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(Unintended) Transport impacts of an energy-environment policy: The case of CNG conversion of vehicles in Dhaka

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Abstract

Motor vehicles are one of the major sources of air pollution in Dhaka, the capital of Bangladesh. The government took various policies to convert the petroleum vehicles on road to run on compressed natural gas (CNG), which allows both air quality improvements and energy security benefits. One of the market friendly policies to encourage the fuel switch was to increase the price differential between CNG and petrol and diesel. This has allowed a wide-scale adoption of CNG as the fuel of choice. However, several years into the policy, there is now a widespread belief among the policymakers that the CNG conversion may have increased car ownership and car travel due to their lower running costs, resulting in more congestion and a reversal of the strategy is on the cards. It is therefore important to test the hypothesis whether CNG conversion had genuinely increased car ownership and car travel in Dhaka city. This paper presents the results of a questionnaire survey and an econometric intervention analysis to understand the impact of CNG conversion on car ownership and car travel in Dhaka. Attention is also given to disentangle the self-selection and price-induced travel effects of CNG conversion. Results show that ownership did not increase, but travel of on-road vehicles increased due to the CNG policy. However, additional congestion costs are still around one-half of the health benefits brought about by the policy.

Key words

CNG vehicle, integrated modeling, transport impact, intervention analysis, vehicle ownership, elasticity

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1. Introduction and Motivation

The use of Compressed Natural Gas (CNG) as a vehicle fuel has been gaining popularity in a number of countries over the last decade. CNG vehicles generally emit much less criteria air pollutants per mile of travel as compared to their petrol and diesel counterparts, especially in countries where vehicle emissions standards is not stringent (Nijboer 2010). Since most megacities in the developing countries have severe air quality problems and petroleum-run motor vehicles are a major source of this pollution, replacing petroleum with CNG as vehicle fuel offers large air quality benefits (Maclean and Lave 2000, Cohen et al. 2003). Accordingly, megacities such as Rio de Janeiro, Mexico City, Delhi, Mumbai and Karachi have all successfully introduced a varied number of CNG vehicles in their vehicle fleet (Balassiano and White 1997, Schifter et al. 2000) during the nineties. Most of the fleet conversion in these cities was particularly for heavy duty diesel buses and trucks and/or two-stroke three-wheelers, which were the most polluting vehicles on road in these cities. However, a number of cities and countries launched a more ambitious natural gas vehicle program. Pakistan and Armenia lead the way having more than 60% of their entire motor vehicle fleet running on CNG, while Argentina, Brazil, China, India, Iran and Pakistan lead the numbers table, having more than a million CNG vehicles each (International Association of Natural Gas Vehicles, IANGV 2012).

Dhaka, the capital of Bangladesh, and a densely populated megacity of 13 million inhabitants, has a poor air quality – particularly during the dry winter season. Chittagong, the second biggest city in the country also has its own air quality problems, and motor vehicles were a major source of pollution in both these cities (Wadud and Ali 2012). Given this situation, fueling vehicles by CNG offers a four-way benefit to the cities and to the country. Firstly, CNG vehicles significantly improve local air quality and reduce associated adverse health impacts (Wadud and Khan 2013). Secondly, net GHG emissions are less than conventional petroleum vehicles (USEPA 2010, Nijboer 2010).[1] Thirdly, natural gas is an indigenous energy source, and its use in vehicles allows saving foreign currency by reducing petroleum import and thus improves external balance of trade. Last, but not the least, using a local energy source improves

[1] Wadud and Khan (2013) argue that the GHG impact of retrofitted CNG conversion is still ambiguous.

energy security of the country.[2] The Government of Bangladesh (GoB) was particularly keen on the energy and local air quality benefits and actively pursued a policy to encourage a fuel switch to CNG for motor vehicles, especially in the large cities, since early 2000.

The GoB has been successful in attaining its intended environmental and energy objectives through converting a major share of Dhaka's vehicles fleet to run on CNG[3] and in reducing air pollution in the two largest cities (Wadud and Ali 2012), however, a third potential (adverse) impact was not considered during policy making. In order to encourage the switch from petroleum to CNG, the GoB actively pursued several strategies, one of which was to increase the price differential between CNG and petroleum. Low prices of CNG meant vehicle running costs were now much less as compared to petrol or diesel and the low prices increased vehicle travel and aggravated the already dire traffic congestion in Dhaka and Chittagong. In order to combat the perceived additional traffic congestion (and potential future scarcity of natural gas) the GoB has recently increased the price of CNG and is contemplating further increase to discourage conversion of petroleum vehicles to CNG, which is a marked departure from the earlier stance. This potential U-turn has generated a debate among the environmental and transport professionals, the GoB and other stakeholders. Central to the debate is the (primarily) health and (potential) GHG benefits of CNG vehicles and the additional congestion brought about by the current CNG encouragement policy, all of which need to be evaluated in an integrated setting if a sound, evidence-based decision is to be made. Unfortunately, there is a severe lack of data and expertise to develop such models.

With this background, in this paper we quantify the impact on local traffic of the CNG vehicle conversion policy. This paper complements the author's earlier work on modeling the health and GHG impacts of CNG conversion (Wadud and Khan 2013) and provides a crucial piece in the integrated approach required in such policy evaluation. Also, there is a substantial literature on the environmental impacts of CNG conversion (e.g. Zusman et al. 2011, Reynolds and Kandlikar 2008), yet none investigated the potential travel and congestion impacts of the CNG conversion policies, neither in Bangladesh nor in any other countries or cities. This research directly contributes to fill this gap in policy assessment. In addition, the research has a wider appeal in the context of the existing debate in Europe on the carbon benefits of dieselization of the vehicle fleet as well as the potential unintended travel impacts of plug in

[2] There can be a limit to energy security benefits if the resources are to be exhausted soon, which is not an implausible scenario either for natural gas in Bangladesh.

[3] A spot survey shows around 83% of the personal vehicles were converted to CNG in 2010 (Wadud and Khan (2013).

electric vehicles (if charged overnight using residential electricity). Especially, we focus on disentangling the price effect and the self-selection effect in the differences between petroleum and CNG vehicle miles/km travelled (VMT/VKT), a key issue in identifying the benefits of diesel as well (Schipper et al. 2002, Schipper and Fulton 2009). The paper thus focuses on modeling the transport impacts of an environmental/energy policy.

The paper is laid out as follows. Section 2 presents the CNG conversion program in Dhaka and Bangladesh and it current status. Section 3 presents the summary of relevant literature while section 4 presents our modeling strategy and results. Section 5 presents the VMT increase in the context of health and GHG impacts and broader policy context and concludes.

2. CNG Fuel Switch in Dhaka

The first CNG refueling station in Bangladesh was established in Dhaka, as early as in 1984 by the Rupantorito Prakritik Gas Company Limited (RPGCL), a government owned subsidiary under PetroBangla (Bangladesh Oil, Gas and Mineral Corporation), and was primarily an energy security initiative. Despite the early beginning, the next four came a decade later – in 1995. Between 1984 and 1997, there were only 174 vehicles running on CNG in Dhaka, indicating that the introduction of CNG for vehicles was neither a priority for the Government, nor a runaway success. Even until 2001, the number of CNG vehicles was very small and refueling facilities were even smaller. A number of factors were responsible for the very slow uptake during the initial years: lack of media interest and thus lack of information among the consumers, minimal commitment from the GoB and a dearth of refueling and vehicle conversion facilities.

By the end of the 1990s, air pollution in Dhaka city and its adverse impact on human health and welfare gained significant media and public interest, which also helped create stronger government commitment to reducing air pollution and to the CNG fuel switch program. The CNG supply industry gained some momentum during early 2001 when some 12,000 CNG run taxis were gradually introduced in Dhaka to alleviate its transportation problem. In addition, the GoB decided to remove the highly polluting old two-stroke petrol run autorickshaws (three-wheelers) from Dhaka (and Chittagong) in order to improve the local air quality, which resulted in 9,000 new CNG run autorickshaws in Dhaka, almost overnight in late 2002. These two initiatives helped the industry gain a critical mass - especially the chicken and egg (build CNG infrastructure first and wait for vehicles to convert to CNG later or convert the vehicles first and wait for CNG filling stations to respond to demand later) problem was directly addressed by ensuring a minimum level of demand from these new vehicles. At the same time, the government took some other important decisions to encourage the development of the CNG industry and to increase CNG switch among the motorists. These decisions include boosting both the demand as well as the supply side and include the following:

1. Private sector was allowed for the first time to participate in retrofitting petroleum vehicles to run on CNG, curbing the previous, not-very-active monopoly of RPGCL, a government owned body
2. Private sector was allowed to set up CNG filling stations, again curbing the monopoly of the RPGCL
3. Given the novel nature of business, private sector was *encouraged* to enter the industry by making available government land to them only for setting up CNG filling stations, at a lower cost than market price
4. CNG and petroleum prices were restructured in order to make CNG more lucrative as a transportation fuel, even after considering the conversion costs; especially subsidies on imported petroleum fuels were either reduced or removed
5. Import duties on CNG conversion/retrofitting kits, CNG storage tanks and refueling station related equipments were removed in order to bring down the conversion costs and expedite conversion rate
6. Import duties on dedicated CNG buses were removed and on dedicated CNG autorickshaws were reduced to encourage more dedicated CNG vehicles on road
7. All government vehicles were asked to convert to CNG
8. Safety campaigns were run to ensure the use of proper CNG storage tanks

The first three of these strategies addressed the supply side to ensure of the availability of CNG as vehicle fuel, while the rest aimed to boost the demand for CNG vehicles or CNG conversion. Although there were some initial glitches (e.g. use of unapproved CNG storage tanks in vehicles by unscrupulous retrofitting workshops resulted in a few explosions and deaths), these initiatives led a large number of different types of vehicles (private cars, SUV's, minibuses, buses) to gradually switch to CNG from petroleum. The supply side initiatives increased the number of CNG filling stations from 7 in 2000 to 580 in 2010. Number of CNG conversion workshops increased from 1 to 170 in those 10 years. The evolution of CNG vehicle fleet and the number of CNG filling stations and conversion workshops in Bangladesh is presented in Fig. 1.

[Fig. 1 here]

The demand side initiatives were equally successful, too. The government statistics in 2010 show that around 117,000 vehicles were converted to run on CNG, while nationwide, the number is around 180,000 (plus there were around 30,000 original equipment CNG vehicles – primarily baby taxis, taxis and some buses). This success in fuel switch puts Bangladesh among the top ten countries in the world in terms of total number of natural gas vehicles (NGV), which also includes Liquefied Petroleum Gas (LPG) vehicles. Also, the number of refueling stations per thousand CNG vehicles in Bangladesh is the highest among these ten countries. Although the absolute numbers of CNG vehicles do not appear large in an international context, it is large in Bangladesh or Dhaka's context, since the CNG fleet in Dhaka represents around 35% of its non-motorcycle vehicle fleet as per BRTA statistics (2010 mid year data). Countrywide penetration is also high, at nearly 19%, which puts Bangladesh among the top five countries with highest NGV penetration rate in the vehicle fleet (IANGV 2012).

A spot survey carried out at different locations in Dhaka indicates that almost 83% of all cars surveyed were running on CNG in 2010. The proportion of buses and minibuses running on CNG was above 70%. This represents around 75% of all motor vehicles (excluding motor-cycles). The large difference with government statistics (35%) is possibly due to the slow updating of the CNG vehicle registrar or the inaccurate vehicle registration data. There is no accurate statistics on the number of vehicles on road in Dhaka, and the statistic that is often used is the cumulative new registrations from Bangladesh Road Transport Authority (BRTA, 2012) or Bangladesh Bureau of Statistics (BBS, 1985-2011). Unfortunately vehicle attrition or scrappage is not tracked and using cumulative registrations without accounting for the attrition underestimates the share of CNG vehicles in Dhaka.

Unlike some other well-known CNG programs, such as Delhi's switch of its diesel bus fleet, Dhaka did not target specifically the diesel buses – i.e. it did not ban diesel buses outright as it did for two-stroke petrol run autorickshaws – and let the price differential between the petroleum fuels and CNG act in the market. Since the diesel prices were still substantially subsidized because of its extensive use in the agriculture sector, the price differential between petrol and CNG remained much larger than that between diesel and CNG. This encouraged a large scale conversion of petrol vehicles, which are primarily used as personal vehicles (e.g. cars, SUVs and microbuses). It is therefore argued that the lower running costs have increased both vehicle ownership and vehicle travel in Dhaka (Hasan 2012), aggravating the already dire state of congestion. Unfortunately, there was no quantitative evidence on larger vehicle ownership and vehicle travel, apart from a cursory presentation of the rising number of vehicles in Dhaka since 2004. In the next few sections we quantitatively investigate these two issues.

3. Literature on Potential Travel Impacts

The major point of contention is not CNG conversion itself, rather the impact of the lower fuel costs of CNG vehicles, which was necessary to encourage the fuel switching behaviour. Since road travel is a 'normal' good, a decrease in the costs of travel (which can include fuel costs, maintenance costs, insurance costs, time costs, etc.) increases the quantity demanded. There is a vast literature in transport economics on transport related demand elasticities which represent the quantitative changes in demand with respect to a given change in one of the causing factors. These include elasticities of demand for fuel use, car use (VMT/VKT), car ownership, rail travel, air travel, business travel, leisure travel, freight, public transit use, number of trips etc. with respect a wide range of explanatory factors, such as own price, price of a substitute or complementary mode, income, socio-economic characteristics, etc. Of these, two are particularly relevant to our case: elasticity of car use or vehicle travel (VMT/VKT) and elasticity of vehicle ownership – both with respect to fuel price. The additional VKT impact is often known as induced traffic in literature (Noland and Lem 2002), which is defined as the increase in traffic due to the reduction in generalized costs of travel, which *generally* takes place as a result of a transport related initiative (e.g. traffic flow improvement, additional roadway capacity, etc.).[4]

Elasticity of car use or vehicle travel with respect to fuel price is a well researched area. Given the limitation of space, we present only the findings from two well-cited reviews of the literature in Table 1. These elasticities indicate that a 10% reduction in fuel price increases the VKT by 1% to 1.5% in the short run and 3% in the long run. Studies on elasticities of vehicle ownership with respect to fuel price is also substantial. The same reviews in Table 1 show that for 10% reductions in fuel price, vehicle ownership is increased by 1% to 2% in the short run, however, there was no consensus on longer run price effect on vehicle ownership. It is not clear whether long run road travel elasticity in these studies includes the effect of long run changes in vehicles ownership in response to fuel price changes.

[Table 1 here]

Depending on where we draw the boundary, a few other strands of literature can be relevant to this work as well. Rebound effect in energy systems is defined as the larger energy use resulting from a more efficient system, since an efficient system would reduce the cost of operations. Green et al. 1999 have found such rebound effects due to fuel economy improvements in vehicles. Relaxing the definition somewhat, we can draw an analogy with CNG conversion since the air quality and climate benefits can show a rebound effect due to lower operating costs and higher travel of CNG vehicles.

The final strand of literature relevant to our work is that on the dieselization of the personal vehicle fleet in the UK and the European Union countries. Since early 1990s there was a significant switch to diesel

[4] For example, we can define induced traffic elasticity in our case as percent increase in traffic/VMT due to percent increase in the number of CNG vehicles - which in turn depends on the price differential of the fuels.

cars, primarily brought about by improved diesel technologies to reduce criteria pollutant emissions and driving comfort, and lower price of diesel compared to petrol. Although a like-for-like diesel car model is almost 30% more fuel efficient (but 20% more carbon efficient due to diesel's larger carbon content) a reduction in fuel consumption or carbon emissions of similar magnitude has not been observed from diesel cars in these countries. Cross sectional data consistently show that average diesel vehicles are often driven 40% - 100% more than the average petrol cars, wiping out potential gains in fuel consumption or carbon emissions. The higher travel, however, includes self-selection effects (described below) as well as rebound effects due to the price differential of the fuels.

In Europe, diesel vehicles of similar size and performance cost more than the petrol cars. Therefore it was rational for diesel car owners to switch from petrol only if they were expecting to drive substantially more so that the additional capital cost is recovered by the savings made every mile due to lower fuel costs. Therefore diesel vehicle owners are a self-selected group who already travel more or intend to travel more, even if they had driven a petrol car, resulting in higher diesel travel. Hivert (1994) and Cerri and Hivert (2003) surveyed diesel vehicle users in France and report that fuel switchers indeed drove their diesel vehicle more than their previous petrol ones. They find that the higher travel in diesel was due to a younger diesel fleet, wealthier diesel car owners, larger commuting distances, and cheaper per mile costs – indicating both self-selection and price rebound effects in action. Schipper and Fulton (2009) also argue that self-selection does not explain all the additional diesel travel and that there is some price induced rebound effect as well. Schipper and Fulton (2009) do not provide any conclusive evidence that price effect was in play, but used the price elasticities of demand, discussed above, to argue that possible rebound effects were sufficient to nullify diesel's carbon advantages.[5] Given the importance of the issue, it is intriguing that there was no study to investigate the contribution of self-selection and price effects to the larger travel distances recorded by the diesel personal vehicles, a challenge we face as well.

4. Modeling Impacts in Dhaka

A straight forward option to determine the additional travel impacts of CNG switch is to use the VKT and vehicle ownership elasticities with respect to price along with the price differential, similar to what Schipper and Fulton (2009) did. However, there are two problems with this approach: firstly, these elasticities are not available for Bangladesh, and using estimates from the developed countries is not appropriate, especially because the price sensitivity can be substantially different in Bangladesh (only

[5] Note that in the UK, currently there are no diesel price advantage over petrol

the wealthier segment of the society owns motor vehicles, who are generally less price sensitive, as shown by Wadud et al., 2010). Secondly, using elasticities to *simulate* the potential impact does not confirm whether vehicle travel had indeed increased and aggravated the traffic congestion. Therefore we follow a more direct approach in quantifying the ownership and travel impacts of CNG conversion using local primary and secondary data.

4.1 Vehicle Ownership Impacts

Increases in vehicle numbers or vehicle ownership are one of the major drivers of road traffic in every country. In order to determine the impact of CNG conversion on vehicle numbers, we follow an intervention approach using data on vehicle registration in Dhaka, focusing only on personal vehicles (i.e. cars, SUVs, station wagons and microbuses). Intervention analysis is widely used in time-series econometrics to quantify the effect of an external policy or event on a variable of interest. In the well-known Box and Tiao (1975) approach, this requires modeling the time-varying variable in a univariate ARIMA framework and including a transfer function to represent the pattern of response. However, since GDP per capita and population are two important determinants in explaining vehicle number or ownership, we prefer a multivariate dynamic regression framework. Our preferred econometric model [Model A] is an autoregressive distributed lag one:

$$lnV_t = \kappa + \sum_{i=1}^{l} \alpha_i lnV_{t-i} + \sum_{j=0}^{m} \beta_j lnGDP_{t-j} + \sum_{k=0}^{n} \gamma_k lnP_{t-k} + \varepsilon_t \qquad (1)$$

where V is the number of vehicles, GDP is real GDP per capita and P is population; subscript t refers to time (year), and l, m and n are chosen such that the error ε_t is white noise. α, β, γ and κ are parameters to be estimated. Our strategy is to use the data prior to CNG conversion policies to fit the model in Eq. 1, and use these parameter estimates along with GDP and population data post policy to predict the vehicle numbers post policy. If CNG conversion and thus lower driving costs have increased vehicle ownership, then the actual vehicle numbers should be larger than the model-based prediction for post-policy periods, which can be observed in graphical representation or statistical tests. Vehicle data are from BBS (1985-2011) and BRTA (2012), while population and real GDP data are from the World Development Indicators database (World Bank 2012). Fig. 2 presents the data used to estimate the model parameters.

[Fig. 2 here]

Given the small length of the time-series data, dropping a number of observations as in the previous approach may not be efficient. Therefore, we also use a dummy variable approach to represent the intervention in Eq. 1 and run the model on full sample. Model B uses a dummy D_g=0 for t<2004 and D_g=t-2004 otherwise, to represent a gradual effect of the policy over the years. Model C uses a dummy D_s=0 for t<2004 and D_s=1 for t>=2004: this represents a step change in vehicle numbers. Model D interacts D_s with $lnGDP$ to include the possible effect that the structural relation between GDP and vehicle numbers may have changed due to the policy. For all these alternate models, a positive and statistically significant parameter for the dummy variables would indicate an increase in vehicle ownership over the business-as-usual scenario.

Table 2 presents the estimation results. Given that the variables are in time-series, there is a strong possibility of non-stationarity in lnV, $lnGDP$ and lnP. Unit root tests indeed indicate that all three variables have a unit root. Therefore we conduct a cointegration test using the long-run parameters to ensure that we do not estimate a spurious regression.[6] Fig. 3 presents the registered number of vehicles for the whole time-series, and predicted number of vehicles from 2004 using Model A. Clearly, there is no significant divergence of the observed number of vehicles from the model predictions. The hypotheses that observed data is larger or equal to the predicted data can be rejected at 99% confidence level using a paired t-test (t=4.69). Therefore, the vehicle numbers or vehicle ownership did not increase as a result of the CNG conversion. This finding is also supported by the results from Models B to D, where the intervention dummy variables are statistically insignificant for each model.[7]

[Table 2 here]

[Fig. 3 here]

4.2 Vehicle Travel Impacts

Given the results of the previous section that CNG conversion did not increase vehicle ownership, travel impacts resulting from price effects are of interest. An earlier spot survey by Wadud and Khan (2013) revealed that on road CNG vehicles run around 35% more than the on road petrol vehicles. This brings us to the earlier discussion on self-selection and price impacts. Unlike in diesel vehicles in Europe, CNG

[6] Cointegration tests in dynamic models are not as common as Engle-Granger's (1987) static two-step process. However, dynamic models are preferred for inference on long-run parameters, especially for small sample. See Banerjee et al. (1986), Patterson (2000) for an explanation, Wadud et al. (2009) for an application. Essentially, we calculate the long run parameters λ and τ for GDP and P in Eq. 1, test for unit root of the series lnV - $\lambda lnGDP$ - τlnP. Because of space limitations here, unit root tests of individual variables are available on request.

[7] We also attempted to model ownership directly (i.e. $ln(V/P)$), but that model did not pass the specification tests.

vehicles need not be bought afresh, rather existing petroleum vehicles are converted to run on CNG. However, similar to diesel vehicles, this imparts an additional cost to the users and thus CNG conversion would make sense to only those users who could overturn the conversion costs from the smaller CNG prices, i.e. users who already tend to drive more. The difference in driving distances of petroleum and CNG vehicles therefore is a result of both self-selection and price effects. Clearly, only price effects are to be included in any calculations of additional travel impacts or rebound effects of CNG conversion.

We conduct a small questionnaire survey in order to determine the direct travel impacts and self-selection impacts.[8] The survey was conducted among 33 petroleum and 161 CNG vehicle drivers to understand their travel pattern. The average travel of these vehicles was similar to our earlier survey: petrol vehicles travelled 45 km/day, while CNG vehicles average 35% more at 60.7 km/day (Table 3), and the difference is statistically significant at 99% confidence level using a t test (t=4.09). We also asked the CNG drivers about their travel pre-conversion. Since most of the vehicles in Dhaka are driven by professional drivers (i.e. not by owners), and all of our survey respondents were not driving the same vehicle before conversion, our sample size got reduced to 45. The average travel among these vehicles before conversion was 49.4 km/day, which indicates that these CNG vehicles used to travel more before conversion than the current petroleum vehicles on road.[9] This difference in driving distances indicates self-selection effect.

[Table 3 here]

The average post-conversion travel among the sample for which we have both pre-conversion and post-conversion VKT information is 57.6 km/day, which is 8.2 km/day larger than their pre-conversion travel and statistically significant at 99% level using a paired t test (t=4.21). We attribute this difference to the price rebound effect. However, there is still a difference between average CNG vehicle travel (60.7 km/day in our larger sample) and the sub-sample, where average post conversion travel is smaller (57.6 km/day). We assume that the pre-conversion travel in the larger sample (better representing the current situation) is proportional to that in the sub-sample, and thus arrive at 52.1 km/day as pre-conversion travel. Thus our estimate for price rebound is 8.6 km/day and self-selection is 7.1 km/day.[10] This indicates that around 45% of the difference in the driving distances between existing CNG and

[8] Note that we do not require the self-selection impacts in order to determine the additional travel impacts, but it is a parameter of practical interest.

[9] Given the smaller number of sample for current petrol (33) and pre-conversion CNG (45) vehicles, we accept a statistical significance at 80% confidence for this result.

[10] CNG 60.7 – pre-conversion 52.1 = 8.6; pre-conversion 52.1 – petroleum 45 = 7.1.

petroleum vehicles can be explained by self-selection, and 55% by the price effect, which is our prime interest. Therefore, the additional price-induced travel of the CNG vehicles is 16.5% over petrol vehicles.

4.3 Impact on Total VMT and Congestion

Reliable statistics for total VKT in Dhaka is not available. Although we have a fairly reliable estimate of travel for different types of vehicles through questionnaire survey, the number of vehicles 'on road' from BRTA may not be reliable because of the lack of scrappage information. Therefore we need to modify the BRTA vehicle numbers using vehicle lifespan in other countries. A car is driven for around 20 years in India (Sarkar and Banerjee 2005), but only 13 to 14 years in the UK or USA. Given the socio-economic conditions in Bangladesh, 20 years of useful life appears a reasonable assumption.[11] Even if the vehicles are not scrapped directly within 20 years, it is highly likely that they are removed from Dhaka and start plying on smaller cities after 20 years. This recalculation leaves us with 265,000 vehicles on road in Dhaka (instead of 309,000 from registration statistics) during early 2010, increasing the recalculated CNG penetration rate to 54% from 35%.

The rebound effect in the previous section finds that the personal CNG vehicles would have run 14% less had they run on petroleum.[12] Given that there is already a shortage of vehicles engaged in providing commercial transport services, e.g. buses, minibuses, autorickshaws and human haulers, their travel increase due to a price effect is negligible. At present, estimated daily VKT in Dhaka by all vehicles (except trucks, as they are not allowed to operate in the city before 10 pm, and motor cycles, since their contribution to congestion is not substantial) is 20.1 million km. Had there been no CNG conversion and price rebound effect, the VKT would have been 19.2 million km. This represents a 4.7% increase in total VKT due to the price effect of CNG conversion. Given the already congested situation of Dhaka, this can be substantial, especially since a marginal increase in VKT can result in a large increase in delay during congested periods.

There is no unique relationship between an increase in VKT and resulting increase in delay. At the best situations, the additional traffic can be during super off-peak hours, with theoretically little additional delay.[13] At worst, the additional traffic can be during the peak hours, aggravating the congestion and

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[11] Most vehicles in Dhaka are bought in reconditioned condition, so they were in service for 3 to 5 years elsewhere.

[12] Post conversion CNG vehicles run 16.5% more than pre-conversion vehicles = pre-conversion vehicles would have run 14% less than post-conversion vehicles.

[13] Dhaka is congested during off-peak hours too. Although 8 am to 10 am and 6 pm to 9 pm can be termed as peak hours, the difference between peak and off-peak is not as strong as in the western cities, and the road network is congested during 8 am to 10 pm.

delay further. The VKT-congestion relationship is also strongly dependant on urban form and land use patterns, road network capacity and layout, traffic and signal operational characteristics and other socioeconomic parameters. Calculations of delay due to the additional traffic generally require microscopic or mesoscopic transport planning or simulation tools which generally use a mathematical speed-flow-density relationship. Unfortunately such a speed-flow-density relationship is not currently available in Dhaka.[14] This makes us rely on literature to quantify the delay effects.

Speed-flow-density relationships for urban areas are unique and difficult to derive without running a full scale simulation of the network. Because of this uniqueness of the relationship, there is a lack of direct elasticity estimates for congestion delay or congestion cost with respect to vehicle travel (VMT/VKT). In a study of congestion pricing in Manhattan, the travel time elasticity with respect to VMT ranged from 0.3 to 6.2 in different regions, with an average of 3.7 (Glynn 2007). Litman (2012) quotes a report that congestion delay elasticity in urban areas in the USA was 3.5 in 1980's. Deakin and Harvey (1996) find from their traffic modeling that fuel tax caused a 4.1% reduction in VMT and a 6.5% reduction in congestion delay in Southern California, with the implied elasticity of delay with respect to VMT being 1.59. Their further results show elasticities lying between 1.36 and 2.05. Although these results are for a different traffic conditions, they are for full urban scale simulation, rather than for a single road or freeway link. Also, given Dhaka's severely congested situation any increase in travel will likely result in more than proportionate increase in congestion and delay (i.e. elasticity larger than 1). Using Deakin and Harvey's (1996) elasticity of 1.59, the congestion and delay costs in Dhaka had increased by 7.4% in year 2010 due to the 4.7% increase in VKT resulting from CNG conversion, as found earlier.

4.4 Uncertainty Assessment

Our preceding estimate of 4.7% increase in VKT and 7.4% increase in congestion costs due to CNG conversion lacks precision because of the reliability issues with the underlying data and the simple assumptions. Therefore, it is important to conduct an uncertainty analysis before any policy suggestion can be made. We follow a Monte-Carlo approach to quantitatively understand the impact of input uncertainties in our results. Instead of a point value, mentioned so far, the input variables are assigned a

[14] Habib (2002) modelled Dhaka's traffic in 2002 and predicted that in 2010, 81% of the roads will have a volume to capacity ratio greater than 1.25. Rahman et al. (2003) developed speed-density relationship based on non-motorised vehicle (NMV) share in the roadway. However, none of the results are valid now. Habib (2002) modelled for a population of 7.5 million in 2010, but in reality it was around 13 million. Also, a number of arterial roads were made NMV free since 2002, changing those relationships substantially. However, it is possibly safe to conclude that almost all of Dhaka's roads are now running at a volume to capacity ratio greater than 1.25.

probability distribution to quantitatively reflect the uncertainty, as explained in Table 4. We then take 15,000 random draws from each of those distributions and calculate the increases in delay and congestion costs from the expected value of the resultant distribution of the output.

[Table 4 here]

Fig. 4 presents the results of the Monte-Carlo simulation for both, percent increase in VKT rebound resulting from CNG conversion and corresponding increase in congestion costs. These histograms nearly represent the probability density functions of the output, given the probability distribution of our input parameters. The expected increase in VKT is 4.4% and in congestion costs is 9.6%.[15] Therefore, considerations of uncertainty in input changes the results substantially from our original results based on point estimates of the input variables. The uncertainty can be reduced in future through developing a proper traffic simulation model for Dhaka.

[Fig. 4 here]

The preceding analysis is conducted using RPGCL data on CNG conversion. Given the discrepancy between RPGCL data and our data from a spot survey, we also carry out a separate sensitivity analysis using our own data. In addition, we use estimates of congestion costs in Dhaka to convert the percent increases in congestion costs to monetary costs. Three congestion cost estimates have recently been mentioned: USD 2.8 Billion (Mamun 2012), USD 1.68 Billion (Salehuddin 2010) and USD 0.8 Billion (Islam 2009). All of these estimates were based on simple assumptions of current average speed, potential free flow speed, average trip length and average value of time. The results of the sensitivity analysis are presented in Table 5. For the mid range congestion costs using RPGCL conversion data, the increase in delay costs is USD 161 Million. Since our spot-survey derived data shows a larger CNG conversion rate, it results in a larger percent increase in travel as well as a larger delay cost.

[Table 5 here]

5. Discussion and Conclusions

There is a wide spread belief among the policymakers in Bangladesh that the CNG conversion and corresponding low prices of CNG had significantly increased vehicle numbers in Dhaka and aggravated its traffic congestion. This arises from a cursory observation of the time-series plot for the number of vehicles as in Fig. 2, which shows a significant change in the trend for personal vehicles from 2003-2004. However, during the same period GDP and population in Dhaka also increased rapidly. After

[15] These are the means of the respective distributions.

incorporating the effects of GDP per capita and population in our dynamic econometric model, we do not find any evidence in favour of the hypothesis that there was an increase in the number of personal vehicles in Dhaka due to CNG conversion. Our results also mean that the vehicle ownership elasticity with respect to fuel price in Dhaka is nearly zero. This is not surprising – in developing countries like Bangladesh, fuel costs are only a small part in the decision to buy vehicles (e.g. chauffeur salary is a larger share of costs).

This result does not mean that congestion or vehicle travel did not increase at all due to CNG conversion. CNG vehicles on road indeed travel more than the petroleum vehicles because of lower running costs. We find that on-road CNG personal vehicles, on average, run 35% more than on-road petroleum vehicles. However, only 55% of this increase is due to the price effect, while the rest is due to self-selection. Considering other vehicles on road and the uncertainties, CNG conversion caused 4.4% increase in VKT in Dhaka and thus aggravated congestion and delay costs by 9.6%. Using the average price differential between CNG and petrol, this represents a road travel elasticity of -0.29 with respect to fuel price. This agrees well with the long run elasticity estimates of Goodwin et al. (2004) or Graham and Glaister (2002). CNG conversion have increased the congestion costs by USD 161 Million (range: USD 77~417 Million): clearly an unintended effect of the policy.

In order to make sound policy decisions, the additional congestion costs should be compared with the environmental costs and benefits of CNG conversion. Wadud and Khan (2013) ran a full impact pathway model to find that in 2010, CNG conversion had resulted in the saving of around 2,000 premature deaths due to reduced emissions of particulates from CNG vehicles as compared to the petroleum vehicles they replaced. This represents a saving of around USD 400 million a year. On the other hand, costs to the climate (primarily due to additional methane emissions from CNG vehicles) were USD 17 Million. Because of some differences in underlying data, the comparable result from this study is the congestion cost of USD 250 million. Although Wadud and Khan (2013) did not consider the environmental costs of this 'rebound travel', it is likely that the congestion costs are around a half of the health benefits and thus negate a half of the gains that would have been possible through CNG conversion.

In the last two years, the price of CNG has been substantially raised in Bangladesh, reducing the price differential with other petroleum fuels. This is especially true for diesel, which is already substantially subsidized for its agricultural use. The smaller differential in prices between CNG and diesel (and petrol) means CNG conversion of the rest of the vehicles will be slowed, and possibly stopped. Worrying further, lower prices of diesel might encourage a larger share of diesel vehicles on the streets in future.[16] Given diesel vehicles' poorer emissions performance as compared to CNG or petrol vehicles, especially under a lax emissions standard and enforcement regime as in Bangladesh, lower CNG-diesel price differential may have a large adverse impact on public health in future. As the health benefits are substantially larger than the additional congestion costs, potential health impacts must have a priority over other considerations while setting the fuel prices in future. While it is understandable that CNG prices need to be raised in order to bring it to parity with world prices, the price differential with other fuels should be maintained (e.g. through increasing diesel prices and supplying subsidized diesel to farmers). Also, in order to reduce any unintended congestion impacts, congestion pricing or road pricing will possibly have larger net benefits than increasing CNG prices, especially since road pricing will not have the same adverse health impacts as increasing CNG prices or as reducing its price differentials with other fuels.

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Tables

Table 1. Elasticities of travel and vehicle ownership with respect to fuel price

Reference	Road travel elasticity		Vehicle ownership elasticity	
	Short run	Long run	Short run	Long run
Goodwin et al. (2004)	-0.1	-0.3	-0.1	-0.25
Graham & Glaister (2002)	-0.15	-0.31	-0.2	-0.9

Table 2. Parameter estimates for different models for vehicle number

	Model A	Model B	Model C	Model D
Dummy specification	None	$D_g=0$ if $t<2004$ $=t-2004$, else	$D_s=0$ if $t<2004$ $=1$, else	$D_{int}=D_s\times lnGDP$
l	2	2	2	2
m	0	0	0	0
n	0	0	0	0
lnV_{t-1}	1.475***	1.497***	1.434***	1.435***
lnV_{t-2}	-0.795***	-0.799***	-0.790***	-0.793***
$lnGDP$	0.369**	0.307**	0.388***	0.393***
lnP	0.386**	0.376***	0.437***	0.437***
$D_g/D_s/D_{int}$	-	-0.002	-0.027	-0.005
constant	-4.734**	-4.416***	-5.268***	-5.286***
Adjusted R^2	0.998	0.999	0.999	0.999
Breusch Godfrey residual autocor test	0.396, p=0.53	0.106, p=0.75	0.257, p=0.61	0.280, p=0.60
Shapiro Wilk W residual normality test	0.958, p=0.49	0.955, p=0.24	0.959, p=0.32	0.959, p=0.31
Pormanteu white noise test	6.285, p=0.62	9.593, p=0.65	11.02, p=0.53	11.08, p=0.52
Unit root test for $lnV - \lambda lnGDP - \tau lnP$	-4.765, p=0.01	-3.550, p=0.05	-3.563, p=0.05	-3.528, p=0.05
N	21	29	29	29

Table 3. Survey data summary

Sample	Sample size	Average travel (km/day)	Comments
A. Petroleum vehicles	33	45	
B. CNG vehicles	161	60.7	
C. Pre conversion CNG vehicles	45	49.4	Sub-sample of B
D. Post conversion CNG vehicles	45	57.6	Same sample as C

Table 4. Distribution of input parameters for uncertainty analysis

Input parameter	Unit	Distribution	Comments
Price rebound effect	% increase	Triangular (0,16.5,30)	It is not impossible that there is no rebound effect. We assign a zero probability to zero rebound effect.
Vehicle scrappage age	year	Triangular (15,20,25)	Based on literature review and earlier comments
VMT	km/day	Triangular (55,60,65)	Varies with different vehicle class. The example here is for cars.
Elasticity of congestion costs	unitless	Triangular (1.3,1.6,3.7)	Based on literature review and earlier comments

Table 5. Sensitivity analysis for alternate CNG conversion data and congestion costs

Cost scenario	Cost estimate	Increase in congestion costs		Increase in congestion costs, USD	
		RPGCL data	Our data	RPGCL data	Our data
Low	USD 800 M			USD 76.8 M	USD 119.2 M
Middle	USD 1,680 M	9.6%	14.9%	USD 161.3 M	USD 250.3 M
High	USD 2,800 M			USD 268.8 M	USD 417.2 M

(Unintended) Transport impacts of an energy-environment policy:

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Figures

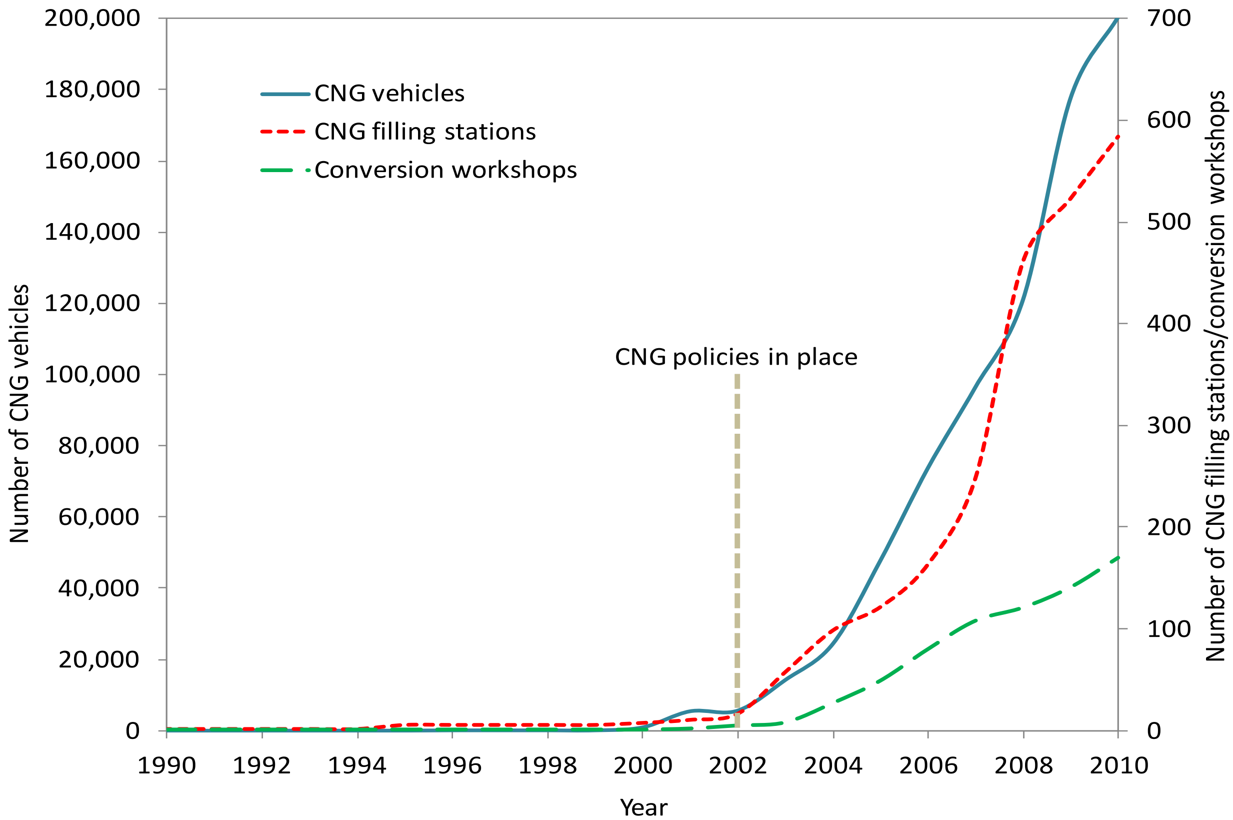


Fig. 1 Evolution of CNG vehicles, CNG filling stations and CNG conversion workshops in Bangladesh

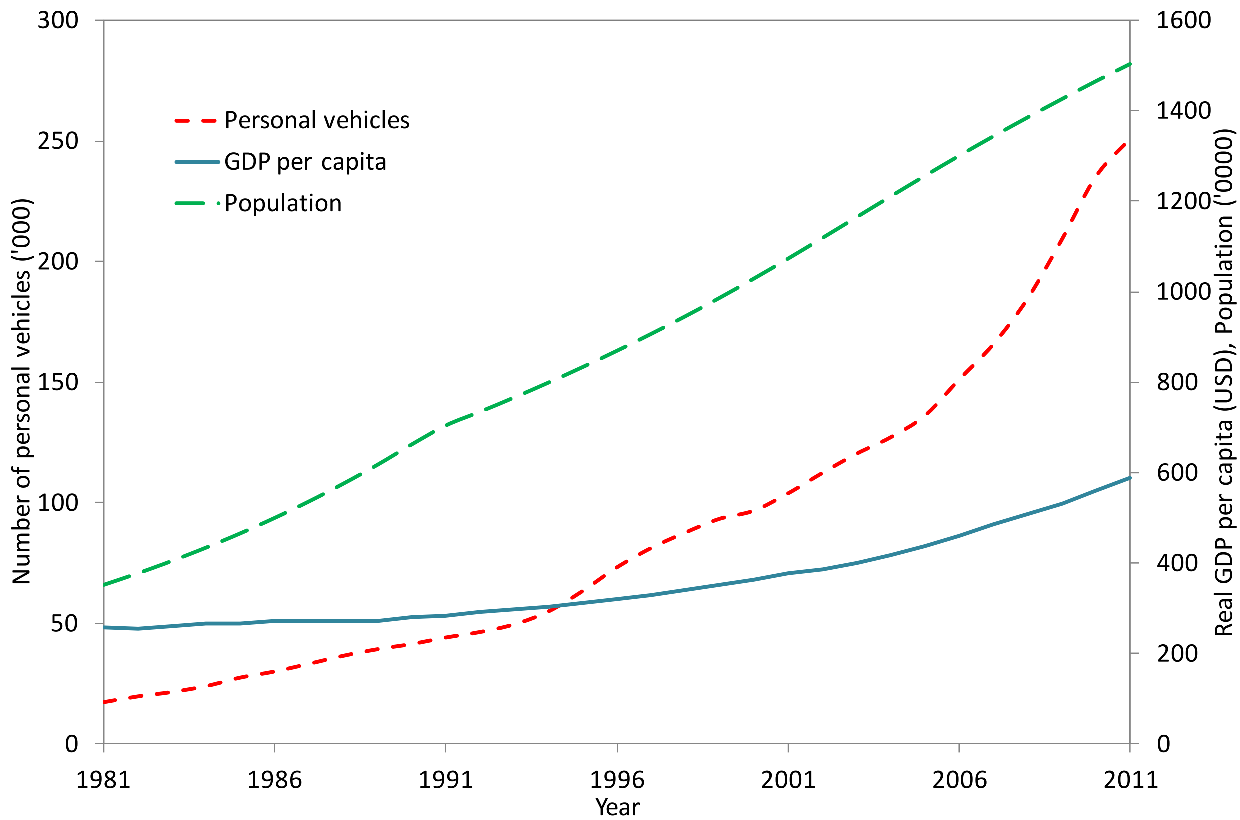


Fig. 2 Evolution of vehicle registration, real GDP per capita and population in Dhaka

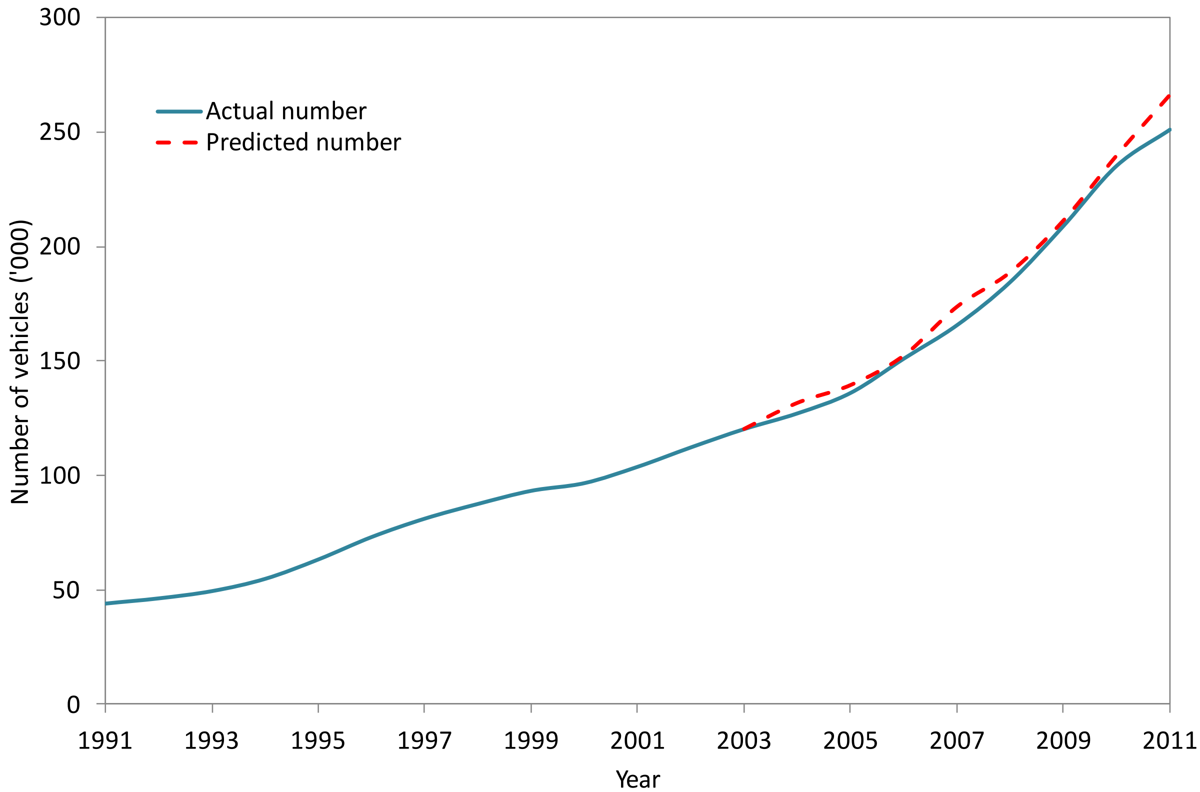
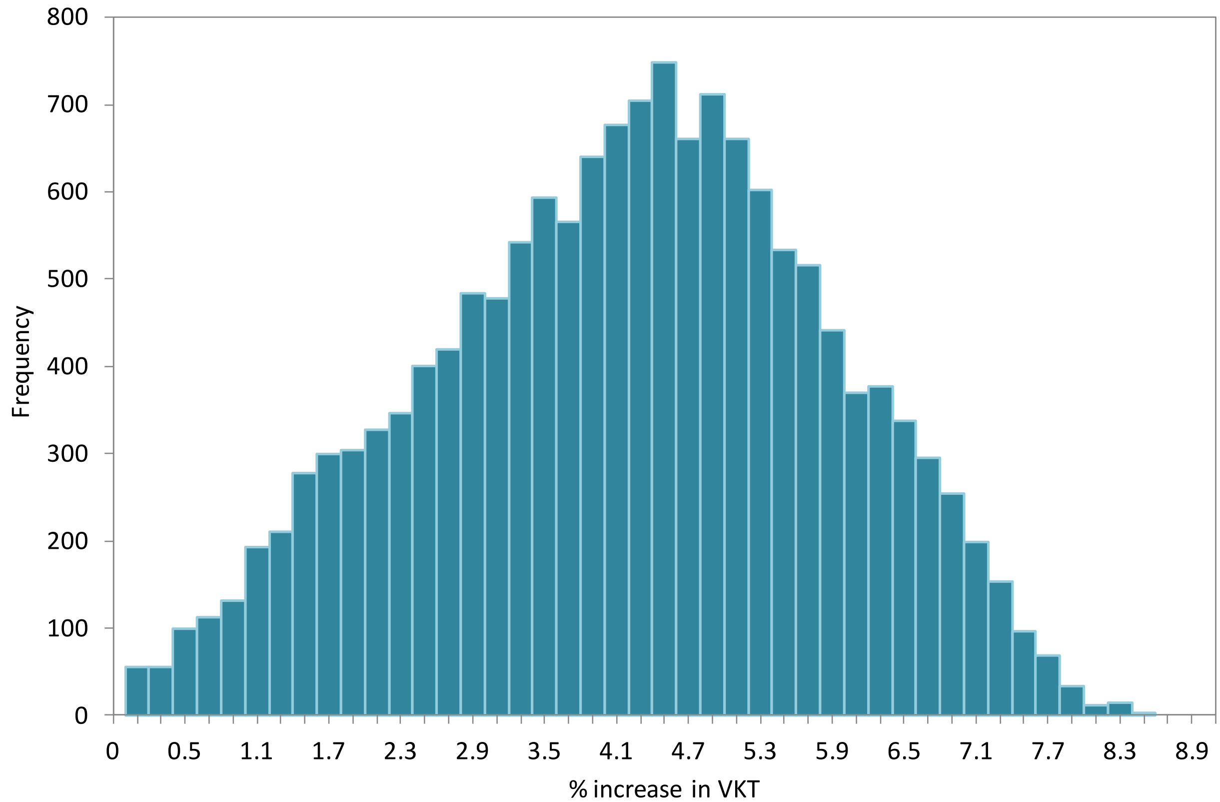


Fig. 3 Comparison of actual vehicle registration and model prediction



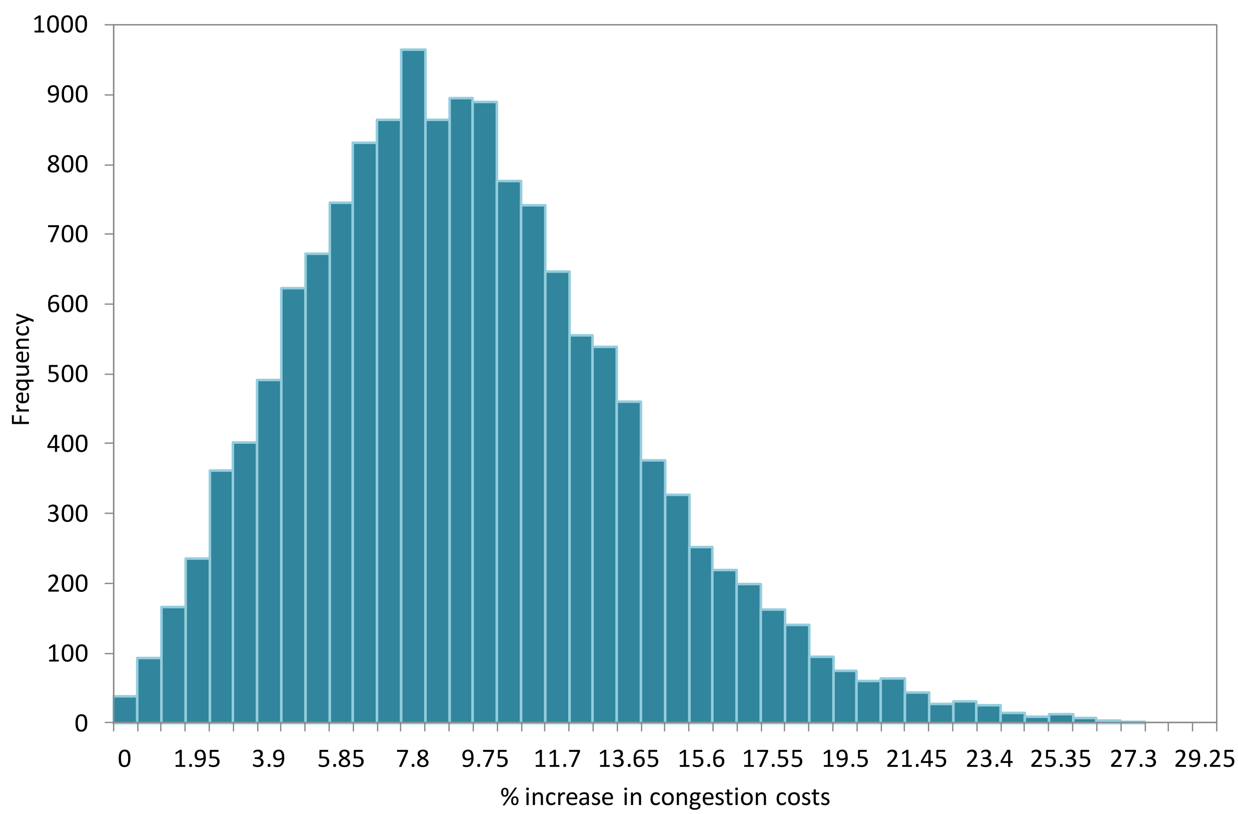


Fig. 4 Distribution of per cent increase in VKT and congestion costs from Monte-Carlo simulations