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WORKING PAPER

The US Dollar Exchange rate and the Demand for Oil

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Abstract

Using recent advances in panel data estimation techniques, we find that an appreciation of the US dollar exchange rate leads to a significant decline in oil demand for a sample of 65 oil-importing countries. The estimated effect turns out to be considerably larger than the impact of a shift in the global crude oil price expressed in US dollar. This finding appears to be the consequence of a stronger pass-through of changes in the US dollar exchange rate to domestic end-user oil products prices relative to changes in the global crude oil price. Furthermore, we demonstrate the relevance of US dollar fluctuations for global oil price dynamics.

JEL classification: C33, F31, Q41
Keywords: Oil demand, US dollar exchange rate, oil price pass-through, panel data

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1 Introduction

There is a growing consensus that global crude oil price fluctuations are mainly driven by changes in the demand for oil. Hamilton (2009), for instance, argues that strong growth in world income was the primary cause of the oil price surge in 2007-08, whereas the subsequent dramatic collapse of oil prices was the result of the global economic downturn in the aftermath of the financial crisis. Furthermore, Peersman (2005), Kilian (2009), Peersman and Van Robays (2009), Lombardi and Van Robays (2011) and Kilian and Murphy (2012) disentangle different sources of oil price shocks within a structural vector autoregressive (SVAR) model, and find a dominant role for shocks at the demand side of the global crude oil market. In order to better understand oil market fluctuations, a more detailed analysis of the drivers of oil demand is thus desirable.

In this paper, we examine the role of the US dollar exchange rate for oil consumption. The US dollar exchange rate has so far been ignored as an independent driver of oil demand in the empirical literature on global oil market dynamics. This is surprising since global oil prices are predominantly expressed in US dollars. According to the local oil price channel, a shift in the dollar exchange rate should then affect the demand for crude oil in countries that do not use the US dollar for local transactions (Austvik 1987). For instance, when the US dollar exchange rate depreciates, oil becomes less expensive in local currency for consumers in non-US dollar regions, boosting their demand for oil. The rise in oil demand for countries that do not use the dollar for local transactions should in turn influence global oil production and oil prices expressed in US dollar. This line of reasoning was raised in the work of Brown and Philips (1984) and Huntington (1986), and is supported by the data shown in Figure 1. The panels in the figure show the evolution of the real effective US dollar exchange rate, as well as the deviation of oil consumption from its trend, for a set of countries (and country aggregates) that are examined in this paper. As can be seen in the figure, an appreciation (depreciation) of the dollar exchange rate is often accompanied by a decline (rise) in oil consumption relative to its trend evolution, indicating a fall (rise) in oil demand. Shifts in the US dollar exchange rate could thus be important for global oil market dynamics.

A similar argument holds for several studies that exclusively focus on the analysis of the determinants of oil demand. In particular, Gately and Huntington (2002), Cooper (2003), Dargay, Gately and Huntington (2007), Narayan and Smyth (2007) and Dargay

and Gately (2010) amongst others estimate oil demand functions for multiple countries. These studies consider oil demand as a positive function of income per capita and a negative function of its own price. For the latter, they typically use global crude oil prices expressed in US dollars due to the lack of sufficient and/or reliable data on local oil prices. The influence of shifts in the US dollar exchange rate on oil demand is hence not taken into account. Some studies (e.g. Griffin and Schulman 2005; Dargay et al. 2007; Dargay and Gately 2010; Fawcett and Price 2012) do use local oil/gasoline prices in the estimations, but do not distinguish between local oil price movements caused by global oil price shifts and movements caused by changes in the value of the US dollar.[1] There is, however, no a priori reason to assume that the pass-through and influence of both sources of oil price shifts on oil demand is the same.

We formally investigate the effects of shifts in the US dollar exchange rate on oil demand in non-US dollar regions, by estimating the determinants of oil consumption per capita for a panel of 65 oil-importing countries over the sample period 1971-2008. A panel data approach is commonly used in the literature on oil (energy) demand, as it allows to exploit both the cross section and the time dimension of the data. We conduct panel estimations for respectively a sample of 23 OECD countries, 42 non-OECD countries and all 65 oil-importing countries. Besides real GDP per capita, we include global real crude oil prices expressed in US dollar, as well as the real US dollar exchange rate in the estimations. An explicit analysis of the role of the US dollar as a possible driver of oil consumption is a first contribution of the paper.[2]

A second contribution of the paper is methodological. In particular, most existing panel data studies on oil demand do not fully take into account the specific salient features of macro panel data sets such as heterogeneity of the coefficients, unit root behavior and cross-country dependence, even though the neglect of these matters can result in misleading

[1] Griffin and Schulman (2005), Dargay et al. (2007) and Dargay and Gately (2010) use end-user price indexes, either in domestic currencies or in US dollar, whereas Fawcett and Price (2012) convert the global crude oil price in US dollar to domestic prices by applying country-specific US dollar exchange rates.

[2] To our knowledge, excluding the earlier Brown and Phillips (1984) and Huntington (1986) studies, the only empirical study which also considers the US dollar exchange rate as a possible determinant of oil demand is Askari and Krichene (2010). They estimate, however, a time series simultaneous equation model for (aggregate) world oil demand and supply between 1970 and 2008, whereas we estimate the impact of the US dollar exchange rate for a panel of 65 countries. In addition, they examine the effect of the exchange rate as part of a monetary policy channel affecting global oil prices, rather than an independent driver of oil demand.

estimation outcomes. We apply recent advances in panel estimation techniques that are capable to handle these econometric issues. Specifically, we (i) take into account the long-run relationship between the variables by estimating a panel error correction oil demand model, (ii) allow for cross-country heterogeneity of the coefficients which is present in the data, and (iii) consider cross-sectional dependence in the error terms. The application of these econometric advances and the addition of the US dollar exchange rate as a driver of oil consumption turn out to matter for some of the estimated elasticities.

We find that an appreciation of the US dollar real effective exchange rate leads to a decline in oil consumption in non-US dollar regions. Strikingly, the short-run US dollar exchange rate elasticity of oil demand turns out to be substantially larger than the elasticity of oil demand with respect to fluctuations in the global price of crude oil expressed in US dollar. A more detailed analysis of the pass-through of changes in global crude oil prices and the US dollar exchange rate to oil products end-user prices for a subset of 20 OECD-countries suggests that the difference in the magnitudes of both elasticities is the consequence of a significant larger pass-through of exchange rate fluctuations. A back-of-the-envelope calculation furthermore suggests that shifts in the US dollar exchange rate are an economically important contributor to the volatility of the global price of crude oil expressed in US dollar, due to its influence on oil demand. These findings underline that the US dollar exchange rate should be taken into account in the analysis of global oil market dynamics and sources of oil price fluctuations.

The remainder of this paper is organized as follows. In the next section, we describe the baseline empirical model for oil demand and discuss some econometric issues. Section 3 discusses the estimation and robustness of the results. The pass-through of changes in global oil prices and the real effective US dollar exchange rate to local end-user oil prices is examined in section 4, while the economic relevance of the US dollar exchange rate for global oil market dynamics is assessed in section 5. Finally, section 6 concludes.

2 Empirical oil demand model

In this section, we describe the benchmark oil demand model that will be used in the estimations. Our sample contains 65 oil-importing countries that do not have the US

dollar as their local currency and covers the period 1971-2008.[3] Details of the data and a list of the countries can be found in Appendix A. Consider the following general oil demand specification for country i at time t:

$$dem_{it} = f\left(gdp_{it}, oilp_t, rer_t, trend_t, c_i\right) \tag{1}$$

where dem_{it} is total oil consumption per capita, gdp_{it} real income per capita, $oilp_t$ the world real US dollar crude oil price and rer_t the real effective US dollar exchange rate, $trend_t$ a linear time trend and c_i a country-specific constant. All variables are converted to natural logarithms, such that the model is of the constant elasticity form. The data are at annual frequency.

The existing empirical literature typically considers oil consumption, or energy consumption more generally, as a positive function of real income and a negative function of its own price (e.g., Dahl and Sterner 1991; Dahl 1993; Espey 1998; Gately and Huntington 2002; Cooper 2003; Griffin and Schulman 2005; Hughes, Knittel and Sperling 2008; Lee and Lee 2010; Dargay and Gately 2010). In line with these studies, we include country-specific real GDP per capita in the general oil demand specification. Real GDP is assumed to represent the energy-using capital stock, such as buildings, equipment and vehicles (Dargay and Gately 2010).

As a measure for the own price of oil demand, most studies use the global price of crude oil expressed in US dollar (supra, page 3). However, as we have explained in the introduction, the price that consumers face in countries that do not use the US dollar as a currency for local transactions, is the price of oil determined in dollars multiplied by the country's exchange rate against the US dollar, i.e. the number of units of national currency needed to buy one US dollar (Austvik 1987). Some studies use local oil/gasoline prices in the estimations (supra, page 3), but this does not allow to distinguish between local oil-price shifts caused by changes in the global price of crude oil, or changes in the US dollar exchange rate, which is the central research question in this paper. Moreover, the lack of availability of country-specific end-user prices would constrain the sample considerably.[4]

[3] The United States is hence not included in the analysis, which should be taken into account when comparing the results with existing studies. We do also not consider oil-exporting countries, since oil demand in these countries has been found to behave very differently. See for example Gately and Huntington (2002).

[4] Country-specific end-user prices are only available for a limited number of OECD countries, which limits the usefulness for the analysis of global oil market dynamics, in particular since non-OECD countries

Accordingly, we include the global real crude oil price expressed in US dollar, as well as the real US dollar effective exchange rate as two separate variables in our empirical oil demand model.

We use the US dollar real effective exchange rate rather than real bilateral exchange rates in the benchmark estimations for three reasons. First, bilateral exchange rates (or domestic CPI) are not available for several countries over the whole sample period, which would reduce the size of the dataset. Second, bilateral exchange rates suffer an endogeneity problem as the demand for oil of an individual country is expected to influence its own exchange rate. Given the moderate weight of each individual country in the US trade basket, this is much less the case for the US dollar effective exchange rate. Third, a multilateral weighted exchange rate is more useful to examine the role of changes in the US dollar for global oil market dynamics. In section 3.2, however, we assess the robustness of the results for a specification with the bilateral exchange rates estimated for a subsample of countries using instrumental variables.

Finally, microeconomic theory (e.g. Mas-Colell, Whinston and Green 2007) suggests that oil demand is also a function of the economy's structure, technology and the prices of substitutes. To capture the former two, all our estimations contain a country-specific constant and a linear trend. In addition, we add proxies for unobserved common factors, as discussed in section 2.3. Unfortunately, prices of substitutes are not available for our sample period. Griffin and Schulman (2005), however, report only weak substitution effects when they include the real price of substitute fuels in a demand model for petroleum products, and argue that omitting cross-price effects does not appreciably alter their results.[5]

constitute an increasingly large share of this market. The use of global oil prices also avoids endogeneity problems of using local oil prices. Specifically, in contrast to local oil (gasoline) prices, it is more plausible to assume that global crude oil prices are exogenous for an individual country's oil demand.

[5] Frankel (2006) argues that oil and other commodity price developments are influenced by interest rates. Specifically, when the interest rate declines, commodities become more attractive as an asset for investors. In addition, a lower interest rate stimulates overall demand, including the demand for oil. Notice, however, that this is not relevant for our analysis since we consider oil consumption (not inventories) at the LHS of the oil demand function, while real GDP is included at the RHS.

2.1 Panel unit root and cointegration tests

To avoid spurious regression results, we first examine the time series properties of the variables. Since cross section dependence tests (CD tests, Pesaran 2004) on the residuals of Augmented Dickey Fuller regressions (ADF regressions, Dickey and Fuller 1979) indicate a significant degree of cross section dependence for the country-specific variables (dem_{it} and gdp_{it}), we employ the Panel Analysis of Non-stationarity in Idiosyncratic and Common components (PANIC) test proposed by Bai and Ng (2004) for both series.[6] The number of common factors (r) is determined by the Bai and Ng (2002) criteria.[7] Table 1 shows that r varies between one and four, depending on the variable and the criterion under consideration. Both series are found to be non-stationary for all specifications, which is due to the non-stationarity of the common component and the idiosyncratic component (or solely to the former).

Given that the global real crude oil price variable and the US dollar real effective exchange rate are observed common factors, we use standard ADF tests for both series. For global crude oil prices, the existence of a unit root cannot be rejected for both a constant only and linear trend model. This is, however, not the case for the US dollar real effective exchange rate, for which the ADF test rejects non-stationarity of the series. This finding is at odds with the empirical purchasing power (PPP) literature, where standard univariate ADF tests typically fail to reject the null hypothesis. Engel (2000) shows that standard unit root tests may, however, be biased in favour of rejecting non-stationarity if the real exchange rate has a stationary and a non-stationary component. For this reason, and to ensure consistency with the other variables in the model, we continue to treat the US dollar real effective exchange rate as a non-stationary variable in the analysis.

In a second step, we test for a long-run relationship amongst the variables using the panel error correction test of Gengenbach, Urbain and Westerlund (2008), henceforth GUW test. The test is based on the significance of the error correction term in the panel error correction model (ECM). Compared to residual-based panel unit root tests, the GUW test has the advantage that it is not subject to the common factor critique

[6] Other panel unit root tests that also use a common factor representation of the data to allow for cross-section dependence (Moon and Perron 2004; Pesaran 2007) impose restrictions on the number of common factors and/or assume stationarity of the common factors. Given the results concerning the number and the stationarity properties of the common factors, these alternative tests are not used.

[7] We consider the IC1, IC2 and BIC3 criteria. The BIC3 criterion is more robust when there is cross correlation in the idiosyncratic errors (Bai and Ng 2002).

(Kremers, Ericsson and Dolado 1992) and that it does not rely on a stepwise testing procedure.[8] Notice that the GUW test is nevertheless more restrictive than residual-based tests by imposing weak exogeneity on the country-specific regressors of the ECM and strong exogeneity on the common factors, whereas residual-based tests allow for full endogeneity. To take this restriction into account, we have also applied residual-based panel cointegration tests in the spirit of Banerjee and Carrion-i-Silvestre (2006) to check the robustness of the results.[9] The results of the tests are shown in Table 2. The pooled GUW tests reject the null hypothesis of no error correction between dem_{it}, gdp_{it}, $oilp_t$ and rer_t for the model under consideration, i.e. including a constant and trend. The alternative residual-based cointegration tests confirm this result. As a consequence, we can safely conclude that dem_{it}, gdp_{it}, $oilp_t$ and rer_t are cointegrated at the panel level.

2.2 Panel error correction oil demand model

Having established cointegration between the variables, we can formulate our general oil demand specification as a panel ECM:

$$\begin{aligned}\Delta dem_{it} &= \alpha_i + \tau_i * trend_t + \lambda_i * dem_{i,t-1} + \gamma_i^l * gdp_{i,t-1} + \beta_i^l * oilp_{t-1} + \theta_i^l * rer_{t-1} + \\ &\quad \gamma_i * \Delta gdp_{it} + \beta_i * \Delta oilp_t + \theta_i * \Delta rer_t + \varepsilon_{it} \qquad (2)\end{aligned}$$

Equation (2) is the baseline empirical specification for the panel ECMs that will be estimated in this paper.[10] Gately and Huntington (2002) and Griffin and Schulman (2005) are most closely related to our study as they both estimate single equation total oil demand models for a panel of multiple countries with a moderate time dimension.[11] Before we

[8] The common factor critique applies to residual-based panel cointegration tests as they rely on residual rather than structural dynamics (Gengenbach *et* al. 2008).

[9] The approach we take to examine the robustness of the GUW test results is the following: we apply the continuously-updated and bias-corrected (CupBC) estimator of Bai, Kao and Ng (2009) to the long-run cointegration equation and we test the (de-factored) residuals for a unit root using the PANIC test procedure.

[10] The lag order of the dynamic adjustment process is imposed to be 0 for all variables for reasons of parsimony. Experiments with more lags, however, do not alter the results.

[11] Gately and Huntington (2002) have a sample of 93 countries over 1971-1997. Griffin and Schulman (2005) use data on 16 OECD countries over 1961-1999. Griffin and Schulman (2005) include retail oil prices instead of the world crude oil price in their model, which makes their estimation outcomes less adequate to serve as a benchmark for the baseline model. Both works consider the standard Fixed Effects (FE) estimator. Notice that this FE estimator suffers small T problems in dynamic panels (Arellano and Bond

estimate the panel ECM, it is important to discuss two econometric issues which are generally disregarded in the existing oil demand literature, namely slope heterogeneity and cross-sectional error dependence.

2.3 Econometric issues

In order to obtain reliable estimates, we need to consider two important econometric features of macro panel data. The first one concerns heterogeneity in the slope coefficients. Heterogeneity in the slope coefficients renders the standard FE estimator biased as the latter assumes homogeneity in the slope coefficients. Some studies, e.g. Gately and Huntington (2002) and Dargay and Gately (2010), notice a substantial heterogeneity within non-OECD countries and split their sample in different groups of countries, i.e. OECD countries, oil exporters, income growers and other non-OECD countries. Given the cross-country differences in economic structures, the assumption of homogenous slope coefficients within groups is nevertheless questionable, including the group of OECD countries. Indeed, the application of Swamy's Wald test consistently reveals that the homogeneity restriction on the slope coefficients is not valid, even for the subsample of OECD countries (see Table 3). The FE estimates are hence potentially misleading. Accordingly, we use the Mean Group (MG) estimator in the analysis, which offers a consistent alternative as the MG estimator does not impose homogeneity.[12]

The second important feature of macro panel data estimations relates to error cross section dependence. In particular, the results of standard FE and MG estimators are inconsistent and have biased standard errors when the observed explanatory variables are correlated with unobserved common factors (Pesaran 2006). For oil demand, this is likely the case. Country-specific income, the real price of crude oil, as well as the US dollar real effective exchange rate could for instance be driven by a common global business cycle. The existing empirical oil demand studies do not consider the potentially far-reaching

1991). Given that the time dimension of our sample is moderately large, we assume that this bias is not relevant for our purposes. Nickell (1981) shows that the upward bias on the error correction term becomes insignificant when $T \to \infty$.

[12] Since the MG estimator requires large N, and allows for cross-country heterogeneity anyway, we pool all non-OECD countries in one group. A further decomposition of the non-OECD countries in e.g. fast-growing and income-growth stagnating countries, as in Gately and Huntington (2002) and Dargay and Gately (2010), might be interesting, but is unfortunately not feasible due to the limited number of income-growers in the sample.

consequences of cross-sectional dependence. The presence of cross section dependence in the error terms of dynamic models could be tested by means of the CD test of Pesaran (2004). Applying the CD test to our panel error correction oil demand model shows that there is a significant degree of cross-sectional correlation in the error terms for both the FE and MG estimators (see Table 3), which confirms the need to attempt to take into account the dependence.

We therefore apply the Bai and Ng (2004) PANIC decomposition to the residuals of the model in order to estimate the common components in the residuals. In the spirit of Bai et al. (2009), the estimated common factor(s) is (are) then in a second step included in the model to get consistent estimates. This procedure allows us to remove, or at least significantly reduce, the common factors that are present in the residuals of the first step.[13] Another advantage is that possible non-linear unobserved common variables such as technological change (as in Griffin and Schulman 2005) can be appropriately controlled for without imposing an homogeneous coefficient. By including the estimated common components of the residuals of the MG regression as a proxy for omitted common variables in the model, we notice a substantial decline of the cross-sectional correlation in the residuals for the sample of OECD countries (Table 3, last two lines). The effect for the non-OECD group is, in contrast, limited.

In sum, in contrast to the existing empirical evidence on the demand for oil, we do not only examine the role of the US dollar exchange rate for the demand for oil, we also apply panel estimators that take both heterogeneity of the coefficients and cross-sectional dependence into account.

3 Empirical results

3.1 Panel estimations

Table 3 summarizes the estimation results of the panel error correction model as described in section 2. In order to compare with the existing evidence, we report the results for respectively OECD countries, non-OECD countries and the total sample of oil-importing

[13] The drawback of this approach, however, is that the estimation error from the first step carries over to the subsequent steps. The presence of multiple observed common factors as explanatory variables in our model makes the more standard application of the Common Correlated Effects (CCE) estimators of Pesaran (2006) to eliminate cross-sectional dependence however unattractive.

countries. For each sample, we show the results for the FE, MG and MG estimator adjusted for cross-sectional dependence (MG_Ft), which should allow us to evaluate the relevance of the econometric features discussed in section 2.3 for the estimation results. Notice that all estimated income and oil price coefficients reported in the paper are very similar when we re-estimate the oil demand models without the exchange rate variable. The corresponding conclusions are thus robust for the inclusion of the exchange rate (unless otherwise mentioned).

Income elasticity We consistently find a significant positive effect of real GDP on the demand for oil. The short-run income elasticity in OECD countries is 0.69, which is larger than the 0.40 found by Griffin and Schulman (2005). Furthermore, the estimated average impact of economic activity on the demand for oil is similar for non-OECD countries (0.53) and the total sample of countries (0.60). The long-run income elasticity coefficients are, in contrast, more diverse across both groups of countries. Specifically, the average long-run income elasticity turns out to be 0.52, 1.06 and 0.94 for respectively OECD, non-OECD and all 65 oil-importing countries, which is in line with most existing studies. A lower income elasticity in more developed countries is, for instance, also found by Gately and Huntington (2002).[14]

The econometric issues that we discussed in section 2.3 seem to matter for the magnitudes of the estimates. Specifically, the long-run income elasticity for OECD countries increases from 0.52 to 0.92 if we do not take into account cross-sectional dependence in the error terms, and even to 1.11 if we also do not allow for cross-country heterogeneity in the coefficients. Interestingly, exactly the opposite happens for non-OECD countries, i.e., the long-run income elasticity declines from 1.06 to respectively 1.02 and 0.73 when there is not allowed for correlation and heterogeneity across countries. In other words, the bias resulting from the use of a FE estimator can be relevant and could work in both directions.

[14] Notice that the baseline specifications of Gately and Huntington (2002) and Griffin and Schulman (2005) are different from our baseline model. In particular, Gately and Huntington (2002) allow for asymmetric responses to increases and decreases in the crude oil price, whereas Griffin and Schulman (2005) add a time effect to capture the non-linear nature of technological change and show that symmetric price responses cannot be rejected once one allows for a time effect. Adding proxies for unobserved common factors (as in MG_Ft) is equivalent to the approach of Griffin and Schulman (2005), with more degrees of freedom. The possibility of asymmetric price-responsiveness is further examined in the next section.

(Global) oil price elasticity There are numerous papers that estimate the effects of a shift in (global) crude oil prices on the demand for oil. Most studies report a relatively low, or even an insignificant (e.g. Askari and Krichene 2010) short-run price elasticity of oil demand, which is important because a low oil price elasticity implies that any disruption in oil production has a considerable impact on the price of oil. As can be seen in Table 3, we find a significant negative (short-run) effect of a change in the global price of crude oil expressed in US dollars on the demand for oil in OECD-countries (-0.05), non-OECD countries (-0.03) and the overall sample of countries that do not use the US dollar for local transactions (-0.04). These short-run elasticities turn out to be very similar for the different estimators and are in line with several other panel studies.[15] We further find a stronger response of oil demand to a global oil price shift in the long run, although the magnitude of the long-run coefficients are much lower for the MG coefficients than for the FE estimates. The estimated long-run price elasticities are respectively -0.12 and -0.15 for OECD and non-OECD countries.

Exchange rate elasticity Our results reveal that there is a strong effect of the US dollar exchange rate on oil demand in the rest of the world, despite the fact that we control for country-specific real GDP and global crude oil prices, which supports the conjecture that the US dollar exchange rate is a significant driver of oil demand. More specifically, when the US dollar real effective exchange rate appreciates by 1 percent, there is a short-run decline in oil demand of 0.19 percent in OECD countries. Strikingly, the estimated elasticity is considerably bigger than the global crude oil price elasticity expressed in US dollar. The equality of the short-run price and real exchange rate elasticity is rejected at the panel level.[16] The negative effect of the exchange rate on oil demand in OECD countries rises even further to -0.31 in the long run, which is also much larger than the long-run elasticity of the global oil price determined in US dollar of -0.12.

The short-run impact of the US dollar exchange rate on oil demand in non-OECD countries is much lower (-0.06) and statistically not significant. Notice that the latter

[15] Larger magnitudes for the short-run oil price coefficient are found by Bodenstein and Guerrieri (2011) within a DSGE framework, and in the SVAR studies of Baumeister and Peersman (2013) and Kilian and Murphy (2012).

[16] Askari and Krichene (2010) estimate a time series simultaneous equation model for global oil demand and supply using quarterly data over a similar sample period (1970-2008) and also find an impact of the US dollar (nominal) exchange rate on oil demand which is stronger in magnitude than the effect of the price of oil, but both elasticities turn out to be insignificant.

is not the case for the FE estimator that is typically used in the oil demand literature, which confirms that not taking into account the features of macro panel data sets could be misleading for the interpretation of the results. A possible explanation for the insignificant exchange rate elasticity coefficient can be the characteristics of the group of non-OECD countries. Specifically, some of the non-OECD countries had varying exchange rate regimes over time or experienced exchange rate crises during the sample period, which could reduce the estimated response of oil consumption to US dollar fluctuations.[17] The estimated long-run exchange rate elasticity coefficient is, however, significant and about twice the size of the long-run price elasticity. This indicates that the factors that prevent oil consumption in these countries to respond to changes in the value of the US dollar diminish over time. Finally, the US dollar real effective exchange rate elasticity for the total sample of 65 oil-importing countries is -0.09 and significant, which is again more than double the global oil price elasticity expressed in US dollar for the same sample of countries. In sum, the US dollar exchange rate matters for oil demand in countries which do not use the dollar as a currency for local transactions. A weakening of the US dollar boosts oil consumption in these countries. In the next subsection, we assess the robustness of this novel finding, while we examine the relevance for global oil market dynamics in section 5.

3.2 Robustness checks

In this section, we assess the robustness of the baseline results. We first check whether the estimated exchange rate elasticities are robust to the choice of a price-symmetric model by allowing for asymmetric oil price reactions. We then examine the robustness of the results for possible endogeneity problems between oil demand and respectively global crude oil prices and the US dollar exchange rate.

Asymmetric-price model The possibility of asymmetric responses of oil consumption to price changes has received attention in several empirical studies.[18] The underlying idea is that higher prices induce more investment in energy-efficient equipment and retrofitting of existing capital. When prices fall, however, there is no switch back to less-efficient

[17] Some countries temporarily had a fixed and/or crawling peg exchange rate regime. The sample, however, does not contain countries which had a fixed peg to the US dollar over the entire sample period.

[18] E.g. Walker and Wirl (1993), Borenstein, Cameron and Gilbert (1997), Haas and Schipper (1998), Gately and Huntington (2002) and Griffin and Schulman (2005).

capital, although there could be more intensive usage (Griffin and Schulman 2005). More recently, Dargay et al. (2007) and Dargay and Gately (2010) even allow for a different reaction of oil demand to price increases that result in a new historical maximum price (pmax), to price increases back to the previous maximum (prec), and to price decreases (pcut). They find that oil demand responds differently to the different price shifts, with the largest (negative) effect of price increases that result in new maximum values.[19]

Table 4 shows the results when we extend our baseline specification with the price decomposition of Dargay et al. (2007) and Dargay and Gately (2010). Using Wald tests at the panel level, we consistently find that the effect of a price increase to a new maximum is significantly larger than both other price movements, whereas there are no significant differences between a price increase back to an earlier maximum and a price cut. More importantly, however, we find that the exchange rate elasticity of oil demand is still significant and similar in magnitude to the benchmark results reported in section 3 and Table 3. Interestingly, a Wald test cannot reject the hypothesis that the responsiveness of oil demand to changes in the US dollar exchange rate and a price increase to a new maximum are significantly different. Overall, we can conclude that the benchmark results are robust when we allow for asymmetric oil price responses of oil consumption. The US dollar exchange rate is still a significant driver of oil consumption, with an impact that is generally larger than shifts in global crude oil prices expressed in US dollar. In the rest of the paper, we therefore continue to use the price-symmetric specification, with the estimated unobserved common factors acting as a proxy for technological change.

Instrumental variables estimation In line with the existing cross-country panel studies on oil demand, we have assumed in the benchmark estimations that the demand for oil of an individual country does not influence the global price of crude oil on impact. However, if a country has a large share in global oil consumption, the assumption of exogenous oil price movements could be violated.[20] A similar reasoning can be applied to the use

[19] These studies also allow for possible asymmetric responses to income changes, but Dargay and Gately (2010) point out that this approach is primarily appropriate for oil exporting countries, a group which is not included in our analysis. We therefore do not extend the model with this type of asymmetry.

[20] Note that this assumption is typically also made when individual country end-user prices are used (e.g. Griffin and Schulman 2005; Dargay and Gately 2010), which is more controversial. Notice also that, in contrast to most existing panel studies on oil demand, we do not have the US in our sample. Since the US has a share in global oil consumption of 27% over the sample period, endogeneity problems are more likely for panels that include the US.

of the US dollar effective exchange rate. When shifts in oil consumption of an individual country affect the bilateral US dollar exchange rate on impact, and this country has a large weight in the US dollar effective exchange rate index, the estimated elasticity could be biased.[21] Remark that, if such a bias is present, the true exchange rate elasticity of oil demand is probably even larger than the one we have reported above. Specifically, if an increase in a country's oil demand raises its demand for US dollars and leads to an appreciation of the dollar, the estimated (negative) elasticity will decline.

To account for possible endogeneity between the demand for oil in individual (non-US dollar) countries, the global oil price, and US dollar exchange rate, we have re-estimated the baseline panel error correction oil demand model with instrumental variables (IV) as another robustness check. In particular, we instrument the first differences of the global price of crude oil and the US dollar real effective exchange rate in equation (2) by the first difference and the level of the US federal funds rate.

As shown in the left panel of Table 5, the results of the IV estimations confirm a relatively strong impact of the US dollar effective exchange rate on oil demand in the three samples but the effect is confined to the long-run coefficients. The differences in magnitudes relative to the global price coefficient even increase for the long-run coefficients, relative to the benchmark results reported in section 3.1. We obviously have to be careful when interpreting the magnitudes of the coefficients, given the loss of power of two-stage regressions with instrumental variables. This is reflected in the relatively large standard errors for the short-run price and exchange rate elasticities.

As a final robustness check, we have estimated a specification with bilateral real exchange rates instead of the US dollar real effective exchange rate. While the effective US dollar exchange rate reflects changes in the overall value of the US dollar, i.e. the currency unit which matters for global oil market dynamics, bilateral exchange rates capture more of the effects on the local oil price that consumers have to pay in each individual country. We again use IV estimations.[22] The right panel of Table 5 shows the results. In general,

[21] Japan has the largest weight in the US dollar effective exchange rate for our sample of countries, notably 18 percent since 1990.

[22] Potential endogeneity problems between the bilateral US dollar exchange rate and the country-specific demand for oil are more likely than for the specification with the effective US dollar exchange rate. We apply the same instruments for the bilateral exchange rates, but use the lagged level of the real effective US dollar exchange rate instead of the lagged level of the bilateral exchange rate to instrument the oil price, given the common nature of the oil price variable. Notice that the sample size for the different groups of

the estimated coefficients turn out to be different from the benchmark results, which is probably due to the loss of power of the two-stage estimation procedure, and the difficulty to find proper instruments. In particular, the estimated global oil price elasticity becomes insignificant for the non-OECD group, and even significantly positive for the total sample of countries in the short run. The exchange rate elasticity estimates are, in contrast, still (significantly) negative in the short run. The magnitudes are however large, in particular for the non-OECD and total sample, while the standard errors increase considerably, which points to an inefficient estimator.

4 Pass-through of USD exchange rate to oil product prices

A striking result is that we consistently find that shifts in the US dollar exchange rate have a stronger impact on oil consumption in non-US dollar oil-importing countries than changes in the global price of crude oil expressed in US dollar. In this section, we analyze this in more detail. More specifically, we examine whether differences in the pass-through of global crude oil prices and the US dollar exchange rate to domestic end-user prices can explain the difference. The inertia of domestic prices of internationally traded goods to exchange rate changes is well-documented in international economics (e.g. Engel 2003; Goldberg and Hellerstein 2013) and might be different for shifts in global crude oil prices. Note that the analysis in this section is restricted to a confined group of 20 OECD countries, and only starts in 1978 due to the availability of end-user oil price data (see appendix). The pass-through analysis thus covers a substantially reduced sample in terms of the number of countries and time observations compared to the entire sample in the baseline oil demand model, but should nevertheless be instructive. The data for the G-7 oil-importing countries that are included in the analysis are shown in Figure 2.

In line with the existing literature on the pass-through of changes in the exchange rate to domestic good prices (e.g. Bussière 2013), we estimate a simple dynamic linear oil product price equation for the panel of 20 OECD countries over the sample period 1978-2008 of the following form:

$$\Delta P_{it}^{end} = \alpha_{0i} + \alpha_{1i}\Delta rac_t + \alpha_{2i}\Delta rer_t + \alpha_{3i}\Delta P_{i,t-1}^{end} + \varepsilon_{it} \tag{3}$$

countries is now smaller due to the non-availability of bilateral exchange rate and/or domestic CPI data for some countries over the time period under consideration (see Appendix A).

where Δrac_t and Δrer_t are again the global price of crude oil expressed in US dollar and the real effective US dollar exchange rate, while ΔP_{it}^{end} represents the domestic end-user oil products prices in local currency of country i. These prices include taxes and are a weighted average of 4 product groups, i.e. motor gasoline, gas/diesel oil, light fuel oil and residual oil. The results are shown in Table 6. According to Wald and CD tests, the preferred estimator is the MG estimator adjusted for cross-sectional dependence. The results reveal that both the pass-through of the US dollar effective exchange rate and the global crude oil price to domestic oil product prices is incomplete (i.e. less than proportional). The incomplete pass-through in percent change terms emphasizes the well-known principle that price elasticities measured at the crude oil level are usually lower than those at the end-use level because the percentage price increase is larger.

More importantly in the context of the present study, however, is the appreciable difference in the magnitudes of the $\widehat{\alpha}_1$ and $\widehat{\alpha}_2$ coefficients. In particular, the magnitude of the exchange rate pass-through is about twice as large as the global crude oil price pass-through to end-user product prices. The difference between both coefficients is statistically significant according to a Wald test. This finding suggests that a different pass-through of US dollar and global crude oil price fluctuations to end-user prices could be an explanation for the different impact on oil demand that we have found.

A stronger pass-through of the US dollar exchange rate to end-user prices relative to changes in the global price of crude oil, however, is not necessarily the only explanation for the larger exchange rate elasticity of oil demand. On top of this, the exchange rate could also affect other conditions that have an impact on oil demand (e.g. by also affecting the cost of borrowing). To further examine this, Table 7 presents the estimation results of the benchmark specification, where we have replaced the global price of crude oil expressed in US dollars by the domestic end-user product prices expressed in local currency.[23] The results reveal that the oil price elasticity indeed increases when local prices are used, a finding which is consistent with Dargay and Gately (2010), and van Benthem and Romani (2009). Moreover, the exchange rate coefficient is now never statistically significant any-

[23] Since local oil prices could be affected by shifts in local oil demand, these results need to be taken with more than the usual degree of caution. Notice also that the inclusion of the exchange rate does not seem to absorb some of the true price and income effects. Specifically, as can be seen in Table 7, the price and income coefficients are very similar when we estimate the model without the US dollar exchange rate. Only the long-run price elasticity coefficient of the MG_Ft seems to be affected, but also the standard errors are quite large.

more, which indicates that there is no additional effect of the US dollar exchange rate on the demand for oil once the pass-through to end-user prices is incorporated in the oil price variable.[24] In other words, we can conclude that differences in the pass-through to local oil product prices appear to be the key reason for the stronger effect of shifts in the US dollar exchange rate on oil demand relative to changes in global crude oil prices.

5 Economic relevance

In this section, we perform a back-of-the-envelope calculation in order to assess the relevance of US dollar exchange rate fluctuations for global oil market dynamics. Given its simplicity, the exact numbers should be interpreted with caution. The calculation does, for instance, not take into account endogenous dynamics. It should nevertheless give an idea about the importance of the US dollar for the oil market.

First, we assume that the estimated exchange rate elasticity for the total sample (-0.088) is representative for global (non-US) oil demand. Given the fact that the US represents on average 27 percent of world oil demand over the sample, this implies that a 1 percent appreciation of the US dollar leads to a decline in global oil demand by $-0.088 * (1 - 0.27) = -0.064$ percent. Based on this number, and the price elasticity estimate, consider the following simplified short-run oil demand function for the global oil market:

$$\Delta q_{oil} = -0.039 \Delta p_{oil} - 0.064 \Delta rer_{US}$$

where q_{oil}, p_{oil} and rer_{US} are respectively global crude oil demand, the global real price of crude oil and the real effective US dollar exchange rate. Furthermore, according to Kilian and Murphy's (2012) reading of the literature, the upper bound on the short-run price elasticity of oil supply is 0.025, which gives us the following simplified short-run global crude oil supply function:

$$\Delta q_{oil} < 0.025 \Delta p_{oil}$$

Solving this model delivers the following effects of a shift in the US dollar exchange

[24] When we re-estimate this specification by converting the local oil product prices to US dollar, the exchange rate coefficient becomes again significant, while the magnitude of the oil price elasticity is hardly affected. These results are available upon request.

rate on oil prices and production:

$$\begin{aligned} |\Delta p_{oil}| &> 1.004\,|\Delta rer_{US}| \\ |\Delta q_{oil}| &> 0.025\,|\Delta rer_{US}| \end{aligned}$$

As a benchmark, the monthly average of $|\Delta rer_{US}|$ in the data is for instance 1.16 percent. According to our simple back-of-the-envelope calculation, this corresponds to an average shift in global oil prices by 1.17 percent. Given the fact that the monthly average of $|\Delta p_{oil}|$ in the data is 4.76 percent, the relevance of US dollar exchange rate fluctuations for global oil price dynamics is considerable. Due to the very low oil supply elasticity, this is less the case for oil production. In particular, the monthly average of $|\Delta q_{oil}|$ in the data is 1.08 percent, whereas exchange rate fluctuations could only explain about 0.03 percent according to our simple calculations.

Average elasticities are, however, not necessarily representative for the global oil market, which is essentially a weighted average of all individual countries in the world. Therefore, we have also calculated weighted MG estimates of the panel error correction oil demand model, where the weights of the country-specific coefficients are determined by the share of the respective country in the total oil consumption over the sample. Accordingly, countries with a larger share in global oil demand have more weight such that the resulting MG estimates better represent global elasticities.[25] The short-run price and exchange rate coefficients that result from this exercise are respectively -0.045 and -0.122. These coefficients in turn result in an impact of US dollar effective exchange rate fluctuations of more than 1.48 percent on world oil price dynamics and 0.03 percent on global oil production using the above described procedure. In sum, our back-of-the-envelope calculations demonstrate that the effective US dollar exchange rate appears to be very important for fluctuations in global crude oil prices through its effect on the demand for oil. The effect on oil production on the other hand is very limited due to the very low short-run price elasticity of oil supply.

6 Conclusions

In this paper, we have examined the role of the US dollar exchange rate for the demand for oil in non-US dollar regions by using recent advances in panel data estimation techniques.

[25] Our sample represents 59 percent of non-US global oil demand.

In particular, we have estimated a panel error correction oil demand model allowing for cross-country heterogeneity in the slope coefficients, and taking into account cross-country common unobserved variables. The results show that an appreciation of the US dollar exchange rate robustly leads to a decline in the demand for oil in countries that do not use the US dollar for local transactions, which supports the premise of a significant exchange rate channel underlying oil demand dynamics. Strikingly, a 1 percent shift in the real US dollar exchange rate seems to have a much stronger effect on oil demand than a 1 percent shift in the global real crude oil price determined in US dollar. A more detailed analysis of the effect of changes in the global crude oil price and the US dollar exchange rate on country-specific end-user prices of oil products suggests that the difference is the result of a much stronger pass-through of exchange rate fluctuations to end-user prices. The reason for the stronger pass-through of the US dollar effective exchange rate is beyond the scope of this paper, but could be a promising avenue for future research. A potential avenue is the lower volatility of the US dollar exchange rate compared to the global crude oil price.

A back-of-the-envelope calculation furthermore suggests that shifts in the US dollar exchange rate are economically important for global (US dollar) crude oil price fluctuations due to its influence on global oil demand. It is thus recommended to include the US dollar exchange rate in the analysis of global oil market dynamics in the spirit of Kilian (2009), Peersman and Van Robays (2009) and Juvenal and Petrella (2012).

Data Appendix

Data sources:

- Total oil demand (1000 barrels per day): International Energy Agency (IEA), Oil Information database
- Total midyear population (number of persons): US Census Bureau, International database
- Global crude oil price (US dollars per barrel): Energy Information Administration (EIA), Refiner acquisition cost of imported crude oil
- Real gross domestic product per capita.: Penn World Tables 7.0, PPP Converted GDP Per Capita (Chain Series), 2005 constant prices
- Real US dollar effective exchange rate: BIS, real effective exchange rate index (CPI-based), Narrow Index (2010=100)
- Monthly Crude oil and NGL production for Figure 1 (1000 barrels per day): IEA, Oil Information database
- Individual country nominal exchange rates [ER] (national currency unit to US $, period average) : IMF, IFS database
- Consumer prices [CPI] (indices, 2005=100): IMF, IFS database
- End-user oil products prices [penduser]: IEA, Energy Prices and Taxes database
- US GNP deflator: Datastream, US chain-type price index for GNP (code: US-GNP..CE)
- US Federal Funds rate: Datastream, US Federal Funds effective rate (code: FRFEDFD?)

Construction variables: -> Total oil demand per capita [DEM] (barrels per day, per 1000 persons) = Total Oil demand/ Total population*1000

-> Real global crude oil price [POIL]: Global nominal crude oil price/ CPIust*100

-> Real exchanges rates [bRER] = ERit * CPIus,t / CPIit, index 2005=100

-> Real end-user oil products price indexes in national currencies [penduser]: quantity weighted real end-user price index (2005=100) of oil products based on Griffin and Schulman (2005), i.e.for 4 product groups: residual oil, light fuel oil, motor gasoline and gas/diesel oil weighted based on their respective importance in aggregated consumption.

Sample coverage: The dataset is balanced for 65 oil-importing countries over the sample period 1971-2008. All variables are converted to natural logarithms, such that the models are of the constant elasticity form.

OECD sample (23 countries): Australia, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Netherlands, New Zealand, Poland, Portugal, Spain, Sweden, Switzerland and Turkey

Non-OECD sample (42 countries) : Bangladesh, Benin, Bolivia, Brazil, Bulgaria, Chile, China, Costa Rica, Cote d'Ivoire, Cyprus, Dominican Republic, El Salvador, Ethiopia, Ghana, Guatemala, Haiti, Honduras, Hong Kong, India, Israel, Jamaica, Jordan, Kenya, Malta, Morocco, Mozambique, Nicaragua, Pakistan, Paraguay, Peru, Philippines, Romania, Senegal, Singapore, South Africa, Sri Lanka, Sudan, Tanzania United Republic, Thailand, Uruguay, Zambia and Zimbabwe

The following countries have been excluded from the analysis because of being a **net oil-exporting country**, i.e. countries for which the production of crude oil has been larger than total oil demand for at least 25 years: Canada, Mexico, Norway, United Kingdom, Algeria, Angola, Argentina, Bahrain, Cameroon, Colombia, Congo, Congo Democratic Republic, Ecuador, Egypt, Gabon, Indonesia, Iran, Iraq, Kuwait, Malaysia, Nigeria, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates and Venezuela

When the model includes the bilateral real US dollar exchange rate instead of the real effective US dollar exchange rate index, the total sample reduces to 44 countries (20 OECD and 24 non-OECD countries) due to missing data for the bilateral nominal exchange rates and/or consumer price indices for the entire time period under consideration.

-> Missing OECD: Hungary, Poland, Turkey

-> Missing non-OECD: Bangladesh, Benin, Bolivia, Brazil, Bulgaria, Chile, China, Ghana, Hong Kong, Israel, Mozambique, Nicaragua, Peru, Romania, Sudan, Uruguay,

Zambia, Zimbabwe

When the model includes end-user oil product prices instead of the real global crude oil price, the total sample reduces to 20 OECD countries due to missing data on end-user oil products price indices for the entire time period under consideration (1978-2008).

-> Missing OECD: Australia, Iceland and Turkey

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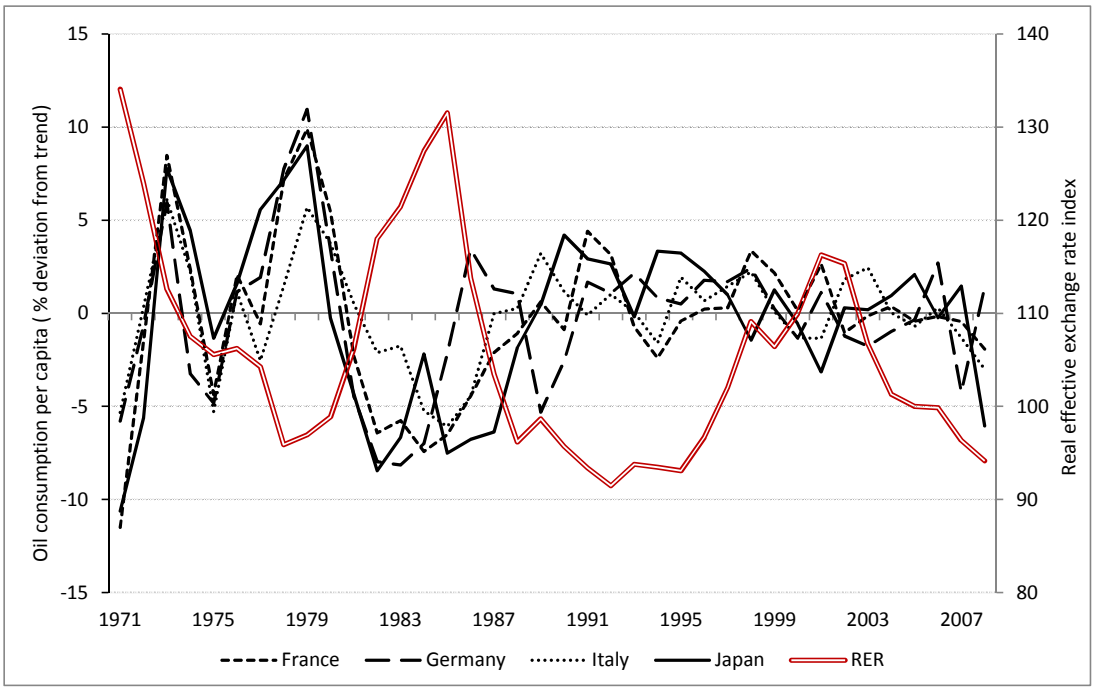
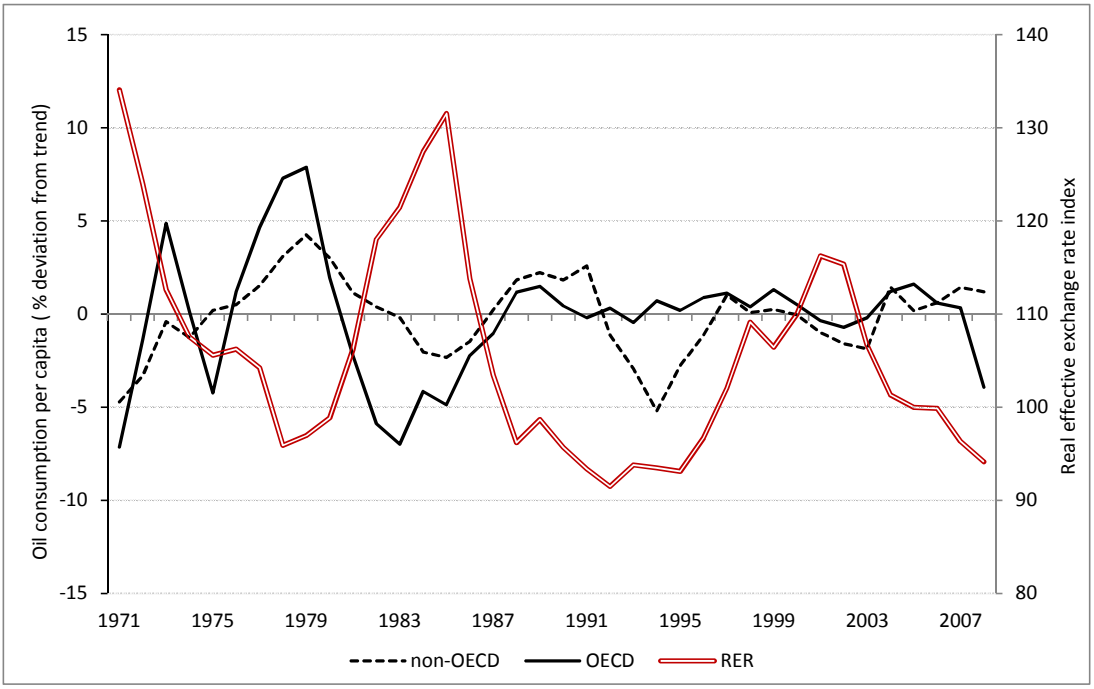
Figure 1: evolutions in oil consumption in G-7 countries in sample and in total OECD and non-OECD aggregates versus the evolution of real effective US dollar exchange rate

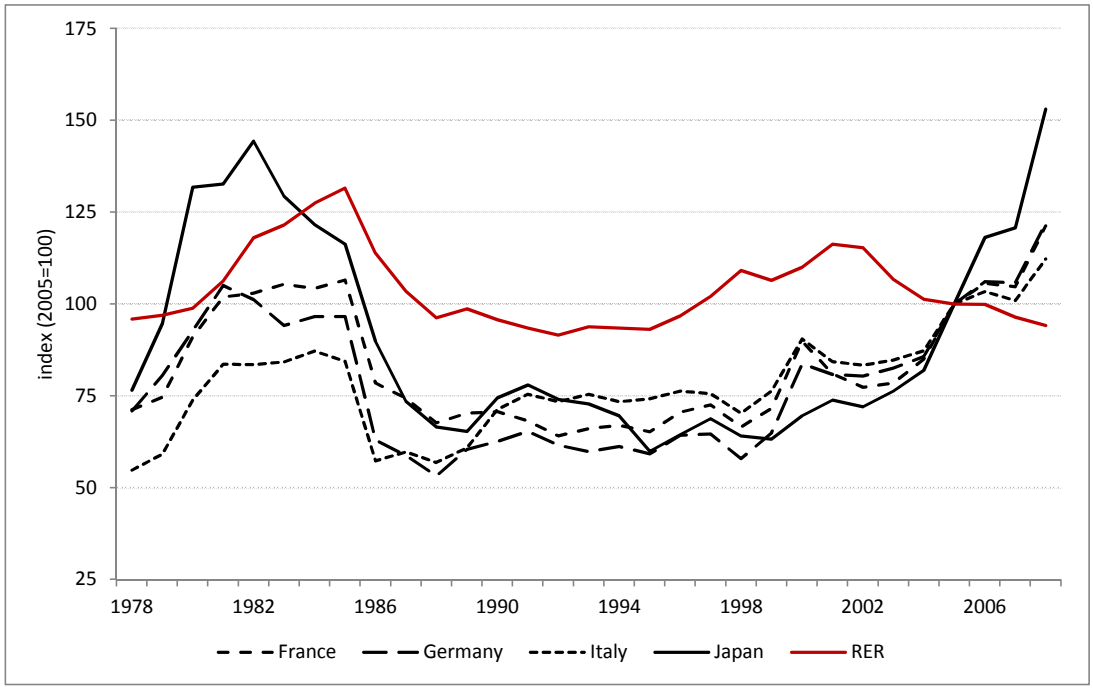


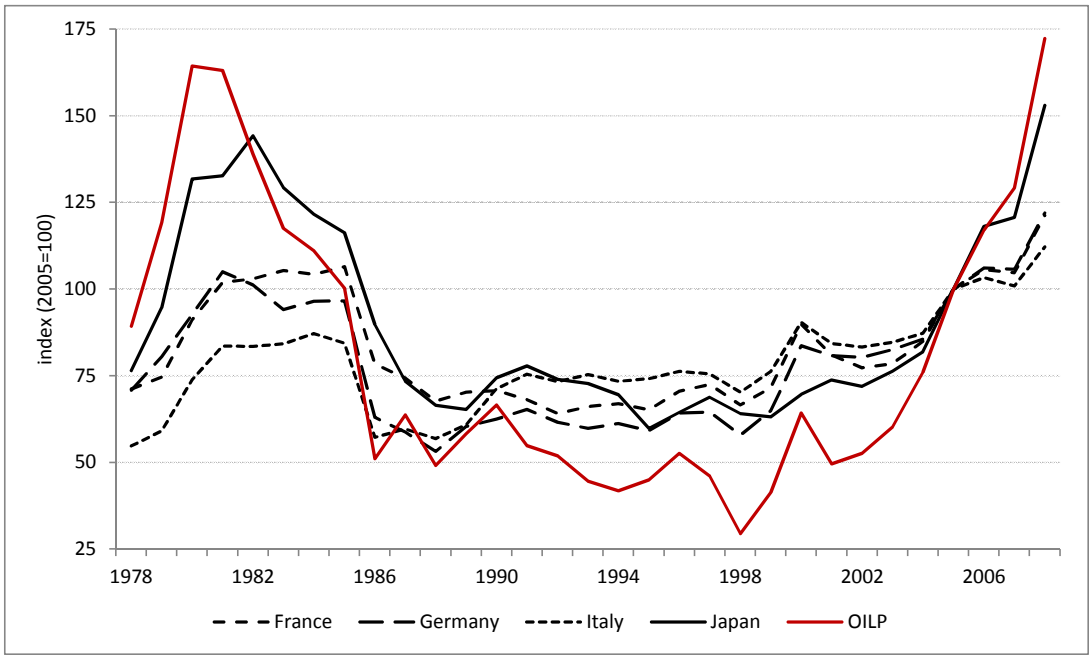


Note: the left axis' units refer the percentage deviation from trend from total oil demand per capita (barrels per day, per 1000 persons), the right axis refers to the real effective US dollar exchange rate (RER) which is an index equal to 100 in base year 2005.

Sources data: total oil demand: IEA / population individual countries: US Census Bureau (international database) / population OECD and non-OECD country aggregates: OECD (population database) / RER: BIS (narrow index).

Figure 2: country-specific real end-user prices for G-7 countries in sample relative to the real effective US dollar exchange rate (panel 1) and to the global real crude price (panel 2)





Note: All series are indexed with base year 2005 equal to 100. The individual country series refer to quantity weighted real end-user price indexes of oil products based on Griffin and Schulman (2005), i.e.for 4 product groups: residual oil, light fuel oil, motor gasoline and gas/diesel oil weighted based on their respective importance in aggregated consumption, the RER series refers to the real effective US dollar exchange rate and the OILP series to the global real crude oil price.

Sources data: end-user oil products prices for individual countries: International Energy Agency (Energy Prices and Taxes database) / OILP: Energy Information Administration website (refiner acquisition cost of imported crude oil) / RER: BIS (narrow index).

Table 1: results PANIC tests, total sample				
	Estimated number of common factors (r)			
	DEMit	GDPit		
IC1	4	2		
IC2	4	1		
BIC3	2	1		
	intercept only model			
	DEMit		GDPit	
	r=2	r=4	r=1	r=2
MW	109.84	100.54	177.77***	217.35***
Choi	-1.25	-1.83	2.96***	5.42***
ADFf	-	-	1.33	-
MQc	-0.93	-0.18	-	-0.18
MQf	-1.58	-0.64	-	-0.34
	linear trend model			
	DEMit		GDPit	
	r=2	r=4	r=1	r=2
MW	163.70**	117.91	130.25	149.75
Choi	2.09**	-0.75	0.02	1.22
ADFf	-	-	0.18	-
MQc	-6.09	-4.8	-	-3.34
MQf	-7.12	-6.43	-	-3.16
	ADF test common observed variables			
	intercept only model		linear trend model	
OILPt	-1.25		-0.46	
RERt	-3.26**		-3.72**	

PANIC test (Bai and Ng, 2004):
Number of common factor determined by IC1, IC2 and BIC3 criteria (Bai and Ng, 2002)
Number of lags in both model specifications: determined by Bai and Ng (2004) rule: $4[\min[N,T]/100]^{1/4}$
MW = Maddala and Wu (1999) pooled unit root test statistic on idiosyncratic term
Choi = Choi (2001) pooled unit root test statistic on idiosyncratic term
ADFf = Augmented Dickey Fuller (ADF) test (Dickey and Fuller, 1979) on estimated common factor if r=1
MQc/MQf = Modified variants of Stock and Watson's (1988) Qf and Qc statistics to determine the number of factors spanning the non-stationary space of the common term

Augmented Dickey Fuller (ADF) test on observed common factors:
Lag order determined by Schwarz Bayesian Criterion (SBC)

***/**/*: respectively refers to significance at the 1/5/10 % level

Table 2: results panel cointegration tests, total sample			
GUW test			
	Model 1	Model 2	Model 3
$\tau^*\_\alpha i$	-1.47	-5.66***	-6.11***
$\omega^*\_\delta i$	24.64***	29.12***	34.20***
PANIC test on CupBC residuals			
		intercept only model	linear trend model
MW		866.68***	704.37***
Choi		45.69***	35.62***

GUW test (Gengenbach, Urbain and Westerlund, 2008): pooled tests for no error correction
Number of lags: determined by Akaike Information Criterion (AIC)
$\tau^*\_\alpha i$ = average of truncated version of the individual t-test statistics of no error correction
$\omega^*\_\delta i$ = average of truncated version of the individual Wald test statistics of no error correction
Model 1 = model with no deterministic terms
Model 2 = model with unrestricted constant
Model 3 = model with unrestricted constant and trend

PANIC test on CupBC residuals:
First step: Continously-updated bias-correcting (CupBC) estimator (Bai et al, 2009) on static long-run specification
Second step: PANIC test (Bai and Ng, 2004) on idiosyncratic part of residuals of first step regression

Table 3: baseline model									
	OECD			**non-OECD**			**TOTAL**		
	FE	MG	MG_Ft	FE	MG	MG_Ft	FE	MG	MG_Ft
gdp	0.739***	0.667***	0.686***	0.494***	0.500***	0.532***	0.530***	0.559***	0.595***
	(0.084)	(0.080)	(0.077)	(0.102)	(0.085)	(0.093)	(0.091)	(0.060)	(0.062)
oilp	-0.047***	-0.052***	-0.054***	-0.029**	-0.025*	-0.027**	-0.036***	-0.041***	-0.039***
	(0.007)	(0.008)	(0.008)	(0.010)	(0.013)	(0.013)	(0.007)	(0.008)	(0.008)
rer	-0.169***	-0.150***	-0.192***	-0.133**	-0.060	-0.057	-0.147***	-0.095***	-0.088***
	(0.030)	(0.032)	(0.035)	(0.051)	(0.056)	(0.056)	(0.034)	(0.032)	(0.034)
trend	-0.002***	-0.001	-0.001	-0.000	-0.001	-0.001	-0.000*	-0.001	-0.001
	(0.000)	(0.002)	(0.001)	(0.000)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)
	long-run coefficients								
EC	-0.074***	-0.244***	-0.202***	-0.110***	-0.429***	-0.391***	-0.093***	-0.356***	-0.326***
	(0.010)	(0.037)	(0.045)	(0.030)	(0.039)	(0.038)	(0.021)	(0.031)	(0.030)
gdp	1.108***	0.915**	0.520**	0.732***	1.019***	1.064***	0.706***	0.872***	0.939***
	(0.010)	(0.416)	(0.219)	(0.018)	(0.157)	(0.177)	(0.014)	(0.143)	(0.157)
oilp	-0.383***	-0.130***	-0.115***	-0.286***	-0.119***	-0.151***	-0.334***	-0.120***	-0.140***
	(0.005)	(0.023)	(0.041)	(0.011)	(0.033)	(0.037)	(0.008)	(0.022)	(0.025)
rer	-0.689***	-0.325***	-0.310***	-0.308***	-0.322***	-0.343***	-0.417***	-0.347***	-0.346***
	(0.022)	(0.096)	(0.102)	(0.031)	(0.089)	(0.088)	(0.021)	(0.070)	(0.069)
	Swamy's Wald test								
statistic	318.57***			468.00***			833.45***		
	Cross section Dependence test								
statistic	10.93***	10.29***	5.67***	4.84***	5.38***	4.59***	13.01***	11.59***	11.01***
ρ	0.113	0.106	0.059	0.027	0.030	0.026	0.047	0.042	0.040

FE= Fixed Effects estimator
MG= Mean Group estimator
MG_Ft= Mean Group estimator adjusted for cross-sectional dependence
ρ = average pair-wise correlation coefficient of residuals

***/**/*: respectively refers to significance at the 1/5/10 % level
standard errors are listed in brackets (robust s.e. for FE)

The empirical analysis was carried out in Stata 12, and we employed the user-written Stata routines xtcd and xtmg written by Markus Eberhardt (Eberhardt, 2012).
An outlier-robust weighting procedure is used to construct the MG estimates, following Bond, Leblebicioglu and Schiantarelli (2010).

Table 4: price decomposition									
	OECD			**non-OECD**			**TOTAL**		
	FE	MG	MG_Ft	FE	MG	MG_Ft	FE	MG	MG_Ft
gdp	0.692***	0.684***	0.717***	0.466***	0.408***	0.467***	0.498***	0.518***	0.558***
	(0.080)	(0.083)	(0.109)	(0.099)	(0.078)	(0.083)	(0.088)	(0.060)	(0.062)
pmax	-0.115***	-0.108***	-0.109***	-0.108***	-0.096***	-0.093***	-0.113***	-0.101***	-0.098***
	(0.016)	(0.014)	(0.015)	(0.018)	(0.019)	(0.019)	(0.012)	(0.012)	(0.012)
prec	-0.057***	-0.034**	-0.042***	-0.062*	-0.006	-0.020	-0.059**	-0.029*	-0.038**
	(0.015)	(0.014)	(0.016)	(0.035)	(0.035)	(0.033)	(0.023)	(0.017)	(0.017)
pcut	-0.023	-0.019**	-0.022**	0.021	0.012	0.000	0.006	-0.003	-0.006
	(0.015)	(0.014)	(0.010)	(0.030)	(0.019)	(0.020)	(0.019)	(0.011)	(0.011)
rer	-0.130***	-0.102***	-0.143***	-0.131**	-0.020	-0.027	-0.135***	-0.073*	-0.069*
	(0.027)	(0.036)	(0.041)	(0.053)	(0.066)	(0.063)	(0.035)	(0.038)	(0.040)
trend	-0.001	-0.003	-0.002	0.007**	0.002	0.002	0.005**	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)	(0.004)	(0.002)	(0.002)	(0.002)
	long-run coefficients								
EC	-0.089***	-0.424***	-0.326***	-0.119***	-0.505***	-0.470***	-0.103***	-0.476***	-0.449***
	(0.012)	(0.054)	(0.060)	(0.033)	(0.043)	(0.041)	(0.024)	(0.034)	(0.033)
gdp	1.006***	0.715***	0.762***	0.766***	0.829***	0.845***	0.731***	0.766***	0.819***
	(0.012)	(0.165)	(0.245)	(0.019)	(0.129)	(0.133)	(0.015)	(0.114)	(0.109)
pmax	-0.711***	-0.253***	-0.223***	-0.806***	-0.243***	-0.223***	-0.840***	-0.245***	-0.233***
	(0.011)	(0.045)	(0.043)	(0.025)	(0.041)	(0.039)	(0.018)	(0.030)	(0.031)
prec	-0.243***	-0.055*	-0.060)	-0.424***	-0.101*	-0.111*	-0.411***	-0.087**	-0.095***
	(0.007)	(0.030)	(0.041)	(0.019)	(0.055)	(0.060)	(0.012)	(0.034)	(0.036)
pcut	-0.225***	-0.038	-0.005	0.118***	-0.077	-0.080	0.036**	-0.069*	-0.066
	(0.009)	(0.039)	(0.059)	(0.022)	(0.061)	(0.063)	(0.014)	(0.039)	(0.042)
rer	-0.713***	-0.400***	-0.358***	-0.466***	-0.281***	-0.302***	-0.563***	-0.329***	-0.329***
	(0.020)	(0.076)	(0.108)	(0.031)	(0.065)	(0.057)	(0.022)	(0.049)	(0.044)
	Swamy's Wald test								
statistic	565.28***			964.91***			1586.41***		
	Cross section Dependence test								
statistic	4.80***	9.33***	4.70***	1.61	5.60***	4.39***	4.62***	10.26***	9.99***
ρ	0.050	0.098	0.049	0.009	0.032	0.025	0.017	0.037	0.037

Table 5: IV estimation [MG_Ft]						
	Real effective US $ exchange rate			Real bilateral US $ exchange rates		
	OECD (N=23)	non-OECD (N=42)	TOTAL (N=65)	OECD (N=20)	non-OECD (N=24)	TOTAL (N=44)
gdp	0.731***	0.537***	0.629***	0.567***	0.184	-0.127
	(0.149)	(0.124)	(0.080)	(0.086)	(0.252)	(0.142)
oilp	-0.141**	-0.076	-0.107***	-0.053**	-0.014	0.077***
	(0.070)	(0.066)	(0.039)	(0.026)	(0.036)	(0.027)
rer / brer	-0.086	0.112	-0.142	-0.181***	-1.408**	-1.309***
	(0.164)	(0.129)	(0.100)	(0.064)	(0.579)	(0.194)
trend	-0.001	-0.001	-0.003**	-0.001	0.010**	0.012***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.005)	(0.002)
	long-run coefficients					
EC	-0.291***	-0.352***	-0.288***	-0.258***	-0.501***	-0.452***
	(0.053)	(0.035)	(0.025)	(0.049)	(0.071)	(0.033)
gdp	0.832***	0.260	0.443***	0.103	0.624**	0.718***
	(0.226)	(0.180)	(0.146)	(0.130)	(0.226)	(0.242)
oilp	-0.027	-0.050**	-0.054***	-0.013**	-0.021	0.013
	(0.020)	(0.022)	(0.015)	(0.005)	(0.041)	(0.020)
rer / brer	-0.289**	-0.622***	-0.429***	-0.004	-0.008	0.029
	(0.140)	(0.117)	(0.079)	(0.008)	(0.071)	(0.044)
	Cross section Dependence test					
statistic	4.46***	7.86***	17.62***	5.98***	5.62***	17.31***
ρ	0.046	0.044	0.064	0.071	0.056	0.093

IV=$dFFR_t$, FFR_t

IV=$dFFR_t$,FFR_t for $drer_{it}$ / $dFFR_t$, FFR_t, $REER_t$ for $drac_t$

Table 6: pass-through to domestic end-user prices			
	0ECD (N=20)		
Δpenduser	FE	MG	MG_Ft
Δrac	0.309***	0.323***	0.306***
	(0.024)	(0.016)	(0.015)
Δrer	0.512***	0.627***	0.629***
	(0.075)	(0.043)	(0.055)
Lagged Δpenduser	0.169***	0.180***	0.284***
	(0.043)	(0.033)	(0.050)
	Swamy's Wald test		
statistic	87.72***		
	Cross section Dependence test		
statistic	21.22***	25.14***	11.19***
ρ	0.286	0.339	0.153

Table 7: domestic end-user prices							
	OECD (N=20)						
	FE	MG	MG_Ft		FE	MG	MG_Ft
gdp	0.686***	0.560***	0.582***	gdp	0.681***	0.527***	0.565***
	(0.090)	(0.088)	(0.088)		(0.088)	(0.086)	(0.091)
penduser	-0.124***	-0.093***	-0.115***	penduser	-0.126***	-0.100***	-0.126***
	(0.016)	(0.013)	(0.017)		(0.016)	(0.013)	(0.016)
rer	-0.044	-0.022	-0.044	-	-	-	-
	(0.028)	(0.031)	(0.037)				
trend	-0.001***	-0.003	-0.002	trend	-0.001*	-0.002	-0.001
	(0.001)	(0.002)	(0.002)		(0.001)	(0.001)	(0.001)
	long-run coefficients						
EC	-0.121***	-0.293***	-0.208***	EC	-0.122***	-0.256***	-0.178***
	(0.018)	(0.049)	(0.058)		(0.018)	(0.042)	(0.041)
gdp	1.151***	0.660***	0.824***	gdp	1.157***	0.627***	1.086***
	(0.014)	(0.253)	(0.310)		(0.015)	(0.220)	(0.303)
penduser	-0.526***	-0.305***	-0.284*	penduser	-0.563***	-0.389***	-0.559***
	(0.012)	(0.059)	(0.158)		(0.014)	(0.059)	(0.184)
rer	-0.223***	-0.119	-0.290***	-	-	-	-
	(0.023)	(0.084)	(0.109)				
	Swamy's Wald test						
statistic	260.08***			statistic	186.63***		
	Cross section Dependence test				Cross section dependence test		
statistic	5.55***	7.75***	6.59***	statistic	5.92***	7.25***	6.34***
ρ	0.074	0.103	0.087	ρ	0.078	0.096	0.084