Discussion Paper No. 10-086

Cost Pass-Through of the EU Emissions Allowances: Examining the European Petroleum Markets

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Non-technical summary

Using advanced time-series techniques, this paper explores the ability of European refineries to pass-through costs associated with the introduction of the EU Emissions Trading Scheme (ETS). The paper thereby fills, the gap in the literature by analysing the interactions between petrol prices and emissions allowances allocated to the refining industry under the EU ETS at the single country level. The analysis is conducted within a multi-national framework and as comprehensive as the weekly data permits, covering 14 EU member states. Given the non-stationarity of variables and the existence of the long-run relationships between the analysed time series, the application of a vector error correction model (VECM) is appropriate. These econometric techniques allow tracking a price transmission process which is induced by the EU ETS in general and by free allocation of allowances in particular while accounting for short-run and long-run dynamics. Our econometric analysis shows that refineries were capable to pass-through prices of EUAs to consumers during the first trading period 2005–2007. It also discloses the heterogeneity across the EU member states in long- and short-run responses of petrol prices to movements of EUA prices. We run two alternative specifications of the VECM at the country level to check the robustness of the results. Our central finding questions the policy outcome in which emissions from the refining sector will be largely benefiting from free allocation of allowances from 2013 onwards, whereas the power sector falls fully under the auctioning regime. This measure has been introduced to minimise the undesirable distribution impacts that resulted from handing out free permits to the power sector in the “warm-up phase”. This paper shows that adverse distributional impacts were also present over the same time horizon in the refining sector.

Das Wichtigste in Kürze

Unter Anwendung moderner ökonometrischer Techniken geht diese Arbeit der Frage nach, inwiefern die europäische Raffineriebranche die Kosten an die Konsumenten weitergeben, die ihnen durch die Einführung des Emissionshandelssystems (EHS) in der EU entstehen. Die Analyse wird durchgeführt in einem multi-nationalen Kontext und ist so umfassend wie die vorhandenen wöchentlichen Daten es erlauben – 14 EU-Mitgliedstaaten sind in die Untersuchung einbezogen. Gegeben die Nichtstationarität der Daten und die Existenz einer langfristigen Beziehung zwischen den untersuchten Variablen, ist die Anwendung von Vektor-Fehlerkorrekturmodellen erforderlich. Diese Modellierungstechnik berücksichtigt die kurz- und langfristige Dynamik in der Anpassung der Einzelhandelspreise an die Veränderung der Preise von CO_2-Emisisonszertifikaten. Ergebnisse dieser Untersuchung verdeutlichen, dass europäische Raffinerien die (Opportunitäts-)Kosten des Emissionshandels an die Konsumenten in der ersten Handelsperiode (2005–2007) weitergeben konnten. Es zeigt sich auch, dass es eine Heterogenität zwischen den EU-Mitgliedstaaten im Hinblick auf die kurz- und langfristige Anpassung der Einzelhandelspreise bleifreien Benzins an die Preise von CO_2-Emisisonszertifikaten herrscht. Wir spezifizieren zwei Modellvarianten, um die Belastbarkeit dieser Ergebnisse zu überprüfen. Das zentrale Ergebnis dieser Arbeit hinterfragt die Regelung, bei der die europäische Raffineriebranche in der dritten Handelsperiode ab 2013 ihre CO_2-Emisisonszertifikate weitgehend frei erhalten wird, während der Stromsektor diese zu 100% per Auktion kaufen muss. Diese Maßnahme wurde eingeführt, um die unerwünschten Distributionseffekte zu minimieren, die im Stromsektor in der ersten Handelsperiode durch eine kostenfrei Vergabe der Zertifikate entstanden sind. Diese Arbeit zeigt, dass derartige Distributionseffekte in der europäischen Raffineriebranche im gleichen Zeitraum zu beobachten sind.

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Abstract: This paper explores the ability of European refineries to pass-through costs associated with the introduction of the EU Emissions Trading Scheme (EU ETS). We estimated a sequence of vector error correction models (VECM) within a multi-national setting which covers 14 EU member states. Using weekly data at the country level, this paper finds a significant influence of prices for European Union Allowances (EUAs) on unleaded petrol retail prices during the trial phase of the EU ETS from 2005 to 2007. Petrol prices are found to be elastic with respect to crude oil prices and exchange rates but rather inelastic with respect to carbon costs. The long-run elasticity of petrol prices with respect to the EUA prices typically ranges between 0.01% and 0.09%. Furthermore, by computing the variance decomposition our analysis shows that a significant fraction of petrol price changes in Austria, Germany, France and Spain can be explained by changes in allowances prices (between 10% and 20%).

JEL Classification: F18, C22, L11

Keywords: Cost Pass-Through, Emissions Trading Scheme, Refineries

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1 Introduction

The EU Emissions Trading Scheme (ETS) as a centrepiece to the European climate change policy has been operating since January 2005 (EU, 2003). The evolvement of the trading scheme encompasses thereby several temporal stages: the first phase of the EU ETS from 2005 until 2007, the second phase from 2008 until 2012 which coincides with the first Kyoto commitment period and the third trading phase from 2013 until 2020 which covers the potential post-Kyoto commitment period.

The trading system applies to installations from energy-intensive sectors that in its opening phase included all major CO_2 producing plants such as power generation, oil refineries, iron and steel production, some parts of mineral industries (e.g. cement) and of pulp and paper manufacturing. Based on the National Allocation Plans (NAP)[1], each member states specified an overall cap on emissions allowances for all installations included in the scheme at the country level and defined how the total amount of allowances will be distributed among individual plants. The main changes to the emissions trading scheme in the third trading period have been the extended scope – i.e. additional economic activities and further greenhouse gases – and the rule alterations with respect to the allocation mechanism based on harmonised allocation and auctioning. The former part of the rule alteration has made the heavily disputed NAPs obsolete, the latter introduced auctions as the basic principle for allocation of carbon allowances beyond 2012, with the auction rate of up to 100% in the power sector.

One of the major characteristics of the ETS during both initial "warm-up phases" is that almost all emissions allowances were allocated free of charge to the covered installations. The impact of freely allocated allowances on product prices has become a source of controversy in both academic and policy papers. At the firm level, holding CO_2 allowances instead of trading them represents opportunity costs that are likely to be added to other costs and passed-through to consumers (Sijm, 2006b). The political perception of this potential is clear enough as it raises severe distributional concerns. At the EU level, the "windfall profits" that were generated by the power sector during the first trading period have formed the political will to minimise the undesirable distribution impacts resulting from handing out free permits (EU, 2008b). National authorities have, on their part, proceeded against companies that were abusing their market power by excessively passing-through CO_2 costs to the consumers. Fell

[1] NAP I and NAP II for the first and second trading period, respectively.

(2008) reports on German Federal Cartel Office (Bundeskartellamt) issuing a warning to German electricity generator RWE in 2006.

In the context of the EU ETS, empirical evidence on the ability to pass-through carbon costs in the early phases of the EU ETS is still rather scarce, with the exception of the power sector. Sijm et al. (2005, 2006a, 2006b) provided initial empirical evidence of passing-through opportunity costs of EUAs to power prices for, among others, Germany, the Netherlands, France, Belgium. Zachmann and Hirschhausen (2008) substantiated the evidence using data from the European Energy Exchange in Leipzig and applying advanced econometric techniques. Walker (2006) and Ponssard and Walker (2008) analysed the impact of EU ETS on the profitability of the cement sector for some European countries and reported rather low pass-through rates. More recently, Alexeeva-Talebi (2010) and Oberndorfer et al. (2010) analysed the cost pass-through relationships in energy-intensive sectors in Germany and in the UK, respectively. De Bruyn et al. (2010) presented some empirical evidence on energy-intensive sectors in the EU, including the refining industry. The major drawback of this study is that data used for the econometric analysis does not allow considering potential heterogeneity in terms of the pass-through across EU member states as it relies – for the refining sector – on German data only.

Another strand of the literature focuses on price transmissions in refining sectors in a broader context. Among others, Meyer and Cramon-Taubadel (2004), Geweke (2004) and more recently Frey and Manera (2007) provided a comprehensive literature review on this item. A large body of empirical literature has focused on passing-through – symmetrically and asymmetrically – crude oil prices and exchange rates to prices of petroleum products within a multi-national framework (among many others: Reilly and Witt, 1998, Galeotti et al. 2003, Wlazlowski, 2007, Wlazlowski et al, 2009). With a strong regional focus on the US, the tax incidence literature studied finally the effects of sales taxes on gasoline prices (e.g. Doyle and Samphantharak, 2008).

Against this background, in this paper we analyse the implications of the EU ETS for the refining sector, notably the impact of freely distributed emissions allowances on prices of unleaded petrol. Since the EU ETS is still in an early stage and price data for sectors of interest are typically available on a monthly basis, the carbon costs are often proxied by labour, material and energy as the second-best option. The availability of weekly price data on petroleum products at the country level is a distinct characteristic of refining sector which allows an envisaged analysis.

The contribution of this paper to the pass-through literature in the context of the climate change policy is twofold: First, we provide robust empirical evidence on the interactions between prices of petroleum products and market-based mechanisms such as the EU ETS. We add to the literature body by revealing that carbon costs enter the cointegration space with petrol prices, crude oil prices and exchange rates in the trial phase of the EU ETS in European petroleum markets. Second, the applied data and modelling techniques allow disclosing potential heterogeneity in terms of pass-through across the EU member states. The estimation results based on a VECM framework detail the ability of producers to pass-through carbon costs to the consumers during the trial phase from 2005 to 2007. The increase of EUA prices by 1% typically leads to an increase of petrol prices by 0.01-0.09% across Europe in the long-run. The relatively low elasticity of the petrol prices with respect to the EUA prices is due to a small share of carbon costs in the total costs of petrol production. The impulse-response analysis shows that petrol prices typically reach the new long-run equilibrium at the latest 20 weeks after the one-time innovation (in carbon costs). The overall conclusion of this paper is that European refineries have been strongly benefiting from the design of the EU ETS, i.e. free allocation of allowance in the first trading period. As to the policy implications, our analysis questions – on grounds of severe adverse distributional impacts – the continuation of the freely allocation of allowances to refining sector beyond 2012.

The remainder of this paper is structured as follows: Section 2 describes the methodological approach and data used for the estimation and presents empirical findings on the pass-through of CO_2 emissions allowances to petrol prices at the EU country level. Section 3 outlines major findings and policy implications.

2 Empirical Analysis

2.1 Methodology and modelling strategy

Empirical literature on pass-through relationships typically applies three modelling techniques: single-equation-based approach, stationary (differenced) vector autoregression (VAR) models and cointegrated VAR models (An, 2006). The latter technique parameterises short-run and long-run dynamics and is therefore used extensively in papers assessing the pass-through linkages between prices of petroleum products and crude oil: Arpa et al. (2006), Wlazlowski (2007), Wlazlowski et al (2009) and de Bruyn et al. (2010) estimated, for example, separately VAR models for different petroleum product at the country level. The analysis in this paper follows this strand of literature by estimating a sequence of cointegrated VAR models for the European refining sector.

The notion of cointegration has been introduced by Engle and Granger (1987). Johansen (1988) and Johansen and Juselius (1990) have developed the cointegration test procedure which specifies as a starting point the VAR of order *p* as a vector-error-correction model (VECM) in its basic form:

$$\Delta x_t = \Pi\ x_{t-1} + \sum_{k=1}^{p-1} \Gamma_k \Delta x_{t-p} + B\ y_t + \varepsilon_t$$

where x_t represents a vector of non-stationary endogenous variables for $t = 1,...,n$:

$$x_t = (p_t^{pet}, p_t^{oil}, p_t^{car}, p_t^{ex})$$

$p_t^{pet} =$ the net-of-taxes nominal retail prices for Euro-95 unleaded petrol (in national currency);

$p_t^{oil} =$ the prices for crude oil (in US$);

$p_t^{car} =$ the prices for EUAs (in national currency);

$p_t^{ex} =$ the exchange rates between the local country's currency and US$.

The matrix Π contains information about the long-run relationships among endogenous variables and can be decomposed as $\Pi = \alpha\beta'$, whereas β and α represent the cointegrating vectors and the matrix with the estimations on the speed of adjustments to equilibrium, respectively. $\text{Rank}(\Pi) = 1$ suggests that there is a unique cointegration relationship among the analysed series. Furthermore, Δ represents the first-difference operator, the matrix Γ_k

includes the estimations of the short-run parameters, $\varepsilon_t \sim \text{Niid}(0,\Sigma)$ is a vector of innovations, y_t is a vector of exogenous variables (e.g. seasonal dummy variables) with B containing respective estimated coefficients. Using carbon costs p_t^{car} in the cointegrated VAR system allows differentiating the analysis in this paper from a substantial literature body on passing-through behaviour in the refining sector.

2.2 Data Issues

This section presents the data basis underlying the pass-through analysis in the refining sector. As a starting point we discuss the issue of the relative allocation of emissions allowances to the refining sectors at the country level during the first trading period. A detailed description of the data used for the subsequent econometric analysis of the pass-through relationships associated with the EU ETS in European petroleum markets follows these introductory remarks.

2.2.1 Relative allocation of allowances in the refining sector

The EU Community Independent Transaction Log (CITL) contains data for 19 member states on the verified emissions and allocated emissions allowances for the economic activities codified as “mineral oil refineries” (EU, 2010). The 2006 data were used for the calculation of a sequence of allocation factors relating allocated allowances to the verified emissions in the refining sector. An allocation factor which exceeds the value of 1 indicates the over-allocation: an installation has received more certificates than it emitted. In contrast, a value of less that 1 suggests that installations have to undertake abatement activities or to purchase certificates in order to comply with their individual emissions cap. Whether the empirical allocation factors represent a suitable measure to trace the relative allocation is a controversial issue in the literature. While Kettner et al. (2007) support this view, Ellerman and Buchner (2008) and Di Maria et al. (2009) emphasise potential distortions of this measurement concept. Notwithstanding, the abatement in the early phases of the EU ETS appears to be rather small. We therefore consider empirical allocation factors to provide valuable insights into the relative allocation of the certificates (Anger and Oberndorfer, 2008).

Figure 1: Allocation factors for the refining sector in the EU (2006)

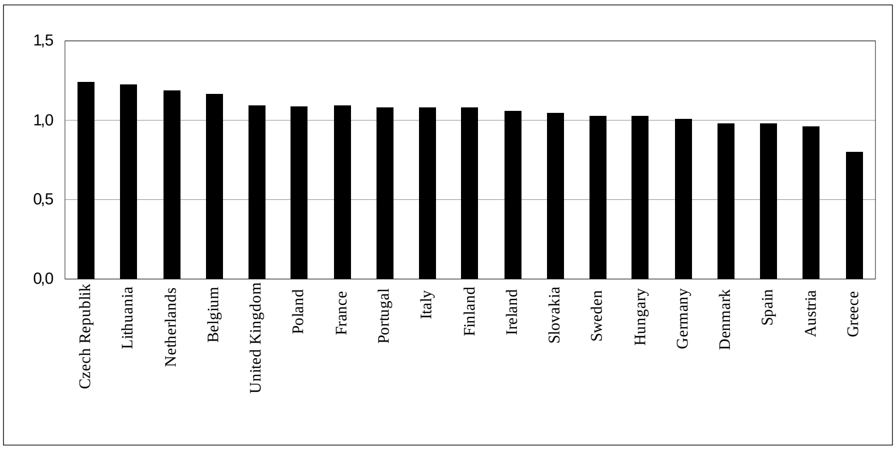

Figure 1 depicts a considerable heterogeneity in terms of the relative allocation of certificates in the refining sector. It shows that refining sector in few countries – Denmark, Spain, Austria and Greece – received less allowances as verified emissions, with Greece showing an allocation factor of around 0.8. Germany represents a border line case, while all other EU member states received more allowances than their respective emissions. The Czech Republic benefited most from the allocation scheme in 2006. In comparison to Kettner et al. (2008) who used the 2005 data we observe some dynamics regarding the relative allocation of allowances. Producers appear to adjust production quantities easily and hence the emissions level. For example, Ireland was short in 2005 but become long in 2006. Whereas, Greece extended the production volume and the emissions level between 2005 and 2006 significantly, ending at a much shorter position.

2.2.2 Data and variables

The data set used for the empirical analysis consists of four weekly time series: net-of-taxes nominal retail prices for Euro-95 unleaded petrol at the EU country level, prices of EUAs, prices of crude oil and exchange rates between a local country's currency and US$.

In order to separate the first and second trading periods, the analysis in this paper relies on the weekly data running from September 16, 2005, to March 22, 2007[2]. We thereby focus only on those EU member states that have received emissions allowances during the first trading

[2] Having started with the weekly data running from September 16, 2005, to September 17, 2010, the testing results (not reported here, but available upon the request) favour the existence of a break between the first and the second trading period. The first trading period has been, however, shortened to March 22, 2007, i.e. until the period where allowance prices geared toward zero (cf. Alberola and Chevallier, forthcoming, Oberndorfer et al., 2010).

period according to the CITL[3]: Austria (AT), Belgium (BE), Czech Republic (CZ), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Hungary (HU), Lithuania (LT), the Netherlands (NL), Poland (PL), Portugal (PT), Sweden (SE), Slovakia (SK), Spain (ES) and United Kingdom (UK). Hence, among the EU-15 all member states are covered, except for Luxemburg; among the EU-12, only six countries are registered to host mineral oil refineries in 2006 and are therefore considered in our analysis.

Retail prices for Euro-95 unleaded petrol are obtained from the Oil Bulletin – a data source published by the European Commission on a weekly basis (EU, 2010b). The Oil Bulletin reports both the net-of-taxes retail prices at the country level in Euro and the corresponding exchange rates. For the purpose of the investigation, all retail prices are used in national currencies. As repeatedly underlined by empirical literature, the choice of crude oil time series does matter for the estimation results. In this paper, we rely on nominal prices for Brent crude oil as suggested by Hagstromer and Wlazlowski (2007) and Wlazlowski et al (2009). Since these data are available in US$ only, an additional data set with exchange rates between US$ and national currencies is needed. Data on crude oil and exchange rates (between US$ and national currencies) stem from Thomson Datastream. Carbon costs of the firms are represented by the spot prices based on Point Carbon enquiry (Point Carbon Spot Index) – the latter data are available from September 2005 onwards from Datastream and converted into the national currencies (other than Euro) by means of the Oil Bulletin's exchange rates. The full data set is available for all countries with the exception of Slovakia. All time series are used in logarithms.

2.3 Estimation procedure

We start our estimating procedure by testing the existence of a unit root in data and cointegration relationship(s) among the employed variables. Both sets of tests relate to the question whether the envisaged VAR models shall be estimated in levels or in first-differences. If variables are non-stationary in levels but stationary in first differences, then they are considered to be integrated of order one, i.e. I(1). Given the non-stationarity of variables and the existence of cointegration relationships, the application of a cointegrated VAR is appropriate. But if testing rejects the existence of cointegration relationships among non-stationary data, estimating VAR in first differences (stationary VAR models) shall be selected to avoid spurious regression.

[3] In 2006.

Using two alternative versions of the Phillips-Perron (PP) test (Phillips and Perron, 1988) for a unit root with and without a trend, 33 out of 35 series are found to be integrated of order one (I(1)) in both model specifications. The null of a unit root in level data for these series cannot be rejected at usual significance levels but it is rejected when applied to the first differenced data (Table 3a,b in the Appendix).[4] A common strategy is to employ additionally a stationarity test, e.g. the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992). The results of the KPSS and the PP are partially in contradiction which is mainly contributed to a pervasive tendency of the former in finding the lower level of integration than a unit root test (Strauß, 2004). Notwithstanding, the KPSS test rejects the null of stationarity when applied to the data in levels in a test specification with a constant and a trend at usual significance levels in all variables with the exception of few exchange rate series, but cannot reject the null when applied to the first-differenced data in all variables[5].

Whether all components of the vector have to be integrated of the same order is disputed in the literature: Engle and Granger (1987) and Hamilton (1994), among others, argue that all variables must be integrated of the same order. Johansen (1995) considers, for example, the possibility of cointegrating relationships between the stationary and the integrated of order one non-stationary variables. The applied work tends to include the stationary variables into the VECM framework as an endogenous variable if economically reasonable (cf. Strauß, 2002, Hüfner and Schröder, 2002). According to the PP and the KPSS tests, some exchange rate series represent a border line case between the I(0) and I(1). The augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) applied to these time series supports our findings on the I(1). We therefore pursue testing the existence of cointegration relationships under the assumption that all time series are integrated of the order one in all countries with the exception of Poland and UK.[6]

Table 4 (Appendix) details the results on the number of cointegrating vectors and the optimal VAR lag length in our sample. The maximum eigenvalue test (Johansen and Juselius, 1990) rejects the null hypothesis of no cointegrating vector $\text{Rank}(\Pi_i) = 0$ against the specific alternative $\text{Rank}(\Pi_i) = 1$ for all countries with the exception of Finland at the 5% significance level. The trace test statistics reject the hypothesis of no cointegration relationships at the 5% significance level in all countries with the exception of Ireland, Denmark and Sweden.

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[4] Prices for petroleum products in Poland and UK ($p_{pet,PL}$ and $p_{pet,UK}$) are found to be I(2).

[5] Since the time trend is significant in each cointegration equation, the problem of some inconsistency in results from the PP and KPSS exists in some exchange rates time series only.

[6] These results can be provided upon request.

Concluding on the existence of the cointegration relationships we rely on the findings from the more powerful maximum eigenvalue tests (Johansen and Juselius, 1990). The most appropriate model in all countries includes a trend and an intercept in cointegration space and permits a constant in the VAR. In the cointegration literature, it is common to consider both specifications – with and without a trend in the cointegration equation (CE) – and to select the most encompassing model with a time trend. This specification is the least restrictive as it does not impose *a priory* any arbitrary restrictions on the VECM (Kaufmann and Cleveland, 2001). It allows avoiding omitted variable bias in the estimated coefficients of the variables under investigation (Welsch, 2008)[7]. Linear time trend captures the effects of further costs (e.g. labour costs) on the retail petroleum prices (Wlazlowski, 2001). Finally, the trend allows accounting for "catch-up" effects in new EU member states (Beirne and Bijsterbosch, 2009). The decision on the number of lags included in the equation is based on the Schwarz information criterion (SIC) but additional lags were added to correct for serial correlation and to achieve normality and homoscedasticity in residuals (Enders, 2004). Given the fact that the number of degrees of freedom shrinks quickly in a (cointegrated) VAR model, the strategy is to develop the most parsimonious model specification which is consistent with well-behaved errors. In most cases two lags were sufficient to receive residuals that are free of autocorrelation and heteroscedasticity and mostly following the normal distribution[8].

We run two alternative specifications of the VECM: in our basic model specification, all variables are endogenous. The results for this model specification are reported in a detailed way. As in Arpa et al. (2006) and Wlazlowski (2007) we estimate a sequence of models for each EU member states. To test the robustness of the result, we then conduct a sensitivity analysis which involves a different treatment of the exchange rate variable. Under this alternative specification, we include the exchange rate as an exogenous variable to address the problem of possible stationarity of these time series (Clostermann and Seitz, 2002).

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[7] We thereby closely follow the procedure suggested by Welsch (2008).

[8] These results are available upon the request. In very few models, there is a sign of non-normality due to the excess kurtosis. As shown in Gonzalo (1994), the test statistics on the cointegration relationships are robust to the non-normality whereas it is due to the excess kurtosis. The violation of normality assumptions (related to both skewness and kurtosis) is found in Czech Republic, while the autocorrelation in the residuals in the VECM for Ireland cannot be removed even at a higher lag order. We therefore decided not to report the estimation results for the latter as the residuals do not fulfil the basic requirements for the model specification.

2.4 Empirical Results

This section presents the results from our basic model specification on how strongly and rapidly the net retail prices of Euro-95 unleaded petrol across the EU member states react to changes in crude oil prices, carbon costs and exchange rates. Table 1 details the long-term elasticities of petrol prices across the EU member states in the normalised cointegrating relationships. The overall results suggest that petrol prices are elastic with respect to crude oil prices and exchange rates but inelastic with respect to the EUA prices.

Table 1 Long-run relationships between petrol prices, crude oil prices, carbon costs and exchange rates

Countries	**Variables**			
	p_t^{pet}	p_t^{oil}	p_t^{car}	p_t^{ex}
Austria	-1.00	1.27 (0.17)	0.08 (0.04)	2.45 (0.83)
Belgium	-1.00	1.38 (0.14)	0.05 (0.04)	2.69 (0.78)
Czech Republic	-1.00	1.97 (0.33)	0.07 (0.06)	0.65 (1.44)
Denmark	-1.00	1.13 (0.14)	0.01 (0.03)	2.05 (0.74)
France	-1.00	1.41 (0.12)	0.04 (0.03)	1.62 (0.65)
Germany	-1.00	1.47 (0.15)	0.05 (0.04)	2.36 (0.77)
Greece	-1.00	1.23 (0.11)	-0.02 (0.03)	0.74 (0.62)
Hungary	-1.00	1.47 (0.10)	-0.09 (0.03)	-1.01 (0.30)
Italy	-1.00	1.05 (0.15)	0.09 (0.04)	3.09 (0.76)
Lithuania,	-1.00	1.15 (0.09)	0.03 (0.02)	1.14 (0.54)
The Netherlands	-1.00	1.18 (0.10)	0.03 (0.03)	1.93 (0.61)
Portugal	-1.00	1.25 (0.19)	0.09 (0.04)	3.49 (0.95)
Spain	-1.00	1.37 (0.11)	0.02 (0.03)	1.64 (0.58)
Sweden	-1.00	1.65 (0.20)	-0.01 (0.05)	0.68 (0.90)

Note: Standard errors of the estimated parameters are indicated in parentheses.

We now turn to the long-run elasticities of petrol prices in response to changes in crude oil prices. A value of 1.05 implies, for example, that producers increase the price of petrol by 1.05% if crude oil prices rise by 1%. All long-term coefficients have the expected sign. The elasticities are likely to be particularly high in the new EU member states (i.e. the Czech Republic and Hungary) but producers in Sweden and Germany tend to increase the retail prices in a comparable vein. In contrast, the pass-through rate in Italy is relatively low, while other EU member states lie in between these extremes. Our results are partly in line with findings of Arpa et al. (2006) who reported lower pass-through rates for most countries in our sample, with the exception of Czech Republic. There are few reasons for diverging results: First, the estimations in Arpa et al. (2006) might be biased as this study does not take into consideration both exchange rates and carbon costs. Second, this study does not report the standard errors of the estimated long-term parameters – this is important to aptly access the pass-through behaviour at the country level. Third, our sample covers a different period of time which is characterised through a significant increase in crude oil prices. The pass-through behaviour of producers over this time horizon might differ from period with the less pronounced price increases.

The long-term elasticities of petrol prices with respect to the carbon costs changes vary typically between 0.01% and 0.09% across the EU member states. First, it stands out that all coefficients with three exceptions have an expected sign. Second, the magnitude of the estimated coefficient is rather small as carbon costs account for a tiny share in the cost structure of the refining industry: de Bruyn et al. (2010) summarises the findings in the literature on the emissions factor for the petrol production with roughly 400 grams of CO_2 per litre. Using the net-of-taxes nominal retail prices of around 550 Euro/1000L and assuming the carbon costs of € 20/ton of CO_2[9], the share of carbon costs in total costs can be estimated at roughly 2%. The values of the estimated coefficients for the pass-through of the EUA prices (and their respective standard errors) are close to 0.02. Hence, the full pass-through (100%) is rather likely for the respective estimates.

Table 2 details the speed of the adjustments to the long-run equilibrium in the VECM at the country level. The lack of the statistical significance of the *t*-test of the loading factors indicates the presence of the long-run weak exogeneity (Masih and Masih, 1996). The adjustment coefficients are statistically significant (with few exceptions) and have the correct sign only in columns two and four, i.e. in the error correction models (ECMs) for petrol prices and carbon prices. For the former, the estimated adjustment coefficients are relatively low across the regions. For the latter, we observe some regional heterogeneity, albeit the speed of the adjustments is found to be markedly higher. Crude oil prices and exchange rates are statistically significant in most cases, but the interpretation of these results is difficult due to the wrong sign of the estimated adjustment coefficients.

Table 2: Loading factors

Countries	**Variables**			
	p_t^{pet}	p_t^{oil}	p_t^{car}	p_t^{ex}
Austria	-0.05** (0.03)	0.21** (0.07)	-1.14** (0.22)	0.08** (0.02)
Belgium	-0.16* (0.08)	0.21** (0.07)	-1.23** (0.19)	0.05** (0.02)
Czech Republic	-0.06** (0.01)	0.10** (0.04)	-0.44** (0.13)	0.01 (0.01)
Denmark	-0.17** (0.08)	0.34** (0.08)	-1.29** (0.30)	0.06** (0.02)
France	-0.04 (0.04)	0.31** (0.09)	-1.46** (0.26)	0.09** (0.02)
Germany	-0.17** (0.06)	0.22** (0.07)	-1.07** (0.20)	0.07** (0.02)
Greece	-0.27** (0.06)	0.21** (0.10)	-0.99** (0.32)	0.05** (0.02)
Italy	-0.08** (0.04)	0.25** (0.07)	-1.19** (0.21)	0.08** (0.02)
Hungary	-0.20** (0.04)	0.19** (0.09)	-0.54** (0.31)	0.06** (0.04)
Lithuania	-0.21** (0.07)	0.49** (0.13)	-1.84** (0.43)	0.06** (0.03)
The Netherlands	-0.11* (0.07)	0.29** (0.08)	-1.47** (0.24)	0.09** (0.02)
Portugal	-0.02 (0.02)	0.19** (0.07)	-0.97** (0.20)	0.08** (0.01)
Spain	-0.03 (0.04)	0.37** (0.09)	-1.46** (0.27)	0.10** (0.02)
Sweden	-0.07* (0.05)	0.21** (0.06)	-0.82** (0.20)	0.04** (0.02)

Note: Standard errors are indicated in parentheses. Asterisks "**" denote significance at the 5% critical level or better; "*" indicates significance at the 10% critical level.

The estimated short-run coefficients for crude oil prices, carbon costs and exchange rates (differenced explanatory variables) are found to be individually significant in the respective ECMs indicating the existence of the short-run causality. The highly significant short-run coefficients for passing-through crude oil prices to consumers have an expected sign in most countries in our sample (Figure 2, Appendix)[10].

In the Netherlands, Germany, France and Sweden the refining industry tends to pass on between 50% and 75% of crude oil price increases to the consumers within two weeks after a shock. Others (Austria, Belgium, Spain, Italy, Lithuania and Denmark) pass-through roughly 50% of the crude oil price increases within this time horizon. In contrast, the refining industry

[9] In most countries in our sample on September 16, 2005 (first observation in our sample).
[10] To save space we restrict the discussion of the short-term coefficients to the ECM for the petrol prices and focus only on the past changes in crude oil and EUA prices.

in Portugal is likely to pass-through only around 25%. In the remaining sectors, price shocks are likely to be borne by producers within a time horizon of two weeks. As to the estimated impact of changes in carbon costs in the ECMs for petrol prices (Figure 3, Appendix), it stands out that all significant coefficients have a negative sign. One of the interpretations of this finding might be that in the short-run producers are likely to increase prices when facing decreasing carbon costs. This is an unexpected result but given the fact the time span in our analysis is characterised through steadily decreasing prices for the EUAs the findings are not implausible. Our results indicate that these shocks are passed-through almost immediately in most countries.

In addition to our findings on the long-run causality as indicted by the significance of the error-correction terms (Table 2), we conduct a sequence of the tests to examine the short-run causality. The related tests evaluate the individual and joint significance of the lagged differences in the respective ECMs. Focusing on the ECM for petrol prices, evidence from a block exogeneity Wald tests shows that in the short run crude oil prices, carbon costs and exchange rates *jointly* Granger cause petrol prices in most countries. Besides the individual significance of the respective variables in the equation for the EUA – most importantly the impact of crude oil price differences on EUA price differences – we do not find in general an indication for a joint significance of crude oil prices, carbon costs and exchange rates in that equation.

Figure 4 and 5 plot the variance decompositions and the impulse response functions (using a standard Cholesky decomposition) for a horizon of 50 weeks.[11] The impulse response analysis largely reinforces the previous findings, particularly, that all prices typically respond positively to innovations with the exception of carbon costs. The impulse-response analysis shows that the one-time innovation has a permanent impact on petrol prices and that the long-run equilibrium in this equation is reached roughly 20 weeks after the innovation at the latest (Figure 5). According to the Figure 4, variations in petrol prices primarily occur due to their own innovations and innovations in crude oil prices. However, in Austria, Germany, France, Spain, the Czech Republic and Hungary a large fraction of petrol price changes can be explained by changes in EUA prices.

[11] The following variable ordering is assumed: POIL $\rightarrow$ PEX $\rightarrow$ PCAR $\rightarrow$ PPET. This ordering is consistent with studies using similar variables (Hüfner and Schröder, 2002, Beirne and Bijsterbosch, 2009). Crude oil prices are ordered first as the most exogenous variable in the scheme, while petrol prices are ordered as the last variable. While checking the alternative ordering (between PEX and PCAR), we found that this did not significantly change the results.

The results in this basic specification are in general found to pass the misspecification and stability tests[12]. In order to additionally test the robustness of the results in this basic model set-up, we run an alternative model specification. Moving from the four-variable model ($p_t^{pet}, p_t^{oil}, p_t^{car}, p_t^{ex}$) to the three-variable model ($p_t^{pet}, p_t^{oil}, p_t^{car}$) with p_t^{ex} as exogenous variable, the results presented for the basic model in general remain very robust. Although we do not observe any drastic variation in sensitivity of petrol prices to crude oil prices and carbon costs, we find that the estimated models do not pass (or pass very narrowly) the misspecification tests for heteroscedasticity. We therefore conclude that the three-variable model specification with exchange rates as an exogenous variable might suffer from the misspecification problems.

3 Conclusions

This paper analyses the ability of the refining sectors to pass-through carbon costs to the consumers by estimating a sequence of vector error correction models covering 14 EU member states. In comparison to the stationary VAR models, this framework allows using information "hidden" in the levels and enabling to deal with non-stationarity of the data in a proper vein. We add to the literature body by revealing that carbon costs were entering the cointegration space with petrol price, crude oil prices and exchange rates in the first trading period of the EU ETS. The estimation of the long-run pass-through coefficients for the carbon costs is thereby essential in both assessing the effects of the trial phase of the EU ETS and in designing the trading scheme in the future phases.

Our results suggest that petrol prices are elastic with respect to crude oil prices and exchange rates but inelastic with respect to the EUA prices in the long-run. The increase of the EUA prices by 1% typically leads to an increase of the petrol prices by 0.01-0.09% across the EU member states. The relatively low elasticity of the petrol prices with respect to the EUA prices is due to the fact that carbon costs account for a tiny share in the total costs of production of petrol (roughly 2%). The full pass-through (100%) is therefore rather likely for the respective estimates. As to the short-run implications, the refining sector is found to pass-through costs to the consumers rather rapidly. In 10 out of 15 countries, the refineries are found to pass-through 50% or more of crude oil price increases to the consumers within two weeks. Roughly in half of the analysed countries, producers are capable to increase petrol prices facing decreasing EUA prices over the same time horizon.

[12] See footnote 8.

We apply a sequence of tests to examine the long-run and short-run dynamic causal relationships among the variables of interest. Focusing on the ECM for petrol prices, evidence from a block exogeneity Wald tests – in addition to the evidence available on the individual significance of the lagged differences in that equation – shows that in the short run crude oil prices, carbon costs and exchange rates *jointly* Granger cause petrol prices in most countries. The variance decomposition indicates thereby that carbon costs play a significant role in explaining the variance of differenced petrol prices in Austria, Germany, France and Spain (between 10% and 20% of variance in petrol prices). In the ECM for the EUA prices, the lagged differences for crude oil prices, petrol prices and exchange rates are individually significant at the country level in the short, but the block exogeneity Wald tests cannot in general reject the hypothesis that EUA prices are *jointly* not Granger-caused by other variables. In contrast, the lagged error-correction terms in the equations for both petrol prices and carbon costs are significant and have an expected (negative) sign. This finding provides a robust indication for the existence of the long-run causal relationships running from crude oil prices, carbon costs and exchange rates to petrol prices, on the one hand, and from crude oil prices, petrol price and exchange rates to the EUA prices, on the other hand. The impulse-response analysis shows that – as expected (Lütkepohl and Reimers, 1992) – shocks do not fade away and that the long-run equilibrium in the equation for petrol prices is reached 20 weeks after the one-time innovation at the latest.

Albeit the relatively small sample poses some limitations on our analysis, we consider the results to be valid as they pass several misspecification and stability tests. The sensitivity analysis which treats the exchange rate as an exogenous variable reaffirms our conclusions on the proper specification of the basic model at the country level.

Analysing both long-term and short-term elasticities of petrol prices, we detect some heterogeneity across the EU member states in terms of how strongly and rapidly the net retail prices of Euro-95 unleaded petroleum react to changes in carbon costs. Notwithstanding this heterogeneity, our results suggest the existence of significant adverse distributional implications in the refining sector during the first trading period of the EU ETS. This is due to the generous allocation of allowances free of charge. Our central finding thereby questions the policy outcome in which emissions from the refining sector will be largely benefiting from free allocation of allowances from 2013 onwards, whereas the power sector falls fully under an auctioning regime.

4 Appendix

Table 3a: Testing for a unit root (Phillips-Perron test)

	Levels		First-differences	
Model, variables	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
Retail prices for Euro-95 unleaded petrol[13]				
$p_{pet,AT}$	-1.28	-1.36	-4.88***	-4.84***
$p_{pet,BE}$	-1.69	-1.73	-6.99***	-6.92***
$p_{pet,CZ}$	-1.10	-1.25	-3.60***	-3.56**
$p_{pet,DE}$	-1.44	-1.61	-8.26***	-8.20***
$p_{pet,DK}$	-1.79	-1.69	-7.55***	-7.51***
$p_{pet,ES}$	-1.39	-1.46	-4.65***	-4.61***
$p_{pet,FI}$	-2.59	-2.52	-11.98***	-12.25***
$p_{pet,FR}$	-1.55	-1.55	-4.84***	-4.80***
$p_{pet,GR}$	-1.55	-1.63	-5.97***	-5.93***
$p_{pet,HU}$	-0.96	-0.95	-5.04***	-4.94***
$p_{pet,IE}$	-1.20	-1.80	-8.42***	-8.20***
$p_{pet,IT}$	-1.07	-1.18	-5.05***	-5.05***
$p_{pet,LT}$	-1.25	-1.39	-5.13***	-5.04***
$p_{pet,NL}$	-1.96	-1.95	-9.12***	-9.06***
$p_{pet,PL}$	-1.45	-1.63	-2.26	-2.24
$p_{pet,PT}$	-0.95	-1.10	-4.98***	-5.01***
$p_{pet,SE}$	-1.59	-1.38	-6.82***	-6.79***
$p_{pet,UK}$	-0.99	-1.18	-3.07**	-3.05
Exchange rates				
$p_{ex,US/EU}$	-0.88	-3.31*	-9.63***	-9.58***
$p_{ex,US/CZ}$	-0.78	-3.56**	-9.61***	-9.54***
$p_{ex,US/DK}$	-0.91	-3.37*	-9.80***	-9.75***
$p_{ex,US/HU}$	-1.39	-2.27	-8.12***	-8.24***
$p_{ex,US/LT}$	-0.81	-3.24*	-9.58***	-9.56***
$p_{ex,US/PL}$	-1.55	-3.62**	-8.50***	-8.45***
$p_{ex,US/SE}$	-0.88	-3.26*	-8.45***	-8.38***
$p_{ex,US/UK}$	-0.73	-3.75**	-9.13***	-9.08***

[13] Prices for petroleum products are in national currencies.

Table 3b: Testing for a unit root (Phillips-Perron test)

	Levels		First-differences	
Model, variables	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
Crude oil price				
$p_{oil,\$US}$	-1.68	-1.65	-7.97***	-7.95***
Carbon costs[14]				
p_{car}	6.29	2.28	-6.87***	-7.50***

Note: The MacKinnon critical values across the sample are -3.52*** / -2.90**/ -2.59* for the model with a constant and -4.09*** / -3.47** / -3.16* for a model with a constant and a trend at the 1% / 5% / 10% levels of significance.

The notation * (**, ***) means the rejection of the hypothesis at the 10% (5% or 1%) significance level, respectively.

Acronyms of the variables: **AT** Austria, **BE** Belgium, **CZ** Czech Republic, **DK** Denmark, **FI** Finland, **FR** France, **DE** Germany, **GR** Greece, **IE** Ireland, **IT** Italy, **HU** Hungary, **LT** Lithuania, **NL** Netherlands, **PL** Poland, **PT** Portugal, **SE** Sweden, **SK** Slovakia, **ES** Spain and **UK** United Kingdom.

[14] To save the space we report only carbon prices which apply to the Euro countries; its counterparts in non-Euro EU Member States are also found to be integrated of order one at usual significance levels.

Table 4: Number of cointegrating relations

	Cointegration test specification	**VAR lags**
Regions	Intercept and trend in CE, no trend in VAR	
Austria	1 [57.46]**	2
Belgium	1 [59.43]**	2
Czech Republic	1 [41.04]**	1
Denmark	1 [36.60]**	1
Finland	0 [27.80]	1
France	1 [56.81]**	2
Germany	1 [61.86]**	2
Greece	1 [42.44]**	1
Ireland	1 [39.23]**	2
Italy	1 [57.73]**	2
Hungary	1 [42.66]**	1
Lithuania	1 [48.60]**	2
The Netherlands	1 [64.27] **	2
Portugal	1 [49.48]**	2
Spain	1 [62.67]**	2
Sweden	1 [32.55]**	1

Note: In parentheses, we indicate the maximum eigenvalue statistics. In 15 out of 16, the null hypothesis of no cointegrating vector against the specific alternative of a unique cointegrating vector is rejected at 5% significance level ("**"). The critical value at the 5% significance level is 32.11832. We do not include any exogenous variables into the tests.

Figure 2: The estimated coefficients of past changes in crude oil prices in the ECM for petrol prices[15]

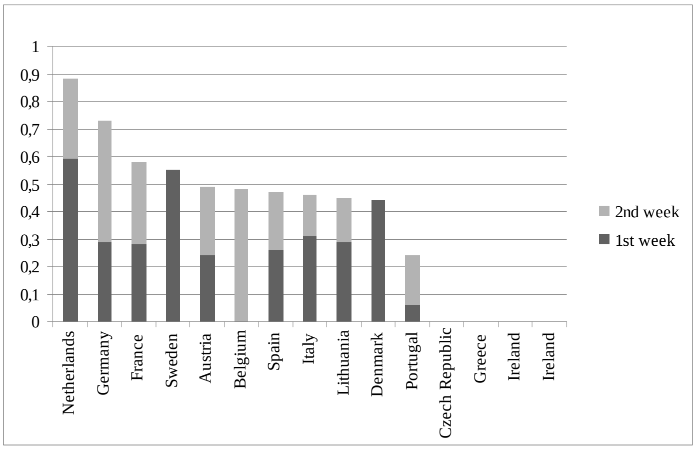
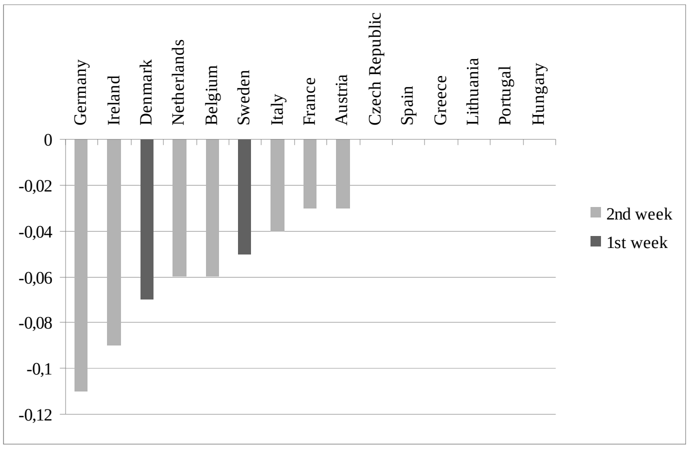


Figure 3: The estimated coefficients of past changes in EUA prices in the ECM for petrol prices[16]



[15] We plot only the statistically significant estimates with the expected sign.
[16] We plot only the statistically significant estimates.

Figure 4: Variance Decomposition (in the equation for petrol prices)

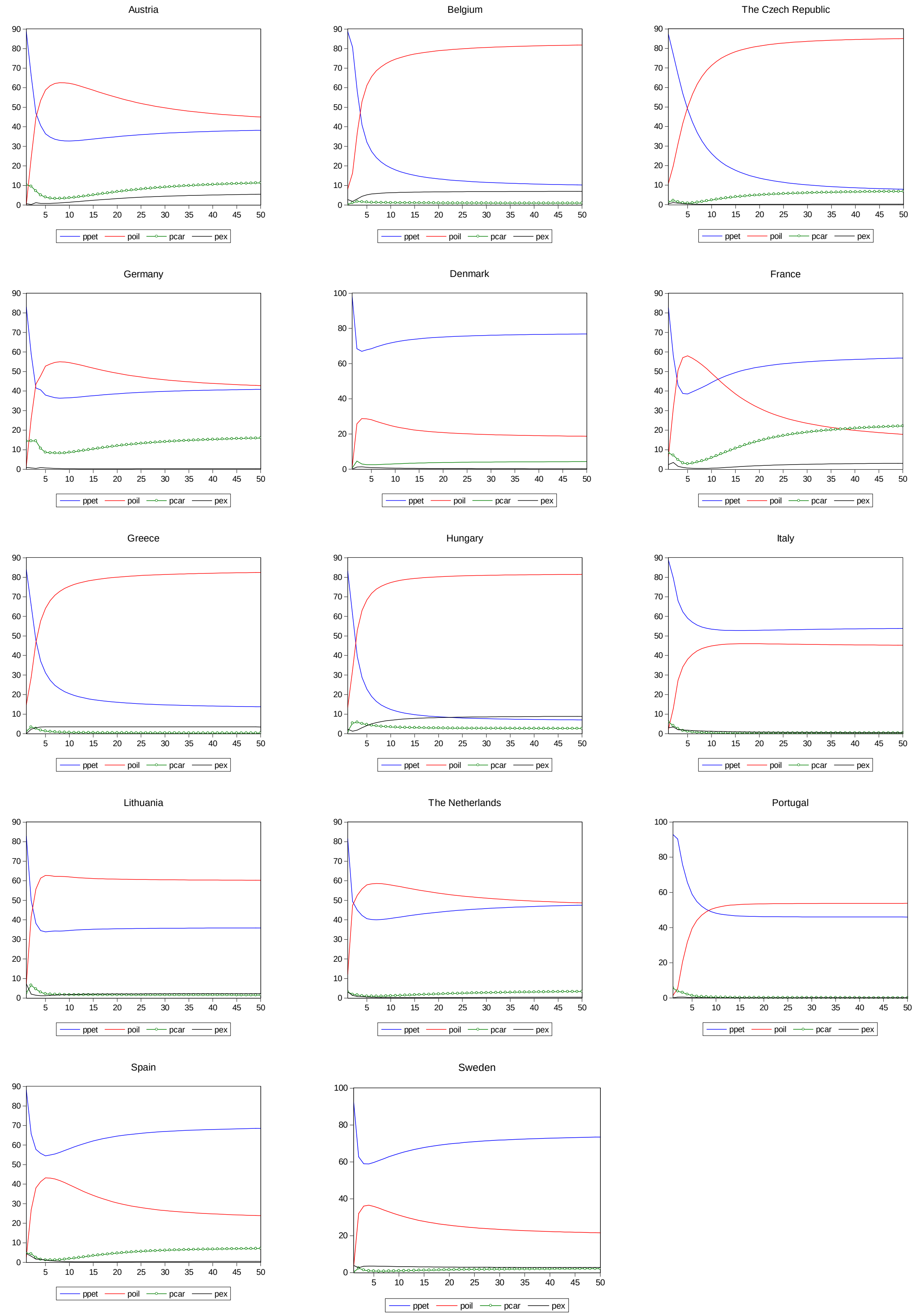
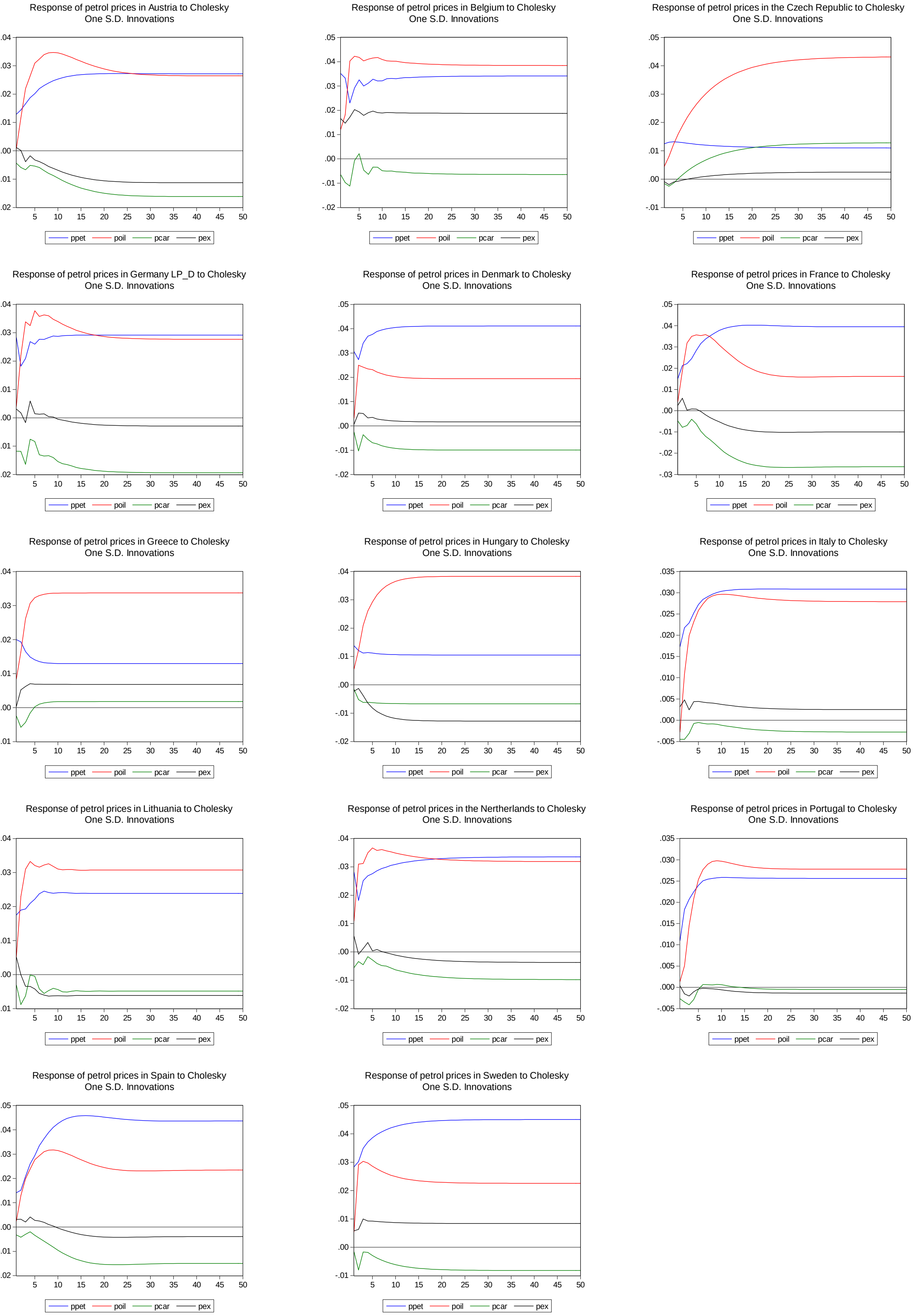


Figure 5: Impulse-Response Function (in the equation for petrol prices)



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