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Asymmetry in transport fuel demand: Evidence from household level data

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Abstract

Models for gasoline demand for transportation activities generally assume that demand is perfectly reversible with respect to gasoline price (and income). The small literature which relaxes the reversibility assumption in gasoline demand argues technological fixation leads to this asymmetry and utilizes aggregate time-series model to find evidence in favour of asymmetry. In this research it is suggested that there could also be behavioural factors behind this asymmetric response, possibly due to the loss aversion nature of human beings as described in the prospect theory. For the first time, household level data was used to understand asymmetry in gasoline demand in response to changes in gasoline price and income. There was statistical evidence that gasoline price and income both can induce asymmetric changes in gasoline demand among households. Specifically, elasticity with respect to rising prices and falling income is larger than the elasticity with respect to falling prices and rising income respectively, which is consistent with loss aversion in gasoline purchase behaviour. There was also some evidence of heterogeneity in the asymmetric responses between urban and rural households. The results have implications for transport-related energy tax policies or subsidies, while the method can be applied directly for non-energy goods as well.

Keywords

Asymmetry, reversibility, gasoline demand, elasticity, transport fuel, behavioural response

Asymmetry in transport fuel demand: Evidence from household level data

1. Introduction

Transportation is responsible for around one-fifth of total global energy consumption (Energy Information Administration 2015). The sector is almost entirely dependent on petroleum fuel and as such provides a substantial challenge in addressing the energy trilemma goals (energy security, energy affordability and environmental sustainability). Within the transport sector, light duty vehicles are responsible for more than half of the total energy consumption. This is also the segment that is experiencing a large growth in the developing and emerging countries. Therefore energy use from the light duty vehicle segment remains high on the policymakers' agenda and gasoline (or diesel) demand remains a key area of research interest.

Demand for transport fuels is possibly one of the most widely researched area in energy economics. Nearly all of this large literature assumes demand to be perfectly reversible, i.e. the demand responses to similar increases and decreases in prices are numerically equal. This view has been challenged in the 1990s by a number of researchers who suggested that gasoline and, to a larger extent, energy demand show substantial asymmetry during price rises and falls - specifically, demand falls faster during price rises, but does not recover as quickly during price reductions (Gately 1992, Gately and Huntington 2002, Dargay 1992, Dargay and Gately 1997, Sentenac-Chemin 2012). Dargay and Gately (1997) argue that this asymmetry is due to asset or technology fixation - during price rises of the two oil shocks, people invested in more fuel efficient cars, which remained in use despite the subsequent price falls. Although no behavioural explanation was offered in this early literature, since Kahneman and Tversky's (1979) prospect theory came to light, it is now accepted that people value losses more than gains, which could also result in asymmetric responses to price and income changes. Therefore, it is likely that the asymmetric demand responses found in the previous transport energy literature were due to both asset fixation as well as behavioural reasons. This paper adds to the existing literature on demand for gasoline or transport fuel by asking three novel research questions: firstly, can asymmetry in gasoline demand be attributed to behavioural factors such as loss aversion, rather than only asset fixation, as hypothesized in previous literature. Secondly, can we use a new type of disaggregate household level data in order to understand asymmetric responses in *gasoline* demand, and if yes, what type of modelling approach can we suggest for using these types of data? Thirdly, are there any differences in the potential asymmetric responses between urban and rural households?

The paper is organized as follows. Section 2 reviews the relevant literature on imperfect reversibility in gasoline demand and its possible explanation through loss aversion. Section 3 presents the econometric method employed while Section 4 describes the data. Section 5 presents the results and Section 6 draws conclusions.

2. Review of the Literature

Perfect reversibility of demand or symmetry in demand responses with respect to price means that demand reductions during an increase in prices will be fully compensated by demand increases during similar price falls (or vice versa), i.e. the elasticity of demand during price rises and price falls are equal. While such symmetry in responses forms the basis of classical demand and supply theory, there has been some evidence of asymmetric response in the supply side in the 1970s (e.g. Wolffram 1971, Traill et al. 1978). In the energy and transport energy domain, there was a general observation in the 1990s that the sustained low gasoline prices after the two oil price shocks in the 1970s did not fully reverse the reduction in consumption caused by the price shocks. Dargay (1991) and Gately (1992) investigated the issue further and concluded that price asymmetry existed in the demand for transportation fuel in the US, UK, France and Germany. They argue that irreversible technology fixation, whereby people invest in fuel efficient technologies during a price rise but do not dispose of these when price falls, is responsible for the asymmetric response. This is the dominant view in the transportation energy literature as well, where behavioural attitudes or responses are not discussed.[1] Gately (1992) and Dargay (1992) also identified a second type of imperfect reversibility, known as hysteresis, which argues that the demand responses to price changes can be different on price history - more precisely, whether current price is above or below a previous maximum. Table 1 summarizes the major studies on imperfect reversibility of gasoline or transportation energy demand.

[Table 1 here]

There is also a large body of literature which studies asymmetry in areas *outside* of transportation fuel demand. On the energy demand side, these include demand for petroleum products (Asali 2011, Dargay and Gately 1995, Broadstock et al. 2011), residential energy (Haas and Schipper 1998), industrial energy (Adeyemi and Hunt 2007), total energy (Dargay 1992, Adeyemi et al. 2010). On the travel demand side, the examples include Gately (1992), Dargay (2001), Greene (2012) and Hymel and Small (2015) for car travel or Wadud (2014, 2015) for air travel; yet Frondel and Vance (2011) use household data to find travel demand in Germany was reversible with respect to prices. On the supply side, Wolffram (1971) and Traill et al. (1978) were the early research in agriculture economics, while recent applications include asymmetry in price transmission in the retail gasoline sector (Bacon 1991, Borenstein et al. 1997). The econometric modelling approach remains the same in all of these studies: decomposition of the price variable into separate series of price rises and price falls in the model specification and utilization of primarily time-series (in some cases panel) information in a reduced form demand equation. Ryan and Plourde (2002) is the only study that employed a demand system framework instead of reduced form models for estimating asymmetric responses (but for non-transport oil demand). Nearly all of the studies use the variables (and their decomposition) at level, although the literature on asymmetric price transmission in the retail

[1] Note that it is possible that the technology fixation results from the energy efficiency policies such as CAFE Standards in the United States rather than a response to price changes. However these researchers find asymmetric responses in countries where there were no such policies in place, too.

gasoline sector generally uses the variables in their first differenced and/or lagged differenced form (e.g. Borenstein et al. 1997) in order to tackle non-stationarity in long time-series data.

The role of technological changes or asset fixity raises some disagreement in the literature on asymmetric transport energy demand. Griffin and Schulman (2005) argue that once technological progress is included in the econometric model specification, then the evidence of asymmetry becomes weak; and as such, gasoline demand is reversible with respect to prices. Huntington (2006) for transport fuel and Adeyemi and Hunt (2007) for industrial energy find that the asymmetric specification is better than the symmetric specification combined with technological change as suggested by Griffin and Schulman (2005); yet Adeyemi et al. (2010) was inconclusive for aggregate energy demand. Given Dargay and Gately's (1997) explanation that the asymmetry in demand was 'caused' by technology fixation, the disagreement is possibly a result of the differences in the underlying definitions of asymmetric responses. Although Griffin and Schulman (2005) do not explicitly mention it, they appear to define asymmetry as the differences in 'behavioural' responses to positive and negative price changes after controlling for technical changes. On the other hand, not controlling for technological changes, as in most other studies, allows both 'behavioural' and 'technical' responses to be included in total asymmetric demand responses. The literature is further expanded to include an underlying stochastic trend to capture both technological changes and other exogenous policies, and still find asymmetry to be present in the UK for transport fuel (Broadstock et al. 2011). In these models the underlying trend could capture behavioural factors such as changes in taste (Hunt and Ninomiya 2003).

The prospect theory by Kahneman and Tversky (1979) and Tversky and Kahneman (1991) offers another perspective to understanding the imperfectly reversible relationship of consumer demand with respect to some of the demand drivers. The three key elements of their theory are reference dependence, loss aversion, and diminishing sensitivity of the utility function. ‘Reference dependence’ means that people derive their utilities through gains and losses relative to a reference point. An example of such a reference point could be a reference price, which in turn could depend on price history, price expectations, current price, etc. The 'loss aversion' characterization of people means that consumers value their losses more than similar gains. Kahneman et al. (1991, pp. 205) argued that "models that ignore loss aversion predict more symmetry and reversibility than are observed in the world, ignoring potentially large differences in the magnitude of responses to gains and to losses" and provide several examples of such asymmetric behaviour in practice. 'Diminishing sensitivity' means that there is a decreasing marginal value to the gains or losses, which is similar in essence to the law of diminishing marginal utility. In order to explain these three key elements, Kahneman and Tversky (1979) proposed a 'value' function, plotted against the gains (or losses), as in the hypothetical example of Fig. 1. It is centred around the reference point where the function is kinked, steeper in the loss region to accommodate loss aversion, and concave (convex) in the gain (loss) region to represent diminishing sensitivity. It is the loss aversion aspect that primarily explains the asymmetry (the slopes are different in the gain and loss region in Fig. 1), specifically, the behavioural asymmetry alluded to earlier with reference to Griffin and Schulman (2005).

[Fig. 1 here]

Extending the loss aversion characterization of consumers to continuous gasoline demand, an increase in price from a current prices (assuming the current status quo as the reference) would result in a loss, while a reduction in price will be akin to a gain to the consumer. This can be depicted through a modification of Kahneman and Tversky's (1979) value function as in Fig 1 (b), which plots the changes in utility (demand) from status quo against the changes in prices. The diminishing sensitivity aspect is dropped for simplification, so the function becomes linear but remains kinked at reference. It is then expected that demand will reduce more in response to a price rise than it will increase for a similar fall. Similarly, an increase or a reduction in income results in a gain or a loss respectively, resulting in the hypothetical demand function of Fig 1 (c). This would also mean a larger reduction in demand during a falling income as compared to a demand increase during similar rise in income. Several researchers incorporated loss aversion in consumer demand models and found empirical evidence of asymmetric demand responses for various types of goods. These include Putler (1992) for eggs, Hardie, Johnson and Fader (1993) for orange juice, and Bidwell et al. (1995) for telephone calls. While the asymmetric response of consumers has received adequate attention in the empirical literature (e.g. Bowman et al., 1999 for asymmetric income effect, Hess et al. 2008 and De Borger and Fosgerau 2008 for asymmetry in discrete choice modelling framework), in the transport energy demand literature the discussion on loss aversion and asymmetric response is absent. As such, the objective of this research is to decipher the presence (or absence) of behavioural asymmetry in gasoline demand. This is achieved by an econometric demand model where technology is kept fixed by construction. While the asymmetric response of income did not feature much in the previous gasoline demand literature (only Dargay and Gately 2010, and Gately and Huntington 2002 for 'total' oil demand), such possibility is also investigated. Also, as opposed to all of the previous studies, this research employs disaggregated household level data in order to understand asymmetry in gasoline demand. Given all previous studies used aggregate national level data, it was also not possible to investigate the presence of *heterogeneity* in the *asymmetric* responses, which is another objective of this research. [2]

3. Methods

In a traditional time-series econometric demand model for gasoline, income and fuel price enter the model specification directly as they are, generally in a logarithmic form. In such a specification, positive and negative changes in the explanatory factors have the same (reversible) effect on demand, whereas the objective here is to identify the difference between the demand responses to a positive and a negative change in price or income. Wolffram (1971) and Traill et al. (1978), the early researchers studying asymmetry - albeit in supply functions - suggested decomposing the price

[2] Note that asset fixation may also be explained by loss aversion. During price rises, people value the losses more and switch to a fuel efficient vehicle; but during price fall, the gain is not valued as much to make them switch to a less fuel efficient vehicles. Our focus, however, is on fixed technology.

into two components: a price fall and a price rise series (or cumulative fall and cumulative rise). Gately (1992) and Dargay (1992) suggested three components of this decomposition: a maximum price series, a cumulative price fall series, and a cumulative below-maximum price recovery series. All of these decompositions included price or income variables (or their logarithms) at level. Although this has become the standard decomposition technique in asymmetric gasoline demand literature, there is also substantial critique of this technique, especially the strong dependence of the decomposition on the initial start point of the data (Adofo et al. 2013).

So far, the literature on imperfectly reversible gasoline demand has utilized country specific nationally averaged time-series data (e.g. Gately 1992, Dargay 1992, Sentenac-Chemin 2012). A few studies followed transport fuel consumption of a number of countries over time, employing fixed effects panel techniques for estimation, which forces a common response among the different countries (e.g. Dargay and Gately 1997, Gately and Huntington 2002).[3] The variable decomposition method works well with such aggregated time-series data and possibly on panel data where the number of countries is smaller relative to the number of temporal observations for each country. However, multi-collinearity between the decomposed series and potential non-stationarity of the long time-series can still be a concern. Only some of these studies considered the potential non-stationarity issues and possibility of cointegration between the variables (e.g. Sentenac-Chemin 2012). Given the substantial literature on imperfect reversibility of gasoline (and energy) demand, it is somewhat surprising that no previous study has attempted to model asymmetry using disaggregate, household level data.

Archibald and Gillingham (1980) first used household level data to derive a gasoline demand model by employing the household production theory. In this classical framework, a household derives utility from the transportation serviced produced by itself through a combination of inputs such as

[3] This can be a concern: Dargay and Gately (2002) mention that they had pooled their observations because individual country-specific estimations were not resulting in statistically significant result in favour of the asymmetry hypothesis.

gasoline, number of vehicles, other goods (e.g. public transport, walking etc.), and its own time. The gasoline demand decision is taken by maximizing utility subject to the constraint of fuel economy, vehicle characteristics, price, income, and preferences. This results in a demand specification which is a function of gasoline price, household income, vehicle characteristics, and household characteristics. This framework was later applied by Wadud et al. (2010), Puller and Greening (1999) and Kayser (2000). For household level data where each household is observed for a few time periods, a simplified version of the log-linear demand specification can be a starting point as the reversible formulation of gasoline demand (Eq. 1).

$$lnGAS_{it} = \kappa + \alpha_i + \beta.lnPRC_{it} + \gamma.lnINC_{it} + \boldsymbol{\theta Z_i} + \varepsilon_{it} \quad (1)$$

Where, GAS, PRC and INC refer to gasoline demand, real gasoline price, and real income (proxied by expenditure) respectively, while $\boldsymbol{Z}$ is a vector of non-time varying socio-economic characteristics, which can include categorical variables. α is household specific non-time varying fixed effect, κ, β, γ and $\boldsymbol{\theta}$ are parameters or parameter vectors to be estimated. Subscripts i and t refers to the cross-section (individual households) and temporal dimension respectively.

Decomposition of the price (or income) variable into two or three components as in the typical time-series models mentioned earlier is still possible using household level data. However, given each household in this study is observed for four quarters only, and the starting months are different for different households, the estimation results could be strongly conditioned by the arbitrary starts. Also, developing an econometric demand model in level would require the incorporation of a large number of socio-economic control variables such as gender, educational status, urban or rural location, number of vehicles, fuel economy of the vehicles etc. (i.e. $\boldsymbol{Z}$ in Eq. 1). Such a model derives almost all of its variances through inter-household cross-sectional differences rather than intra-household temporal differences. Yet, it is the intra-household temporal changes in consumption pattern in response to rising or falling prices that is of interest here. Also, in prospect theory, it is the intra-household 'change' resulting from the relative changes in price or income that drives consumers buying behaviour. Therefore, a first differenced modelling approach, where temporal changes in fuel consumption within each household is regressed against changes in income and price (and/or other time varying variables), is chosen in this study. Such a model acknowledges the heterogeneity of the households, but explicit modelling of the socio-economic characteristics is not possible since the differencing process cancels out the non-time varying socio-economic characteristics (e.g. gender, education) within each household.[4] Eq. 1, in the first differences form, becomes:

$$\Delta lnGAS_{it} = \beta.\Delta lnPRC_{it} + \gamma.\Delta lnINC_{it} + \varepsilon_{it} - \varepsilon_{i,t-1} \qquad (2)$$

Note that this differencing occurs within each household for its temporal observation, i.e. the panel nature is still retained with all households still present, but each household now loses one observation in the temporal dimension due to differencing. This is still a 'reversible' specification as the effects of the positive and negative changes in price or income are not differentiated. In order to model asymmetry, following the literature of aggregate studies, the changes in the logarithms of price and income are decomposed into two components: positive and negative changes. Monthly dummy variables are also added to the model specification to control for seasonality in the changes in fuel consumption between months, as shown in Eq. 3.

$$\Delta lnGAS_{it} = \beta^{+}.\Delta^{+}lnPRC_{it} + \beta^{-}.\Delta^{-}lnPRC_{it} + \gamma^{+}.\Delta^{+}lnINC_{it} + \gamma^{-}.\Delta^{-}lnINC_{it} + \sum_{j=2}^{12}\delta_j.MONTH_j$$
$$+\varepsilon_{it} - \varepsilon_{i,t-1} \qquad (3)$$

where, $\Delta^{+}lnPRC_{it} = \max\{lnPRC_{it} - lnPRC_{i,t-1}, 0\}$

$$\Delta^{-}lnPRC_{it} = \min\{lnPRC_{it} - lnPRC_{i,t-1}, 0\}$$

[4] Given the effects of socio-economic characteristics is not our focus, this does not pose any problem. See Wadud et al. 2010, Kayser 2000 to understand the effects of socio-economic characteristics on gasoline demand.

$$\Delta^{+} lnINC_{it} = \max\left\{lnINC_{it} - lnINC_{i,t-1}, 0\right\}$$

$$\Delta^{-} lnINC_{it} = \min\{lnINC_{it} - lnINC_{i,t-1}, 0\}$$

The effects of price is perfectly reversible or symmetric if $\beta^{+} = \beta^{-}$, while the effects of income is symmetric if $\gamma^{+} = \gamma^{-}$. Therefore, tests for these restrictions act as tests for asymmetry or imperfect reversibility in gasoline demand with respect to price or income. If $|\beta^{+}| > |\beta^{-}|$ and $\gamma^{+} < \gamma^{-}$, then the results will also be consistent with Kahneman and Tversky's (1979) loss aversion hypothesis. This formulation can test only the asymmetry aspect of imperfect reversibility and not hysteresis as per Dargay and Gately (1997). Given the short term period of observations as long as the dependence of hysteresis on the initial start point, the large cross-sectional, short temporal observations in this study are possibly not suited to study hysteresis or any long term effects.

An additional model specification differentiates the asymmetric responses between urban and rural households. This choice follows the earlier findings of Wadud et al. (2009, 2010) that rural households are less price elastic than urban households after controlling for other socio-economic characteristics, although income elasticities do not vary systematically between these two groups. In this specification, the price change variable is interacted with a Rural Dummy variable.

The econometric model in Eq. 3 can be estimated using Ordinary Least Squares (OLS) on the pooled data. However, because of the differencing process, the errors will likely be moving average and correlated within each household, yet independent across households. Therefore, a pure cross-sectional OLS estimation process will not be appropriate, and we cluster the OLS errors within each unique household. This allows correlation of the errors within each household, but they are independent across households.

4. Data

This study utilizes disaggregate household level data on gasoline consumption, income, and gasoline prices. This dataset is sourced from US Consumer Expenditure Survey's (CEX) public use microdata

(Bureau of Labor Statistics 1997-2002). Each household in the CEX is interviewed for four consecutive quarters over a year, where the households are asked about their expenditure on different items including gasoline during the previous three months. The survey, however, is a rolling one, i.e. not all households are interviewed at the same point in time, although the gap between the interviews for a specific household remains three months. This allows the interview periods for the sample households to be distributed over the entire year. Barring missing interviews, this leads to an observation of gasoline expenditure and total expenditure of the households for four consecutive quarters, which forms the basis of analysis. Fuel price for different states for all the months are collected from the Energy Information Administration (2006) – this is the average over the whole state. Each household was assigned a quarterly average fuel price depending on the reporting quarter and state.[5] Dividing the quarterly gasoline expenditure by nominal gasoline prices provides the gasoline consumption. Quarterly total expenditure was used as a proxy for income for two reasons. Firstly, Friedman (1957) suggested expenditure as a better proxy for lifetime income compared to annual income and accordingly previous studies by Wadud et al. (2010), Metcalf (1993) and West and Williams (2004) all used expenditures instead of income. Secondly, and more importantly, income is reported only twice - at the beginning and end of the survey - thus not allowing a quarterly variation, but expenditure is reported quarterly. Both the nominal gasoline price and expenditure were then deflated using the Consumer Price Index of Bureau of Labor Statistics (2007).

Households who have been interviewed during all four quarters are included in the estimation sample, therefore t=4 in the original dataset where the variables are in level. Also, in order to fix the technology - i.e. fuel economy of the vehicles - over the observation periods, only those households who have not changed their vehicle stock over the four quarters are considered. The final dataset

[5] We acknowledge that the prices within state can vary depending on locations (e.g. upstate vs. downstate New York, or urban vs. rural locations), but such detail price data is not available from EIA (2006). Even if the price data had been available, we do not know precise location of the households to match the price data with the household.

includes a total of 53,004 observations from 13,251 such households, spread between 1997 and 2002. Table 2 presents the summary statistics for the relevant variables.

[Table 2 here]

5. Results and Discussion

The econometric model in Eq. 3 is estimated using OLS. Tests show that the moving average term was statistically not significant, however, the OLS standard errors are still corrected for possible clustering of observations within households. A separate fixed effects panel estimation method reveals that the household specific intercepts are not different from zero (F=0.28. p=1.00), lending further justification for the use of OLS estimation corrected for clustering at the household level instead of panel estimation technique.[6]

Table 3 presents the parameter estimates for the demand models assuming perfect and imperfect reversibility. Model 1 presents the results for the reversible model (Eq. 2), while Model 2 is the primary specification for asymmetric responses (Eq. 3), both employing the cluster option to correct the standard errors. A comparison between the reversible (Model 1) and asymmetric (Model 2) models show that the asymmetric model has a lower AIC, indicating a better fit; although BIC points to a different conclusion. Testing the reversible price response of Model 1 with each of positive and negative price elasticities of Model 2 shows that they are both different in a statistically significant way (χ^2=4.36, p=0.037 for positive price changes; χ^2=3.71, p=0.054 for negative price changes); the same is true for the income parameter (χ^2=6.56, p=0.010 for positive income changes, χ^2 =6.43, p=0.011 for negative income changes). This indicates the parameter estimates using a reversible model can be substantially different. Dargay and Gately (1997) also found similar bias in reversible model estimates compared to the imperfectly reversible ones.

[6] Note that our first differenced model is not a typical error correction model used in timeseries modelling. Our approach of first differencing and then applying OLS has some similarity with fixed-effects panel data method, too, whereby data is demeaned for each cross-sectional unit instead of first-differencing as in here.

Results for the same asymmetric specification as Model 2 (Eq. 3), but estimated without correction for the household clusters using OLS is presented in the fourth column (Model 3) for comparison. Model 4 interacts a Rural Dummy with the price change variables, as described earlier. Although the overall explanatory power of all of these models is not large, it is not unusual for household level first-differenced data - e.g. Wadud (2010) find that most of the explanatory power for models using household level data comes from inter-household differences, rather than from within household differences in the time dimension. Nearly all of the parameters are statistically significant and the parameters have the expected signs as well. All but one of the monthly dummy variables are statistically significant at 95% level, indicating the seasonality of gasoline consumption.

[Table 3 here]

All three asymmetric specifications point to similar conclusions. Models 2 and 3 are essentially the same specification with different standard errors only. As such parameter estimates are exactly the same. Although Model 4 included two extra interaction variables the, overall model fit by Bayesian Information Criteria (BIC) becomes worse, while model fit by Akaike Information Criterion (AIC) improves only marginally.[7] Therefore Model 2 is the *preferred* asymmetric specification. The model specification means that the responses in these models are short-run, rather than long-run.

The asymmetric Model 2 shows that the parameter estimates for price increases is around 50% larger than that for price falls. Using a Wald test, this difference is statistically significant at 95% level ($F=4.08$; $p=0.043$) and indicates that the gasoline demand responses to an increased price is indeed larger than the responses during a reduction in price. Although the demand response during a reduction in income is only 0.06 larger than that during an increase in income, it still represents a 24% difference.[8] More importantly the difference is statistically significant ($F=6.49$, $p=0.011$). Since

[7] Another model controlled for variations in family size that had occurred in a few hundred households. Parameter estimate for changes in family size was statistically insignificant.
[8] The relatively small income elasticity is the result of not considering changes in car ownership in the long run, since we are interested in keeping the vehicle stock constant.

technological changes are controlled for already, together these findings indicate the likely presence of behavioural asymmetry in gasoline demand behaviour. The statistical significance of the differences and relative sizes of these elasticities during positive and negative changes are consistent with the stylized Fig. 1 earlier and as such consistent with the loss aversion hypothesis. [9]

Model 4 results show that rural households are marginally less price elastic compared to urban households *when price rises*, although the difference is statistically insignificant. However, responses to a fall in gasoline price is significantly lower in rural households than urban households, lending support to the earlier findings using reversible model (Wadud et al. 2009). Also, the gap between the responses to positive and negative price changes in rural households is substantially larger than the gap in urban households, i.e. the price asymmetry is more pronounced in rural households. Given the dominance of urban households in the sample (90%), Model 4 parameter estimates for urban households do not deviate much from the overall estimates of Model 2. However, the statistical significance of the F-test for differences between demand elasticities for price rises and falls deteriorates from 96% in Model 2 to 93% in Model 4.

6. Conclusions

This research argues that the asymmetry in gasoline demand is not only due to technology fixation, as the earlier literature had suggested, but can *also* be due to behavioural reasons. Also, unlike any previous study on gasoline demand asymmetry, this research used household level gasoline consumption data, where every household's gasoline consumption is followed over four quarters. Using econometric demand model and keeping the technology fixed for each household between

[9] Note that although vehicle stock were kept constant, it is still possible for a change in average fuel efficiency of the vehicles, as some households could opt to drive their more fuel efficient vehicle more or drive in a more fuel efficient manner. However, this is also a behavioural response and not a technical one and falls within the remit of behavioural asymmetry.

the observations, it is shown that there indeed exist statistically significant differences in price and income elasticities during falling and rising prices and income respectively. This indicates the presence of asymmetric *behavioural* response in gasoline demand – at least in the short-run. This does not necessarily mean that technological fixation has no role in asymmetric responses, rather emphasizes that both behavioural and technological factors are in play. Results also suggest that there is a difference in the asymmetric responses between urban and rural households. This *heterogeneity* aspect in asymmetric responses were not studied before as well. Note that, while the loss aversion characteristic of consumers appears to be the most plausible explanation behind this asymmetric response, the finding of asymmetry does not necessarily confirm the loss aversion hypothesis.

The finding of asymmetric behavioural response in gasoline fuel demand has important significance for transport and energy policy makers. For example, if a gasoline tax policy is designed to reduce gasoline consumption, using the reversible model elasticities would predict a reduction which would be 23% less than the asymmetric model predictions in the short-run.[10] In other words, considering the asymmetric response would result in a reduced design tax rate in order to bring about the same changes in gasoline consumption as compared to traditional reversible models. In addition, the demand effects of a rise in income would be over-predicted by 11% if the reversible model is used.[11] Therefore, any policy to compensate for the increases in gasoline demand during a period of economic growth, e.g. a fuel economy regulation, could be less stringent if the asymmetric response is considered. These differences can have substantial effect on the efficiency and effectiveness of various policies to reduce transport related fuel consumption or carbon emissions. It is important to note that the short-run nature of the elasticities makes them less useful in the longer-run context.

[10] 0.696 (asymmetric price elasticity)/0.562 (reversible price elasticity)=1.23
[11] 0.298 (reversible income elasticity)/0.268 (asymmetric income elasticity)=1.11

The distribution of burden of a gasoline tax or personal carbon trading (Wadud 2011) is another area for practical policy setting, where the short-run impact can be quite important. Using price elasticities from a reversible model for burden calculations would result in a larger short-run burden to households as compared to calculations based on asymmetric responses. Similarly, the recent fall in gasoline prices have also raised interest on the potential windfall gains to households. Such windfall gains to the households as a result of the price drops would be smaller in the asymmetric model in comparison to a reversible model.

Asymmetric responses can also be relevant for rebound effects, whereby reduction in energy consumption due to efficiency improvements is partially offset by an increase in demand due to lower costs of energy use resulting from the efficiency improvements. Rebound effects are often estimated from fuel price elasticities, and the presence of asymmetric responses would require the use of an elasticity during the price reduction phase in order to derive the rebound effects, as suggested by Frondel et al. (2011). As such, rebound effects would likely be overestimated if asymmetric responses are not considered.

Our method of using household data and using first differencing to understand asymmetric responses can be further applied to non-energy goods, such as travel demand as well, as long as relevant data are available. The use of household level data provides some additional advantages. The dataset spans from 1997 and 2002, when gasoline prices did not fluctuate substantially as in the seventies or the past few years. It is highly unlikely that an aggregate time-series demand model along the lines of previous work in this area would have been able to pick up the imperfectly reversible relationship. This observation arises since some of the previous country-wide estimations needed to be pooled together to arrive at statistically significant estimates, even when the data contained large fluctuations in gasoline prices. The issue about data non-stationarity does not arise for household level data, given the shorter time dimension. The household level data also allowed the detection of asymmetric demand responses to changes in income, which has generally been overlooked in the previous literature. A drawback of the modelling approach was its inability to pick up the effects of memory in setting the reference price, in other words, the effects of previous maximum prices could not be separated from the effects of rising prices because of the rather limited availability of data in the time dimension. However, this possibly does not affect the results substantially given gasoline prices were historically low during 1997-2002. Also, only short-run responses could be modelled because of a lack of long-term observations per household. A longer time-series of household observations that include large fluctuations can possibly circumvent both these limitations.

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Tables

Table 1. Summary of studies on imperfect reversibility in the demand for gasoline or transport fuel

Study	Data type	Econometric method	Results	Comment
Sentenac-Chemin (2012)	Cross-country (2), time series (1978-2005)	Error correction for each country	Price asymmetry exists in the US, but not in India. Income asymmetry not studied.	Explicit test for cointegration
Broadstock et al. (2010)	Time series (1960-2008), two fuels	Structural time series	Evidence of price asymmetry for both fuels	Model has an underlying stochastic trend
Huntington (2010)	Time series (1950-2005)	Error correction	Limited evidence of price asymmetry in the US	Explicit test for cointegration
Dargay & Gately (2010)	Cross-country & region (6), time series (1971-2008)	Fixed effects panel	Price asymmetry exists for OECD countries. Income asymmetry mixed evidence.	Separate estimation for 6 regions. For each region with >1 country, fixed effects model
Griffin & Schulman (2005)	Cross-country (16), time series (1961-1999)	Non-linear OLS	Price asymmetry does not exist. Income asymmetry not studied.	Specification controls for technological changes
Gately & Huntington (2002)	Cross-country (96), time series (1971-1997)	Fixed effect panel	Price and income asymmetry exists.	Results are for oil demand, not 'transport fuel'
Nagata (2002)	Single country (Japan), time series (1968-1997)	Autoregressive	Price asymmetry exists. Income asymmetry not studied.	Asymmetry observed in sectors other than transport fuel, too.
Dargay & Gately (1997)	Cross-country (11), time series (1962-1990)	Fixed effects panel	Price asymmetry exists. Income asymmetry not studied.	Concern that individual time series may not produce statistically significant results.
Gately (1992)	Single-country (US) time series (1960-1990)	Dynamic OLS	Price asymmetry exists. Income asymmetry not studied.	Only gasoline results included in this table.
Dargay (1991)	Cross country (3) time series (1962-1988)	Error correction for each country	Price asymmetry exists. Income asymmetry not studied.	No tests for cointegration

Table 2. Summary statistics

Variables and sample characteristics*	Mean (std. dev.)
Quarterly gasoline consumption (gallons)	221.5 (180.9)
Quarterly nominal expenditure (USD)	8379.7 (6043.7)
Nominal gasoline price (US cent/gallon)	151.9 (20.3)
No. of households	13,251
No. of time periods observed	4 quarters each
Share of urban households	89.8%
Share of observations where real price changes are positive	51.7%
Share of observations where real expenditure changes are positive	51.0%

* further detail on socio-economic characteristics of the households (which are not used here) are available in Wadud et al. (2010).

Table 3. Parameter estimates for different model specifications (t-stat in parenthesis)

	Model 1	Model 2	Model 3	Model 4
$\Delta lnPRC$	-0.562 (-14.05) ***			
$\Delta lnINC$	0.298 (25.69) ***			
$\Delta^{+} lnPRC$		-0.696 (-9.00)***	-0.696 (-8.51)***	-0.703 (-8.98)***
$\Delta^{-} lnPRC$		-0.467 (-7.59) ***	-0.467 (-6.84) ***	-0.502 (-7.96) ***
$\Delta^{+} lnINC$		0.268 (16.43) ***	0.268 (17.80) ***	0.268 (16.43) ***
$\Delta^{-} lnINC$		0.331 (18.74) ***	0.331 (20.92) ***	0.330 (18.73) ***
$\Delta^{+} lnPRC \times RuralDummy$				0.066 (0.42)
$\Delta^{-} lnPRC \times RuralDummy$				0.407 (2.77) ***
Feb	-0.036 (-3.21) ***	-0.021 (-1.80) *	-0.021 (-1.81) *	-0.021 (-1.76) *
Mar	-0.029 (-2.62) ***	-0.013 (-1.10)	-0.013 (-1.11)	-0.013 (-1.08)
Apr	0.032 (2.97) ***	0.046 (3.87) ***	0.046 (3.94) ***	0.047 (3.91) ***
May	0.034 (3.17) ***	0.049 (4.23) ***	0.049 (4.21) ***	0.049 (4.23) ***
Jun	0.027 (2.48) ***	0.048 (3.71) ***	0.048 (3.55) ***	0.048 (3.72) ***
Jul	0.004 (0.41)	0.026 (1.98) **	0.026 (1.92) **	0.026 (1.98) **
Aug	0.008 (0.77)	0.025 (2.14) **	0.025 (2.13) **	0.025 (2.13) **
Sep	0.033 (3.22) ***	0.045 (4.15) ***	0.045 (4.12) ***	0.045 (4.15) ***
Oct	0.013 (1.26)	0.026 (2.25) **	0.026 (2.32) **	0.026 (2.25) **
Nov	-0.045 (-4.43) ***	-0.031 (-2.83) ***	-0.031 (-2.80) ***	-0.031 (-2.83) ***
Dec	-0.069 (-6.80) ***	-0.056 (-5.21) ***	-0.056 (-5.06) ***	-0.056 (-5.20) ***
N	39,753	39,753	39,753	39,753
Estimation method	OLS with std. error correction for clusters	OLS with std. error correction for clusters	OLS with no corrections	OLS with std. error correction for clusters
R^2	0.034	0.035	0.035	0.035
AIC	72447.75	72441.05	72441.05	72439.78
BIC	72559.43	72569.91	72569.91	72585.82
$\Delta^{+} lnPRC = \Delta^{-} lnPRC$	-	F=4.08, p=0.04**	F=3.55, p=0.06*	F=3.12, p=0.07*
$\Delta^{+} lnINC = \Delta^{-} lnINC$	-	F=6.49, p=0.01***	F=6.29, p=0.01***	F=6.42, p=0.01***

statistically significant at *** 99%, ** 95%, * 90%

Figures

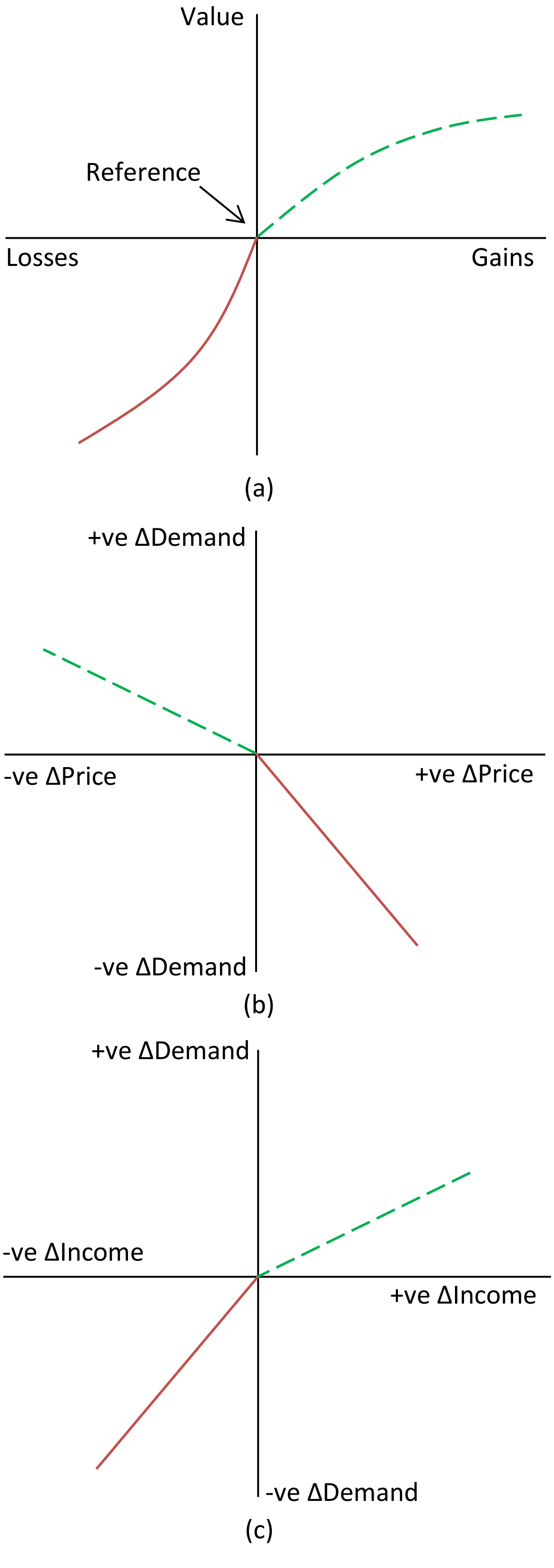

Fig. 1 (a) value function proposed by Kahneman and Tversky (1979), (b) stylized changes in demand to changes in prices, (c) stylized changes in demand to changes in income (green dashed line = gains)