Cooperate or Compete? Insights from Simulating a Global Oil Market with No Residual Supplier

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APPENDIX A: FORMULATION OF THE COMPETITIVE EQUILIBRIUM MODEL

A.1 Optimality conditions of the competitive equilibrium model

(A1)

$E_{jt} \geq q_{jt} \quad \perp \lambda_{jt} \geq 0 \quad \forall\, jt$ (A1.1)

$(b_{kt'} F_{kt+\Delta t})|_{T_k \leq t'} \geq x_{kt't} \quad \perp \mu_{kt't} \geq 0 \quad \forall\, k, T_k \leq t' \leq t$ (A1.2)

$\sum_{T_k \leq t'} b_{kt'} \leq 1 \quad \perp \gamma_k \geq 0 \quad \forall\, k$ (A1.3)

$\widehat{\mathrm{H}}_{t'} \geq \sum_{k_S} K_{k_S t'+\Delta t} b_{k_S t'} + \sum_{j_S, t=t'} K_{j_S t} \frac{q_{j_S t}}{E_{j_S t}} \quad \perp \varphi_{t'} \geq 0 \quad \forall\, t$ (A1.4)

$\widehat{\mathrm{K}}_{t'} \geq \sum_{\tau \geq t}^{\infty} \sum_{k_L} \frac{K_{k_L \tau+\Delta t} b_{k_L t}}{(1+r)^{(\tau - t_S)}} \quad \perp \sigma_{t'} \geq 0 \quad \forall\, t \geq T_k$ (A1.5)

$C_{jt} + \lambda_{jt} + \varphi_t \frac{K_{jt}}{E_{jt}}\Big|_{j=j_S} \geq p_t M_{jt} \quad \perp q_{jt} \geq 0 \quad \forall\, jt$ (A1.6)

$C_{kt+\Delta t'} + \mu_{kt't} \geq p_t M_{kt} \quad \perp x_{kt't} \geq 0 \quad \forall\, kt't$ (A1.7)

$\gamma_k + \sum_{\tau \geq t'} K_{k,\tau+\Delta t'} \left(\frac{1}{(1+r)^{(\tau - t_S)}} + \frac{\sigma_{t'}}{(1+r)^{(\tau - t_S)}} \right) \geq \sum_t \mu_{kt't} F_{k,t+\Delta t} +$
$\sum_{\tau > t_N} \frac{(p_{t_N} M_{k\tau+\Delta t'} - C_{k\tau+\Delta t'}) F_{k\tau+\Delta t'}}{(1+r)^{(\tau - t_S)}} \quad \perp b_{kt'} \geq 0 \quad \forall\, k = k_L t' \geq T_k$ (A1.8)

$\gamma_k + \varphi_{t'} K_{kt'+\Delta t'} \geq \sum_t \frac{\mu_{ktt'} F_{kt+\Delta t'}}{(1+r)^{(t - t_S)}} \quad \perp b_{kt'} \geq 0 \quad \forall\, k = k_S t' \geq T_k$ (A1.9)

$D_t = A_t \bar{p}_t^{\varepsilon} Y_t^{\gamma}$ (A1.10)

$Y_t = Y_{t-1} \left(1 + \tilde{g}_t (\bar{p}_t / \tilde{p}_t)^{\theta}\right)$ (A1.11)

$\sum_j q_{jt} + \sum_{kt'} x_{kt't} \geq D_t \quad \perp p_t \geq 0 \quad \forall\, it$ (A1.12)

To solve the supply and demand problems simultaneously we formulate an equilibrium model as a Mixed Complementarity Problem (MCP). The reader is referred to Table 1 for a list of all the model components.

The MCP defined in equation block (A1) combines the optimality conditions of the supply model from equation block (5), equations (A1.1) to (A1.9), the demand functions (A1.10) and (A1.11), and the independent demand constraint (A1.12). The first five equations are primal equations from the supply model. (A1.4) and (A1.5), are the additional financial constraints on short-term tight oil production and new long-term projects. In the former capital development costs for all tight oil production in a given year (associated with new projects $b_{k_S t'}$ and the ratio of production $q_{j_S t}$ relative to existing capacity $E_{j_S t}$) are capped by the coefficient $\widehat{\mathrm{H}}_{t'}$. In the latter, the present value (PV) of the capital approved for all new long-term projects k_L is capped by $\widehat{\mathrm{K}}_{t'}$.

Equations (A1.6), (A1.7), (A1.8) and (A1.9) are the complementarity conditions for the primal variables q_{jt}, $x_{kt,t'}$, $b_{k_L t'}$ and $b_{k_S t'}$, respectively. They are expressed in terms of the dual variables λ_{jt}, $\mu_{kt't}$, γ_k, $\varphi_{t'}$ and $\sigma_{t'}$ and coefficients, derived from the stationarity conditions of the Lagrangian corresponding to (5).

Returning to the financial constraints, when (A1.4) and (A1.5) are binding the dual variables $\varphi_{t'}$ and $\sigma_{t'}$ represent the scarcity premium on capital available for tight oil, and new long-term projects, respectively. For example, on the left-hand side of optimality condition (A1.8) $\sigma_{t'}$ inflates the capital development cost adjusting the profitability of investing in new long-term projects.

The model is built using the General Algebraic Modeling System (GAMS) and solves numerically using the PATH solver. The Extended Mathematical Programing (EMP) framework (Ferris et al. 2009) is used to facilitate the construction of the MCP.

A.2 The residual supplier version of the equilibrium model

$$\hat{P}_t \geq p_t \quad \perp r_t^+ \geq 0 \quad \forall\, t \qquad \text{(A2.1)}$$

$$\check{P}_t \leq p_t \quad \perp r_t^- \geq 0 \quad \forall\, t \qquad \text{(A2.2)}$$

We use complementary slackness to set up a residual supplier version of (5) with price targets, as discussed in the main text. Additional constraints, representing a price ceiling (A2.1) and price floor (A2.2), are added to the equilibrium problem, using the coefficients $\hat{P}_t$ and $\check{P}_t$, respectively. These signal the residual supplier to add or remove capacity, $r_t^+$and r_t^-, respectively in anticipation of production by the competitive fringe to achieve the price targets. They are defined as dual variables on each of the price constraints and are added or subtracted from the total production of the residual supplier in (A1.1), respectively. The latter presents the aggregate spare capacity of the residual supplier.

These production additions and removals can be distributed across the residual supplier's projects in several ways. For example, withhold the most expensive assets (revenue maximization), or by distributing it relative to the share of capacity of each asset. The optimal strategy will depend on various technical characteristics negotiations among different suppliers and participating countries. This process can be quite political in nature. For simplicity we select a strategy that distributes spare capacity relative to the weighted production of all projects operated by the residual supplier.

Given that the price target is fixed, the fringe and residual supplier's production level could also be evaluated using a pure accounting approach. However, we leverage the flexibility of the equilibrium model to evaluate production and investment decisions under different constraints, to avoid constructing a more complex accounting logic.

A.3 The recursive problem

The full MCP in (A1) can either be solved as a single problem over $t = \{t_s, t_{s+1}, \dots\ t_N\}$, or recursively for several smaller time steps $\vec{t}$ of size n, $\vec{t} = \{t_s, t_{s+1}, \dots\ t_{s+n}\}$. All t and t' are replaced by $\vec{t}$ and $\vec{t}$', with $n < N$ and s denoting the start year in each recursive step. After solving the equilibrium model for the first period, we perform the recursive operations outlined in (A3) to update the model coefficients, move forward the start year, $s = s + 1$, and repeat until we reach the last period, $s + n = N$.

The number of years solved during each step can be adjusted to represent suppliers as myopic or forward-looking. In the former a limited amount of information or expectations about demand and production in future years is available. In the extreme case suppliers only consider decisions made in the current start years, $s = n$.

(A3)

$$j = j \cup k; \qquad if\ b_{kt_s'} > 0 \qquad \text{(A3.1)}$$

$$C_{kt} = (\tilde{C}_{kt+\Delta t'} b_{kt_s'} F_{k,t+\Delta t'} + E_{kt} C_{kt}) / (b_{kt_s'} F_{k,t+\Delta t_s'} + E_{kt}) \qquad \forall\ kt \geq t_s \qquad \text{(A3.2)}$$

$$E_{kt} = E_{kt} + b_{kt_s'} F_{k,t+\Delta t'} \qquad \forall\ kt \geq t_s \qquad \text{(A3.3)}$$

$$B_k = B_k + b_{kt_s'} \qquad \forall\ k \qquad \text{(A3.4)}$$

$k = false; \quad if\ B_k = 1$ (A3.5)

$s = s + 1$ (A3.6)

In (A3.1) we include all new projects i' that are built in the current start period ($b_{i't'_s} > 0$) to the set of existing projects. In (A3.2) the projected cost profiles for new projects built in t' are adjusted based on the shift parameter $\Delta t' = t_s - t'$. We define $\tilde{C}_{kt}$ as a copy of the original C_{kt}, to track cost profiles of new projects partially built in different years. Notice the updated cost parameter is a weighted average of the production profile corresponding to the current build ($b_{kt'_s}F_{k,t+\Delta t'}$) of a new project and the existing production resulting from the partial build of the same project in past years, where E_{kt}, is initially 0. In (A3.3) we add the production profiles for new projects built in the current start year to the existing capacity parameter E_{it}, again accounting for the shift parameter $\Delta t'$.

In Eq. (A3.4) we introduce the unitless coefficient B_k that keeps track of all new build decisions from previous start years, initialized to 0. Any new project built to completion ($B_k = 1$) are removed from the subset k in (A3.5). Under the recursive approach, we add $B_{kt'}$ to the left-hand side of (A1.3) since we are solving the model over the reduced time period $\vec{t}$ that excludes values from previous start years. Finally, in (A1.6) we move forward to the next start year, then solve the next equilibrium problem and repeat.

A.4 Estimation of θ and calibration of A_t in the demand equation

To estimate an approximate value of θ in Eq. (2) we consider the following equation:

$$ln\frac{g_t}{g_{t-1}} = \theta ln\frac{p_t}{p_{t-1}} + u_t \quad \text{(A.4)}$$

where u_t is an error term. To get Eq. (A.4) we consider the growth equation given in Eq. (2) (i.e. $g_t = \tilde{g}_t\left(\frac{\bar{p}_t}{\bar{\tilde{p}}_t}\right)^{\theta}$), take the natural logarithm of both sides and replace $\tilde{g}_t$ and $\bar{\tilde{p}}_t$ by g_{t-1} and p_{t-1}, respectively. To avoid spurious regression, we test for stationarity of the variables in Eq. (A.4) using the augmented Dickey-Fuller (Dickey and Fuller 1981) and the Phillips and Perron (1988) unit root tests. Both series are found to be stationary, which allows us to estimate Eq. (A.4) by means of ordinary least squares (OLS). The estimated value for θ from the OLS regression is -0.2, which will thus be used in the following simulations to replace θ in Eq. (2).[1]

[1] In both ADF and PP tests the Akaike information criterion (AIC) is used to choose the lag length. The OLS regression includes time dummies for the years 2009 and 2010 to control for the effects of global financial crisis.

For the sake of completeness, the sensitivity of the results is evaluated against a range of plausible values for θ (such as -0.5 and -0.8). The results of the sensitivity analysis (unreported here) show that our simulation results are robust to different values of θ.

The reference prices, demand, and GDP from the WEO state policies scenario (IEA 2019) and IEO reference scenario (EIA 2019) used to calibrate the scaling coefficient A_t with a price elasticity of -0.25 and income elasticity of 0.75 are provided in Table A.1. Notice the slower average demand and price growth in the IEO resulting in reduced scaling coefficients, A_t.

Table A.1. IEA WEO 2019 oil demand, oil price (Brent) GDP, and corresponding calibration coefficients A_t

Year	Oil Demand, $\widetilde{\boldsymbol{D}}_{\boldsymbol{t}}$ (MMb/d)		Oil Price, $\widetilde{\boldsymbol{P}}_{\boldsymbol{t}}$ ($/b)		GDP PPP Growth (%)		$\boldsymbol{A_t}$ $\boldsymbol{\varepsilon = -0.25}$, $\boldsymbol{\gamma = 0.75}$	
	IEA	*EIA*	*IEA*	*EIA*	*IEA*	*EIA*	*IEA*	*EIA*
2012	117.66		89.72		3.5			
2013	112.28		90.74		3.5			
2014	101.54		96.11		3.6		0.0476	
2015	52.46		42.05		3.5		0.0444	
2016	44.55		48.04		3.5		0.0414	
2017	96.60		54.16		3.7		0.0381	
2018	99.20		70.81		3.7		0.0392	
2019	98.75	99.83	61.04	61.04	3.6	3.2	0.0389	0.0380
2020	99.83	102.20	65.53	63.00	3.6	3.5	0.0391	0.0384
2021	100.90	102.56	70.03	67.00	3.6	3.5	0.0385	0.0373
2022	101.98	102.92	74.52	68.00	3.6	3.3	0.0386	0.0368
2023	103.05	103.28	79.01	69.00	3.6	3.3	0.0386	0.0363
2024	104.13	103.64	83.51	70.00	3.6	3.2	0.0386	0.0357
2025	105.20	104.00	88.00	71.15	3.6	3.3	0.0385	0.0352
2026	105.70	104.36	89.60	72.31	3.6	3.2	0.0382	0.0346
2027	106.20	104.72	91.20	73.46	3.6	3.2	0.0377	0.0340
2028	106.70	105.08	92.80	74.61	3.6	3.2	0.0371	0.0335
2029	107.20	105.44	94.40	75.77	3.6	3.1	0.0365	0.0330
2030	107.70	105.80	96.00	76.92	3.6	3.1	0.0359	0.0325

Source: IEA (2019b), EIA (2019), KAPSARC analysis.

While time dummies are significant, the parameter θ is found to be insignificant at conventional levels. To ensure the goodness of fit of the model a series of diagnostic and stability tests are also conducted. To conserve space, we do not report the econometric results here.

A.5 Data used for modeling oil supply

We use the Rystad Energy Ucube dataset, downloaded from Rystad Ucube client portal in July 2019, to construct aggregate piecewise-linear supply curves. The dataset includes existing and new (not yet approved for investment) oil-producing assets.

Ucube is constructed using a bottom-up approach based on the private sector and government reporting. It includes more than 21,000 individual assets covering the major sources of global oil production, with historical and projected data up to the year 2100. Data includes production profiles, fixed and variable production costs, investment costs, and investment plans. Ucube provides an approval year (when the development was or is expected to be sanctioned), and the lead time between the approval year and first year of production of an asset.

All hydrocarbon liquids are considered, including crude oil, condensate, NGLs, refinery gains, and other liquids. Liquids produced from gas-condensate fields (gas fields with condensate-to-gas-ratio exceeding 1 b/million cubic feet) are assumed to be a byproduct with no additional costs in our model.

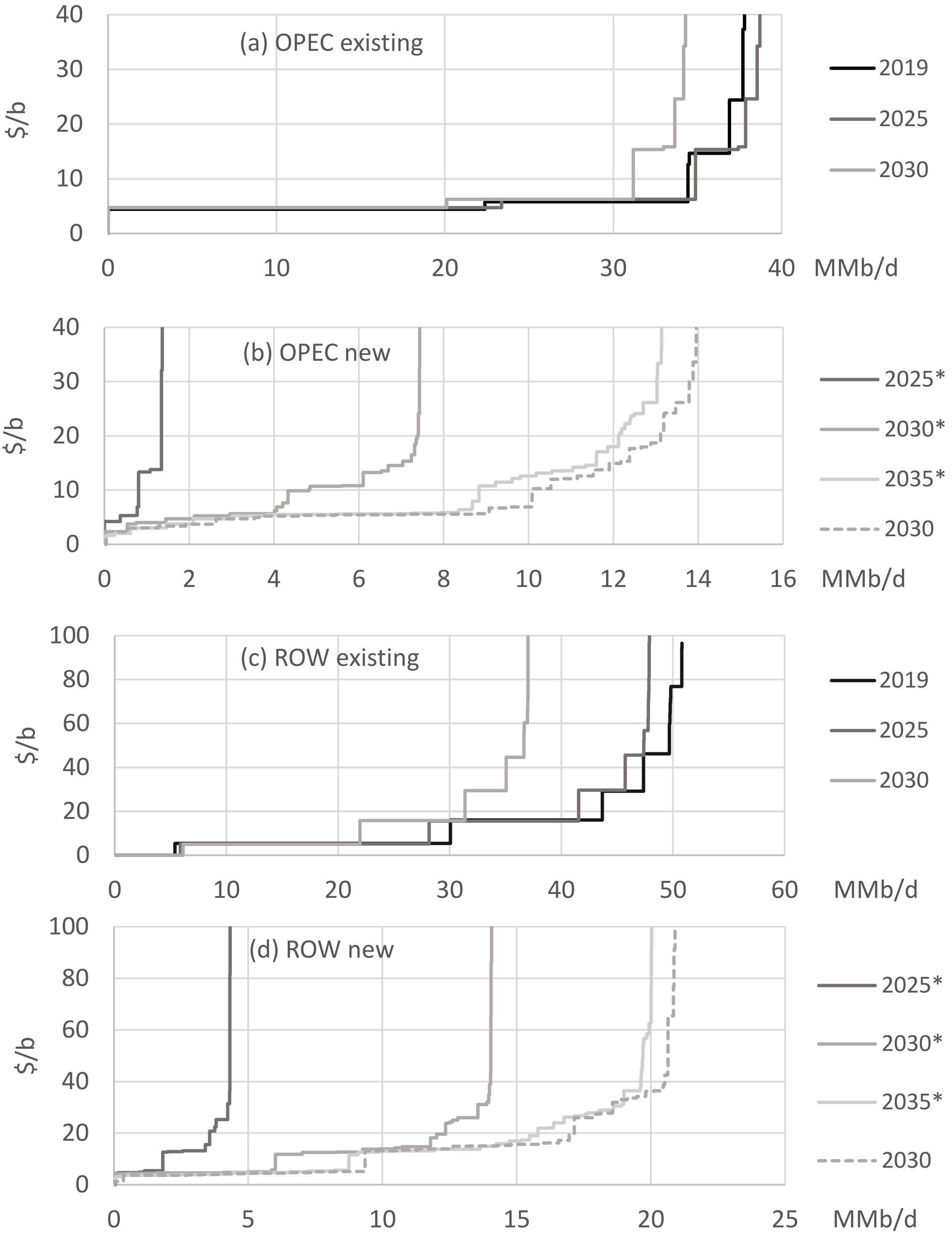
Tight oil fields are treated separately. Due to the inability to disaggregate production profiles of individual wells from the extracted Rystad supply data, we chose to use the full cycle breakeven prices for a series of wells, as opposed to the breakeven price of each well. Breakeven prices are calculated by estimating the oil price that gives an NPV of zero-based on future free cash flow. Cash flows incorporate all production costs (CAPEX and OPEX) as well as any government taxes. A discount rate of 10% is applied to calculate the NPV.

We also use Rystad data to calculate the price coefficient M_{it} for all hydrocarbon liquids at the asset level based on the API, other discount elements (sulfur content, etc.), and regional price markers. This estimates the difference between the price paid for production from an asset and the Brent price used to calibrate the demand curve in our model. Prices for condensates, NGL and natural gas are estimated within the Rystad supply data based on defined links to oil prices.

A.6 Aggregate supply curves

Using an aggregate version of the Rystad data allows us to solve the numerical problem over the full model horizon by significantly reducing the number of supply variables. Figures A.1 and A.2 provide a snapshot of the annual aggregate supply curves constructed for existing and new projects from OPEC (A.1(a) and A.1(b), respectively), the rest of the world (ROW) (A.1(c) and A.1(d), respectively), and finally the production from all tight oil projects (Figure A.2). Most of the tight oil production comes from the US, with less than 1 MMb/d from plays in Canada, Argentina, and others. Finally, Figure A.3 represents the global supply curves combining all production, existing and new. We also present a relaxed supply curve for 2030, denoted by a dashed line in the figures above, assuming all projects with approval years between 2020 and 2050 are instead potentially available for investment starting in 2020. This reflects the supply potential in scenarios where the model approves projects based on financial viability, as opposed to the Rystad investment plan.

Figure A.1. Aggregate supply curves for existing and new non-tight-oil production by OPEC (a,b) and ROW (c,d) at different time horizons.

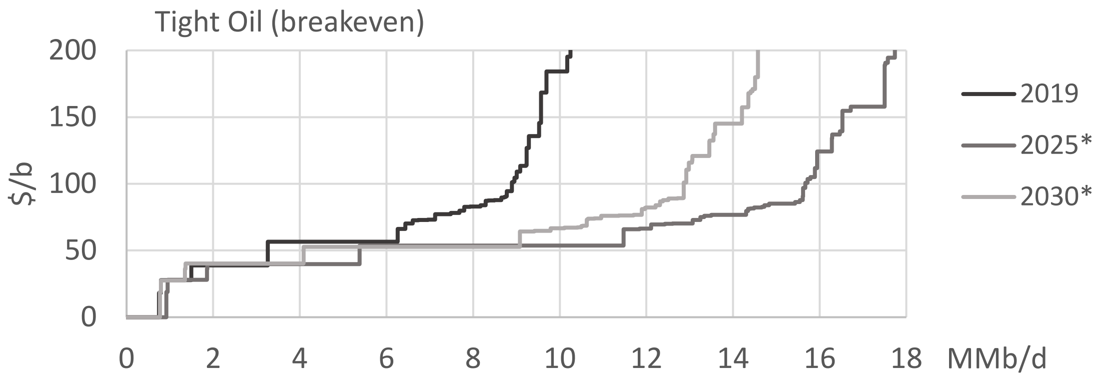


*Supply curves following the Rystad investment plan.

Source: Rystad, KAPSARC analysis.

Note: Rest of world (ROW) designates all non-OPEC producers. The dashed lines depict supply curves in 2030 assuming all new projects approved between 2020 and 2050 under Rystad's investment plan are approved in 2020 (i.e., not constrained by approval dates).

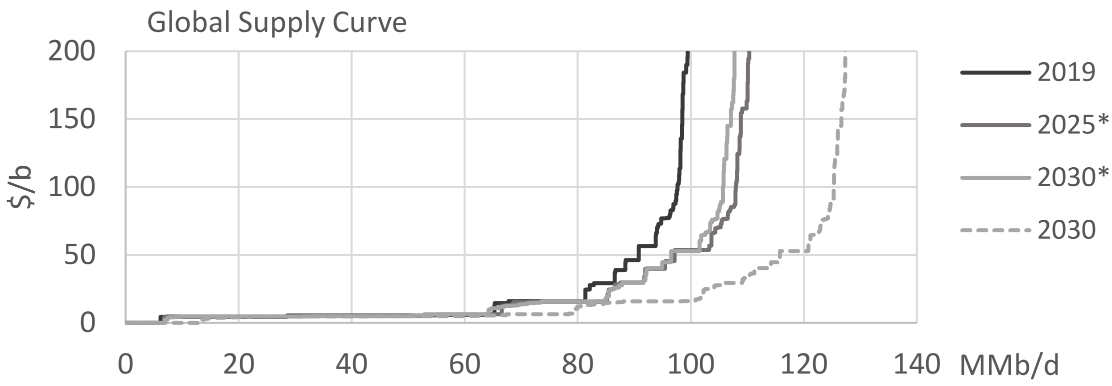
Figure A.2. Aggregate supply curves for tight oil production at different time horizons



* Supply curves following the Rystad investment plan.

Source: Rystad, KAPSARC analysis.

Figure A.3. Aggregate supply curves for global liquids production at different time horizons



* Supply curves following the Rystad investment plan.

Source: Rystad, KAPSARC analysis.

Note: Figure A.3 represents global supply curves for all liquids, including tight oil, existing and potential new projects. The dashed line depicts the global supply curve in 2030 assuming all new projects approved between 2020 and 2050 under the Rystad investment plan are approved in 2020 (i.e., not constrained by approval dates).

For existing projects, the vertical axis represents the variable production cost. For new projects, we consider the long-run production cost by adding a capital cost to the operating production cost. The added capital cost is equal to the present value of investment costs divided by the discounted sum of the volumes produced over the project's lifetime. As explained earlier, breakeven prices are used for tight oil.

Note that in Figure A.1(a), for OPEC's existing assets the 2025 curve is on the right side of the curve for 2019 since new but already approved projects more than compensate the decline in production of already-producing assets.

Except for the relaxed 2030 supply curves (dashed lines), the development of new assets, labeled by an asterisk in the figures above, is constrained by the approval dates, and the further the time horizon, the larger the set of assets that can be put in production. As a result, the supply curve shifts to the right when the time horizon considered increases, except when potential new projects do not compensate for the natural decline in the production of existing assets.

Regarding Figure A.3 the supply curve slightly shifts to the left between 2025 and 2030, due to depletion of existing oil fields (and despite potential new projects). However, when the approval years of new projects are relaxed the supply curve shifts to the right through 2030.

Before aggregating the original supply data, we divide the original cost parameters by the price coefficients M_{it}. This way the production costs of the original assets i are adjusted to reflect differences in the value of the oil produced. Next, the original assets are organized into new groupings i' of the adjusted production cost coefficients over a specified range. The weighted averages of each group are calculated, denoted $C^*_{i'{t}}$, based on the annual production of each asset. For each group, the weighted average price coefficients, $M^*_{i't}$, aggregate annual production and capital expenditures of each group are also found. Finally, $C^*_{i't}$ is multiplied by $M^*_{i't}$ to get the unadjusted production cost coefficients to calibrate the supply curves.

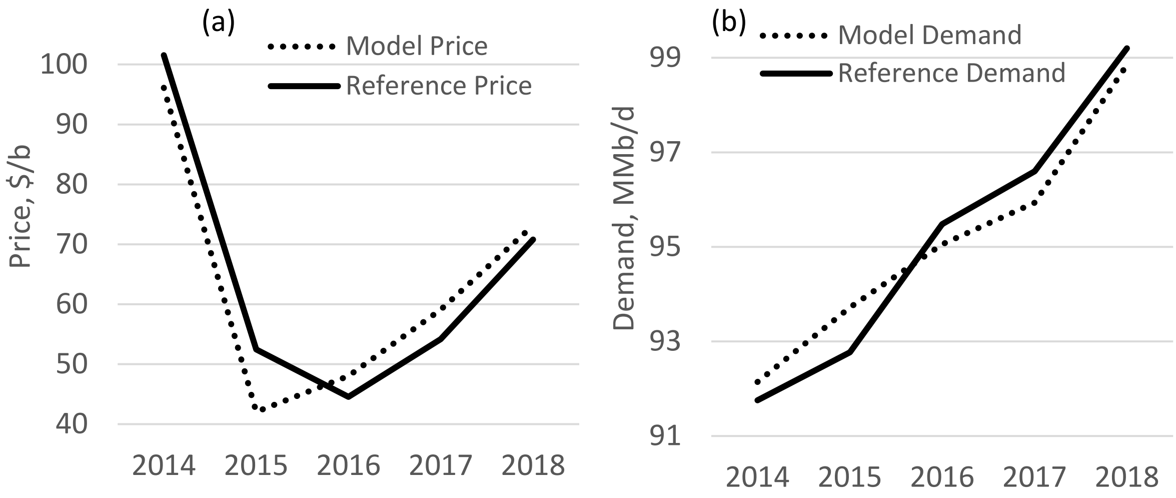
When choosing the cost range of the asset grouping, we set a coarser resolution (e.g. 0-10 $/b) to lower down the supply curve, increasing resolution to (e.g. to 1 $/b) as we approach the marginal production unit. This reduces the number of original assets from 19,830 (excluding decommissioned assets) to 438, while preserving important structural features of the supply curves.

APPENDIX B: ADDITIONAL SCENARIO ANALYSIS

B.1 Model backtesting

The results of the model scenarios calibrated to historic market conditions (reference) from 2014 to 2018 are shown in Figure B.1 In this scenario, OPEC production is fixed to historic levels and the equilibrium model is solved for production from all other suppliers. The normalized root mean squared errors and correlation coefficients between observed and model-generated data are 0.093 and 0.97, respectively, for demand, and 0.11 and 0.95 for price.

Figure B.1. Price (a) and demand (b) from the competitive market scenario calibrated to observed data (reference level) from 2014 to 2018

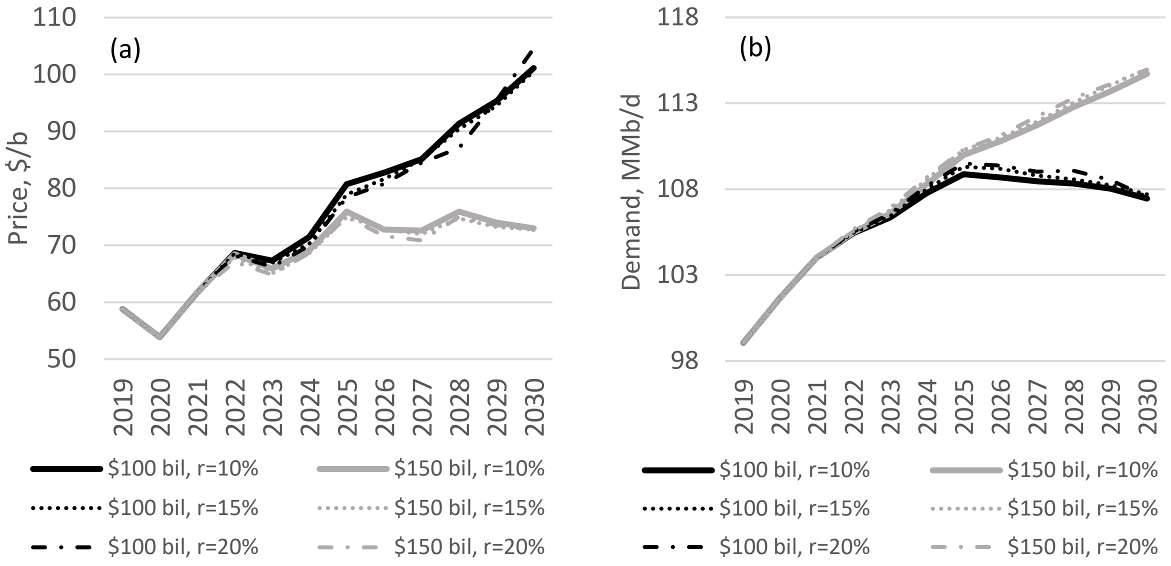


Source: IEA (2019b) World Energy Outlook, KAPSARC analysis.

B.2 Sensitivity analysis under different discount rates

Figure B.2 shows price and demand from the competitive market scenarios with the $100 and $150 billion investment constraints when applying higher discount rates. Overall, there is a minor impact on the equilibrium prices and demand when applying a 15% discount rate. Increasing the discount rate to 20% also did not change the equilibrium significantly. We observe larger deviations in prices when tightening the investment cap (e.g. $100 billion). Between the years 2023 and 2030 the magnitude of the change in prices, relative to the scenario with the 10% discount rate, was on average within one $/b (1.3%) with a standard deviation of no more than 2.1 $/b (2.2%).

Figure B.2. World oil price (a) and demand (b) simulations using a 10%, 15% and 20% discount rate

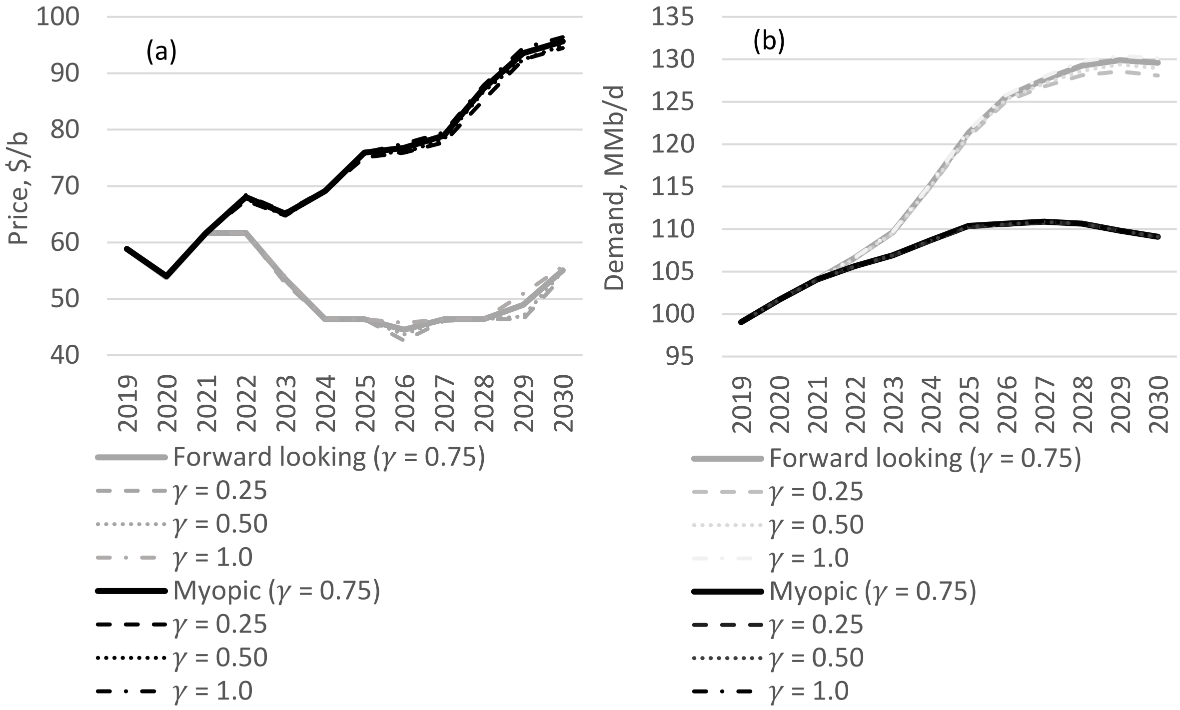


Source: KAPSARC analysis.

B.3 Sensitivity analysis under different income and price elasticity assumptions

B.3.1 Sensitivity with respect to income elasticity

Figure B.3. World oil price (a) and demand (b) for the competitive scenario under the Rystad investment plan for different income elasticity assumptions.



Source: KAPSARC analysis.

B.3.2 Sensitivity with respect to price elasticity

The results from the equilibrium problem solved in the competitive scenario under the Rystad investment plan are listed in Table B.1, alongside the reference values from the IEA's stated policies scenarios.

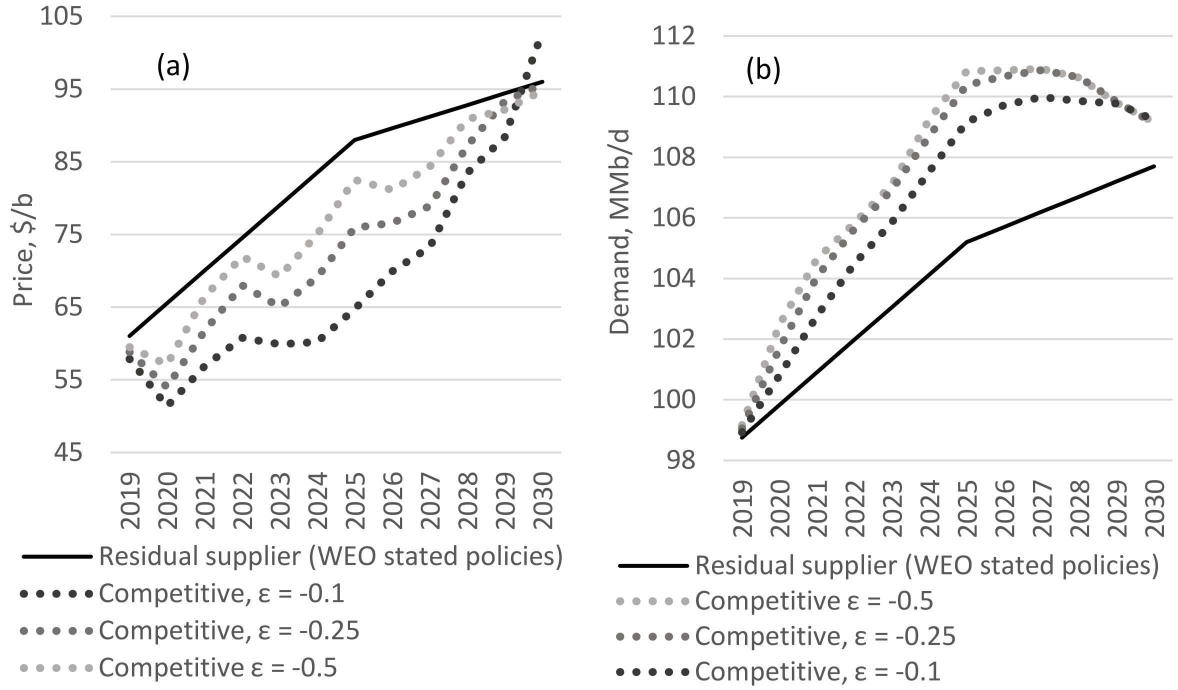
Table B.1 Scenario results for demand, price, and GDP in the competitive market scenarios under the Rystad investment plan.

	Demand (MMbbl/d)				Oil price ($/bbl)				GDP Growth (%)				
Year	**IEA WEO**	**ε = -0.1**	**ε = -0.25**	**ε = -0.5**	**IEA WEO**	**ε = -0.1**	**ε = -0.25**	**ε = -0.5**	**IEA WEO**	**Growth**	**ε = -0.1**	**ε = -0.25**	**ε = -0.5**
2018	*99.2*				*70.81*				*131,908*				
2019	98.8	98.9	99.0	99.2	61.0	57.9	58.8	59.5	136,657	3.7 %	3.4%	3.4%	3.4%
2020	99.8	100.8	101.7	102.5	65.5	51.4	54.0	57.1	141,576	3.7 %	3.5%	3.4%	3.4%
2021	100.9	102.8	104.0	104.6	70.0	56.9	61.7	66.4	146,673	3.6 %	3.5%	3.5%	3.4%
2022	102	104.5	105.6	105.8	74.5	60.8	68.0	72.0	151,953	3.6 %	3.6%	3.5%	3.4%
2023	103.1	105.8	106.9	107.1	79.0	59.9	65.0	69.2	157,424	3.6 %	3.6%	3.5%	3.5%
2024	104.1	107.5	108.7	109.2	83.5	60.2	69.1	75.0	163,091	3.6 %	3.6%	3.5%	3.5%
2025	105.2	109.2	110.4	110.8	88.0	64.8	75.9	82.5	168,962	3.6 %	3.6%	3.5%	3.5%
2026	105.7	109.7	110.7	110.9	89.6	69.9	76.6	81.1	175,045	3.6 %	3.6%	3.5%	3.5%
2027	106.2	110.0	110.9	110.9	91.2	73.3	78.9	84.3	181,346	3.6 %	3.6%	3.5%	3.5%
2028	106.7	109.9	110.6	110.6	92.8	83.4	87.2	90.9	187,875	3.6 %	3.5%	3.5%	3.4%
2029	107.2	109.8	109.8	109.8	94.4	88.4	93.3	92.2	194,638	3.6 %	3.5%	3.4%	3.4%
2030	107.7	109.2	109.1	109.2	96.0	102.9	95.6	94.8	201,645	3.6 %	3.4%	3.4%	3.4%

Source: IEA (2019b), KAPSARC analysis.

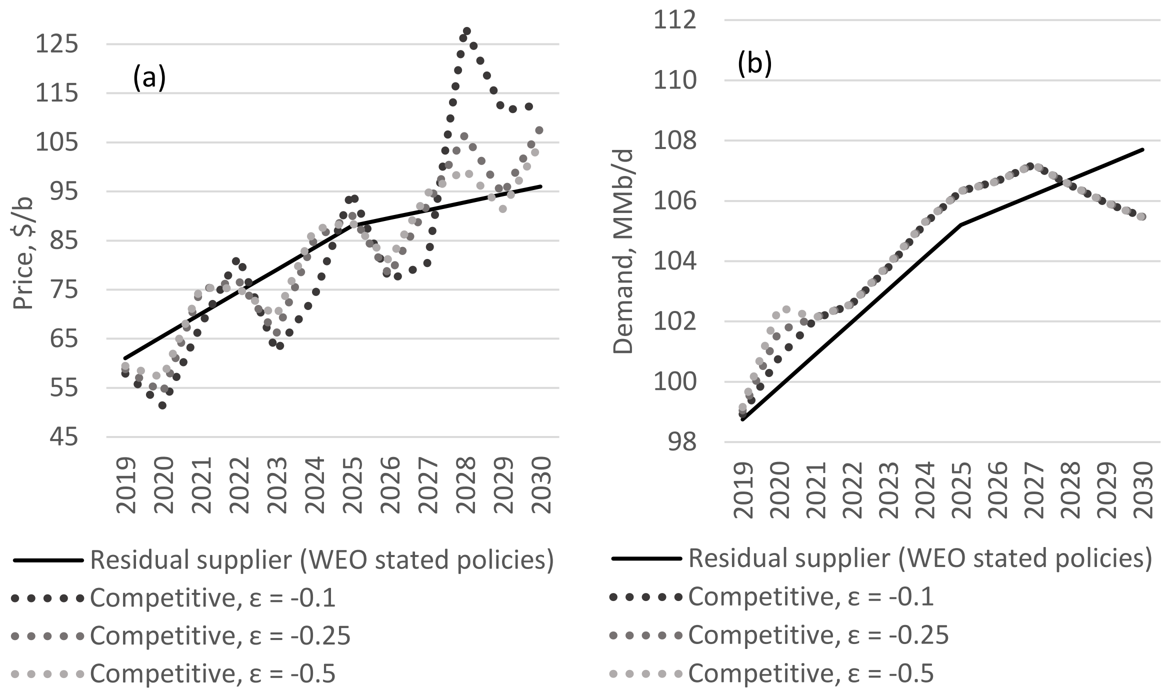
In Figure B.4 we present the results for total oil demand and price under different assumptions for the price elasticity of demand with no residual supplier. As expected, we find a much faster price recovery in the no residual supplier scenario when the absolute value of the elasticity is higher, and consumers are more responsive to the shift in OPEC supplies. Notice that when consumers are less responsive to the structural change, over time the equilibrium price grows at a rapid rate and surpasses reference. This occurs because of the slow price recovery delaying the approval of new projects scheduled under the Rystad investment plan, and therefore available capacity towards the end of the decade.

Figure B.4. World oil price (a) and demand (b) for the competitive scenario under the Rystad investment plan for different price elasticity assumptions



Source: IEA (2019b), KAPSARC analysis.

Figure B.5. World oil price (a) and demand (b) in the Competitive scenarios under Rystad's projected investment plan, 50% tight oil investment cap, and different price elasticities



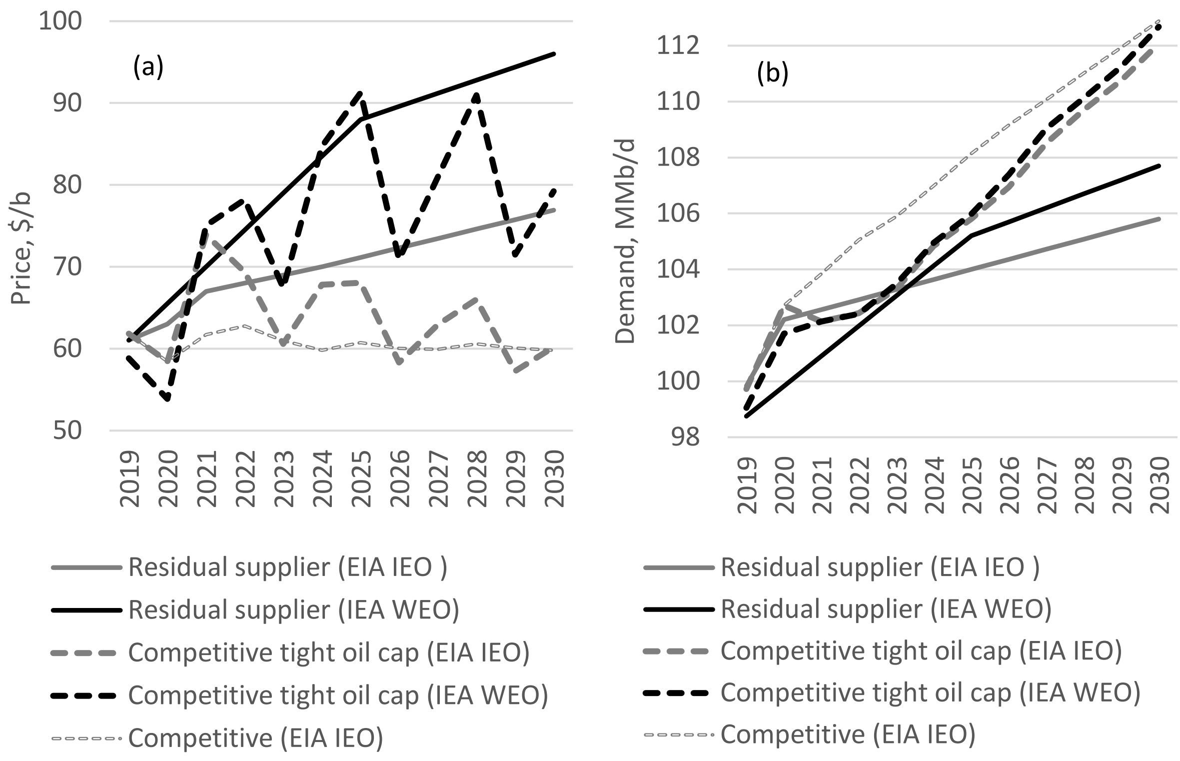
Source: IEA (2019b), KAPSARC analysis.

Figure B.5 shows the same set of scenarios as Figure B.4 after applying the 50% cap on investments in tight oil projects. Notice that the price volatility increases as the absolute value of the elasticity is reduced. Since supplies are tighter in these scenarios, reduction in consumer price response and associated changes in production decisions have a more pronounced impact on the market equilibria over a shorter time period (e.g. 3 years). Also, the total demand converges in each case because of the elevated price levels and nearly identical investment decisions.

B.4 Sensitivity analysis: applying the EIA's demand outlook

To assess the sensitivity of our model to the reference case (IEA NPS) we also calibrate the demand curve to the EIA's IEO. We compare the results with the original IEA calibration in Figure B.6, when applying the $150 billion cap on long-term investments and the tight oil cap.

Figure B.6. World oil price (a) and demand (b): Comparing results under the IEA NPS and EIA IEO reference calibration



Source: IEA (2019b), EIA (2019), KAPSARC analysis.

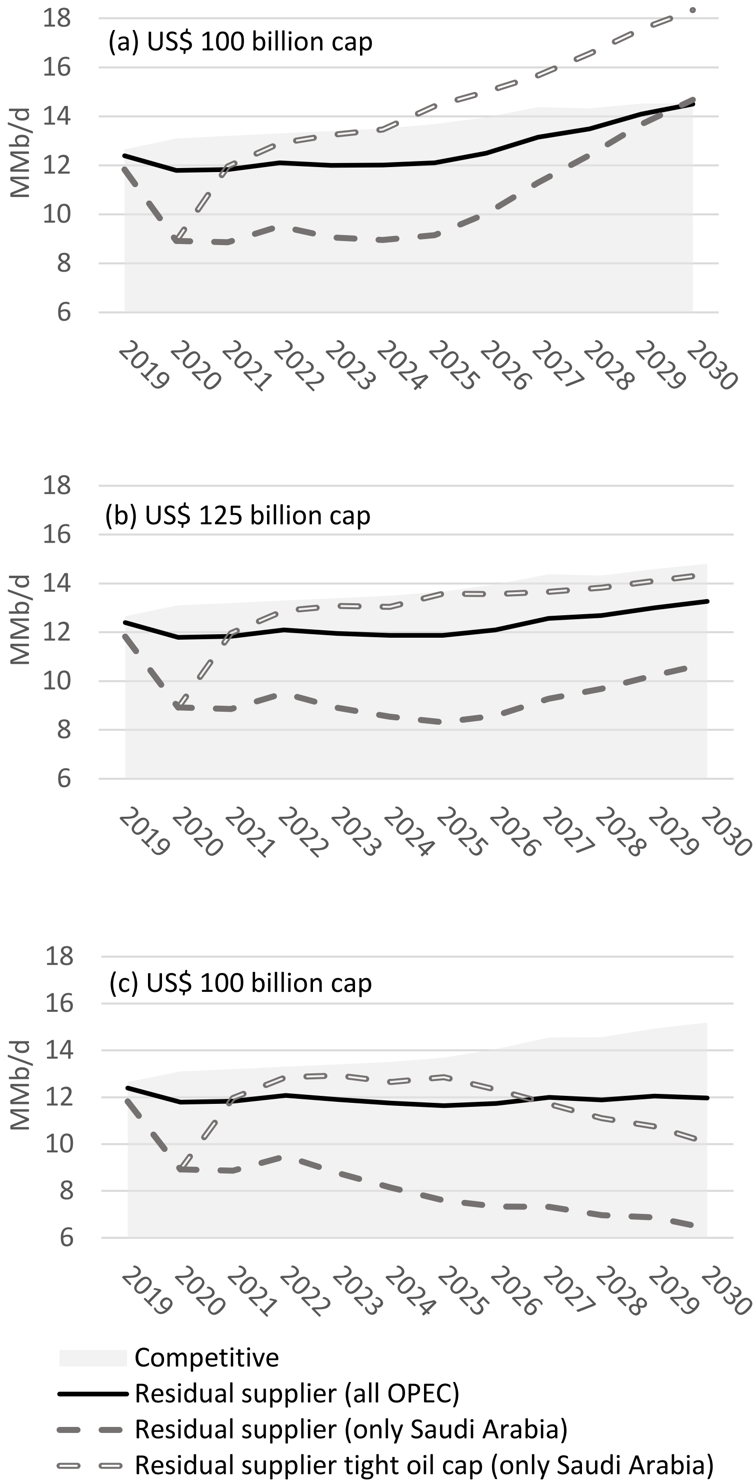
Note: All competitive market scenarios use the $150 billion cap on new long-term investments.

Clearly, the EIA adopts a more moderate growth trajectory overall with prices consistently below the WEO. Following accelerated demand growth in the year 2020, it is consistently slower over the next 10 years, with total demand falling 2 MMbbl/d below the WEO in 2030. Overall, the IEO calibration produces both lower and slightly more stable oil prices. A contributor to the lower price volatility is that demand is slightly lower under the IEO calibration, and therefore supplies are less tight. Keep in mind this is assuming that investors spend on average $150 billion per year in both scenarios.

B.5 Saudi Arabia’s oil production

Figure B.7 depicts Saudi Arabia’s liquids production under different investment constraints. Notice that under the $ 100 billion investment cap (Figure 4a) with the tight oil cap (hollow dashed line), by the end of the decade Saudi Arabia’s production exceeds the total sustainable production in the competitive scenario. As a lone residual supplier, Saudi Arabia would have to expand its existing production capacity to meet the demand (and price) outlook of the WEO. A more realistic expectation is that the residual supplier would produce at the sustainable production levels, and a different price equilibrium would be reached.

Figure B.7. Total liquids production by Saudi Arabia in the residual supplier scenarios, under different investment constraints; (a) $100, (b) $125, and (c) $150 billion cap



Source: KAPSARC analysis.

Note: Dashed lines depict production by Saudi Arabia when it is the residual supplier without support from OPEC. Shaded areas show total production in the competitive scenarios.