The minimum and maximum values are weighted averages from the literature where each study is counted as a single observation.

Table 32 Overview of the range of average expected cost pass-through in selected sectors from the literature

Sector	Product	Minimum*	Maximum*	*# of studies*
Iron and steel	Flat products	60%	100%	4
	Long products	66%	80%	3
Cement	Portland cement, white cement	30%	50%	4
Glass	Container glass	20%	50%	2
	Hollow and other glass	30%	60%	3
Refineries	Petrol	50%	>100%	5
	Diesel	40%	>100%	3
Petrochemicals	Plastics, PE, PVC, PS	25%	80%	3
Fertilisers	Fertiliser and nitrogen compounds	15%	75%	3

* Minimum and maximum values have been determined as the average of minimum and maximum values found in the cited studies and our own interpretation of the quality of the estimated and assessment of the potential range. No attempt has been made to correct for the number of products or regression estimates in the literature so this table should not be regarded as a formal meta-analysis.

The values from Table 632 show that actual cost pass-through varies widely between sectors. There is (not given in this table) an even greater variation in estimates between studies. The most obvious reason for the variation is that the data used and methods employed vary substantially between studies and that these tend to influence the results.

6.2 Methodological approach and data collection

For the empirical analysis carried out in this paper, the methods employed and data sources used in previous empirical ex-post studies were of particular interest. When scrutinising the methods used, two approaches could be distinguished: a market-equilibrium approach and a cost-price approach. Whilst the market-equilibrium approach exploits price movements on domestic and foreign output markets, the cost-price approach estimates the relationship between the price of the product and the costs of main input variables (labour, capital, materials, energy) and adds the (opportunity) costs of carbon to these costs. For the econometric estimation carried out in this study we decided to apply the cost-price approach. Although this method is relatively data-intensive, it has the advantage that fewer assumptions are required compared with the market-based approach.

The estimation is carried out under the null hypothesis that the opportunity costs of CO_2 have not been passed through. If this null hypothesis is rejected, there is evidence that (some amount) of costs have been passed through. This implies a standardised “cautious approach” by presuming that there is no relationship between marginal carbon costs and product prices unless this is explicitly revealed by statistical tests.

Although the cost-price approach does provide an estimate of the average cost share of carbon costs in the final product prices, it is difficult to interpret this coefficient directly in terms of cost pass-through rates because of confidence bounds, potential data issues and the challenge of a divergence between average and marginal cost price increases. Therefore, the prime information that can be derived using this approach is related to the fact whether costs were passed through or not, whereas the indicative value of costs pass-through rates estimated are afflicted with greater uncertainty.

The data collection process set up followed a three-tiered approach, which preferred actual price data from client industry or market quotations (Tier 1) over producer price indices (Tier 2) and implied prices derived from trade statistics (Tier 3). As CO_2 costs in production are relatively small compared to other inputs, estimation results tend to be sensitive against the quality of the data, especially regarding the price of outputs. We took great care in collecting data of adequate quality, length and frequency, however, the data collection process was more difficult for some sectors than others. As could have been expected ex-ante, the cement and glass sectors proved to be particularly challenging.

Following the determination of the cost-price approach as the adequate one for the research questions to be answered in this study, an estimation strategy framework was developed that was applied to each regression carried out in this study. Based on statistical tests of the data series themselves and robustness indicators of the regression at hand, the estimation strategy follows a clear rule-based path to arrive at the most appropriate method in each case. In this way, unbiased and robust results are obtained. The only pre-selection criteria implemented before applying the framework were the decision on which time frame to consider for each product. While we generally had collected data for the time-frame 2005-2014, we often limited the analysis to only Phase 2/3 because of scope changes (relevant, for example, for the petrochemical and fertiliser industry) and the fact that Phase 1 is widely regarded as a “learning phase” during which the carbon price was nearly zero for a long period of time.

6.3 Econometric estimation and results

The empirical estimation was conducted for a variety of products from six sectors that were selected ex-ante on the basis of emissions, (direct) carbon costs and data availability. These sectors, with their corresponding NACE Rev.2 codes, are:

- iron and steel (NACE 2410);
- refineries (NACE 1920);
- cement (NACE 2351);
- organic basic chemicals (NACE 2014);
- fertiliser (NACE 2015);
- glass (NACE 231).

For each of these sectors monthly and/or weekly data was gathered on the output prices of a number of products, as well as input prices of labour, capital, materials, energy and carbon. The relationship between input and output prices is estimated for 2-3 products in 2-3 countries for each sector. In total, over 50 unique product price series were investigated in this study using individual time-series regressions for each product/country combination.

Tableau 233 summarises the results of those empirical estimations. For every product included in the regression analysis, the table provides information by country/region on the cases where prices of this product were significantly influenced by carbon costs and where not. Overall, the econometric results showed that in about 60% of the cases evidence was found that carbon costs were a significant factor in the price of products, often with a delay of 1-3 months. In all sectors some evidence of cost
pass-through could be found but evidence was more mixed in the glass and petrochemical sectors than in the refineries, cement, fertiliser and iron and steel sectors.

The carbon coefficient resulting from the econometric estimation represents the average fraction of carbon costs contained in final product prices. This fraction can be used to calculate the cost pass-through rate representing the percentage of carbon costs that was passed through in the product prices. However, the exact calculation of this cost pass-through rate is characterised by a larger uncertainty than the conclusion about whether or not carbon costs were passed through at all. Therefore, the cost pass-through rates presented in Table 33 should be interpreted as ‘indicative values’.

Table 33 Overview of main empirical results of this study

Sector	Products	Cost pass-through not significant	Cost pass-through significant*	Average cost share	Indicative cost pass through rates^	Remarks
Cement	Clinker	UK, CZ	FR, DE, PL	0.07 to 0.09	35-40%	Primarily valid for Phase 2/3
	Total cement	UK, IT	FR, DE	0.02	20-40%	Primarily valid for Phase 2/3
	Portland cement		CZ,PL	0.06-0.1	90-100%	Primarily valid for Phase 2/3
Petrochemicals	Ethylene		NWE, MED	0.03-0.12	>100%	Only valid for Phase 2/3
	Mono ethylene glycol	MED		NA	Not sign.	
	Propylene oxide		NWE	0.021	~100%	Only valid for Phase 2/3
	Propylene glycol ether**	NWE	NWE	0.06	>100%	Only valid for Phase 2/3
	Methanol, Butadiene, Propylene	NWE, MED		NA	NA	No relevant models found
Iron and steel	Flat steel HRC		NE, SE	0.04-0.08	75->100%	Only valid for Phase 2/3
	Flat steel CRC		NE, SE	0.03-0.05	55-85%	Only valid for Phase 2/3
Fertiliser	Ammonia	NWE		NA	Not sign	Only valid for Phase 3
	Ammonium nitrate	FR	UK	0.12	>100%	Only valid for Phase 2/3
	Calcium ammonium nitrate		DE	0.13	>100%	Only valid for Phase 3
	Urea ammonium nitrate		FR	0.24	>100%	Only valid for Phase 3
	Urea	NL	NWE	0.09-0.1	Not sign ->100%	Only valid for Phase 2/3
Refineries	Diesel	DE	BE, FR, GR, IT, PL	0.03 to 0.05	>100%	Only valid for Phase 2/3
	Gasoil	GR, PL, IT	BE, DE, FR	0.02-0.07	>100%	Only valid for Phase 2/3
	Petrol	GR, PL	BE, DE, FR, IT	0.01	80-95%	Only valid for Phase 2/3
Glass	Hollow glass	DE, ES	FR, IT	0.004-0.01	40-100%	Valid for Phase 1/2/3
	Fibre glass	DE		NA	Not sign.	Valid for Phase 1/2/3

Notes:

* BE=Belgium, CZ=Czech Republic, DE=Germany, ES=Spain, FR=France, GR=Greece, IT=Italy, NE=Northern Europe, NL=Netherlands, NWE=North-Western Europe, MED=Mediterranean countries (Southern-Europe), PL=Poland, SE=Southern Europe, UK=United Kingdom. Decision whether CO_2 cost coefficient was significant made on the basis of a 10% critical threshold level (based on one-sided T-statistics).[78]

** For propylene glycol ether we use three different spot prices for NWE. Estimates show that in the regression employing one price series, CO_2 prices were found to be significant, whilst not for the other two.

^ Conjectured estimate of the percentage of costs passed through into product prices.

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78 One-sided confidence levels are more appropriate because we are testing here whether the opportunity costs of freely obtained allowances are not passed through in the product prices. Since it does not make sense to assume that a negative value of opportunity costs is passed through in the product prices, a one-sided confidence level seems appropriate.

The indicative values listed in Table 33 show that there may well be differences between sectors in the rates of cost pass-through observed. In the cement sector they seem to be lowest and range, in general, between 20-40% (with the exception of Portland cement in Poland). This is consistent with earlier results in the literature that has identified cost pass-through in the cement sector of about 30%. Our estimations further show that CO_2 prices are passed through with a delay of about one month in the cement sector.

Indicative cost pass-through rates in the iron and steel sector range, in general, between 55-85% (except for hot rolled coil in Southern Europe for which a higher cost pass-through rate was found). This result also confirms earlier ex-ante estimations in the literature. Models show a slightly longer delay of pass-through of about 2-3 months in the iron and steel sector.

For refineries, we find signs of higher indicative cost pass-through rates, ranging from 80-100% for petrol and at, or over, 100% for diesel and gasoil. Although this confirms earlier results in the literature, the very high rates estimated for diesel and gasoil may depend on other factors, including asymmetric pricing behaviour on the market.

Such high indicative cost pass-through rates were also found in the fertiliser and petrochemical sector, for those products where estimated coefficients were significant. For fertiliser products, a number of estimations only apply to Phase 3 of the EU ETS, since scope changes resulted in more emissions covered by the ETS since Phase 3 and onwards. Generally, weekly data was used for the fertiliser sector and showed that costs were passed through with a delay of about two months.

The glass sector, finally, shows somewhat lower indicative cost pass-through rates between 40-100%.However, the overall results for glass are mixed, which is related to the relatively poor data situation for glass and the fact that CO_2 costs in glass production are in general quite low making it difficult with econometrics to discern whether they are significantly different from zero.

6.4 Potential drivers of cost pass-through

To improve the understanding of price formation in the respective industries and identify potential drivers of cost pass-through, we conducted interviews with client industries and market experts to inquire about both their experience with price formation in supplier industries and their view on main price determinants.
Their assessments differed by industry and also by size, bargaining power and product portfolio of the client industry in question. Energy prices were perceived to play a major role in product price formation. Transportation costs on the other hand – even though considerable in some industries – only seem to play a role in price variation if transportation capacity becomes scarce and expensive (such as in the pre-crisis year 2008) or if goods are difficult to transport in the first place (e.g. fragile glass or hazardous chemicals). Therefore, we cannot deduct generalised rules regarding these potential drivers, but note that their influence may vary from industry to industry.

In addition to these interviews, this study also presented some quantitative evidence on potential factors that influence the process of price formation and could explain the ability or inability to pass through carbon costs. Utilisation rates may in some sectors be a driver explaining differences in cost pass-through – with higher capacity utilisation generally being associated with higher cost pass-through rates. The lowest utilisation rates were found in the cement sector (substantial overcapacity), somewhat higher rates in the iron and steel sector and the highest in the fertiliser industry where installations run at high capacity and we have found corresponding differences in cost pass-through rates. This finding also confirms the theoretical literature on this subject. Market power, both of the EU in global markets and the concentration of power within EU markets, also seem to be important variables. Generally, a higher market concentration seems to be associated with a higher ability to pass through costs. However, lack of empirical data prevents a clear estimation of this relationship.

Finally, a weak coincidence between trade intensity and cost pass-through could be observed for the product/country pairs investigated in this study. The trade intensity of products for which cost pass-through was found, is in general lower than the trade intensity of products for which no cost pass-through could be found. However, the link is not statistically significant when comparing both groups. Furthermore, the potential relation between the indicative rates of cost pass-through and trade intensity is less clear. More research would be needed – in particular on more products – to draw decisive conclusions. Obviously, the exposure to international competition which might explain cost pass-through is affected not only by the activity of trade (trade intensity) but also by the reactivity of foreign demand to price changes (elasticity of demand), which are again influenced by factors such as market power, product characteristics, capacity utilisation etc. Therefore it cannot be concluded that trade intensity alone would be a good criterion for the amount of costs that can be passed through.

6.5 Implications of this study

An implication of this study concerns the fact that industry was seemingly capable of passing through a substantial share of the opportunity cost of freely obtained allowances. Higher product prices may on the one hand have stimulated the profitability of the EU ETS firms (at the expense of client industries and consumers), but may, on the other hand, have resulted in a loss in market shares. This study has not investigated whether market shares had been lost by passing through the opportunity costs of freely obtained allowances. Such may be investigated in more detail in future work. However, empirical evidence so far has not documented carbon leakage for EU industries.

It is also important to note that the evidence of cost pass-through itself is not a precise indicator of carbon leakage risks. Carbon leakage may occur through a loss in market shares or through a loss in investments. If marginal producers have forwarded carbon costs in their product prices, the whole industry has seen price levels increase which may have enhanced profitability but hampered international competitiveness. This latter effect may have resulted in a loss in market shares in domestic and export markets but this is not very well documented in empirical work so far. In the absence of more precise empirical work into the development of domestic and international market shares, the consequence of cost pass-through on carbon leakage cannot be determined.

Moreover, the mechanisms discussed in this study may imply that companies are not necessarily aware of passing through carbon costs. If only the marginal producer passed through its carbon costs, the market price would contain CO_2 cost components to which all other producers would adjust without knowing that they are (implicitly) passing through carbon costs. Only price-setters can make a formal decision to pass through carbon costs explicitly. Price-takers ‘automatically’ pass through carbon costs without ever taking a formal decision about the role of carbon costs in price formation by the sales department. The findings of this study are thus consistent with the observation that the majority of firms claim - in surveys or public statements - that they do not pass through carbon costs.

Finally, the results show that econometrics can be a valuable method to determine whether or not product prices contain carbon cost components for products with a relatively high carbon content. Econometrics can thus provide information additional to the existing work that has surveyed companies participating in the EU ETS. However, the question as to how much of these costs are exactly passed through in product prices (i.e. the magnitude of cost pass-through rates) is more difficult to answer. The literature review has shown that estimation results of cost pass-through rates depend - to a large extent - on the models and data used in the process. Therefore, results from econometric studies can, for the time being, be especially useful for determining the relevance of indicators approximating cost pass-through. Given the high relevance of empirical carbon cost pass through for devising a well-targeted carbon leakage and free allocation policy it is recommended to continue and intensify efforts to derive more solid estimates and indicators. In addition to trade intensity, this study has pointed to the potential importance of other indicators, such as utilisation rates and market power, to explain cost pass-through, both of which also deserve further investigation.

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Annex A. General data source

A.1. Introduction

This Annex gives account of the data sources that have been used in this study. General data sources that have been used across sectors are given in this Annex A. Specific data sources for each sector on prices of outputs and prices of material inputs are given in Annex A-Annex G.

A.2. Labour costs

As a proxy for labour costs we have used personnel costs at the NACE 4-digit level taken from Eurostat structural business statistics (SBS). Personnel costs are defined as the total remuneration, in cash or in kind, payable by an employer to an employee (regular and temporary employees, as well as home-workers) in return for work done by the latter during the reference period.

Personnel costs are made up of wages, salaries and employers' social security costs. They include taxes and employees' social security contributions retained by the employer, as well as the employer's compulsory and voluntary social contributions.

Average personnel costs (or unit labour costs) equal personnel costs divided by the number of employees (persons who are paid and have an employment contract).

A.3. Energy prices

A sector-specific energy price index has been constructed for each country. This index is based on the average input of energy carriers in the final product and the country specific prices for energy carriers in industry.

Division of energy carriers into production of final products

Based on SimaPro (LCA tool), the contribution of various energy carriers to the European average have been calculated. These can be defined as follows:

Table 34 Energy shares used for the different products

	Coal	Heavy Fuel Oil	Light Fuel Oil	Natural gas	Electricity	Cokes
Carbon Steel, Flat products, hot rolled coil, domestic ex-works	0%	0%	0%	2%	2%	96%
Flat Glass	0%	16%	0%	73%	10%	0%
Hollow Glass	0%	0%	0%	78%	22%	0%
Glass Fibres	0%	0%	0%	71%	29%	0%
Portland Cement	41%	42%	0%	0%	17%	0%
Kerosene	0%	62%	0%	0%	38%	0%
Gasoil	0%	0%	0%	0%	100%	0%
Petrol/Gasoline	0%	68%	0%	0%	32%	0%
Diesel	0%	60%	0%	0%	40%	0%
Polyethylene*	0%	0%	80%	0%	20%	0%
PolyPropylene*	0%	0%	80%	0%	20%	0%
Butadiene*	0%	0%	80%	0%	20%	0%
HDPE*	0%	0%	80%	0%	20%	0%

	Coal	Heavy Fuel Oil	Light Fuel Oil	Natural gas	Electricity	Cokes
Mono-ehtylene or propylene*			95%		5%	
Ammonia	0%	59%	0%	38%	4%	0%
Urea	0%	61%	0%	30%	10%	0%

* Implies estimation based on expert judgement as no information from SimaPro could be found.

These SimaPro values give general values which can be regarded as a (Western) European average. In various cases, additional sources have been used for calculating the energy input. Waste gases, such as refinery gas and coke oven gas have not been included in this estimation, as these would be used with preference if needed by the companies.

Country specific energy price developments

For each energy carrier a specific price path has been estimated using publicly available data to the extent possible. For coal, cokes and fuel oil, EU average prices have been estimated while for natural gas and electricity country specific prices have been established.

For coal, the price has been estimated as the weighted average of import price of hard coal from Australia, South-Africa and Colombia, as presented by the Worldbank Commodity Statistics. This price was weighted by the average import-share of coal from these countries to the EU27, as given by Eurostat.[79] All values have been converted to Euros.

For heavy fuel oil, the price has been based on Brent London spot exchange.

Table 35 gives an overview of the energy carriers distinguished and the source of price data.

Table 35 Overview of price information used for calculating the energy price index

Energy carrier	Indicator	Main data sources	Manipulations
Hard Coal	Coal imports, Australian, South-African, Colombian	Worldbank, Coal Week, Eurostat	Weighted with import-share in the EU from 2008, prior to 2008 import shares have been assumed to be similar to January 2008.
Cokes	Export FOB shipped from either Poland / Czech Republic or China	Steelonthenet	-
Heavy fuel oil	Crude Oil 2 Brent 38% API Gravity Spot Free on Board London Monthly Average	Datastream	$ to € conversion.
Natural gas	Gas prices for industrial consumers.	Eurostat and Worldbank	Excluding VAT and other recoverable taxes. Monthly

79 Eurostat import data present figures from January 2008 and on. Prior to January 2008 the assumption is that the division is as of that of average 2008.

Energy carrier	**Indicator**	**Main data sources**	**Manipulations**
	Band I5: 1,000,000 GJ < Consumption < 4,000,000 GJ		Worldbank data and bi-annual Eurostat data have been synchronised on each other.
Electricity	Band IF : 70 000 MWh < Consumption < 150,000 MWh Kilowatt-hour Excluding VAT and other recoverable taxes and levies For glass sector: Y+1 electricity prices for the respective country	Eurostat, ICIS	Excluding VAT and other recoverable taxes. Bi-annual Eurostat data have been interpolated to achieve monthly series.

A.4. CO_2 prices

The CO_2 price for phase I is based on the spot price published by Carbix (October 2004–June 2005) and Bluenext (July 2005-February 2008). It is converted from a daily series to a monthly series by taking averages.

The CO_2 price for phase II and III is based on the spot price published by SendeCO_2. It is converted from a daily series to a monthly series by taking averages.

A.5. Interest rates

The interest rate is taken from the ECB website. It is the Long-term interest rate for convergence assessment purposes. It is published at a monthly frequency.

A.6. Control variables

Euro/Dollar exchange rate

Monthly averages have been obtained from Eurostat. The monthly average data are the average of the business day rates. Data are taken from the European system of central banks (Eurosystem). The source is the European Central Bank.

Stock exchange

Stock exchange data have been used for reducing the volatility in the data series. More in particular we have used the following index: Dow Jones Euro Stoxx 50 - free-float market capitalisation-weighted index of 50 Eurozone stocks. Provides a blue-chip representation of Supersector leaders in the Eurozone and thus a picture of the general economic climate. Daily figures have been transformed to monthly averages.

The volume of production

Output indicators have been used for controlling for the general economic climate. Specifically, we have included monthly values of sectoral output, based on Eurostat's short term business statistics. This concerns the indicator 'PROD', the volume of production in industry (index; 2010=100) for the specific sector.

Annex B. Additional details refineries

B.1. Data sources

The following table reports the sources for data in the refineries sector.

Table 36 Data sources fort he sector refineries

Variable	Source
Price petrol, diesel gasoil	Oil bulletin
CO_2 price	Carbix, BNS (Phase 1) & Sende CO_2 (Phase 2 & 3)
Crude oil price	Thomson Reuters Datastream
Energy price index	ICIS
Euro$ Exchange rate	Eurostat
Wages	Eurostat
Volume	Eurostat

Crude oil price

There is no single benchmark of oil, and therefore, no one price for any barrel of oil. Instead, oil is priced via a method known as 'formula pricing.' At the heart of formulae pricing is the identification of the price of key 'physical' benchmarks, such as West Texas Intermediate (WTI), Dated Brent and Dubai-Oman. The benchmark crudes are a central feature of the oil pricing system and are used by oil companies and traders to price cargoes under long-term contracts or in spot market transactions; by futures exchanges for the settlement of their financial contracts; by banks and companies for the settlement of derivative instruments such as swap contracts; and by governments for taxation purposes (Fattouh, 2011; Dunn and Holloway, 2012).

We have selected two variants of crude oil prices in our analysis.

A. Brent dated price. These are the value of crudes to be delivered between, in general 10-21/25 days after the date the price assessment was published. They are typical of the value of the crudes delivered to refineries for further processing. Dated Brent has sometimes referred to as the 'spot' price for Brent - is the most commonly used reference price for the physical sale of oil by tanker. These series originate to Platts and was frequently used before 2000.
B. The ICE Brent index. This is a newer variant of the crude oil price index and is more frequently used nowadays, primarily by large oil suppliers such as Saoudi Arabia. Although highly complex, the ICE Brent index is based on a futures contract specifying the delivery of 1,000 barrels of Brent crude oil at some determined future date.

B.2. Summary of VECM results

Diesel

The following tables summarise the results of VECM estimations that explain the price of Diesel.

ETS all phases

Table 37 Summary of VECM results of models that explain the price of Diesel in various countries, for the time period associated with ETS phase 1, 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	No			ARDL
Germany	No			ARDL
France	No			ARDL
Greece	Yes	No		ARDL
Italy	No			ARDL
Poland	No			ARDL

ETS Phase 2 and 3

Table 38 Summary of VECM results of models that explain the price of Diesel in various countries, for the time period associated with ETS phase 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	No			ARDL
Germany	No			ARDL
France	No			ARDL
Greece	No			ARDL
Italy	No			ARDL
Poland	No			ARDL

Petrol

The following tables summarise the results of VECM estimations that explain the price of Petrol.

ETS all phases

Table 39 Summary of VECM results of models that explain the price of Petrol in various countries, for the time period associated with ETS phase 1, 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	No			ARDL
Germany	Yes	No		ARDL
France	Yes	No		ARDL
Greece	No			ARDL
Italy	No			ARDL
Poland	No			ARDL

ETS Phase 2 and 3

Table 40 Summary of VECM results of models that explain the price of Petrol in various countries, for the time period associated with ETS phase 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	Yes	No		ARDL
Germany	Yes	No		ARDL
France	No			ARDL
Greece	No			ARDL
Italy	No			ARDL
Poland	No			ARDL

Gasoil

The following tables summarise the results of VECM estimations that explain the price of Gasoil.

ETS all phases

Table 41 Summary of VECM results of models that explain the price of Gasoil in various countries, for the time period associated with ETS phase 1, 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	No			ARDL
Germany	No			ARDL
France	No			ARDL
Greece	No			ARDL
Italy	No			ARDL
Poland	No			ARDL

ETS Phase 2 and 3

Table 42 Summary of VECM results of models that explain the price of Gasoil in various countries, for the time period associated with ETS phase 2 and 3

Country	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Belgium	No			ARDL
Germany	No			ARDL
France	No			ARDL
Greece	No			ARDL
Italy	No			ARDL
Poland	No			ARDL

B.3. Unit root tests

In the following tables, we present unit root tests all variables in the models for the refineries sector. The first two tables cover the tests using the weekly data, the final two tables cover the tests using monthly data.

B.3.1. Variables in models for diesel and gasoil

ETS all phases

Table 43 Unit root tests of the variables in models that explain Gasoil and Diesel, full sample

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
In levels					
Price of gas oil in					
Belgium	-2.144	0.227	-2.153	0.224	yes
Germany	-2.120	0.237	-2.003	0.286	yes
France	-2.250	0.189	-1.897	0.334	yes
Greece	-2.202	0.206	-2.265	0.184	yes
Italy	-1.892	0.336	-1.843	0.360	yes
Poland	-2.411	0.139	-2.420	0.137	yes
Price of Diesel in					
Belgium	-1.882	0.341	-1.899	0.333	yes
Germany	-2.291	0.175	-2.253	0.188	yes
France	-2.007	0.284	-1.952	0.309	yes
Greece	-2.063	0.260	-1.996	0.289	yes
Italy	-2.025	0.276	-1.975	0.298	yes
Poland	-2.476	0.122	-2.678	0.079	Yes
EU-wide variables					
CO_2	2.566	1.000	2.727	1.000	yes
Crude oil	-2.192	0.210	-2.231	0.196	yes
In first differences					
Price of gas oil in					
Belgium	-24.428	0.000	-24.429	0.000	no
Germany	-22.401	0.000	-22.358	0.000	no
France	-18.931	0.000	-19.081	0.000	no
Greece	-25.509	0.000	-25.652	0.000	no
Italy	-19.537	0.000	-19.658	0.000	no
Poland	-21.781	0.000	-21.790	0.000	no
Price of Diesel in					
Belgium	-30.513	0.000	-30.794	0.000	no
Germany	-28.281	0.000	-28.275	0.000	no
France	-17.677	0.000	-17.621	0.000	no
Greece	-17.428	0.000	-17.464	0.000	no
Italy	-16.271	0.000	-16.375	0.000	no
Poland	-9.549	0.000	-20.552	0.000	no
EU-wide variables					
CO_2	-20.959	0.000	-20.975	0.000	no
Crude Oil	-22.750	0.000	-22.803	0.000	no
Stock XX	-20.418	0.000	-20.418	0.000	no
€/$ Exchange	-27.430	0.000	-27.435	0.000	no

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend). The cut-off value is set at 5%.

From the table, we see that both tests indicate all variables in levels are I(1), while those in first differences are I(0). This points to the appropriateness of testing for cointegration in the error correction term of the ARDL (see below).

ETS Phase 2 and 3

Table 44 Unit root tests of the variables in models that explain Gasoil and Diesel, limited to 2008-2015

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
In levels					
Price of gasoil in					
Belgium	-1.360	0.602	-1.481	0.543	yes
Germany	-1.621	0.471	-1.517	0.524	yes
France	-1.422	0.572	-1.391	0.587	yes
Greece	-1.265	0.647	-1.534	0.515	yes
Italy	-1.332	0.616	-1.479	0.543	yes
Poland	-1.411	0.577	-1.481	0.542	yes
Price of diesel in					
Belgium	-1.486	0.540	-1.580	0.492	yes
Germany	-1.581	0.491	-1.538	0.514	yes
France	-1.513	0.526	-1.413	0.577	yes
Greece	-1.562	0.501	-1.634	0.464	yes
Italy	-1.562	0.501	-1.487	0.539	yes
Poland	-1.767	0.397	-1.608	0.478	yes
EU-wide variables					
CO_2	-1.747	0.407	-1.660	0.451	yes
Crude oil	-1.354	0.605	-1.675	0.443	yes
In first differences					
Price of Diesel in					
Belgium	-22.835	0.000	-22.944	0.000	no
Germany	-19.778	0.000	-19.775	0.000	no
France	-13.456	0.000	-13.475	0.000	no
Greece	-11.028	0.000	-10.985	0.000	no
Italy	-11.396	0.000	-11.422	0.000	no
Poland	-7.670	0.000	-16.253	0.000	no
Price of Gasoil in					
Belgium	-17.000	0.000	-17.006	0.000	no
Germany	-16.450	0.000	-16.450	0.000	no
France	-14.180	0.000	-14.145	0.000	no
Greece	-18.003	0.000	-18.238	0.000	no
Italy	-14.043	0.000	-14.226	0.000	no
Poland	-17.428	0.000	-17.435	0.000	no
EU-wide variables					
CO_2	-18.977	0.000	-19.227	0.000	no
Crude Oil	-10.927	0.000	-18.264	0.000	no
Stock XX	-15.238	0.000	-15.254	0.000	no
€/$ Exchange	-19.189	0.000	-19.203	0.000	no

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend). The cut-off value for significance is set at 5%.

From the table, we see that both tests indicate all variables in levels are I(1), while those in first differences are I(0). This points to the appropriateness of testing for cointegration in the error correction term of the ARDL (see hereafter).

B.4. Variables in models for Petrol

ETS all phases

Table 45 Unit root tests of variables in models that explain Petrol, full sample

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
In levels					
Petrol Price in					
Belgium	-1.702	0.428	-1.808	0.375	Yes
Germany	-2.026	0.275	-2.065	0.259	Yes
France	-1.793	0.383	-1.584	0.488	Yes
Greece	-2.140	0.230	-1.812	0.374	Yes
Italy	-2.026	0.276	-1.775	0.392	Yes
Poland	-2.702	0.077	-2.089	0.250	Yes
EU-wide variables					
CO_2	1.022	0.997	1.426	0.999	Yes
Crude Oil	-2.160	0.222	-2.177	0.216	Yes
€/$ Exchange	-3.458	0.011	-3.141	0.026	No
In first differences					
Petrol price in					
Belgium	-10.207	0.000	-10.136	0.000	No
Germany	-8.509	0.000	-8.363	0.000	No
France	-8.021	0.000	-7.515	0.000	No
Greece	-7.755	0.000	-7.184	0.000	No
Italy	-7.146	0.000	-6.394	0.000	No
Poland	-6.357	0.000	-6.378	0.000	No
Energy price index for					
Belgium	-9.107	0.000	-9.080	0.000	No
Germany	-9.323	0.000	-9.458	0.000	No
France	-9.421	0.000	-9.441	0.000	No
Greece	-9.013	0.000	-8.993	0.000	No
Italy	-9.101	0.000	-9.056	0.000	No
Poland	-9.065	0.000	-9.177	0.000	No
EU-wide variables					
CO_2	-5.594	0.000	-5.901	0.000	No
Crude oil	-12.395	0.000	-12.397	0.000	No
Wages in					
Belgium	-4.198	0.001	-9.168	0.000	No
Germany	-11.374	0.000	-11.395	0.000	No
France	-2.280	0.180	-2.407	0.142	Yes
Greece	-3.512	0.009	-11.138	0.000	No
Italy	-6.567	0.000	-11.907	0.000	No
Poland	-9.646	0.000	-17.245	0.000	No
Volume in					
Germany	-7.801	0.000	-29.680	0.000	No
France	-12.029	0.000	-36.153	0.000	No
Greece	-11.724	0.000	-35.991	0.000	No
Italy	-5.445	0.000	-29.073	0.000	no

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend). The cut-off values for significance are 5%.

From the table, we see that both tests indicate all variables in levels are I(1), while those in first differences are I(0). This points to the appropriateness of testing for cointegration in the error correction term of the ARDL (see hereafter).

ETS Phase 2 and 3

Table 46 Unit root tests of the variables in models that explain Petrol, limited to 2008-2015

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
In levels					
Petrol price in					
Belgium	-1.942	0.311	-1.480	0.537	yes
Germany	-1.667	0.443	-1.457	0.549	yes
France	-1.701	0.426	-1.358	0.597	yes
Greece	-1.958	0.305	-1.520	0.517	yes
Italy	-1.984	0.293	-1.479	0.538	yes
Poland	-2.130	0.234	-1.719	0.417	yes
EU wide variables					
CO_2	-1.355	0.600	-1.303	0.625	yes
Crude oil	-2.299	0.175	-1.915	0.324	yes
€/$ Exchange	-2.051	0.265	-2.008	0.283	yes
In first differences					
Petrol price in					
Belgium	-6.311	0.000	-6.394	0.000	No
Germany	-5.586	0.000	-5.614	0.000	No
France	-4.644	0.000	-4.605	0.000	No
Greece	-4.504	0.001	-4.383	0.001	No
Italy	-4.201	0.001	-4.266	0.001	No
Poland	-4.528	0.001	-4.528	0.001	No
Energy price index for					
Belgium	-5.684	0.000	-5.763	0.000	No
Germany	-5.745	0.000	-5.811	0.000	No
France	-5.357	0.000	-5.470	0.000	No
Greece	-5.762	0.000	-5.844	0.000	No
Italy	-5.764	0.000	-5.449	0.000	No
Poland	-4.949	0.000	-5.020	0.000	No
EU-wide variables					
CO_2	-6.522	0.000	-6.500	0.000	No
Crude oil	-7.586	0.000	-7.748	0.000	No
Wages in					
Belgium	-10.378	0.000	-10.267	0.000	No
Germany	-8.756	0.000	-8.954	0.000	No
France	-3.142	0.028	-12.596	0.000	No
Greece	-1.637	0.458	-1.696	0.428	No
Italy	-3.012	0.038	-11.705	0.000	No
Poland	-9.347	0.000	-11.031	0.000	No
Volume in					
Germany	-13.283	0.000	-26.686	0.000	No
France	-8.807	0.000	-34.771	0.000	No
Greece	-14.299	0.000	-16.288	0.000	No
Italy	-3.564	0.009	-18.177	0.000	No

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend). The cut-off values for significance are 5%.

From the table, we see that both tests indicate all variables in levels are I(1), while those in first differences are I(0). This points to the appropriateness of testing for cointegration in the error correction term of the ARDL (see hereafter).

B.5. Results for models spanning all ETS phases

B.5.1. Diesel

The tables below displays the results for models that explain the price of diesel. The first table treats models that cover the time span form 2005 to 2013, and that use a combined CO_2 price for Phase 1, 2 and 3. These models show a cointegration relationship between crude oil and Diesel. The CO_2 price is negative or insignificant, indicating no cost pass-through of the combined price of CO_2 over Phase 1, 2 and 3.

Table 47 Results Diesel, ETS all phases

Country	Belgium	Germany *	France	Greece	Italy	Poland *
CO_2_delay	1		3	0	0	
Crude oil_delay	0		0	0	0	
Maxlags	4		2	3	6	
CO_2_coef	0.000		0.000	0.002	0.003	
CO_2_t_stat	0.024		0.066	0.264	0.449	
CO_2_pval	0.490		0.474	0.396	0.327	
Crude oil_coef	**0.825**		**0.828**	**0.780**	**0.756**	
CRUDE OIL_t_stat	17.612		27.526	21.512	18.539	
CRUDE OIL_pval	0.000		0.000	0.000	0.000	
adj. coef	**-0.132**		**-0.104**	**-0.064**	**-0.062**	
t_adj. coef	-4.773		-6.192	-5.111	-3.863	
p_adj. coef	0.000		0.000	0.000	0.000	
SIC	-5.548		-6.926	-7.541	-7.417	
Bounds F-statistic	**8.084**		**13.800**	**9.452**	**5.855**	

* All models exhibit negative cpt of CO_2.
Figures in bold indicate statistical significance of at least 10%.

B.5.2. Petrol

The tables below present the results of models in which the price of petrol is explained. For Phase 1, 2 and 3 (the table below), the ARDL model performed not as good as for Phase 2 and 3 separate. Over the time span of all three phases, only for half of the countries, the models produce acceptable results. These countries are France, Greece and Italy. For France significant cost pass-through of CO_2 is found, for Greece and Italy, the NULL hypothesis of no cost pass-through can not be rejected.

Table 48 Results Petrol, ETS all phases

Country	Belgium*	Germany*	France	Greece	Italy	Poland*
CRUDE OIL_delay	0	2	0	0	0	0
CO_2_delay	3	1	0	1	1	3
Maxlags	2	1	2	8	2	8
CRUDE OIL_coef	**0.762**	**1.387**	**0.801**	**0.691**	**0.683**	**0.739**
CRUDE OIL_t_stat	20.091	1.886	29.044	74.810	25.849	19.348
CRUDE OIL_pval	0.000	0.031	0.000	0.000	0.000	0.000
CO_2_coef	0.006	0.011	**0.016**	0.003	0.002	**0.027**
CO_2_t_stat	0.493	0.133	1.730	0.634	0.333	1.302
CO_2_pval	0.312	0.447	0.043	0.264	0.370	0.099
adj. coef	**-0.516**	**0.081**	**-0.442**	**-1.489**	**-0.431**	**-0.565**
t_adj. coef	-5.508	0.868	-5.503	-7.113	-4.775	-5.306
p_adj. coef	0.000	0.194	0.000	0.000	0.000	0.000
SIC	-4.582	-3.781	-4.913	-4.923	-5.446	-4.445
Bounds F-statistic	**10.696**	1.075	**9.809**	**17.739**	**7.538**	**11.497**

* Only few models satisfy the criteria on residual behaviour.
Figures in bold indicate statistical significance of at least 10%.

B.5.3. Gasoil

The results for models with weekly data for gasoil are presented in the table below. The first table treats results using the full sample of data over the timespan covered by ETS Phase 1, 2 and 3. The models for Greece and Poland performed poorly, while the models for Belgium, Germany, France and Italy had satisfactory residuals. Using a combined price series for Phase 1, 2 and 3, no cost pass-through of CO_2 was found for these countries.

Table 49 Results gasoil, ETS all phases

Country	Belgium	Germany	France	Greece *	Italy	Poland **
CO_2_delay	0	0	0		0	0
CRUDE OIL_delay	0	0	0		0	0
Maxlags	1	3	1		1	1
CO_2_coef	0.000	0.008	0.001		0.001	0.000
CO_2_t_stat	0.099	1.128	0.320		0.181	0.045
CO_2_pval	0.461	0.130	0.374		0.428	0.482
CRUDE OIL_coef	**0.863**	**0.837**	**0.836**		**0.797**	**0.911**
CRUDE OIL_t_stat	41.945	21.131	32.752		37.811	29.536
CRUDE OIL_pval	0.000	0.000	0.000		0.000	0.000
adj. coef	**-0.233**	**-0.111**	**-0.129**		**-0.128**	**-0.152**
t_adj. coef	-11.248	-5.163	-9.232		-10.141	-8.038
p_adj. coef	0.000	0.000	0.000		0.000	0.000
SIC	-6.037	-6.282	-6.827		-7.244	-6.105
Bounds F-statistic	**43.346**	**9.906**	**30.678**		**37.089**	**22.884**

* All models exhibit negative cpt of CO_2.
** Only few models have well behaved residuals and positive cpt of CO_2.
Figures in bold indicate statistical significance of at least 10%.

Annex C. Additional details iron and steel sector

C.1. Unit root tests

Table 50 reports two different unit root tests, notably the ADF-test (with a constant, without trend) and the DF-test (with constant, without trend). We have also ran a third test, the KPSS-test (not reported, results available on request).

Tests are applied for the time span under investigation, i.e. 08/2008 – 12/2014.

Table 50 Unit root tests of the variables in models that explain steel prices, sample limited to 08/2008-12/2014

Variable	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root?	Final result using KPSS
HOTROLL_ALT_SE	-3.95	0.003	-3.00	0.040	No	
HOTROLL_ALT_SE_FD	-5.45	0	-5.12	0	No	
COLDROLL_IMP_SE	-4.06	0.002	-2.87	0.053	No	
COLDROLL_IMP_SE_FD	-4.56	0	-4.25	0.001	No	
HOTROLL_ALT_NWE	-3.84	0.004	-2.88	0.052	No	
HOTROLL_ALT_NWE_FD	-5.45	0	-5.16	0	No	
COLDROLL_IMP_NWE	-4.00	0.002	-2.83	0.059	No	
COLDROLL_IMP_NWE_FD	-4.15	0.002	-4.15	0.002	No	
ORE_CN	-2.17	0.219	-2.09	0.248	Yes	
ORE_CN_FD	-6.85	0	-6.81	0	No	
ORE_BR	-1.64	0.455	-1.64	0.455	Yes	
ORE_BR_FD	-7.89	0	-7.86	0	No	
ORE_SCRAP	-1.57	0.494	-1.72	0.415	Yes	
ORE_SCRAP_FD	-8.43	0	-8.43	0	No	
COKE_CN	-0.83	0.804	-0.86	0.796	Yes	
COKE_CN_FD	-7.95	0	-7.93	0	No	
COKE_EE	-1.77	0.392	-1.75	0.401	Yes	
COKE_EE_FD	-7.01	0	-7.17	0	No	
SCRAP	-2.62	0.094	-2.84	0.057	Yes/No	Yes
SCRAP_FD	-5.87	0	-7.48	0	No	
PIG_IRON	-3.72	0.006	-3.12	0.029	No	
PIG_IRON_FD	-4.47	0.001	-4.31	0.001	No	
ENERGY_SE	-2.35	0.159	-7.06	0	Yes/No	Yes
ENERGY_SE_FD	-11.91	0.000	-19.38	0	No	
ENERGY_NWE	-2.43	0.137	-4.42	0	Yes/No	Yes
ENERGY_NWE_FD	-4.79	0	-19.84	0	No	
XRATE	-4.00	0.002	-3.64	0.007	No	
XRATE_FD	-6.50	0	-6.50	0	No	
INTEREST	1.81	1.000	1.63	1.000	Yes	
INTEREST_FD	-6.54	0	-6.50	0	No	
STOXX	-2.51	0.117	-2.41	0.144	Yes	
STOXX_FD	-6.98	0	-7.01	0	No	
PROD_SE	-3.60	0.008	-4.81	0	No	
PROD_SE_FD	-3.16	0.027	-13.36	0	No	
PROD_NWE	-3.31	0.018	-3.30	0.018	No	
PROD_NWE_FD	-10.19	0	-10.43	0	No	
WAGE_SE	-1.93	0.316	-0.68	0.843	Yes	
WAGE_SE_FD	-1.58	0.487	-1.63	0.462	Yes	
WAGE_NWE	-2.03	0.275	-1.19	0.672	Yes	
WAGE_NWE_FD	-1.14	0.695	-1.15	0.690	Yes	
CO_2_SPOT_P2	-1.93	0.317	-1.91	0.325	Yes	

Variable	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root?	Final result using KPSS
CO_2_SPOT_P2_FD	-6.43	0	-6.36	0	No	

Note: FD denotes first difference of variable in question.

C.2. Detailed estimation results

Table 51 Results Iron and Steel products

	Flat steel, hot rolled coil	Flat steel, cold rolled coil	Flat steel, hot rolled coil	Flat steel, cold rolled coil
	Northern Europe	Northern Europe	Southern Europe	Southern Europe
Scrap coeff	0.58	0.31	0.58	0.44
Scrap t-Stat	15.40	4.92	15.56	5.00
Scrap p-value	0.00	0.00	0.00	0.00
Scrap delay	0	0	1	0
Coke (CN) coeff	0.17	0.03	0.09	0.11
Coke (CN) t-Stat	4.83	0.95	2.68	3.60
Coke (CN) p-value	0.00	0.17	0.01	0.00
Coke (CN) delay	1	1	1	1
Ore coeff		0.16		0.04
Ore t-Stat		3.87		0.66
Ore p-value		0.00		0.26
Ore delay		1		1
CO2 spot coeff	0.04	0.05	0.08	0.03
CO2 spot t-Stat	2.04	2.66	4.11	1.56
CO2 spot p-value	0.02	0.01	0.00	0.06
CO2 spot delay	3	2	3	1
Adj. coeff.	-0.84	-0.51	-0.87	-0.53
Adj. coeff. t-Stat	-10.41	-6.98	-10.21	-6.99
Adj. coeff. p-value	0.00	0.00	0.00	0.00
AIC	-3.60	-4.81	-3.49	-4.41
SIC	-2.96	-4.08	-2.89	-3.75
Bounds test (F-Stat)	signif. at all levels	signif. at all levels	signif. at all levels	signif. at all levels

Note: One sided p-values reported.

C.3. Production cost information

Table 52 reports the information used to calculate CO_2 cost shares.

Table 52 Basic Oxygen Furnace Route Steelmaking Costs March 2015

Item $/unit	Factor	Unit	Unit cost	Fixed	Variable	Total
Iron ore	1.560	t	86		134.16	134.16
Iron ore transport	1.560	t	6.50		10.14	10.14
Coking coal	0.898	t	103		92.49	92.49
Coking coal transport	0.898	t	7.50		6.74	6.74
Steel scrap	0.150	t	260		39.00	39.00
Scrap delivery	0.150	t	5		0.75	0.75
Industrial gases	261	m^3	0.086		22.45	22.45
Ferroalloys	0.014	t	900		12.60	12.60
Fluxes	0.536	t	40		21.44	21.44
Refractories	0.011	t	700		7.85	7.85

Item $/unit	Factor	Unit	Unit cost	Fixed	Variable	Total
Other costs	1		19.50	4.88	14.63	19.50
By-product credits					-14.73	-14.73
Thermal energy, net	-7.80	GJ	9.35		-72.93	-72.93
Electricity	0.177	MWh	127	3.37	19.11	22.48
Labour	0.523	Man hr	30.5	3.99	11.96	15.95
Capital charges				52.87		52.87
Total				**65.1**	**305.6**	370.7

Source: www.steelonthenet.com/cost-bof.html.

Annex D. Additional details fertilisers

D.1. Unit root tests

Table 53 report two different unit root tests, notably the ADF-test (with a constant, without trend) and the DF-test (with constant, without trend). We have also ran a third test, the KPSS-test (not reported, results available on request).

Tests are applied for the time span under investigation for the product at hand.

Table 53 Unit root tests of the variables in model for non opt-in countries (Jan 2013-Feb 2015)

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root?
AMM_NWE	-1.95	0.31	-2.15	0.22	Yes
AMM_NWE_FD	-8.34	0.00	-8.73	0.00	
AN_FR	-0.67	0.85	-0.95	0.77	Yes
AN_FR_FD	-8.90	0.00	-8.90	0.00	
CAN_DE	-0.88	0.79	-0.88	0.79	Yes
CAN_DE_FD	-8.54	0.00	-8.54	0.00	
CO_2_SPOT_P2	-2.50	0.12	-2.06	0.26	Yes
CO_2_SPOT_P2_FD	-8.03	0.00	-8.20	0.00	
DE_ELEC_Y_1	-2.30	0.17	-2.37	0.15	Yes
DE_ELEC_Y_1_FD	-7.47	0.00	-7.06	0.00	
FR_ELEC_Y_1	-2.61	0.09	-2.37	0.15	Yes
FR_ELEC_Y_1_FD	-8.45	0.00	-8.34	0.00	
FUEL_OIL	-0.71	0.84	0.08	0.96	Yes
FUEL_OIL_FD	-4.48	0.00	-7.16	0.00	
GAS_SPOT	-1.25	0.65	-1.25	0.65	Yes
GAS_SPOT_FD	-8.62	0.00	-8.52	0.00	
STOXX	-1.01	0.75	-0.71	0.84	Yes
STOXX_FD	-8.36	0.00	-8.11	0.00	
UAN_FR	-1.07	0.72	-1.01	0.75	Yes
UAN_FR_FD	-8.20	0.00	-8.20	0.00	
UREA_GRAN_NWE	-1.21	0.67	-1.26	0.65	Yes
UREA_GRAN_NWE_FD	-7.75	0.00	-7.72	0.00	
UREA_NWE	-1.18	0.68	-1.28	0.64	Yes
UREA_NWE_FD	-6.47	0.00	-6.55	0.00	
WAGE_DE	-0.86	0.80	-0.86	0.80	Yes
WAGE_DE_FD	-10.25	0.00	-10.26	0.00	
WAGE_FR	-0.85	0.80	-0.85	0.80	Yes
WAGE_FR_FD	-10.25	0.00	-10.25	0.00	
XRATE	1.23	1.00	2.00	1.00	Yes
XRATE_FD	-7.82	0.00	-7.73	0.00	

Notes: FD denotes first difference, ELEC_Y_1 denotes year-ahead electricity price.

Table 54 Unit root tests of variables in model for AN UK (Jan 2011-Feb 2015)

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root
AN_UK	-1.54	0.51	-2.27	0.18	Yes
AN_UK_FD	-15.41	0.00	-15.60	0.00	
CO2_SPOT_P2	-1.66	0.45	-1.79	0.38	Yes
CO2_SPOT_P2_FD	-9.11	0.00	-9.96	0.00	
GAS_SPOT	-1.25	0.65	-1.25	0.65	Yes
GAS_SPOT_FD	-8.62	0.00	-8.52	0.00	
FUEL_OIL	-2.37	0.15	-2.54	0.11	Yes
FUEL_OIL_FD	-10.76	0.00	-18.32	0.00	
STOXX	-1.96	0.30	-2.02	0.28	Yes
STOXX_FD	-22.88	0.00	-22.86	0.00	
WAGE_UK	-2.03	0.28	-1.58	0.49	Yes
WAGE_UK_FD	-4.17	0.00	-29.99	0.00	
XRATE	-2.97	0.04	-2.88	0.05	No
XRATE_FD	-20.57	0.00	-20.57	0.00	
UK_ELEC_Y_1	-1.72	0.42	-1.80	0.38	Yes
UK_ELEC_Y_1_FD	-17.87	0.00	-18.61	0.00	

Table 55 Unit root tests of variables in model for PPI NL (Sept 2009-Dec 2014)

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root
UREA_NL_PPI	-2.68	0.08	-2.62	0.09	Yes
UREA_NL_PPI_FD	-5.63	0.00	-5.34	0.00	
CO_2_SPOT_P2	-1.33	0.61	-1.20	0.67	Yes
CO_2_SPOT_P2_FD	-5.92	0.00	-5.85	0.00	
ENERGY_U_NL	-1.69	0.43	-1.71	0.42	Yes
ENERGY_U_NL_FD	-4.18	0.00	-4.18	0.00	
GAS_SPOT	-3.49	0.01	-3.64	0.01	No
GAS_SPOT_FD	-7.50	0.00	-7.50	0.00	
STOXX	-1.39	0.58	-1.46	0.55	Yes
STOXX_FD	-7.43	0.00	-7.43	0.00	
WAGE_NL	-1.11	0.71	-0.67	0.85	Yes
WAGE_NL_FD	-2.86	0.06	-2.82	0.06	
XRATE	-2.47	0.13	-2.12	0.24	Yes
XRATE_FD	-6.07	0.00	-6.07	0.00	

Notes: ENERGY_U denotes energy price index for urea.

D.2. Detailed estimation results

Table 56 Detailed results for VAR in first differences

Regression	Ammonia NWE		AN France	
	Coefficient	T-Stat	Coefficient	T-Stat
AR(1)	0.19	1.99	0.1	0.92
AR(2)	-	-	0.01	0.08
Gas spot(1)	0.05	0.62	0.01	0.16
Gas spot(2)	-	-	-0.02	-0.23
CO_2 spot(1)	-0.03	-0.73	-0.03	-0.58
CO_2 spot(2)	-	-	0.03	0.7
Controls	Energy, wage, xrate, stock market index		Energy, wage, xrate, stock market index	
R2adj	0.13		-0.04	

Table 57 Detailed results for ARDL in first differences

	Ammonium nitrate UK*	Calcium ammonium nitrate Germany	Urea ammonium nitrate France	Urea granular NWE	Urea prilled bulk NWE
Gas coeff	0.11	0.26	0.14	0.15	0.16
Gas T-Stat	1.59	3.87	1.63	1.92	2.04
Gas p-value	0.06	0.00	0.05	0.03	0.03
Gas delay	4	7	0	1	0
CO_2 coeff	0.12	0.13	0.24	0.10	0.09
CO_2 T-Stat	3.68	3.32	4.28	2.38	2.18
CO_2 p-value	0.00	0.00	0.00	0.01	0.02
CO_2 delay	6	11	8	8	8
Adj coeff.	-0.89	-0.93	-0.89	-0.78	-0.61
Adj. Coeff. T-Stat	-5.95	-9.86	-9.27	-8.41	-7.28
Adj. Coeff. p-value	0.00	0.00	0.00	0.00	0.00
SIC	-5.05	-4.23	-4.02	-4.33	-4.99
Bounds test (F-Stat)					

* In the regression for AN UK, only results were used where the coefficient of gas was greater than 0; this was always the case in the other regressions.

Table 58 Detailed results for ARDL in levels

	Urea PPI NL
Gas coeff	0.27
Gas T-Stat	7.63
Gas p-value	0.00
Gas delay	1
CO_2 coeff	0.04
CO_2 T-Stat	0.80
CO_2 p-value	0.21
CO_2 delay	2
Wage coeff	0.15
Wage T-Stat	0.96
Wage p-value	0.17
Wage delay	0
Adj coeff.	-0.36
Adj. Coeff. T-Stat	-5.76
Adj. Coeff. p-value	0.00
SIC	-4.66
Bounds test (F-Stat)	6.80

Annex E. Additional details cement

E.1. Data sources

The following data have been used and collected for the cement sector.

Table 59 Overview of data used in the cement sector

Variable	Source
Total cement price	Eurostat structural business statistics, own calculations
Portland cement	Comext trade data, own calculations
Cement clinker	Comext trade data, own calculations
CO_2 price	Carbix, BNS (Phase 1) & SendeCO_2 (Phase 2 & 3)
Energy price index	ICIS
Euro$ Exchange rate	Eurostat
Wages	Eurostat
Volume	Eurostat

E.2. Unit root tests

The table below reports unit root tests for these variables. A unit root test is a test on whether a variable has a (stochastic) trend. If variables in a model do have a trend, then one should test for cointegration between these variables. If cointegration is not present, estimating a model with these variables will lead to spurious results. If, on the other hand, cointegration is present, then the estimation results are more reliable when compared to an estimation with variables without a unit root.

Table 60 reports two different unit root tests, notably the ADF-test (with a constant, without trend) and the DF-test (with constant, without trend). We have also ran a third test, the KPSS-test (not reported, results available on request).

Table 60 Unit root tests of the variables in models that explain cement prices, full sample

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
In levels					
Total cement price in					
Germany	0.107	0.965	-0.446	0.897	Yes
France	-1.455	0.554	-2.710	0.075	Yes
Italy	-2.250	0.190	-2.208	0.204	Yes
United Kingdom	-0.966	0.765	-0.904	0.785	Yes
Portland cement price in					
Poland	-2.651	0.086	-2.261	0.186	Yes
Czech Republic	-2.353	0.157	-3.118	0.027	Yes*
Cement clinker price in					
Germany	-1.806	0.376	-7.712	0.000	Yes*
France	-2.509	0.115	-10.335	0.000	Yes*
Italy	-2.514	0.114	-3.416	0.012	Yes*
United Kingdom	-5.200	0.000	-8.574	0.000	No
Poland	-2.638	0.088	-3.944	0.002	Yes*
Czech Republic	-5.794	0.000	-8.097	0.000	No
CO_2					
CO_2 Ph 1,2&3	2.080	1.000	1.818	1.000	Yes
CO_2 ph 2&3	-1.400	0.581	-1.575	0.493	Yes
Energy price in					
Germany	-1.807	0.376	-1.888	0.337	Yes

Variable	Adf t-value	Adf P-value	PP t-value	PP P-value	Unit root?
France	-1.758	0.400	-1.848	0.356	Yes
Italy	-2.466	0.126	-1.817	0.371	Yes
United Kingdom	-1.760	0.399	-1.691	0.434	Yes
Poland	-1.865	0.348	-1.864	0.348	Yes
Czech Republic	-1.709	0.424	-1.796	0.381	Yes
In first differences					
Total cement price in					
Germany	-9.421	0.000	-9.992	0.000	No
France	-1.356	0.602	-14.879	0.000	Yes*
Italy	-10.154	0.000	-10.153	0.000	No
United Kingdom	-9.270	0.000	-9.082	0.000	No
Portland cement price in					
Poland	-10.628	0.000	-16.935	0.000	No
Czech Republic	-12.583	0.000	-29.881	0.000	No
Cement clinker price in					
Germany	-12.502	0.000	-46.322	0.000	No
France	-9.228	0.000	-56.182	0.000	No
Italy	-12.636	0.000	-31.749	0.000	No
United Kingdom	-12.270	0.000	-36.469	0.000	No
Poland	-11.684	0.000	-28.015	0.000	No
Czech Republic	-12.972	0.000	-23.745	0.000	No
CO_2					
CO_2 Ph 1,2&3	-5.393	0.000	-5.516	0.000	No
CO_2 ph 2&3	-8.976	0.000	-8.943	0.000	No
Energy price in					
Germany	-9.160	0.000	-8.892	0.000	No
France	-9.132	0.000	-8.876	0.000	No
Italy	-9.026	0.000	-8.743	0.000	No
United Kingdom	-8.760	0.000	-8.385	0.000	No
Poland	-9.497	0.000	-9.287	0.000	No
Czech Republic	-9.236	0.000	-8.973	0.000	No
Interest rate in					
Germany	-8.296	0.000	-8.342	0.000	No
France	-8.121	0.000	-7.998	0.000	No
Italy	-9.266	0.000	-9.202	0.000	No
United Kingdom	-8.047	0.000	-7.988	0.000	No
Poland	-8.696	0.000	-8.749	0.000	No
Czech Republic	-7.669	0.000	-7.568	0.000	No
Wages in					
Germany	-11.495	0.000	-11.496	0.000	No
France	-7.739	0.000	-12.359	0.000	No
Italy	-4.493	0.000	-7.145	0.000	No
United Kingdom	-4.121	0.001	-4.080	0.001	No
Poland	-2.932	0.044	-3.768	0.004	No
Czech Republic	-6.511	0.000	-7.680	0.000	No
Production volume in					
Germany	-14.740	0.000	-19.984	0.000	No
France	-3.520	0.009	-31.496	0.000	No
Italy	-4.269	0.001	-31.179	0.000	No
EU-wide variables					
Stock XX	-9.479	0.000	-9.528	0.000	No
€/$ Exchange	-9.079	0.000	-9.006	0.000	No

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend). Cut-off value for significance at 5%.

* ADF and PP-tests are contradictory at 5% level. KPSS tests rejects NULL of stationarity.

E.3. VECM results

The following tables summarise the results of VECM estimations that explain the price of Cement.

ETS all phases

Table 61 Summary of VECM results of models that explain the price of Cement in various countries, for the time period associated with ETS phase 1, 2 and 3

Country	Product	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Germany	Cement total	No			ARDL
France	Cement total	No			ARDL
Italy	Cement total	No			ARDL
UK	Cement total	Yes	No		ARDL
Poland	Cement total	Yes	No		ARDL
Czech	Cement total	Yes	No		ARDL
Germany	Cement Clinker	yes	To energy prices	No	VAR in fd's
France	Cement Clinker	Yes	No		ARDL
Italy	Cement Clinker	Yes	No		ARDL
UK	Cement Clinker	Yes	No		ARDL
Poland	Cement Clinker	Yes	To energy prices	No	VAR in fd's
Czech	Cement Clinker	Yes	No		ARDL

ETS Phase 2 and 3

Table 62 Summary of VECM results of models that explain the price of Cement in various countries, for the time period associated with ETS phase 2 and 3

Country	Product	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Germany	Cement Total	Yes	Yes/No	Yes/No	ARDL*
France	Cement total	Yes	No		ARDL
Italy	Cement total	Yes	No		ARDL
UK	Cement total	Yes	No		ARDL
Poland	Cement total	Yes	No		ARDL
Czech	Cement total	Yes	No		ARDL
Germany	Cement Clinker	Yes	No		ARDL
France	Cement Clinker	Yes	No/Yes		ARDL*
Italy	Cement Clinker	Yes	No/Yes		ARDL*
UK	Cement Clinker	Yes	To CO_2 Ph2/3	No	VAR in fd's
Poland	Cement Clinker	Yes	No		ARDL

Country	Product	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Czech	Cement Clinker	Yes	Yes/No		ARDL*

* The results are instable to the amount of lagged first differences included in the model.

E.4. Results of estimations over the entire sample (2005-2014)

E.4.1. Total cement

Below, we develop our results for models that explain the price of total cement using a combined series for the CO_2 price in Phase 1 and in Phase 2 and Phase 3 and an energy price index. These models typically have the best behaved residuals when the energy price enters with a delay of three months (see table below).
The energy price makes up about 20% of total cement costs in Germany, France and Italy. For the UK, the percentage is considerably higher. Significant cost pass-through of the CO_2 price into the product price is found for total cement in Germany and France. For Germany and Italy, cointegration is significant. However, the 0-hypothsis of no cost pass-through could not be rejected for the latter country. For the UK, the bounds test detected no cointegration. For France, the evidence on cointegration is inconclusive.

Table 63 Estimations results, total cement (PPI), 2005-2014

Country	Germany	France	Italy	UK
PE_delay	3	3	3	3
CO_2_delay	0	0	0	0
PE_coef	**0.186677**	**0.239753**	**0.219949**	**0.343718**
PE_t_stat	1.318554	3.353567	4.98698	1.693064
PE_pval	0.09505	0.00055	0	0.04665
CO_2_coef	**0.021617**	**0.016563**	0.000003	0.022434
CO_2_t_stat	1.323135	1.344428	0.000484	0.942238
CO_2_pval	0.0943	0.0909	0.4998	0.1741
adj. coef	**-0.03153**	**-0.07584**	**-0.10702**	**-0.03028**
t_adj. coef	-2.77255	-2.63522	-3.49389	-2.33259
p_adj. coef	0.0033	0.00485	0.00035	0.01075
SIC	-8.55028	-7.60632	-7.80439	-7.6957
Bounds F-statistic	**5.392925**	3.302252**	**5.122481**	3.162955

** This value lies between the I0 and I1 bound for the 10% significance level.
Figures in bold indicate statistical significance of at least 10%.

For Germany and France, cost pass-through of CO_2 into the price of total cement is found but the cost shares are very low indicating a cost pass-through of 20-30% when the whole sample is investigated.

E.4.2. Portland cement

Below, we develop our results for models that explain the price of Portland cement using a combined series for the CO_2 price in Phase 1 and in Phase 2 and 3 and an energy price index (see table below). These models typically have the best behaved residuals when the energy price enters with a delay of three months. For Poland, no models satisfy our criteria of positive cost pass-through rates.
For Czech Republic, cointegration is significant. However, the 0-hypothsis of no cost pass-through for CO_2 costs could not be rejected.

Table 64 Estimations results, Portland cement (Tier 3 data), 2008-2014

Country	Poland*	Czech
PE_delay		3
CO_2_delay		0
PE_coef		**0.4912**
PE_t_stat		4.803218
PE_pval		0
CO_2_coef		-0.00197
CO_2_t_stat		-0.12788
CO_2_pval		*
adj. coef		**-0.32811**
t_adj. coef		-5.44256
p_adj. coef		0
SIC		-3.8164
Bounds F-statistic		**7.185823**

* All selected models generated negative coefficients; no p-value reported.

E.4.3. Cement clinker

Below, we display our results for models that explain the price of Cement Clinker, using the combined CO_2 price for Phase 1 and 2 and 3 and an energy price index. The delays by which energy and CO_2 enter to generate the best residuals differ depending on country (see table below). Energy typically makes op around 70-90% of total costs, except in Poland where it accounts for around 40%. Significant cost pass-through of the CO_2 price is found in France[80], with the NULL of no cointegration rejected by the bounds-test. For Germany and Poland, the Bounds test can not reject the NULL of no cointegration by any standards. The model for Italy has no specifications that satisfy our criteria for no significant autocorrelation in the residuals. In the UK and Czech, cointegration is found, but cost pass-through of CO_2 is insignificant.

Table 65 Estimations results, cement clinker (Tier 3), 2005-2014

Country	Germany	France	Italy	UK	Poland	Czech
PE_delay	**	1	*	0	**	1
CO_2_delay		0		1		2
PE_coef		**0.717164**		**0.860379**		**0.900015**
PE_t_stat		5.861217		3.194369		2.307637
PE_pval		0		0.0009		0.0115
CO_2_coef		**0.039842**		0.012917		0.02918
CO_2_t_stat		2.367504		0.404965		0.452922
CO_2_pval		0.00985		0.34315		0.3258
adj. coef		**-1.03429**		**-0.66264**		**-0.70322**
t_adj. coef		-10.8796		-7.2503		-7.72835
p_adj. coef		0		0		0
SIC		-1.30568		-0.94302		0.206849
Bounds F-statistic		**37.68868**		**16.55042**		**19.32412**

* For Italy, no models satisfy the criteria on the behaviour of the residuals.
** The VECM results point to estimating the equation in a VAR in first differences, which did not yield any models that satisfy the criterion of positive cost pass-through.
Figures in bold indicate statistical significance of at least 10%.

80 A limitation of this model is the rather large value of the adjustment coefficient.

Annex F. Additional details petrochemicals

F.1. Data sources

In the petrochemical sector we have used weekly and monthly output prices.
Weekly prices come from ICIS and reflect prices of:

A. Mono Ethylene Glycol, Europe Spot Cost, Insurance and Freight Amsterdam, Rotterdam and Antwerp with the origin inside the EU (Euros per Metric Tonne).
B. Ethylene, Free Delivered North West Europe, Contract, Month Euros Per Metric Tonne.

Both are weekly prices. All ICIS-published spot assessments in the weekly ethylene glycol reports are so-called 'week's range' assessments. That is, they are intended to represent the tradable value throughout the week leading up to the date of the report.

For Butadiene, Propylene and Methanol, we have collected data but these have finally not been included in this report since the pretesting of these variables have been showing substantial problems with our models in terms of higher order autocorrelation and heteroscedasticity. Therefore we have removed them from the analysis here.

The following data have been used and collected for the petrochemicals sector.

Variable	Source
Prices of petrochemical products	Thomson Reuters datastream
Naphta	Thomson Reuters datastream
CO_2 price	Carbix, BNS (Phase 1) & SendeCO_2 (Phase 2 & 3)
Energy price index	ICIS
Euro$ Exchange rate	Eurostat
Wages	Eurostat
Volume	Eurostat

F.2. VECM results

The following tables summarise the results of VECM estimations that explain the prices of petrochemical products.

ETS all phases

Table 66 Summary of VECM results of models that explain the prices of petrochemical products, for the time period associated with ETS phase 1, 2 and 3

Product, market	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Ethylene ife, NWE	No			ARDL
Ethylene ife, MED	Yes	No		ARDL
Ethylene sfd, NWE	No			ARDL
Meg isf, NWE*	Yes	To Naphta	No	Var in fd's
Meg isf, MED*	No			ARDL
PGE SFD, NWE	No			ARDL
PGE SFD2, NWE	No			ARDL
PGE SPMA, NWE	No			ARDL
Propylene oxide sfd, NWE	No			ARDL

* The price for Meg isf is an EU price. In the NWE model, explanatory variables come from NWE countries (Germany), in the MED model, explanatory variables are for MED countries (Italy).

ETS Phase 2 and 3

Table 67 Summary of VECM results of models that explain the prices of petrochemical products, for the time period associated with ETS phase 2 and 3

Product, market	Autocorrelation-tests satisfying?	Granger-causality?	Cointegration?	Next step
Ethylene ife, NWE	No			ARDL
Ethylene ife, MED	yes	No		ARDL
Ethylene sfd, NWE	No			ARDL
Meg isf, NWE*	Yes	To Naphta	No	Var in fd's
Meg isf, MED*	No			ARDL
PGE SFD, NWE	No			ARDL
PGE SFD2, NWE	No			ARDL
PGE SPMA, NWE	No			ARDL
Propylene oxide sfd, NWE	No			ARDL

* The price for Meg isf is an EU price. In the NWE model, explanatory variables come from NWE countries (Germany), in the MED model, explanatory variables are for MED countries (Italy).

F.3. Unit root tests

We present here only the results where the sample is limited to the time period associated with ETS phase 2&3 (2008–2015) because of the scope changes between Phase 1 and 2.

Table 68 Unit root tests of the variables in models that explain petrochemicals prices, sample limited to 2008-2015[81]

Variable	Region	Adf t-value	Adf P-valuel	PP t-value	PP Pval	Unit root?
In levels						
Outputs						
Ethylene ife	NWE	-3.271	0.019	-2.405	0.143	Yes*
Ethylene ife	MED	-3.477	0.011	-2.311	0.171	Yes*
Ethylene sfd	NWE	-3.301	0.018	-2.402	0.144	Yes*
Meg isf	EU	-3.064	0.033	-2.151	0.226	No
PGE SFD	NWE	-2.332	0.165	-1.699	0.428	Yes
PGE SFD2	NWE	-1.880	0.340	-1.620	0.468	Yes
PGE SPMA	NWE	-2.114	0.240	-1.626	0.465	Yes
Propylene oxd sfd	NWE	-1.854	0.353	-2.004	0.285	Yes
Inputs						
CO_2 Ph 2&3	EU	-1.452	0.553	-1.421	0.568	Yes
Naphta	NWE	-2.541	0.110	-1.825	0.366	Yes
Naphta	MED	-2.540	0.110	-1.829	0.364	Yes
In first differences						
Outputs						
Ethylene ife	NWE	-6.862	0.000	-6.191	0.000	No
Ethylene ife	MED	-6.651	0.000	-5.806	0.000	No
Ethylene sfd	NWE	-7.016	0.000	-5.947	0.000	No
Meg isf	EU	-4.916	0.000	-4.409	0.001	No

81 Abbreviations: MEG=Mono Ethylene Glycol; PGE=Propylene glycol ether, methanol based; PGE PMA=Propylene Glycol Ether, Propylene Glycol Methyl Ether Acetate based; NWE=North-West Europe. MED=Mediterranean. CIF=costs insurance and freight.

Variable	Region	Adf t-value	Adf P-valuel	PP t-value	PP Pval	Unit root?
PGE SFD	NWE	-4.097	0.002	-4.108	0.002	No
PGE SFD2	NWE	-4.755	0.000	-4.844	0.000	No
PGE SPMA	NWE	-4.193	0.001	-4.318	0.001	No
Propylene oxd sfd	NWE	-8.633	0.000	-8.634	0.000	No
Inputs						
CO_2 Ph 1,2&3	EU	-6.554	0.000	-6.477	0.000	No
CO_2 Ph 2&3	EU	-6.617	0.000	-6.591	0.000	No
Naphta	NWE	-5.592	0.000	-4.707	0.000	No
Naphta	MED	-5.618	0.000	-4.739	0.000	No
Energymix	Germany	-4.881	0.000	-8.516	0.000	No
Energymix	Italy	-4.868	0.000	-8.496	0.000	No
Production	Germany	-7.884	0.000	-12.420	0.000	No
Production	Italy	-10.622	0.000	-12.190	0.000	No
Wages	Germany	-4.904	0.000	-4.904	0.000	No
Wages	Italy	-2.026	0.275	-2.122	0.237	Yes
Interest	Germany	-4.673	0.000	-4.561	0.000	No
Interest	Italy	-6.324	0.000	-6.316	0.000	No
Stock XX	EU	-7.342	0.000	-7.283	0.000	No
€/$ Exchange	EU	-6.514	0.000	-6.452	0.000	No

Notes: Reported values are for the Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests (both with constant and without trend).

* ADF and PP-tests are contradictory or close to significance at 5% level. KPSS tests rejects NULL of stationarity at at least 5% level.

The table reports two different unit root tests, notably the ADF-test (with a constant, without trend) and the DF-test (with constant, without trend).
We have also ran a third test, the KPSS-test (not reported, results available on request).

From the table we observe that we find evidence that prices of all petrochemical products contain a unit root, although the evidence differs in conclusiveness. The CO_2 price contains a unit root, with evidence on this quite strong. The Naphta price for NWE and MED also contains a unit root[82].

The controls do not contain a unit root (except for Italian wages in first difference), as well as other variables in first difference.

[82] The evidence on unit roots for Naphta is stronger in the time span associated with Phase 2 and 3 than over the whole sample.

Annex G. Additional details glass

G.1. Unit root tests

Table 69 and Table 70 and report two different unit root tests, notably the ADF-test (with a constant, without trend) and the DF-test (with constant, without trend). We have also ran a third test, the KPSS-test (not reported, results available on request).

Tests are applied for the two different times spans under investigation, i.e. 2005–2014 and 2008–2014.

Table 69 Unit root tests, 2005-2014

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root	Final result using KPSS
ALU_DE	-4.11	0.00	-9.46	0.00	No	
ALU_DE_FD	-9.80	0.00	-77.32	0.00		
ALU_ES	-4.63	0.00	-4.59	0.00	No	
ALU_ES_FD	-13.20	0.00	-16.81	0.00		
ALU_FR	-3.06	0.03	-10.74	0.00	No	
ALU_FR_FD	-11.75	0.00	-42.45	0.00		
ALU_IT	-1.03	0.74	-5.25	0.00	Yes/No	No
ALU_IT_FD	-11.54	0.00	-26.33	0.00		
CO_2_SPOT_1_2	2.11	1.00	1.86	1.00	Yes	
CO_2_SPOT_1_2_FD	-5.46	0.00	-5.89	0.00		
CO_2_SPOT_P2	-1.45	0.55	-1.42	0.57	Yes	
CO_2_SPOT_P2_FD	-6.62	0.00	-6.59	0.00		
ENERGY_FIB_DE	-2.95	0.04	-2.38	0.15	No	
ENERGY_FIB_DE_FD	-9.01	0.00	-9.24	0.00		
ENERGY_HOL_DE	-4.06	0.00	-3.17	0.02	No	
ENERGY_HOL_DE_FD	-8.72	0.00	-8.87	0.00		
ENERGY_HOL_ES	-3.56	0.01	-3.50	0.01	No	
ENERGY_HOL_ES_FD	-9.60	0.00	-9.60	0.00		
ENERGY_HOL_FR	-3.84	0.00	-3.25	0.02	No	
ENERGY_HOL_FR_FD	-8.85	0.00	-9.00	0.00		
ENERGY_HOL_IT	-2.12	0.24	-2.48	0.12	Yes	
ENERGY_HOL_IT_FD	-8.02	0.00	-8.10	0.00		
FIBR_DE	-2.15	0.22	-2.02	0.28	Yes	
FIBR_DE_FD	-12.63	0.00	-13.41	0.00		
HOLL_DE	-2.56	0.10	-2.20	0.21	Yes	
HOLL_DE_FD	-8.95	0.00	-9.35	0.00		
HOLL_ES	-2.05	0.26	-2.07	0.26	Yes	
HOLL_ES_FD	-10.09	0.00	-10.08	0.00		
HOLL_FR	-2.64	0.09	-2.64	0.09	Yes	
HOLL_FR_FD	-11.03	0.00	-11.03	0.00		
HOLL_IT	-2.67	0.08	-2.29	0.18	Yes	
HOLL_IT_FD	-12.29	0.00	-20.88	0.00		
SILDI_DE	-0.78	0.82	-6.14	0.00	Yes/No	No
SILDI_DE_FD	-9.89	0.00	-54.64	0.00		
SILDI_ES	-8.12	0.00	-8.47	0.00	No	
SILDI_ES_FD	-9.05	0.00	-49.96	0.00		
SILDI_FR	-3.97	0.00	-7.77	0.00	No	
SILDI_FR_FD	-12.31	0.00	-78.78	0.00		
SILDI_IT	-3.17	0.02	-5.32	0.00	No	
SILDI_IT_FD	-18.05	0.00	-29.60	0.00		

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root	Final result using KPSS
SILS_DE	-1.60	0.48	-8.89	0.00	No	
SILS_DE_FD	-9.75	0.00	-43.84	0.00		
SILS_ES	-1.62	0.47	-3.87	0.00	No	
SILS_ES_FD	-15.34	0.00	-45.63	0.00		
SILS_FR	-3.26	0.02	-6.47	0.00	No	
SILS_FR_FD	-19.22	0.00	-36.85	0.00		
SILS_IT	-10.06	0.00	-10.30	0.00	No	
SILS_IT_FD	-11.84	0.00	-27.27	0.00		
STOXX	-1.67	0.45	-1.68	0.44	Yes	
STOXX_FD	-8.65	0.00	-8.65	0.00		
WAGE_DE	-1.49	0.54	-0.91	0.78	Yes	
WAGE_DE_FD	-5.98	0.00	-9.99	0.00		
WAGE_ES	-2.01	0.28	-4.83	0.00	Yes/No	No
WAGE_ES_FD	-8.36	0.00	-11.53	0.00		
WAGE_IT	-0.84	0.80	-0.84	0.80	Yes	
WAGE_IT_FD	-8.40	0.00	-8.37	0.00		
WAGE_FR	-1.04	0.74	-1.04	0.74	Yes	
WAGE_FR_FD	-6.33	0.00	-11.42	0.00		
XRATE	-2.56	0.10	-2.50	0.12	Yes	
XRATE_FD	-8.24	0.00	-8.25	0.00		

Note: ALU = Aluminium oxide, ENERGY_FIB = Energy price index for fibre glass, ENERGY_HOL = Energy price index for hollow glass, FIBR = fibre glass, HOLL = hollow glass, SILDI = Silican dioxide, SILS = Silica sands.

Table 70 Unit root tests, 2008-2014

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root	Final result using KPSS
ALU_DE	-4.53	0.00	-8.04	0.00	No	
ALU_DE_FD	-8.14	0.00	-82.17	0.00		
ALU_ES	-3.60	0.01	-3.66	0.01	No	
ALU_ES_FD	-9.78	0.00	-11.01	0.00		
ALU_FR	-4.19	0.00	-6.57	0.00	No	
ALU_FR_FD	-9.36	0.00	-32.81	0.00		
ALU_IT	-1.34	0.61	-5.33	0.00	Yes/No	No
ALU_IT_FD	-9.66	0.00	-31.76	0.00		
CO_2_SPOT_P2	-1.45	0.55	-1.42	0.57	Yes	
CO_2_SPOT_P2_FD	-6.62	0.00	-6.59	0.00		
ENERGY_FIB_DE	-1.24	0.65	-1.73	0.41	Yes	
ENERGY_FIB_DE_FD	-7.39	0.00	-7.49	0.00		
ENERGY_HOL_DE	-1.57	0.49	-2.05	0.27	Yes	
ENERGY_HOL_DE_FD	-7.79	0.00	-7.88	0.00		
ENERGY_HOL_ES	-1.94	0.31	-2.18	0.22	Yes	
ENERGY_HOL_ES_FD	-8.28	0.00	-8.30	0.00		
ENERGY_HOL_FR	-1.59	0.48	-2.03	0.27	Yes	
ENERGY_HOL_FR_FD	-7.61	0.00	-7.71	0.00		
ENERGY_HOL_IT	-1.95	0.31	-2.37	0.15	Yes	
ENERGY_HOL_IT_FD	-7.84	0.00	-7.91	0.00		
FIBR_DE	-2.60	0.10	-2.68	0.08	Yes	
FIBR_DE_FD	-9.75	0.00	-9.74	0.00		
HOLL_DE	-3.32	0.02	-3.22	0.02	No	
HOLL_DE_FD	-8.74	0.00	-8.69	0.00		
HOLL_ES	-3.00	0.04	-3.01	0.04	No	

Currentvar	Adf t-value	Adf p-value	PP t-value	PP p-value	Unit root	Final result using KPSS
HOLL_ES_FD	-10.03	0.00	-10.44	0.00		
HOLL_FR	-2.33	0.17	-2.72	0.08	Yes	
HOLL_FR_FD	-9.74	0.00	-9.74	0.00		
HOLL_IT	-4.33	0.00	-4.26	0.00	No	
HOLL_IT_FD	-9.75	0.00	-10.99	0.00		
SILDI_DE	-2.07	0.26	-4.53	0.00	Yes/no	No
SILDI_DE_FD	-11.55	0.00	-21.42	0.00		
SILDI_ES	-6.96	0.00	-7.01	0.00	No	
SILDI_ES_FD	-15.26	0.00	-43.21	0.00		
SILDI_FR	-2.26	0.19	-5.80	0.00	Yes/no	No
SILDI_FR_FD	-10.69	0.00	-22.55	0.00		
SILDI_IT	-3.82	0.00	-5.64	0.00	No	
SILDI_IT_FD	-15.28	0.00	-37.93	0.00		
SILS_DE	-4.01	0.00	-6.88	0.00	No	
SILS_DE_FD	-7.70	0.00	-42.61	0.00		
SILS_ES	-2.43	0.14	-6.51	0.00	Yes/no	No
SILS_ES_FD	-12.90	0.00	-20.70	0.00		
SILS_FR	-2.26	0.19	-4.18	0.00	Yes/no	No
SILS_FR_FD	-7.43	0.00	-27.18	0.00		
SILS_IT	-4.69	0.00	-8.40	0.00	No	
SILS_IT_FD	-9.13	0.00	-62.26	0.00		
STOXX	-3.21	0.02	-3.08	0.03	No	
STOXX_FD	-7.28	0.00	-7.29	0.00		
WAGE_DE	-0.42	0.90	-0.25	0.93	Yes	
WAGE_DE_FD	-4.15	0.00	-8.56	0.00		
WAGE_ES	-1.86	0.35	-1.49	0.53	Yes	
WAGE_ES_FD	-7.47	0.00	-9.03	0.00		
WAGE_IT	-1.61	0.47	-1.51	0.52	Yes	
WAGE_IT_FD	-7.39	0.00	-7.46	0.00		
WAGE_FR	0.03	0.96	0.02	0.96	Yes	
WAGE_FR_FD	-11.71	0.00	-11.22	0.00		
XRATE	-2.57	0.10	-2.36	0.16	Yes	
XRATE_FD	-6.75	0.00	-6.70	0.00		

G.2. Detailed estimation results

Table 71 Detailed results ARDL estimation

	Hollow glass DE		Hollow glass ES		Hollow glass IT		Fibre glass DE	
	2005-2014	2008-2014	2005-2014	2008-2014	2005-2014	2008-2014	2005-2014	2008-2014
Energy coeff	0.49	0.14	0.12	0.04	0.10	0.09	0.05	0.07
Energy T-Stat	2.74	1.76	1.04	1.30	4.28	3.48	4.81	3.57
Energy p-value	0.01	0.04	0.15	0.10	0.00	0.00	0.00	0.00
Energy delay	3	3	5	5	6	6	3	2
CO_2 coeff	-0.025	-0.031	0.01	0.002	0.013	0.013	-0.002	0.0003
CO_2 T-Stat	-1.76	-3.14	0.99	0.17	4.68	1.98	-2.25	0.06
CO_2 p-value	0.04	0.001	0.16	0.43	0.00	0.02	0.01	0.48
CO_2 delay	0	1	0	1	6	6	6	2

	Hollow glass DE		Hollow glass ES		Hollow glass IT		Fibre glass DE	
Wage coeff	-	-	0.79	0.57	0.31	0.31	0.24	0.29
Wage T-Stat	-	-	3.16	5.94	7.64	5.14	4.97	3.01
Wage p-value	-	-	0.00	0.00	0.00	0.00	0.00	0.002
Wage delay	-	-	5	6	6	5	6	6
Stoxx coeff	-	-	-	-	0.08	0.08	-	-
Stoxx T-Stat	-	-	-	-	3.48	3.02	-	-
Stoxx p-value	-	-	-	-	0.00	0.002	-	-
Stoxx delay	-	-	-	-	1	1	-	-
Controls	Wage, silica sand, silican dioxide, aluminium oxide, stoxx, xrate		Silica sand, silican dioxide, aluminium oxide, stoxx, xrate		Silica sand, silican dioxide, aluminium oxide, xrate		Silica sand, silican dioxide, stoxx, xrate	
Adj coeff.	-0.03	-0.11	-0.08	-0.32	-0.88	-0.86	-0.29	-0.30
Adj. Coeff. T-Stat	-3.15	-2.00	-2.16	-3.81	-7.19	-6.82	-5.13	-4.05
Adj. Coeff. p-value	0.002	0.05	0.03	0.00	0.00	0.00	0.00	0.00
SIC	-7.63	-7.60	-6.15	-6.73	-5.51	-5.46	-8.27	-8.13
Bounds test (F-Stat)	7.98	3.88	1.22	4.04	9.50	9.23	5.53	4.70

Table 72 Detailed results VECM estimation

	Hollow glass FR		Hollow glass IT	
	2005-2014	2008-2014	2005-2014	2008-2014
Energy coeff	-	-0.17	-	-
Energy T-Stat	-	-4.80	-	-
CO_2 coeff	-0.006	-0.006	-0.004	0.02
CO_2 T-Stat	-1.40	-0.61	-1.33	1.30
Wage coeff	-0.31	-	-0.34	-0.12
Wage T-Stat	-5.68	-	-5.73	-1.01
xrate coeff	-0.52	-	-	-
xrate T-Stat	-7.37	-	-	-
Controls	Energy, silica sand, silican dioxide, aluminium oxide, stoxx	Wage, silica sand, silican dioxide, aluminium oxide, stoxx, xrate	Energy, silica sand, silican dioxide, aluminium oxide, stoxx, xrate	
Coint. coeff	-0.21	-0.19	-0.52	-0.61
Coint. T-Stat	-3.40	-1.96	-5.53	-5.96
R2adj	0.15	0.12	0.22	0.39

Annex H. Analysis of effect crude oil price on CO_2 price

Some have argued that econometric estimations of cost pass-through is hampered by the fact that the crude oil prices are acting as a precursor for the carbon price. Therefore, part of the carbon price signal that would be monitored in econometric work would actually be the result from measuring the impact of crude oil prices in products from refineries, petrochemicals or fertilizer sectors (for the fertilizer through the natural gas price).

The argument itself is odd as the expected causality would be the other way around: high oil prices will rather stimulate energy saving investments and thus supress carbon prices, *ceteris paribus*. But because the argument keeps popping up now and then we decided to test for this influence.

Below, we present an analysis of the impact of the oil price on the CO_2-price.
We estimated models that explain the CO_2-price over the period of Phase 2/3 of the ETS. We estimated models with a weekly frequency and a monthly frequency, both in VECM and ARDL-form. Data with weekly frequency runs from the first week of 2008 to the 8th week of 2015. Data with a monthly frequency runs from the January 2008 to November 2014.

The VECM results pointed to a one-way causal relation running from the Crude oil price to the CO_2-price. Hence we estimated ARDL-models. The results (see Table 73) point to the conclusion that there is no cointegrating relation between crude oil and CO_2. Therefore we conclude that there does not exist a long-term relationship between the crude oil prices and carbon prices that would justify the claim that crude oil price is a precursor of the CO2 price.

Table 73 Summary of estimation results of ARDL-models that explain the price of CO_2 by the price of crude oil

Frequency	Monthly	Monthly	Monthly	Weekly	Weekly	Weekly
controls?	No	Xrate	d (Xrate)	No	Xrate	d (Xrate)
Crude oil_delay	2	2	5	0	0	0
Maxlags	2	2	2	1	1	1
Crude oil _coef	-1.779	-1.529	-2.119	-0.602	-0.753	-0.513
Crude oil _t_stat	-2.079	-2.124	-2.622	-0.552	-1.125	-0.453
Crude oil _pval	0.041	0.037	0.011	0.581	0.261	0.651
adj. coef	-0.048	-0.058	-0.057	-0.014	-0.023	-0.014
t_adj. coef	-2.325	-2.404	-2.473	-1.812	-2.351	-1.755
p_adj. coef	0.023	0.019	0.016	0.071	0.019	0.080
SIC	-3.464	-3.418	-3.386	-3.978	-3.968	-3.998
Bounds F-statistic*	3.390	3.651	3.025	1.735	2.905	1.647

* The F-statistics are not significant at the 10% confidence level, for any combination of I0 and I1 variables in the cointegrating relation.

Annex I. Derivation of the cost price model from the accounting identity

The model with prices in logarithms can be derived from the accounting identity:

$$Y_t * P_{y,t} \stackrel{\text{def}}{=} X_t * P_{x,t} + CO2_t * P_{co2,t}$$

where Y denotes the volume of output, P_y its price, X the volume of non-CO_2 inputs (e.g. labour, materials, energy) and P_x its price, $CO2$ the volume of CO_2 allowances used in production and P_{co2}its price. The index t denotes time.

If we rewrite this equation in growth rates (marked by the symbol $\widehat{\ }$), we obtain:

$$\widehat{Y_t * P}_{y,t} = \frac{X_t * P_{x,t}}{Y_t * P_{y,t}} \widehat{X_t * P}_{x,t} + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} \widehat{CO2_t * P}_{co2,t}$$

In this equation, the ratio's $\frac{X_t * P_{x,t}}{Y_t * P_{y,t}}$ and $\frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}}$ are the two cost shares for inputs and CO_2 respectively. If we assume that capital costs and/or profits are a constant mark-up over other costs, we can think of the X's as variable inputs and equation the equation above still holds.

If we accept the assumption that physical volumes change slower than prices, the equation above can be approximated by

$$\hat{P}_{y,t} = \frac{X * P_{x,t}}{Y_t * P_{y,t}} \widehat{P_{x,t}} + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} \widehat{P_{co2,t}}$$

Rewriting growth rates in log-form (using the definition: $\hat{x} = \frac{1}{x} dx = dlnx$), this becomes

$$dlnP_{y,t} = \frac{X * P_{x,t}}{Y_t * P_{y,t}} dlnP_{x,t} + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} dlnP_{co2,t}$$

which, after integration, yields

$$lnP_{y,t} = constant + \frac{X_t * P_{x,t}}{Y_t * P_{y,t}} lnP_{x,t} + \frac{CO2_t * P_{co2,t}}{Y_t * P_{y,t}} lnP_{co2,t}$$

which translates into the regression equation:

$$lnP_{y,t} = \beta_0 + \sum_x \beta_x lnP_{x,t} + \beta_{co2} lnP_{co2,t} + \varepsilon_t$$

Annex J. Development of trade intensities other sectors

In Chapter 5 the development of trade intensities in the iron and steel sector was shown. Below we will present the trade intensities in other sectors.

Figure 54 Trade intensities within the glass sector, 2002-2014

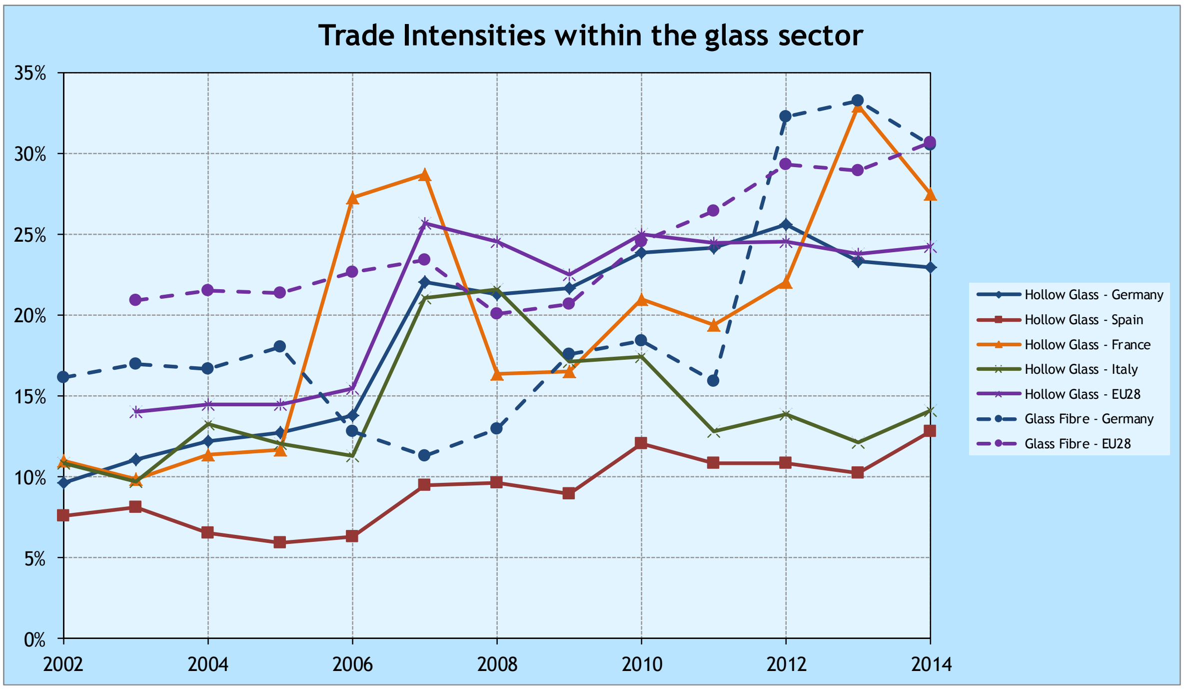


Figure 55 Trade intensity for cement, 2002-2014

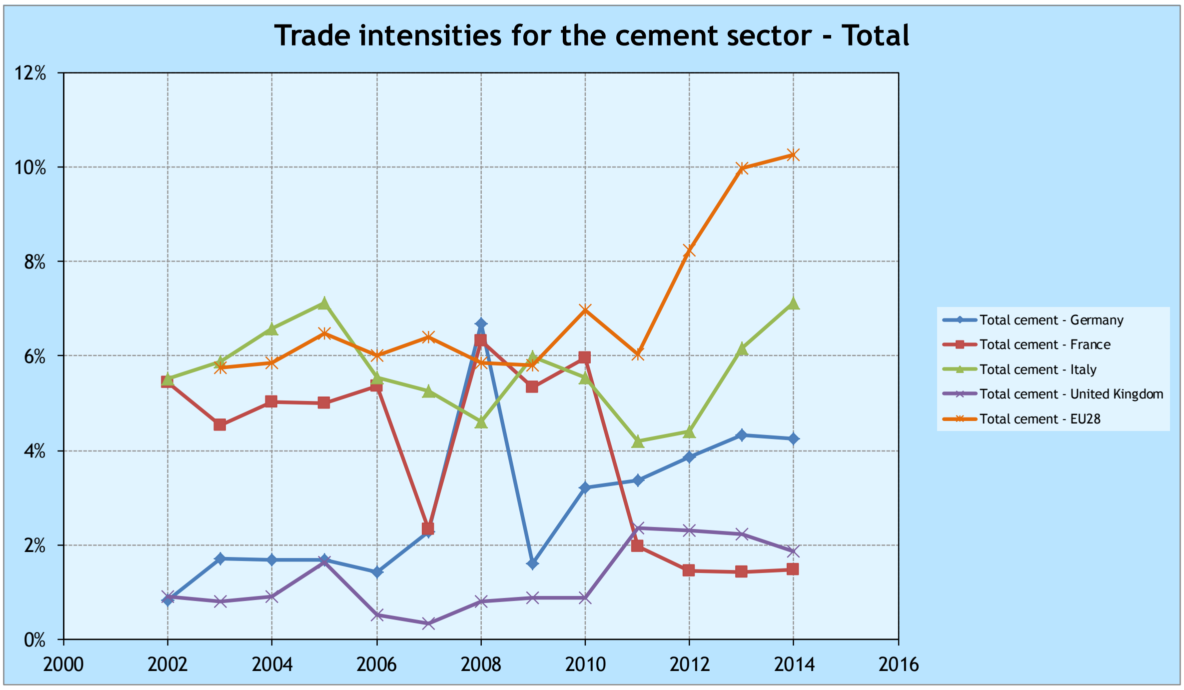


Figure 56 Trade intensities for the cement sector – cement clinker

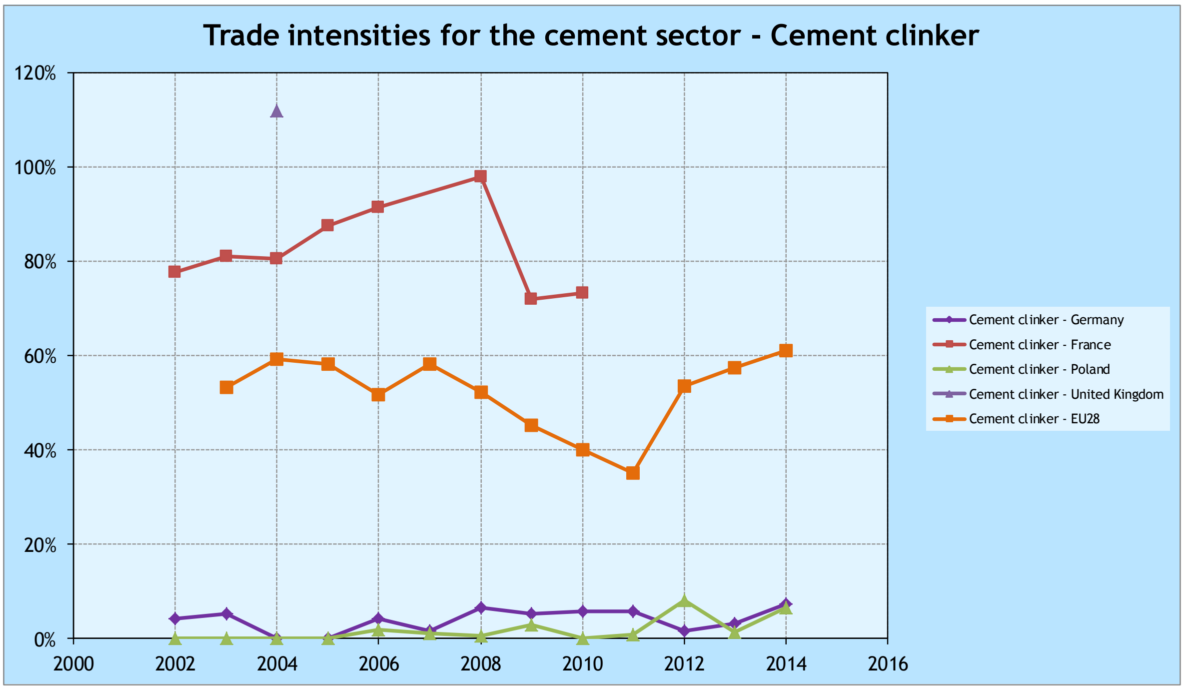


Figure 57 Trade intensities for the sector organic chemicals

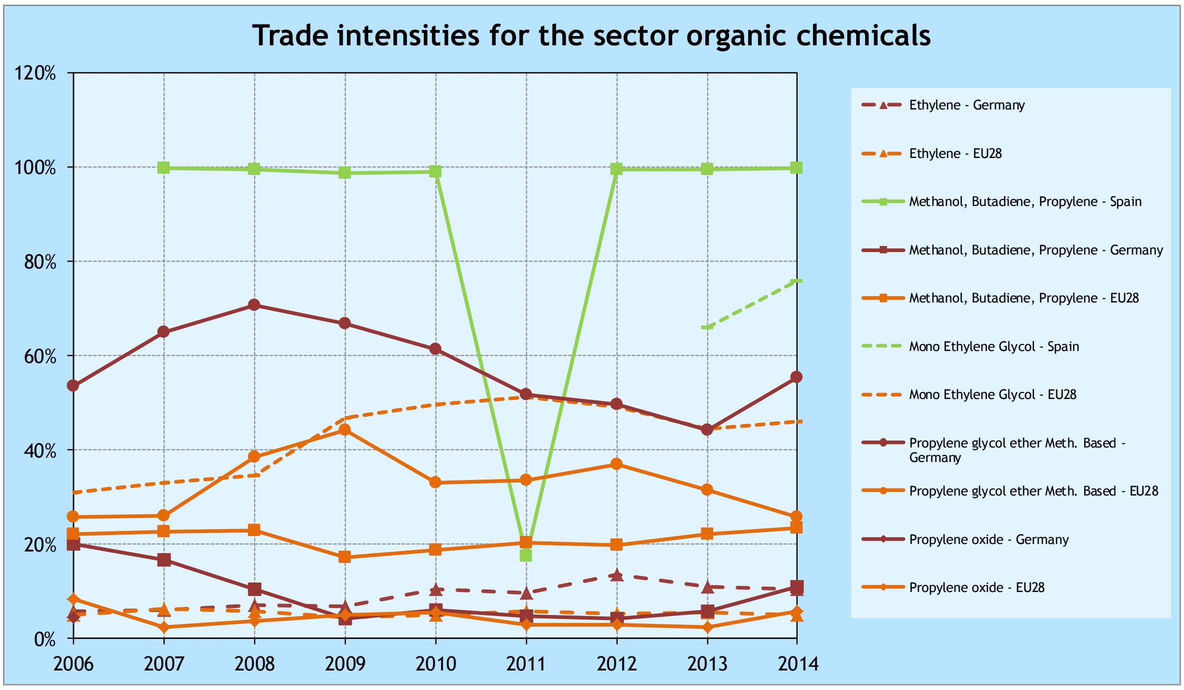


Figure 58 Trade intensities for several products of the sector fertilisers

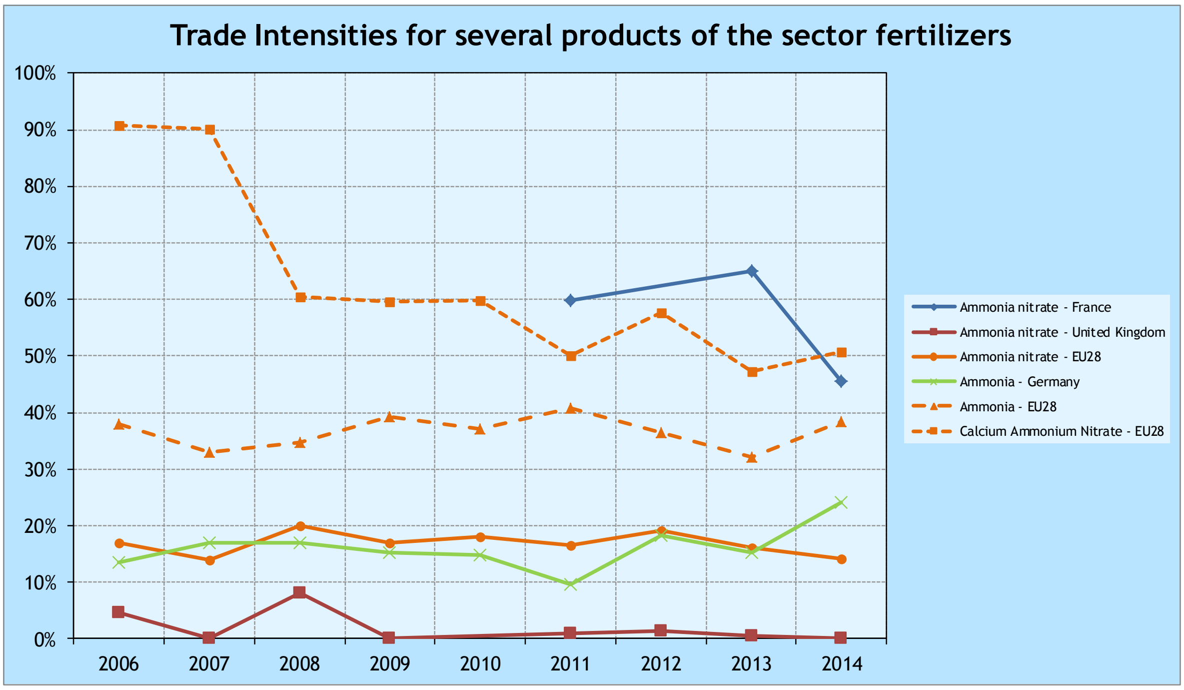
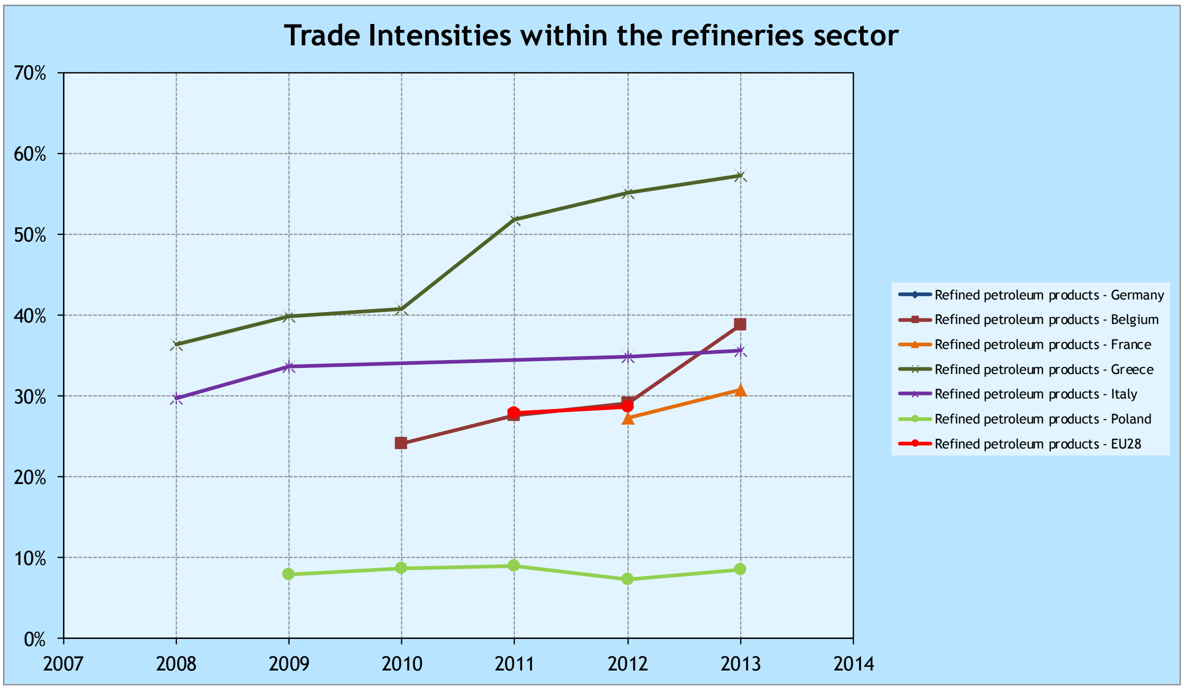
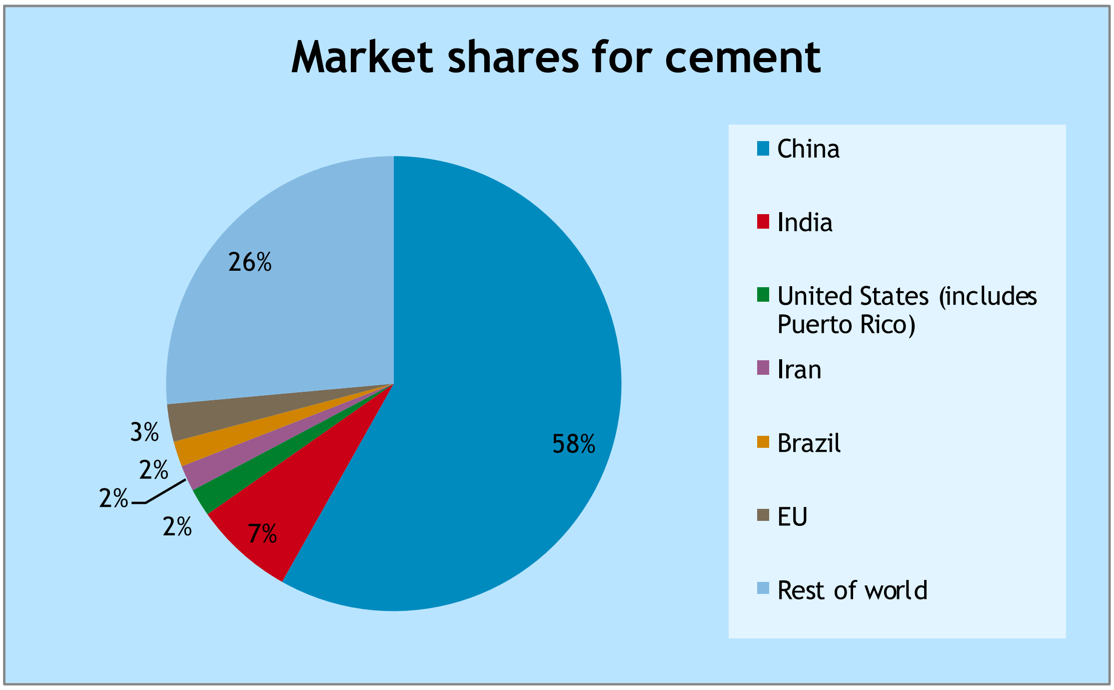


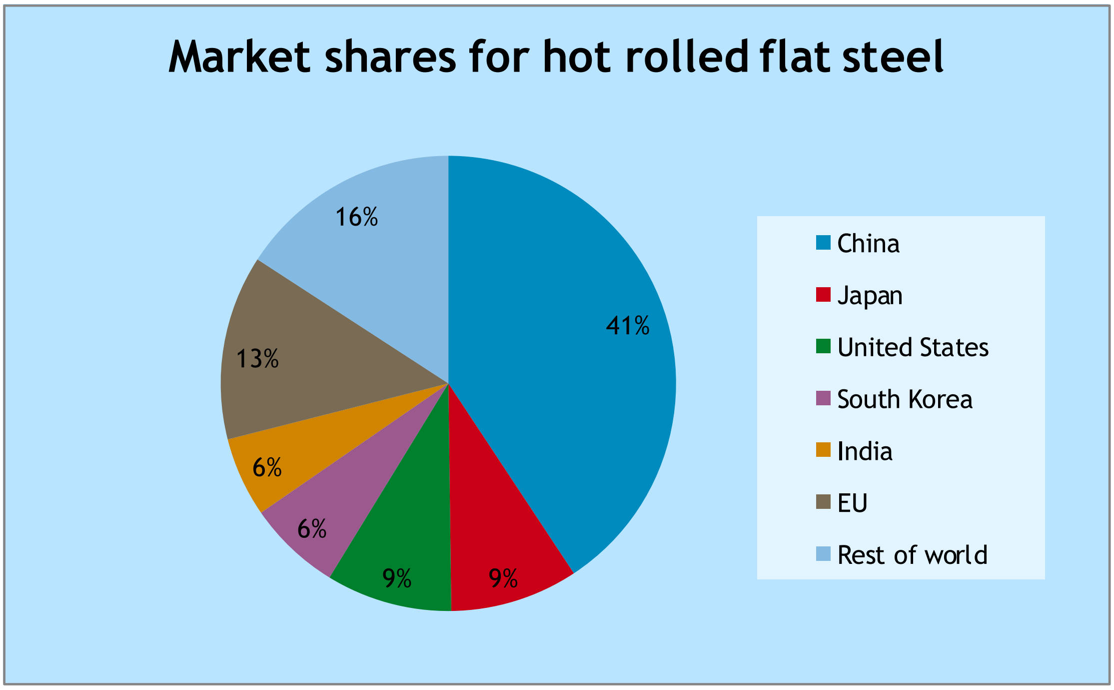
Figure 59 Trade intensities within the refineries sector

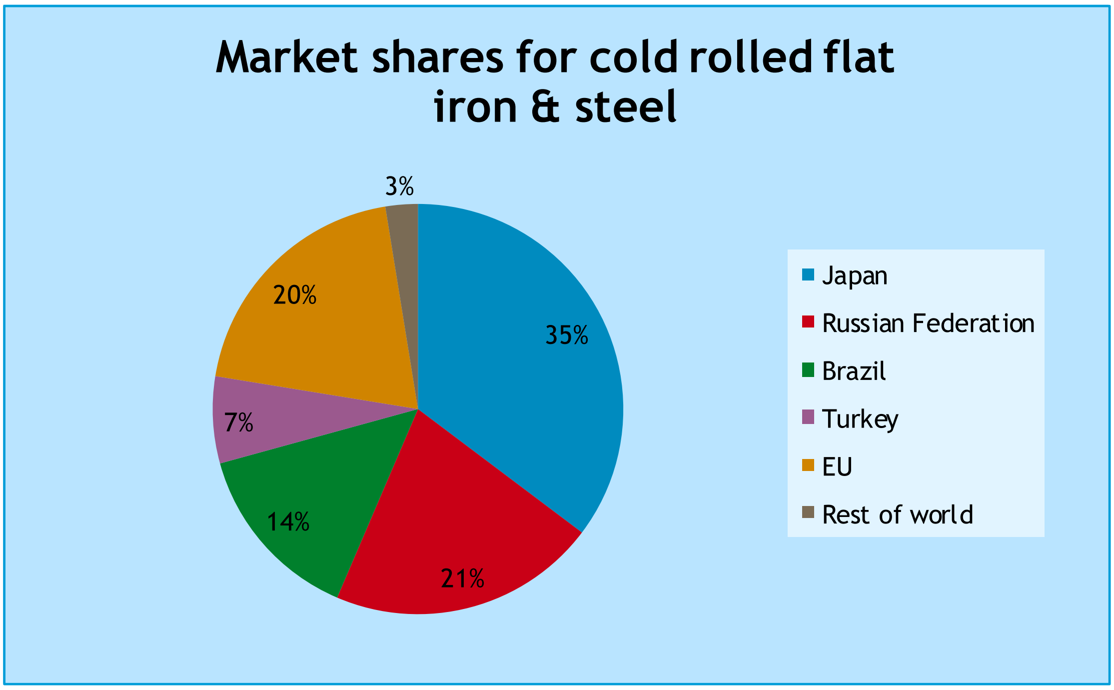


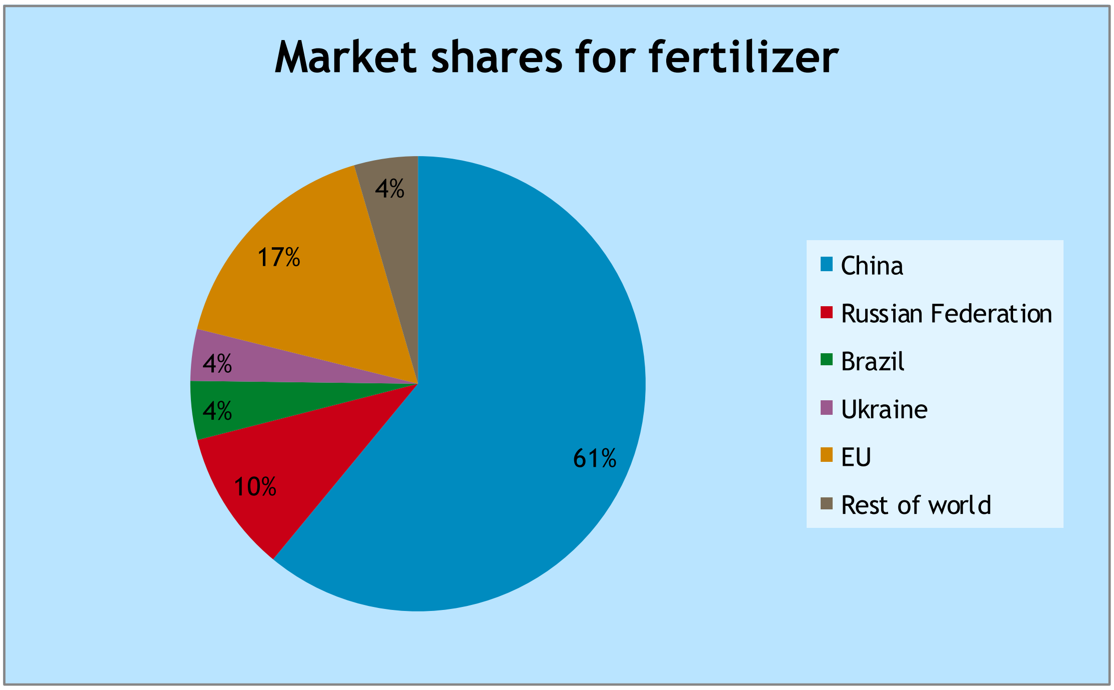
Annex K. EU market shares in global production

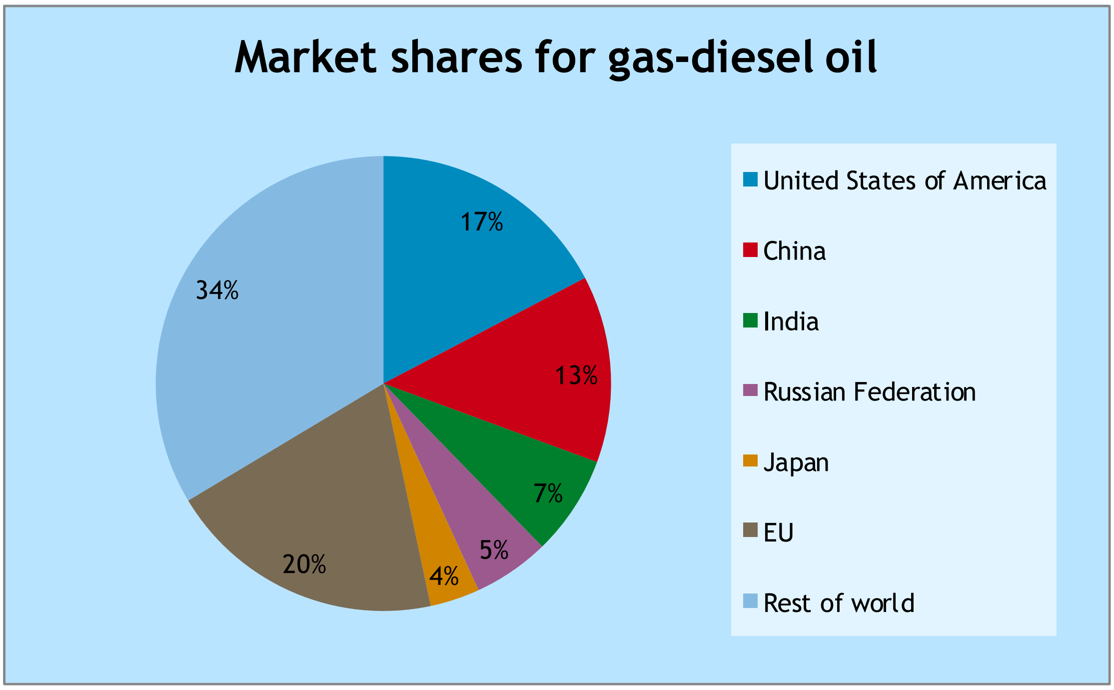
Information on market shares for global production for major producing countries including the EU is shown below. Source for all graphs is the UNSD Industrial Database, except for hot rolled coil World Steel Association (2015) and cement http://www.cembureau.be/about-cement/key-facts-figures






Market shares for cold rolled flat iron & steel
3%
20%
35%
7%
14%
21%
Japan
Russian Federation
Brazil
Turkey
EU
Rest of world


Market shares for fertilizer
4%
17%
4%
4%
10%
61%
China
Russian Federation
Brazil
Ukraine
EU
Rest of world


Market shares for gas-diesel oil
17%
13%
7%
5%
4%
20%
34%
United States of America
China
India
Russian Federation
Japan
EU
Rest of world

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