KAPSARC

مركز الملك عبدالله للدراسات والبحوث البترولية

King Abdullah Petroleum Studies and Research Center

Impact of Domestic Fuel Price Reforms on the use of Public Transport in Saudi Arabia

Ibrahim M. Algunaibet

July 2017 / KS-2017--DP012

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

Legal Notice

Key Points

In 2016, policymakers in Saudi Arabia increased domestic transportation fuel prices, which are expected to approach market levels in the near future. Current low crude oil prices offer an excellent opportunity for policymakers to deregulate the passenger transportation sector without a significant change in local fuel prices. We developed a bottom-up transportation sub-model and integrated it with the KAPSARC Energy Model (KEM) to assess whether consumers could afford such reforms; and the resulting travel mode choices, energy consumption levels and revenue. We do not consider price-induced efficiency improvements; hence, the results would represent an upper bound for the shift to public modes.

Despite a deregulation of the passenger transportation sector, Saudi households would continue to allocate one of the lowest transport budgets (as a percentage of income) in Gulf Cooperation Council (GCC) countries and also stay within Saudi Arabian historical boundaries.

Deregulating fuel prices would encourage consumers to travel by more efficient public transport modes, as they become available in the near future, leading to significant energy savings and CO2 emissions reductions of between 4 million to 26 million metric tons (mt) per year.

The Kingdom would receive an annual average $8.2 billion as additional revenue from domestic sales and exports in the varying crude price scenario and $5 billion in the fixed $60/bbl scenario.

Despite the increase in transport fuel price, the net gain for Saudi Arabia in the varying crude oil price scenario remains positive as a result of substantial increase in revenue and the introduction of more convenient public travel modes.

Our findings show that analyzing energy policies using empirical estimates are generally valid even for large variations in price; however, if new transport modes and technologies are introduced in Saudi Arabia, consumer response may be slightly greater than that of empirical estimate, which did not account for such new modes.

Executive Summary

Policymakers in Saudi Arabia recently imposed energy price reforms, which increased low- and high-grade gasoline, diesel and jet fuel prices by 67, 50, 79 and 12 percent, respectively. These fuel prices are expected to increase further in the near future, reducing the energy subsidies in the transport sector. The global prices of these fuels are greatly influenced by crude prices. In 2013, the average crude price was much higher than it is currently. Hence, the gap between the administered and market gasoline prices was around 346 percent, while today this difference is a mere 15 percent as a result of low crude prices (Figure 1).

Therefore, current low crude prices offer policymakers in Saudi Arabia the opportunity to deregulate transport fuel prices without significantly increasing them – i.e. an increase in gasoline price of $0.03 per liter. Ultimately, fuel prices would increase as crude prices rise; however, in the long-run consumers' income (Oxford Economics 2016) would also increase as would the diversification of the

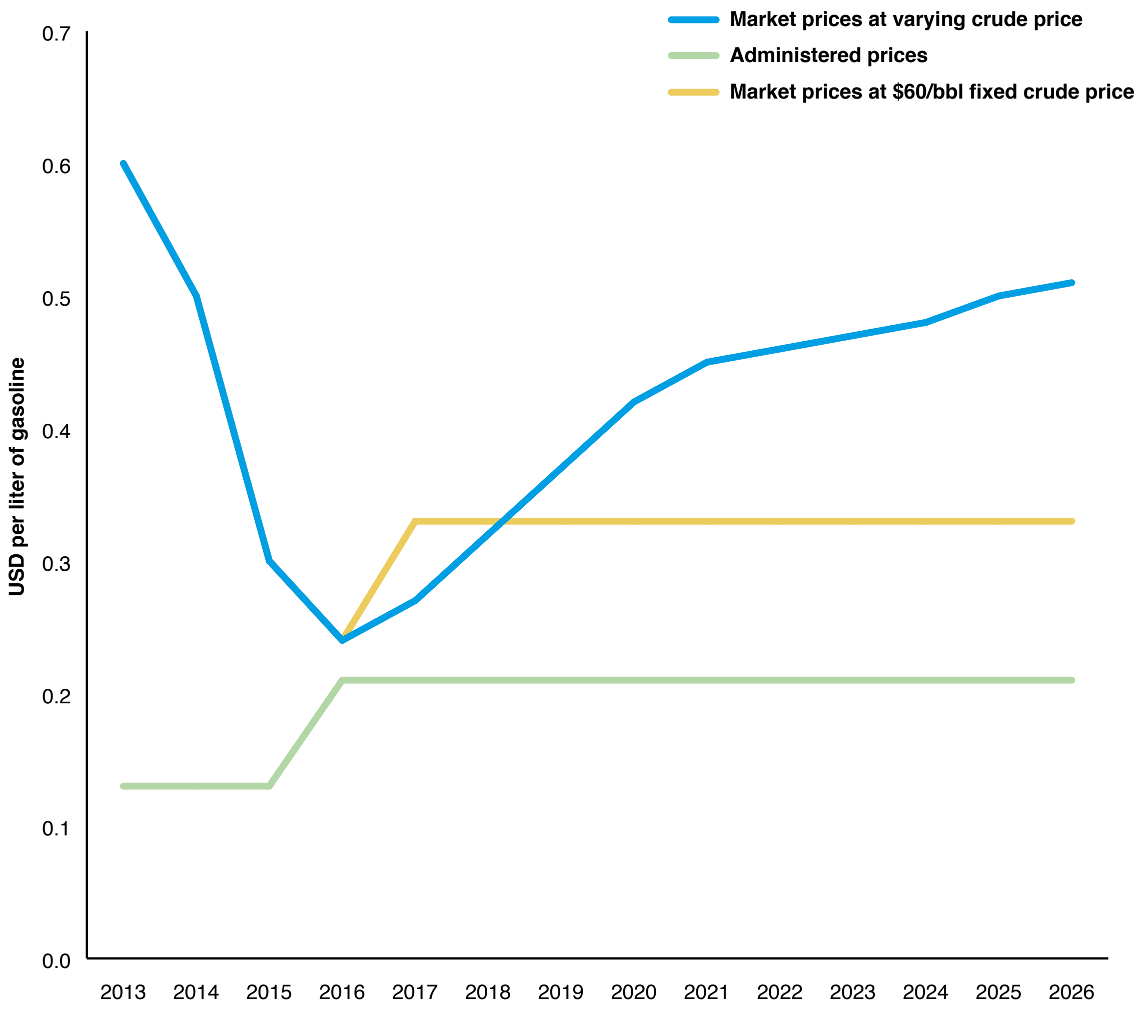

Figure 1. Administered and market gasoline prices set at the marginal value from 2013 to 2026.

Source: KAPSARC.

Note: These administered prices represent the weighted average of the two grades of gasoline available in Saudi Arabia.

Saudi Arabian public transport system, which in turn would help citizens adapt to higher market prices.

In 2013, Saudi Arabian households allocated 4.3 percent of their income to transportation needs, excluding the capital cost of vehicles. This has increased due to the 2016 energy price reforms, but households in Saudi Arabia continue to allocate one of the lowest shares of monthly income to transportation in comparison to other GCC countries and within historical income shares devoted to transportation budgets.

Here, we developed a bottom-up transportation sub-model and integrated it with a refining sub-model to evaluate consumers' travel mode choices and demand for fuel in a completely deregulated market in Saudi Arabia. We also evaluate domestic and export revenue following a full deregulation. This modeling approach is calibrated and validated using Saudi Arabian data for 2013, 2014 and 2015.

Deregulating the Saudi Arabian transport sector can encourage consumers to shift to emerging more efficient and convenient public modes (e.g., high-speed rail and metro). This would reduce energy consumption and carbon dioxide emissions of between 4 million to 26 million metric tons (mt) per year. In spite of introducing market fuel prices, which are much higher than current prices, especially in the long run, the emerging rapid public transportation modes can alleviate the increase in consumers' budget for travel. In fact, the budget remains within historical boundaries for Saudi Arabia and within the range of other GCC countries. Moreover, deregulating the transport sector can offer the government an annual average of $8.2 billion in additional revenue from domestic sales and export income in the varying price scenario and $5 billion in the $60/bbl fixed crude price scenario. Furthermore, the net gain is estimated to be positive in the varying price scenario despite an increase in the cost of travel for consumers as a result of the substantial increase in revenue for the government.

Our gasoline consumption estimates do oscillate around the empirical estimate even with large deviations in gasoline prices and the introduction of new transportation modes and technologies. Hence, this gives policymakers in Saudi Arabia the confidence to use the empirical estimate.

This paper can help policymakers in Saudi Arabia determine whether consumers could adapt to market fuel prices and the resulting energy consumption levels. Furthermore, it illustrates the additional revenue the government would earn if such a policy was introduced. It can also help the refining sector in Saudi Arabia plan for future demand variations as a consequence of emerging transportation modes.

Transportation Fuel Prices in Saudi Arabia

Historically, the deviation in transport fuel prices in Saudi Arabia is small. From 2006 to 2015, the weighted-average price of the two gasoline grades was $0.13 per liter. Recently, however, the government imposed energy price reforms and this price increased to $0.21 per liter (see Appendix A).

Since the average crude price in 2013 was around $106.50 per barrel, the difference between gasoline at market and administered price was 346 percent. However, in 2016, the average crude price decreased to $36.90 per barrel, and this difference dropped to 15 percent. Indeed, this offers policymakers in Saudi Arabia an opportunity to deregulate transport fuel prices without substantially increasing retail prices, which would allow consumers the ability to adapt to market prices. Furthermore, as crude prices might increase in the future (Oxford Economics 2016) so would gasoline prices, but at the same time availability of alternative convenient public transportation modes and consumers' income would grow. Thus, consumers may be able to cope with the higher fuel prices, even if the gap between market and administered prices expands. The sub-section on Household Transportation Budgets discusses how consumers could alter their travel behavior in order to adapt to the deregulated fuel prices.

Transportation Budgets in Selected GCC Countries

Table 1 shows household transportation budgets, excluding the purchase of vehicles. Saudi Arabian households have one of the lowest budgets among GCC countries. In 2016, the difference between the administered and market prices was minimal, 15 percent in comparison to the new administered prices (see Figure 1). Thus, deregulating the market today would still keep households' transportation budgets near (if not lower than) those of other GCC countries over a long period of time. Furthermore, household budgets will ultimately increase, which will make the share of transport spending almost constant despite higher market prices.

Table 2 shows households' transportation budgets and gasoline prices in 1999, 2007 and 2013. Since gasoline-powered vehicles have remained the main transportation mode, households' transportation budgets have been sensitive to gasoline prices. However, when other modes are available, this relationship between transportation budgets and gasoline prices could be alleviated since consumers would have alternative transport modes to choose.

Table 1. Households' transportation budgets in some GCC countries in 2013 and gasoline prices in USD per liter.

Country	Gasoline price (USD/liter)	Transport monetary budget share of household's income
Saudi Arabia	0.13	4.40%
UAE	0.37	5.05%
Qatar	0.27	5.93%
Kuwait	0.23	2.95%

Source: GASTAT (2013), Statistics Center - Abu Dhabi (2013), Ministry of Development Planning and Statistics (2013), Kuwait Central Statistical Bureau (2013).

Note: Following the survey that was published by the General Authority for Statistics (GASTAT) in 2013, we assume that 28.2 percent of total transportation and communication spending (48 percent of total transport spending) goes to fuel, maintenance and fares due to the lack of published data for this share in countries other than Saudi Arabia.

Table 2. Households' historical transportation budgets in Saudi Arabia and gasoline prices in USD per liter.

Year	Gasoline price (USD/liter)	Transport budget share of household income
1999	0.18	7.27%
2007	0.13	4.44%
2013	0.13	4.40%

Source: GASTAT (1999), GASTAT (2007), GASTAT (2013).

Note: During the survey, which was conducted in 1999, the gasoline price was $0.16 per liter for nine months and $0.24 per liter for three months. Hence, the price shown in this table is a weighted average. Also, gasoline prices for 2007 and 2013 are the weighted averages of the two gasoline grades.

Model Description

Building on Algunaibet and Matar (2016), we developed a simplified bottom-up transport sub-model to minimize the total cost perceived by consumers (Appendix B enumerates all the equations used in our model). This total cost includes both monetary and non-monetary behavioral costs. While consumers obviously consider monetary costs in their decision-making, the non-monetary behavioral costs improve the sub-model's ability to capture consumers' practical behaviors. Thereafter, this sub-model is integrated and solved with a refining sub-model as a mixed complementarity problem to better represent the subsidies in the Saudi Arabian economy. This section illustrates the modeling approach used in this analysis. The model is calibrated and validated using Saudi Arabian data for 2013, 2014 and 2015 (see Appendix C).

Transportation sub-model

Figure 2 shows the four regions represented in the sub-model. This feature of the sub-model enables the representation of inter-regional (limited to long-distance travel) and intra-regional (both long- and short-distance travel, including travel within urban areas) demand for transportation. Additionally, the international demand for transportation is represented in this sub-model.

Figure 2. Regional transport flows represented in the sub-model (Algunaibet and Matar, 2016).

Source: KAPSARC.

Table 3 shows the availability of transportation modes and technologies in Saudi Arabia and year of availability. Consumers can choose from various modes and technologies. However, some are limited to certain geographic regions, demand types or time horizons. For instance, high-speed rail is only available in the western region for inter-regional demand beginning in 2017. These limits are represented by imposing a certain capacity for each transportation mode (see Appendix B, Equation B10). For example, the metro will be available in Riyadh (central region) in early 2019, serving more than 1 million passengers per day, and forecast to carry more than 3 million passengers per day in 10 years (Riyadh Metro 2016).

Policymakers in Saudi Arabia continue to invest in convenient public modes, such as the high-speed rail network in the western region. This 450-km network connects major cities and religious destinations including Medinah, King Abdullah Economic City, Jeddah and Makkah. It is expected that this high-speed rail network will serve more than 50 million passengers per year once fully operational in 2017 (Briginshaw 2015).

The northern rail, another mode for long-distance travel that will commence in 2017, will serve 2 million passengers per year between the central and northern regions (Kable 2016). Additionally, a railway already exists between the central and eastern regions (Riyadh-Dammam) for long-distance travel that can transport more than 1.3 million passengers per year (Saudi Railways Organization 2015). The majority of Saudi Arabian personal vehicles fleet constitutes of gasoline-powered vehicles, which can be used for both short- and long-distance travel in each region. At the same time, consumers can travel by airplane between all regions for long-distance travel (Saudia 2013).

Consumers are categorized into low- and high-income groups, which play a major role in modeling the non-monetary behavioral costs. According to Abrantes and Wardman (2011), consumers value time differently based on their income (see Appendix B, Equation B3). For instance, low-income consumers tend to ignore waiting time when they make transportation choices. In other words, they value time less, while high-income consumers tend to value time much more.

Table 2. Households' historical transportation budgets in Saudi Arabia and gasoline prices in USD per liter.

Fuel type	Car	Bus	Rail	High-speed Rail	Metro	Airplane
Gasoline	2013 (all regions)	-	-	-	-	-
Diesel	-	2013 (all regions; except southern for short-distance travel)	2013 (eastern and central); 2017 (northern)	-	-	-
Jet-fuel	-	-	-	-	-	2013 (all regions)
Electricity	-	-	-	2017 (western)	2019 (central)	-

Source: Argaam (2015), Argaam (2016), Briginshaw (2015) Saudi Arabia Public Transport Company (SAPTCO) (2015), Aljunedy (2015), Saudia (2013), SRO (2015).

Hence, they are more likely to travel by faster modes, such as airplanes or cars, despite higher fuel prices and fares. Daly et al. (2014) and Litman (2009), show that consumers tend to value time differently based on demand type. Consumers tend to appreciate time more when they travel internationally than when they travel domestically. For example, consumers tend to travel internationally by airplane regardless of their income level.

Each transportation mode, and sometimes the technology, has an associated speed, waiting time, congestion factor, preference factor and external crash risk, which we use to improve the representation of non-monetary behavioral aspects that may alter consumer choices (see Appendix B, Equation B1). Cars, airplanes and high-speed rail are faster than other modes, which makes them much more attractive to high-income consumers. However, every public mode has an independent waiting time that discourages consumers from using them.

The congestion factor represents the likelihood of a transportation mode being delayed during traffic (Litman, 2009). For instance, larger vehicles are more likely to be delayed than smaller vehicles during traffic. Furthermore, the congestion density is more likely and thus has a higher impact on short-distance travel than long-distance (Litman 2009), since highways between regions have a lower probability of being congested than roads within cities.

External crash risk differs by transportation mode and demand type (Litman 2009). For instance, cars have much more damaging crashes in long-distance travel than in short-distance, since they are traveling at higher speeds. Buses, however, have a higher probability of crashing within cities due to their size and higher congestion levels. Since buses travel at much lower speeds than cars, crashes that occur during long-distance travel involving buses are generally less catastrophic than those involving cars.

The preference factor aims to capture the personal and cultural inclinations toward particular transportation modes chosen by consumers (Girod et al. 2013). These preference factors are considered only for international travel because the diversity of modes remained constant since the calibration year in 2013 (see Appendix B, Equation B2). Introducing new modes and technologies – that were not available in the calibration year – would alter these preference factors and thus they were not considered for domestic travel.

The perceived monetary costs for transportation modes and technologies are considered in this sub-model as well (see Appendix B, Equations B2 and B4). These costs include fuel and maintenance of private vehicles and fares for public modes. Although fuel and maintenance costs for private vehicles remain constant for all regions and consumers, they vary from year-to-year as a result of efficiency improvements in gasoline-powered vehicles. This efficiency improvement rate is for the whole Saudi Arabian fleet and it is exogenously defined. In other words, we do not account for price-induced efficiency. Therefore, the results would represent an upper bound for the shift to public modes while considering the non-monetary behavioral costs. Fares change for each demand type and regional destination.

Low- and high-income consumers in each region have associated monetary budgets that preclude them from traveling by unaffordable transportation modes (Zahavi and Talvitie 1980). This constraint, however, is removed from 2017 onward, since one of the goals of this study is to estimate how consumers would alter their monetary budgets in the future to adapt to new fuel prices and modes (see Appendix B, Equation B4). Overall, these monetary budgets are rising every year in accordance with the income projections for Saudi Arabia as published by Oxford Economics (2016).

Refining sub-model

Following Matar et al. (2013), the refining sub-model maximizes profits while meeting local demand (see Appendix B, Equation B22). It enables the choice of investing in capacity expansion to meet domestic demand or simply importing from the international market (Appendix B, Equation B12). Furthermore, it enables investments in capacity expansion if it is profitable to export certain refined products in the future (Appendix B, Equation B13). The cost of capacity expansions alters the marginal value of certain refined products.

This refining sub-model also enables the choice of crude input (Appendix B, Equation B17). Six grades can be used: Arabian Super Light, Arabian Extra Light, Arabian Light, Arabian Medium, Arabian Heavy crudes and gas condensate. The refining sector buys crude streams at market price since the majority of local refineries in Saudi Arabia are controlled by Saudi Aramco. The output includes nine refined products: two grades of gasoline, diesel, liquefied petroleum gas (LPG), jet fuel, heavy fuel oil (HFO), naphtha, petroleum coke and asphalt. We assume a myopic horizon of five years. In other words, we assume that the refining sector can predict the future demand for refined products for up to five years.

This sub-model considers four refineries in Saudi Arabia by aggregating all the refining capacities in each region (Figure 2). The cost of shipping a certain refined product between regions in Saudi Arabia influences the marginal value of that product (see Appendix B, Equation B14). Refined products have different specifications set to Saudi Aramco requirements, which alter the marginal value as well (Appendix B, Equations B24 and B25).

This sub-model considers the use of electricity for operation purposes (Appendix B, Equation B28). Power can be generated on-site or purchased from the grid (Appendix B, Equation B29). If it is purchased from the grid, it would affect the marginal value of the refined product.

Results and Discussion

Figures 3a and 3b show the transportation demand in million passenger-KM (PKM) traveled under administered and market fuel prices and fares at a varying crude price and a fixed price of $60/bbl. Typically, transportation demand depends on socioeconomic drivers, mainly income and costs. Therefore, it can be seen that the growth of the overall demand for transportation drops when the cost increases even in the reference scenario (see Figure 3a).

Energy price reforms significantly affect the total growth of demand for transportation. This phenomenon can be seen clearly in 2016 when administered fuel prices were increased in Saudi Arabia, thereby reducing the growth rate of total transportation demand. Moreover, in both deregulation scenarios, the decline in the growth rate for transportation is more evident due to the introduction of greater energy price reforms (Figure 3b).

Figure 3b shows that consumers shift more readily to public modes in both deregulation scenarios when fuel prices and fares are set by the market. This shift, however, is dampened when crude is fixed at

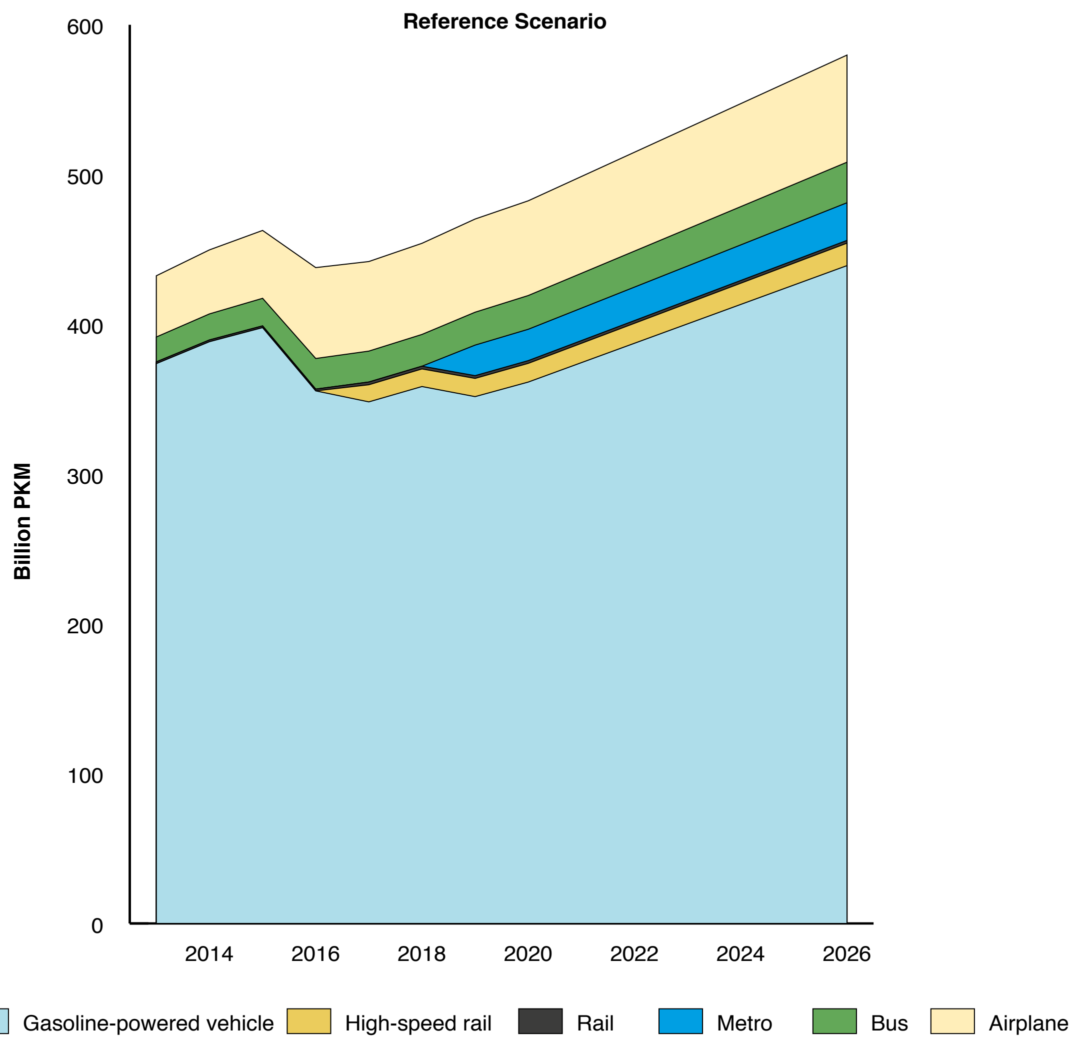

Figure 3a. Total passenger demand for various modes under reference scenario.

Source: KAPSARC.

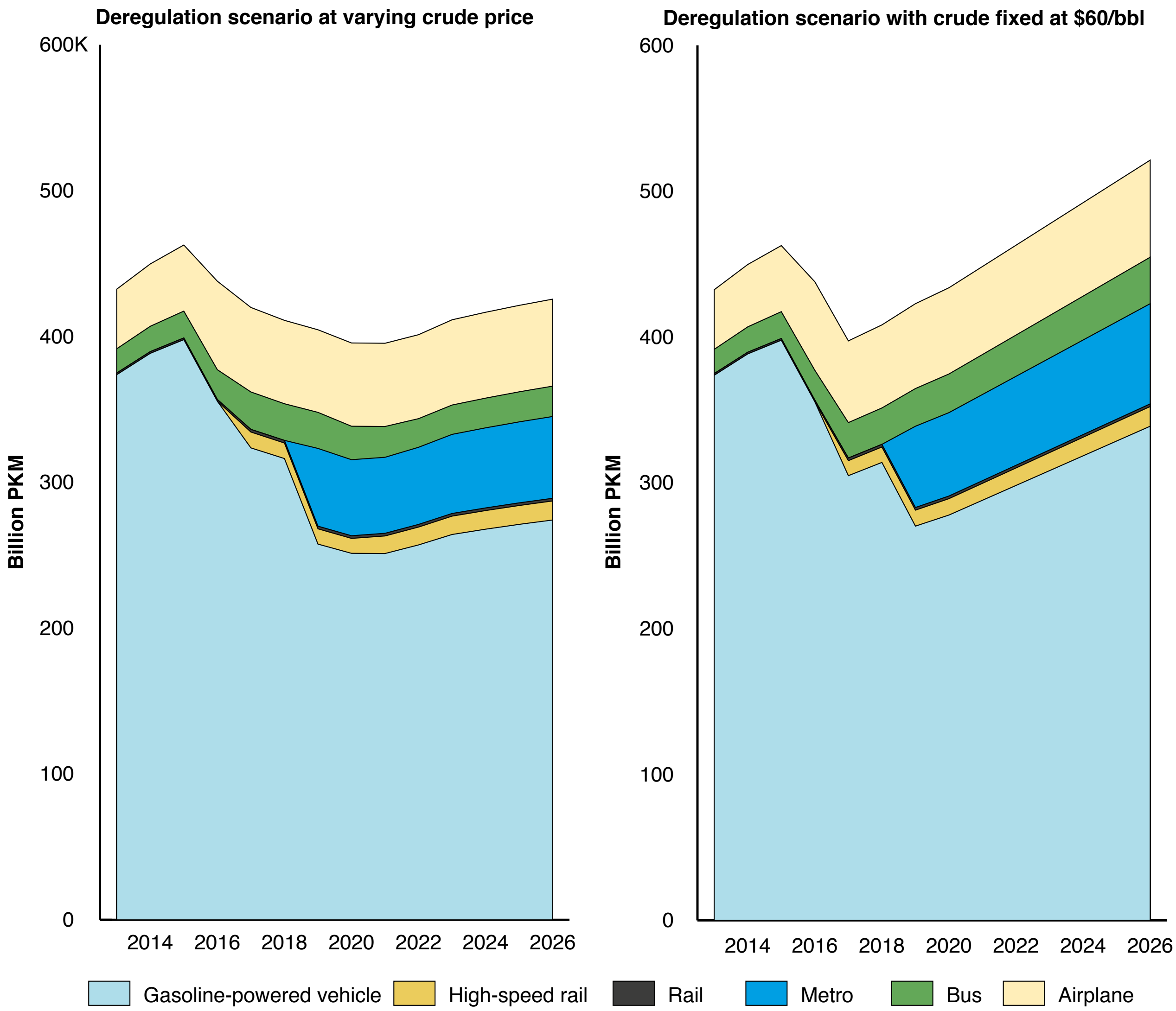

Figure 3b. Total passenger demand for various transportation modes under varying and fixed crude price scenarios.

Source: KAPSARC.

$60/bbl resulting in lower transport fuel prices and fares. In 2016, the difference between deregulated and subsidized gasoline in Saudi Arabia is minimal, around 15 percent, due to the recent plunge in crude prices. Therefore, deregulating fuel prices would allow consumers to continue to travel using current transportation modes, i.e., mainly gasoline-powered vehicles, with a slight shift to buses for long-distance travel among low-income consumers.

As the price of crude rises, however, so would the price of refined products. Hence, this would incentivize consumers to reduce their overall demand for transportation. For instance, rather than traveling to a favorable distant destination, consumers may choose to alter their lifestyle to save money spent on fuel. This reduction in total transportation demand is mitigated in the fixed crude price scenario as a result of lower costs across modes. Another option that high-income consumers tend to choose when fuel prices are deregulated is to shift to faster and more convenient mass public transit modes, which include high-speed rail and metro. Moreover, consumers can also decide to buy energy efficient vehicles; however, this investment option is only captured in our modeling approach by the exogenous efficiency improvement rate. In other words, our results represent the upper bound for the shift to public transportation modes when gasoline prices are increased while accounting for non-monetary behavioral costs. On the other hand, in the reference scenario, high-income consumers are more inclined to travel by gasoline-powered vehicles.

Therefore, deregulating the transportation market can encourage high-income consumers to weigh directly incurred costs, such as fuel, above convenience and other intangible factors, which in turn leads them to travel using efficient public modes. Low-income consumers tend to shift to buses, especially for long-distance travel and metro for short-distance if it is available. Both high- and low-income consumers travel internationally mainly by airplanes, which agrees with the conclusion derived by Algunaibet and Matar (2016) and Seraj et al. (2001) because international fares in Saudi Arabia are already set to market prices and consumers are accustomed to them.

Household Transportation Budgets

Figures 4a and 4b show households' share of income allocated to transportation in the reference and deregulation scenarios at both a $60/bbl fixed and a varying crude price. This budget excludes the capital cost of a vehicle. Three factors play a major role in allocating a particular share: the change in fuel prices and fares, availability of alternative modes and increase in income. In the short term, any price increase would have a noticeable impact on consumers' transportation budgets. For instance, the energy price reforms of 2016 are clearly shown in Figures 4a and 4b as a spike. However, in the long term, even in both deregulation scenarios, the budget shock is absorbed as a result of introducing alternative modes, such as metro and high-speed rail, and the increase in household income.

We can see in Figures 4a and 4b that transportation budgets are not constant across all regions. In the deregulation scenario at a varying crude price, for instance, consumers in the southern region allocate an annual average of 5.3 percent of their income to transportation, whereas consumers in the central region allocate an annual average of 4.4 percent. This difference is caused by the introduction of the northern rail and metro in the central region, which can satisfy a portion of inter- and intra-regional demand, respectively, while consumers can only travel within the southern region by gasoline-powered vehicles.

Similarly, consumers in the western region allocate an annual average of 5 percent of their income to transportation, whereas consumers in the eastern

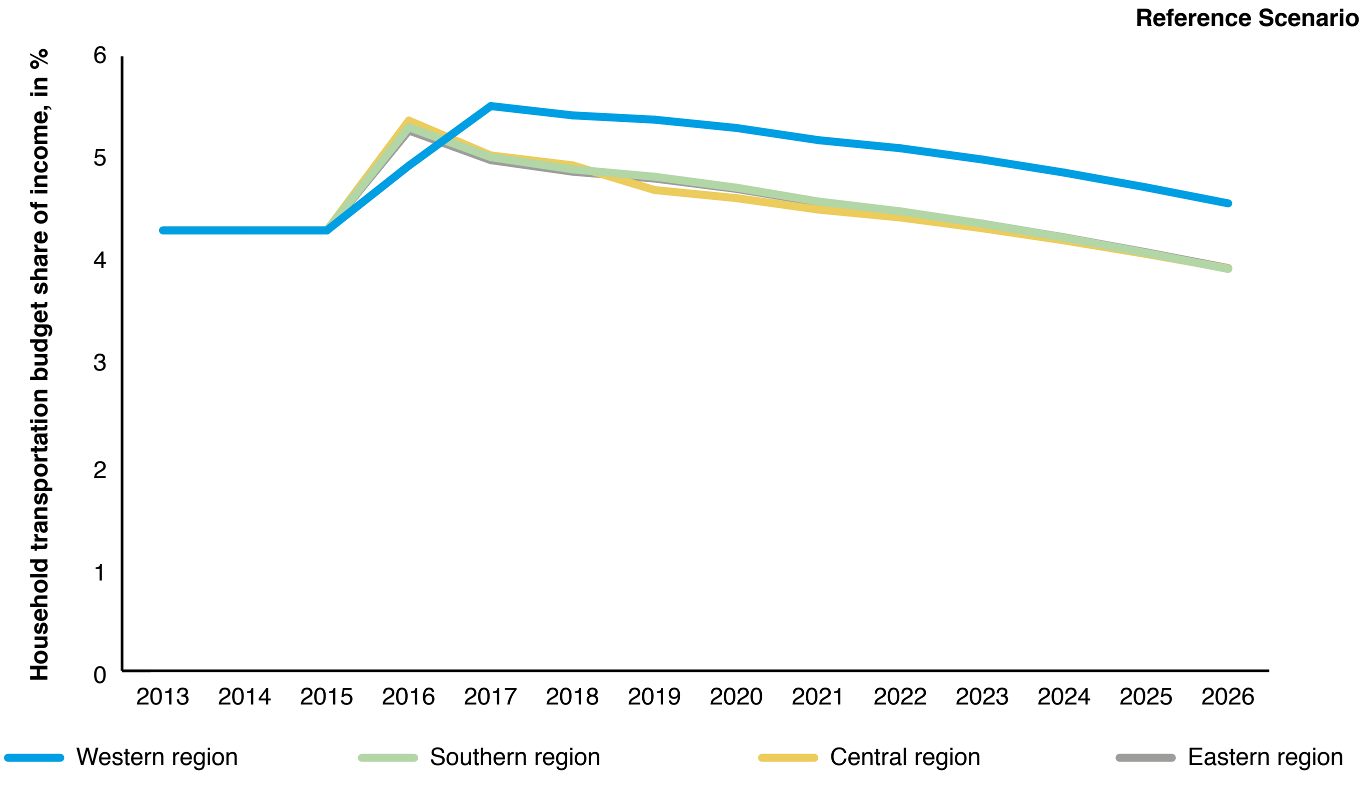

Figure 4a. Households' transportation budgets per region under reference scenario.

Source: KAPSARC.

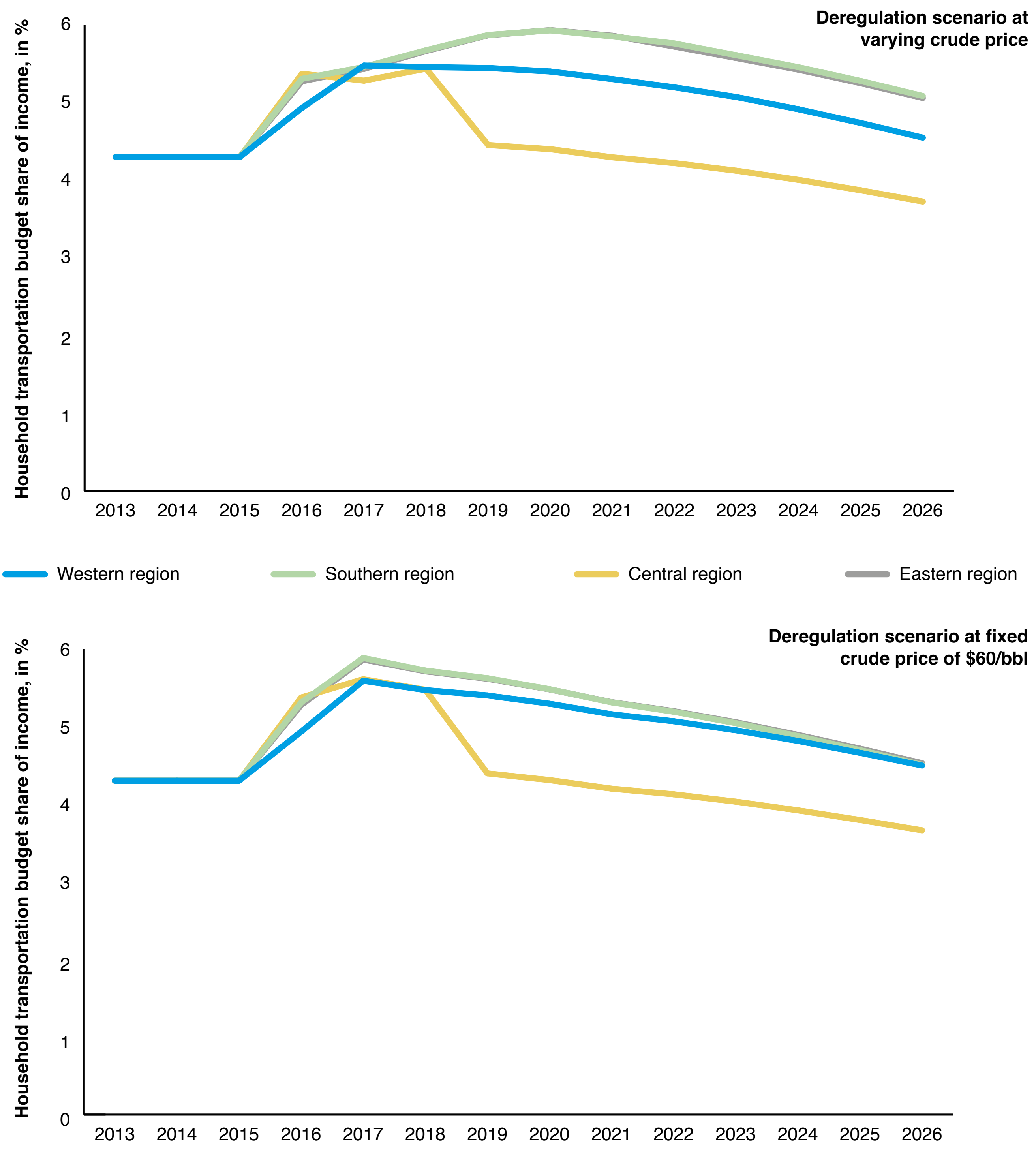

Figure 4b. Households' transportation budgets per region under varying and fixed crude price scenarios.

Source: KAPSARC.

Note: Since international fares reflect the market price, the reference scenario at a fixed crude price is slightly different. This difference, however, is negligible. The first year of deregulation is 2017.

region allocate an annual average of 5.3 percent. This difference, again, is due to the introduction of alternative transport modes in the western region, including high-speed rail.

In the deregulation scenario at a fixed crude price of $60/bbl, consumers in the western and central regions allocate an annual portion of their income to transportation that is similar to the corresponding portions in the deregulation scenario at a varying price due to the availability of alternative modes. In the southern and eastern regions, however, consumers' transportation budgets are very sensitive to gasoline prices due to the lack of alternative modes. Therefore, in the deregulation scenario with a fixed crude price, consumers – in both the southern and eastern regions – allocate an annual average of 5 percent. This drop in transportation budget, in comparison to the varying crude price scenario, is due to lower gasoline prices.

Emerging transportation modes play an important role in absorbing the shock caused by these energy price reforms. The lack of mass-transit projects in the southern and eastern regions have required consumers to increase their transportation budgets in the varying crude scenario, in comparison to those of 2013, by an average 23 percent. On the other hand, consumers in the central and western regions have increased their transportation budgets in the varying crude price scenario by an average 3 percent and 15 percent, respectively, due to the emergence of public modes. Although consumers' transportation budgets in the eastern and southern regions are within those used by consumers in GCC countries (Table 1) and historical boundaries in Saudi Arabia (Table 2), introducing alternative modes in these regions could alleviate the need for this to increase.

Net Gain

Figure 5 represents the estimated net gain in the reference and deregulation scenarios at both a fixed crude price of $60/bbl and a varying crude price. The equation that was used to estimate the net gain is:

Net Gain=domestic sales of transport fuels+export revenues of refined products-monetary and behavioral transport costs perceived by consumers

Equation (1)

as a result of the low oil prices in 2017 (Oxford Economics 2016), the estimated net gain is negative in 2017. From 2018 onward, the estimated net gain in the deregulation scenario at a varying crude oil price scenario is positive and continues to be positive throughout the considered time horizon. The gap in the net gain between the reference and deregulation scenarios continues to grow in the future as a result of higher oil prices, which will lead to higher export revenue and domestic sales of fuels. Furthermore,

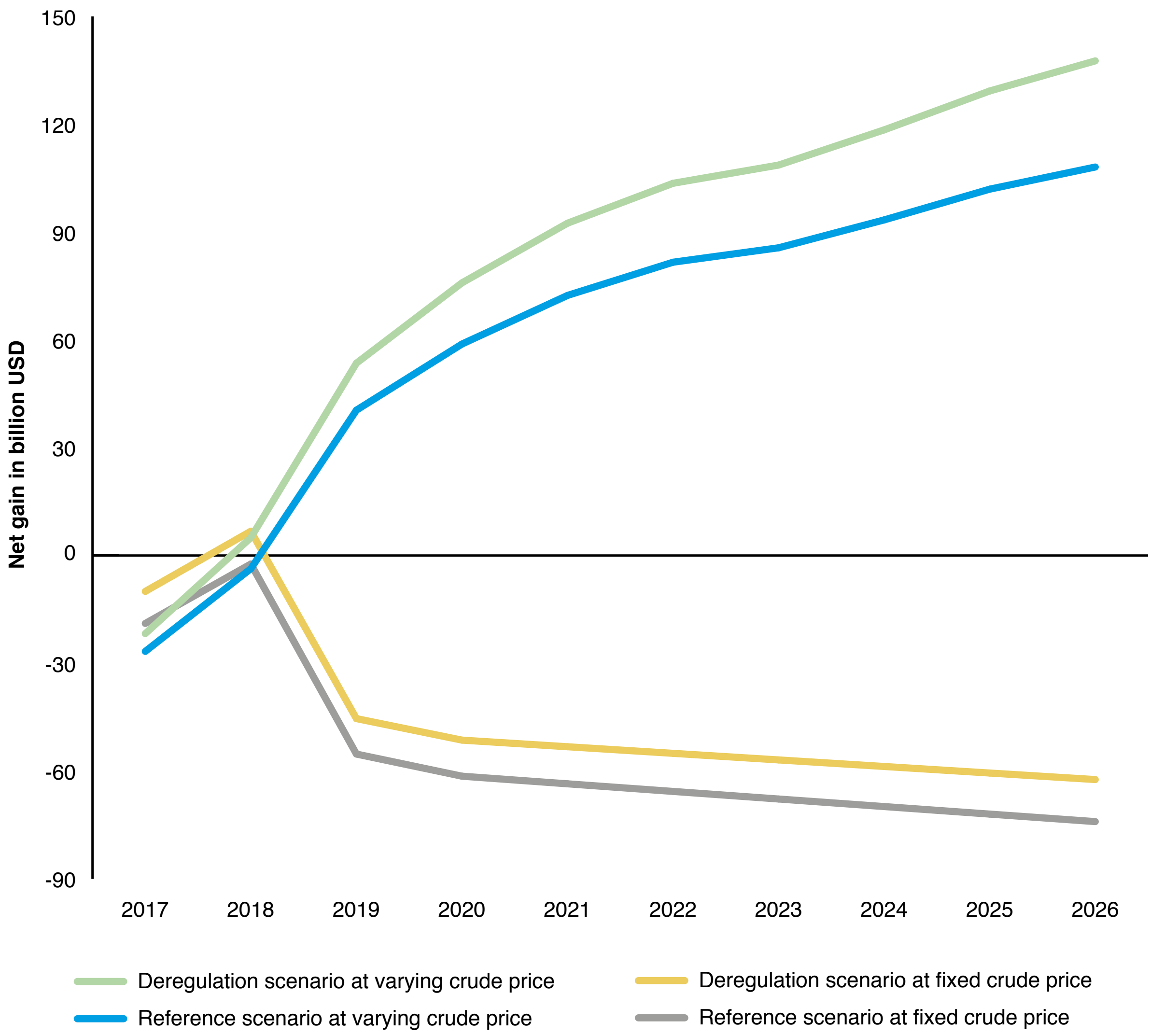

Figure 5. Annual net gain in the reference and deregulation scenarios at both a varying crude price and fixed price of $60/bbl in Saudi Arabia.

Source: KAPSARC.

Note: The results in the reference scenario at a varying crude price are different from that at a fixed price due to the higher international prices of refined products. The first year of deregulation is 2017.

consumer's monetary and non-monetary behavioral perceived costs is reduced as a result of new, fast and convenient public transportation modes (e.g., metro and high-speed rail).

In the $60/bbl fixed price scenario, the gains obtained by selling fuels at market prices do not offset the additional costs incurred by consumers, leading to further losses (Figure 5). Although the total transportation costs incurred by consumers have an impact on the net gain, selling crude at a price higher than $60/bbl is essential for the Kingdom to generate a positive net gain (i.e., selling excess refined products and crude resulting from lower domestic demand at the higher price).

The present value of the net gain in the varying crude price scenario is estimated to be $123 billion and the equation that was used to calculate it is:

$$\text{Present Value} = \sum_{t}^{2026} \frac{change\ in\ the\ net\ gain}{(1+r)^t}$$

Equation (2)

where r represents the social discount rate and t represents the year. Following Pierru and Matar (2012), the social discount factor is assumed to be 5 percent.

Energy Consumption

Figures 6a and 6b show the demand for transportation fuels in millions of barrels of oil equivalent (MMboe) per year for the reference and deregulation scenarios at both a varying and a fixed crude price. There is a clear drop in the overall demand for energy in both deregulation scenarios compared to the reference scenario due to several factors: these include the shift to more efficient public modes, efficiency improvements in gasoline-powered vehicles and tendency to reduce the demand for overall transportation services. This drop in the overall demand for energy is mitigated in the deregulation scenario at a fixed crude price due to the smaller increase in fuel prices in comparison to that in the varying price scenario. From 2019, this reduction is moderated, since consumers start to adapt to market prices by continuing to use efficient and convenient public transport, such as metro in the central region and high-speed rail in the western region.

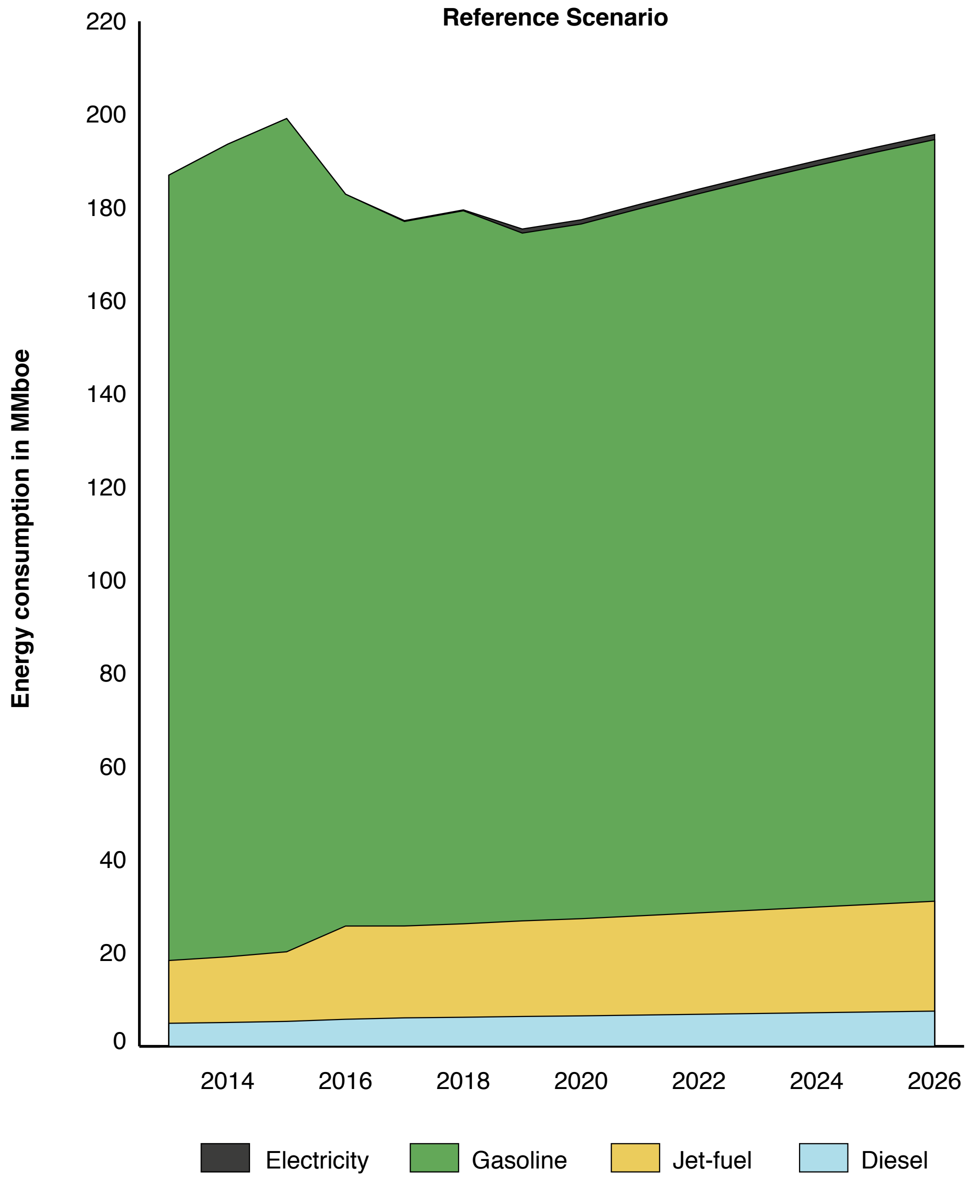

Figure 6a. Total passenger demand for energy under reference scenario.

Source: KAPSARC.

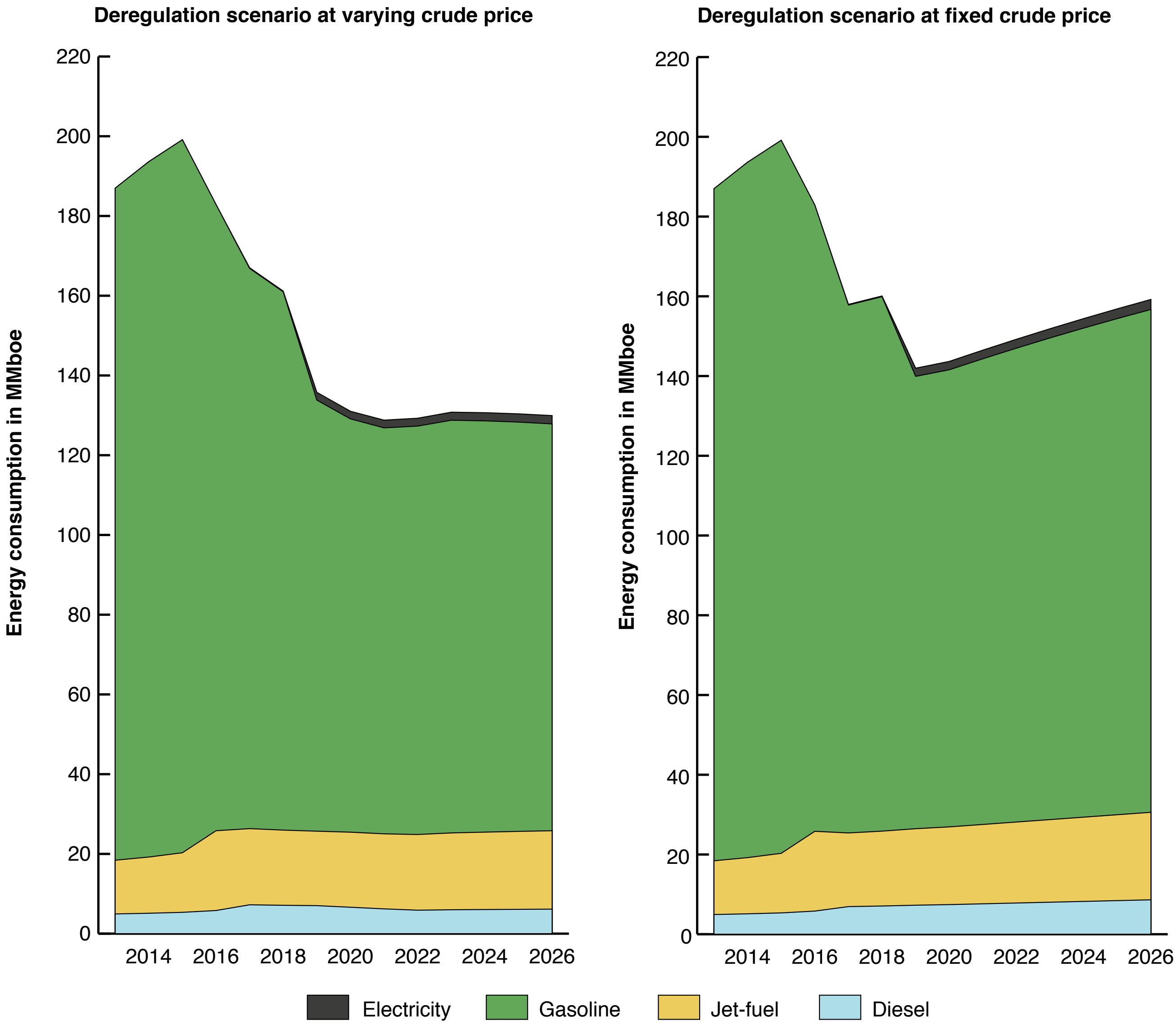

Figure 6b. Total passenger demand for energy under varying and fixed crude prices.

Source: KAPSARC.

Note: The results in the reference scenario at a varying crude price are similar to that at a fixed price. The first year of deregulation is 2017.

Despite the significant increase in gasoline prices in the deregulation scenario, particularly beyond 2020, gasoline consumption continues to dominate that of other fuels due to the relatively unlimited capacity of gasoline-powered vehicles compared with other transportation modes. Despite the limited capacity, deregulating fuel prices incentivizes consumers to travel by public transport, thereby reducing demand for gasoline. For instance, low-income consumers partially satisfy their inter-regional transportation demand by bus, especially when no other faster modes are available.

Deregulating this sector at a varying crude price decreases the average annual demand for diesel by 4 percent and jet fuel by 11 percent relative to the reference scenario as a result of the increase in fares and the reduction in overall transportation services caused by deregulation of the sector. Demand for gasoline falls by the most in comparison to other fuels, by about 29 percent, due to the price increase. Demand for electricity, however, rises the most among other energy resources, by around 82 percent, because modes that consume electricity such as metro and high-speed rail remain competitive. In other words, public modes are fast and efficient and can carry more passengers per trip; thus, deregulating energy prices would introduce a minimal increase in their fares (Krishnan et al. 2015).

Deregulating the transport sector at a fixed crude price dampens the reduction in total demand for transportation along with the substitution effect across modes. This scenario results in a drop in jet fuel and gasoline demand by 7 percent and 21 percent, respectively; while, doubling the demand for electricity and increasing the demand for diesel by 14 percent. This indicates, in comparison to the varying crude scenario, a smaller increase in fuel prices results in a lower decline in the total demand for transportation and a shift to fast public modes that consume electricity (e.g. metro and high-speed rail).

Carbon Emissions

Figure 7 shows the equivalent carbon dioxide emissions in million metric tons (mt) in the reference and deregulation scenarios. The emission factors are obtained from the United States Environmental Protection Agency (2016). Deregulating transportation fuel prices can reduce CO2 emissions in the range of 4 million to 26 million mt per year. In the varying crude price scenario, the CO2 savings in the long run are four to five times that of the short run as a result of fast and convenient public transit systems being introduced in Saudi Arabia along with higher fuel prices, which encourage consumers to switch to public transport. In the fixed crude price scenario, the CO2 savings are lower than that at a varying price due to the smaller increase in fuel prices and hence a lower

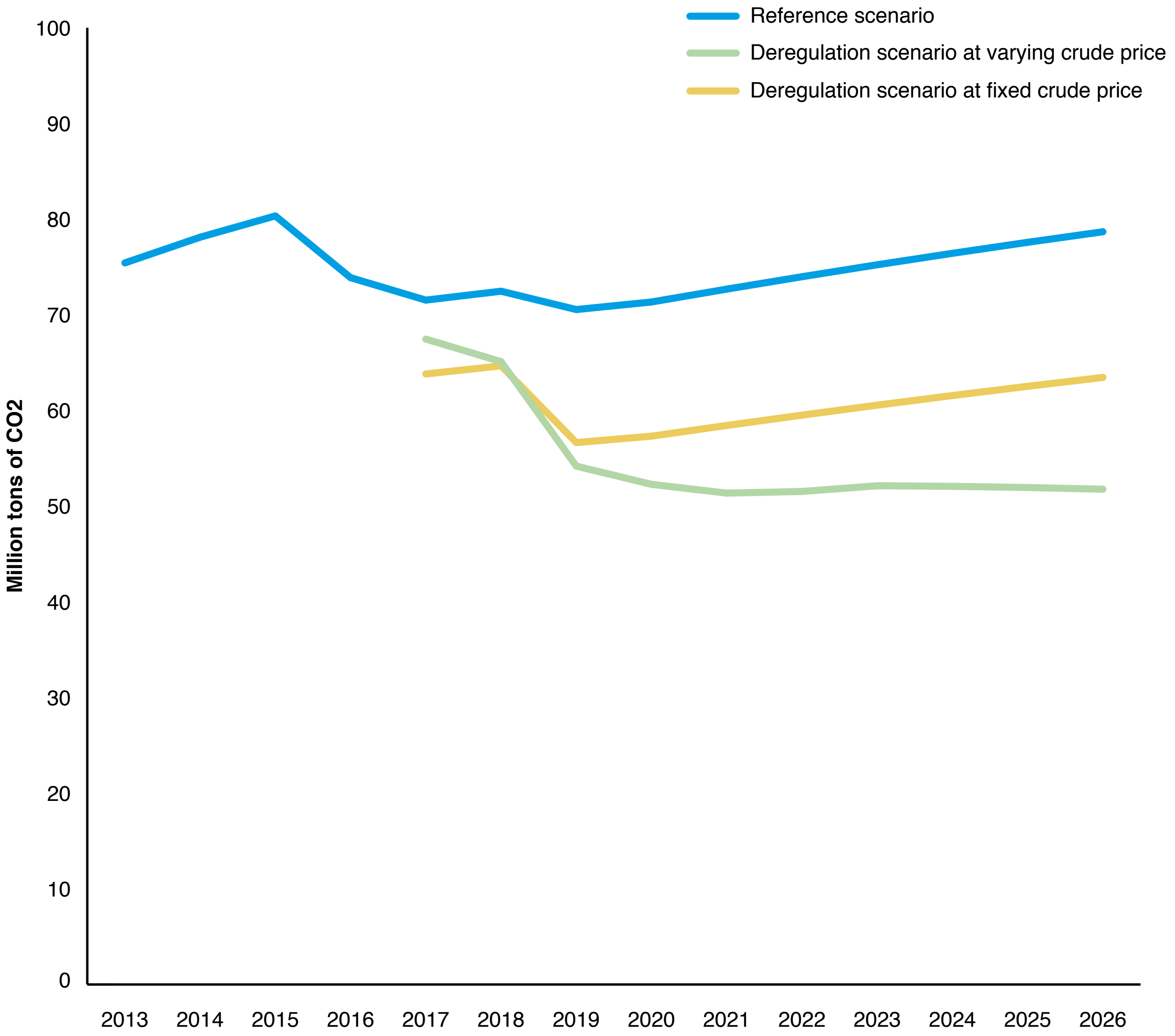

Figure 7. Carbon dioxide emissions.

Source: KAPSARC.

Note: The results in the reference scenario at a varying crude price are similar to that at a fixed price. The first year of deregulation is 2017.

drop in the total demand for transportation and shift to public modes.

In order to reduce CO_2 emissions even further in Saudi Arabia, convenient and fast transportation modes (e.g., high-speed rail and metro) should be introduced in other regions. Furthermore, a policy that encourages consumers to invest in efficient private vehicles should be introduced by the government. An example of such a policy is taxing inefficient vehicles and subsidizing efficient ones. If the efficiency of the Saudi Arabian fleet is improved, significant CO_2 emission savings may be observed in the passenger transportation sector. Furthermore, such a policy can be more practical than investing in other expensive public transit projects.

Additional Revenue

Figure 8 shows the net revenue to the Kingdom from selling transport fuels in the reference and deregulation scenarios at both a varying and fixed crude price. As a result of selling heavily subsidized fuels, the government is gaining far less than what it would earn if fuels were sold overseas. In the reference scenario, the government would earn an annual average of $6.4 billion from selling transport fuels domestically. In the deregulation scenario, at a varying price, however, it would earn an annual average of $10.6 billion. The lower market prices, offset by higher demand for refined products, in the fixed crude price scenario results in annual average earnings of $9.3 billion. Following changes in consumers' transportation choices after deregulation of the sector and the resulting reduction in energy consumption, the government would earn in the varying crude price scenario an average of 66 percent more than in the reference scenario.

Furthermore, as crude prices increase in the varying price scenario, so will the gap in earnings between the reference and deregulation scenarios. Selling at administered prices would ultimately

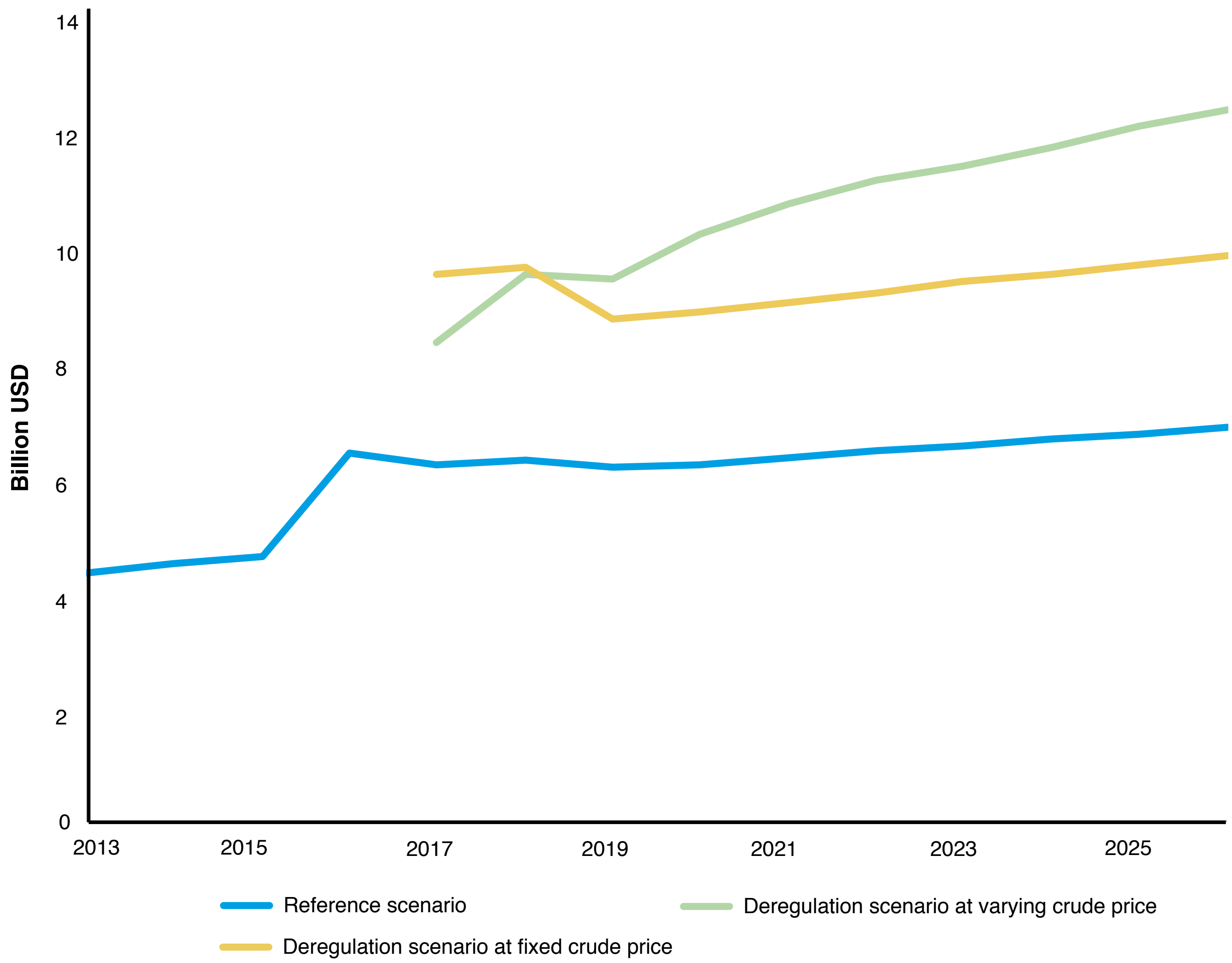

Figure 8. Net revenue from domestic transportation fuel sales.

Source: KAPSARC.

Note: The results in the reference scenario at a varying crude price are similar to that at a fixed price.

cost the government more, while deregulating the transportation sector would generate higher revenue. This can be seen clearly in the reference scenario where revenue is relatively constant although crude prices are rising substantially (Figure 8).

Figure 9 shows the difference in export revenue between the deregulation and reference scenarios at both a varying and fixed crude price. This gap widens as a result of the substantial amount of fuels saved locally, particularly gasoline, and being sold in the international market at a higher price. Moreover, this reduction in demand for refined products offers refineries the opportunity to produce fuels that give the highest export profits.

Furthermore, as crude prices increase in the varying price scenario, so will the prices of refined products and thus export revenue. Hence, allowing refineries to earn greater profits in the long run. Figure 9 shows that the annual average of additional export income in the varying crude price scenario is around $4 billion while at a fixed price is about $2.1 billion.

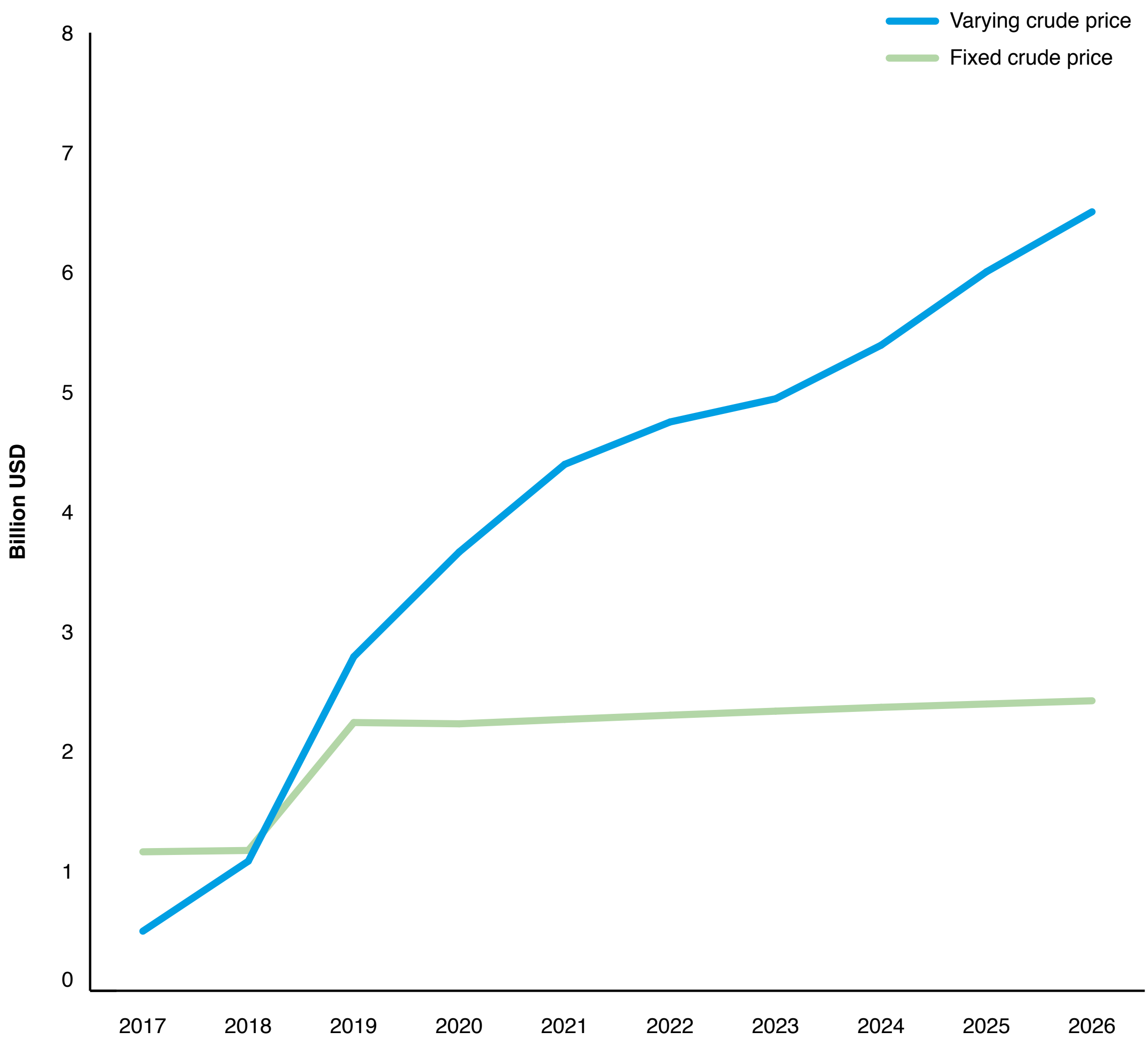

Figure 9. Additional export revenue when passenger transportation sector is deregulated.

Source: KAPSARC.

Note: The reference scenario at a varying crude price is substantially different from that at a fixed price due to the greater international prices of refined products that are driven by crude prices.

Comparison Between Our Estimation Method and Published Estimation

Figure 10 shows gasoline consumption in the deregulation scenarios at both a varying and fixed crude price using our modeling approach and the empirical estimate published by Dahl (2012). Our modeling approach estimates a gasoline consumption trend that oscillates around the result obtained using the empirical estimate. The consumer response obtained by our model is

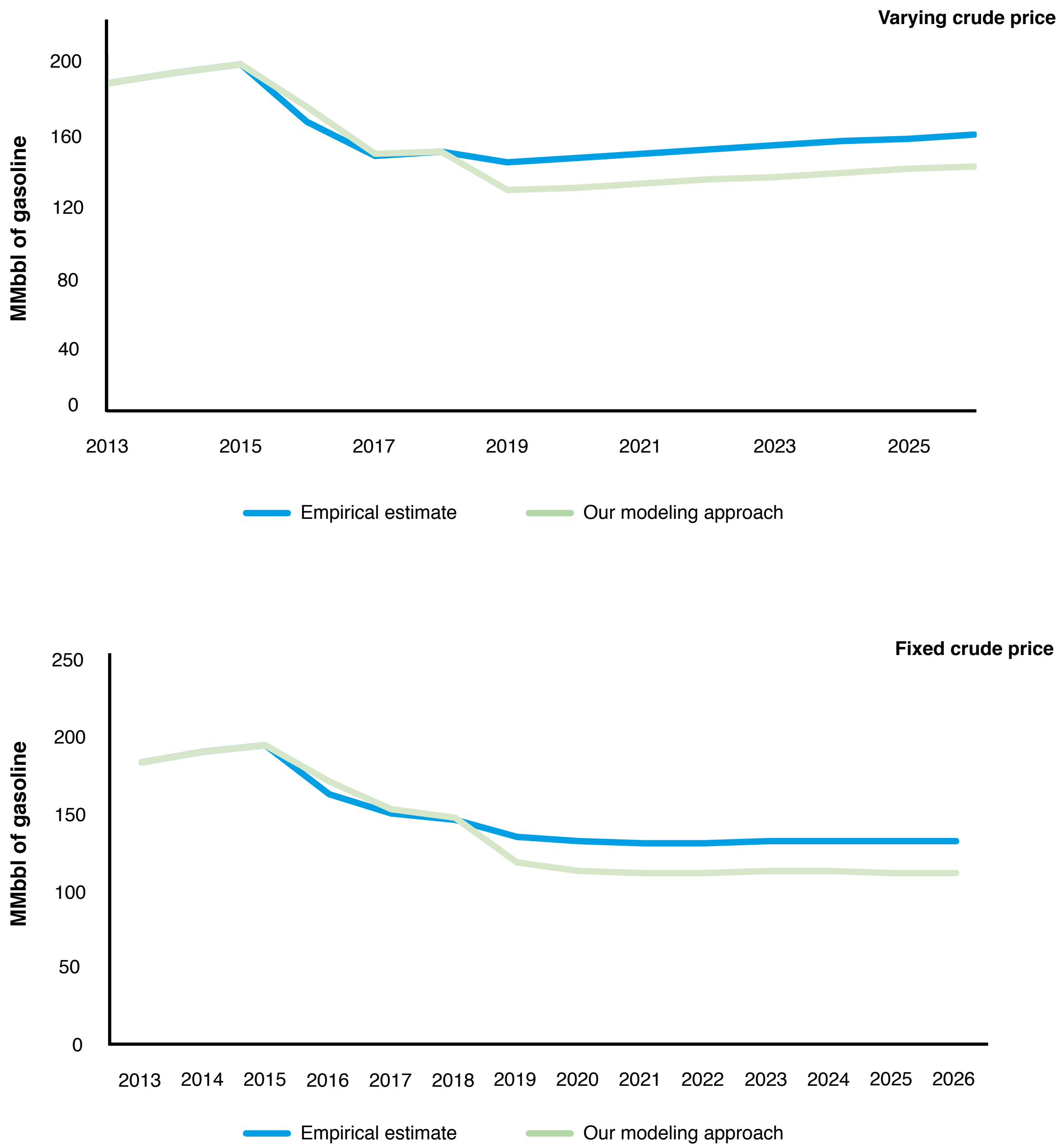

Figure 10. Gasoline consumption curves.

Source: KAPSARC.

Note: Results obtained using the empirical estimate published by Dahl (2012) and our modeling approach for the deregulation scenarios at both a varying and fixed crude price.

close to that of the empirical estimate even when gasoline price goes beyond the historical variations. When new modes and technologies are introduced in Saudi Arabia; the response obtained using our model is slightly greater than that of the empirical estimate, which did not account for such new modes (Figure 1). In spite of introducing new modes and evaluating fuel prices beyond the historical boundaries, our results are within 2 percent to 16 percent of that calculated using the empirical estimate — the difference widens slightly as new modes and higher gasoline prices are introduced. This difference is lower at the fixed crude price scenario due to the lower shift from gasoline-powered vehicles. Therefore, our analysis can give policymakers the confidence in using the empirical results. Since our results represent an upper bound of the shift to public modes while considering non-monetary behavioral costs, our results could be much closer to that of the empirical estimate had we considered a price-induced efficiency in our modeling approach.

Conclusion

Policymakers in Saudi Arabia recently introduced new transport fuel prices, and it is possible that these will reach market levels in the near future. For instance, today's market price of gasoline is within 15 percent of the administered price. This offers policymakers the opportunity to deregulate the market before crude prices increase in the future. Hence, they would be keen to know if consumers would be able to adapt to market fuel prices while meeting their demand for transportation. Also, what determines consumers' travel mode choices and the resulting energy consumption levels.

Accordingly, we developed a bottom-up passenger transportation sub-model and integrated it with a refining sub-model to evaluate consumers' decision-making processes under the new energy price reform policies. The transportation sub-model accounted for the perceived monetary and non-monetary behavioral costs, consumers with different income levels, and several modes and technologies. Additionally, the refining sub-model maximized profit while meeting domestic demand and had the flexibility to enable the use of different crude slates, investment in capacity expansion, and import and export of refined products.

Consequently, we evaluated consumers' travel mode choices and the change in households' transportation budgets at administered and market fuel prices at both a varying and fixed crude price. Furthermore, we considered the resulting energy consumption and revenue to the government under both scenarios. Energy consumption projections from 2017 to 2026 were shown as well.

Our research showed that despite deregulating the passenger transportation sector, the use of gasoline-powered vehicles dominates that of other modes due to the limited capacity of other modes and attractiveness of private vehicles. We also found that deregulating the transportation market encourages consumers to travel by efficient public transport, particularly high-speed modes if they are available. The share of air travel remains constant for international demand due to its attractiveness for long-distance travel.

Despite the greater demand for gasoline relative to other energy resources, in the deregulation scenario at a varying crude price, demand shrinks by an annual average of 9 percent for the first two years of deregulation. This reduction grows to an average of 33 percent per year beyond the first two years of deregulation due to higher crude and refined products prices. This drop is substituted by other energy resources, mainly electricity. The decline in energy consumption, as a result of introducing convenient public modes and higher fuel prices, decreases CO2 emissions by an average of 19 million mt per year in the varying crude price scenario.

Market-based fuel prices would still affect household's transportation budgets. Deregulating the passenger transport sector in both the fixed and varying price scenarios would increase households' transportation budgets, in comparison to those of 2013, by an average of 16 percent and 21 percent, respectively. This increase in consumers' budgets is alleviated in the fixed price scenario due to the lower transport fuel prices. Despite this rise, consumers in Saudi Arabia would continue to allocate one of the lowest transportation budgets in GCC countries because the household budgets would continue to grow in the future. However, consumers in the southern and eastern regions need to allocate greater transportation budgets in comparison to users in other regions due to the lack of alternative modes. Nonetheless, this increase is still within the Saudi Arabian historical range of transportation budgets.

Conclusion

Deregulating the passenger transportation sector would offer the government substantial revenue. Our analysis shows that the government would earn an additional annual average $4.2 billion and $2.9 billion from domestic fuel sales in the varying and fixed crude price scenarios, respectively. In addition, a reduction in energy consumption would offer refineries the flexibility to manufacture and export more profitable refined products due to lower capacity expansion spending, thereby increasing annual export revenue by an average $4 billion and $2.1 billion in the varying and fixed price scenarios, respectively.

Furthermore, our results do oscillate around empirical estimates. We find that even with the introduction of new transportation modes and gasoline prices beyond historical variations, consumers' response to market fuel prices are broadly within that of the empirical estimate. Overall, the range of the gap between our results and that of the empirical estimate is between 2 percent and 16 percent – the gap widens slightly as new transportation modes and greater gasoline prices are introduced. However, had we considered a price-induced efficiency, our results could have been closer to that of the empirical estimate. Therefore, our findings give policymakers in Saudi Arabia the confidence in using the empirical estimate.

Finally, this paper can support policymakers in Saudi Arabia by providing a quantitative and qualitative assessment of deregulating passenger transportation. It can also be used collectively with other modeling techniques to validate the outcomes of certain energy policies, specifically if the policies are untested or exceed historical variations in a particular region. As part of our future work, we will evaluate the prospect of alternative private transportation modes and technologies. In addition, a better representation of a price-induced efficiency should be investigated, for example developing an agent-based model may address this issue.

References

Abed, Seraj Y., Abdullah O. Ba-Fail, and Sajjad M. Jasimuddin. 2001. "An econometric analysis of international air travel demand in Saudi Arabia." Journal of Air Transport Management 7 (3): 143-148.

Abrantes, Pedro A.L., and Mark R. Wardman. 2011. "Metaanalysis of UK values of travel time: An update." Transportation Research Part A: Policy and Practice 45 (1): 1-17.

Aircraft Commerce. 2005. "Analyzing the options for 757 replacement." No. 42: 25-31.

Alabbadi, Naif M. 2012. "Energy Efficiency in KSA: Necessity and Expectations." Royal Commission at Yanbu.

Al Ali, Abdulla Y. 2015. "Energy Efficient Dubai Metro." UAE State of Energy Report: Transport and Mobility: 199.

Alarabiya. 2016. "Haramain train by the end of 2017 and competitive fares." Alarabiya.

Algunaibet, Ibrahim M., and Walid Matar. 2016. "The Responsiveness of Fuel Demand to Gasoline Price in Passenger Transport: A Case Study of Saudi Arabia." KAPSARC discussion paper.

Aljunedy, Ibrahim. 2015. "Northern Rail starts its first steps" Alyaum.

Al-Ohaly, Abdulaziz. 2015. "Public Transport in Saudi Arabia." Global Competitiveness Forum.

ALSTOM. 2016. "METROPOLIS." ALSTOM SA.

Arab News. 2016. "SR25: Weekly ticket for Riyadh Metro." Saudi Research & Publishing Company.

Argaam. 2015. "Haramain train: SAR 225 fare for first-class and SAR 148 for second-class" Argaam.com.

Argaam. 2016. "Metro Riyadh will start in 2018 and no intention for delay" Argaam.com.

Al Yousef, Nourah. 2013. "Demand for oil products in OPEC countries: A panel Cointegration Analysis." International Journal of Energy Economics and Policy 3 (2): 168.

Belenky, Peter. 2011. "The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations." Office of the Secretary of Transportation, US Department of Transportation, Washington DC.

Briginshaw, David. 2015. "Saudi HS line "on schedule" for 2017 opening." International Railway Journal.

Cerić, Emir. 2001. "Crude Oil Assay." INA-Industrija nafte: 10-13.

Construcciones y Auxiliar de Ferrocarriles. 2013. "Push-pull train for the Saudi Railway Company (SAR)."

Dahl, Carol A. 2012. "Measuring global gasoline and diesel price and income elasticities." Energy Policy 41: 2-13.

Daly, Hannah E., Kalai Ramea, Alessandro Chiodi, Sonia Yeh, Maurizio Gargiulo and Brian Ó. Gallachóir. 2014. "Incorporating travel behaviour and travel time into TIMES energy system models." Applied Energy, 135: 429-439.

Electricity & Cogeneration Regulatory Authority. 2015. Accessed August 18, 2015. http://www.ecra.gov.sa/en-us/DataAndStatistics/NationalRecord/pages/NationalRecord.aspx.

Favennec, Jean-Pierre. 2001. "Petroleum Refining: Refinery operation and management." Editions Technip: 220, 225, 278.

Flynas. 2015. "Flynas Schedule." Accessed August 18, 2015. http://www.flynas.com.

Gary, James H., and Glenn E. Handwerk. 2005. "Petroleum Refining: Technology and Economics." Marcel Dekker, Inc. (4).

References

General Authority for Statistics. 1999. “Household expenditure and income survey.”

General Authority for Statistics. 2007. “Household expenditure and income survey.”

General Authority for Statistics. 2013. “Household expenditure and income survey.”

General Authority for Statistics. 2013. “Labor Force Survey.”

General Authority for Statistics. 2014. “Statistical Yearbook.”

Girod, Bastien, Detlef P. van Vuuren, and Bert de Vries. 2013. “Influence of travel behavior on global CO 2 emissions.” Transportation Research Part A: Policy and Practice 50: 183-197.

IHS Markit. 2015. “IHS Midstream Database.” IHS Inc.

International Civil Aviation Organization - ICAO. 2013. “Annual Report of the ICAO Council.”

International Energy Agency. 2009. “Transport Energy and CO2: Moving Towards Sustainability.” OECD Publishing.

Kable. 2016. “North-South Railway Line, Saudi Arabia.”

Karavali Times. 2013. “Dubai Metro train etiquette: Space jam at the doors leads to battle for territory.”

Krishnan, Venkat, Eirini Kastrouni, V. Dimitra Pyrialakou, Konstantina Gkritza and James D. McCalley. 2015. “An optimization model of energy and transportation systems: Assessing the high-speed rail impacts in the United States.” Transportation Research Part C: Emerging Technologies 54: 131-156.

Kuwait Central Statistical Bureau. 2013. “Household income and expenditure survey.”

Litman, Todd. 2009. “Transportation cost and benefit analysis.” Victoria Transport Policy Institute 31.

Matar, Walid, Frederic Murphy, Axel Pierru, Bertrand Rioux. 2013. “Modeling the Saudi energy economy and its administered components: The KAPSARC energy model.” USAEE Working Paper: 13-150.

Ministry of Development Planning and Statistics. 2013. “Final Results of Household Expenditure and Income Survey (HEIS).”

Ministry of Labor. 2013. “Statistical Yearbook.”

Mishra, Gouri Shankar, Page Kyle, Jacob Teter, Geoffrey M. Morrison, S. Kim, and Sonia Yeh. 2013. “Transportation module of global change assessment model (GCAM): model documentation.” No. UCD-ITS-RR-13-05.

Oxford Economics. 2016. “Global Economic Model.”

Oxford Economics. 2016. “Global Industry Model.”

Pierru, Axel and Walid Matar. 2012. "The impact of oil price volatility on welfare in the Kingdom of Saudi Arabia: implications for public investment decision-making." The Energy Journal: 35.

Proc, K., K. Barnitt, and R. R. Hayes. 2006. “100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20).” Paper presented at the Powertrain and Fluid Systems Conference and Exhibition.

Riyadh Metro. 2016. “Project Overview.” Accessed July 15, 2016. http://riyadhmetro.sa/en/project-overview.

Santos, Adelia, Nancy McGuckin, Hikari Y. Nakamoto, Danielle Gray and Susan Liss. 2009. “Summary of Travel Trends: 2009 National Household Travel Survey.” U.S. Department of Transportation.

Saudi Railways Organization. 2015. “Saudi Railways Organization (SRO) website.” SRO. Accessed August 10, 2015. https://www.saudirailways.org/sites/sro/Pages/home.aspx.

Saudia. 2015. “Saudia website.” Accessed August 10, 2015. http://www.saudiairlines.com.

Saudia. 2013. “Passenger Flight Schedule.”

Saudi Arabia Public Transport Company. 2015. “Annual Report 2014.”

Saudi Arabian Monetary Agency. 2015. “Appendix of Statistical Tables of the 46th Annual Report.” Saudi Arabian Monetary Agency.

Schäfer, Andreas and David G. Victor. 2000. “The future mobility of the world population.” Transportation Research Part A: Policy and Practice 34 (3): 171-205.

Statistics Center - Abu Dhabi. 2013. “Household Expenditure and Income Survey.”

U.S. Energy Information Administration. 2016. “Electric Power Monthly.” U.S Department of Energy.

U.S. Environmental Protection Agency. 2016. “Direct Emissions from Mobile Combustion Sources.” U.S. Environmental Protection Agency.

Zahavi, Yacov and Antti Talvitie. 1980. “Regularities in travel time and money expenditures.” National Academy of Sciences 750.

Appendix A: The Considered Prices in Each Scenario

Table A1. The assumptions considered in estimating fuel prices and fares for the reference and deregulation scenarios.

Fuel price or fare	Reference scenario	Deregulation scenario
Gasoline prices	A weighted average of the administered prices of 91 and 95 octane gasoline based on historical consumption	Market prices at marginal value
Diesel and jet-fuel prices	Administered prices	International prices (influenced partially by crude prices)
Fares of airplane for international travel	Market prices (influenced partially by crude prices)	
Fares of airplane for domestic travel	Saudi Airlines' prices in 2013	Kept constant, since Saudi Airlines' prices in USD/km are higher than that in the U.S.
Fares of bus for domestic travel	Administered prices	Market prices (influenced partially by crude prices)
Fares of bus for international travel	Market prices (influenced partially by crude prices)	Market prices (influenced partially by crude prices)
Fares of rail	Prices in 2013 – these are close to market prices and mass transportation modes are not very much affected by crude prices	
Fares of high-speed rail and metro	The proposed prices by the ministry, which are close to market prices, are not very much affected by crude prices because they have large load factors (passenger/vehicle) and high efficiency, and consume electricity	

Source: KAPSARC.

Table A2. Market and administered fuel prices used in the model.

Year	Market prices at varying crude prices (USD per liter)			Market prices at fixed crude price scenario (USD per liter)			Administered prices scenario (USD per liter)		
	Gasoline	Diesel	Jet fuel	Gasoline	Diesel	Jet fuel	Gasoline	Diesel	Jet fuel
2013	0.60	0.71	0.78	0.60	0.71	0.78	0.13	0.07	0.14
2014	0.50	0.65	0.73	0.50	0.65	0.73	0.13	0.07	0.14
2015	0.30	0.41	0.49	0.30	0.41	0.49	0.13	0.07	0.14
2016	0.24	0.32	0.40	0.24	0.32	0.40	0.21	0.12	0.16
2017	0.27	0.35	0.44	0.33	0.42	0.51	0.21	0.12	0.16
2018	0.32	0.42	0.50	0.33	0.42	0.51	0.21	0.12	0.16
2019	0.37	0.48	0.56	0.33	0.42	0.51	0.21	0.12	0.16
2020	0.42	0.54	0.62	0.33	0.42	0.51	0.21	0.12	0.16
2021	0.45	0.58	0.66	0.33	0.42	0.51	0.21	0.12	0.16
2022	0.46	0.60	0.68	0.33	0.42	0.51	0.21	0.12	0.16
2023	0.47	0.61	0.68	0.33	0.42	0.51	0.21	0.12	0.16
2024	0.48	0.62	0.70	0.33	0.42	0.51	0.21	0.12	0.16
2025	0.50	0.64	0.72	0.33	0.42	0.51	0.21	0.12	0.16
2026	0.51	0.66	0.74	0.33	0.42	0.51	0.21	0.12	0.16

Source: KAPSARC.

Note: Market gasoline prices are set to marginal value. Diesel and jet-fuel prices are calculated as a function of crude oil. The projection of crude prices is obtained from Oxford Economics (2016) in the varying and fixed at $60/bbl price scenarios.

Appendix B: Model Description

B1: Indices

Table B1. Indices used in the model.

Index	Description
HH	Income types of households
Tpe	Energy source used for transportation demand
t	Time period
r	Region
rr	Region
TPd	Types of travel demand
TPo	Types of Transportation modes and technologies
RFcr	Crude oil grades
RFcf	Final refined products
RFs	Process severity
RFf	All types of refining fuels
RFp	Refining processes
RFu	Refining units
RFqlim	Upper and lower limits for quality specifications
prop	Final product properties
allmaterials	All the types of materials represented in the model
f	Types of fuels
ELl	Load segments
ELs	Seasons
ELday	Types of the day

Source: KAPSARC.

B2: Variables

Table B2. Indices used in the model.

Parameters and variables	Description
Valueoftime(HH)	Domestic value of time in USD per passenger hour
ValueoftimeINTL(HH)	International value of time in USD per passenger hour
TPAPe(TPe,t,r)	Administered energy price in USD per L or kWh
TPbudget(HH,t,r)	Household budget for transportation in million USD for all households per year
Efficiency(TPo,TPe,TPd,t)	Fuel use in L or kWh per km traveled
LoadFactor(TPo,TPd)	Occupancy in passenger per vehicle
TPomcst(TPo,TPd)	Non-fuel operations and fare in USD per PKM
TPdomfarecst(TPo,TPd,r,rr,t)	Domestic fares for public transport in USD per passenger per trip
TPintlfarecst(TPo,TPd,r,t)	International fares for public transport in USD per passenger per trip
Uf(TPo,TPd)	Average vehicle speed for transport modes in km per hour

TPwaittime(TPo,TPd)	Waiting time in hours per trip for transport modes (zero for private transport options).
TPdemvaldom(HH,TPd,t,r,rr)	Regional demand for domestic transportation service in million PKM per year
TPdemvalintl(HH,TPd,t,r)	Regional demand for international transportation service in million PKM per year
TPexistdomcap (TPo,TPe,TPd,r,rr,t)	Existing domestic capacity of transport modes in million PKM per year
TPexistintlup(TPo,TPe,r)	Existing international capacity of transport modes in million PKM per year
TPRFconv(TPe)	Conversion factor from L to metric tons
LMTON(TPe)	Total number of liters in a metric ton
TPdistanceintl(r)	Distance between departure region and international destination in km
TPdistancedom(TPd,r,rr)	Distance between domestic regional nodes in km
Intan(TPo,TPd)	Crash and congestion intangible costs in USD per KM by transport mode
TPdomtravel(TPo,TPd,TPe,HH,t,r,rr)	Total demand for domestic travel in million PKM
TPintltravel(TPo,TPd,TPe,HH,t,r)	Total demand for international travel in million PKM
TPexistcp(TPo,TPe,TPd,t,r,rr)	Existing domestic capacity for various transport modes in million PKM
TPopandmaint(t)	Total maintenance costs incurred by households in million USD
TPtimeinvest(TPo,TPd,t,r,rr)	Travel time investment costs incurred by households in million passenger hours
TPeconsump(TPe,TPo,TPd,HH,t,r)	Amount of energy used by HH in each region in million units of energy
TPtimecst(t)	Time cost for travel by different modes in million USD
TPIntan(t)	Crash risk and congestion burden perceived by consumers in million USD
TPeconsumpdom(TPe,TPo,TPd,HH,t,r)	Total domestic demand for energy in million liter or million kWh
TPeconsumpINT(TPe,TPo,TPd,HH,t,r)	Total international demand for energy in million liters
PFINT(TPo)	International preference factors for transportation modes
TPelast	Price elasticity for transportation services
Gasolineshare(TPe,t)	The share of 91 or 95 gasoline grade from the total demand for gasoline per year
Population(HH,t,r)	Number of people in millions per year by region and household type
RFcrudesupply(RFcr,t,r)	Crude supply in millions of metric tons
RFdemval(RFcf,t,rr)	Regional exogenous domestic demand in millions of metric tons
RFyield(RFs,RFf,RFcf,RFp)	Mass ratio
RFcapfactor(RFu,RFp)	Capacity factor for each unit
RFExist(RFu,r)	Initial capacity in millions of metric tons
RFLeadtime(RFu)	Lead time for installing units
RFELexist(r)	Initial on-site electricity generation capacity in GW
RFELin(RFs,RFp)	Electricity used per unit of production in MWh per metric ton
RFpurcst(RFu,t)	Equipment purchase cost in USD per unit
RFconstcst(RFu,t)	Construction or installation cost in USD per unit
RFomcst(RFs,RFp,t)	Non-feedstock operations cost in USD per metric ton
RFELpurcst(t)	Purchase cost of on-site power generation in USD per kW
RFELconstcst(t)	Construction cost of on-site power generation in USD per kW
RFELomcst(t)	Power generation operations cost in USD per MWh
RFtranscst(r,rr)	Transportation costs within the same regions or between regions in USD per metric ton
RFimportprice(RFcf,t,r)	Finished products import price in thousand USD per metric ton
RFintlprice(RFcf,t)	Finished products export price in USD per metric ton
RFdomprice(RFcf,t)	Domestic sales price of refined products in USD per metric ton

QSpecification(RFqlim,RFcf,t,prop)	Final product quality specifications
Qattributes(RFf,prop)	Attributes for blending
RFconv(RFf,prop)	Conversion factor from mass to volume
RFfconv(RFcr)	Unit conversion factors from barrels to metric tons
RFaddition(RFu,t,r)	Already-planned capacity addition in millions of metric tons per year
RFop(RFs,RFf,RFp,t,r)	Operation level of feedstock in refining processes in millions of metric tons
RFbld(RFu,t,r)	Building activity for capacity in millions of metric tons per year
RFExistcp(RFu,t,r)	Existing capacity measured by how much input can be processed in millions of metric tons
RFOpandmaint(t)	Operations and maintenance costs in million USD
RFConstruct(t)	Construction costs in million USD
RFImports(t)	Equipment purchased costs in million USD
RFtrans(f,t,r,rr)	Products transported in millions of metric tons
RFcrconsump(f,t,r)	Consumption of crude as feedstock in millions of metric tons
RFprodimports(RFcf,t,r)	Amount of refined products imported in millions of metric tons
RFRevenues	Sales revenue in million USD
RFExports(RFcf,t,r)	Amount of refined products exported in millions of metric tons
RFnatExports(RFcf,t)	National amount of exports in millions of metric tons
RFELexistcp(t,r)	Existing electricity generation capacity in GW
RFELbld(t,r)	Building activity for electricity capacity in GW
RFELop(ELl,ELs,ELday,t,r)	Operation of on-site electricity capacity in TWh
RFtotELconsump(ELl,ELs,ELday,t,r)	Sum of on-site and purchased electricity in TWh
RFELconsump(ELl,ELs,ELday,t,r)	Electricity consumed from the power sector in TWh
RFPCconsump(allmaterials,t,r)	Consumption of petrochemical products in the refining sector in millions of metric tons
RFELlchrsfraction(ELl)	Distributes the consumption evenly across the year
ELnormdays(ELs,ELday)	Days in season normalized by total days in a year

Source: KAPSARC.

B3: Equations and Constraints

The model was solved using PATHMCP. The impeded objective in this model is to minimize the total cost perceived by households while maximizing the profits of the refining sector (units in million USD). This section shows all the equations and constraints used in this model. The dual problem's constraints are not shown here.

This equation sums the intangible non-monetary costs imposed by transport mode and demand type (units in million USD):

Note: $TPintltravel_{TPo,TPd,TPf,HH,t,r}$ is only for long-distance travel.

$$TPIntan_t = \sum_{TPo,TPd,TPe,HH,r} \left\{ \frac{TPintltravel_{TPo,TPd,TPe,HH,t,r} \times Intan(TPo,TPd)}{LoadFactor_{TPo,TPd}} + \sum_{rr} \left[\frac{TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr} \times Intan(TPo,TPd)}{LoadFactor_{TPo,TPd}} \right] \right\}$$

Eq.(B1)

This equation sums all the operational and fares associated with transport modes (units in million USD per year):

Note: $TPintltravel_{TPo,TPd,TPf,HH,t,r}$ is only for long-distance travel.

$$TPopandmaint_{TPo,TPd,t} = \sum_{TPe} \sum_{HH} \left[TPomcst_{TPo,TPd} \sum_{r} \left(TPintltravel_{TPo,TPd,TPe,HH,t,r} + \sum_{rr} TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr} \right) \right] + \sum_{TPe} \sum_{HH} \left(\sum_{r} \sum_{rr} \frac{TPdomfarecst_{TPo,TPd,r,rr}}{TPdistancedom_{TPd,r,rr}} TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr} \right) + \sum_{TPe} \sum_{HH} \left(\sum_{r} \frac{TPintlfarecst_{TPo,TPd,r}}{TPdistanceintl_{TPd,r}} PFINT(TPo) \times TPintltravel_{TPo,TPd,TPe,HH,t,r} \right)$$

Eq.(B2)

This equation calculates the cost attributed to waiting and commute times (units in million USD per year):

Note: $TPintltravel_{TPo,TPd,TPf,HH,t,r}$ is only for long-distance travel. The value of $TPtimeinvest_{TPo,TPd,TPf,HH,t,r}$ is always zero for transportation modes that have nonzero capacity, however, its marginal value determines consumers' desire to travel by a particular transportation mode between specific regions in order to mitigate the time spent on travel.

$$TPtimecst_t = \sum_{TPd} \sum_{TPo} \sum_{r} \sum_{rr} \sum_{HH} Valueoftime_{HH} \times TPtimeinvest_{TPo,TPd,HH,t,r,rr} + \sum_{TPo} \sum_{TPd} \sum_{HH} \sum_{TPe} \left(Valueoftime_{HH} \sum_{r} \left[\sum_{rr} TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr} \cdot \left(\frac{1}{uf_{TPo,TPd}} + \frac{TPwaittime_{TPo,TPd}}{TPdistancedom_{TPd,r,rr}} \right) \right] + ValueoftimeINTL_{HH} \sum_{r} \left[TPintltravel_{TPo,TPd,TPe,HH,t,r} \cdot \left(\frac{1}{uf_{TPo,TPd}} + \frac{TPwaittime_{TPo,TPd}}{TPdistanceintl_{r}} \right) \right] \right)$$

Eq.(B3)

This constraint imposes a monetary budget limit for transportation services (units in million USD per year):

Note: Only energy and operational costs directly incurred by households appear in the monetary budget constraint. If the energy prices are deregulated, $DRFdem_{TPee,t,r}$ is the price of gasoline, which is the marginal value of the demand constraint for refined products. This constraint is relaxed beginning of 2017 – the first year of deregulation – in both scenarios.

$$\sum_{TPo}\sum_{TPe}\sum_{TPd}\left[TPomcst_{TPo,TPd}\left(TPintltravel_{TPo,TPd,TPe,HH,t,r}+\sum_{rr}TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr}\right)\right]+$$
$$\sum_{TPo}\sum_{TPe}\sum_{TPd}\sum_{rr}\frac{TPdomfarecst_{TPo,TPd,r,rr,t}}{TPdistancedom_{TPd,r,rr}}TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr}+$$
$$\sum_{TPo}\sum_{TPe}\sum_{TPd}\frac{TPintlfarecst_{TPo,TPd,r,t}}{TPdistanceintl_{r}}TPintltravel_{TPo,TPd,TPe,HH,t,r}+$$
$$\begin{cases} \text{if prices are administered}, \sum_{TPe,TPo,TPd} TPeconsump_{TPe,TPo,TPd,HH,t,r}TPAPe_{TPe,t,r} \\ \text{if prices are deregulated}, \sum_{TPee,TPe} TPeconsump_{TPe,TPo,TPd,HH,t,r}TPRFconv_{TPee}DRFdem_{TPee,t,r}Gasolineshare_{TPee,t} \end{cases} \leq$$
$$TPbudget_{HH,t,r}$$

Eq.(B4)

This constraint calculates how much energy is used for passenger transport (units in GWh or million L per year):

$$TPeconsump_{TPe,TPo,TPd,HH,t,r}=TPeconsumpdom_{TPe,TPo,TPd,HH,t,r}+TPeconsumpINT_{TPe,TPo,TPd,HH,t,r}$$

Eq.(B5)

This constraint calculates how much energy is used for domestic passenger transport (units in GWh or million L per year):

$$TPeconsumpdom_{TPe,TPo,TPd,HH,t,r}=\sum_{rr}\left(TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr}\cdot\frac{Efficiency_{TPo,Tpe,Tpd,t)}}{LoadFactor_{TPo,TPd}}\right)$$

Eq.(B6)

This constraint calculates how much energy is used for international passenger transport (million L per year):

Note: $TPintltravel_{TPo,TPd,TPf,HH,t,r}$ is only for long-distance travel.

$$TPeconsumpINT_{TPe,TPo,TPd,HH,t,r}=TPintltravel_{TPo,TPd,TPe,HH,t,r}\cdot\frac{Efficiency_{TPo,Tpe,Tpd,t)}}{LoadFactor_{TPo,TPd}}$$

Eq.(B7)

This constraint ensures demand for domestic travel is satisfied (units in million PKM per year):

Note: The elasticity for transportation services applies only for the change in gasoline price since the majority of the demand for transportation services is satisfied by gasoline-powered vehicles.

$$\sum_{TPo}\sum_{TPe}TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr}\geq TPdemvaldom_{HH,TPd,t,r,rr}+$$
$$\begin{cases} \text{if prices are administered}, TPelast\cdot TPdemvaldom_{HH,TPd,t,r,rr}\cdot\frac{(TPAPe_{TPe,t,r}-TPAPe_{TPe,t1,r})}{TPAPe_{TPe,t1,r}} \\ \text{if prices are deregulated}, TPelast\cdot TPdemvaldom_{HH,TPd,t,r,rr}\cdot \\ \frac{(\sum_{TPee}TPRFconv_{TPee}DRFdem_{TPee,t,r}Gasolineshare_{TPee,t}-TPAPe_{TPe,t1,r})}{TPAPe_{TPe,t1,r}} \end{cases}$$

Eq.(B8)

This constraint ensures demand for international travel originating domestically is satisfied (units in million PKM per year):

Note: The elasticity for transportation services applies only for the change in gasoline price since the majority of the demand for transportation services is satisfied by gasoline-powered vehicles. $TPintltravel_{TPo,TPd,TPf,HH,t,r}$ is only for long-distance travel.

$$\sum_{TPo}\sum_{TPe} TPintltravel_{TPo,TPd,TPe,HH,t,r} \geq TPdemvalintl_{HH,TPd,t,r} + \begin{cases} if\ prices\ are\ administered, TPelast \cdot TPdemvalintl_{HH,TPd,t,r} \cdot \frac{(TPAPe_{TPe,t,r} - TPAPe_{TPe,t1,r})}{TPAPe_{TPe,t1,r}} \\ if\ prices\ are\ deregulated, TPelast \cdot TPdemvalintl_{HH,TPd,t,r} \cdot \\ \frac{(\sum_{TPee} {}^{TPRFconv_{TPee} DRFdem_{TPee,t,r} Gasolineshare_{TPee,t}} - TPAPe_{TPe,t1,r})}{TPAPe_{TPe,t1,r}} \end{cases}$$

Eq.(B9)

The two below constraints are used to impose modal capacity restrictions for domestic and international travel, respectively (units in million PKM per year):

For example, rail capacity is only available between two regions, and airplane seat capacity is limited.

Note: The capacity is indexed by fuel to allow for distinct electricity-powered or diesel-powered rail capacities.

$$TPexistcp_{TPo,TPe,TPd,t,r,rr} \geq \sum_{HH} TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr}$$

$$TPexistintlup_{TPo,TPe,t,r} \geq \sum_{HH} TPintltravel_{TPo,TPd,TPe,HH,t,r}$$

Eq.(B10)

This constraint imposes a time budget limit for passengers (units in million passenger hours per year):

Note: The time budget is restricted to time spent in motorized transport modes, as discussed by Schäfer and Victor (2000). However, this constraint does not influence the obtained results because $TPtimeinvest$ ensures feasibility. This equation helps in indicating consumers' desire for a particular transportation mode without having any impact on the final results.

$$\sum_{TPo}\sum_{TPd}\sum_{HH}\sum_{TPe}\left(\sum_{r}\left(\sum_{rr} TPdomtravel_{TPo,TPd,TPe,HH,t,r,rr} \cdot \left(\frac{1}{uf_{TPo,TPd}} + \frac{TPwaittime_{TPo,TPd})}{TPdistancedom_{TPd,r,rr}}\right)\right) + TPintltravel_{TPo,TPd,TPe,HH,t,r} \cdot \left(\frac{1}{uf_{TPo,TPd}} + \frac{TPwaittime_{TPo,TPd}}{TPdistanceintl_{TPd,r}}\right)\right) - \sum_{TPo}\sum_{TPd}\sum_{r}\sum_{rr}\sum_{HH} TPtimeinvest_{TPo,TPd,HH,t,r,rr} \leq TPtimebudget \cdot \sum_{HH,r} Population_{HH,t,r}$$

Eq.(B11)

Accumulates all equipment capital and product import costs (units in million USD per year):

$$\sum_{RFu}\sum_{r}\left(RFpurcst_{RFu,t}RFbld_{RFu,t,r}\right)+\sum_{r}\left(RFELpurcst_{t}RFELbld_{t,r}\right)+$$
$$\sum_{RFcf}\sum_{r}RFImportprice_{RFcf,t,r}RFprodimports_{RFcf,t,r}=RFImports_{t}$$

Eq.(B12)

Accumulates all construction capital costs (units in million USD per year):

$$\sum_{RFu}\sum_{r}\left(RFconstcst_{RFu,t}RFbld_{RFu,t,r}\right)+\sum_{r}\left(RFELconstcst_{t}RFELbld_{t,r}\right)=RFConstruct_{t}$$

Eq.(B13)

Accumulates non-feedstock operations and maintenance costs (units in million USD per year):

$$\sum_{RFs}\sum_{r}\sum_{RFp}\sum_{RFf}\left(RFomcst_{RFs,RFp,t}RFop_{RFs,RFf,RFp,t,r}\right)+\sum_{r}\sum_{ELl}\left(RFELomcst_{t}RFELop_{ELl,ELs,ELday,t,r}\right)+$$
$$\sum_{RFcf}\sum_{r}\sum_{rr}\left(RFtranscst_{r,rr}RFtrans_{RFcf,t,r,rr}\right)=RFOpandmaint_{t}$$

Eq.(B14)

Accumulates all export revenue (units in million USD per year):

Note: If prices are deregulated, diesel and jet-fuel consumed domestically are sold at $RFIntlprice_{RFcf,t}$. While, gasoline is sold at $DRFdem_{TPee,t,r}$, which is the marginal value of the demand constraint for refined products.

$$\sum_{RFcf}\sum_{r}\left(RFintlprice_{RFcf,t}RFexports_{RFcf,t,r}\right)+\sum_{RFcf}\sum_{r}\left(RFdomprice_{RFcf,t}RFdemval_{RFcf,t,r}\right)+$$
$$\begin{cases} if\ prices\ are\ administered, \sum_{RFcf,r}\left(RFdomprice_{RFcf,t}RFdemval_{RFcf,t,r}\right) \\ f\ prices\ are\ deregulated, \sum_{RFcf,r}\left(RFIntlprice_{RFcf,t}RFdemval_{RFcf,t,r}\right) \end{cases}+$$
$$\begin{cases} if\ prices\ are\ administered, \\ \sum_{r,RFcf,TPo,TPd,HH}\left(RFdomprice_{RFcf,t}TPeconsump_{RFcf,TPo,TPd,HH,t,r}TPRFconv_{RFcf}\right) \\ if\ prices\ are\ deregulated, \sum_{r,RFcf,TPo,TPd,HH}\left(RFIntlprice_{RFcf,t}TPeconsump_{RFcf,TPo,TPd,HH,t,r}TPRFconv_{RFcf}\right) \\ \sum_{r,RFcf,TPo,TPd,HH}\left(DRFdem_{RFcf,t,r}TPeconsump_{RFcf,TPo,TPd,HH,t,r}Gasolineshare_{RFcf,t}TPRFconv_{RFcf}\right) \end{cases}+=$$
$$RFrevenues_{t}$$

Eq.(B15)

Balances mass flows between processing units (units in millions of metric tons per year):

$$\sum_{RFs}\sum_{RFf}\sum_{RFp}\left(RFyield_{RFs,RFf,RFci,RFp}RFop_{RFs,RFf,RFp,t,r}\right)+RFPCconsump_{RFci,t,r}-$$
$$\sum_{RFs}\sum_{RFp}RFop_{RFs,RFci,RFp,t,r}\geq 0$$

Eq.(B16)

Total consumption of feedstock input to refineries (units in millions of metric tons per year):

$$RFcrconsump_{RFcr,t,r} - \sum_{RFs} \sum_{RFp} RFop_{RFs,RFcr,RFp,t,r} \geq 0$$

Eq.(B17)

Enforces feedstock availability, if supply is limited (units in millions of metric tons per year):

Currently, there are no constraints on the supply of all crude grades.

$$-RFcrconsump_{RFcr,t,r} \geq -RFcrudesupply_{RFcr,t,r}$$

Eq.(B18)

Capacity balance for refining units (units in millions of metric tons per year):

$$RFexistcp_{RFu,t,r} + RFaddition + RFbld_{RFu,t-RFleadtime_{RFu},r} - RFexistcp_{RFu,t+1,r} \geq 0$$

Eq.(B19)

Ensures production level does not exceed capacity (units in millions of metric tons per year):

$$RFexistcp_{RFu,t,r} + RFbld_{RFu,t-RFleadtime_{RFu},r} - \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFcapfactor_{RFu,RFp} RFop_{RFs,RFf,RFp,t,r} \right) \geq 0$$

Eq.(B20)

Supply constraint (units in millions of metric tons per year):

$$\sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFyield_{RFs,RFf,RFcf,RFp} RFop_{RFs,RFf,RFp,t,r} \right) - RFexports_{RFcf,t,r} - \sum_{rr} RFtrans_{RFcf,t,r,rr} \geq 0$$

Eq.(B21)

Satisfying demand (endogenous and exogenous demands in millions of metric tons):

$$- \sum_{RFcf,TPo,TPd,HH} TPeconsump_{RFcf,TPo,TPd,HH,t,r} \cdot TPRFconv_{RFcf} + RFprodimports_{RFcf,t,rr} + \sum_{r} RFtrans_{RFcf,t,r,rr} \geq RFdemval_{RFcf,t,rr}$$

Eq.(B22)

Aggregates regional exports to the national level (units in millions of metric tons per year):

$$RFnatexports_{RFcf,t} - \sum_{r} RFexports_{RFcf,t,r} = 0$$

Eq.(B23)

Ensures upper limit of blend properties is satisfied:

$$Qspecification_{max,RFcf,prop} \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFyield_{RFs,RFf,RFcf,RFp} RFconv_{RFf,prop} RFop_{RFs,RFf,RFp,t,r} \right) - \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFyield_{RFs,RFf,RFcf,RFp} RFconv_{RFf,prop} RFop_{RFs,RFf,RFp,t,r} Qattributes_{RFf,prop} \right) \geq 0 \; ^{-}$$

Eq.(B24)

Ensures lower limit of blend properties is satisfied:

$$-Qspecification_{min,RFcf,prop} \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFyield_{RFs,RFf,RFcf,RFp} RFconv_{RFf,prop} RFop_{RFs,RFf,RFp,t,r} \right) + \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFyield_{RFs,RFf,RFcf,RFp} RFconv_{RFf,prop} RFop_{RFs,RFf,RFp,t,r} Qattributes_{RFf,prop} \right) \geq 0 \text{ Eq.}$$

Eq.(B25)

Capacity balance for on-site power generation (units in GW per year):

$$RFELexistcp_{t,r} + RFELbld_{t,r} - RFELexistcp_{t+1,r} \geq 0$$

Eq.(B26)

Ensures on-site electricity generation does not exceed capacity (units in TWh per year):

$$RFELexistcp_{t,r} + RFELbld_{t,r} - RFELexistcp_{t+1,r} \geq 0$$

Eq.(B27)

Measures total electricity requirement – as base load (units in TWh per year):

$$-RFELlchrsfraction_{ELl} ELnormdays_{ELs,ELday} \sum_{RFs} \sum_{RFf} \sum_{RFp} \left(RFELin_{RFs,RFp} RFop_{RFs,RFf,RFp,t,r} \right) + RFtotELconsump_{ELl,ELs,ELday,t,r} \geq 0 \quad \text{Eq. (B28)}$$

Eq.(B28)

Ensures electricity requirement is satisfied by either on-site generation or the grid (units in TWh per year):

$$RFELop_{ELl,ELs,ELday,t,r} + RFELconsump_{ELl,ELs,ELday,t,r} - RFtotELconsump_{ELl,ELs,ELday,t,r} = 0$$

Eq.(B29)

Appendix C: Model Calibration

Table C1. Sources used to calibrate the parameters in the model.

Parameter	Source
Transportation monetary budgets	GSTAT (2013)
Demand for transportation services	Girod et al. (2013)
The national demands for gasoline in 2013	Arabian Monetary Agency (SAMA) (2015)
Load factor of gasoline-powered vehicles and buses	International Energy Agency (IEA) (2009)
Load factor of high-speed rail	International Railway Journal (2015)
Load factor of metro	ALSTOM (2016) and Karavali Times (2013)
Load factor of rail	Construcciones y Auxiliar de Ferrocarriles (2013)
Load factor of airplanes	Mishra et al. (2013)
Efficiency of gasoline-powered vehicles	Alabbadi (2012)
Efficiency of metro	Al Ali (2015)
Efficiency of high-speed rail and diesel rail	Krishnan et al. (2015)
Efficiency of airplanes	Aircraft Commerce (2005)
Efficiency of buses	Proc et al. (2006)
Inter and inter-regional demand distribution	IEA (2009)
Transportation demand in PKM for buses	SAPTCO (2015)
Transportation demand in PKM for airplanes	International Civil Aviation Organization (2013)
Transportation demand in PKM for rail	GASTAT (2014)
Fares of buses	SAPTCO (2015)
Fares of airplanes	Saudia (2015)
Fares of rail	SRO (2015)
Fares of high-speed rail	Argaam (2015)
Fares of metro	Arab News (2016) and Santos et al. (2009)
The domestic capacity for buses	Al-Ohaly (2015)
The domestic capacity for airplanes	Saudia (2013) and Flynas (2015)
The domestic capacity for trains	SRO (2015)
The domestic capacity for metro	Riyadh Metro (2016)
The domestic capacity for the northern rail	Construcciones y Auxiliar de Ferrocarriles (2013) and aljunedy (2015)
The domestic capacity for high-speed rail	Alarabiya (2016)
The international capacity for buses	SAPTCO (2015)
Inter-, intra-regional and international distances	GASTAT (2014)
Value of time for domestic travel	Litman (2009)
Value of time for international travel	Belenky (2011)
The average wage rates	Ministry of Labor (2013)
Number of working hours per week	GASTAT (2013)
Congestion burden	Litman (2009)
Crash risk	Litman (2009)
Preference factor	Girod et al. (2013)
Discount rate	Litman (2009)
Price elasticity of gasoline demand	Dahl (2012)

Crude oil prices	Oxford Economics (2016)
Growth of natural gas and oil production	Oxford Economics (2016)
Growth of industrial production index	Oxford Economics (2016)
Growth of petrochemical gross output	Oxford Economics (2016)
Growth of cement gross output	Oxford Economics (2016)
Growth of refining gross output	Oxford Economics (2016)
Population and salary growth	Oxford Economics (2016)
GDP growth	Oxford Economics (2016)
Growth of metro capacity	Riyadh Metro (2016)
Total refined products income elasticity	Al Yousef (2013)
Unit capacity data for refineries	IHS Midstream Database
Mass yields of processes	Ceric (2001), Favennec (2001) and Gary and Handwerk (2005)
Existing electricity generation capacity in the refining sector	Electricity & Cogeneration Regulatory Authority (2016)
Electricity market price	U.S. Energy Information Administration (2016)

Source: KAPSARC.

Notes

About the Team

Ibrahim M. Algunaibet

Ibrahim is a visiting researcher from Saudi Aramco developing energy systems models with emphasis on transportation. He holds a bachelor's degree in mechanical engineering from Arizona State University.

About the Project

We developed the KAPSARC Energy Model for Saudi Arabia (KEM-SA) to understand the dynamics of the country's energy system. It is a partial equilibrium model formulated as a mixed complementarity problem to capture the administered prices that permeate the local economy. KEM-SA has been previously used to study the impacts of various industrial fuel pricing policies and improved residential efficiency on the energy economy. The passenger transportation model presented in this paper helps understand more of the end-use energy demand.

KAPSARC

مركز الملك عبدالله للدراسات والبحوث البترولية

King Abdullah Petroleum Studies and Research Center

www.kapsarc.org