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A dynamic carbon tax on gasoline

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ABSTRACT

We propose a dynamic carbon tax (DCT) that stabilises gasoline prices by adjusting inversely to crude oil prices. By virtue of reducing gasoline price uncertainty and thus promoting the purchase of more fuel efficient vehicles, the DCT is expected to be more effective in cutting CO_2 emissions than an equivalent ordinary fixed-rate carbon tax. By virtue of preventing or limiting gasoline price spikes, the DCT is also expected to receive greater public support. The analysis is structured into three parts. First, we show how any policy that reduces uncertainty about future gasoline prices improves the expected utility of more fuel efficient vehicles relative to that of less efficient ones. Second, we show how the DCT could be designed to stabilise gasoline prices and thereby reduce gasoline price uncertainty. Third, we test whether gasoline price volatility, taken as a proxy for gasoline price uncertainty, negatively affects the fuel efficiency of light-duty vehicles bought by US households. Using micro-data from the 2017 National Household Transport Survey, we find a negative correlation as expected despite limited volatility of gasoline prices in the study period.

1. Introduction

To limit global warming and the worst consequences of climate change, global greenhouse gas (GHG) emissions must peak as soon as possible and then hit net zero by around mid-century (IPCC, 2022). Achieving this goal entails drastic and unprecedented reductions in GHG emissions across all major emitting economies and sectors. Some important policy developments have materialised in the last few years, such as the European Green Deal, China’s commitment to achieving climate neutrality by 2060, and the US Inflation Reduction Act (its climate measures), only to mention a few. But whether national governments will remain committed and be able to establish timely pathways to global climate neutrality is all to be seen.

As most economists have come to recognise, political feasibility is a criterion of priority in the choice of climate mitigation policies (Goulder, 2020, Hepburn et al., 2020). Accordingly, effective policies for climate mitigation would normally represent a compromise between economic efficiency, equity, and social acceptability more generally. This reality of climate policy directly speaks to carbon pricing, which can come in the form of carbon taxation or emissions trading, as a case in point of an economically efficient approach subject to political constraints (Jenkins, 2016, Jenkins, 2014). While carbon pricing has gained traction worldwide, less than 5 % of global GHG emissions are currently priced at levels consistent with the 1.5–2 °C target of the Paris Agreement (WB, 2023). Arguably, for carbon pricing to be used more profitably, both stronger international cooperation and innovative policy designs are needed.

The use of the revenues generated by carbon pricing, for the purpose of improving its effects and social acceptability, is a question

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that has received much attention in the scientific literature and policy discussions (Edenhofer et al., 2021, Beiser-McGrath and Bernauer, 2019). In fact, provisions on how carbon revenues should or must be used have become common features of carbon pricing schemes. An equally relevant but less explored question is whether and how carbon pricing should be designed in such a way as to take into account volatile and mostly unpredictable energy prices. The problem arises as any impact of carbon pricing on final prices of fossil fuels is likely to be dwarfed by the effects of trends or events originated in global energy markets. Notably, the swings of the crude oil and natural gas markets can compromise the very environmental effectiveness of carbon taxation as well as the cost effectiveness of emissions trading.

In this paper, we propose a mechanism for carbon taxes applied to gasoline with a view to accelerating the decarbonisation of road transport. Universally road transport is a major emitting sector with stubbornly high carbon dioxide (CO_2) emissions.[1] In theory, Pigouvian carbon taxes or equivalent fuel taxes are the most economically efficient instruments for curbing CO_2 emissions (Anderson and Sallee, 2016). In practice, the volatility of oil prices entails that much of the time ordinary fixed-rate carbon taxes (hereafter 'ordinary carbon taxes') are either irrelevant in influencing consumer choices when oil prices are low, or they are socially unacceptable when oil prices are high. A dynamic carbon tax (DCT) that stabilises gasoline prices by adjusting inversely to the deviations of oil prices from a given target level could both cut more CO_2 emissions and receive greater public support than an equivalent ordinary carbon tax. Specifically, greater emission reductions may be achieved by inducing demand for more fuel efficient vehicles. The rationale being that the DCT would reduce uncertainty about future gasoline prices and, thus, people deciding which vehicle to buy would discount expected future fuel costs less than they otherwise would. This means fuel efficiency as a vehicle attribute would effectively be valued more by buyers. In addition, most drivers of gasoline vehicles would likely favour such a carbon tax over an equivalent ordinary carbon tax as it would prevent or at least limit gasoline price spikes.

The idea of a tax on gasoline adjusting inversely to oil prices is not new. In fact, schemes aimed at stabilising or smoothing fuel prices have been implemented in many developing and emerging economies over the last three decades (Coady et al., 2012, Bacon and Kojima, 2008, Federico et al., 2001). In advanced economies too, indirect taxes adjusting inversely to oil prices have been adopted or proposed. In France, a mechanism whereby the energy tax on oil products moved inversely to changes in the Brent price[2] was in force between 2000 and 2002. The *taxe flottante*, as it was called, was eventually abandoned due to its excessive cost for the state.[3] Prompted by the 2008 oil price shock, similar mechanisms were introduced in Italy and in the UK, but neither was ever applied (Di Giacomo et al., 2015, Di Giacomo et al., 2012, Bolton, 2022). In Chile, by contrast, a fuel price stabiliser mechanism has been in force since 2014 (Lemus and Luco, 2021). More recently, fuel price stabiliser mechanisms were proposed: a) in France again, in connection with the *Gilets Jaunes* protests (Bureau et al., 2019); and b) in California, after exceptionally high gasoline prices in the spring of 2022 (Borenstein, 2022).

Compared to past experiences and proposals of floating fuel taxes, the DCT presented in this paper fundamentally differs in the objective. The usual motivation for stabilising or for smoothing fuel prices is to shield consumers from highly volatile global energy markets, as volatile prices at the pump usually reduce consumer welfare (Federico et al., 2001). While also providing the welfare benefits of price stabilisation, however, our DCT is a carbon tax in the first place. As such, its purpose is to improve on ordinary carbon taxation, with respect to both environmental effectiveness and social acceptability. A second element of differentiation is that the proposed DCT would operate within the limits of self-financing. Specifically, the DCT rate could only be reduced insofar as a revenue reserve (or 'buffer') fed by tax rate increases in previous periods would allow. This feature of the DCT is not of secondary importance, as experience clearly shows that the cost of a price stabiliser mechanism can preclude its adoption or continuation. Moreover, the limit posed by the reserve ensures that world oil producers could not profit from the DCT by raising oil prices.

The analysis supporting the DCT proposal comprises three parts. First, using a standard theoretical model of vehicle choice, we show how any policy that reduces uncertainty about future gasoline prices can be expected to make fuel-efficient vehicles more attractive options in vehicle purchase decisions. Second, we show how the DCT mechanism could be designed to stabilise gasoline prices and thereby reduce gasoline price uncertainty. Third, we test econometrically whether gasoline price volatility – taken as a proxy for gasoline price uncertainty – negatively affects vehicle fuel efficiency. A negative correlation would confirm our intuition and give us an indication of the environmental benefit that could be achieved by stabilising gasoline prices.

Using a large dataset which combines monthly cross-sectional micro-data from the US National Household Travel Survey and monthly state-level data on gasoline prices, we test for the effect of gasoline price volatility on fuel efficiency of new vehicles sold in the US between May 2015 and February 2017. To our knowledge, we are the first to do this. While many studies have tested for the effect of gasoline price levels on vehicle fuel efficiency (e.g. Leard et al., 2019; Antweiler et al., 2016; Barla et al., 2016; Klier and Linn, 2013, 2010; Li et al., 2014, Li et al., 2009), they did not consider the effect of gasoline price volatility or any other proxy for gasoline price uncertainty on the same variable. Lin and Prince (2013) and Scott (2015) tested for the effect of gasoline price volatility on gasoline demand, but not on vehicle fuel efficiency specifically. Importantly, their results are consistent with the conjecture that gasoline demand can be more effectively reduced in the medium-long run by making gasoline prices more predictable.

[1] In the US, road transport alone makes up almost a quarter of total anthropogenic greenhouse gas emissions (EPA, 2023).

[2] Changes greater than 10% in the two-month average.

[3] The impact on the government budget was estimated to be €2.7 billion lower fiscal revenues (Conseil des Impôts, 2005).

The rest of the paper is organised as follows. Section 2 shows how uncertainty about future gasoline prices can influence consumer choices as to which vehicle to buy. Section 3 shows how the DCT mechanism could be designed and work in practice. Section 4 tests for the effect of gasoline price volatility on fuel efficiency of new vehicles sold. Section 5 concludes.

2. Gasoline prices and vehicle choice

2.1. Structure and volatility of gasoline prices

Three facts about the formation of gasoline prices are particularly relevant to our analysis and policy proposal. First, the cost of crude oil is by far the main component of retail gasoline prices. This is especially true in the US, as taxes make up only a small share of retail gasoline prices as compared to other countries, most notably European ones (Sterner, 2007). As Fig. 1 shows, over the period 2000–2021 the cost of oil alone represented between a third and three quarters of retail gasoline prices at minimum and maximum price levels, respectively.

Second, the evolution of retail gasoline prices over time is closely related to that of crude oil prices, which are determined on the global market.[4] Again with reference to the US, Fig. 2 shows how the evolution of retail gasoline prices closely follows that of oil prices (here represented by the 'refiner acquisition cost of crude oil'). Whenever gasoline prices temporarily break away from the trend of oil prices, this is usually due to refinery outages or other downstream events.

Third, historically crude oil prices exhibit significant and continued volatility. Due to structural features of the oil industry and of the oil market, including sensitivity of the latter to macroeconomic and geopolitical events (e.g. economic recessions and booms, regional conflicts), oil prices are naturally volatile and subject to somewhat frequent supply–demand shocks (Hamilton, 2009). In turn, given the previous two facts about the formation of gasoline prices, the volatility of oil prices translates into volatile gasoline prices at the pump.

2.2. Gasoline price uncertainty

Predicting future crude oil prices is a notoriously difficult exercise (Baumeister and Kilian, 2016, Alquist et al., 2013, Hamilton, 2009). The difficulty is due to the complexity of the global oil market and, above all, to the dual nature of crude oil, which is a commodity and a politically strategic resource: as such, a good subject to producer decisions that are hard or just impossible to anticipate. Moreover, as gasoline prices closely depend on crude oil prices, the very low predictability of the latter equally applies to the former.

The predictability of (oil and) gasoline prices can only diminish with the forecast horizon. In the case of vehicle purchases, the relevant horizon, i.e., the number of years the buyer expects to use the vehicle, would normally exceed a period of five years, which implies a very long time span for price predictions made with any minimum level of confidence. Moreover, most people surely do not have access to sophisticated models nor are they sufficiently familiar with the functioning of energy markets to make accurate predictions about future gasoline prices. As shown empirically by Anderson et al. (2013, 2011), people's best guess of future gasoline prices is – barring exceptional economic circumstances – that these will be equal to current prices adjusted by expected inflation.

Such no-change price forecasts are explained by the erratic nature of oil prices. Still, the same forecasts come with a degree of uncertainty which increases with the forecast horizon and also vary over time depending on new information. Concerning this type of uncertainty, any direct evidence offered by the literature is very limited. Again the studies by Anderson et al. (2013, 2011), who analyse gasoline price forecasts by US citizens over many years, are probably the most relevant references. Among other important results, the authors find that the dispersion of individual gasoline price forecasts correlated positively with two different measures of oil price volatility. Given the strong correlation between oil and gasoline prices, this result provides empirical justification for considering gasoline price volatility a proxy for gasoline price uncertainty – which is what we do in the econometric analysis below. In the next section, we are going to show how gasoline price uncertainty may in turn influence vehicle choices.

2.3. Gasoline price uncertainty and vehicle choice

In the vast literature on vehicle choice, how consumers evaluate fuel efficiency (or fuel economy) is probably the topic that has attracted greatest interest from both researchers and policymakers. In particular, whether, to what extent, and why vehicle buyers undervalue – or seem to undervalue – fuel efficiency, is the question that has been investigated more than any other (Greene, 2010; Helfand and Wolverton, 2009).,[5,6] Very high uncertainty about future gasoline prices is one of the main factors that can explain fuel

[4] Borenstein et al. (1997) document that oil prices shocks are fully passed through to wholesale gasoline prices, but the adjustment process can take several weeks. Borenstein and Shepard (2002) show that wholesale gasoline prices adjust with a delay because of adjustment costs for oil refiners.

[5] The question is very closely related to what is known in the literature as the 'energy paradox': the notion that some energy efficiency technologies that would be profitable for adopters are nevertheless not adopted, as people – for a variety of reasons – undervalue energy savings (Jaffe and Stavins, 1994).

[6] Allcott and Knittel (2019) stress that there is disagreement in the empirical literature about the significance of fuel efficiency undervaluation, with more of the recent studies finding no consumer bias or only mild bias against more fuel efficient vehicles.

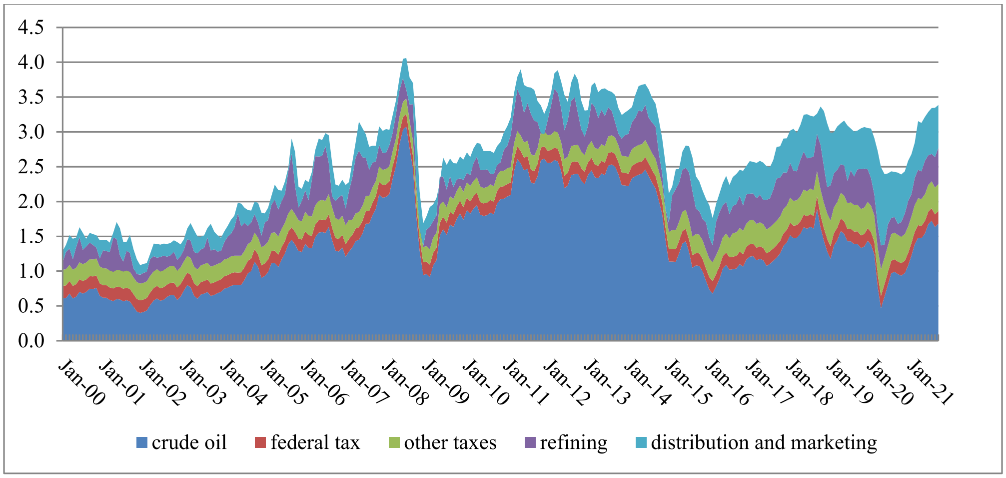

Fig. 1. US average retail gasoline prices: level and composition (Jan. 2000 — Sep. 2021). .
Source: Authors' elaboration on data from the Energy Information Administration

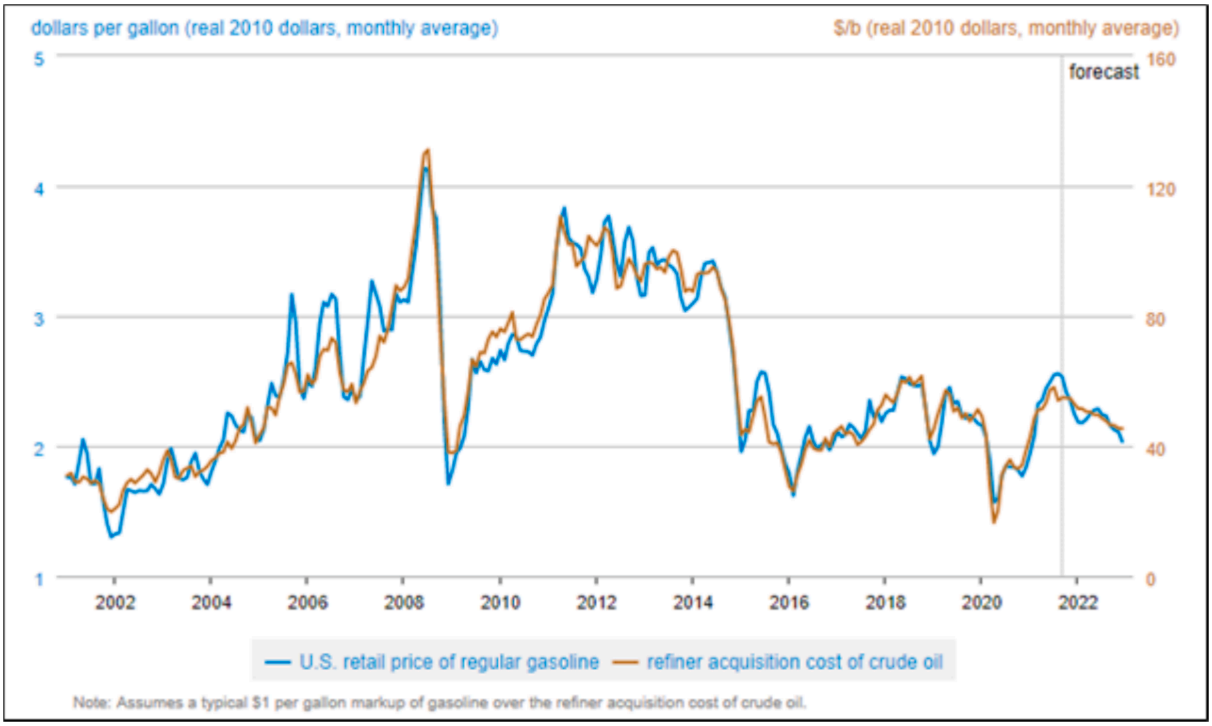

Fig. 2. Evolution of US average gasoline price and cost of crude oil (real 2010 dollars). .
Source: Energy Information Administration

efficiency observed 'undervaluation'.[7] However, little is really known about gasoline price uncertainty. Little is known about the uncertainty associated with 'point forecasts' of gasoline prices, even though it likely plays a role in vehicle purchase decisions.[8] In the following, we are going to show why greater uncertainty about future gasoline prices likely favours the purchase of less fuel efficient vehicles.

Vehicles are multi-attribute durable goods, implying that the choice of which vehicle to buy depends on the buyer's evaluation of multiple vehicle characteristics, such as size, acceleration, safety, comfort, design, …, and fuel efficiency. Geater uncertainty about future gasoline prices leads the buyer to more heavily discount expected future fuel costs and, therefore, also the fuel cost savings that could be achieved by buying a more fuel efficient vehicle.[9] As the (private) economic value of greater fuel efficiency consists in fuel savings, gasoline price uncertainty effectively reduces the evaluation of fuel efficiency. By contrast, it does not affect the evaluation of any of the other vehicle attributes.

To illustrate, let us consider the problem of a consumer who has decided to buy a vehicle. Using the multi-attribute utility framework underlying most of the literature on vehicle choice, the buyer will choose the vehicle that maximises her expected utility subject to a budget constraint. Specifically, the utility that consumer *i* expects to derive from purchasing vehicle *j* at time *t*, u_{ijt}, depends on: a) the price of the vehicle, p_{jt}, b) the present value of expected fuel costs over the vehicle's lifetime, and c) a number of vehicle characteristics other than fuel efficiency. Expected fuel costs depend on the buyer's expectation about future gasoline prices, the number of miles that she expects to drive, and on the vehicle's fuel efficiency. Using Anderson et al.'s (2013) notation,

$$u_{ijt} = -\alpha p_{jt} - \gamma \left[\sum_{k=0}^{T} (1+r_i)^{-k} \mu_{it,t+k} m_{ij,t+k} MPG_j^{-1} \right] + \beta X_j \quad (1)$$

where: T is the vehicle's lifetime; r_i is i's discount rate; $\mu_{it,t+k}$ is i's expected gasoline price, g, in year $t+k$ given her current information set (I), i.e., $\mu_{it,t+k} = E_{it}\{g_{t+k}|I_{it}\}$; $m_{ij,t+k}$ is the number of miles that i plans to drive with the vehicle in year $t+k$; MPG_j is the vehicle's fuel efficiency as measured by miles per gallon (MPG); and X_j is a vector of vehicle characteristics other than fuel efficiency.

With reference to the model in [1], consumer taste and risk preferences are embedded in the parameters α, γ, and β. Risk attitudes are relevant in the context of vehicle choices because they determine the importance attributed to fuel efficiency relative to other vehicle characteristics. Notably, risk aversion (/neutrality/seeking) would be reflected in γ being greater (/no different from/smaller) in absolute value than α.[10] A richer model version would allow for differences in taste and risk preferences between individuals, by letting α, γ, and β vary across *i*.[11] The same parameters could be let to vary across time, thus allowing for time-varying preferences. Our focus, however, is on showing the direct effect of gasoline price uncertainty on u_{ijt}. So, we take [1] as the reference model and augment it by explicitly introducing gasoline price uncertainty.[12]

Our modification of [1] consists in letting the buyer's discount rate vary over time and making it dependent on the expected variability of the gasoline price in each period between t (the year the vehicle is purchased) and $t+T$ (the last year the vehicle will be

[7] Helfand and Wolverton (2009) list a series of possible explanations for fuel efficiency undervaluation found in the literature: "consumers who put little weight on the future; consumer disinterest in fuel economy; bundling of fuel economy with other attributes; consumer difficulty calculating expected fuel savings; uncertain fuel savings contrasted with certain and immediate increased costs; consumer heterogeneity; and the role of vehicles and fuel economy in signaling a consumer's social status". See all footnote 13 below.

[8] Based on 57 interviews with US households, Turrentine and Kurani (2007) came to a sobering conclusion: "when consumers buy a vehicle, they do not have the basic building blocks of knowledge assumed by the model of economically rational decision-making, and they make large errors estimating gasoline costs and savings over time." Nonetheless, one of the most robust results in the empirical literature on vehicle choice is that the gasoline price at the time of vehicle purchase is a significant predictor, positively correlated with the fuel efficiency of vehicles sold.

[9] As future energy costs are inherently uncertain, risk-adjusted discount rates are a key variable in any model of vehicle choice and energy efficiency investment more generally (Wang and Daziano, 2015; Allcott and Greenstone, 2012; Greene, 2010). Heavier discounting of expected future energy costs due to greater uncertainty about future energy prices constitutes rational economic behaviour.

[10] Risk aversion is a preference for a sure outcome over a gamble with higher or equal expected value. Here, $|\gamma| > |\alpha|$ implies that the representative consumer attaches greater importance to a \$1 increase in the expected present value of fuel costs than to a \$1 increase in the vehicle price. Such a preference exemplifies risk aversion.

[11] Bento et al. (2012) show that consumer preference heterogeneity is important in explaining the energy paradox found by many studies.

[12] Kaufmann (2023) suggests that greater gasoline price uncertainty could increase the importance that vehicle buyers attach to future fuel costs and, hence, to fuel efficiency. If so, γ would increase relative to α and the β's, which are associated with the other vehicle attributes, with the implication that greater gasoline price uncertainty could result in greener vehicles becoming more – not less – attractive. However, for at least two reasons we are skeptical that this indirect effect, operating through changed preferences, could dominate the direct effect of discounting. First, energy efficiency is negatively correlated with other vehicle characteristics, such as size and power, and positively correlated with vehicle price, all of which are also dearly valued by buyers (see, e.g., Moskalik and Newman, 2020; Whitefoot et al., 2017; Klier and Linn, 2012; Knittel, 2012). Second, buyers' trading-off of fuel efficiency for other vehicle attributes including price may run into well-documented psychological biases such as present bias and loss aversion (Greene et al., 2013, 2011).

used), with greater variability reflecting greater uncertainty. An individual (or 'subjective') risk-adjusted discount rate is thus considered, $\widetilde{r}_{it,t+k}$, which increases with gasoline price uncertainty.[13] In formal terms,

$$u_{ijt} = -\alpha p_{jt} - \gamma\left[\sum_{k=0}^{T}\left(1+\widetilde{r}_{it,\,t+k}\right)^{-k}\mu_{it,t+k}m_{ij,t+k}MPG_j^{-1}\right] + \beta X_j \tag{2}$$

$$\widetilde{r}_{it,t+k} = \rho_i + \psi_{it,t+k} \tag{3}$$

$$\psi_{it,t+k} = f\left(\sigma_{it,t+k}\right) \tag{4}$$

$$f_\sigma^{'} > 0 \tag{5}$$

where: ρ_i is the time-invariant component of i's discount rate; $\psi_{it,t+k}$ is the time-variant component of i's discount rate which depends (positively) on gasoline price uncertainty via f; and $\sigma_{it,t+k}$ is i's expected standard deviation of the gasoline price, g, in year $t+k$, i.e. $\sigma_{it,t+k} = E_{it}\{(|g_{t+k} - \mu_{it,t+k}|)|I_{it}\}$;

The augmented model (Eqs. (2)–(5)) implies that, all else equal, an increase in uncertainty about the level of future gasoline prices ($\sigma_{it,t+k}\uparrow$) has a positive effect on the utility of each and every vehicle considered by the buyer merely because it raises her discount rate ($\widetilde{r}_{it,t+k}$). Crucially, however, the effect is larger for less fuel efficient vehicles than for more fuel efficient ones. In other words, higher uncertainty about future gasoline prices has a positive effect on the utility of any vehicle simply because it results in more heavily discounted fuel costs.[14] The effect is larger for less fuel efficient vehicles, however, because their expected fuel costs are larger in the first place. This result is shown by the derivative of u_{ijt} with respect to $\sigma_{it,t+k}$ as MPG_j appears in the denominator:

$$\frac{du_{ijt}}{d\sigma_{it,t+k}} = \gamma k\frac{\mu_{it,t+k}m_{ij,t+k}}{\left(1+\rho_i+f\left(\sigma_{it,t+k}\right)\right)^{k+1}}\frac{1}{MPG_j}f_\sigma^{'} \tag{6}$$

Eq. (6) tells us that, all else equal, higher uncertainty about future gasoline prices plays in favour of less fuel efficient vehicles by increasing their relative utility. In turn, since the positive effect of higher gasoline price uncertainty on new vehicles' utility is bigger for less fuel efficient vehicles, it is plausible that more of these would be sold as a result. The same logic applies to the case of lower uncertainty about future gasoline prices, leading to the opposite outcome. Here, smaller negative effects on the utility of more fuel efficient vehicles may result in more of these being chosen by consumers. A clear policy implication is thus derived: the average fuel efficiency of vehicles sold may be improved by reducing uncertainty about future gasoline prices.

3. Dynamic carbon taxation

3.1. Rationale

Economists often indicate Pigouvian carbon pricing or equivalently fuel taxes as the most economically efficient policy instruments for decarbonising road transport, at least in theory (Anderson and Sallee, 2016). Economists also justify the use of fuel efficiency standards or CO_2-based vehicle 'feebates' on the grounds of people's supposed undervaluation of future fuel costs in vehicle purchase decisions or as a second-best alternative to Pigouvian pricing (Allcott and Greenstone, 2012). These instruments can be critical for limiting CO_2 emissions of road transport, all the more in contexts where carbon prices or fuel taxes are inefficiently low, as in the US case (Parry and Small, 2005). We know little, however, about the relative importance of the different factors explaining undervaluation of fuel costs. Along with behavioural factors, such as myopia or inattention, uncertainty about future gasoline prices also likely

[13] In the energy efficiency domain, there exists a wide literature on subjective discounting which is typically concerned with inferring discount rates from investment choices ('implicit discount rates') and explaining the heterogeneity of the results with personal preferences, psychological biases, and external contextual factors (see, e.g., Meissner et al., 2023; Schleich et al., 2019; Haq and Weiss, 2018; Schleich et al., 2016; Newell and Siikamaki, 2015; Wang and Daziano, 2015; Greene, 2011). More specifically, Schleich et al. (2016) distinguish between three categories of factors: "(i) preferences such as time preferences, risk preferences, reference-dependent preferences and pro-environmental preferences; (ii) predictable (ir) rational behaviour, i.e. bounded irrationality, rational inattention, and behavioural biases, such as present bias or status quo bias; and (iii) external barriers to energy efficiency, such as split incentives, lack of information or lack of capital". Uncertainty about future gasoline prices falls into the last category.

[14] It would be important to know whether and to what extent it has been observed that people do tend to discount more expected future fuel costs in periods of growing uncertainty about gasoline prices. Unfortunately, we were not able to find a single study estimating this effect. Empirical evidence on the many determinants of individual discounting is still limited in the first place (Foudi, 2024; Vonlanthen, 2024; Schleich et al., 2019). Then, when it comes to estimates of time-varying effects of these determinants, such as uncertainty about future gasoline prices, evidence is seriously lacking, most likely due to limited availability of suitable longitudinal data. Stephens and Krupka (2006) is the most relevant study that we were able to identify. Using US household survey data from the early 1970s, the authors find that (elicited) subjective discount rates increased dramatically during an inflationary period. Other empirical studies may be considered relevant for our analysis, but in an even more tenuous way. For example, in an experimental setting Haushofer and Fehr (2019) identify a strong causal effect of negative income shocks on subjective discount rates.

contributes to heavier discounting of future fuel costs in vehicle choices. To the extent that this is true, any intervention that reduces such uncertainty – we have shown it analytically – will also improve the relative utility of fuel efficient vehicles.

A dynamic carbon tax (DCT) can be designed so as to automatically stabilise gasoline prices and thereby reduce uncertainty about their future levels. The mechanism we propose involves adjustments of the DCT rate applied to the wholesale gasoline price that are inverse and proportional to the deviations of a reference crude oil price (e.g. the West Texas Intermediate (WTI) price or the Brent price) from a target level (e.g. $60/barrel or $80/barrel). The proposed mechanism is self-financed, as the carbon tax rate could only be reduced insofar as a revenue reserve fed by tax rate increases in previous periods would allow. Not only does this make the DCT mechanism independent of external financial resources for its own functioning, but – as tax cuts would only be possible after tax increases – it also rules out undue profit opportunities for oil producers or refiners.[15] The purpose of the DCT may be defined in relation to its equivalent fixed-rate carbon tax (eFCT), by which we mean an ordinary carbon tax with a rate equal to that imposed by the DCT on average over time. Given this definition, the purpose of the DCT is to outperform the eFCT with respect to both environmental effectiveness (i.e., emissions reduction) and social acceptability.

But why exactly should we expect that the DCT would cut more CO_2 emissions than the eFCT? The volume of emissions released by vehicles into the atmosphere depends on the amount of gasoline consumed, hence on both the ‘intensive margin’, as measured by vehicle miles travelled (VMT), and the ‘extensive margin’, as measured by MPG. People who are sufficiently attentive to fluctuations in gasoline prices and able to reduce driving at price peaks without increasing it at price lows, would drive less (/more) under more volatile (/stable) gasoline prices. On the other hand, we have shown why stable gasoline prices would likely result in the purchase of more fuel efficient vehicles – hence lower emissions. The typically large differences between long-run and short-run price elasticities of gasoline demand let us expect that the positive impact of stable gasoline prices on MPG would be greater than that on VMT, with a net benefit in terms of emissions reduction.

As regards social acceptability, the DCT would likely appeal more to the public than the eFCT because it would prevent or limit gasoline price spikes.[16] This prediction rests on economic reasoning whereby plausibly people tend to dislike more gasoline price increases when gasoline prices are already high – what you may get with the eFCT – than gasoline price increases when gasoline prices are low – what you may get with the DCT.[17] We are not aware of empirical studies testing people’s attitudes toward anything that resembles our DCT. However, besides economic reasoning, one recent anecdote, at least, supports the assumption that people would prefer less volatile gasoline prices over more volatile gasoline prices. In 2018, France’s planned carbon tax increase – at a time when gasoline prices were on the rise – was cancelled after massive street protests. Then, precisely to make the carbon tax more socially acceptable, President Macron proposed the introduction of a flexible carbon tax that would vary depending on world oil prices (“taxe carbone flottante”).[18] This said, something to keep in mind when considering the equity implications of the DCT is that the revenue raised by the tax (any time the oil price is below the target price) is effectively earmarked to finance possible future tax cuts whenever the oil price is above the target price. Therefore, unless other financial resources were made available, part of the revenue generated by the DCT would have to be set aside to help citizens most affected by the tax. The implication being that the DCT reserve for financing tax cuts would be smaller in size.

Crucially, while stabilising gasoline prices around a certain level, the DCT may be geared toward the pursuit of: a) economic efficiency, if so by internalizing the climate externality, or b) cost effectiveness (i.e., cost minimisation) in relation to a decarbonisation target. The policymaker would be able to choose between the two options by setting the oil target price accordingly. If economic efficiency is pursued, the oil target price should be set equal to the expected future average price over the ‘DCT working period’, i.e., the period within which the parameters of the mechanism are expected not to be revised. Conversely, if carbon pricing is used for minimising the cost of achieving a decarbonisation target, the level of the oil target price should be set equal to whatever the policymaker deems most appropriate. In this case, many different factors would be considered, including the ambition of the

[15] In theory, while still not being able to make a net profit, upstream operators in the gasoline value chain could respond to the DCT by raising output prices to quickly make up for previous losses. In practice, we doubt that this is a plausible scenario. Oil refiners are price takers and as such they could not afford to keep prices high when the DCT goes down (else they would suffer market losses). As to oil producers, those in non-OPEC+ countries are generally regarded as price takers too; that is, they respond to market prices rather than attempt to influence world prices. Those in OPEC+ countries, instead, do attempt to influence world prices by managing production. Is it then plausible that world oil prices would go up in response to the DCT? We doubt it, for two reasons. First, OPEC+ producers currently produce about 60 % of global oil production; that is, they are far from representing 100 % of world supply. Second, for the DCT to become a determinant of world oil prices, the DCT would have to apply to a very large share of global oil demand. If we take the US as a representative example of petroleum products consumption, in 2022 gasoline made up 43 % of all petroleum products consumed in the country (source: US Energy Information Administration). Therefore, even if the DCT was adopted by all countries, it is questionable whether that would be enough for the DCT to become a driver of global oil prices.

[16] What we imagine here is a situation in which citizens compare ex-ante two policy options, the DCT and the eFCT, and express a preference for the former.

[17] Federico et al. (2001), who analyse petroleum price smoothing programs – often subsidy programs in developing and emerging economies –, provide theoretical support for this conjecture. Drawing on the literature on the welfare effects of price stabilization (e.g., Gilbert, 1993; Turnovsky et al., 1980; Newbery and Stiglitz, 1979), the authors conclude that consumers would prefer to have stable petroleum prices: “retail petroleum price volatility is likely to have a negative welfare impact on consumers. […] The high impact of consumption of petroleum products on households’ budgets, the relatively low price elasticity of demand for these products, and the likely presence of both risk-aversion and adjustment costs all seem to suggest that consumers would prefer to have stable petroleum prices.”.

[18] Macron’s proposal eventually did not gain sufficient support within the government, apparently due to concerns about the financing of tax cuts.

environmental target, the policy mix, the cost of emissions abatement technologies, distributional concerns, and political considerations.[19]

3.2. Illustration

We now show how the proposed DCT would work in practice. First of all, the DCT rate (\$/gallon) at any point in time is given by the sum of two components: a) a fixed (i.e., time-invariant) element, $\widehat{C}$, and b) a relatively frequent (say, weekly) adjustment, A, which can vary in size depending on the observed distance of the reference oil price, P, from the chosen target level, $\widehat{P}$. The criterion for setting $\widehat{C}$ could be economic efficiency, in which case the rate would be equal to the estimated marginal social cost of carbon (MSCC), or it could be any other criterion that for whatever reason is preferred by the policymaker. In any case, it is important to realise that if and when the DCT reserve, R, is exhausted – meaning all revenues have already been used for limiting gasoline prices in previous periods and implying no further tax cuts are possible until the oil price falls below the target level again – then: a) an average carbon tax equal to $\widehat{C}$ will have been imposed over all previous periods (i.e., eFCT $= \widehat{C}$), and b) the DCT rate would be constant (i.e., DCT $= \widehat{C}$) in the subsequent periods – just as with ordinary carbon taxation – so long as oil prices exceed the target price.[20]

On a more practical level, to minimise the volatility of gasoline prices, the tax adjustment, A, would fully offset the impact of any deviation of the oil price from the target level on the wholesale gasoline price. Therefore, an estimate of such impact is needed to operationalise the mechanism. Since oil price shocks are passed through to wholesale gasoline prices with a few weeks' delay, an estimate of the medium run impact would be appropriate. Besides, the parameters of the mechanism would be reviewed on a regular basis. The oil target price, in particular, would be revised to reflect either changed expectations about the future oil price or its desired trajectory over time – which of the two depending on the objective of the DCT, i.e., economic efficiency or cost effectiveness. More generally, all the parameters of the mechanism would be reviewed on a regular basis and revised if needed to re-align the DCT to an ever-changing context or to new targets. As the review process would be self-defeating if it itself created uncertainty about future gasoline prices, we imagine it structured in intervals of a few years (e.g., three-year long intervals) and informed as much as possible by predefined rules rather than discretionary decisions.

In formal terms, the level of the proposed DCT at time t, C_t, is determined as follows:

$$C_t = \widehat{C} + A_t \tag{7}$$

$$A_t = \begin{cases} \beta(\widehat{P} - P_{t-1}) & \text{if} \quad P_{t-1} < \widehat{P} \\ 0 & \text{if} \quad P_{t-1} = \widehat{P} \\ -MIN\{-1[\beta(\widehat{P} - P_{t-1})]; R_{t-1}\} & \text{if} \quad P_{t-1} > \widehat{P} \end{cases} \tag{8}$$

$$R_t = \sum_{i=1}^{t} A_i \tag{9}$$

where:

- C_t is the DCT rate (\$/gallon) at time t, $\widehat{C}$ is its time-invariant component, and A_t is the rate adjustment;
- $\widehat{C}$ is the oil target price, and P_{t-1} is the observed oil price at time t-1;
- β is an estimated parameter measuring the change in the wholesale gasoline price (\$/gallon) for a \$1 change in the oil price (\$/barrel); and
- R_t is the sum of all (positive and negative) adjustments in all previous periods since the start of the DCT up to time t included.[21]

Had the DCT been applied in the past, how would have retail gasoline prices looked like? To answer this question, let us consider a hypothetical \$25/tCO_2 carbon tax, which translates into a tax on gasoline of about \$0.22/gallon ($\widehat{C}$), and two different oil target prices ($\widehat{P}$): \$60/barrel and \$80/barrel. Borenstein (2008) conveniently provides us with an estimate for β that specifically applies to the US market. The author calculated that, "in the medium run", every \$1 change in the crude oil price (\$/barrel) translated into a \$0.024 change in the wholesale gasoline price (\$/gallon). We use this estimate to derive counterfactual monthly series of the US average retail gasoline price under different carbon tax regimes. Full pass-through of carbon taxation is assumed, which is a harmless simplification in this analysis both given the indications of the relevant empirical literature and given that the differences between scenarios would be preserved under any other plausible assumption.[22]

With reference to the period 2000–2021, Fig. 3 compares the historical US average retail gasoline price (blue line) against three

[19] This is no different from ordinary carbon taxation, as any carbon tax is mainly used either for achieving economic efficiency or cost effectiveness.

[20] The DCT reserve has no upper limit. Oil prices persistently below the target level would result in a growing reserve.

[21] Assuming no change in gasoline demand over time, equations [8] and [9] together ensure that the DCT reserve never falls below zero.

[22] Chouinard and Perloff (2004, 2007), Alm et al. (2009), Davis and Kilian (2011), Marion and Muehlegger (2011), and Li et al. (2014), all find that, on average, changes in state gasoline taxes are fully passed onto consumers. Tsvetanov (2024) analyses data from 108 American cities to examine the pass-through of gasoline tax reductions following the 2022 oil crisis. His findings reveal significant heterogeneity across cities, with an average pass-through rate of 80 % from gasoline taxes to final consumers.

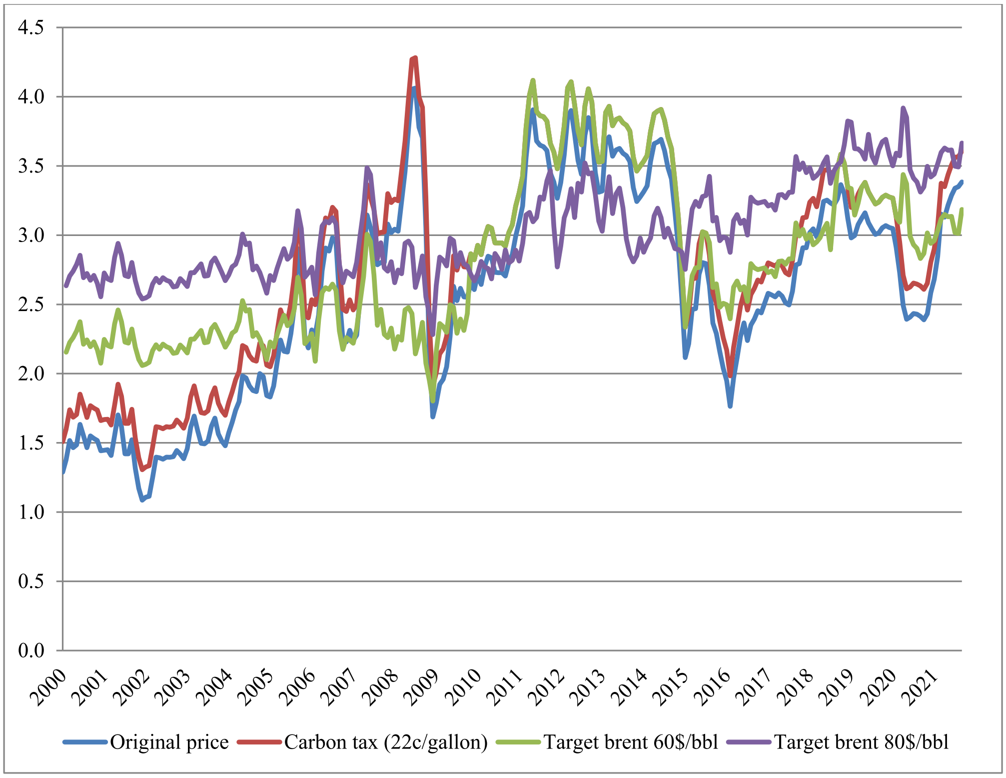

Fig. 3. US average retail gasoline prices: historical vs counterfactual scenarios.

hypothetical counterfactuals. Each counterfactual represents the US average retail gasoline price under a given carbon tax regime, specifically: a) an ordinary carbon tax of $25/t$CO_2$, translating into a fixed-rate gasoline tax of $0.22/gallon ('FCT' – red line); b) a DCT of $25/t$CO_2$ (hence, $\widehat{C}=$ $0.22/gallon) with a $60/barrel oil target price ('DCT60′ – green line); and c) a DCT of $25/t$CO_2$ (hence, again, $\widehat{C}=$ $0.22/gallon) with a $80/barrel oil target price ('DCT80′ – purple line).

Two main remarks are in order. First, compared to both historical prices and prices inclusive of the ordinary carbon tax (FCT), gasoline prices turn out to be clearly much less volatile under DCT60 and DCT80. Notably, the dramatic fluctuations of the years 2008–2009 would have been absorbed, or 'filtered out', by both DCT mechanisms. Second, over the whole period 2000–2021, DCT80 clearly does a better job than DCT60 at reducing price volatility. Up until 2007, oil prices stayed well below $60/barrel, which implies the reserve of DCT60 and even more so that of DCT80 would have increased substantially. Only the reserve of DCT80, however, would have grown sufficiently to finance tax cuts in all subsequent periods, when crude oil prices often far exceeded the $60 target price. As this example shows, the ability of the DCT mechanism to keep gasoline prices stable over time directly depends on the level of $\widehat{P}$. In short, the higher the oil target price, both the higher gasoline prices and the longer the duration of stable gasoline prices.

4. Testing the effect of gasoline price volatility on vehicle fuel efficiency

The added value of the proposed DCT depends on its ability to reduce gasoline price uncertainty by stabilising prices and on the ensuing positive effect on vehicle fuel efficiency. Having explained why we can expect both of these conditions to hold, we now turn to consider whether the same conjecture is supported by empirical evidence. Since we do not have suitable data for assessing how gasoline price volatility affects gasoline price uncertainty, nor how price uncertainty in turn affects vehicle fuel efficiency, we test for the effect of price volatility directly on fuel efficiency. A negative effect would corroborate the greater effectiveness of the DCT in reducing gasoline consumption, and hence CO_2 emissions, compared to ordinary carbon taxation. To conduct such test, we use household survey data including data on individual vehicles purchased by US households, between May 2015 and February 2017, and on the corresponding state-level average retail gasoline prices at the time of purchase. The empirical model and the estimation method, the data used, and the estimation results are illustrated below.

4.1. Model and estimation method

Our empirical model for vehicle fuel efficiency, measured in miles per gallon (MPG), is a modified version of that used by Li et al. (2014) in a highly cited study. In our model, the MPG of a purchased light-duty vehicle, be it a car, a van, an SUV or a pickup truck, is a function of: a) the gasoline price level at the time (month) of vehicle purchase; b) the monthly volatility of gasoline prices prior to vehicle purchase; and c) a series of control variables related to the household that bought the vehicle and to the local context. The model differs from Li et al.'s (2014) in three main ways. First, it includes gasoline price volatility, our main variable of interest, among the regressors.[23] Second, it includes both the difference in the gasoline price between the time (month) of purchase and 3, 6, 9, or 12 months prior, and the interaction between this price difference and price volatility over the same time interval. We can thus check whether the direction of price changes (in addition to price levels at the time of purchase) also influences vehicle purchase decisions.[24] Third, the statistical unit is different, reflecting a more convenient organisation of the survey data in pooled cross sections. In our model, MPG_{it} refers to vehicle *i* purchased in month *t*, which can correspond to any time between 0 and 12 months before the household was interviewed. In Li et al.'s model, MPG_{it} is the average efficiency of all vehicles purchased during the past 12 months by household *i* interviewed in month *t*. As in the survey the total number of vehicle purchase months is greater than the total number of household interview months, our approach results in a sample with a longer time dimension. That is, we obtain a larger number of pooled cross sections.[25]

Using Ordinary Least Squares, we estimate the following model:

$$MPG_{it} = \alpha + \beta g_{st} + \gamma \sigma_{st,K} + \lambda \Delta g_{st,K} + \xi \Delta g_{st,K} \sigma_{st,K} + X_j \Psi + \eta_s + \theta_\tau + u_{it} \tag{10}$$

where: *i* denotes the vehicle, *t* the vehicle purchase month, *j* the household, *s* the state where the household lives, and *K* the number of months prior to *t*; *g* is the average real tax-inclusive gasoline price; Δg is the difference in *g* between *t* and *K*; σ is the volatility of *g* between *t* and *K*; *X* is a vector of variables controlling for (a) household income, size, and composition, (b) age, sex, and education level of the survey respondent, and (c) local transport- and other context-related conditions; η and θ are state fixed effects and year fixed effects, respectively; and finally *u* is the error term.

Focusing on σ, the rolling standard deviation of the gasoline price is our proxy for future gasoline price uncertainty (Scott, 2015)[26]:

$$\sigma_{st,K} = st.dev.(g)_{st,K} = \sqrt{\frac{1}{K}\sum_{j=1}^{K}\left(g_{s,t-j+1} - \overline{g}_{st,K}\right)^2} \tag{11}$$

where $\overline{g}_{st,K} = \frac{1}{K}\sum_{j=1}^{K} g_{s,t-j+1}$ and *K* is the number of months in the rolling window.

But what number should *K* be? In other words, how long is the time window of past gasoline prices that tends to most strongly correlate with uncertainty about future gasoline prices? As this is ultimately an empirical question, our approach is to consider different plausible values for *K*. Accordingly, the same model [10] is estimated four times, with $K = 3$, 6, 9, and 12 (months), respectively.

4.2. Data

Our dataset was constructed by combining two types of data: a) cross-sectional household survey data, containing information on US households' transport habits and means, as well as on their socio-demographic characteristics; and b) monthly state-level data on gasoline prices. The survey data were sourced from the 2017 wave of the National Household Travel Survey (NHTS), which is published by the Federal Highway Administration every six or seven years (FHWA, 2017). The price data were derived by adding together pre-tax monthly gasoline prices – publicly available for nine states[27] and purchased from HIS Markit for all other states – and corresponding annual gasoline taxes, which are also published by the FHWA.[28] Furthermore, monthly state-level data on the Consumer Price Index, which were needed to derive real gasoline prices, were taken from the Bureau of Labor Statistics.

In the 2017 NHTS, data from a total of 126,969 households interviewed between May 2016 and May 2017 were included in the initial dataset. However, as our interest is in the determinants of fuel efficiency of vehicles sold, we focused on the subset of households that bought a light-duty vehicle within 12 months prior to the interview.

While the choice of a 12-month period is arbitrary, we deemed it represented an acceptable compromise for our purposes. On the one hand, a wider interval would have given us a larger sample, notably a longer series of pooled cross sections. On the other, this precise advantage would have come to the cost of increasing measurement error in the explanatory variables recorded at the time of

[23] Li et al. (2014) did not consider gasoline price uncertainty at all nor, therefore, did their empirical model include a proxy for it.

[24] It is not obvious which way a price increase or decrease would influence future price expectations. A price increase (/decrease) could strengthen the expectation of a further increase (/decrease). Conversely, as gasoline prices tend to revert to their long-term mean, consumers might anticipate a price decrease (/increase) following an increase (/decrease).

[25] With household survey data, *N* is always large. The same is not necessarily true for T, especially if only one survey wave is considered. Extending T in some way would normally be desirable. In our application, the greater the T dimension of the estimation sample, the greater the time variation of gasoline prices that can be and, therefore, the greater the chances of identifying statistically significant effects.

[26] This approach implies that uncertainty about future prices is influenced by past price volatility. As Scott (2015) puts it: "Price volatility may be taken as a rough proxy for future price uncertainty because it implies that future prices are harder to predict; volatility may also lead consumers to believe that current price changes will be short-lived.".

[27] The Energy Information Administration publishes pre-tax gasoline prices for the following nine states: California, Colorado, New York, Washington, Texas, Florida, Massachusetts, Minnesota, and Ohio.

[28] https://www.fhwa.dot.gov/policyinformation/statistics.cfm.

Table 1
Summary statistics, estimation sample.

Variable	N	Mean	Std. Dev.	CV	Min	Max
Miles per gallon	30,221	22.41	5.15	0.23	6.00	50.00
Gasoline price ($/gallon)	30,221	2.21	0.34	0.15	1.46	3.76
Gasoline tax ($/gallon)	30,221	0.44	0.06	0.14	0.26	0.77
3-month gasoline price volatility	30,221	0.09	0.05	0.56	0.00	0.33
6-month gasoline price volatility	30,221	0.14	0.07	0.50	0.02	0.41
9-month gasoline price volatility	30,221	0.18	0.08	0.44	0.03	0.42
12-month gasoline price volatility	30,221	0.22	0.08	0.36	0.06	0.51
Age of respondent	30,221	52.16	15.36	0.29	18	92
Sex of respondent[(a)]	30,221	1.52	0.54	0.36	1	2
Educational attainment of respondent[(b)]	30,221	2.49	0.75	0.30	1	3
Race of respondent[(c)]	30,221	1.17	0.37	0.32	1	2
Household size	30,221	2.59	1.32	0.51	1	13
Number of adults	30,221	2.05	0.80	0.39	1	10
Number of workers	30,221	0.98	0.89	0.91	0	7
Household income category[(d)]	30,221	5.97	2.61	0.44	1	11
Census block population density[(e)]	30,221	4,065	5,587	1.37	50	30,000
MSA population size category[(f)]	30,221	3.75	1.70	0.45	1	6
Urban/rural indicator[(g)]	30,221	2.83	1.31	0.46	1	5
Rail indicator[(h)]	30,221	1.15	0.36	0.31	1	2

Notes: **(a)** 1 = "Male", 2 = "Female"; **(b)** 1 = "Less than high school", 2 = "High school (or GED)", 3 = "More than high school"; **(c)** 1 = "White", 2 = "Other"; **(d)** 1 = "<$10,000", 2 = "$10,000-$14,999", 3 = "$15,000-$24,999", 4 = "$25,000-$34,999", 5 = "$35,000-$49,999", 6 = "$50,000-$74,999", 7 = "$75,000-$99,999", 8 = "$100,000-$124,999", 9 = "$125,000-$149,999", 10 = "$150,000-$199,999", 11 = "$200,000 or more"; **(e)** Persons per square mile, 50 = "0–99", 300 = "100–499", 750 = "500–999", 1500 = "1,000–1,999", 3000 = "2,000–3,999", 7000 = "4,000–9,999", 17,000 = "10,000–24,999", 30,000 = "25,000–999,999"; **(f)** Population of metropolitan statistical area (MSA), 1 = "<250,000", 2 = "250,000–499,999", 3 = "500,000–999,999", 4 = "1,000,0000–2,999,999"; 5 = "3,000,000 or more"; 6 = "Not in MSA"; **(g)** 1 = "Second city", 2 = "Rural", 3 = "Suburban", 4 = "Small town", 5 = "Urban"; **(h)** 1 = "MSA does not have rail, or household not in an MSA", 2 = "MSA has rail".

the interview and not at the time of vehicle purchase (e.g., household income, household size, the household's place of residence). It thus seemed to us a tenable assumption that household characteristics key to our analysis would not substantially change within a few months or a year at most. These considerations and the fact that gasoline price data were only available up to February 2017, resulted in an estimation sample comprising over 30,000 light-duty vehicles bought between May 2015 and February 2017. The dataset was completed with monthly state-level data on gasoline prices which were matched on the vehicle purchase month. Table 1 above shows summary statistics for the variables used in the estimation.

Focusing on gasoline prices, cross-state variation is substantial and – as one might expect – this is mainly due to differences in taxation levels (see Fig. 4). Gasoline tax rates themselves were constant or virtually constant for almost all states in the study period. Noteworthy is the exception of California, where the tax rate increased by 20 % between 2015 and 2017.

Furthermore, as far as the rolling volatility of the gasoline price ($\hat{\sigma}$) is concerned, this exhibits similar trends across states, given highly correlated gasoline prices. Also, the same volatility necessarily varies more smoothly over time as the relevant time window (i.e., the number of months considered, $K = 3$, 6, 9, and 12) increases (see Fig. 5).

4.3. Results

Table 2 reports the estimation results for our preferred model specification (eq. (10)). The four sets of results correspond to model variants that only differ from one another by the time window of both the rolling price volatility and the differenced price, namely K = 3, 6, 9, and 12 months. In the following, before presenting the results – first focusing on the effects of gasoline prices and then on those of socio-demographic and other factors – we discuss the issue of state fixed effects in our empirical setting.[29]

4.3.1. State fixed effects

Ideally our empirical model would include state fixed effects. By controlling for any relevant time-invariant factor within a state, state fixed effects would allow us to more comfortably interpret estimation results on gasoline price volatility as a test of our main hypothesis, i.e., that greater uncertainty about gasoline prices negatively affects the fuel efficiency of new vehicles sold. In practice, however, estimation with state fixed effects runs into a severe multicollinearity problem due to high correlation between state dummies and monthly average gasoline prices at the state level. The problem arises with our sample as differences in gasoline taxes between states tend to result in persistent differences in gasoline prices at the pump. In other words, gasoline prices in different states tend to move parallel or almost parallel to one another (see Fig. 4 showing 'typical' patterns of gasoline taxes and prices). Consequently, estimates of the coefficients on the gasoline price and its volatility are not robust. In addition, the multicollinearity issue associated with state fixed effects is compounded by the presence of year fixed effects in the model. Here, the combination of state

[29] This is a well-known issue in the literature on gasoline demand that uses state-level gasoline price data.

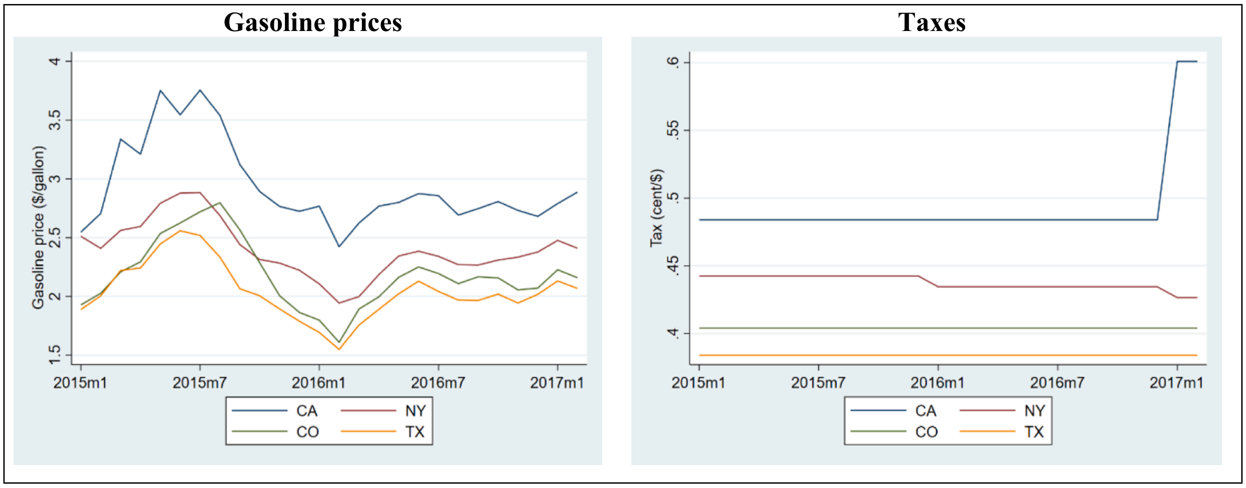

Fig. 4. Nominal gasoline prices and taxes, selected states (2015–2017).

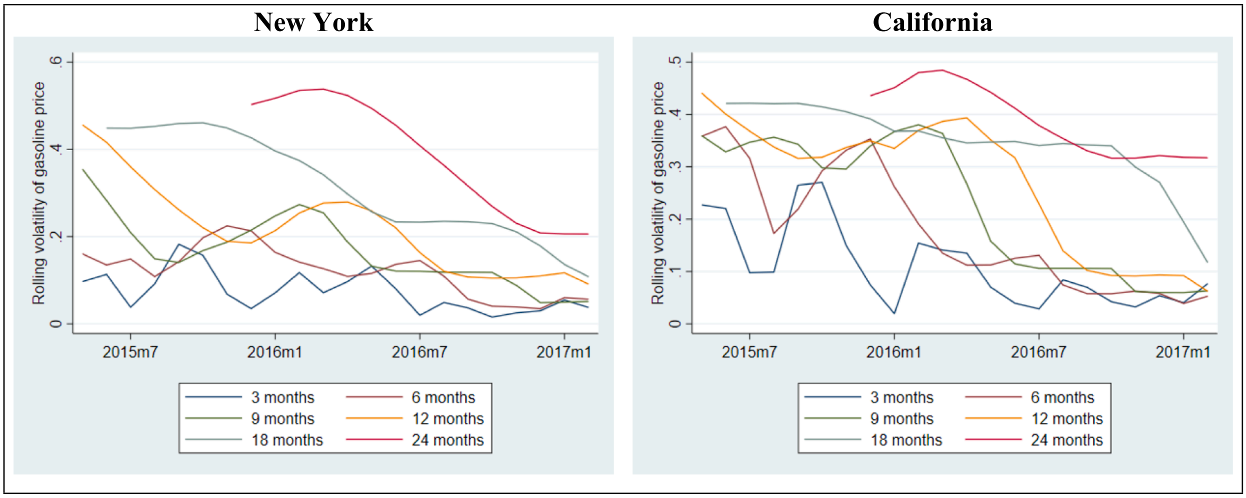

Fig. 5. Gasoline rolling price volatility, selected states.

dummies and year dummies makes identification of any effect of gasoline prices hardly possible given limited within-year variation of state-level monthly prices. For these reasons, our preferred model specification (equation [10] above) does not include state fixed effects.

4.3.2. *Gasoline price effects*

With reference to Table 2, the estimated coefficients of the gasoline price ($\hat{\beta}$) indicate that, depending on the model variant, fuel efficiency of new vehicles sold increases between 0.46 MPG and 0.52 MPG for a $1 increase in gasoline price. In elasticity terms (elasticity of fuel efficiency relative to gasoline price), the corresponding effects at sample mean values (Table 1) are 0.04 and 0.05. These numbers, which probably seem small, are comparable to those found in the closest empirical literature. In Li et al. (2014), notably, the same estimated elasticity ranges between 0.06 and 0.08.

The estimated coefficient of gasoline price volatility ($\hat{\gamma}$) turns out to be -1.53 and -1.38 for $K = 3$ months and $K = 6$ months, respectively. This means that a $1 average deviation of the gasoline price from its mean over a period of three and six months, respectively, prior to vehicle purchase is associated with a worsening of fuel efficiency of new vehicles sold by 1.53 and 1.38 MPG, respectively. For longer time intervals ($K > 6$), the same estimated coefficients, $\hat{\gamma}$, while with a negative sign as expected, are not statistically different from zero. On the one hand, this could be interpreted as evidence that consumers tend to have limited memory of gasoline price volatility (not exceeding six months) at the time of vehicle purchase. On the other, the same result may simply reflect the fact that the variability of gasoline price volatility decreases as the time window (K) increases (see the curves in Fig. 5 and the coefficients of variation in Table 1). In fact, both explanations may be valid, as one does not exclude the other.

In any case, the two coefficients statistically different from zero, $\hat{\gamma} = -1.53$ ($K = 3$) and $\hat{\gamma} = -1.38$ ($K = 6$), indicate that gasoline

Table 2
Estimation results.

	K = 3		K = 6		K = 9		K = 12	
	Coeff.	St. Err.	Coeff.	St. Err.	Coeff.	St. Err.	Coeff.	St. Err.
Price level	0.477***	(0.113)	0.460***	(0.114)	0.447***	(0.116)	0.526***	(0.128)
Price volatility:								
3-month (K = 3)	−1.538*	(0.875)						
6-month (K = 6)			−1.384**	(0.654)				
9-month (K = 9)					−0.718	(0.672)		
12-month (K = 12)							−0.850	(0.598)
Differenced price:								
3-month (K = 3)	0.338	(0.249)						
6-month (K = 6)			−0.063*	(0.0369)				
9-month (K = 9)					−0.011***	(0.003)		
12-month (K = 12)							−0.000	(0.000)
Price volatility x Differenced price:								
3-month (K = 3)	−1.339	(1.924)						
6-month (K = 6)			0.366**	(0.151)				
9-month (K = 9)					0.035***	(0.011)		
12-month (K = 12)							−0.000	(0.001)
Household size	−0.483***	(0.026)	−0.483***	(0.026)	−0.483***	(0.026)	−0.484***	(0.026)
Number of adults	0.312***	(0.082)	0.312***	(0.082)	0.313***	(0.082)	0.312***	(0.082)
Number of workers	0.094*	(0.055)	0.096*	(0.055)	0.094*	(0.055)	0.093*	(0.055)
Household income (0/1):								
<$10,000	Ref. cat.		Ref. cat.		Ref. cat.		Ref. cat.	
$10,000-$14,999	0.125	(0.246)	0.125	(0.246)	0.123	(0.246)	0.126	(0.247)
$15,000-$24,999	0.395*	(0.198)	0.388*	(0.199)	0.391*	(0.199)	0.395*	(0.198)
$25,000-$34,999	0.421*	(0.231)	0.419*	(0.229)	0.418*	(0.229)	0.422*	(0.230)
$35,000-$49,999	0.439**	(0.206)	0.437**	(0.204)	0.437**	(0.205)	0.440**	(0.205)
$50,000-$74,999	0.249	(0.193)	0.245	(0.191)	0.246	(0.192)	0.249	(0.191)
$75,000-$99,999	0.118	(0.224)	0.115	(0.222)	0.116	(0.222)	0.119	(0.223)
$100,000-$124,999	0.157	(0.207)	0.152	(0.205)	0.153	(0.205)	0.156	(0.205)
$125,000-$149,999	−0.041	(0.206)	0.046	(0.204)	−0.044	(0.204)	−0.044	(0.203)
$150,000-$199,999	−0.248	(0.266)	−0.250	(0.264)	−0.247	(0.265)	−0.243	(0.265)
$200,000 or more	−0.534*	(0.269)	−0.536*	(0.267)	−0.534*	(0.268)	−0.530*	(0.268)
Age of respondent	0.014***	(0.003)	0.014***	(0.003)	0.014***	(0.003)	0.014***	(0.003)
Sex of respondent (0/1): female	0.315***	(0.042)	0.317***	(0.042)	0.316***	(0.042)	0.316***	(0.042)
Education of respondent (0/1):								
< High school	0.213	(0.174)	0.212	(0.173)	0.213	(0.173)	0.215	(0.173)
High school	Ref. cat.		Ref. cat.		Ref. cat.		Ref. cat.	
> High school	1.054***	(0.099)	1.055***	(0.999)	1.056***	(0.100)	1.054***	(0.100)
Race of resp. (0/1): non-white	0.001	(0.001)	0.001	(0.001)	0.001	(0.001)	0.001	(0.001)
MSA population size cat. (1–6)	−0.087***	(0.023)	−0.087***	(0.023)	−0.087***	(0.023)	−0.086***	(0.023)
Population density cat. (1–8)	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)	0.000***	(0.000)
Rail (0/1)	0.928***	(0.165)	0.930***	(0.166)	0.932***	(0.168)	0.926***	(0.163)
Urban/rural (0/1):								
Second city	0.656***	(0.098)	0.656***	(0.098)	0.657***	(0.097)	0.659***	(0.097)
Urban	0.852***	(0.139)	0.857***	(0.135)	0.861***	(0.134)	0.854***	(0.138)
Suburban	0.807***	(0.077)	0.809***	(0.076)	0.808***	(0.076)	0.812***	(0.076)
Town/rural	Ref. cat.		Ref. cat.		Ref. cat.		Ref. cat.	
Constant	19.53***	(0.347)	19.65***	(0.375)	19.55***	(0.394)	19.45***	(0.351)
State dummies, Year dummies	NO, YES		NO, YES		NO, YES		NO, YES	
Observations	30,221		30,221		30,221		30,221	
R^2	0.040		0.040		0.040		0.040	

Notes: a) Robust standard errors (in parentheses) clustered at state level. b) *** p < 0.01, ** p < 0.05, * p < 0.1.

price volatility is a relevant variable both in a statistical and economic sense.[30] Notably, if we interpret these parameters in relation to the proposed DCT mechanism, we realise that their magnitude is not negligible. Taking the model with K = 6, which is the best fitting model, we can make a simple simulation. If σ is set equal to zero, which is what a DCT that perfectly stabilises gasoline prices would entail, the model predicts (at sample mean values) an average increase in MPG equal to 0.19. Therefore, price stabilisation alone, i.e., it independent of the gasoline price level, would have an impact on fuel efficiency exceeding a third of the effect of a $1 price increase. This ratio between the two effects, which exceeds 1:3, is probably the most relevant result of our econometric analysis as it points to a potential substantial improvement of carbon pricing in terms of environmental effectiveness. What is more, the effect of a gasoline price stabilisation scheme on fuel efficiency may be even larger than that in real life. These econometric results come from data generated in a context where nothing resembling a policy for gasoline price stabilisation was in place. Thus, to the extent that gasoline

[30] At sample mean values (see Table 1), the elasticity of MPG with respect to σ is equal to −0.006 and −0.008 for K = 6 and K = 8, respectively.

price uncertainty was only partially captured by gasoline price volatility, a price stabilisation scheme such as the DCT would probably have a greater impact on fuel efficiency than these estimated parameters indicate.

The estimated coefficients for the differenced gasoline price ($\hat{\lambda}$) and for its interaction with gasoline price volatility ($\hat{\xi}$) are also insightful. The estimated coefficient for the price change is negative and statistically different from zero for K = 6 and K = 9, while it is not statistically significant for other time intervals. This indicates that if at the time of purchase buyers observed a higher gasoline price than 6 or 9 months earlier, they would more likely buy a vehicle with lower MPG. The result can be explained with prevailing expectations among buyers of mean-reverting gasoline prices. In other words, if today's gasoline price is higher than it was six or nine months earlier, buyers anticipate a price decline and, thus, they buy (slightly) less fuel-efficient vehicles than they would buy otherwise. Furthermore, the estimated interaction between the differenced price and price volatility is positive and statistically different from zero again for K = 6 and K = 9. The economic interpretation of this result is meaningful in relation to both variables. One could say that the negative effect of gasoline price volatility on MPG is diminished in the context of growing prices.[31] The idea being that uncertainty weighs less on vehicle choices in such a context. At the same time, the negative effect of growing gasoline prices (as such) on MPG is diminished in a context of volatile prices.[32] The idea being that the expectation of mean-reverting prices is weakened by the volatility of prices themselves.

4.3.3. Socio-demographics and other factors

The richness of the NHTS data also offers us some interesting results on correlations between fuel efficiency of new vehicles sold and both buyers' socio-demographics and local contextual factors. We comment on these results by distinguishing three groups of variables which refer, respectively, to characteristics of the family, of the survey respondent, and of the place where the family lives. As regards household income, we note a pattern whereby the effect on fuel efficiency grows across the first income categories, it then decreases and stabilizes, with coefficients statistically not different from that of the lowest-and-reference income category, and finally it becomes negative, with a rather large coefficient (−0.54) when compared to that of the gasoline price (representing the effect of an extra $1 at the pump). Among the other household-level variables, we note that fuel efficiency is negatively correlated with the number of household members (−0.48), but positively correlated with the number of adults (0.31). These relationships make sense if one imagines that it is usually larger households and especially households with children who need bigger cars. Coming to the characteristics of the survey respondent, the results are interesting – also probably expected – whereby fuel efficiency is positively correlated to the level of educational attainment (1.06 for the highest category compared to the lowest reference category) and to female gender (0.32 compared to male). By contrast, a positive correlation between fuel efficiency and the age of the survey respondent appears to be more modest (0.01 per extra year). Furthermore, urban and infrastructural factors characterising the place where the household lives turn out to be very important. We find here clear differences between urban and suburban contexts (0.85 and 0.81) relative rural contexts, as well as quite a large coefficient on a variable capturing proximity to a rail (0.93).

5. Concluding remarks

This study shows the potential added value of policies that stabilise gasoline prices and related agents' expectations. The estimated negative effect of gasoline price volatility on fuel efficiency of new vehicles sold supports the research hypothesis that uncertainty about future gasoline prices makes fuel efficient vehicles less likely to be purchased. Given the important policy implications of this result, we wish to stress first of all the desirability of conducting further empirical tests of the same hypothesis using different data, models, and approaches.

It is important to recognise that the proposed DCT or any other similar mechanism would not operate in a policy vacuum nor would it likely be the main instrument for decarbonising road transport. Absent a cap-and-trade system that already covers emissions from road transport, the proposed DCT would operate in a complementary manner alongside a series of other policy instruments including, e.g., CO2-based vehicle taxes, purchase subsidies for electric vehicles, fuel efficiency standards. Future work should thus look at the how the DCT would complement the policy mix best. In this connection, if the DCT is used to pursue cost effectiveness in relation to a given decarbonisation target, then the key question is what the oil target price should be (e.g., $80/barrel, $100/barrel, $120/barrel …?). Answering this question requires identification of an ideal trajectory of the crude oil price. Furthermore, a potential follow-up study on the proposed DCT should delve into aspects more closely related to its implementation. Such aspects would regard, for example, the frequency with which the DCT is regularly adjusted in response to oil price movements (e.g., on a weekly basis? On a daily basis?) and the frequency with which the DCT parameters should be reviewed and revised if needed.

More generally, in the context of the ecological transition, the environmental benefits achievable through policies that reduce uncertainty about future energy prices seem to us a topic as important as it is understudied. It is indeed legitimate to expect that over the next two to three decades the progressive abandonment of fossil energy sources at the global level will be accompanied by erratic fluctuations in energy markets, no less than those of the past. Strong volatility of fossil fuel prices and high uncertainty about their future levels, potentially combined with low fossil fuel prices as predicted by the Green Paradox (Sinn, 2012), would penalise investments for climate change mitigation. Under mandatory carbon markets, the question of energy price uncertainty could be addressed, for example, through fluctuation bands ('collars') for carbon prices (see, e.g., Doda et al., 2022, and Philibert, 2009). By

[31] $.\partial MPG/\partial\sigma = \gamma + \xi\Delta g$

[32] $.\partial MPG/\partial\Delta g = \lambda + \xi\sigma$

contrast, how carbon taxes could be designed and implemented in such a way as to address energy price uncertainty in relation to climate change mitigation, is the question that this paper addresses and which to our knowledge has not yet been studied or debated in any depth.

CRediT authorship contribution statement

Stefano F. Verde: Writing – original draft, Formal analysis, Conceptualization. **Valeria Di Cosmo:** Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors do not have permission to share data.

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