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Price dynamics in European petroleum markets

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ABSTRACT

This paper analyses horizontal and vertical price dynamics in the EU petroleum markets. The results indicate that the cross-country price differentials have significant impact on the local price adjustments. We investigate the cross-national price spill-overs and find that the extent of the welfare transfer due to asymmetric price transmission, when analysed in a cross-country setting, is less pronounced than claimed in previous contributions in this area. We also find empirical evidence, although indirect, for the politically charged concept of "fuel tourism", using a pan-European cross-product time series dataset.

1. Introduction

1.1. Motivation

Modelling the impact of crude oil prices on retail petroleum prices continues to receive significant attention in the applied literature, particularly with respect to asymmetries in price transmission. Understandably, the focus is on asymmetries that involve a slower adjustment of downstream (retail) prices to increases in upstream (crude oil) prices decreases, since they result in the marketable idea of welfare transfers (from ordinary drivers downstream to "Big Oil" companies upstream — see inset in Fig. 1).

Up until now, the analysis in the large majority of the literature on price transmission has been limited to one-country setting and has neglected the notion that disequilibria in neighbouring countries can affect home prices. In other words it has neglected the horizontal (multinational) dimension of the transmission effect. This dimension is usually associated with the notion of the "fuel tourism" i.e. cross-country purchases of petroleum products (mainly motor spirits), which given the EU-wide differences in energy taxation (see European Parliament, 2003)[2], represent a significant drain on budget revenues in high-petroleum-tax countries. The significance of energy taxes and the dangers associated with their decreases in the European context cannot be understated, since:

> (…) fuel and vehicle taxes have usually been introduced for fiscal rather than environmental reasons. (they) represent a much higher share of GDP in EU countries than in most other OECD countries (…)
>
> Joumard (2002, p. 112)

Given the above, it is hardly surprising that the issue of decreased energy taxation due to adverse pricing dynamics receives significant political attention — House of Commons Report (2001). The more general issue of cross-border shopping as a result of arbitrage opportunities has been addressed in the tax competition literature (e.g. see Kanbur and Keen, 1993). The theoretical results of this area of literature have been used to explain cross-border shopping in cigarettes, alcohol and petrol, driven by price differentials across different countries in only a limited number of empirical contributions (for recent examples see Banfi et al., 2005, for Europe, and Devereux et al., 2007, for the US). Data obtained from EUROSTAT confirms that a number of countries have exceptionally

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[2] Directive 2003/96/EC.

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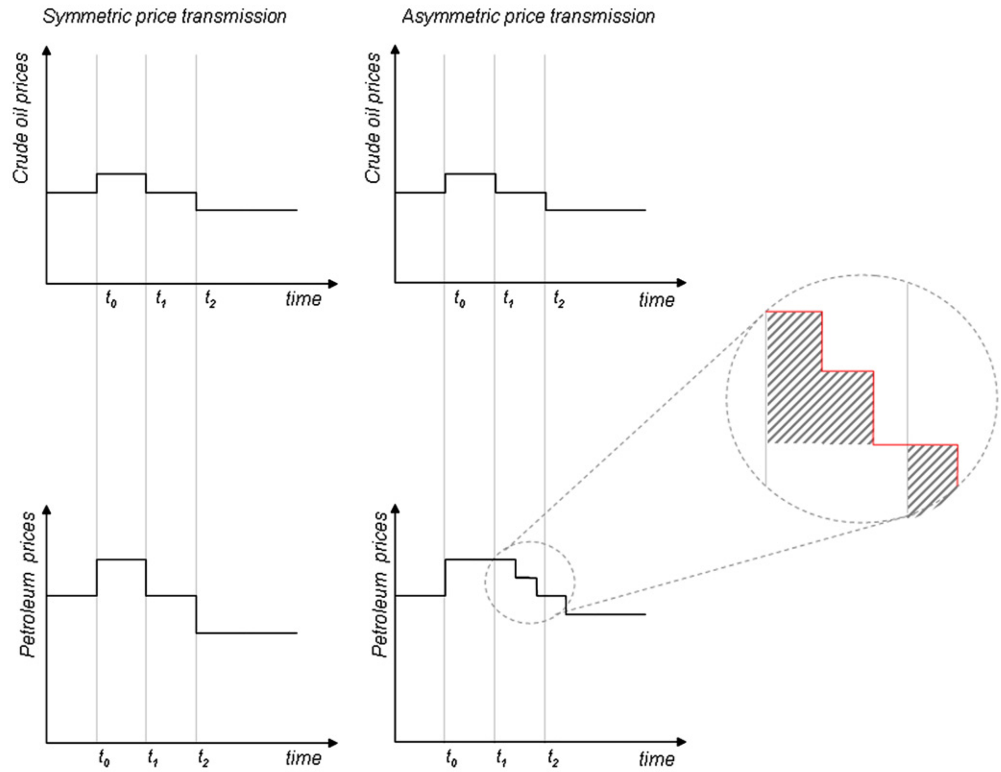

Fig. 1. Example of asymmetries in price transmission. Shaded area represents per-unit welfare transfer from downstream to upstream agents.

large consumption of motor spirit per locally-registered vehicle, which might indicate significant cross-border purchases. Table 1 presents the 2000 data on both variables and compares them to the median of the sample. The most visible outliers include Luxembourg and Ireland.[3]

This paper analyses cross-country dynamics in the EU petroleum markets using a multi-product and multi-country framework, with a focus on price dynamics rather than on tax competition issues, due to the lack of suitable data to match our extensive retail price dataset. The purpose of the analysis is to check for possible differences between EU countries and to assess the impact that these differences have on price transmission, particularly from the point of view of asymmetric price transmission. Due to the characteristics of the data available for this work, the focus of the analysis is the short-term adjustment to deviations from long run equilibrium. Given the fact that tax adjustments take place rather infrequently the empirical analysis of tax competition issues would have to focus on long-term changes but this approach would not allow us to capture the nature of the day-to-day adjustments made by European drivers, particularly those who have to travel a short distance to obtain petrol at better prices from neighbouring countries. This type of behaviour has been extensively discussed by Banfi et al. (2005). Our approach involves a dynamic analysis which introduces the previously neglected time dimension into the adjustment of prices with respect to price differentials.

Our analysis is developed in two stages, with the first involving analysis of cross-country linkages and focused on testing for the existence of phenomena of cross-border shopping, and the second focused on its impact on asymmetries (rigidities) in price transmission. By doing so this study links two strands of literature: the one on cross-national price dynamics (summarised in Section 1.2) and the one on asymmetric price transmission (briefly summarised in Section 1.3).

The empirical analysis relies on a dataset covering 25 countries and 7 products, as described in Section 2.1. In Section 2.2 we analyse the price series and apply cointegration techniques to check for the presence of long-run crude oil–end product relationship to which retail prices revert. In Section 2.3 we check for the presence of cross-country dynamics and link them with price differentials, and in Section 2.4 we check how the results of the typical non-linear testing framework change once the cross-country effects are included in the modelling framework. Conclusions and suggestions for further research follow.

1.2. Literature on cross-country dynamics

Journalists like to paint the romantic picture of drivers travelling to neighbouring low-tax countries in order to tank-up and avoid high taxation levied at home. Politicians and environmentalists are aware of the implications of this behaviour in terms of tax revenues and local levels of pollution. For instance, the European Parliament (2002) deemed it important enough to vote on harmonisation of petroleum taxation, while an Expert Group on the UN Framework Convention on Climate Change (1997) claimed that such trade might be even responsible for increased pollution and CO_2 emission in the low-tax EU countries.

For North America, Slade (1992) reported a shift in demand from Canada to USA that followed a reverse in price differentials between those two countries. Slade (1992, p. 263) claimed that the resulting "fuel tourism" was so significant that it resulted in a price war and local market disruptions both in the USA and Canada. Devereux et al. (2007), on the other hand, provide empirical evidence on the extent of tax competition between US states but find no evidence of horizontal tax competition on petrol in the US. They claim that this outcome should be expected due to the high cost of cross-border shopping for petrol.

[3] Although the border between the UK and Ireland is confined to a thinly populated areas of Northern Ireland Fitz et al. (2008, Box 5.4, p. 110) estimate that:

> (…) in 2005 between 5 and 9 per cent of total petrol sales in Ireland were consumed abroad. The figure for diesel is 15 to 20 per cent.

Similarly, Tax Strategy Group (2003, p. 14) claims that:

> While the relative strength of the Euro has narrowed the differential with fuel prices in the North, there is still a considerable incentive for so called fuel tourism.

Table 1
Ratio of inland market consumption of motor spirits (000s of tonnes) to stock of passenger cars (000s) in selected EU countries year 2000

	Consumption (*A*)	Stock of cars (*B*)	Ratio (*A*/*B*)
Austria	1980	2598	0.762
Belgium	2248	2732	0.823
Cyprus	206	237	0.869
Czech Republic	1861	3049	0.610
Denmark	1970	1748	1.127
Estonia	284	416	0.683
Finland	1837	1903	0.965
France	13,716	18,080	0.759
Germany	28,832	37,406	0.771
Hungary	1340	2128	0.630
Ireland	1494	1146	1.304
Italy	17,227	26,195	0.658
Luxembourg	582	193	3.016
Malta	61	151	0.404
Netherlands	4036	5346	0.755
Poland	5004	9043	0.553
Slovakia	808	779	1.037
Spain	8334	12,747	0.654
Sweden	3982	3804	1.047
United Kingdom	21,655	21,233	1.020
Median	1975	2665	0.741

Source: Eurostat.

Cross-border shopping of this kind is only to be expected in the EU given the cross-national differences in taxation of petroleum products (see Newbery, 2001 for details) and decreasing barriers to movements within EU, mainly due to the removal of or the reduction in passport and custom controls (seeWilliams, 1996 for an overview of 1995 Schengen accord and similar policies).

Despite the tax and environmental implications of "fuel tourism", the cross-country dynamics have received relatively little attention from applied energy economists. The notable exceptions are described below.

Rietveld et al. (2001) analyse the consequences of spatial distribution of fuel taxes, and cross-border petrol purchases between the Netherlands and Germany. The results of a drivers' survey indicate that approximately 30% of the Dutch drivers fuel in Germany at the time which confirms the view that "fuel tourism" is indeed widespread.

Bentzen (2003) analyses retail petroleum price convergence in 20 OECD countries over the 1978–2002 period with the help of standard time series techniques (existence of common trends using Dickey Fuller (DF) tests). The results indicate that there is very little or no support for the notion of price convergence either in nominal or purchasing-power-parity-adjusted prices. However, no detailed analysis of cross-border purchases was performed in this study.

Michaelis (2004) analyses the incentives for "fuel tourism" and shows that even comparably small price differences induce a strong incentive for cross-border purchases which could potentially be utility-decreasing. The author concludes that it is necessary for the drivers to learn the complete private costs of purchasing the fuel abroad. Unfortunately, the analysis is not backed-up by estimation and relies mainly on the simulations based on price differentials.

Dreher and Krieger (2008) analyse the prices of petroleum, diesel, gasoil and fuel oils in the old EU-15 countries over the period 1994–2005. Using univariate and panel techniques they show consumer price arbitrage (i.e. arbitrage between retail tax-inclusive prices) to be weaker than producer price arbitrage (i.e. arbitrage between retail prices net of taxes). This is hardly surprising as the latter requires both tax convergence and realisation of arbitrage opportunities by the drivers while the former does not depend on synchronisation of taxes. The results do not focus on the pattern of the adjustment or on whether the adjustments differ between high and low-price countries.

Banfi et al. (2005) analyse "fuel travels" to Switzerland from Germany, France and Italy. Based on the estimates of a panel demand model, they argue that as long as price differentials persist the foreign drivers cannot be easily convinced to stop fuelling in Switzerland. The simulations indicate that from 1985 to 1992 "fuel tourism" accounted for about 15% of overall petrol sales in the three neighbouring regions, falling to about 7% from 1992 to 1997.

1.3. Literature on price transmission

Having started with the contributions of Bacon (1991) and Kirchgassner and Kubler (1992), the analysis of vertical price dynamics continues to receive significant attention in the applied literature (see Meyer and Cramon-Taubadel, 2004; Frey and Manera, 2007; Radchenko, 2005 for recent literature reviews), but research in this area continues to rely on a single-country, single-product framework. The notable exceptions are briefly described below.

Indejehagopian and Simon (2000) focus on the German and French heating oil market and attempt to link them via cointegration techniques to Brent prices and the respective currency-USD exchange rates. The results obtained using January 1987–December 1997 data, confirm the existence of a long-run relationship between the price series and the predominance of the Rotterdam spot market. The analysis of exogeneity revealed that the German market directly affects the Rotterdam markets (feedback relationship), while the French market follows both German and Rotterdam markets. Interestingly, the results indicate that the observed asymmetry is caused by the exchange rates but not by the upstream (Rotterdam) prices.

Bremmer and Christ (2002) analyse the effects of cross-section data aggregation on the transmission between weekly prices of:

- retail and spot unleaded petrol;
- WTI crude oil prices.

over the period January 1991–May 2002. In order to analyse the effects of spatial aggregation, the authors analyse the prices aggregated across the following regions:

- the USA as a whole;
- five multi-state regions;[4]
- three sub-regions;
- five states (California, Colorado, Minnesota, New York and Texas);
- six cities (Chicago, Denver, Houston, Los Angeles, New York City and San Francisco).

The testing strategy assumes that the vertical price dynamic follows an Error Correction Process in which the downstream (retail) price adjusts to the long-run equilibrium given by the upstream (crude oil) prices via short-run changes (i.e. impact of lagged changes — Reilly and Witt, 1998) and long-run adjustment (i.e. lagged residuals from the level equation) to the disequilibrium. This could be summarised as:

$$\Delta y_t = \alpha_0 + \sum_{l=1}^{n} \alpha_l \Delta y_{t-1} + \sum_{j=0}^{m} \beta_j \Delta x_{t-j} + \gamma(y_{t-1} - \delta_0 - \delta_1 x_{t-1}) + \nu_{\boldsymbol{t}} \tag{1}$$

where:

- y_t are the downstream prices which are linked to upstream prices x_t;
- Δ is the difference operator;
- $y_{t-1} - \delta_0 - \delta_1 x_{t-1}$ is the disequilibrium proxy, i.e. residuals $\epsilon_{\boldsymbol{t}}$ from the level price equation $y_t = \hat{\delta}_0 + \hat{\delta}_1 x_t$, lagged one period.

The analysis of vertical dynamics involves splitting the series in Eq. (1) in a way that allows for different adjustments to positive and negative shocks in the system (following Wolfram, 1971). This results in:

$$\begin{aligned} \Delta y_t = {} & \alpha_0 + \textstyle\sum_{j=0}^{m+} \beta_j^+ (\Delta x_{t-j})^+ + \sum_{i=0}^{m} \beta_i (\Delta x_{t-i}) \\ & + \gamma^+ (y_{t-1} - \delta_0 - \delta_1 x_{t-1})^+ + \gamma (y_{t-1} - \delta_0 - \delta_1 x_{t-1}) + \nu_t \end{aligned} \tag{2}$$

where $(\ldots)^+$ is the slope dummy (Heaviside indicator) set to unity when the argument is positive, zero otherwise.

[4] The East region, the Midwest region, the Gulf region, the Rockies region and the West region.

In such a setting, the asymmetries or rigidities in price transmission persist when the coefficients on the slope dummies are significantly different from zero. If that's the case, the adjustment to increases and decreases is asymmetrical and prices respond (in absolute values) differently to upstream increases and decreases.

For example, in Eq. (2) the coefficients on the dummy variables are significantly different from zero, the difference between negative and positive adjustment is statistically significant. This difference is equal to β_j^+ for a short-run adjustment and γ^+ for a long-run adjustment. Since the positive disequilibria persist when the actual price is above its long-run equilibrium value, they coincide with times of high-margins. It follows that, when the coefficient γ^+ is positive, the adjustment speed is *lower* at times of increased margins as compared to times of constant margins. These results imply a welfare transfer, as described in Section 1 and depicted in Fig. 1.

Unfortunately, the modelling techniques discussed above are partially incorrect (Wolfram's split of first differences was questioned by Cramon-Taubadel and Meyer, 2001) and disregard the possible cross-regional effects (although the authors admit these are likely to occur and affect transmission).

Galeotti et al. (2003) analyse the transmission between monthly prices of:

- international c.i.f. crude oil;
- Rotterdam LP (f.o.b. spot);
- the appropriate exchange rate (necessary as crude oil prices are expressed in USD);
- local retail leaded petrol prices;

in France, Italy, Spain, and the UK (for the period January 1985–June 2000) and Germany (for the period January 1985–February 1997). The study analyses the transmission between crude oil and wholesale tiers, wholesale and retail tiers, and indirect transmission from crude oil to retail tiers. The analysis begins with Augmented Dickey Fuller (ADF) tests for the presence of the unit root in level variables and cointegration tests. The results indicated that the residuals were stationary, which was taken as a proof that all series in question do cointegrate.

Testing the null of no asymmetries in transmission is performed for all tiers described above using Eq. (2), but with $m^+ = m = 1$, i.e. assuming that the short-run adjustment was complete after only one month. The results indicated widespread presence of non-linearities in price transmission. However, it is important to notice that the lag structure imposed allows only for the one-month short-run adjustment, which might lead to over-estimation of other coefficients (e.g. long-run elasticities) and under-estimation of the short-run adjustment.[5]

The cointegration tests performed included only ADF tests on the residuals from the level equation. As indicated by Cook et al. (1999), when testing for asymmetries using Eq. (2), traditional ADF tests should be accompanied by the tests for the joint significance of the ECM terms, split in the Wolfram's manner. Since the coefficients on ECM terms are not statistically different from zero at 5% and 1% — Galeotti et al. (2003, p. 21), the cointegration between variables in question for some countries (e.g. Italy and the UK) is dubious. Given the above, the results are not necessarily credible. Again, despite using multinational data, the analysis is done in a piece-wise manner disregarding the cross-country dynamics.

Ye et al. (2005) analyse regional dynamics in the USA over the period January 2000–December 2003 for five Petroleum Administration for Defence Districts, the state of California and US. The analysis is focused on the asymmetries in price transmission and the only finding related to intra-regional dynamics was that individual trade between regions might be present as the speed of adjustment estimated for one region is higher than the weighted average of corresponding values for the sub-regions.

Table 2
Products analysed

Product	Name	Usage	Source
Unleaded petrol	EURO	Motor spirit	Crude oil
Diesel oil	DIESEL	Motor spirit	Crude oil
Heating oil	HGASOIL	Heating	Crude oil
Liquefied petroleum gas	LPG	Motor spirit, cooking	Natural gas/crude oil
Fuel oil — high sulphur	RFO.2	Heat/electricity	Crude oil
Fuel oil — low sulphur	RFO.1	Heat/electricity	Crude oil
Lead replacement petrol	SUPER	Motor spirit	Crude oil

2. Empirical analysis

2.1. Data

The data used for our empirical analysis involves three sets of weekly series:

- USD nominal prices of Brent crude oil (denoted xBrent) which was found to be the price leading crude oil for European Union — Hagströmer and Wlazlowski (2007);
- *k*-th country's net-of-taxes nominal retail prices for:
  - unleaded petrol ($y_t^{(\mathrm{EURO},k)}$);
  - Diesel fuel ($y_t^{(\mathrm{DIESEL},k)}$);
  - heating oil ($y_t^{(\mathrm{HGASOIL},k)}$);
  - Lead replacement petrol ($y_t^{(\mathrm{SUPER},k)}$);
  - Liquefied Petroleum Gas — LPG ($y_t^{(\mathrm{LPG},k)}$);
  - two kinds of heavy oils (low and high sulphur) ($y_t^{(\mathrm{RFO.1},k)}$ and $y_t^{(\mathrm{HRFO.2},k)}$);
- exchange rates between *k*-th country's local currency and USD, necessary as crude oil prices are quoted in USD (ex_t^k).

Retail prices were obtained from the OilBulletin published by the European Commission. They cover 25 EU countries, i.e. Austria (AT), Belgium (BE), Cyprus (CY), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), United Kingdom (UK), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Lithuania (LT), Luxembourg (LU), Latvia (LV), Malta (MT), Netherlands (NL), Poland (PL), Portugal (PT), Sweden (SE), Slovenia (SI) and Slovakia (SK). When we analyse the international setting, in Section 4, i.e. countries which border countries for which the data is available, this results in the total of 71 cases of which 30 for the EU-15 countries, whereas the products analysed are summarised in Table 2.[6]

The length of period covered differs on a country and product basis. The longest sample for the EU-15 countries[7] stretches back to January 1994, while the data for the EU-10 countries[8] starts in mid-2004. All series end in December 2005.

Data on the exchange rates between local EU currencies and USD at relevant times were obtained from DataStream. The data follow the official exchange rates until the introduction of Euro (January 2002), after which the exchange rate follows the EUR/USD exchange rate. The quotes were taken for the same (or the earliest available) day as the crude oil data. The prices expressed in Euro were converted to the

[5] This seems to be supported by the fact that the γ coefficients on the error term are greater than unity. In the traditional one-regime ECM, adjustment speed greater than unity indicates that the relationship between prices is not stable, but rather explosive. The introduction of the second regime might address that.

[6] It was assumed that the UK borders another EU country — Ireland. While this is might be questioned, recent research into integration of UK energy market (gas) into continental network — Panagiotidis and Rutledge (2007) suggests that the economic integration had already taken place, even prior to the physical one.

[7] The EU-15 countries are: Austria, Belgium, Denmark, Germany, Finland, France, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK.

[8] The EU-10 countries are: Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Slovenia, Slovakia.

original currencies using fixed parities established by the European Central Bank.

Using the standard ADF tests, all series were found to be integrated of order one.[9] It was assumed that the price discovery emanates from the larger, more liquid markets where trading volume is concentrated — e.g. Adrangi et al. (2001).

2.2. Cointegration

Since the series in question are integrated of order one, they have to be analysed in the cointegrating framework — Maddala and Wu (1999). Only when a common stochastic trend between the series in question exists, the possibility of spurious regression is rejected and an economically valid link between crude oil and energy product prices can be identified.

As specified by Engle and Granger (1987), cointegration implies an error correction model mechanism, which describes short and long run responses of prices to external shocks and allows for testing for endogeneity of the variables. Intuitively, variables that do react to shocks in other variables should be modelled on the left-hand side, while those which remain exogenous (determined outside the system), should be treated as explanatory and the model should be conditioned upon them.

As the first step in the analysis, the following cointegrating equation was estimated for every crude oil-product pair.

$$\ln\left(y_t^{(j,k)}\right) = \alpha_{(j,k)} + \beta_{(j,k)}\ln(x) + \gamma_{(j,k)}\ln\left(ex^k\right) + \epsilon_t \tag{3}$$

where:

- j stands for product;
- k stands for country.

For every equation, the Phillips–Ouliaris Z_α test for cointegration was conducted, under the null hypothesis of no cointegration, the long truncation parameter ($n/30$) and a constant.[10] For product-crude pairs for which the null of no cointegration was rejected at 5%, the following VAR(p) model was estimated:

$$B(\mathfrak{L})\boldsymbol{z_t} = \boldsymbol{z_t} - \Phi_1\boldsymbol{z_{t-1}} - \ldots - \Phi_p\boldsymbol{z_{t-p}} = \epsilon_t \tag{4}$$

where:

- $B(\mathfrak{L})\boldsymbol{z_t}$ is the lag polynomial;
- $\boldsymbol{z_t} = (\ln(y_t^{(\mathrm{Product,Country})}, \ln(x), \ln(ex^{\mathrm{Country}}))'$ is the column vector of the variables (per country, per product);
- ϵ_t is the disturbance vector.

The VAR model was used to confirm the results of the test for cointegration with the help of eigenvalue and trace tests — i.e. rejection the null of $r = 0$ and failure to reject $r \le 1$ and $r \le 2$. These results should be interpreted as a confirmation that the relationship between retail prices, crude oil prices and exchange rate is not spurious.

The only remaining part is to establish the direction of the transmission and its properties. As the next step, Eq. (4) was re-parameterised to the VECM model, where:

$$\Delta\boldsymbol{z_t} = \boldsymbol{\Pi}\boldsymbol{z_{t-1}} - \sum_{i=1}^{p-1}\Gamma_i\Delta\boldsymbol{z_{t-i}} + \epsilon_t \tag{5}$$

For the purposes of this study specified in Section 1 it is necessary to examine the properties of the $\boldsymbol{\Pi}$ matrix, which contains the information about the dynamic stability of the system. After ascertaining the presence of one cointegrating vector in the system, the matrix in question can be normalised and re-written as $\boldsymbol{\Pi} = \alpha\beta'$. In this setting, β contains the cointegrating vector and α represents the speed of adjustment from the errors $(\beta'\boldsymbol{z_{t-1}})$ towards the long-run equilibrium. If the coefficient is zero in the particular equation, that variable is considered to be weakly exogenous, i.e. determined outside the system and driving the retail prices.

2.3. Cross-country links

A significant drawback of the testing framework provided by the VECM model (5) is that cross-country effects cannot be readily tested, unless some restrictions are placed on other parts of the model. As an example consider a situation when one is interested in analysing the pricing system in the two-country framework, and test whether the retail prices in the respective countries affect each other. In such a setting, the standard solution for testing the null hypothesis of no effect of foreign retail prices on domestic retail prices involves estimation of:

$$B(\mathfrak{L})\boldsymbol{z_t^*} = \boldsymbol{z_t^*} - \Phi_1\boldsymbol{z_{t-1}^*} - \ldots - \Phi_p\boldsymbol{z_{t-p}^*} = \epsilon_t \tag{6}$$

where:

- country* stands for countries bordering the country analysed;
- $\boldsymbol{z_t^*} = (\ln(y_t^{(\mathrm{Product,Country})}), \ln(y_t^{(\mathrm{Product,Country^*})}), \ln(x), \ln(ex^{\mathrm{Country}}), \ln(ex^{\mathrm{Country^*}}))'$ is the column vector of the variables (by country, its neighbours, and by product);

and testing linear restrictions on Eq. (6) in the form of a vector with zero values for the foreign prices and ones otherwise — $(1,0,1,1,1)'$. Unfortunately, this specification restricts all other effects (such as marginal effects of crude oil and the exchange rate) to be of equal magnitude, which is often implausible.

In this section we deal with a situation similar to the example presented above, as we are interested in establishing whether disequilibria in prices abroad could affect prices at home. In particular, we want to verify the anecdotal evidence about the potential impact of high petrol prices on cross-border purchases, as a result of cross-country retail price differentials.

The reasoning is that if a bordering country has constantly higher prices, a certain portion of users from that country regularly purchase petrol abroad and this is reflected via aggregated demand in the home country's prices. This portion of total demand is assumed to be constant and cannot be distinguished from domestic demand based on aggregated data. However, this demand is likely to increase when prices of products abroad increase and are close to their long-run equilibrium. This phenomenon is unlikely to be driven by variations in the level of taxation, which are usually pre-announced and predictable, and will affect the long-term equilibrium of petrol prices, but rather by unexpected changes in market conditions which will generate short-term adjustment by petrol retailers.

In order to test for the presence of such a pattern and overcome the restrictions of the VAR framework described above, we estimated the auxiliary ECM model of the following form:

$$\Delta\ln\left(y_t^{(j,k)}\right) = \pi^{(j,k)}\hat{\epsilon}_{t-1}^{(j,k)} + \sum_{k^*=1}^{n^*}\pi^{(j,k^*)}\hat{\epsilon}_{t-1}^{(j,k^*)} + \sum_{i=0}^{p}\iota_i^{(j,k)}\Delta\ln\left(ex_{t-i}^k\right) + \sum_{i=0}^{q}\kappa_i^{(j,k)}\Delta\ln(x_{t-i}) + \nu_t \tag{7}$$

where:

- k^* describes the neighbourhood of the country k, i.e. other countries from the sample that border country k, n^* denotes the number of these countries;

[9] Detailed results for so many series would require a large amount of space, so the results of the tests are not reported here — they can be provided by the authors on request.

[10] Z_α test is similar to typical ADF and Z_t tests, i.e. it is also based on residuals from level estimation. However it has slower rate of divergence and better small-sample properties, i.e. higher power — Phillips and Ouliaris (1990).

Table 3
Results of the cross-country analysis for unleaded petrol

	AT	BE	DE	DK	ES	FI	FR	UK	IE	IT	LU	NL	PT	SE
AT														
BE			*0.063*				*0.026*				**0.025**	*−0.038* *		
DE	**0.072** ***	**−0.024**		*0.025*			*0.005*				**0.028**	*0.000*		
DK			**−0.015**											
ES							*−0.039* *						*0.049* *	
FI														**0.002**
FR		**0.077**	**−0.119** **		**0.045** ***					*0.038* ***	**−0.005**			
UK									**0.043** **					
IE								*−0.056* ***						
IT	**−0.044** *						**−0.093** ***							
LU		*−0.022*	*0.076*				*0.124* ***							
NL		**0.298** ***	**0.316** ***											
PT					**−0.017** ***									
SE						*0.129* ***								

Notes:
- Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
- Home countries are represented in columns. Rows represent neighbouring countries.
- Significance levels:*significant at 10%, **significant at 5%, *** significant at 1%.
- AT — Austria, BE — Belgium, DE — Germany, DK — Denmark, ES — Spain, FI — Finland, FR — France, UK — United Kingdom, IE — Ireland, IT — Italy, LU — Luxembourg, NL — Netherlands, PT — Portugal, SE — Sweden.

- $\hat{\epsilon}_{t-1}^{(j,k)}$ are lagged residuals from the level equation $\hat{\epsilon}_t^{(j,k)} = \ln(y_t^{(j,k)}) - \hat{\alpha}_{(j,k)} - \hat{\beta}_{(j,k)}\ln(x) - \hat{\gamma}_{(j,k)}\ln(ex^k)$ for country k and product j;
- $\hat{\epsilon}_{t-1}^{(j,k^*)}$ are lagged residuals from the level equations $\hat{\epsilon}_t^* = \ln(y_t^{(j,k^*)}) - \hat{\alpha}_{(k^*,\ j)} - \hat{\beta}_{(k^*,\ j)}\ \ln(x) - \hat{\gamma}_{(k^*,\ j)}\ln(ex^{k^*})$ for the all the countries that border country k, i.e. k^* and product j;

In the setting described above, the focus is on the π and π^* coefficients. In the traditional one-product setting, the $\pi^{(j,k)}$ coefficients represent the adjustment of the system towards the long-run equilibrium after a disequilibrium. In the setting given by Eq. (7), the $\pi^{(j,k^*)}$ coefficients show the response of the local prices to disequilibria in neighbouring countries. If the coefficients are positive it means that local prices increase when disequilibria in the neighbourhood are positive, i.e. when the actual prices in neighbouring countries are above their long-run equilibrium levels. Intuitively, this could lead to an increase in cross-border purchases, thus resulting in increases in the so-called "fuel tourism" and in demand in the low-price/tax country.[11]

2.4. Asymmetries in price transmission

As the last step, the traditional tools used to test for asymmetries in price transmission and described in Eq. (2) were augmented to account for cross-country spillover effects captured by Eq. (7). In such setting the following model was estimated:

$$\Delta \ln\left(y_t^{(j,k)}\right) = \sum_{i=0}^{p} \iota_i^{(j,k)} \Delta \ln\left(ex_{t-i}^k\right) + \sum_{i=0}^{q} \kappa_i^{(j,k)} \Delta \ln(x_{t-i}) + \pi^{(j,k)} \hat{\epsilon}_{t-1}^{(j,k)} + \pi^{+(j,k)} \hat{\epsilon}_{t-1}^{+,(j,k)} + \nu_t \quad (8)$$

In this setting the focus is on the parameter $\pi^{+\,(j,k)}$ which captures the asymmetries in price transmission. As described in Section 1.3, if the disequilibrium is positive, the coefficient on the dummy $-\ \hat{\epsilon}_{t-1}^{+,(j,k)}$ gives the measure of asymmetry in transmission with positive values occurring when the asymmetry involves a welfare transfer to companies upstream and negative values occurring when prices fall faster than they rise, therefore causing a welfare transfer to final customers downstream.

Then, the results are compared to those obtained when using the model that accounts for the cross-country effects (i.e. Eq.(7)). This results in:

$$\Delta \ln\left(y_t^{(j,k)}\right) = \sum_{i=0}^{p} \iota_i^{(j,k)} \Delta \ln\left(ex_{t-i}^k\right) + \sum_{i=0}^{q} \kappa_i^{(j,k)} \Delta \ln(x_{t-i}) + \pi^{(j,k)} \hat{\epsilon}_{t-1}^{(j,k)} + \pi^{+(j,k)} \hat{\epsilon}_{t-1}^{+,(j,k)} + \sum_{k^*=1}^{n^*} \pi^{(j,k^*)} \hat{\epsilon}_{t-1}^{(j,k^*)} + \nu_t \quad (9)$$

In such model, the typical tools for testing for asymmetries (i.e. whether the coefficients $\pi^{+(j,k)}$ are significantly different from zero) are accompanied by tools that allow for cross-country dynamics and are captured by the $\pi^{(j,k^*)}$ coefficients.

3. Discussion of results

3.1. Cross-country links

In the majority of cases, crude oil was found to have a long-run equilibrium relationship with all the final products. This result is consistent with previous research (see Asche et al., 2003; Gjolberg and Johnsen, 1999 for examples of analysis on different market levels and different countries).

The results of the estimation of Eq. (7) with the p and q parameters set equal to 4 (one-month coverage) are presented in Tables 3–8.[12] To ease the comparisons the prices were ordered by their tax-inclusive, common-currency (USD) values, averaged over the available data. The resulting pattern indicates that the fully-loaded prices are highest in the Netherlands and lowest in the new-EU members from Eastern Europe.

The signs of the $\pi^{(j,k^*)}$ coefficients and the comparison of average prices over the sample size reveal that in the countries with lower all-inclusive prices compared to their neighbours retail prices increase when the prices in the neighbouring countries are above their long-run equilibrium level. This fits the stylised story of drivers travelling abroad to buy cheaper petrol and therefore affecting demand conditions in neighbouring countries.

[11] Obviously, this can occur only when *after-tax* prices in a neighbouring country are higher than in the home country so that such trade is profitable for most users. The tax portion of the retail price is irrelevant for some users (via VAT reimbursement), but the majority of buyers consider only fully-loaded prices. Relative levels of fuel taxes represent another relevant driver of cross-border purchases which is not captured directly in our analysis as a result of the retail prices net of tax.

[12] We explored further the issue of neighbour effects by looking at endogeneity issues in terms of current and lagged values of the neighbour countries but this did not affect the core results and did not offer any statistical improvements on empirical results reported here. For a full list of results see Wlazlowski et al. (2007).

Table 4
Results of the cross-country analysis for diesel oil

	AT	BE	DE	DK	ES	FI	FR	UK	IE	IT	LU	NL	PT	SE
AT														
BE			_−0.011_				_0.015_				__0.017__	_0.025_		
DE	__0.041__**	__−0.041__		_−0.024_			__0.005__				__0.034__	_−0.006_		
DK			__−0.007__											
ES							_0.011_						_0.112***_	
FI														_0.026_
FR		__0.164__***	_0.037_		__0.043__**		__−0.029__			_0.018_	__0.052__			
UK									__0.026__*					
IE								_−0.025**_						
IT	__−0.031__*													
LU		_−0.111**_	_−0.017_				_0.031_							
NL		__0.299__***	__0.231__***											
PT					__−0.008__									
SE						__0.026__*								

Notes:
• Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
• Home countries are represented in columns. Rows represent neighbouring countries.
• Significance levels:*significant at 10%, **significant at 5%, ***significant at 1%.
• AT — Austria, BE — Belgium, DE — Germany, DK — Denmark, ES — Spain, FI — Finland, FR — France, UK — United Kingdom, IE — Ireland, IT — Italy, LU — Luxembourg, NL — Netherlands, PT — Portugal, SE — Sweden.

Table 5
Results of the cross-country analysis for gas oil

	AT	BE	CZ	DE	DK	ES	FI	FR	UK	IE	IT	LT	LU	NL	PT	SE	SK
AT			_−0.122_														
BE				_0.063*_				_0.047**_					_0.064**_	_0.033_			
CZ																	
DE	_0.13***_	__0.166__***	_0.038_	_−0.09*_	_0.018_			_0.009_					__0.121__***	_−0.014_			
DK				__0.028__													
ES								_−0.04*_									
FI																_0.056***_	
FR		__0.032__		__0.006__		__0.084__***					_−0.031**_		__0.03__				
UK										_−0.021_							
HU																	
IE									__−0.018__*								
IT	__−0.081__***							__0.038__									
LT																	
LU		__0.048__		_−0.09_				_−0.057*_									
NL		__0.083__**		__0.039__													
PL			_0.419**_									__0.265__**					
PT																	
SE							__0.056__**										
SK			_−0.166**_														

Notes:
• Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
• Home countries are represented in columns. Rows represent neighbouring countries.
• Significance levels:*significant at 10%, **significant at 5%, ***significant at 1%.
• AT — Austria, BE — Belgium, CZ — Czech Republic, DE — Germany, DK — Denmark, ES — Spain, FI — Finland, FR — France, UK — United Kingdom, HU — Hungary, IE — Ireland, IT — Italy, LT — Lithuania, LU — Luxembourg, NL — Netherlands, PL — Poland, PT — Portugal, SE — Sweden, SK — Slovakia.

Table 6
Results of the cross-country analysis for fuel oils

	AT	BE	DE	DK	ES	FI	FR	UK	HU	IT	LT	LU	NL	PT	SE
AT									__0.505__***						
BE							_0.003_					_0.018_			
DE	_0.055**_	__0.045__		_0.101***_			_0.075***_					__0.024__	_0.073***_		
DK			__0.114__***												
ES														_0.095***_	
FI															_0.038*_
FR		__0.192__***			_0.152***_					_0.113***/0.071**_		__0.088__**			
IE								__0.028__*							
IT	__0.082__**						__−0.074__**								
NL		__0.022__	0.06**												
PL											_0.126_				
PT					__−0.004__										
SE						__0.047__*									
SI									__0.083__						

Notes:
• Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
• Home countries are represented in columns. Rows represent neighbouring countries.
• Significance levels:*significant at 10%, **significant at 5%, ***significant at 1%.
• For Italy, data for two kinds of fuel oil was available.
• AT — Austria, BE — Belgium, DE — Germany, DK — Denmark, ES — Spain, FI — Finland, FR — France, UK — United Kingdom, IE — Ireland, IT — Italy, LU — Luxembourg, NL — Netherlands, PL — Poland, PT — Portugal, SE — Sweden, SI — Slovenia.

As an example consider first the model for unleaded petrol in Austria (Table 3). The mean tax-inclusive prices in Austria over the sample period are amongst the lowest in the region (lower than in Italy and Germany). The results of estimation of Eq. (7) indicate that when prices for unleaded petrol in Germany are 1% above their long-run values (1% positive disequilibrium), Austrian prices increase by 0.07%.

We can summarise the results presented in Tables 3–8 by stating that the observed pattern of $\pi^{(j,k^*)}$ coefficients generally indicate that:

- when neighbours' prices are further above equilibrium levels compared to home prices the coefficients of interest are positive, i.e. home prices increase whenever neighbours' prices are above their equilibrium values;
- when neighbours' prices are further below equilibrium levels compared to home prices the coefficients of interest are zero, i.e. home prices are not affected.

Basically, our results show that local buyers who are able to do it are already buying abroad and even the extra low prices abroad do not change that pattern. This is in line with the results obtained by Rietveld et al. (2001) and Michaelis (2004).

Our results also confirm the specific conclusions of the qualitative study by Rietveld et al. (2001) — in both countries bordering the Netherlands (Germany and Belgium) the results of estimation of Eq.(7) for both motor spirits (diesel and petroleum — Tables 3 and 4) show that when Dutch prices are even higher than usual (i.e. the disequilibrium is positive), the German and Belgian prices increase via the supply and demand link. However it is important to point out that our study differs from the other two in that we are considering prices net of taxes, i.e. we are better able to focus on retailers' pricing strategies in different countries for given level of fuel taxation. As a result of this consideration another potential explanation of the observed price behaviour could be linked to the nature of the competitive environment in the local retail market. Indeed it could be argued that retailers react to positive deviations from the long run equilibrium as a result of the existence of local price coordination, due to collusion or to situations of price leadership by major retailers. On the other hand, adjustments to negative deviations from the long run equilibrium could be interpreted as deviations for collusive agreements which could trigger a price war and are therefore avoided by retailers for fear of long-term losses as a result of breaking the price agreement.

The results presented in Tables 3–8 indicate a good proportion of significant (at 10% level maximum) estimated effects out of all the possible combinations of countries, conditional on data availability. The most satisfactory results are registered for the EU-15 countries, with 16 significant coefficients out of 30 for unleaded petrol and 19 out of 34 for gasoil. The most meaningful significant results, in terms of expected sign of the estimated coefficients, are observed for countries which share a large proportion of their borders, where one would expect cross-border shopping to take place in response to price changes in the short run, for example in Germany and France, Spain and Portugal and Sweden and Finland.

Table 7
Results of the cross-country analysis for LPG

	BE	FR	LU
FR	**−0.058**		**−0.018**
IT		0	
LU	**0.132****	*0.04****	
NL	**0.072**		

Notes:
• Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
• Home countries are represented in columns. Rows represent neighbouring countries.
• Significance levels:*significant at 10%, **significant at 5%, ***significant at 1%.
• BE — Belgium, FR — France, IT — Italy, LU — Luxembourg, NL — Netherlands.

Table 8
Results of the cross-country analysis for leaded petrol

	BE	DE	DK	ES	FR	IT	LU	PT
BE		*0.127*					**0.089****	
DE			**0.151**					
ES					*−0.002*			*0.083*
FR	**0.109****	**0.216**		**0.048*****		**0.007**	**0.004**	
LU		*0.17*						

Notes:
• Entries in italics denote cases when neighbouring prices are lower than home prices. Entries in bold denote the opposite.
• Home countries are represented in columns. Rows represent neighbouring countries.
• Significance levels:* significant at 10%, ** significant at 5%, *** significant at 1%.
• BE — Belgium, DE — Germany, DK — Denmark, ES — Spain, FR — France, HU — Hungary, IT — Italy, LU — Luxembourg, PT — Portugal.

Considering the impact of a positive disequilibrium in the price of motor spirits first the results presented in Table 3 indicate that this disequilibrium generates a positive reaction in the form of a significant price increase, while a negative disequilibrium does not generate statistically significant effects. In the case of unleaded petrol and diesel fuels this is observed mostly within the EU-15 countries. Furthermore, contrary to the predictions of the tax competition literature which state that small countries have an incentive to undercut large countries, we observe price reactions of similar size for both large (France and Germany) and small countries (Luxembourg and Belgium). A similar pattern of price behaviour is observed for the other two motor spirits (LPG and SUPER), however it is interesting to note that the significant price reactions are observed mainly in the countries bordering France and Belgium. Finally, when we analyse the behaviour of other fuels (heating oil, RFO1 and RFO2), which are not primarily used for transportation, we observe significant price reactions for some EU-10 countries. However, these results should be considered with caution because the prices in these countries are observed over a relatively short period of time covering less than two years, due to lack of consistent data for the period before inclusion in the EU.

Data obtained from EUROSTAT confirms that a number of countries have relatively large consumption of motor spirit per vehicle which might indicate significant cross-border purchases. Table 1 presents the 2000 data on inland market consumption, number of vehicles and the ratio between these two variables. The most obvious outliers include Luxembourg, Ireland and Denmark. The difference for Luxembourg might be due to the fact that prices there are so significantly lower and petrol tourism so deeply rooted that cross-country disequilibria do not affect the sales.[13]

3.2. Asymmetries in price transmission

The estimated coefficients on the asymmetry speed are presented in Table 9.[14]

We found significant asymmetries in 16 out of 71 cases analysed. The results of estimation of Eqs.(8) and (9) indicate that the inclusion of cross-country effects significantly changes the results of the tests for non-linearity. In 13 out of 16 cases, we found a reversion of the direction of asymmetry with the most prominent examples for motor spirits being in Belgium, Finland, Luxembourg, Portugal and Spain. This is not surprising given the increasing levels of economic integration across the EU-15 countries, particularly after the introduction of a common

[13] In the year 2000 nominal prices for unleaded fuel in Luxembourg, Belgium, Germany and France were 764, 965, 941 and 1010 USD per 1000 l respectively. This makes Luxembourg the most attractive country for fuel tourism in our sample.

[14] The cases when the null of no asymmetries were *not* rejected were omitted from the table. For comparative purposes, the difference between estimates was reported, even for cases when one of the estimates was not statistically significant.

Table 9
Asymmetries in price transmission — one country (A) and cross-country

Country	Product	(A)	(B)	Asymmetry — (A)	Asymmetry — (B)	Difference
BE	EURO	√		0.239		−0.106
DE	EURO	√		0.186		−0.129
FI	EURO		√		−0.185	−0.046
UK	EURO		√		0.08	0.017
UK	DIESEL	√	√	0.077	0.083	0.006
PT	DIESEL		√		−0.068	−0.025
SE	DIESEL	√	√	−0.144	−0.168	−0.024
UK	HGASOIL		√		−0.088	−0.008
LU	HGASOIL	√	√	−0.152	−0.182	−0.03
AT	RFO.1		√		−0.104	−0.039
DE	RFO.1	√	√	0.14	0.154	0.014
IT	RFO.1	√	√	−0.096	−0.102	−0.006
LU	RFO.1		√		−0.163	−0.084
BE	SUPER		√		−0.225	−0.135
DE	SUPER	√		0.463		−0.176
ES	SUPER		√		−0.087	−0.031

Notes:
• AT — Austria, BE — Belgium, CZ — Czech Republic, DE — Germany, DK — Denmark, EE — Estonia, ES — Spain, FI — Finland, FR — France, UK — United Kingdom, HU — Hungary, IE — Ireland, IT — Italy, LT — Lithuania, LU — Luxembourg, LV — Latvia, NL — Netherlands, PL — Poland, PT — Portugal, SE — Sweden, SI — Slovenia, SK — Slovakia.

currency amongst some of them, which facilitates price comparisons both by suppliers and consumers in neighbouring markets.

This result clearly indicates that the traditional one-country approach adopted in most price transmission studies could lead to over-rejection of the symmetry hypothesis and to incorrect inference on the direction of the welfare transfer.

4. Conclusions and suggestions for further research

The limited empirical literature on tax competition, and on fuel tourism in particular, seems to indicate that drivers react rationally to cross-border price differentials. The price variations observed in our data as a result of an exogenous shock in one country are generated by complex demand and supply interactions for a given level of taxation, and therefore do not originate simply from differentials across countries in the level of fuel taxation. However, our results still provide support for the view of a rational behaviour by drivers who reap arbitrage opportunities arising from fuel price differentials in neighbouring countries. Indeed the visible pattern in our results offers indirect support for the view of Rietveld et al. (2001) and Michaelis (2004) — that the drivers in high-tax countries tend to travel to neighbouring low-price countries exploiting the price differentials, thus contributing to demand abroad. Furthermore, the intensity of cross-border travel increases whenever prices in the drivers' own country are above their long-run equilibrium levels, thus resulting in extra incentives to fill up abroad.

The results for other products which are not subject to “fuel tourism” are less obvious. In particular, the existence of the France–Germany relationship found by Indejehagopian and Simon (2000) for heating oil is not confirmed in our results. This might be due to different sample coverage and inclusion of other bordering countries (such as Spain, Italy and Belgium), which were found to be linked to the German and French markets.

Perhaps even more interestingly, the inclusion of cross-country effects significantly affects the framework used for the analysis of symmetry in price transmission. In particular, the nature of asymmetry and the direction of the associated welfare transfer seem to be reverted once cross-country effects are taken into account.

The results of the analysis have wide-ranging implications. In particular the potential role of cross-country effects needs to be taken into account when discussing benefits from fuel-tax harmonisation within the EU. If drivers are likely to travel abroad in response to price differentials, the EU-wide harmonisation might be the only viable option to achieve environmental objectives and to prevent tax-base erosion. Partial attempts that do not account for geographical features of the EU borders might not necessarily be successful. In this context the tax competition literature indicates that the introduction of a minimum tax would allow countries to maximise joint tax revenue and to reduce the extent of cross-country shopping as a result of price undercutting.

Furthermore, from the point of view of asymmetric price transmission, our results suggest that at least some of the claims of the presence of non-linearities in price transmission and associated welfare transfer raised in the existing literature should be re-visited in a multinational framework to account for the complexity of cross-country price interactions.

Our work aims to contribute to the literature on the issue of cross-border price adjustments and consequent shopping in a way that is still partial but which we think advances the existing knowledge about these phenomena. However we are aware that our conclusions need to be verified with the use of appropriate data on volumes of trade and intensity of cross-border travels in the countries of interest. A further area of future research is the possibility of explaining cross-border shopping with reference to the degree of competition and the level of local retail concentration in different European countries. These additional explanatory factors could contribute a more complete picture of the long-term relationship between prices both at the vertical and at the horizontal level. This information unfortunately is not currently available for all EU countries in a consistent manner, but if collected consistently could be used to explain the cross-border behaviour of EU drivers and provide a rigorous grounding for political decisions about fuel tax harmonisation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.eneco.2008.08.009.

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