The Economics of CO_2 Sequestration through Enhanced Oil Recovery

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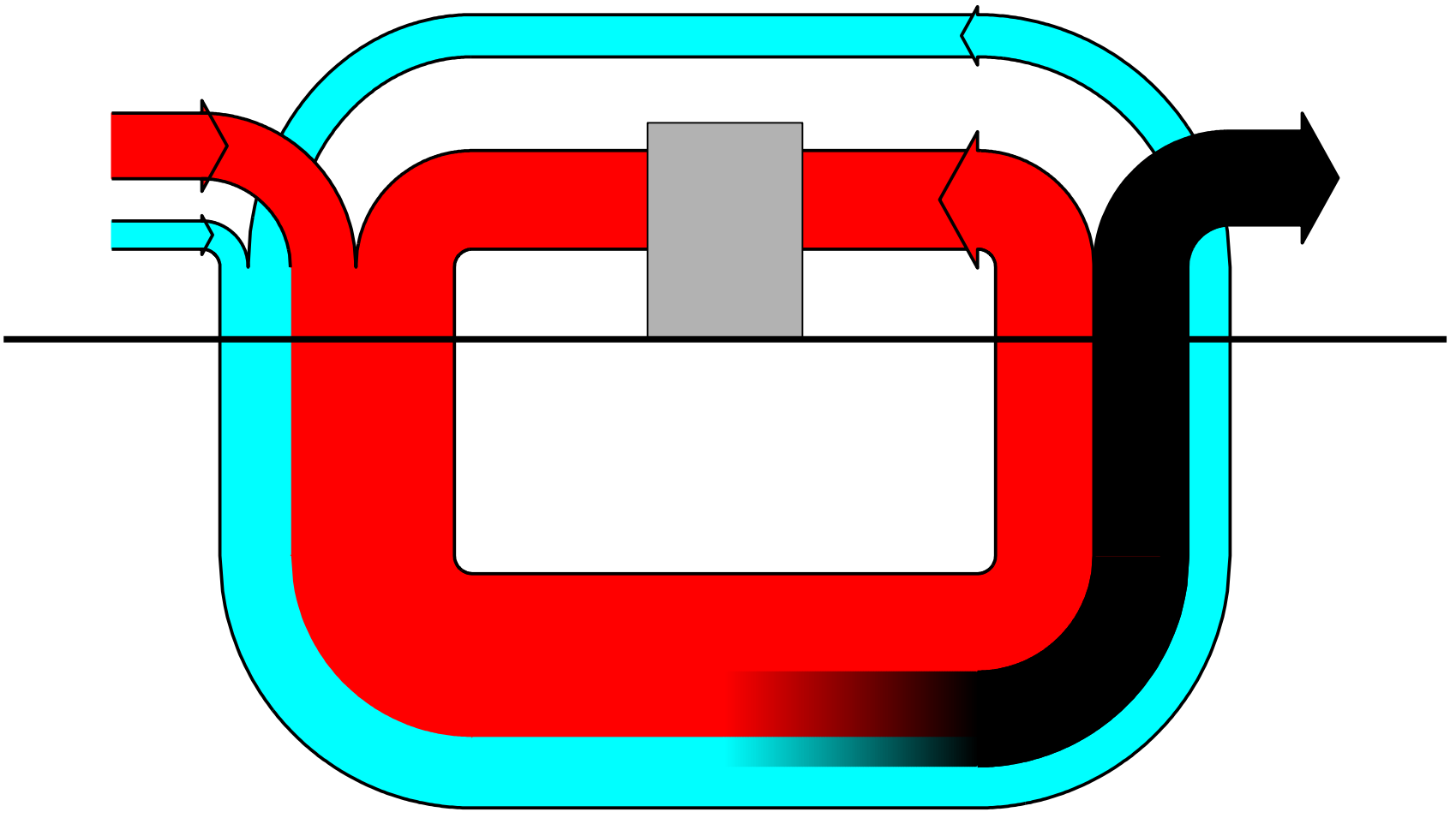
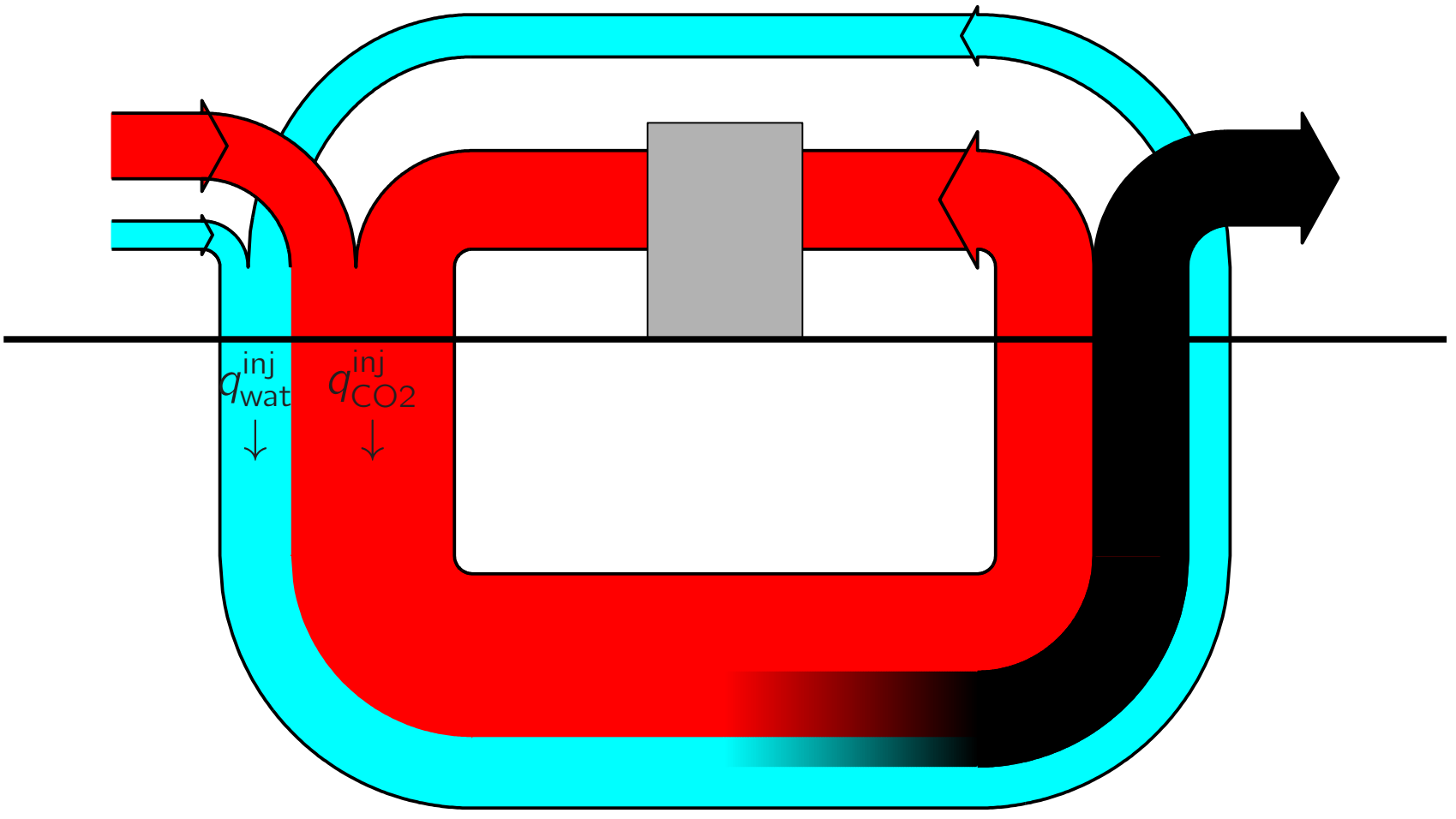
(co-authored with Klaas van 't Veld, University of Wyoming, and Andrew Leach, University of Alberta)

- Enhanced Oil Recovery (EOR) is the process of injecting CO_2 into mature oil fields to encourage increased production
  - typically undertaken after secondary production (water flood)
  - hence called *tertiary production*
- CO_2 mixes with oil, raising pressure and lowering viscosity
- so oil flows to well bore more efficiently, resultant production is mix of oil, water and CO_2
- process involves combination of incremental purchases of CO_2 and recycled CO_2
- CO_2replaces oil in pore space — resulting in carbon sequestration
- many examples in US (mainly Texas and Wyoming), also some in Europe

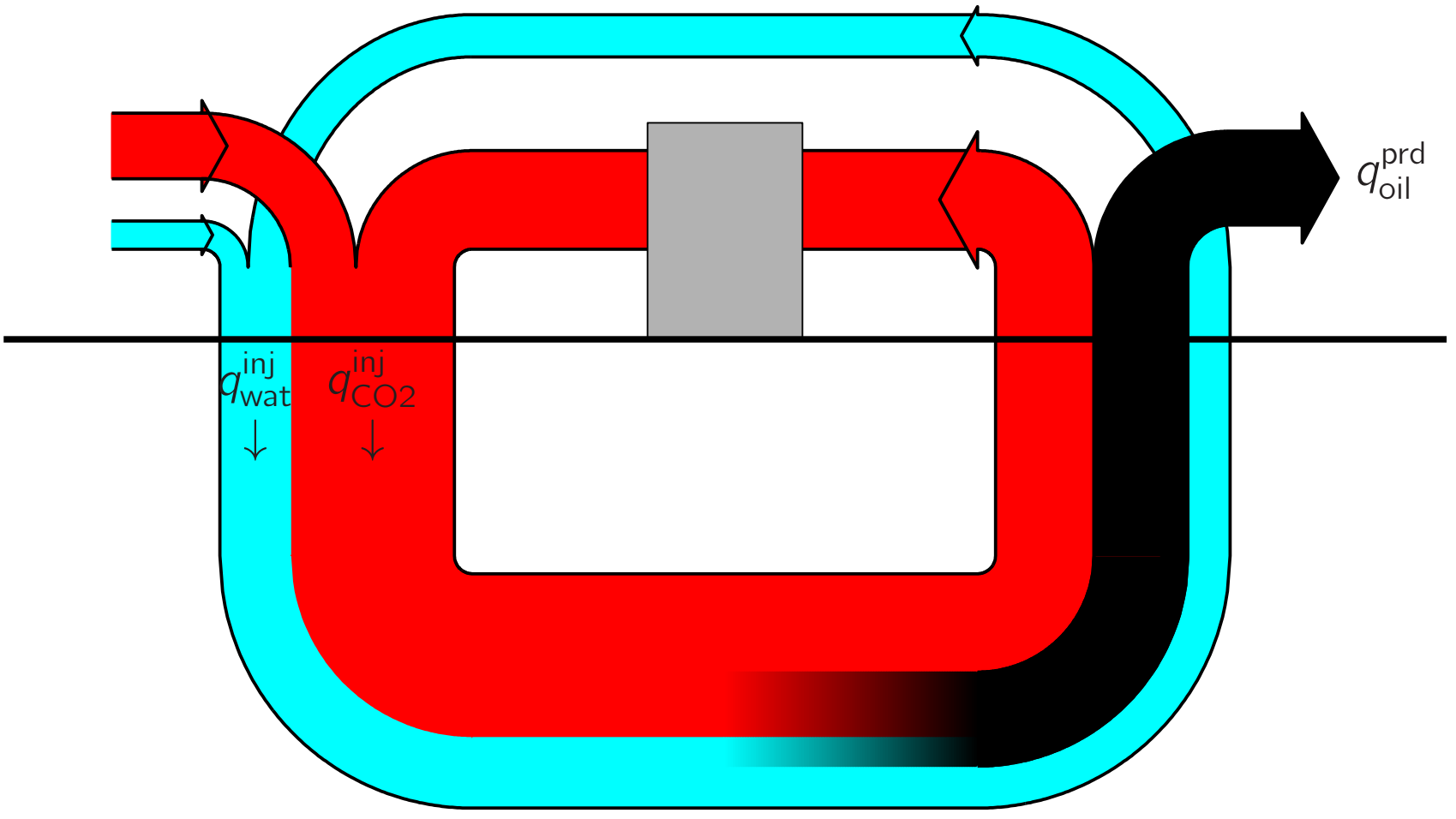
CO_2-EOR Flows



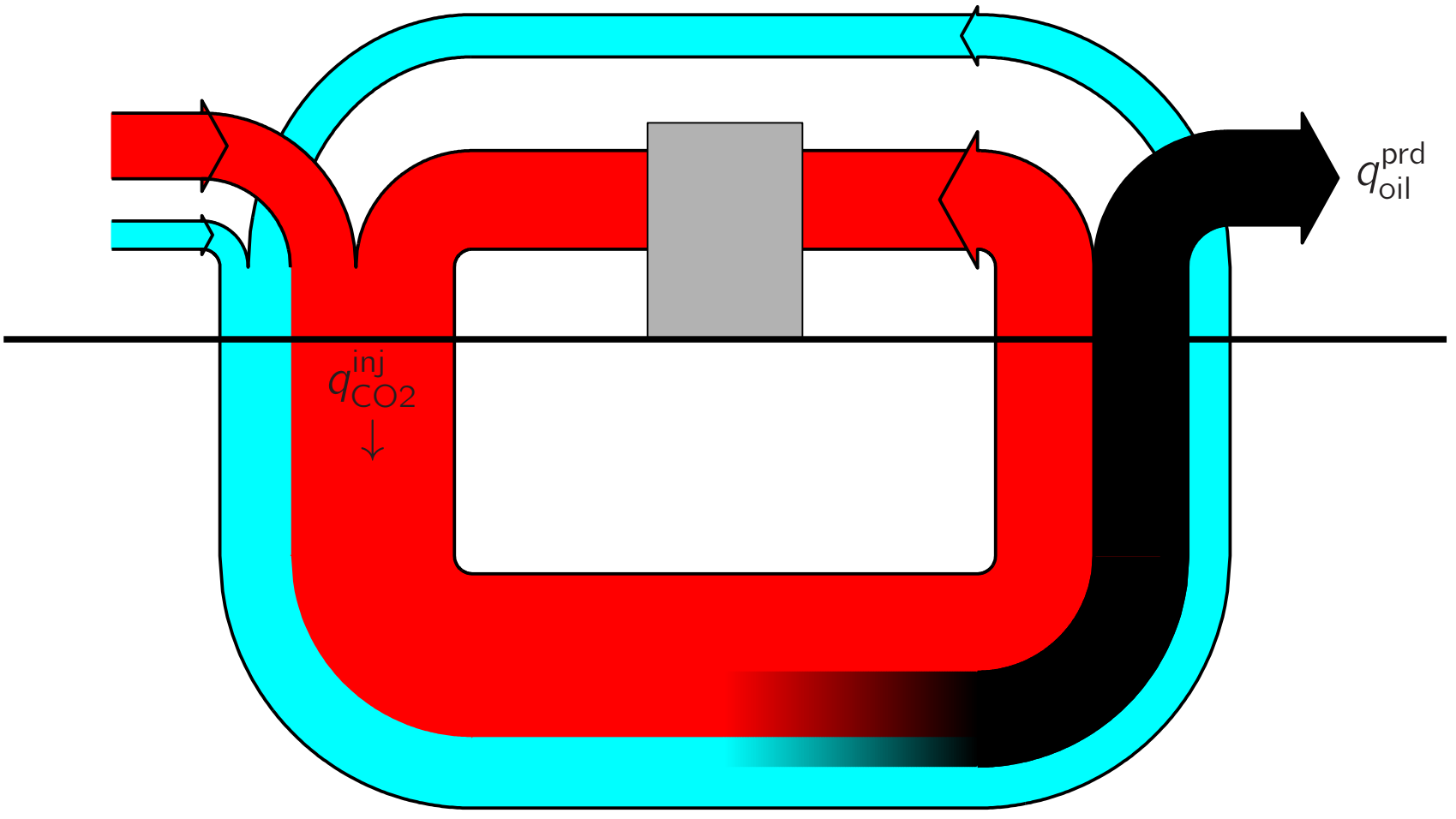
CO_2-EOR Flows



CO_2-EOR Flows



CO_2-EOR Flows



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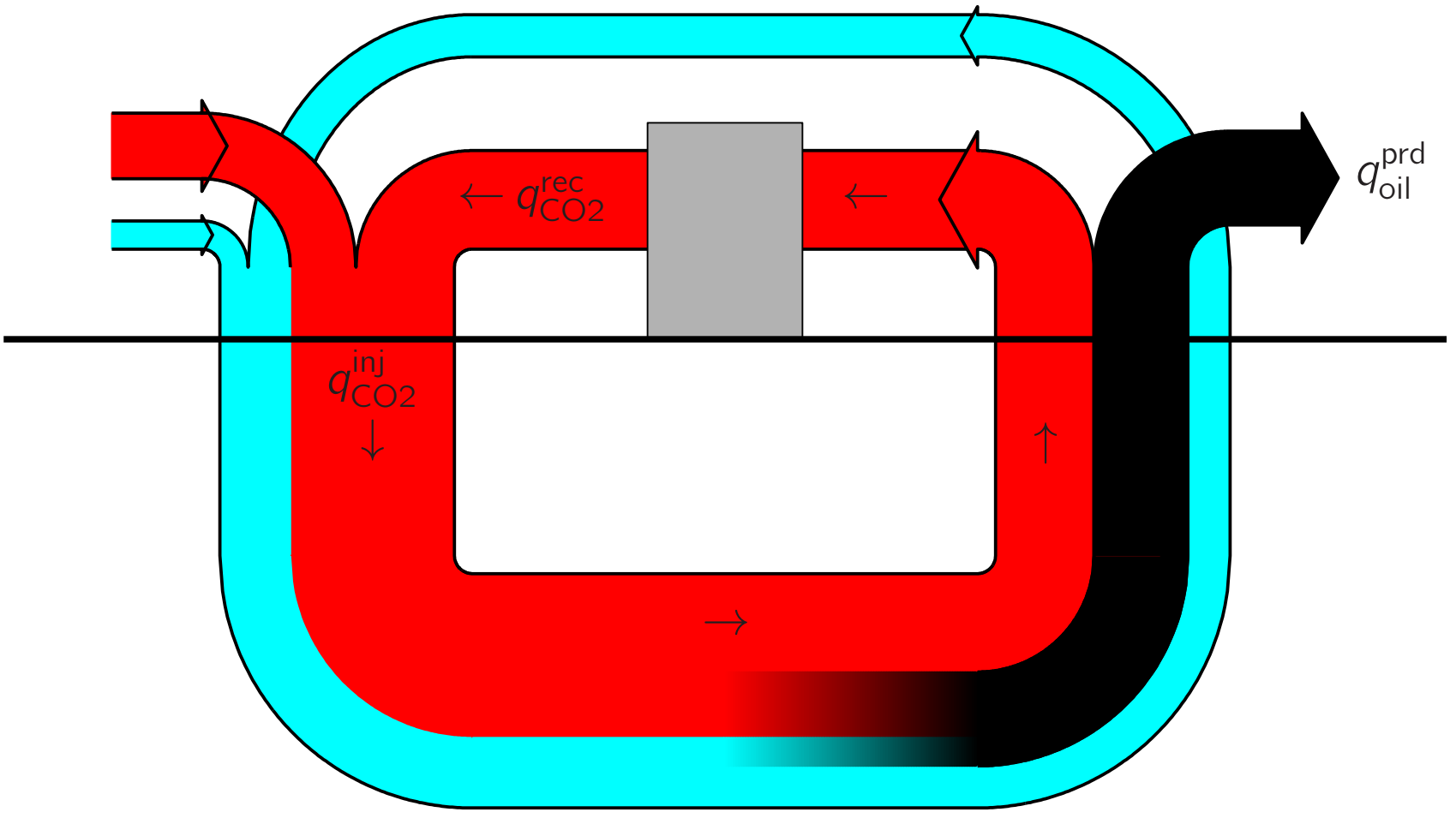

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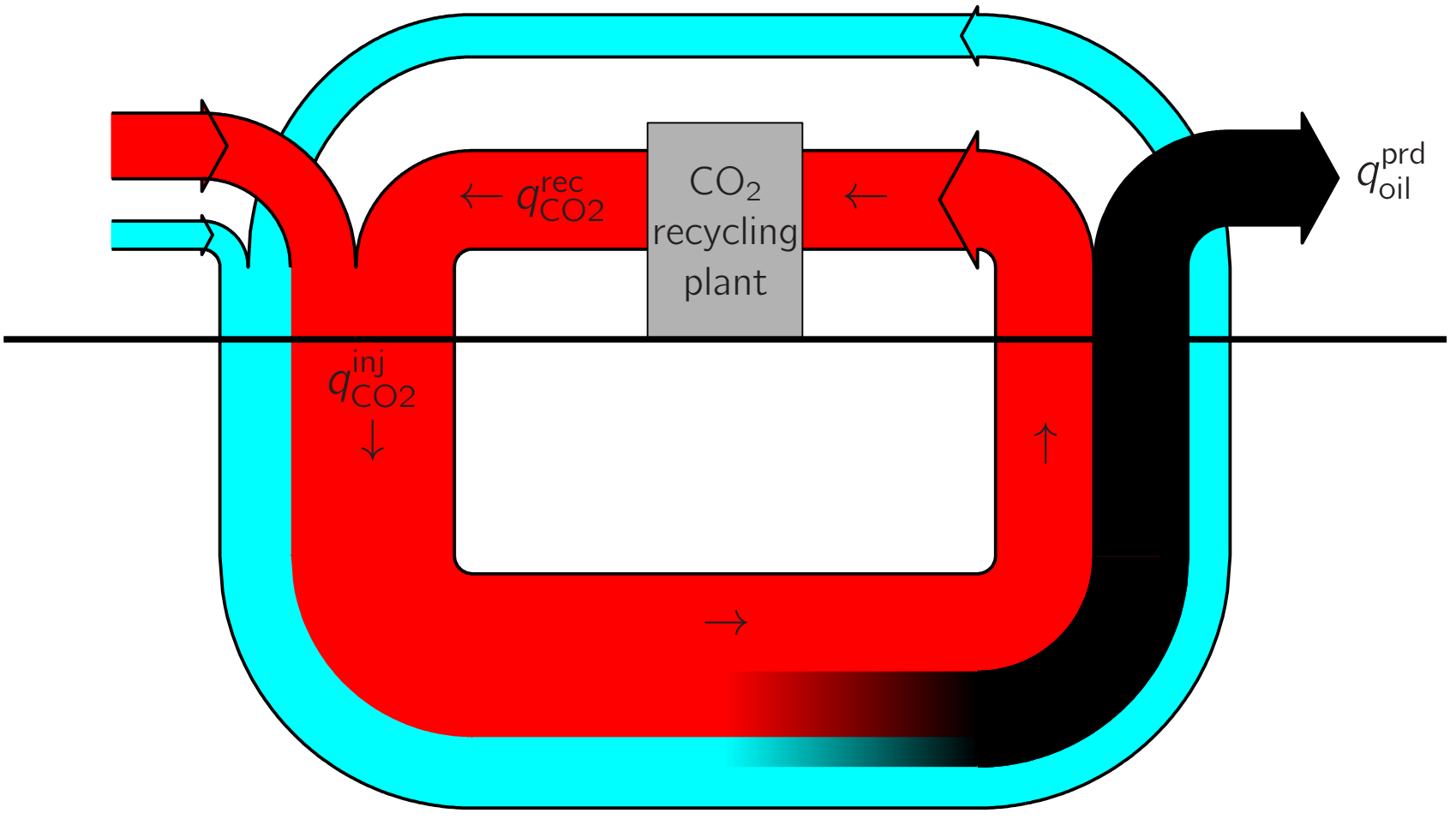

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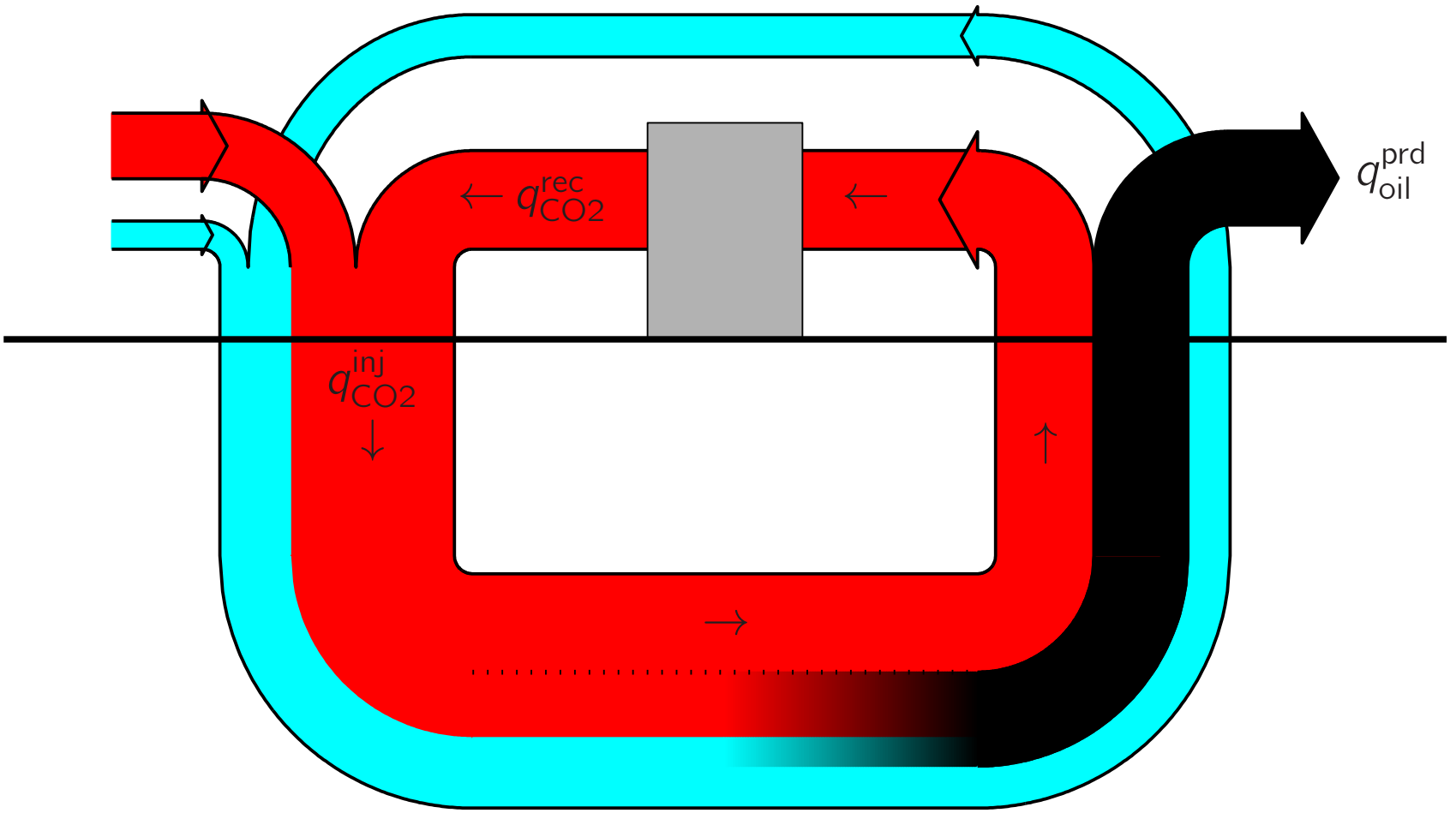

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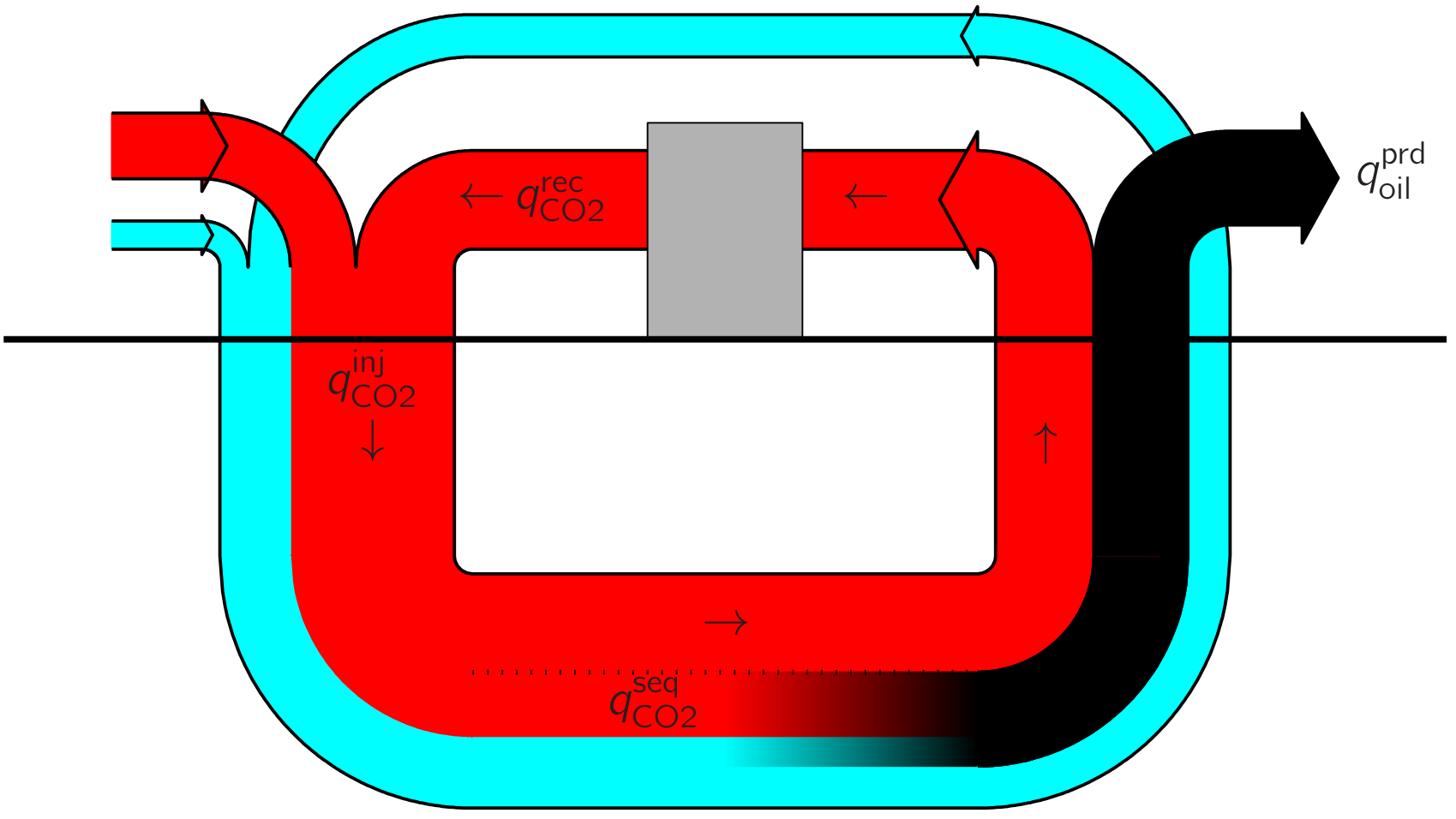

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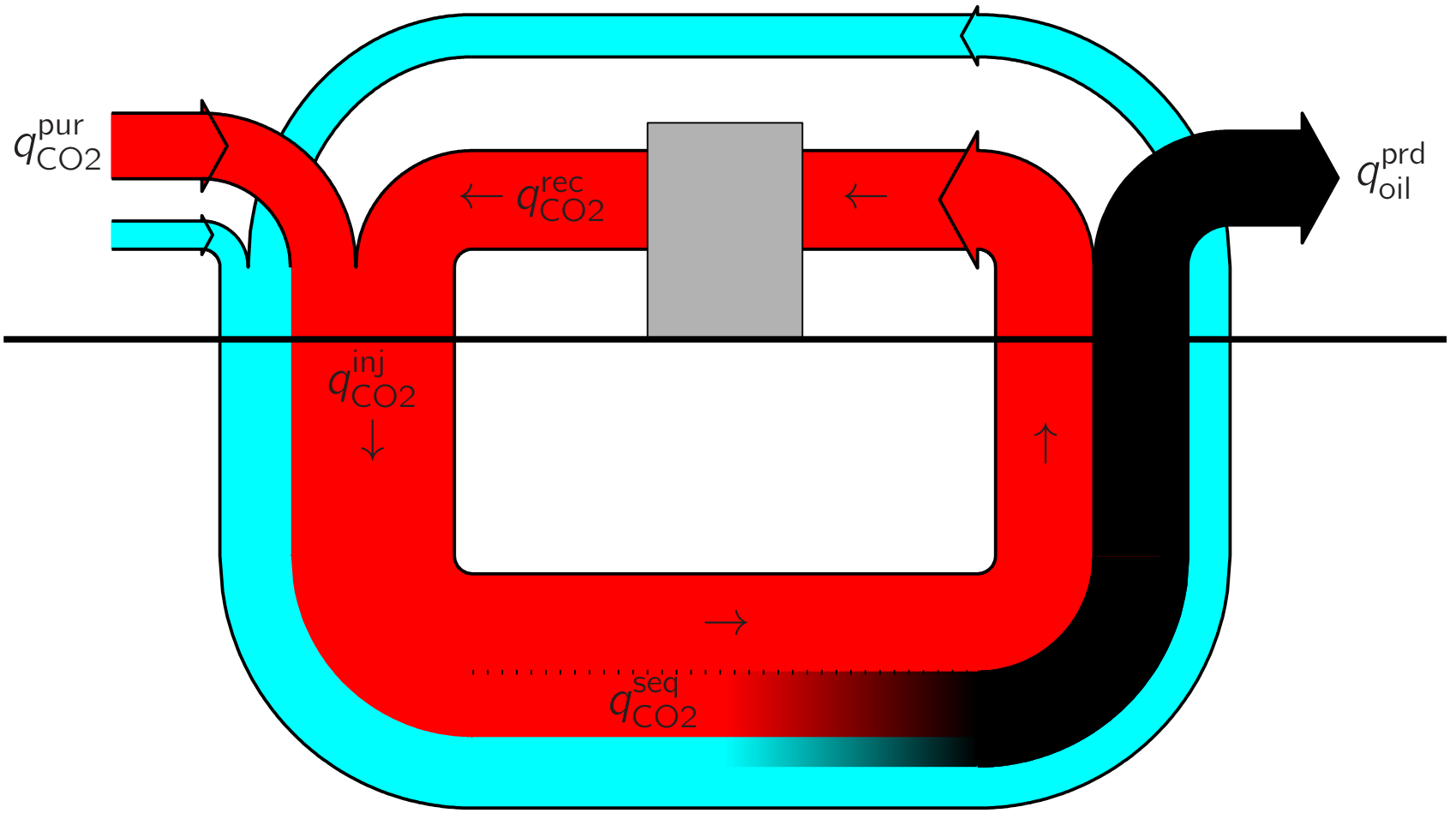

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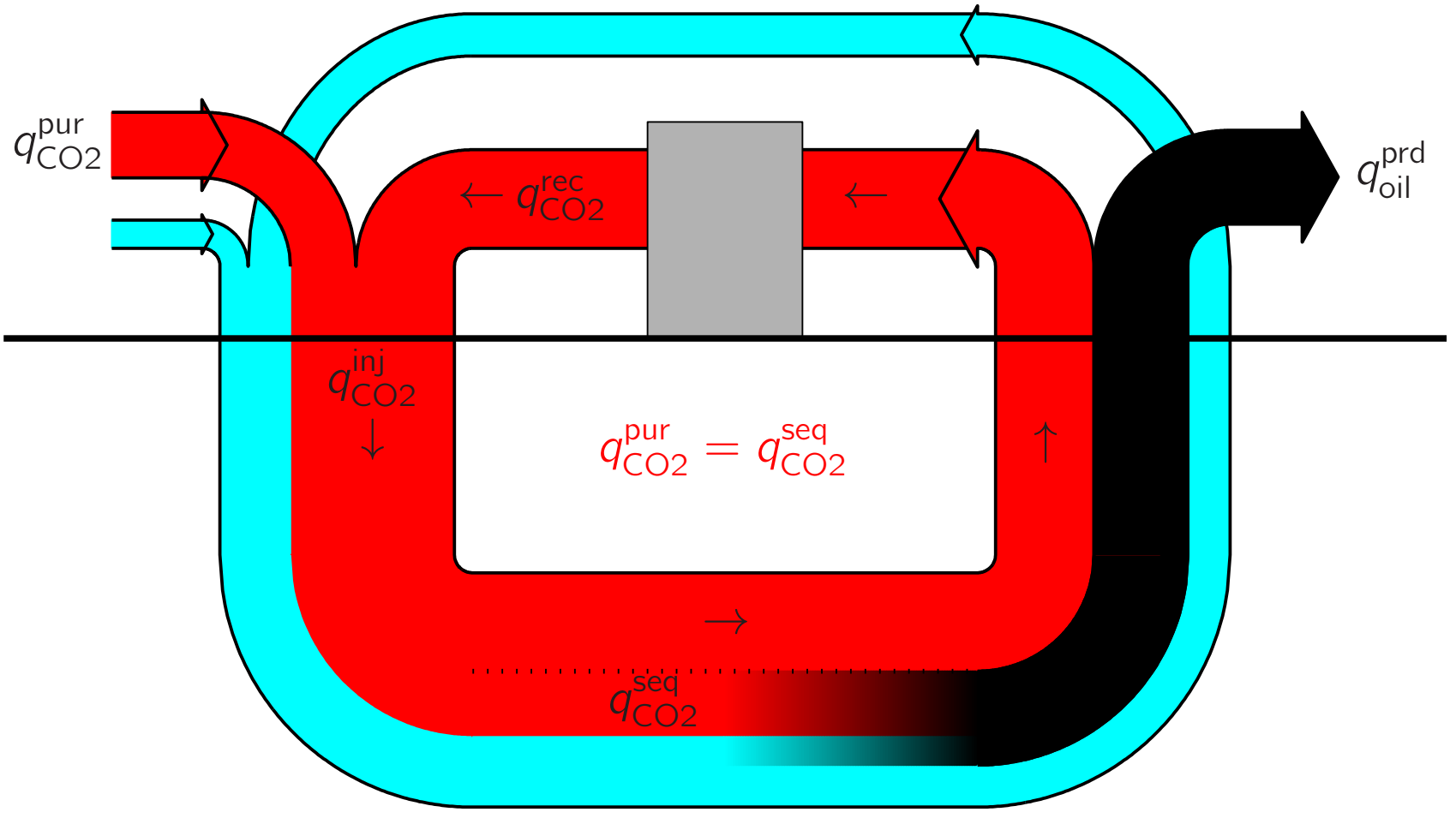

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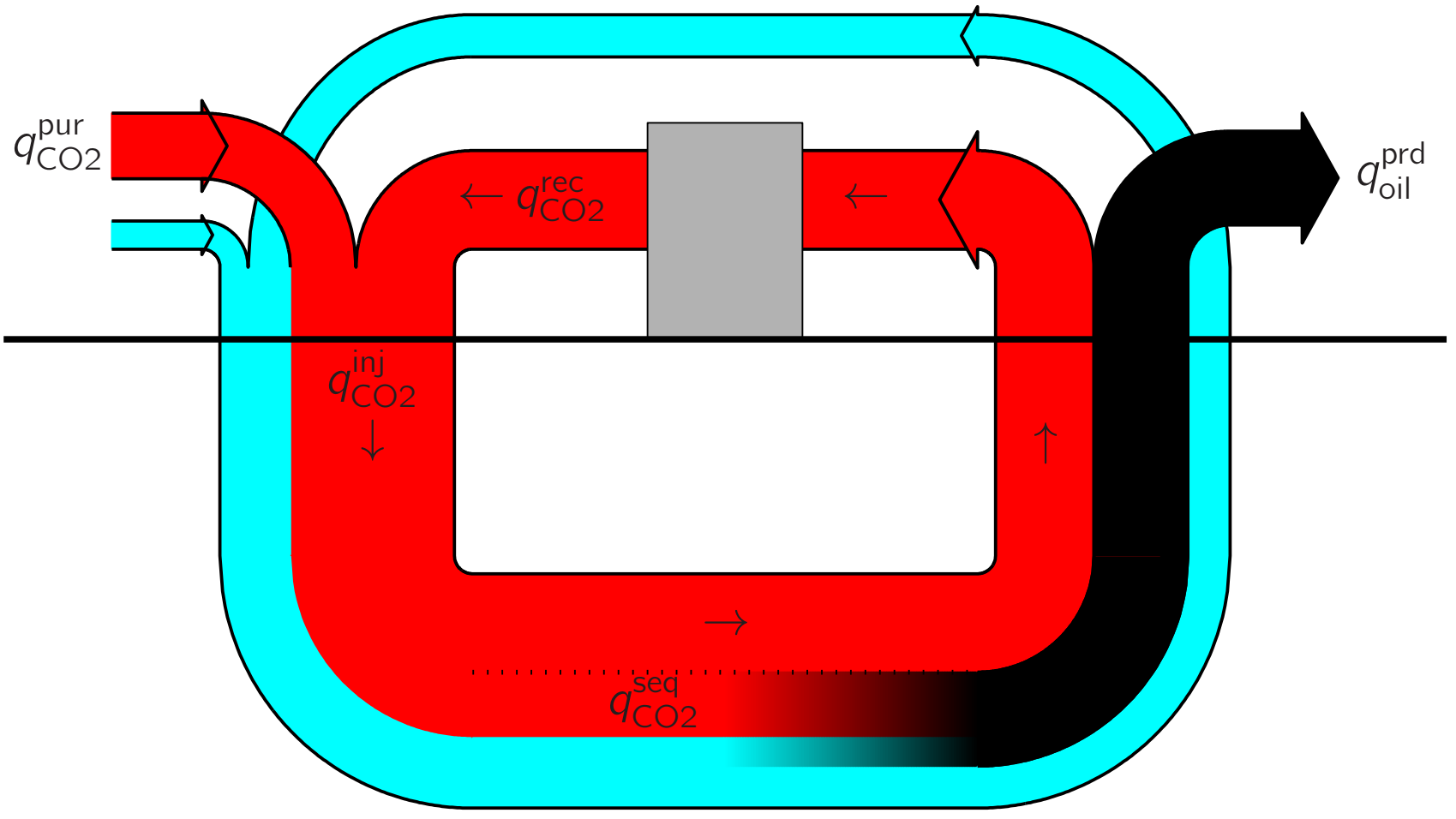

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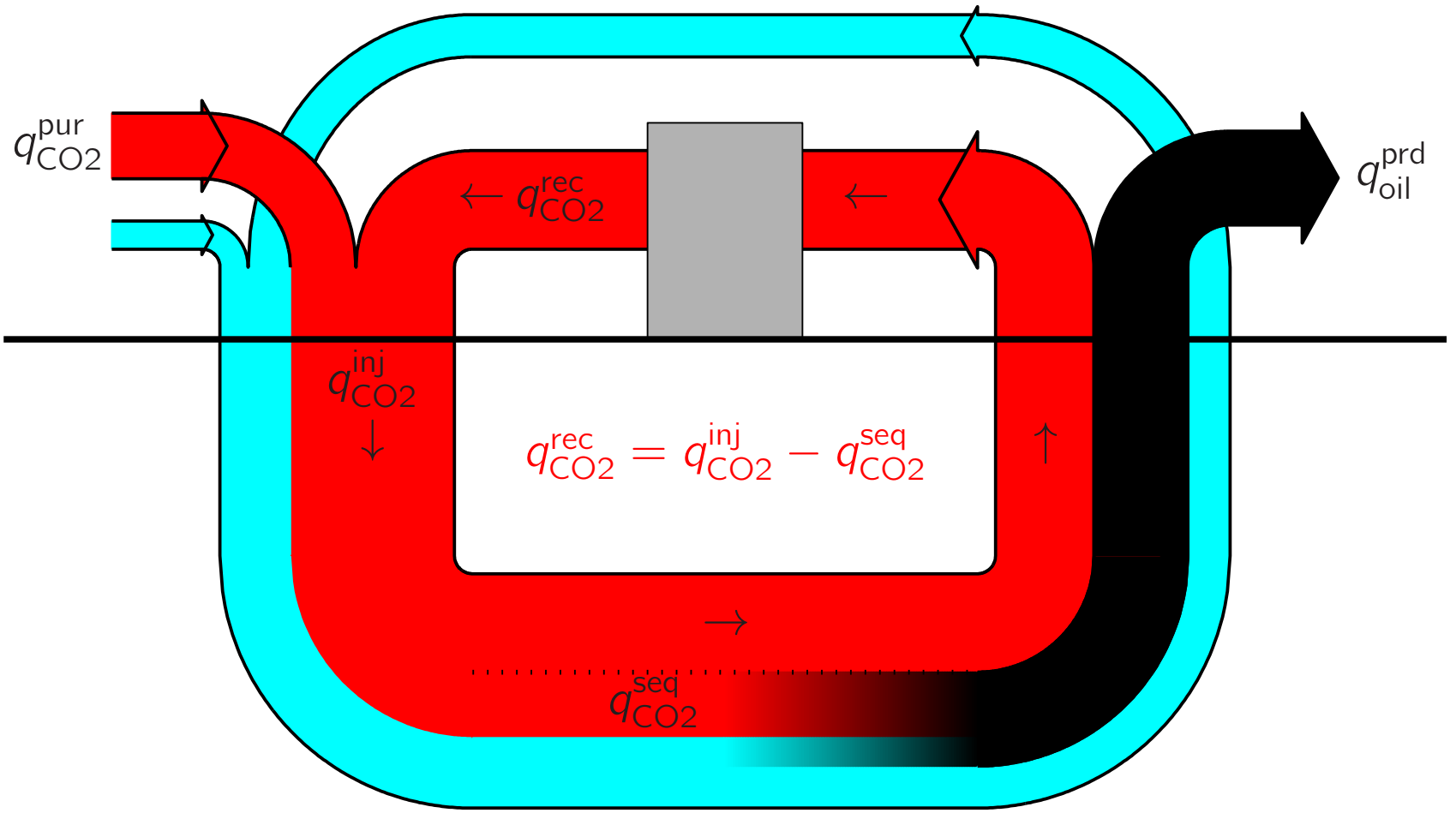


Profit objective function

$$profit = \underbrace{p_{\text{oil}} q_{\text{oil}}^{\text{prd}}}_{\substack{\text{oil} \\ \text{revenues}}} - \underbrace{p_{CO_2} q_{CO_2}^{\text{pur}}}_{\substack{CO_2 \\ \text{purchase} \\ \text{costs}}} - \underbrace{c^{\text{rec}} q_{CO_2}^{\text{rec}}}_{\substack{CO_2 \\ \text{recycling} \\ \text{costs}}} - \underbrace{c^{\text{oth}}}_{\substack{\text{other} \\ \text{costs}}}$$

Profit objective function

$$profit = \underbrace{p_{oil} q_{oil}^{prd}}_{\text{oil revenues}} + \underbrace{s_{CO_2} q_{CO_2}^{seq}}_{\text{CO}_2\text{ sequestration subsidies}} - \underbrace{p_{CO_2} q_{CO_2}^{pur}}_{\text{CO}_2\text{ purchase costs}} - \underbrace{c^{rec} q_{CO_2}^{rec}}_{\text{CO}_2\text{ recycling costs}} - \underbrace{c^{oth}}_{\text{other costs}}$$

Profit objective function

$$q^{pur}_{CO_2} = q^{seq}_{CO_2}$$

$$\downarrow$$

$$profit = \underbrace{p_{oil}\, q^{prd}_{oil}}_{\text{oil revenues}} + \underbrace{s_{CO_2}\, q^{seq}_{CO_2}}_{\substack{CO_2 \\ \text{sequestration} \\ \text{subsidies}}} - \underbrace{p_{CO_2}\, q^{pur}_{CO_2}}_{\substack{CO_2 \\ \text{purchase} \\ \text{costs}}} - \underbrace{c^{rec}\, q^{rec}_{CO_2}}_{\substack{CO_2 \\ \text{recycling} \\ \text{costs}}} - \underbrace{c^{oth}}_{\substack{\text{other} \\ \text{costs}}}$$

Profit objective function

$$profit = \underbrace{p_{\text{oil}} q_{\text{oil}}^{\text{prd}}}_{\substack{\text{oil} \\ \text{revenues}}} + \underbrace{(s_{CO_2} - p_{CO_2}) q_{CO_2}^{\text{seq}}}_{\substack{\text{net } CO_2 \\ \text{sequestration} \\ \text{revenues}}} - \underbrace{c^{\text{rec}} q_{CO_2}^{\text{rec}}}_{\substack{CO_2 \\ \text{recycling} \\ \text{costs}}} - \underbrace{c^{\text{oth}}}_{\substack{\text{other} \\ \text{costs}}}$$

Profit objective function

$$q^{\text{rec}}_{CO_2} = q^{\text{inj}}_{CO_2} - q^{\text{seq}}_{CO_2}$$

$$\downarrow$$

$$\textit{profit} = \underbrace{p_{\text{oil}} q^{\text{prd}}_{\text{oil}}}_{\substack{\text{oil} \\ \text{revenues}}} + \underbrace{(s_{CO_2} - p_{CO_2}) q^{\text{seq}}_{CO_2}}_{\substack{\text{net } CO_2 \\ \text{sequestration} \\ \text{revenues}}} - \underbrace{c^{\text{rec}} q^{\text{rec}}_{CO_2}}_{\substack{CO_2 \\ \text{recycling} \\ \text{costs}}} - \underbrace{c^{\text{oth}}}_{\substack{\text{other} \\ \text{costs}}}$$

Profit objective function

$$profit = \underbrace{p_{\text{oil}} q_{\text{oil}}^{\text{prd}}}_{\substack{\text{oil} \\ \text{revenues}}} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{\text{rec}}) q_{CO_2}^{\text{seq}}}_{\substack{\text{net } CO_2 \\ \text{sequestration} \\ \text{revenues}}} - \underbrace{c^{\text{rec}} q_{CO_2}^{\text{inj}}}_{\substack{\text{gross } CO_2 \\ \text{recycling} \\ \text{costs}}} - \underbrace{c^{\text{oth}}}_{\substack{\text{other} \\ \text{costs}}}$$

Profit objective function

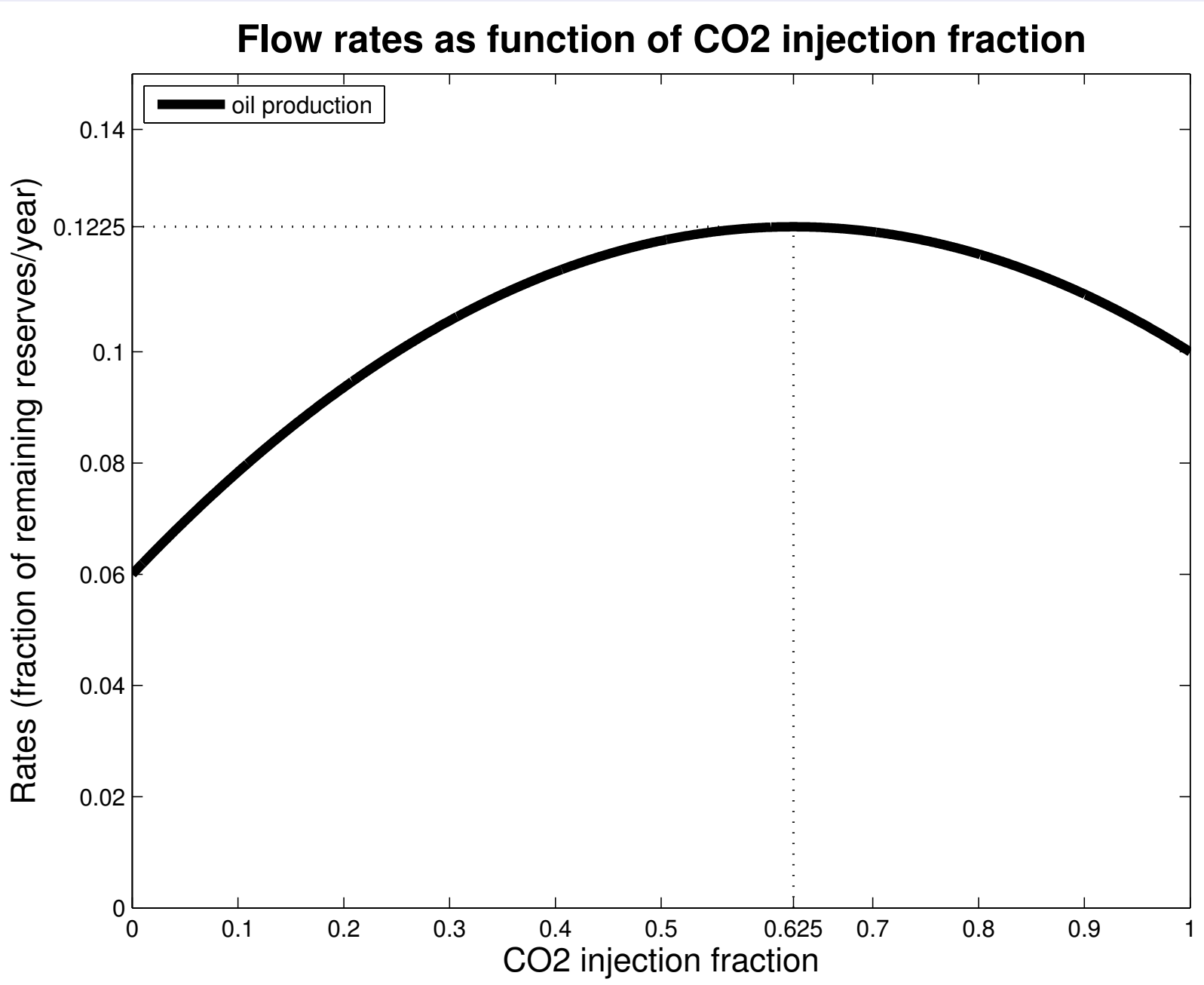
fall over time

constant?

$$profit = \underbrace{p_{\text{oil}}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} q_{\text{oil}}^{\text{prd}} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{\text{rec}})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} q_{CO_2}^{\text{seq}} - \underbrace{c^{\text{rec}} q_{CO_2}^{\text{inj}}}_{\substack{\text{gross } CO_2\\ \text{recycling}\\ \text{costs}}} - \underbrace{c^{\text{oth}}}_{\substack{\text{other}\\ \text{costs}}}$$

Problem: ad hoc engineering assumptions

Assumption 1: Oil production is an inverse U-shaped function of the CO_2 injection fraction $q^{\text{inj}}_{CO_2}/(q^{\text{inj}}_{CO_2} + q^{\text{inj}}_{\text{wat}})$.

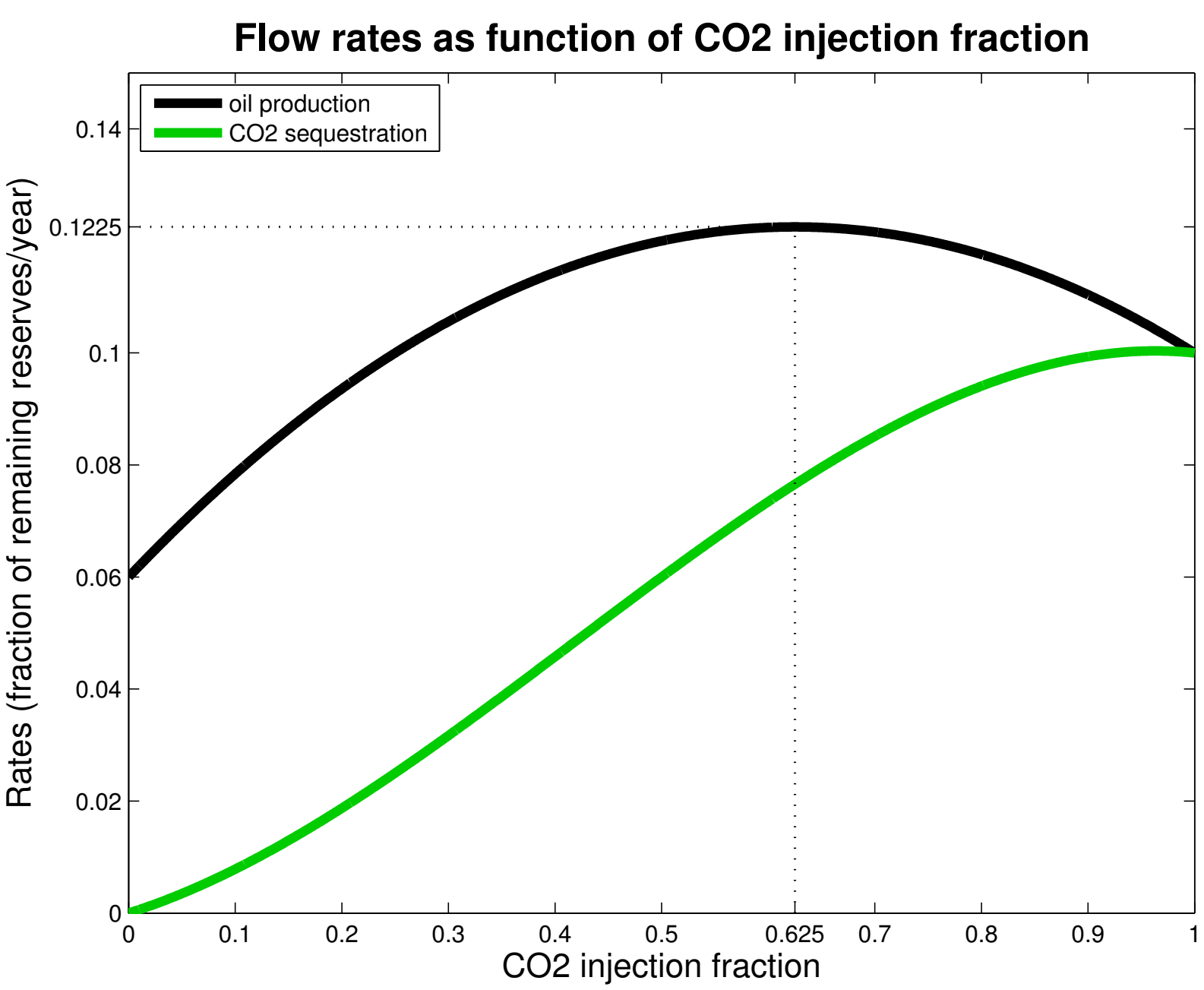

Flow rates as function of CO2 injection fraction
oil production
Rates (fraction of remaining reserves/year)
0.14
0.1225
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.625
0.7
0.8
0.9
1
CO2 injection fraction

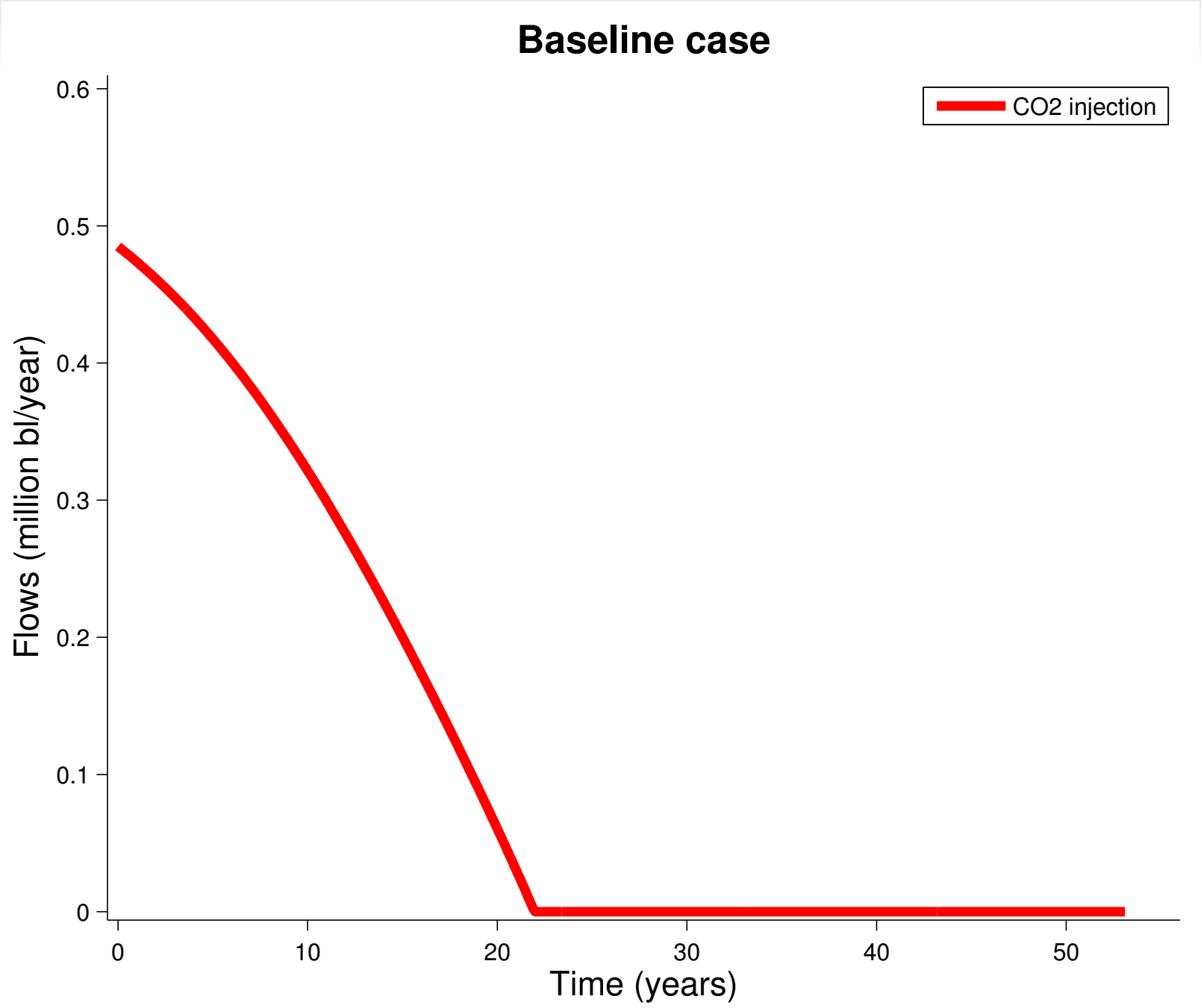
Problem: ad hoc engineering assumptions

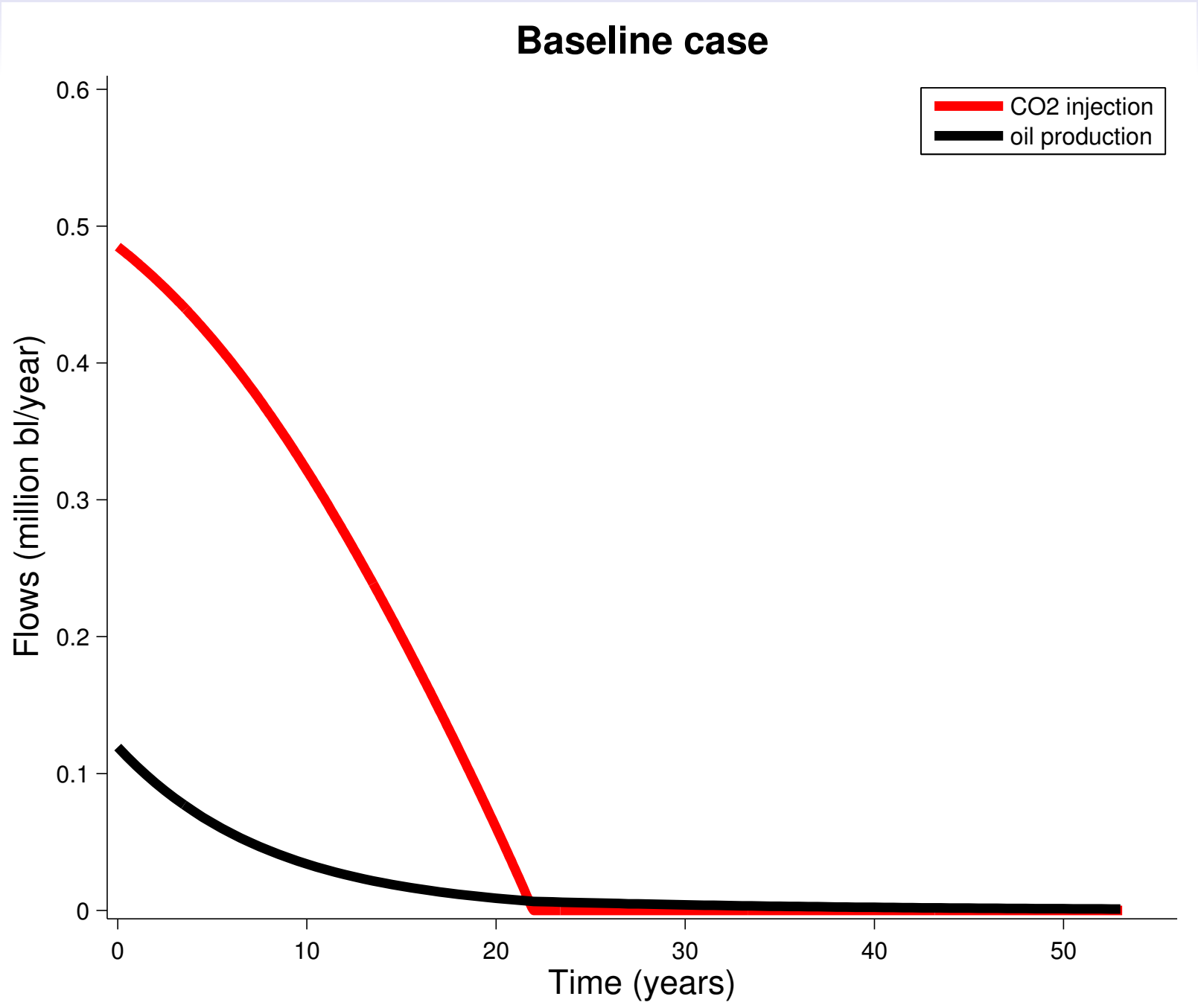
Assumption 1: Oil production is an inverse U-shaped function of the CO_2 injection fraction $q^{\text{inj}}_{CO_2}/(q^{\text{inj}}_{CO_2} + q^{\text{inj}}_{\text{wat}})$.

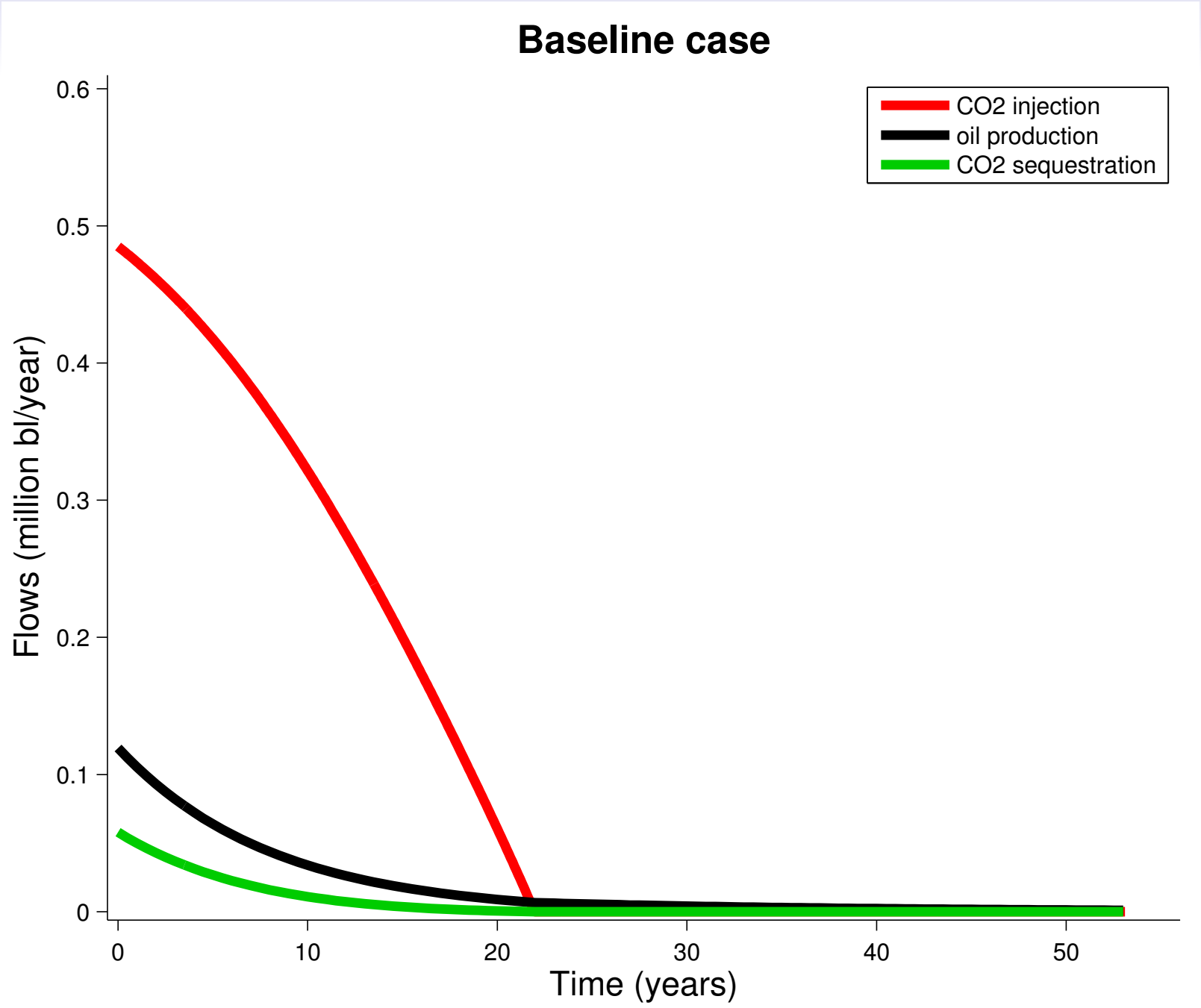
Assumption 2: CO_2 sequestration is the product of the CO_2 injection fraction and oil production:

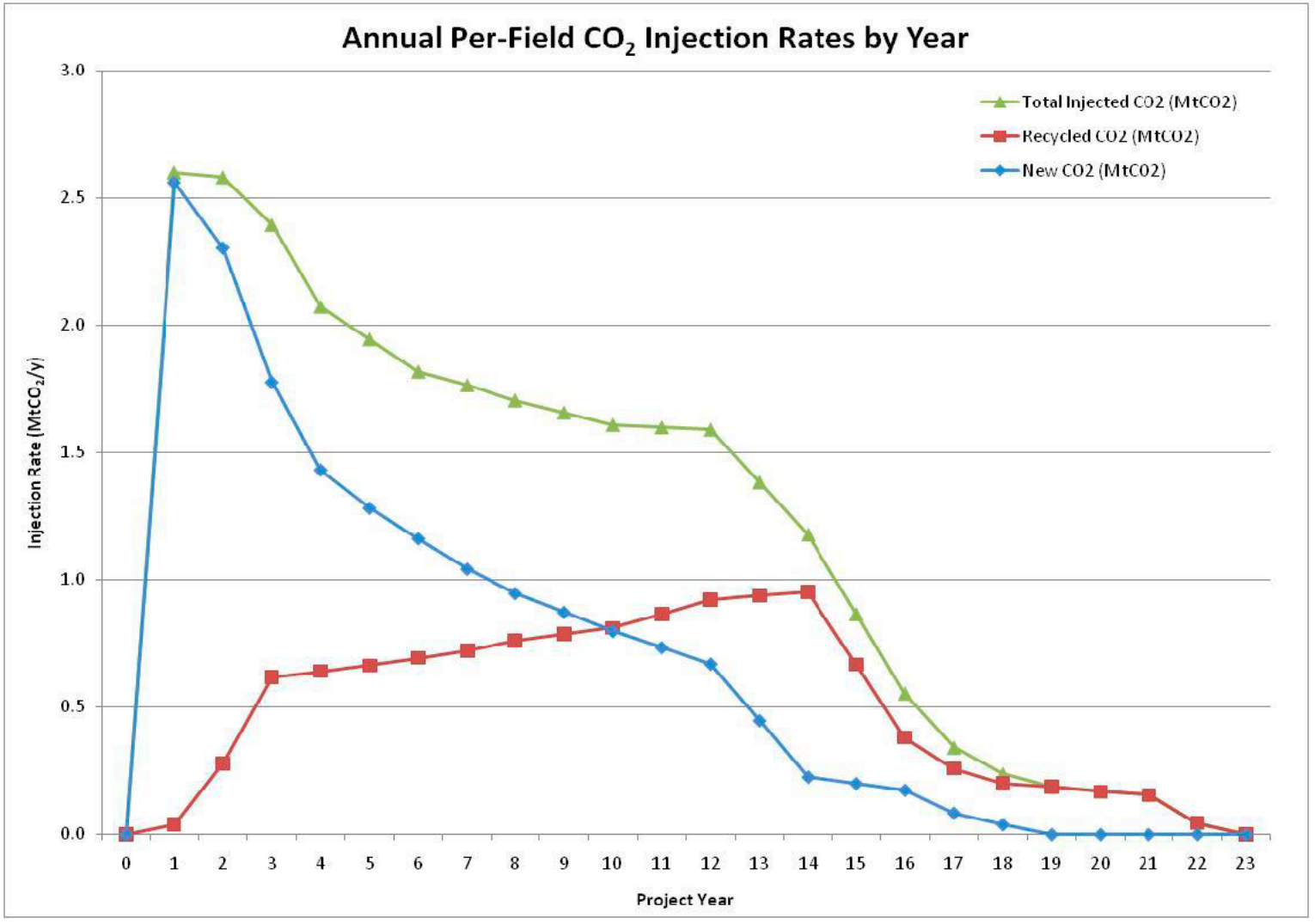
$$q^{\text{seq}}_{CO_2} = \frac{q^{\text{inj}}_{CO_2}}{q^{\text{inj}}_{CO_2} + q^{\text{inj}}_{\text{wat}}} \times q^{\text{prd}}_{\text{oil}}$$


Flow rates as function of CO2 injection fraction
oil production
CO2 sequestration
Rates (fraction of remaining reserves/year)
0.14
0.1225
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.625
0.7
0.8
0.9
1
CO2 injection fraction


Baseline case
CO2 injection
Flows (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
Time (years)


Baseline case
CO2 injection
oil production
Flows (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
Time (years)


Baseline case
CO2 injection
oil production
CO2 sequestration
Flows (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
Time (years)



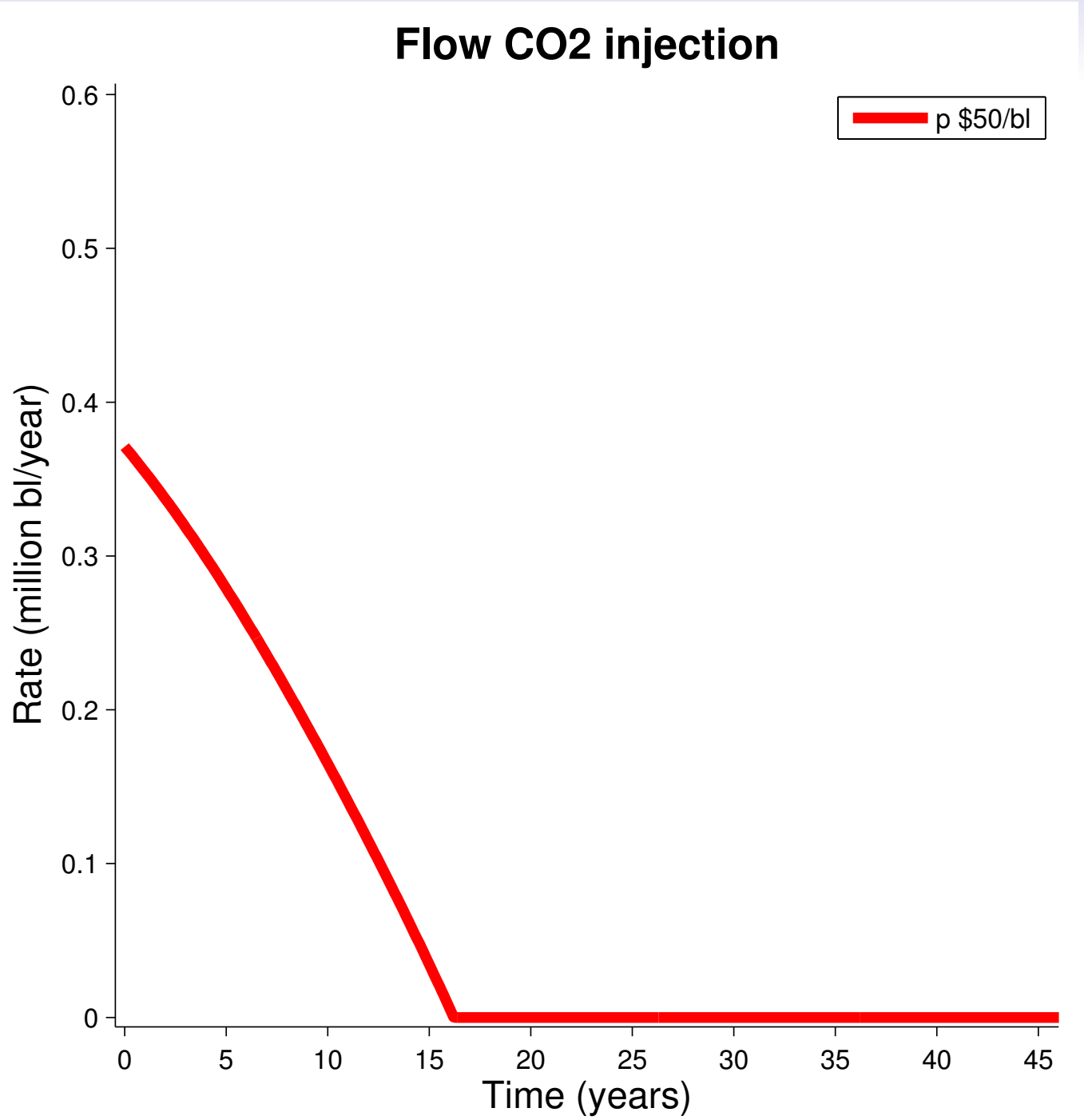
Source: Davidson, C.L. et al. (2011) "A quantitative comparison of the cost of employing EOR-coupled CCS supplemented with secondary DSF storage for two large CO_2 point sources," *Energy Procedia* 4: 2361–2368

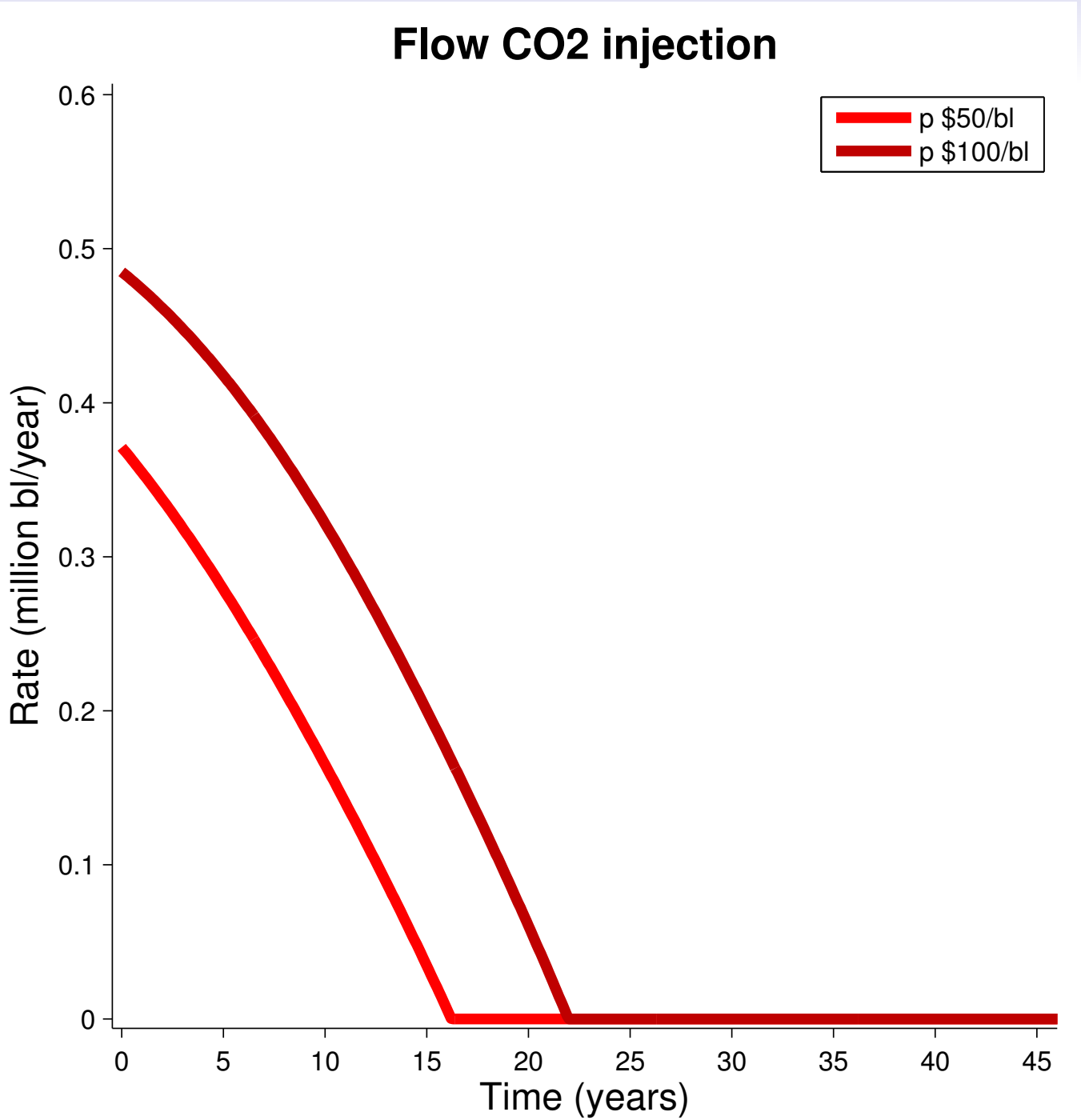
Profit objective function

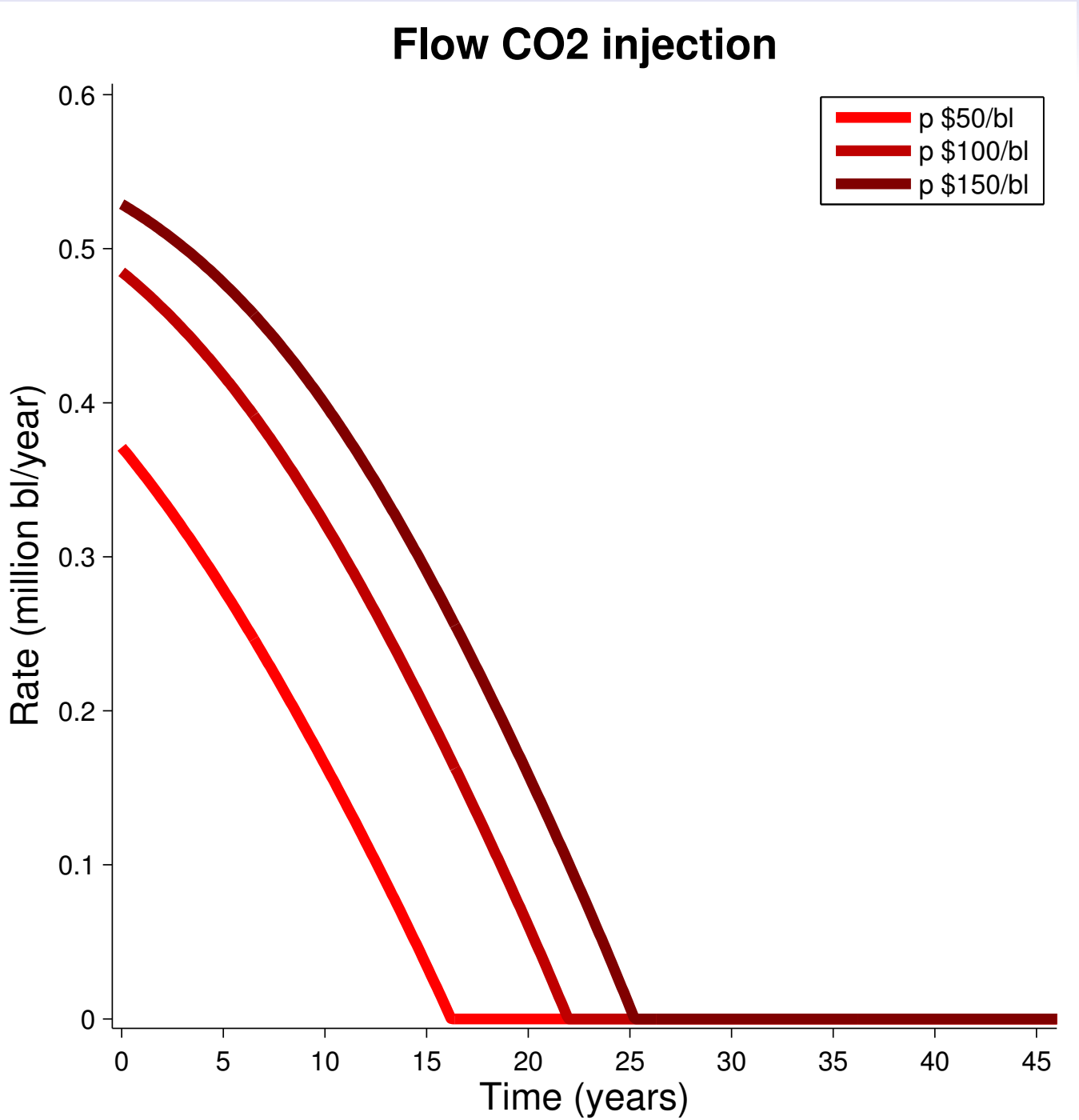
Benefits of CO_2 injection fall over time

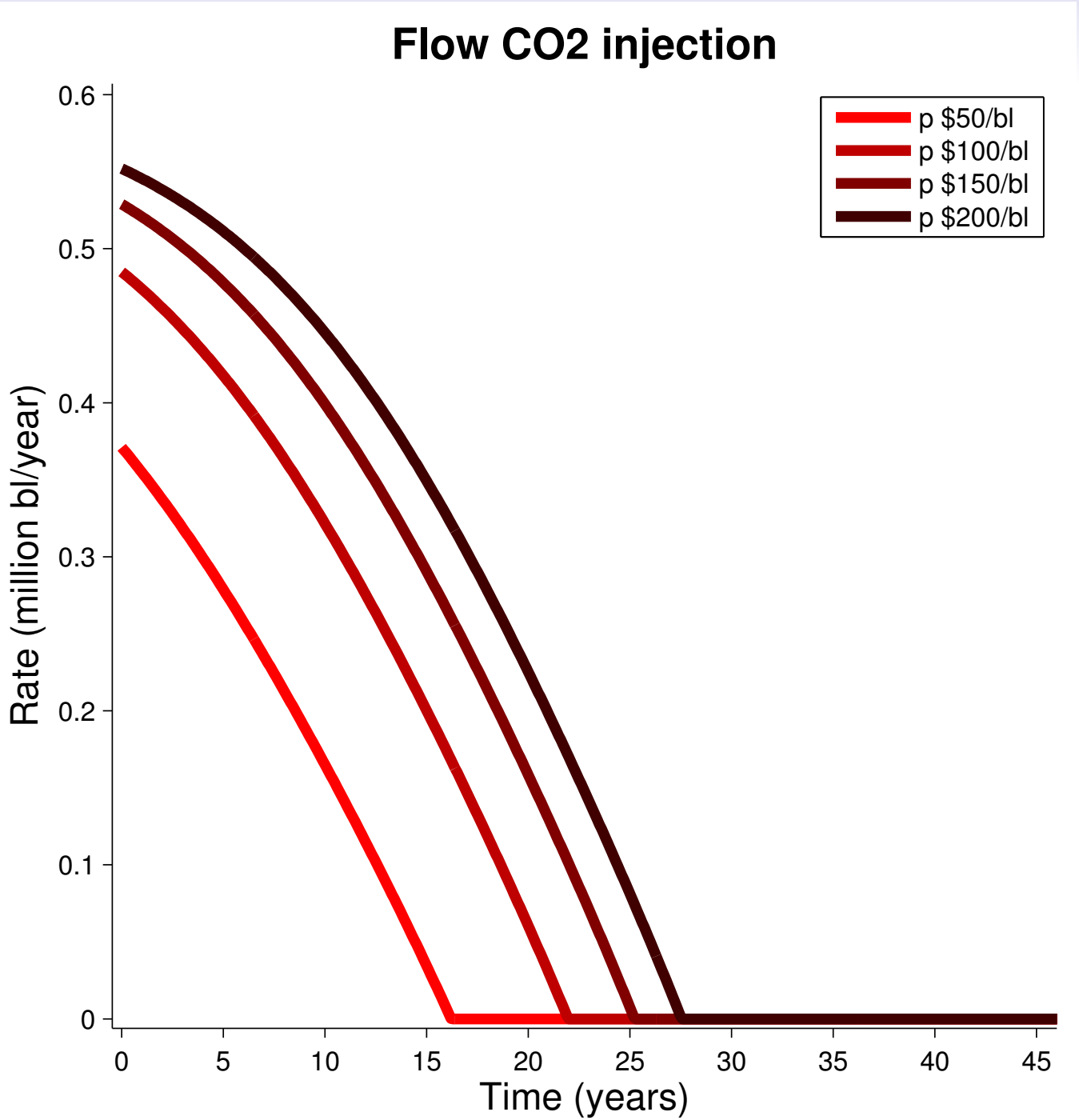
Costs must fall over time

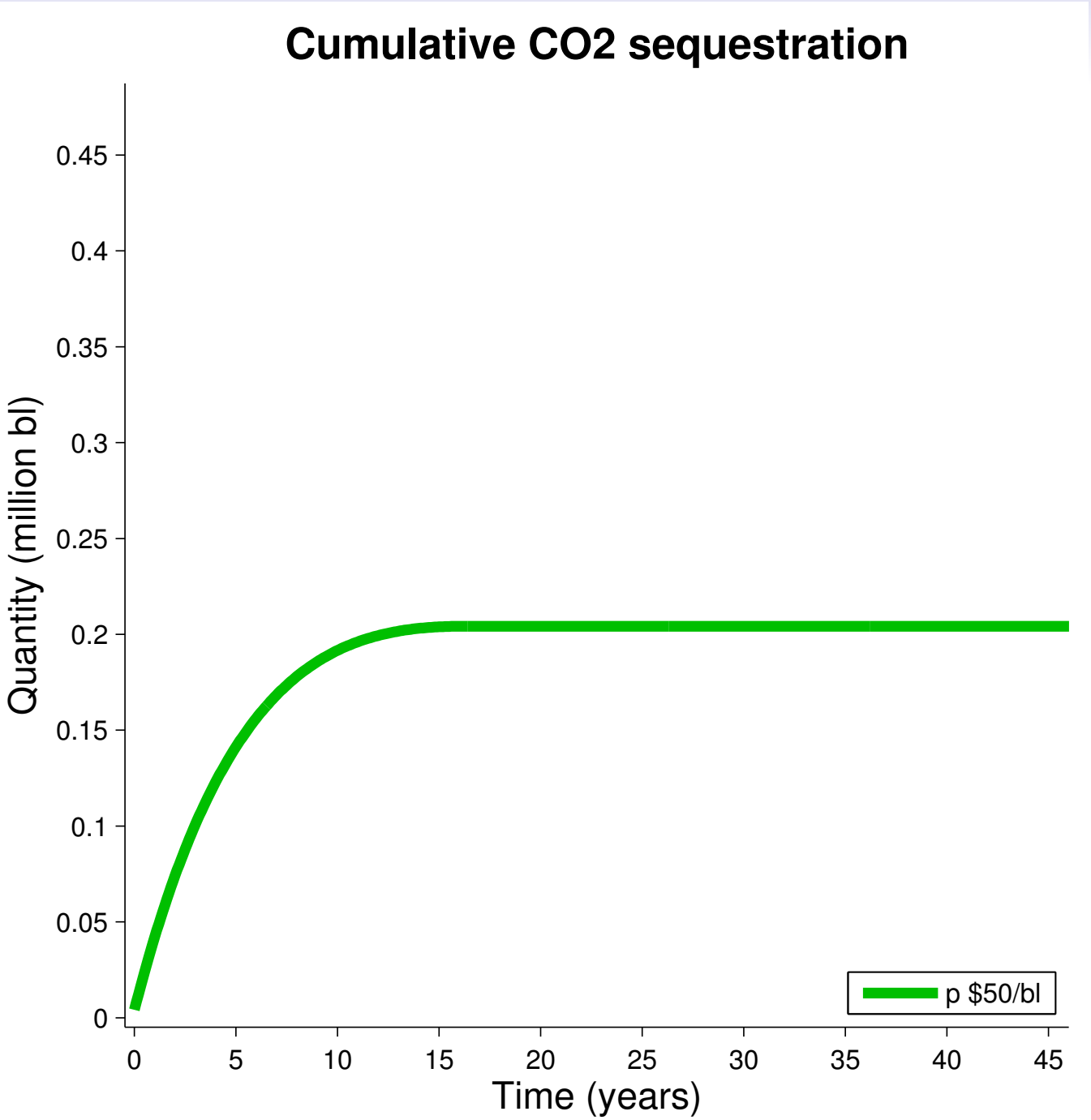
$$profit = \underbrace{p_{oil}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} q_{oil}^{prd} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{rec})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} q_{CO_2}^{seq} - \underbrace{c^{rec}}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{recycling}}} q_{CO_2}^{inj} - \underbrace{c^{oth}}_{\substack{\text{other}\\ \text{costs}}}$$

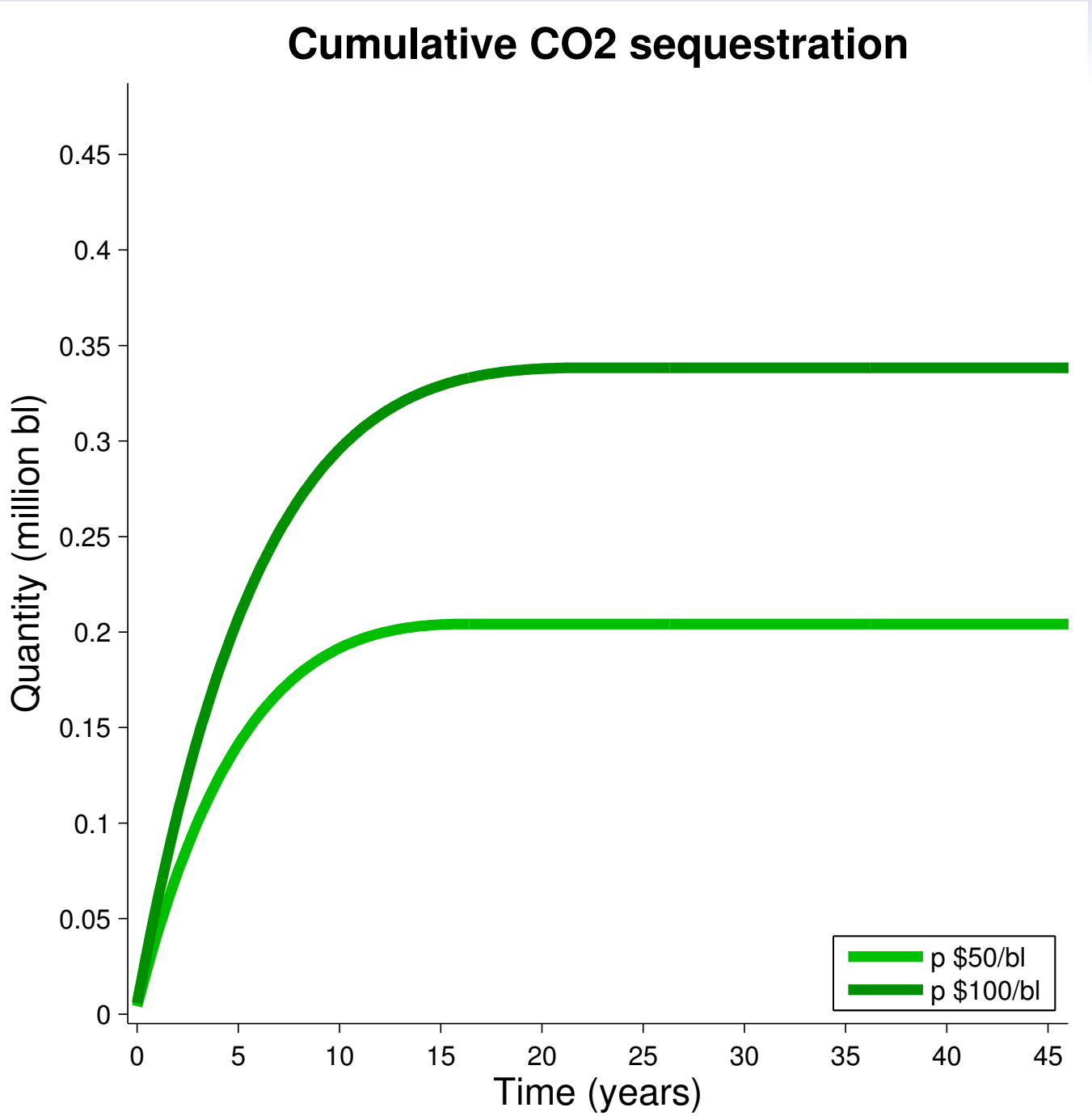

Flow CO2 injection
p $50/bl
Rate (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
Time (years)

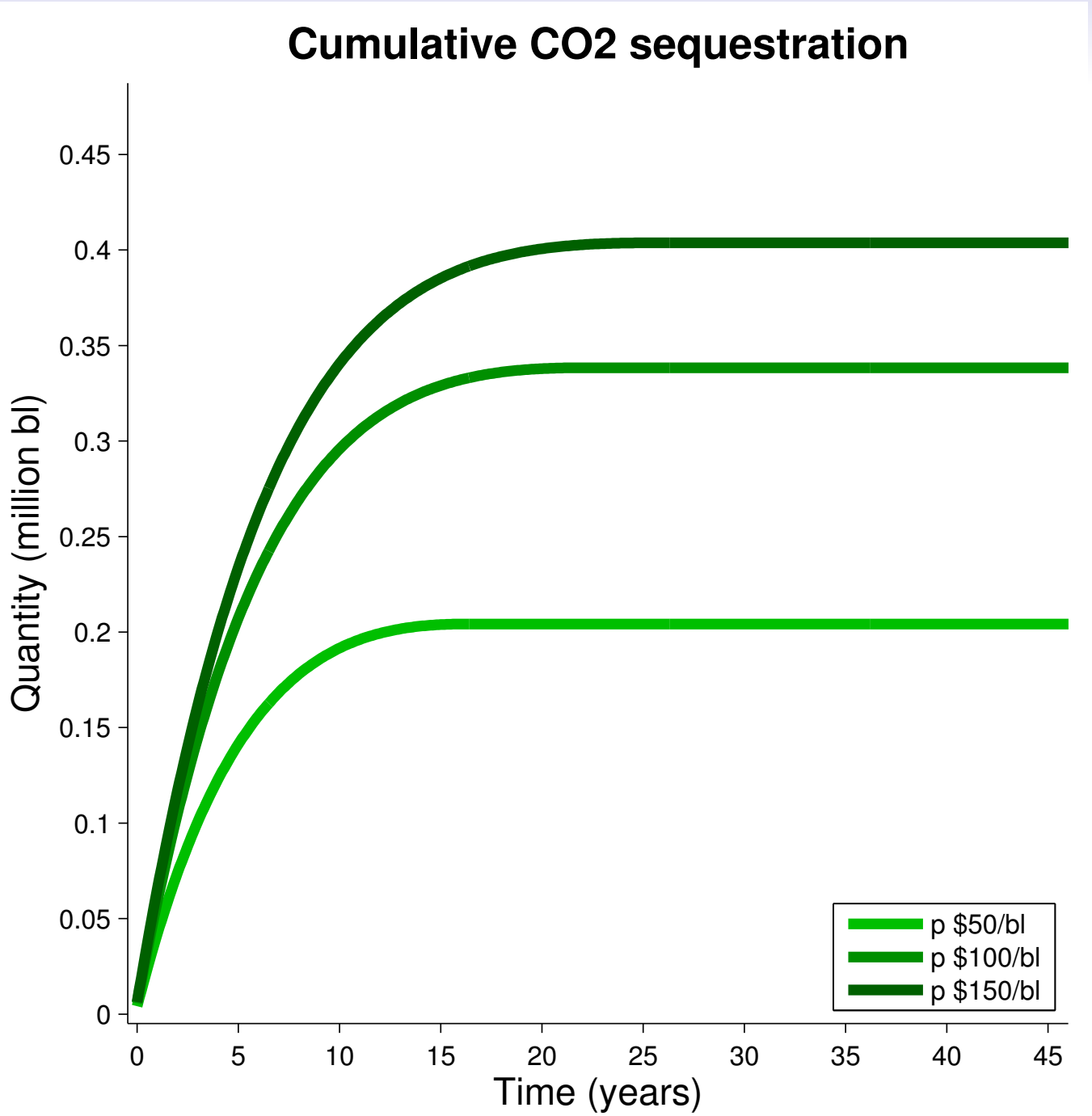

Flow CO2 injection
p $50/bl
p $100/bl
Rate (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
Time (years)

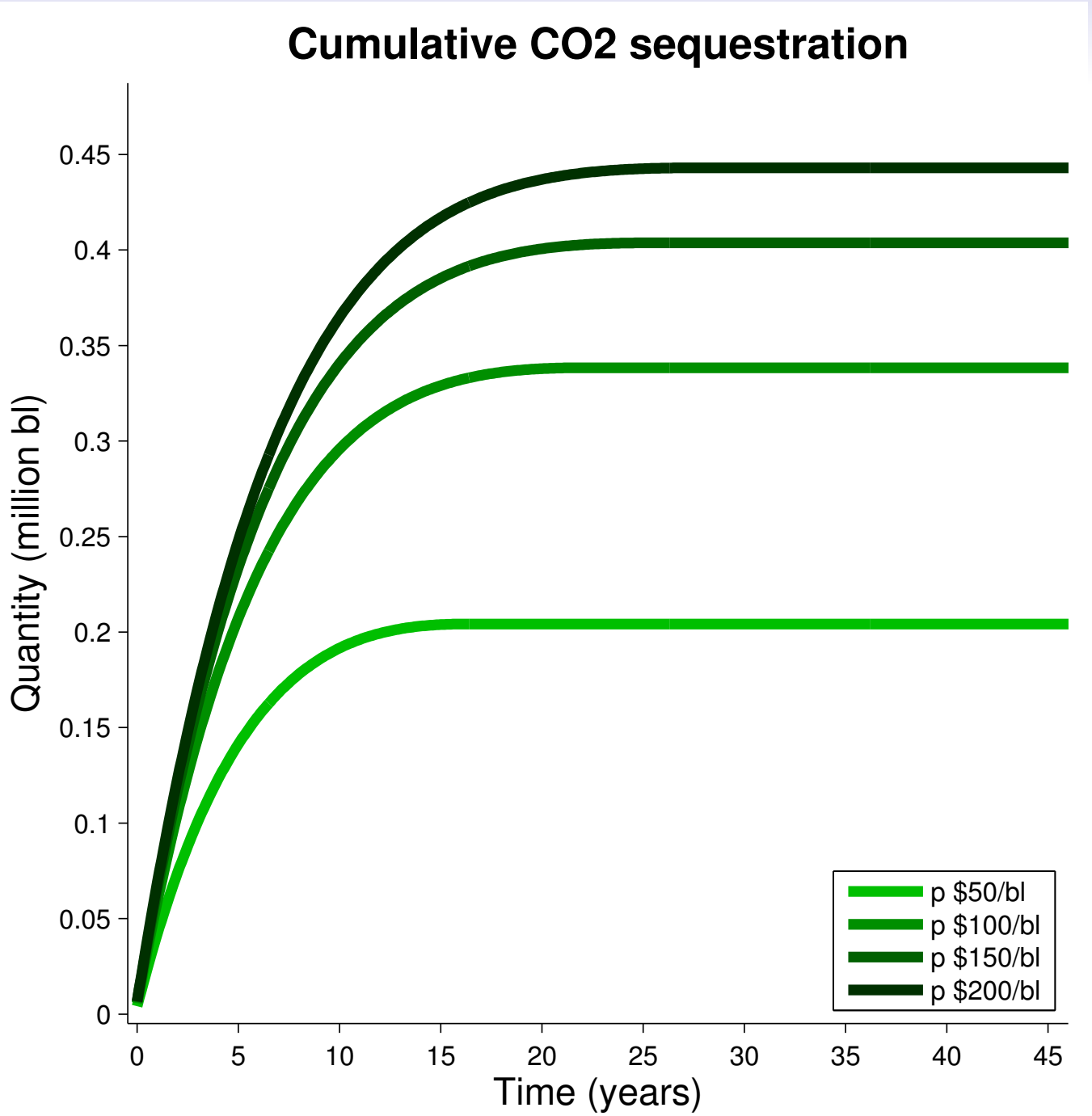

Flow CO2 injection
p $50/bl
p $100/bl
p $150/bl
Rate (million bl/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
Time (years)

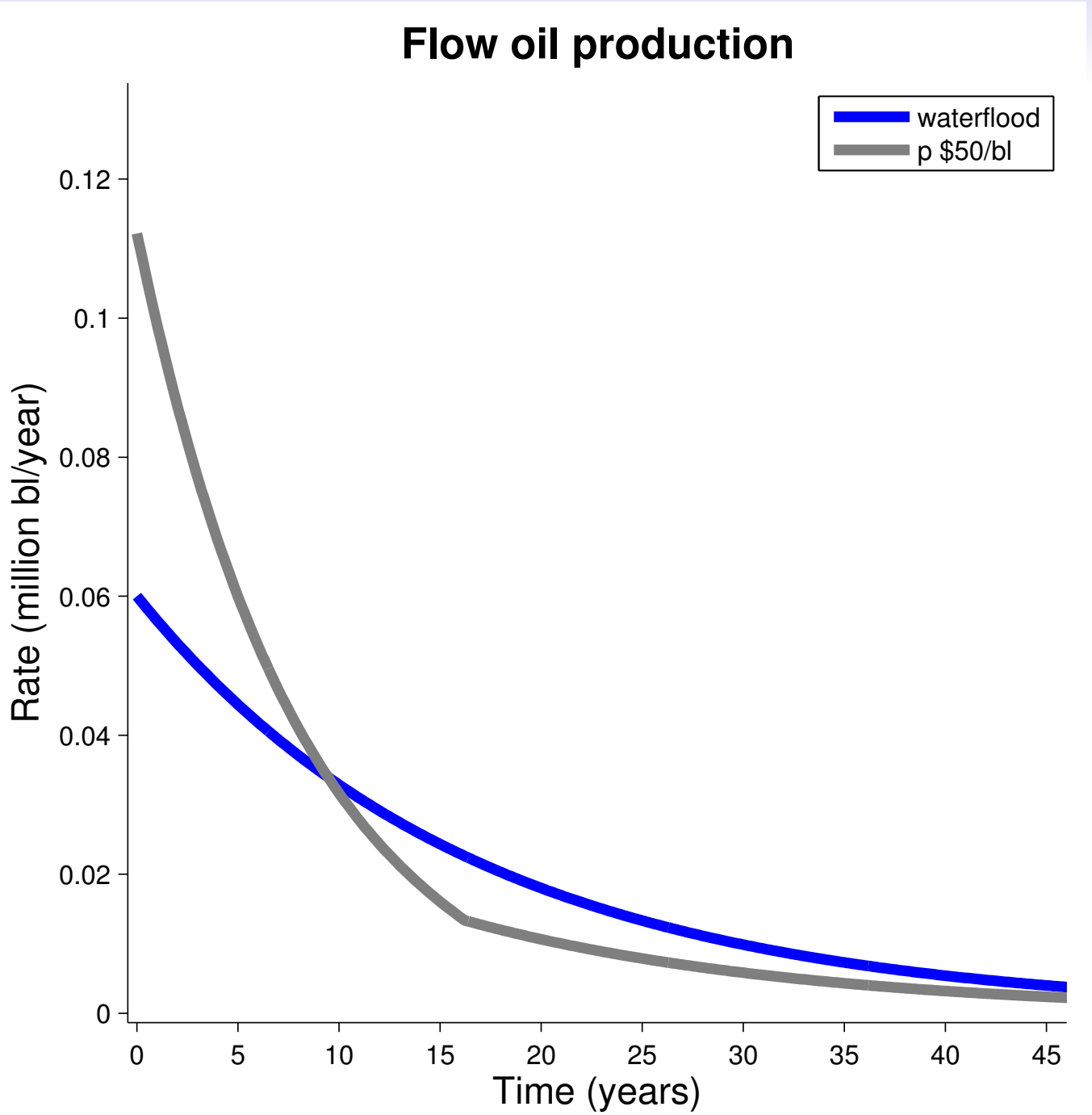

Flow CO2 injection
p $50/bl
p $100/bl
p $150/bl
p $200/bl
Rate (million bl/year)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
35
40
45
Time (years)

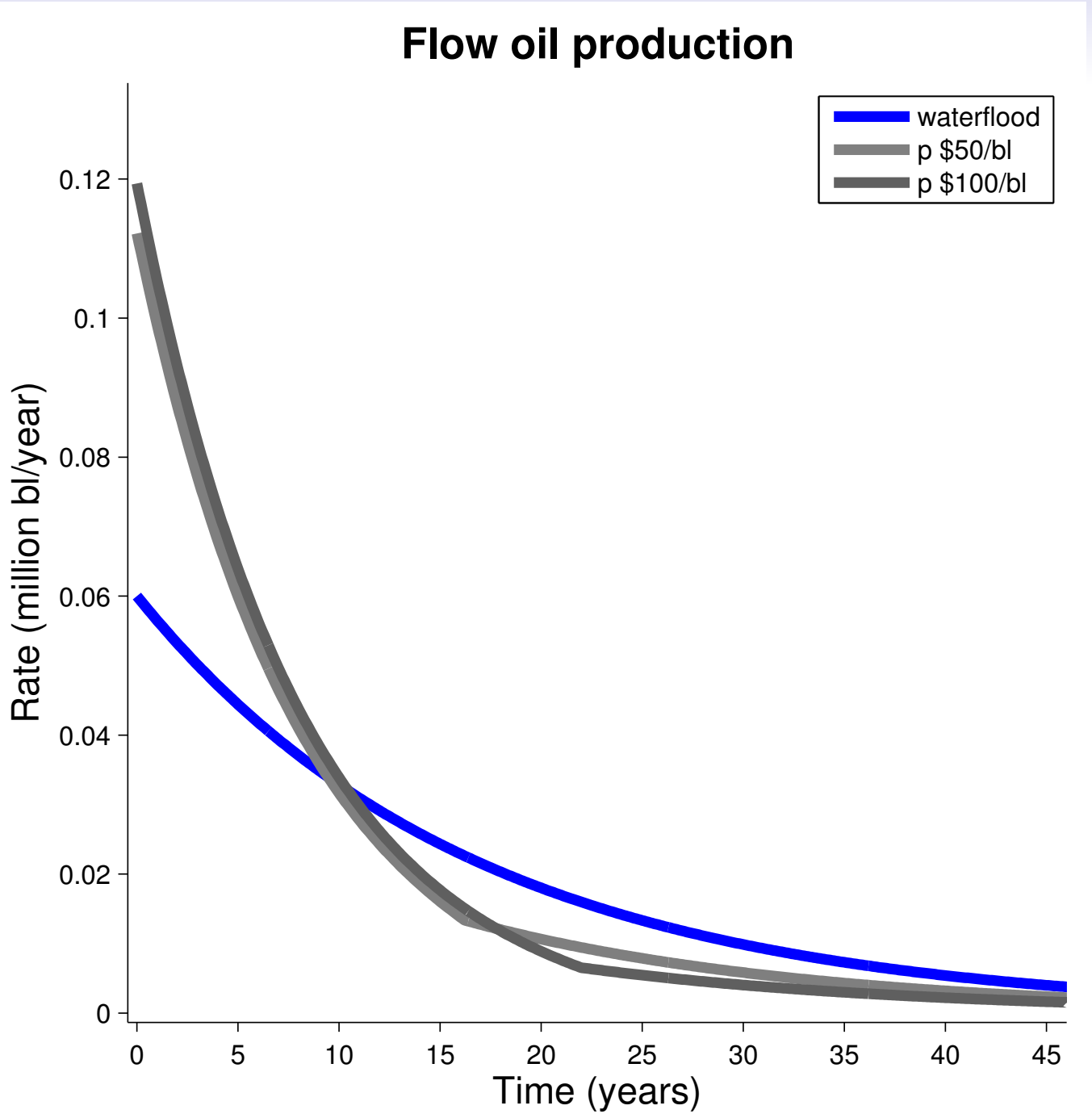

Cumulative CO2 sequestration
Quantity (million bl)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p $50/bl


Cumulative CO2 sequestration
Quantity (million bl)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p $50/bl
p $100/bl


Cumulative CO2 sequestration
Quantity (million bl)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
5
10
15
20
25
30
35
40
45
Time (years)
p $50/bl
p $100/bl
p $150/bl


Cumulative CO2 sequestration
Quantity (million bl)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
5
10
15
20
25
30
35
40
45
Time (years)
p $50/bl
p $100/bl
p $150/bl
p $200/bl


Flow oil production
waterflood
p $50/bl
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)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0.08
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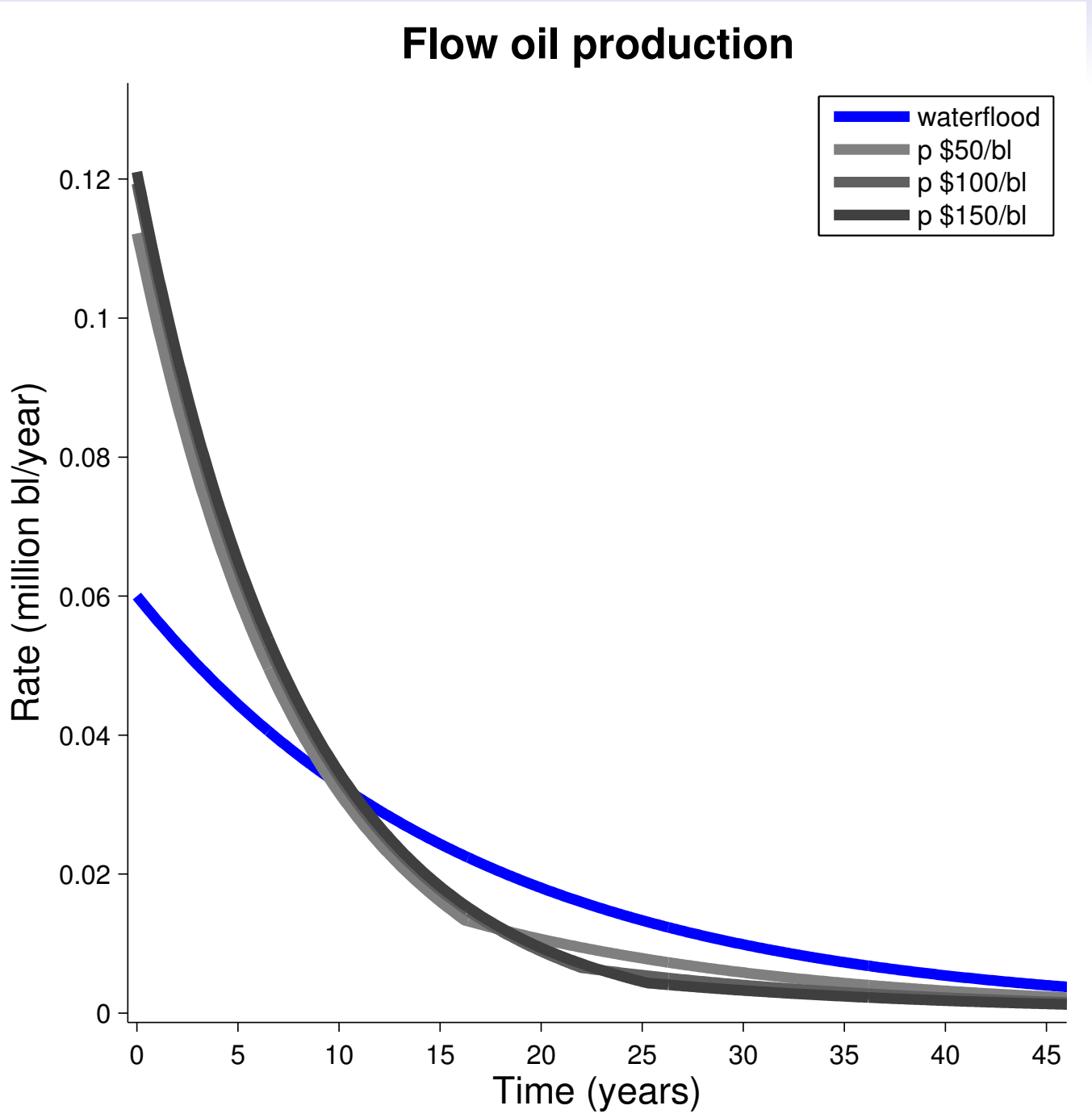
0
5
10
15
20
25
30
35
40
45
Time (years)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p $150/bl
Rate (million bl/year)
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0
0
5
10
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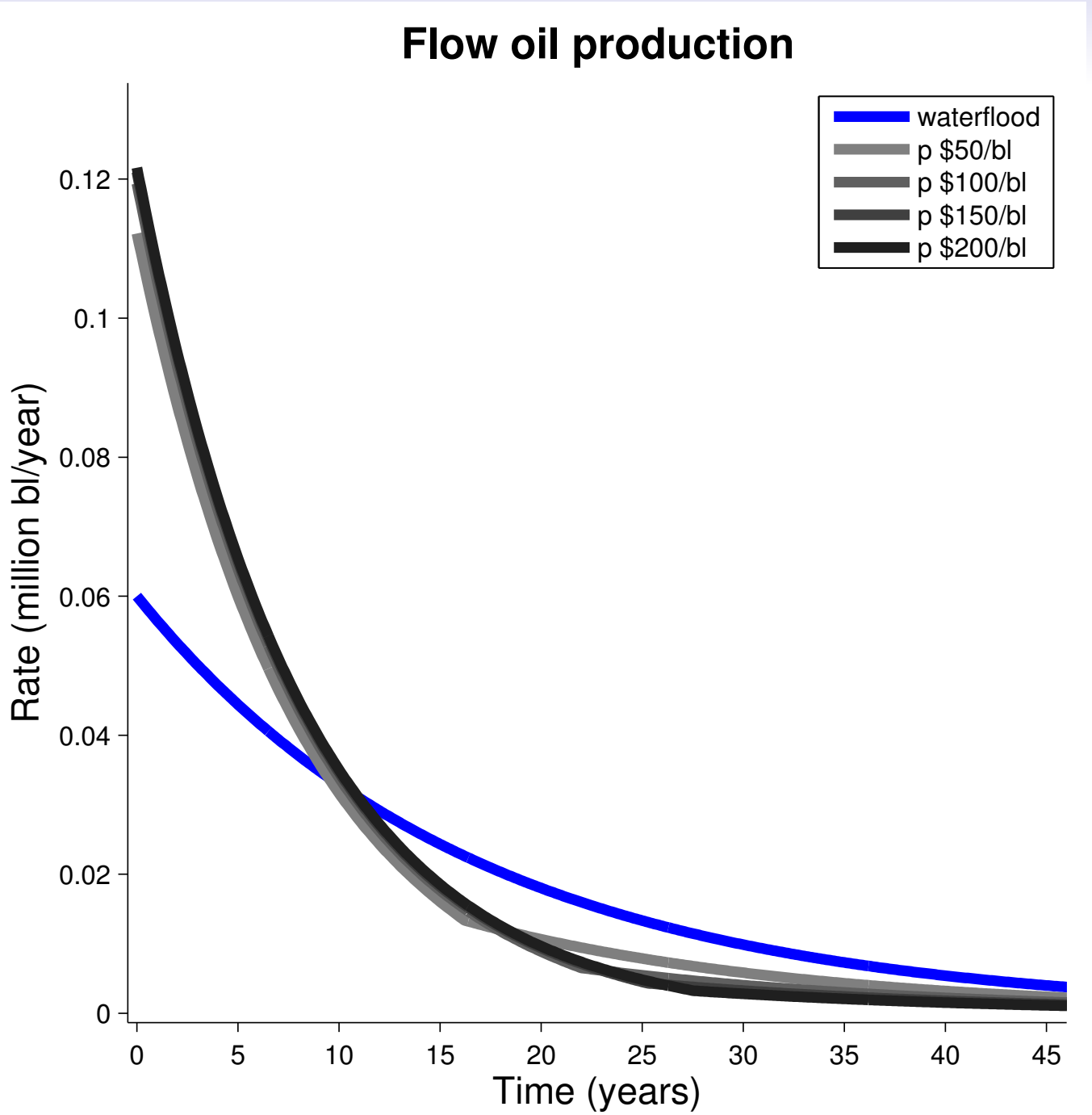
20
25
30
35
40
45
Time (years)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p $150/bl
p $200/bl
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0
0
5
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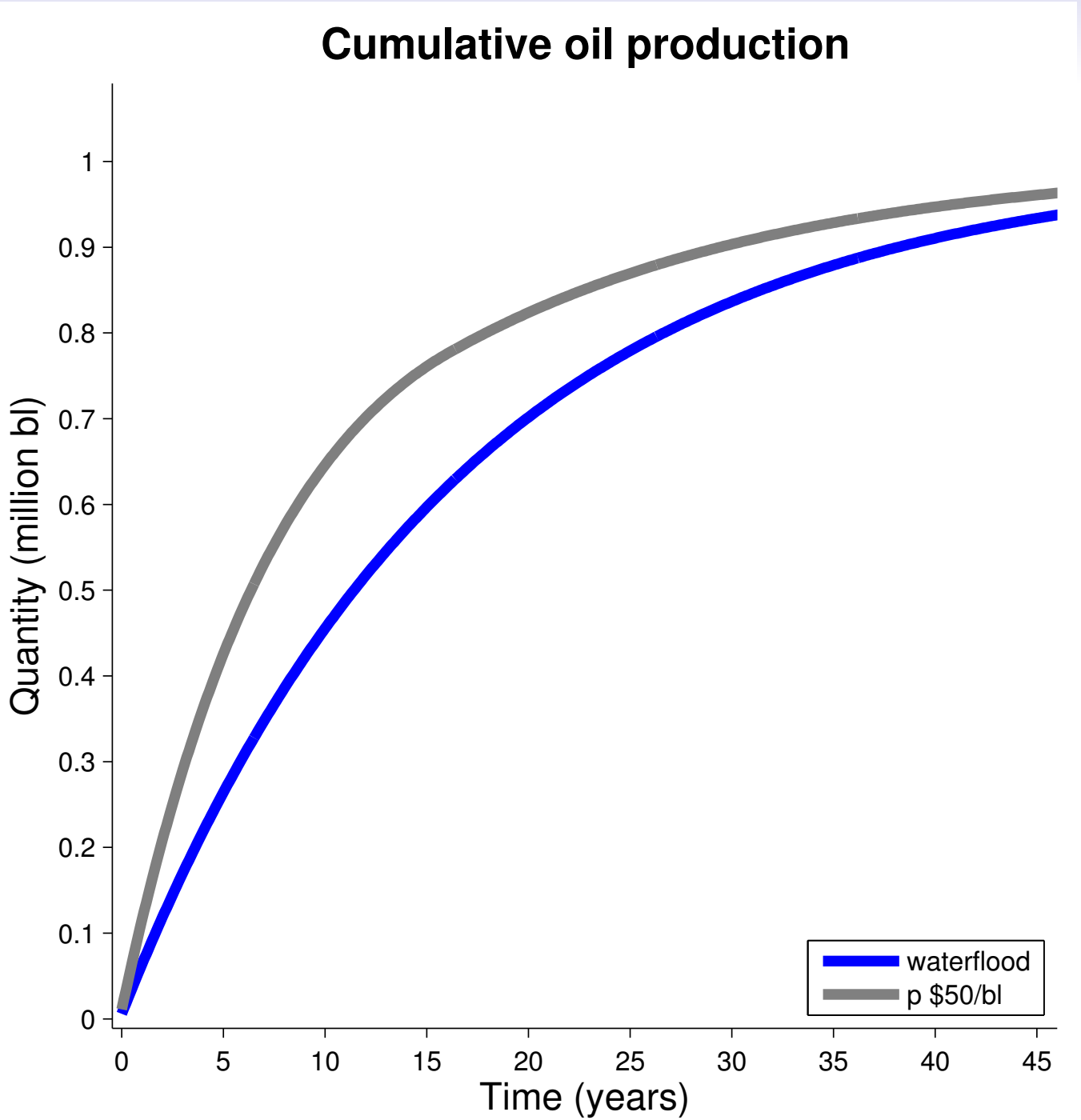
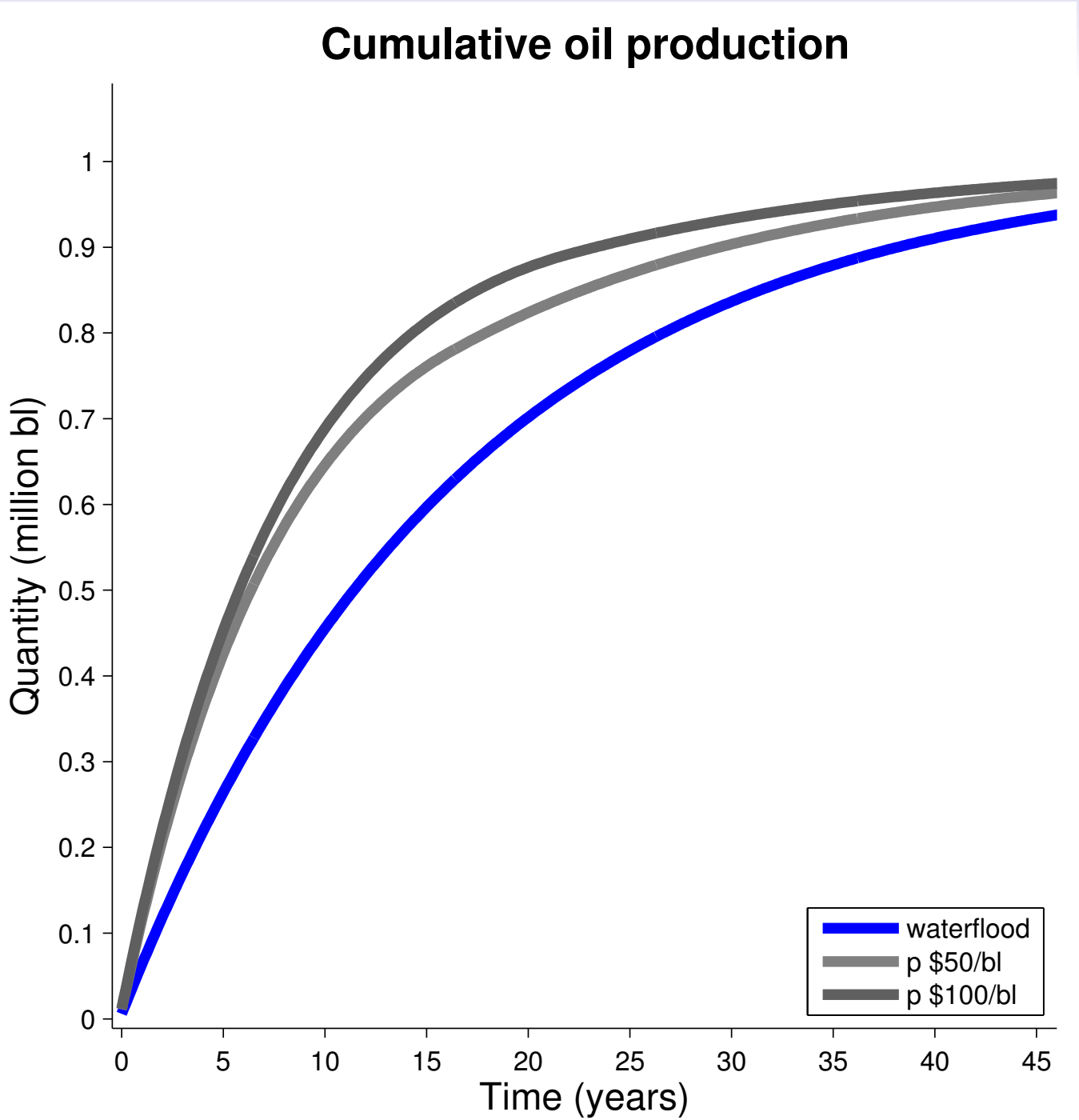
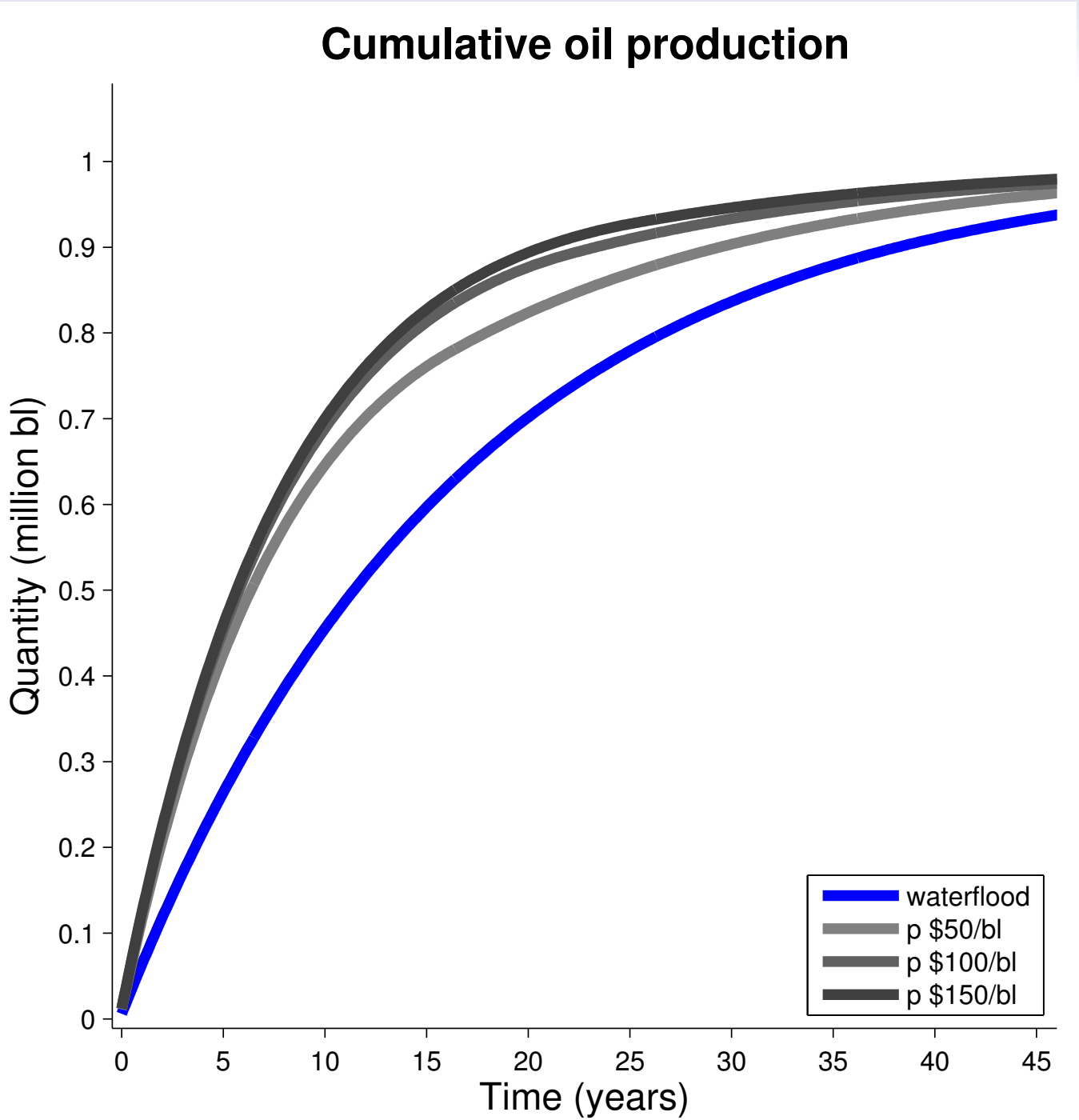
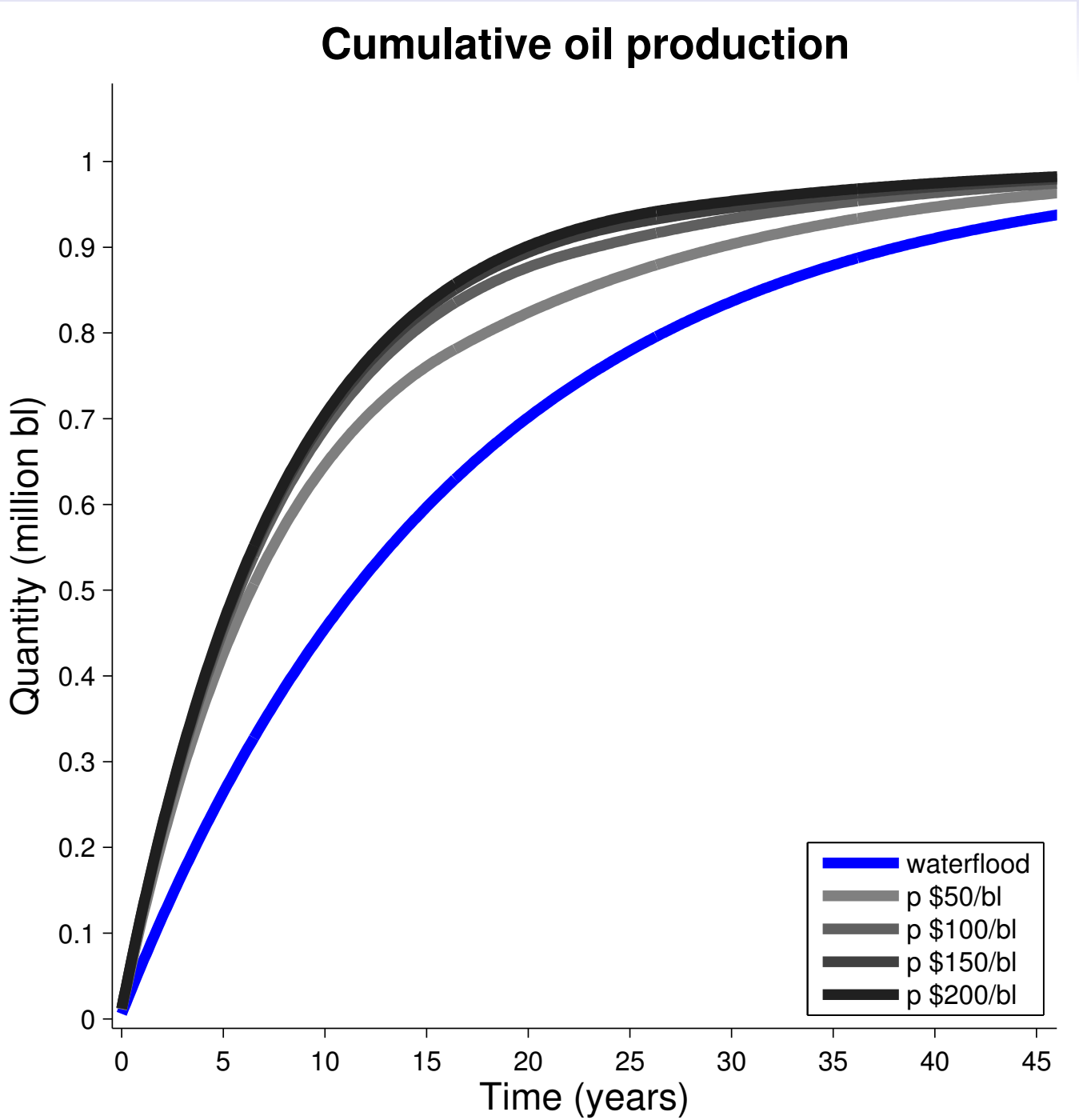
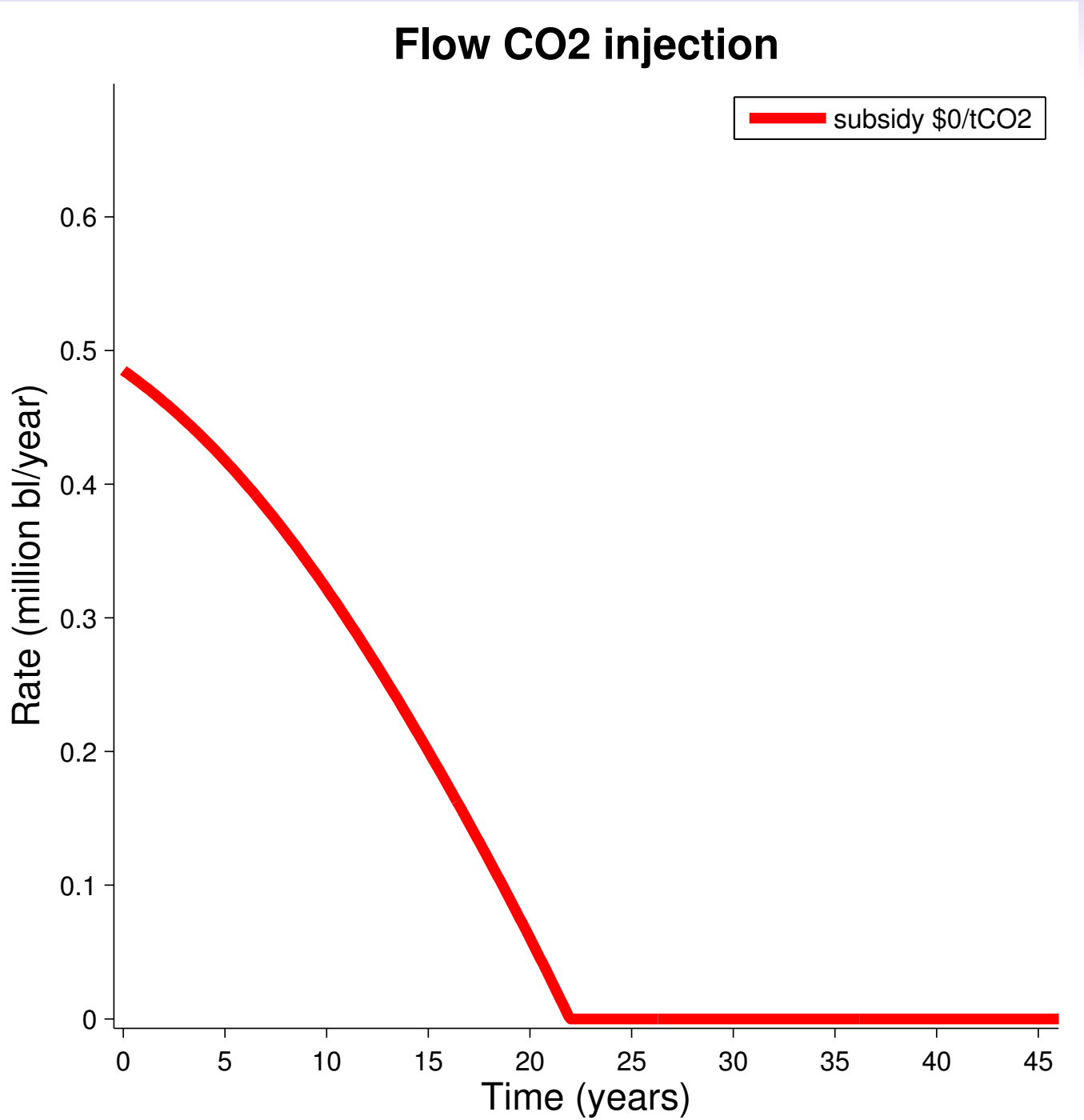
15
20
25
30
35
40
45
Time (years)

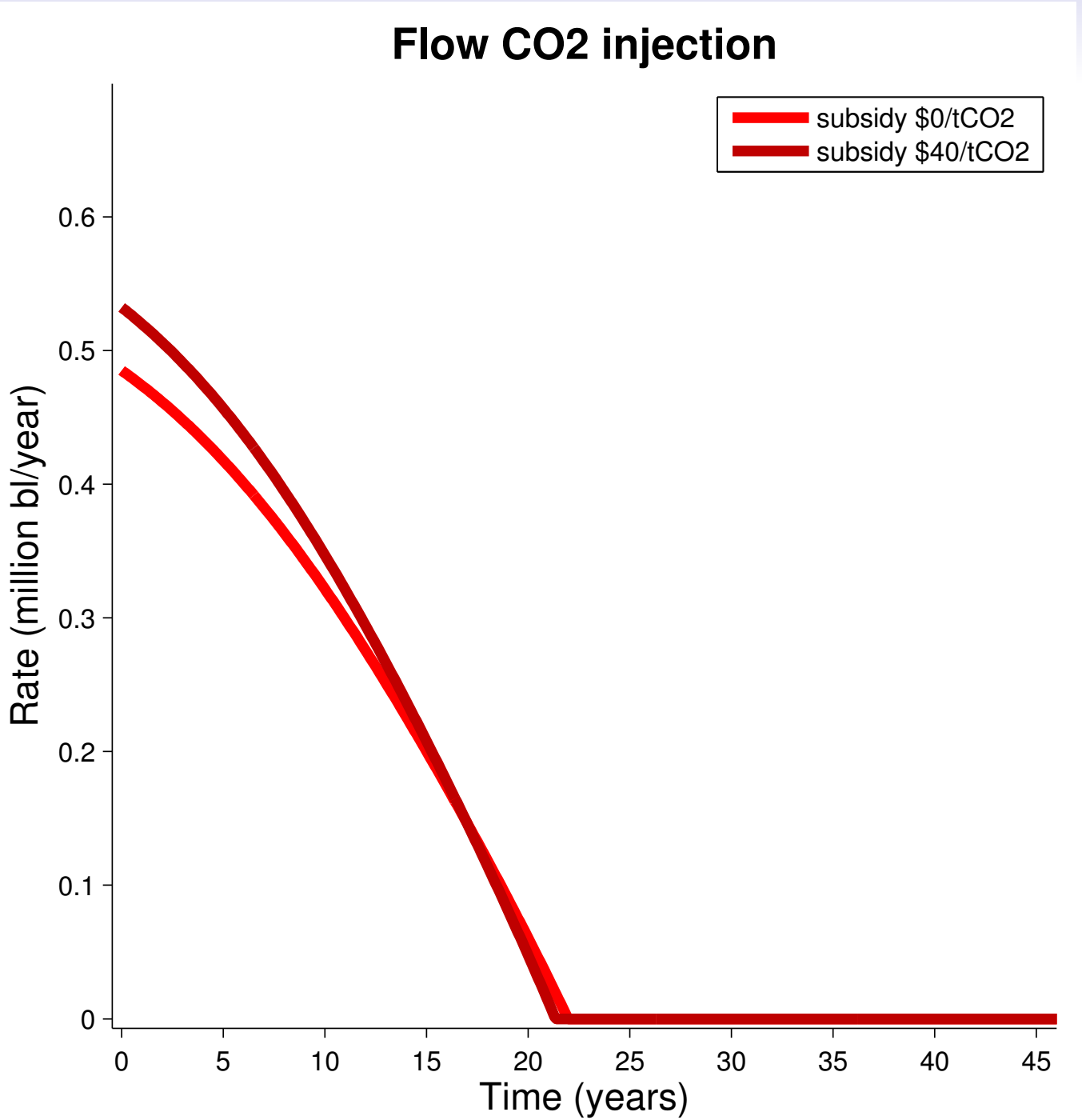

Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
p $50/bl

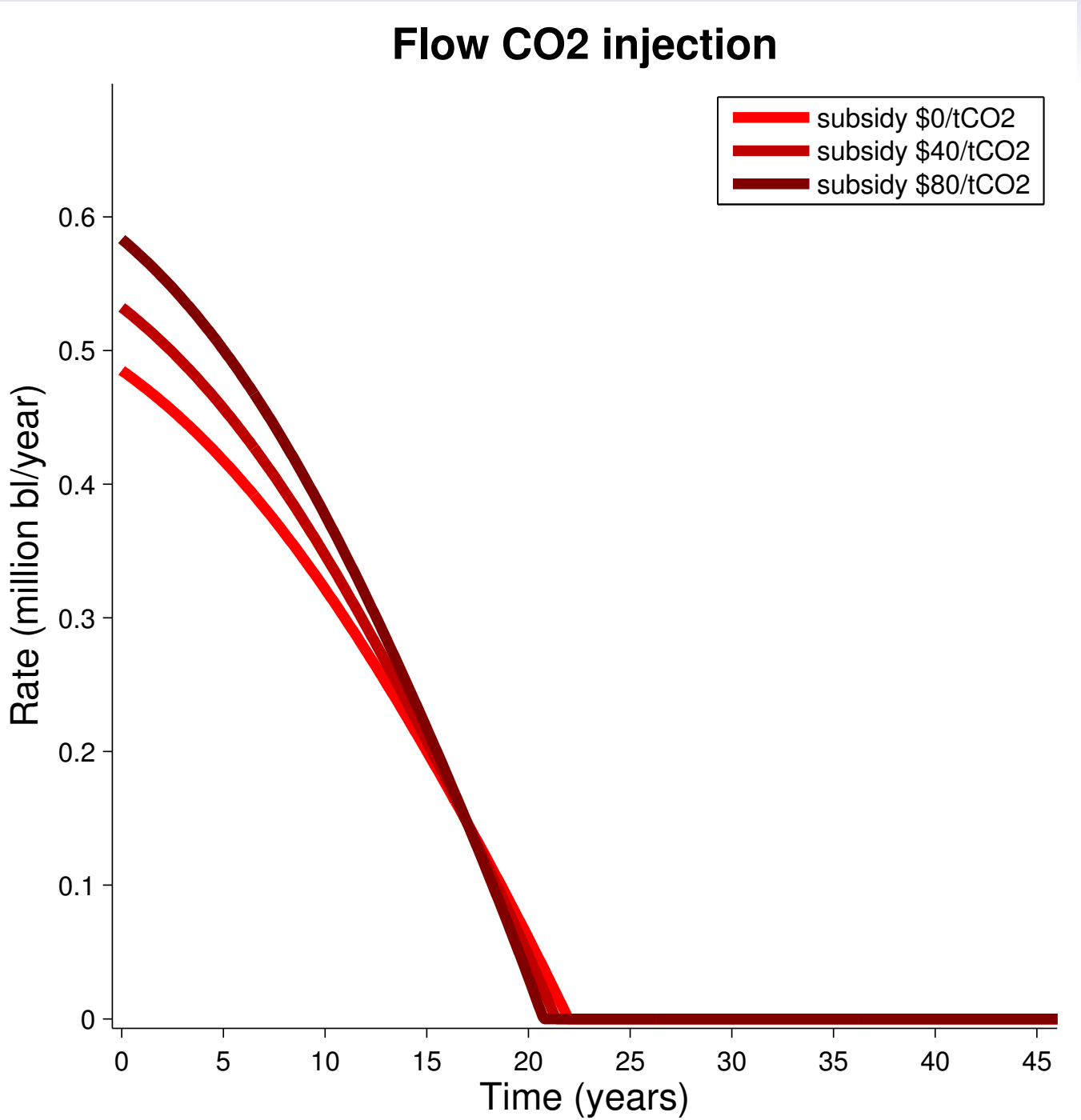

Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
p $50/bl
p $100/bl

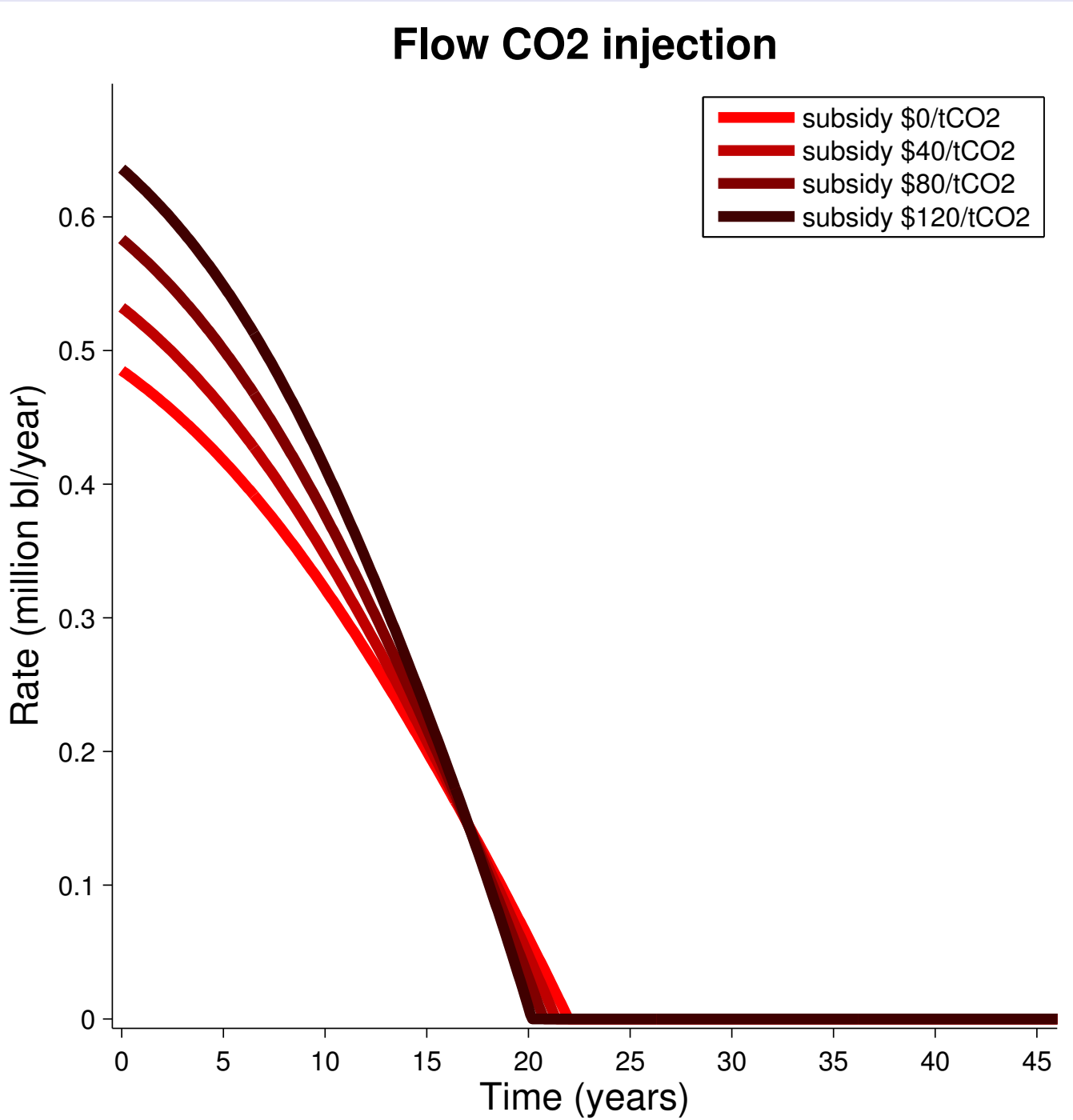

Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
p $50/bl
p $100/bl
p $150/bl

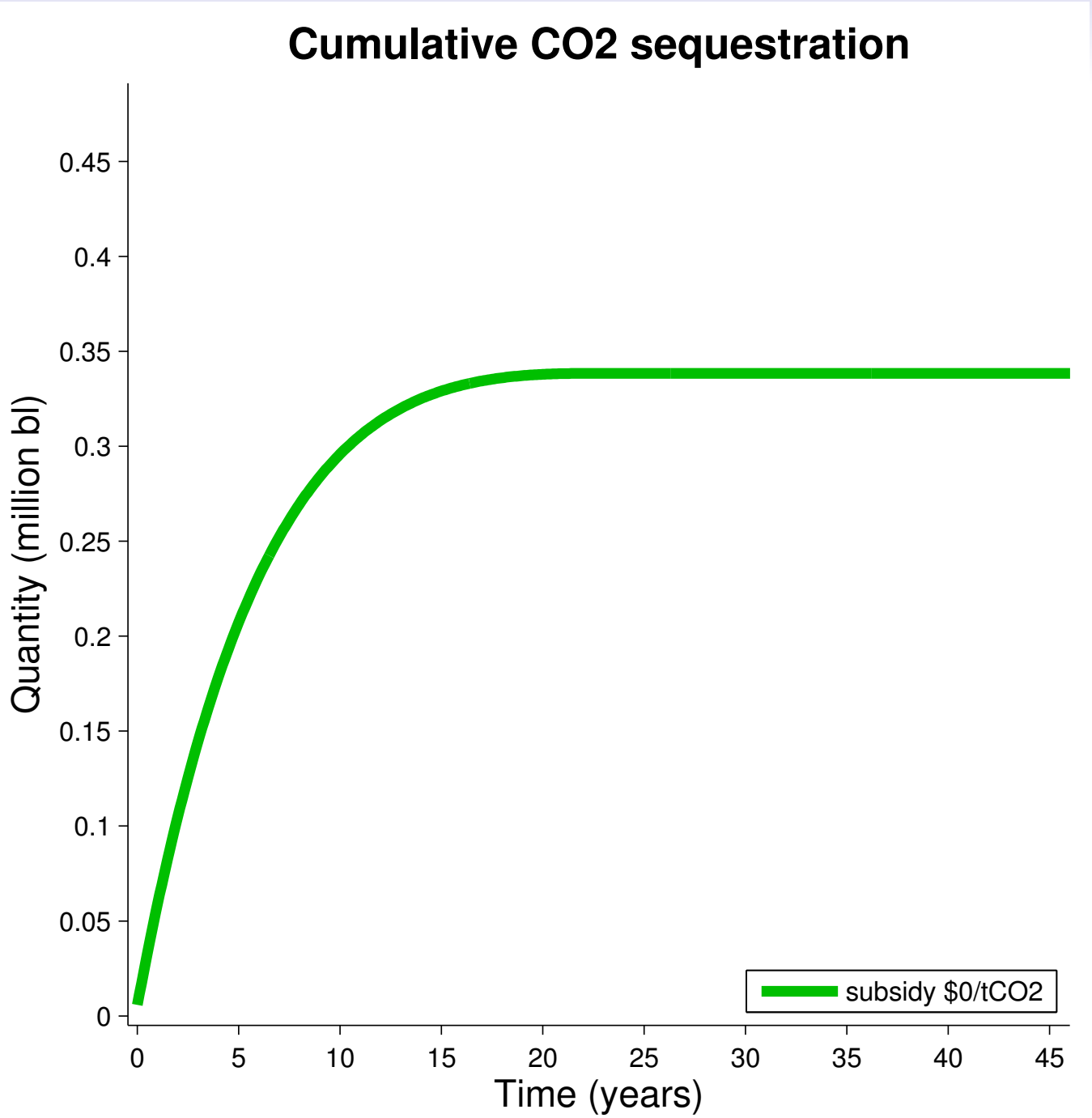

Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
p $50/bl
p $100/bl
p $150/bl
p $200/bl

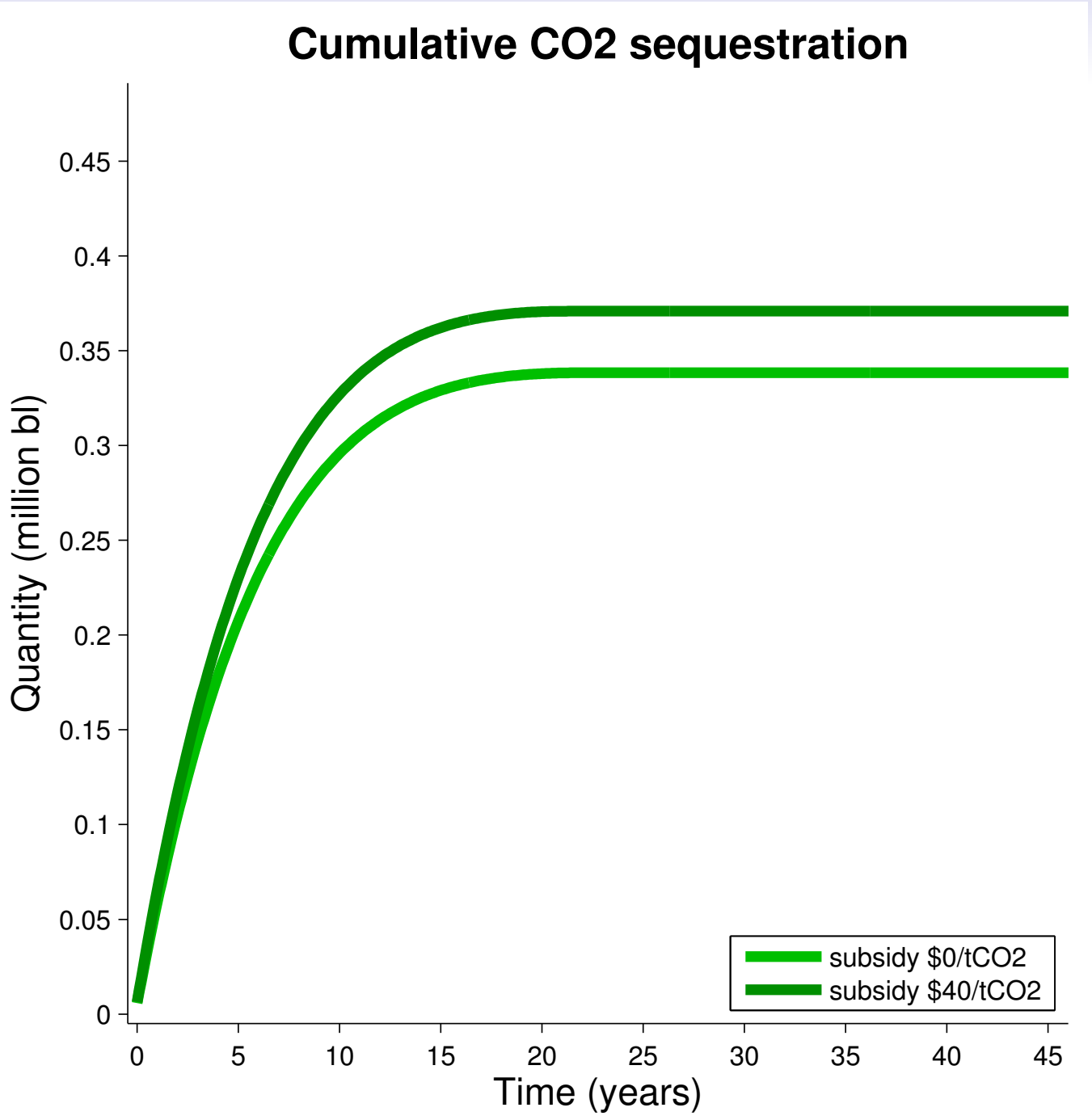

Flow CO2 injection
subsidy $0/tCO2
Rate (million bl/year)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
35
40
45
Time (years)

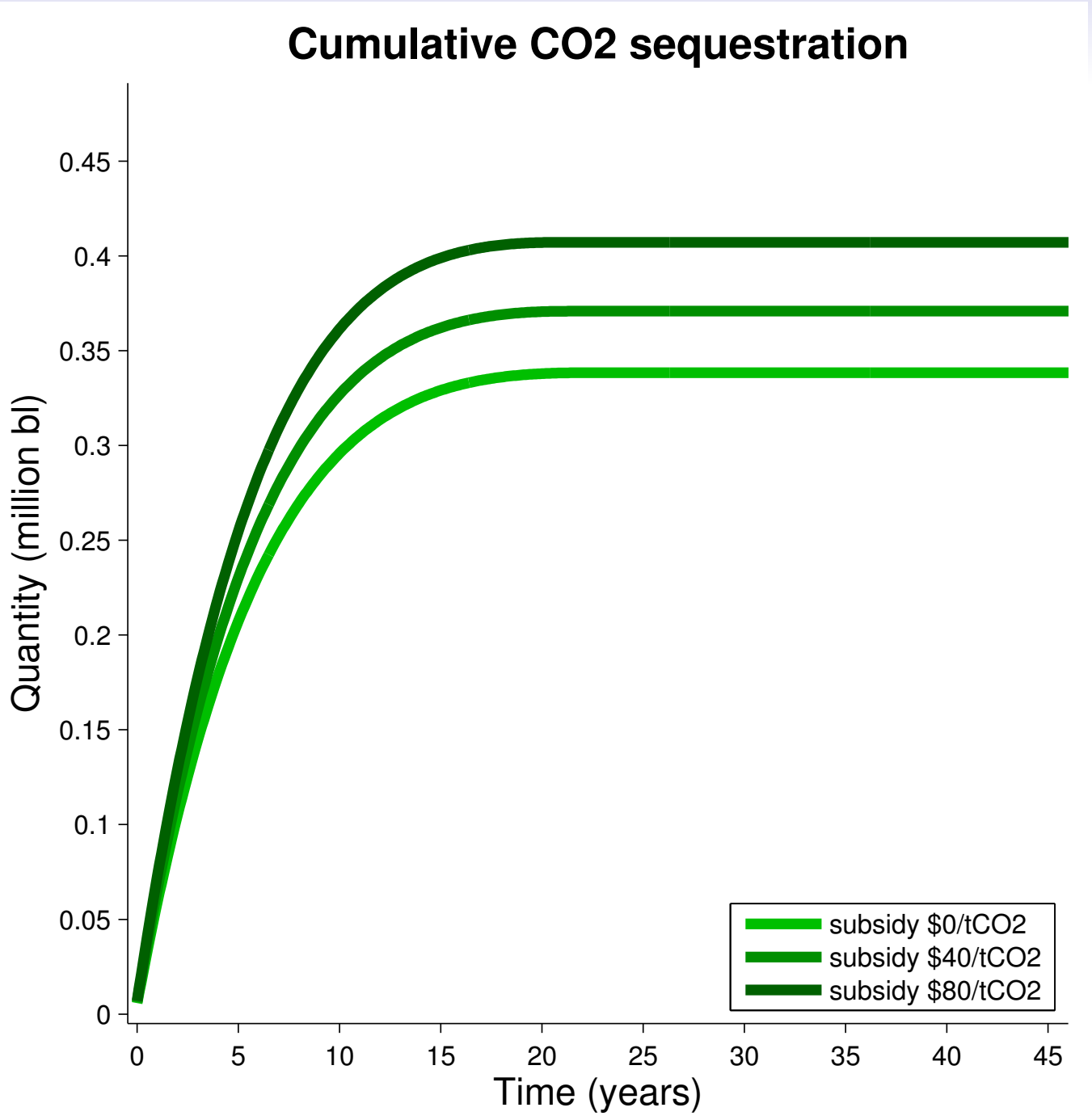

Flow CO2 injection
subsidy $0/tCO2
subsidy $40/tCO2
Rate (million bl/year)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
35
40
45
Time (years)

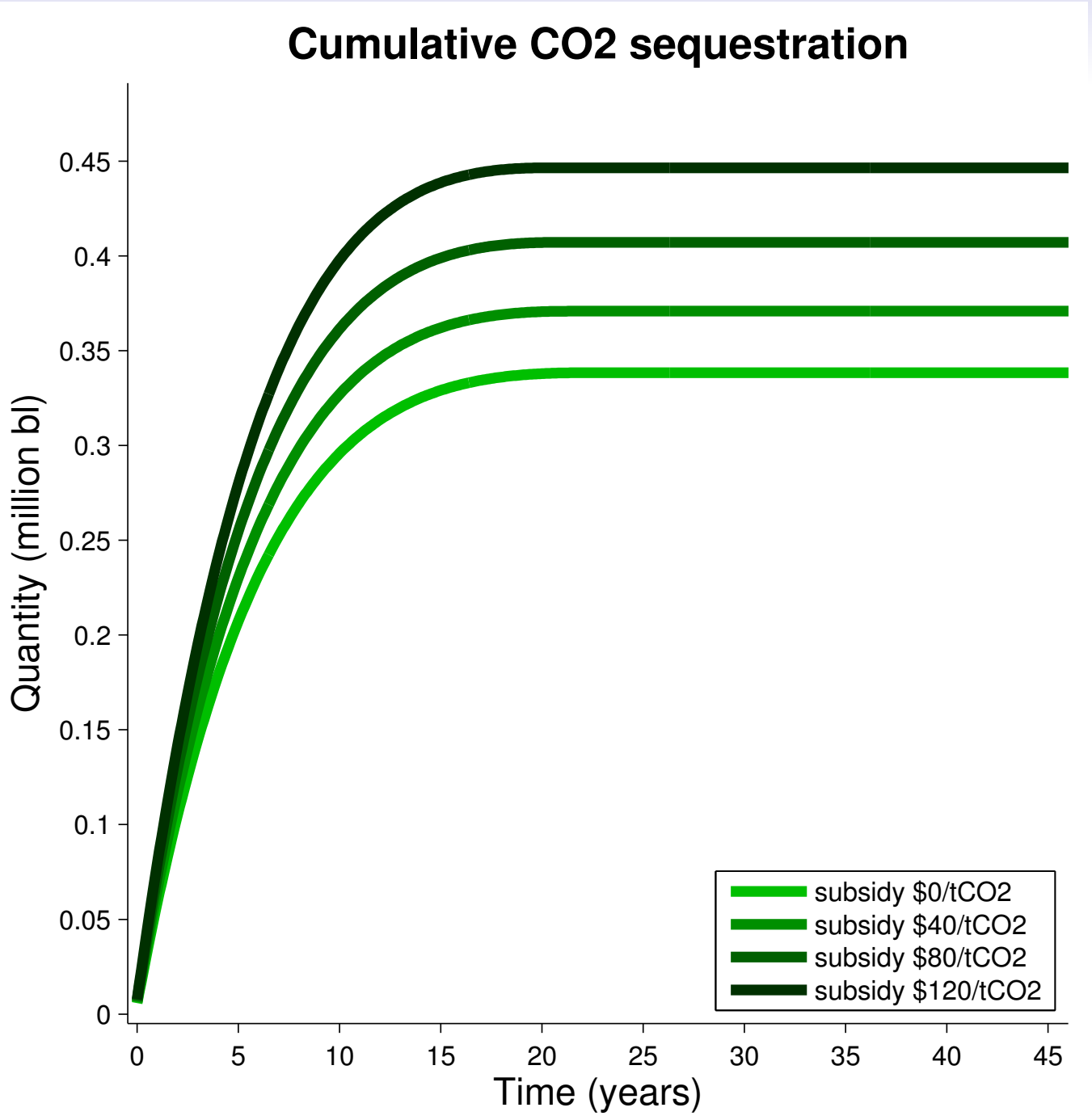

Flow CO2 injection
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
Rate (million bl/year)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
35
40
45
Time (years)

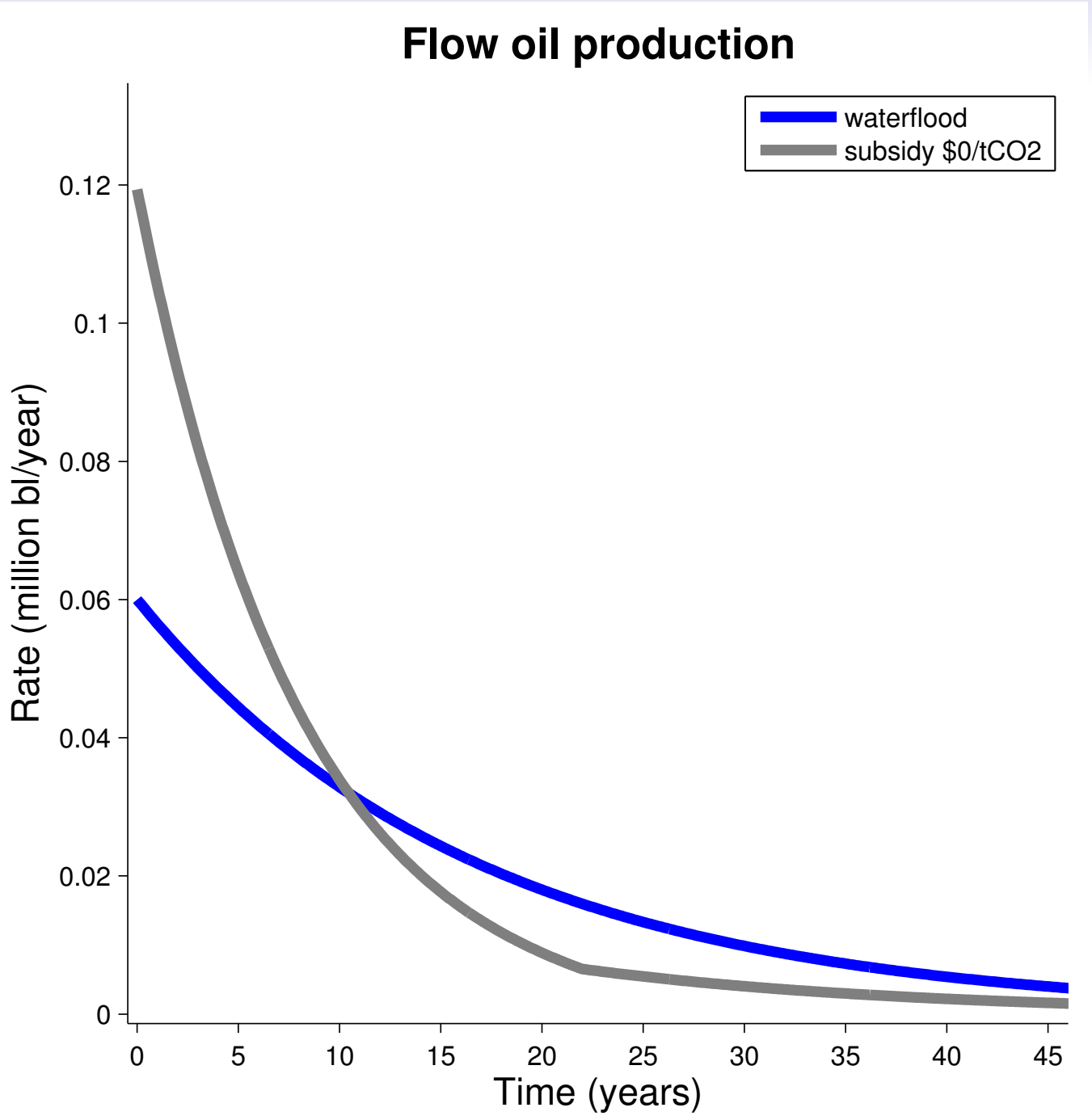

Flow CO2 injection
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
subsidy $120/tCO2
Rate (million bl/year)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
35
40
45
Time (years)

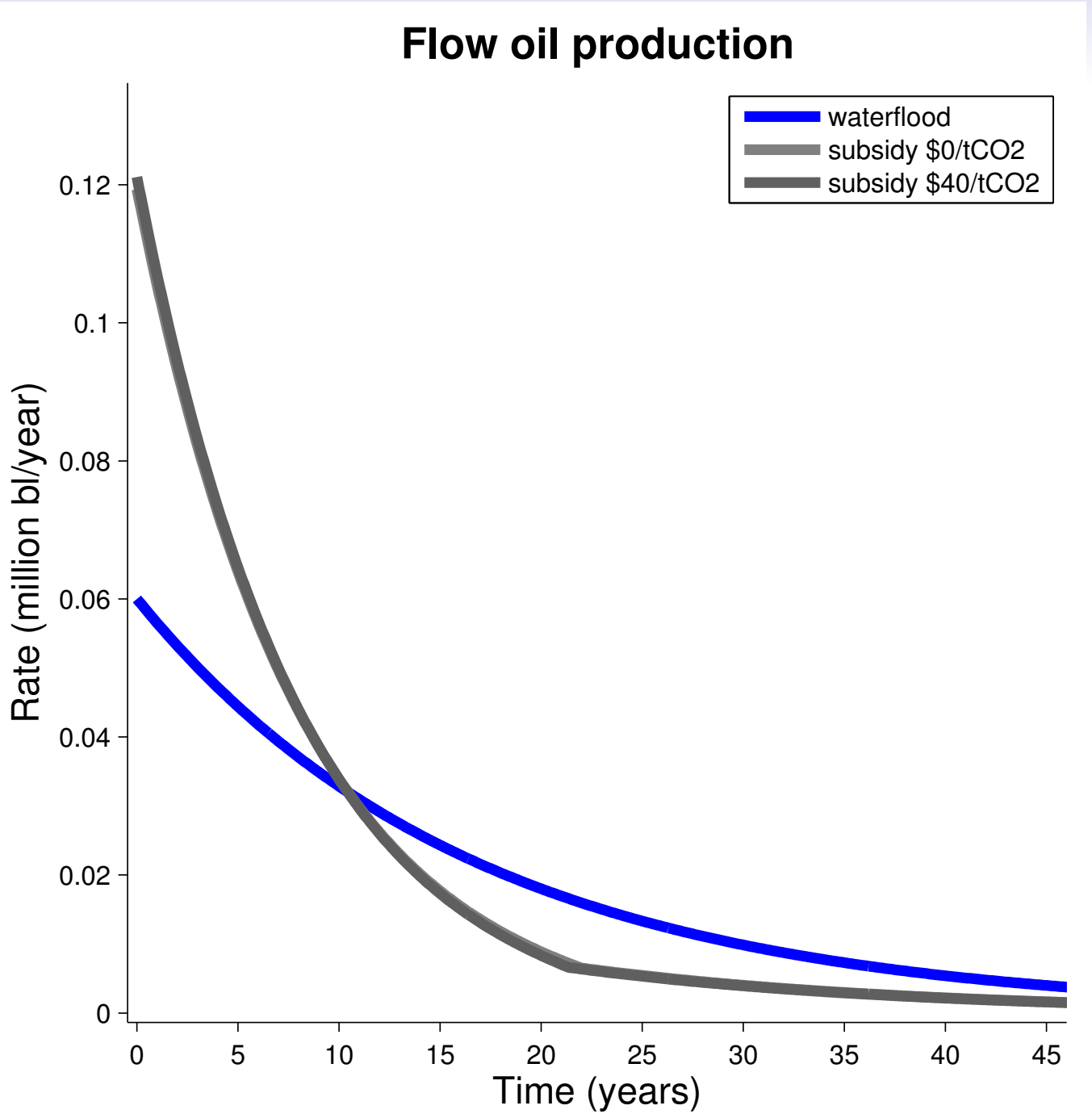

Cumulative CO2 sequestration
Quantity (million bl)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
subsidy $0/tCO2

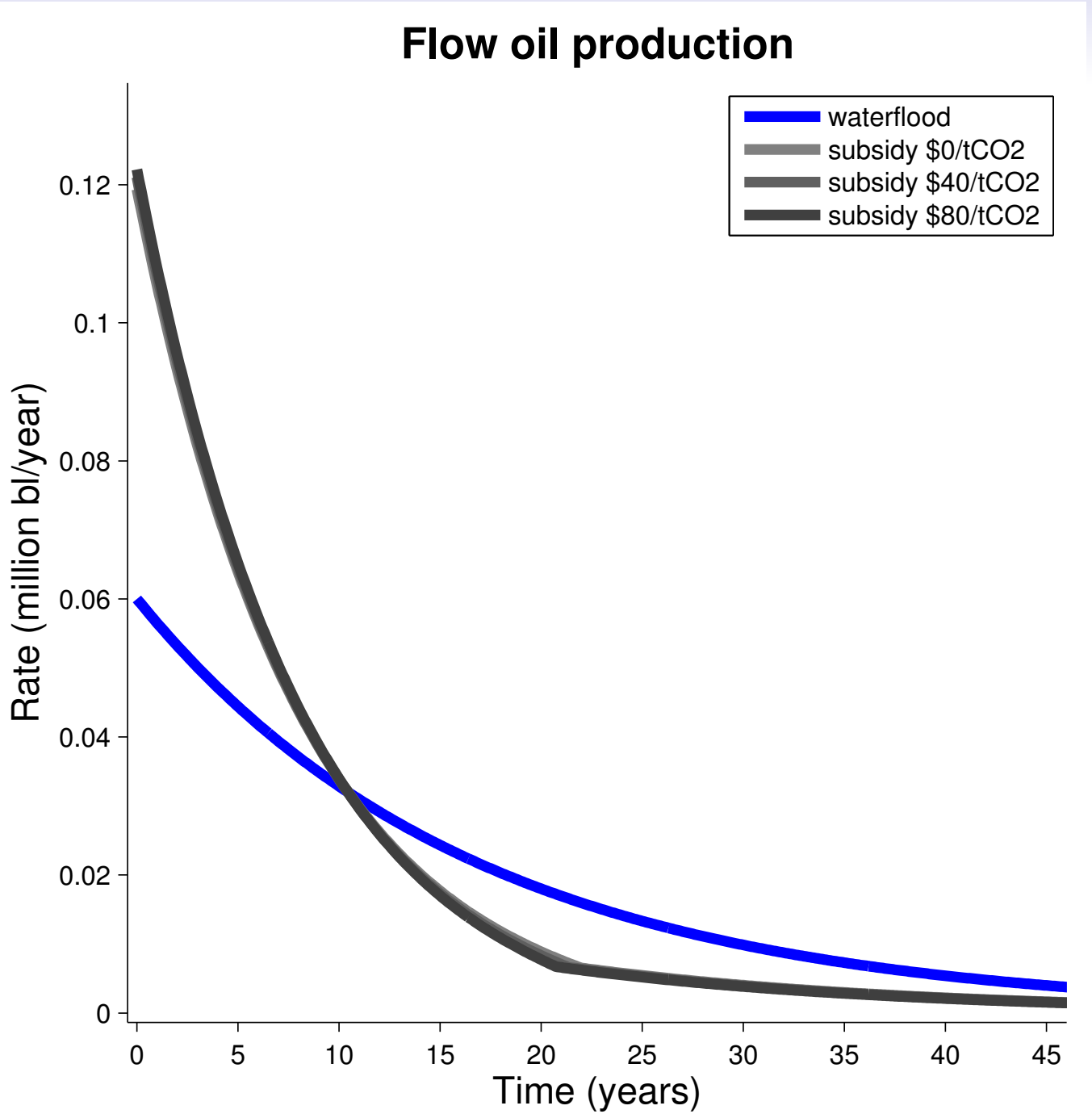

Cumulative CO2 sequestration
Quantity (million bl)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
5
10
15
20
25
30
35
40
45
Time (years)
subsidy $0/tCO2
subsidy $40/tCO2

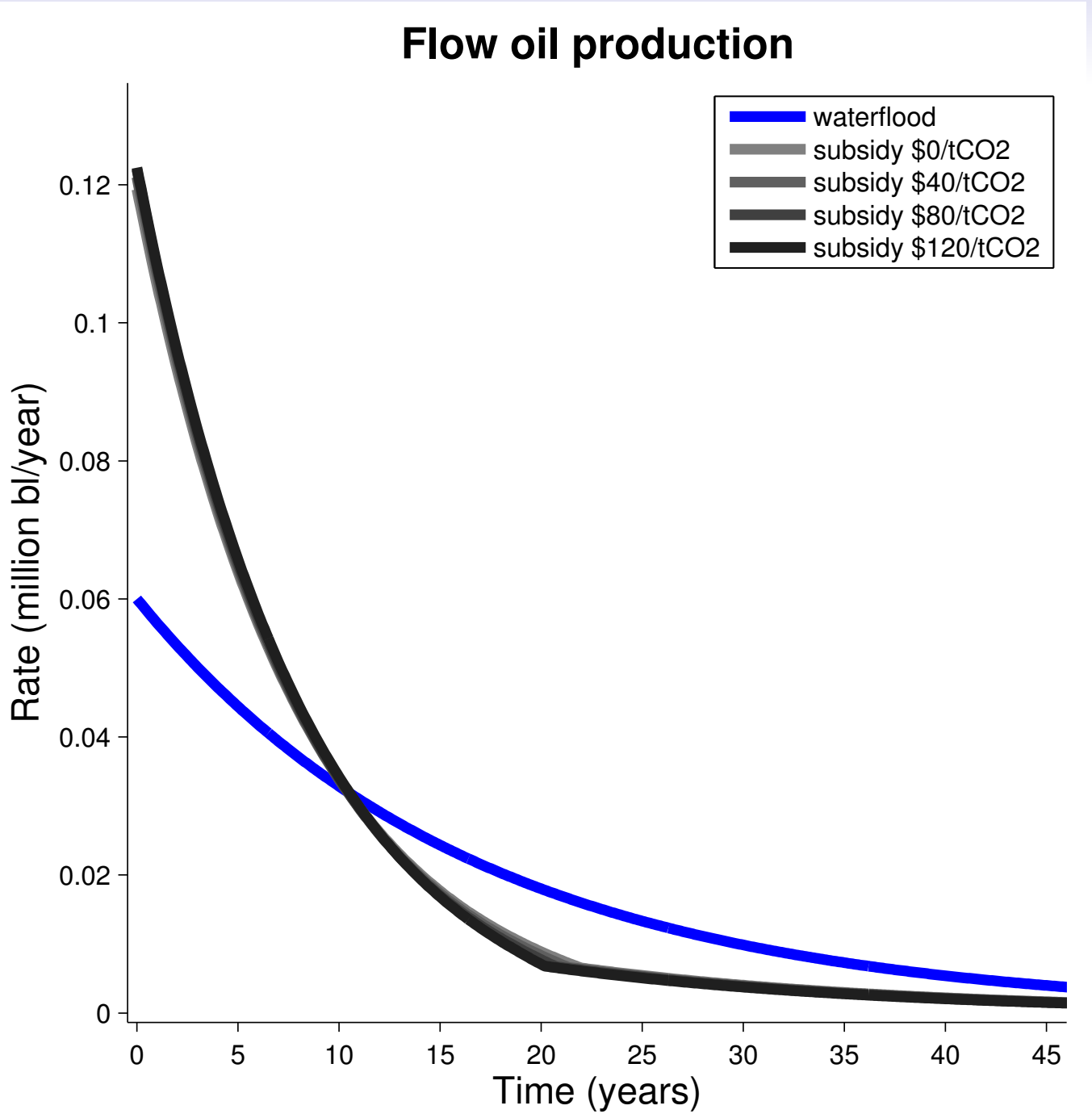

Cumulative CO2 sequestration
Quantity (million bl)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
5
10
15
20
25
30
35
40
45
Time (years)
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2

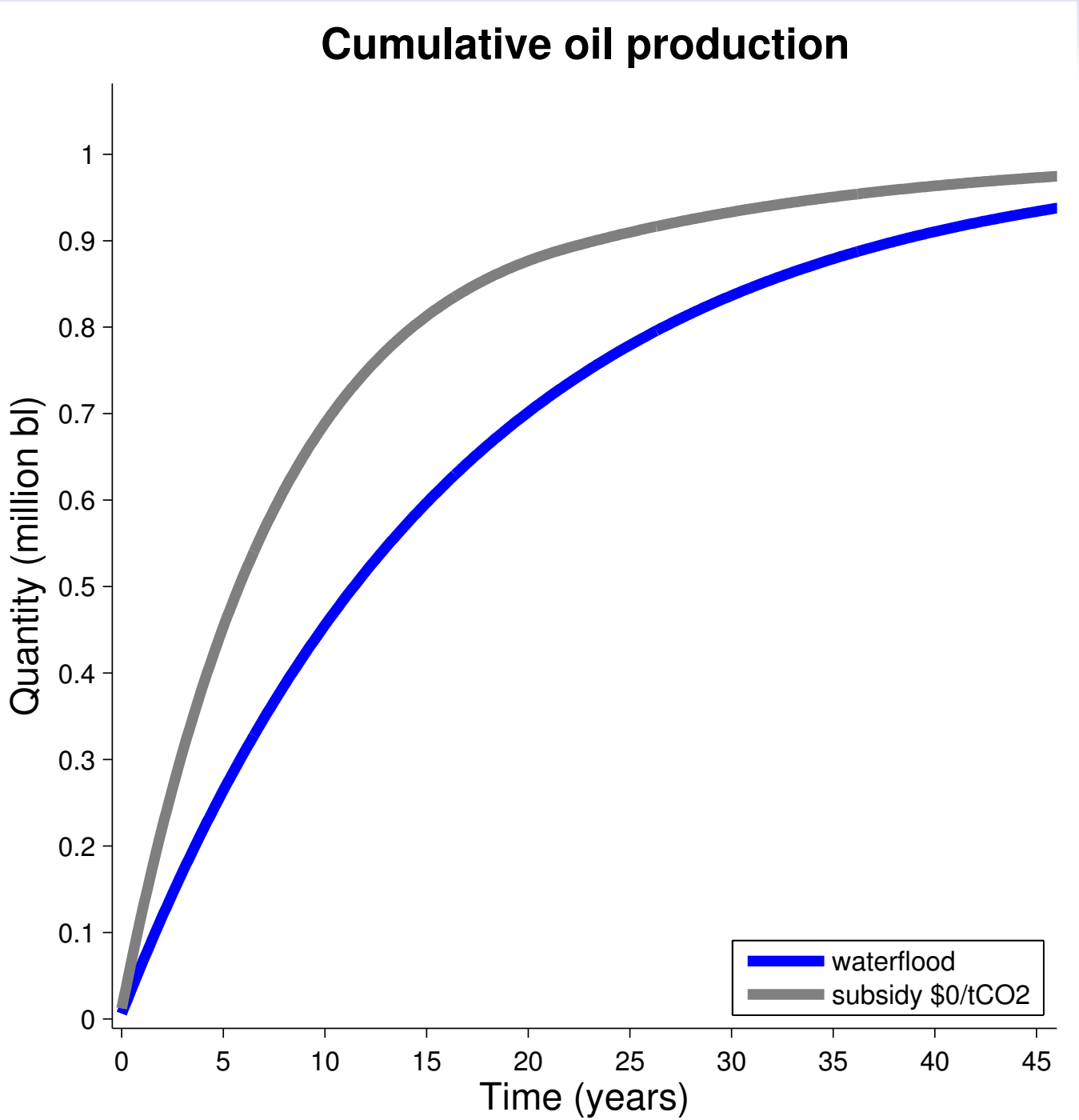

Cumulative CO2 sequestration
Quantity (million bl)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
5
10
15
20
25
30
35
40
45
Time (years)
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
subsidy $120/tCO2

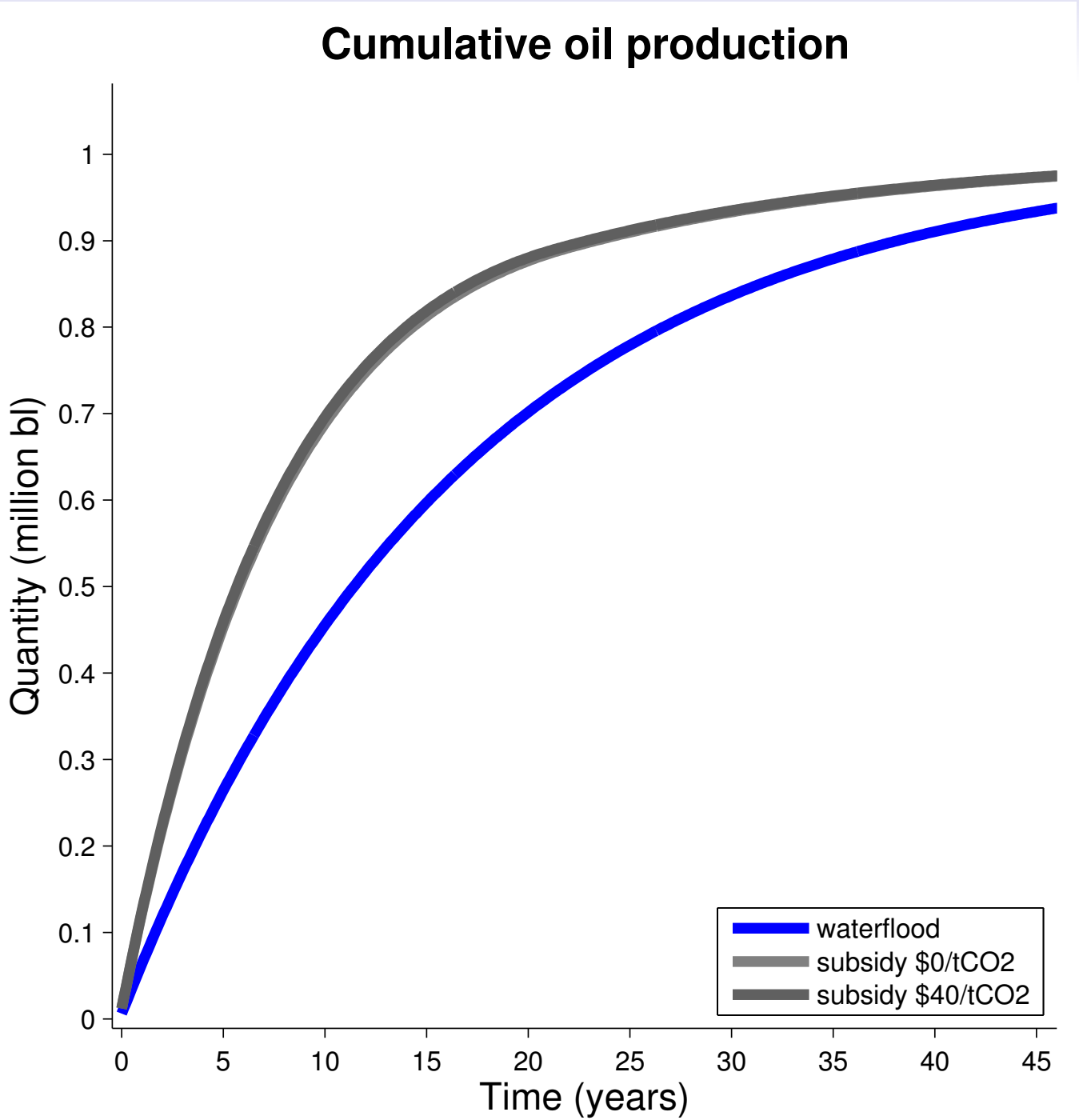

Flow oil production
waterflood
subsidy $0/tCO2
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)

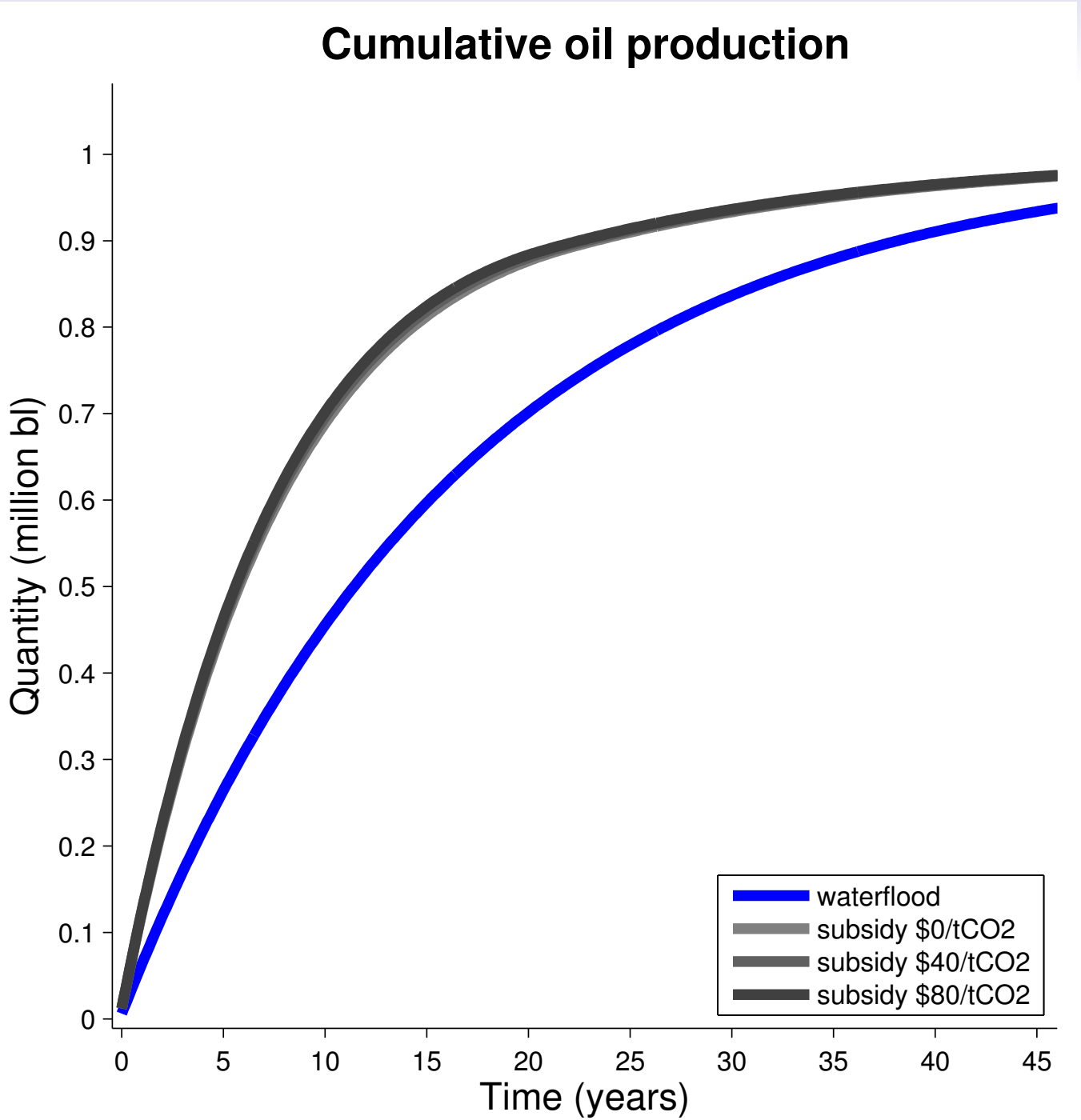

Flow oil production
waterflood
subsidy $0/tCO2
subsidy $40/tCO2
Rate (million bl/year)
0
0.02
0.04
0.06
0.08
0.1
0.12
0
5
10
15
20
25
30
35
40
45
Time (years)

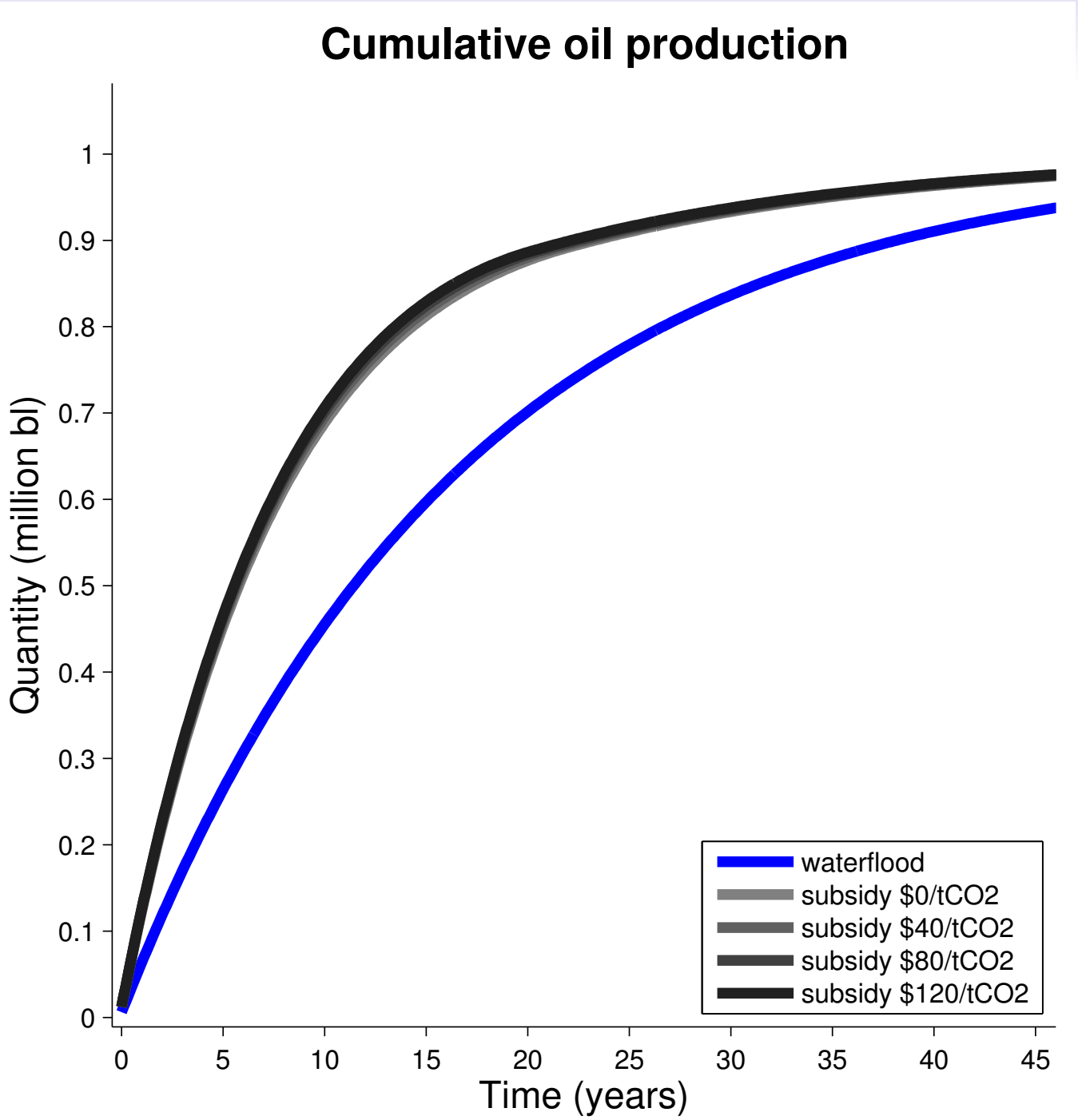

Flow oil production
waterflood
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)


Flow oil production
waterflood
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
subsidy $120/tCO2
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)


Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
subsidy $0/tCO2


Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
subsidy $0/tCO2
subsidy $40/tCO2


Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2


Cumulative oil production
Quantity (million bl)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
35
40
45
Time (years)
waterflood
subsidy $0/tCO2
subsidy $40/tCO2
subsidy $80/tCO2
subsidy $120/tCO2

CO_2-EOR profits

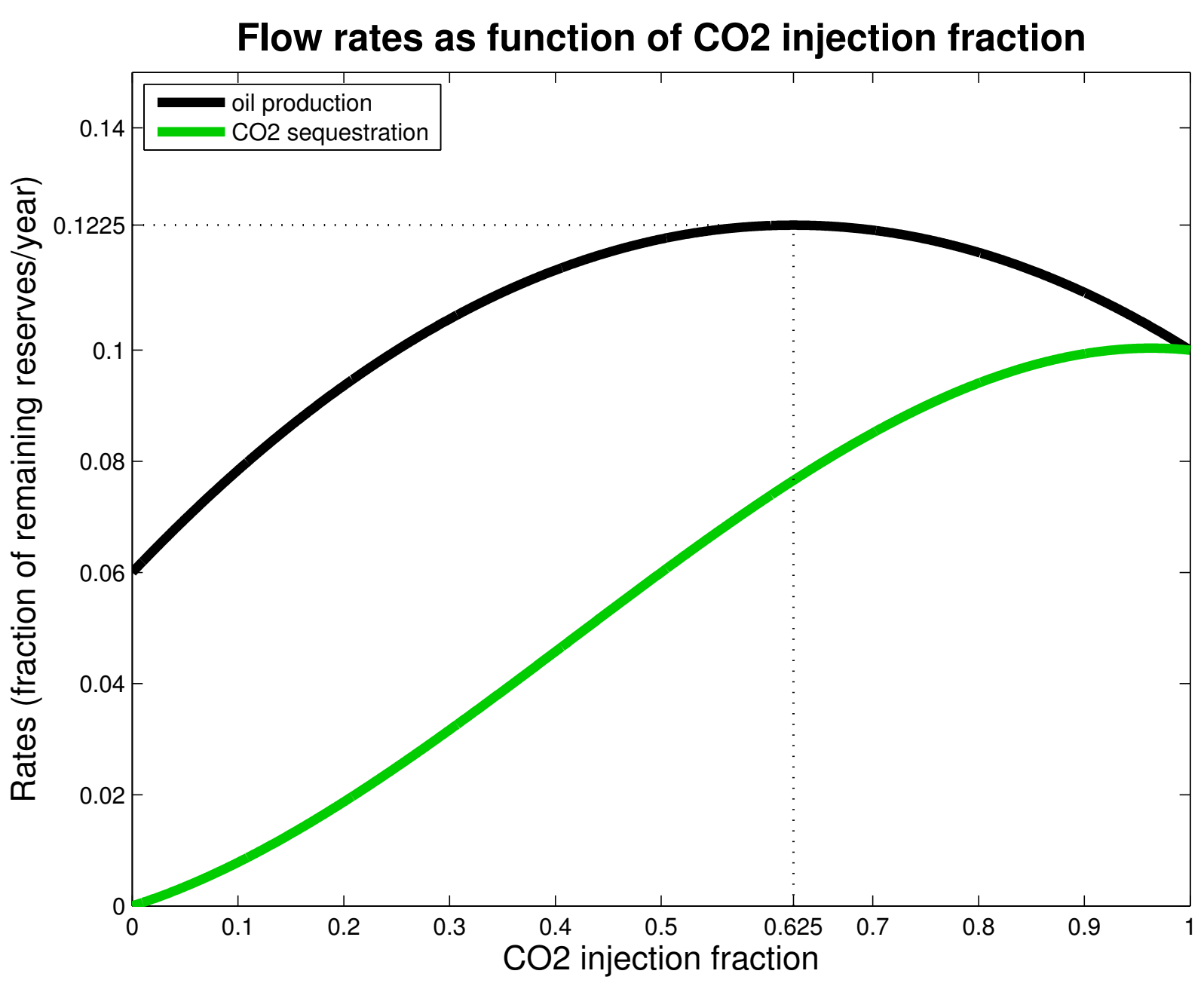
$$NPV = \underbrace{p_{oil}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} Q_{oil}^{prd} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{rec})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} Q_{CO_2}^{seq} - \underbrace{c^{rec}}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{recycling}}} Q_{CO_2}^{inj} - \underbrace{C^{oth}}_{\substack{\text{other}\\ \text{costs}}}$$

$\approx \$100 \rightarrow \$200$

CO_2-EOR profits

$$NPV = \underbrace{p_{oil}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} Q_{oil}^{prd} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{rec})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} Q_{CO_2}^{seq} - \underbrace{c^{rec}}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{recycling}}} Q_{CO_2}^{inj} - \underbrace{C^{oth}}_{\substack{\text{other}\\ \text{costs}}}$$

$\approx \$100 \rightarrow \$200$ $\quad$ $\approx \$1 \rightarrow \$5$


Flow rates as function of CO2 injection fraction
oil production
CO2 sequestration
Rates (fraction of remaining reserves/year)
0.14
0.1225
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.625
0.7
0.8
0.9
1
CO2 injection fraction

So . . .

. . . are high oil prices the environmentalist's best friend?

- On the demand side: discourage oil use
- On the supply side: promote CO_2 storage through EOR

Not necessarily, for two reasons:

So . . .

. . . are high oil prices the environmentalist's best friend?

- On the demand side: discourage oil use
- On the supply side: promote CO_2 storage through EOR

Not necessarily, for two reasons:

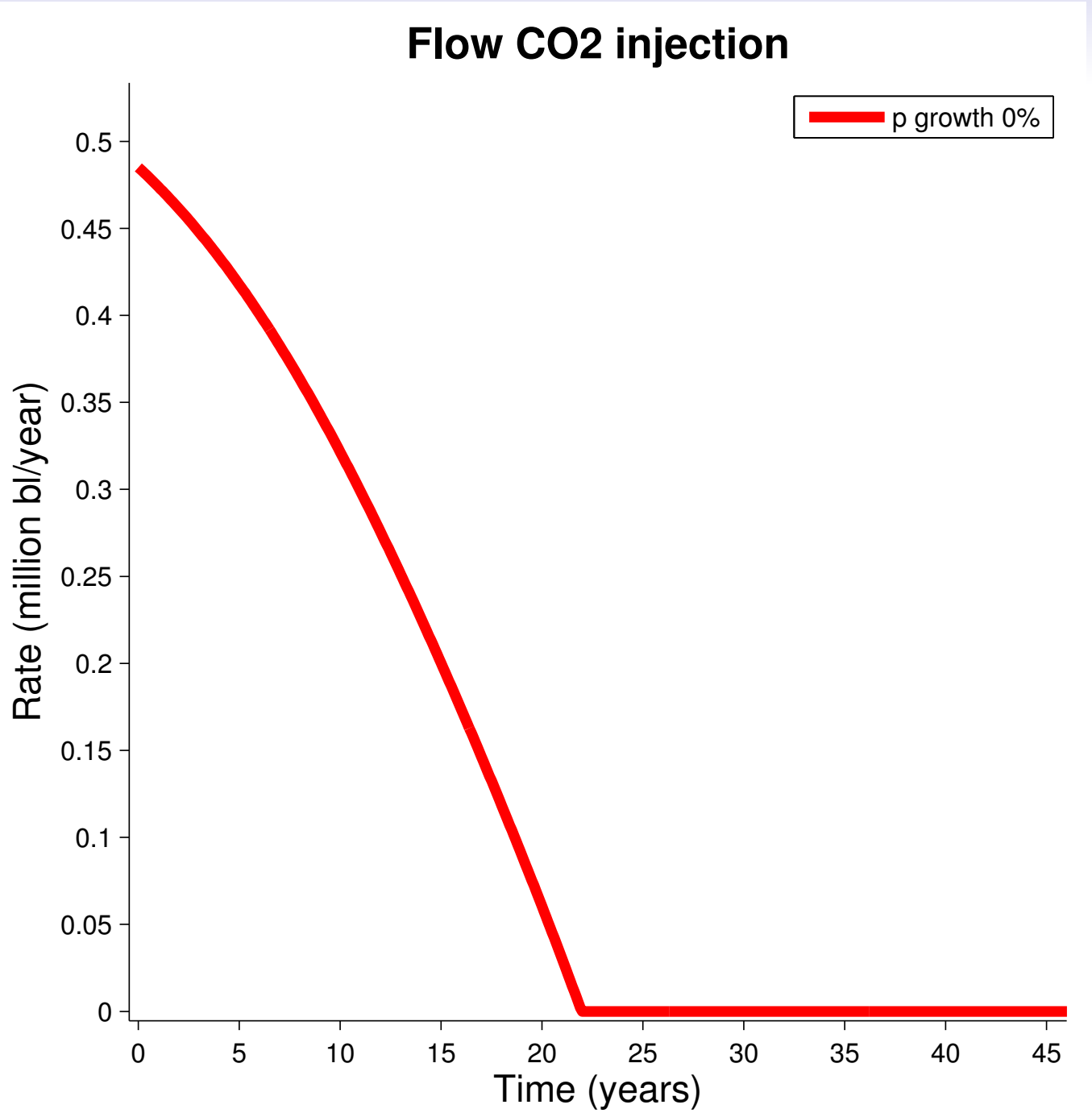
- *Increasing* oil prices may *reduce* CO_2 storage through EOR

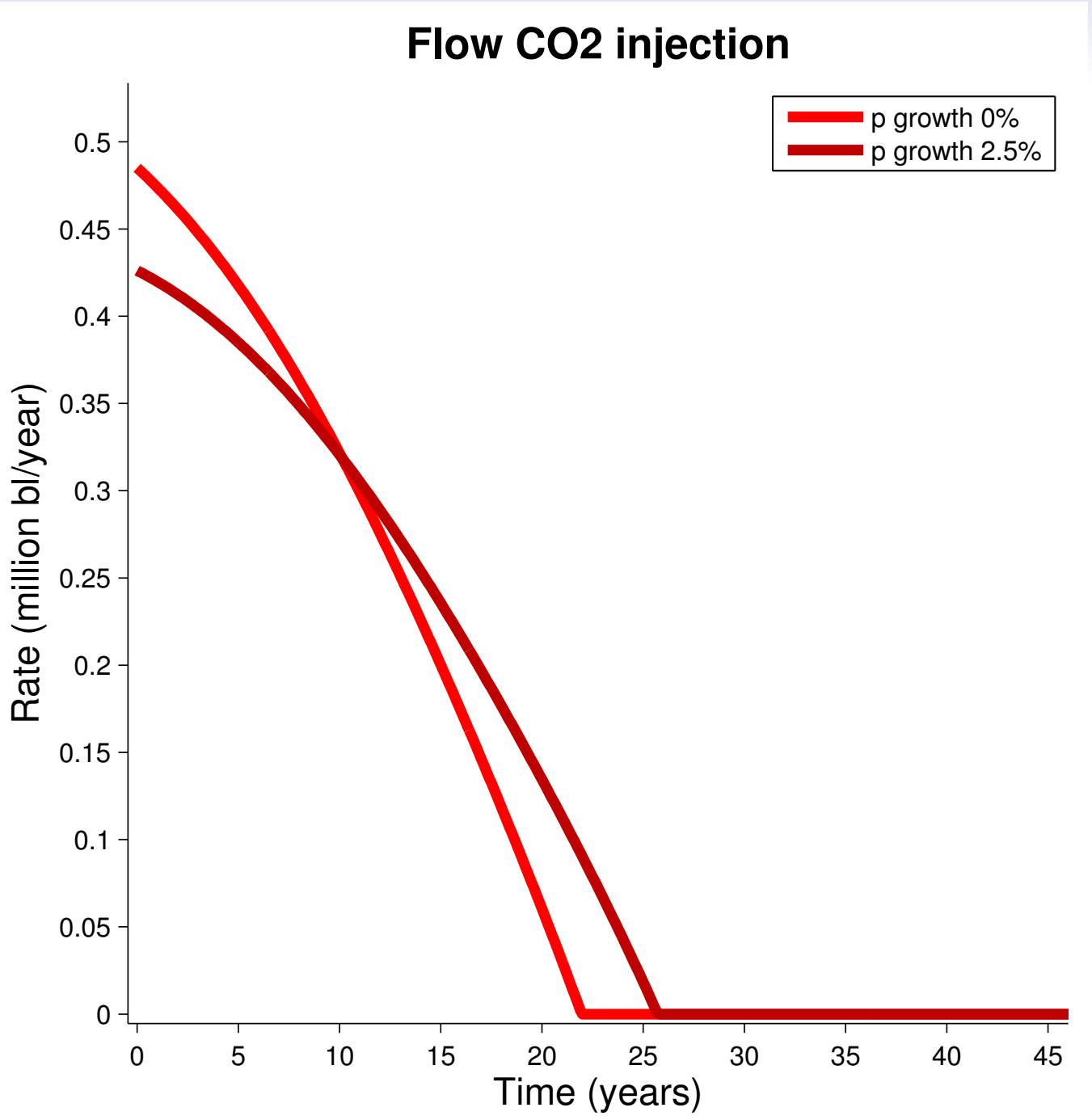
CO_2-EOR profits

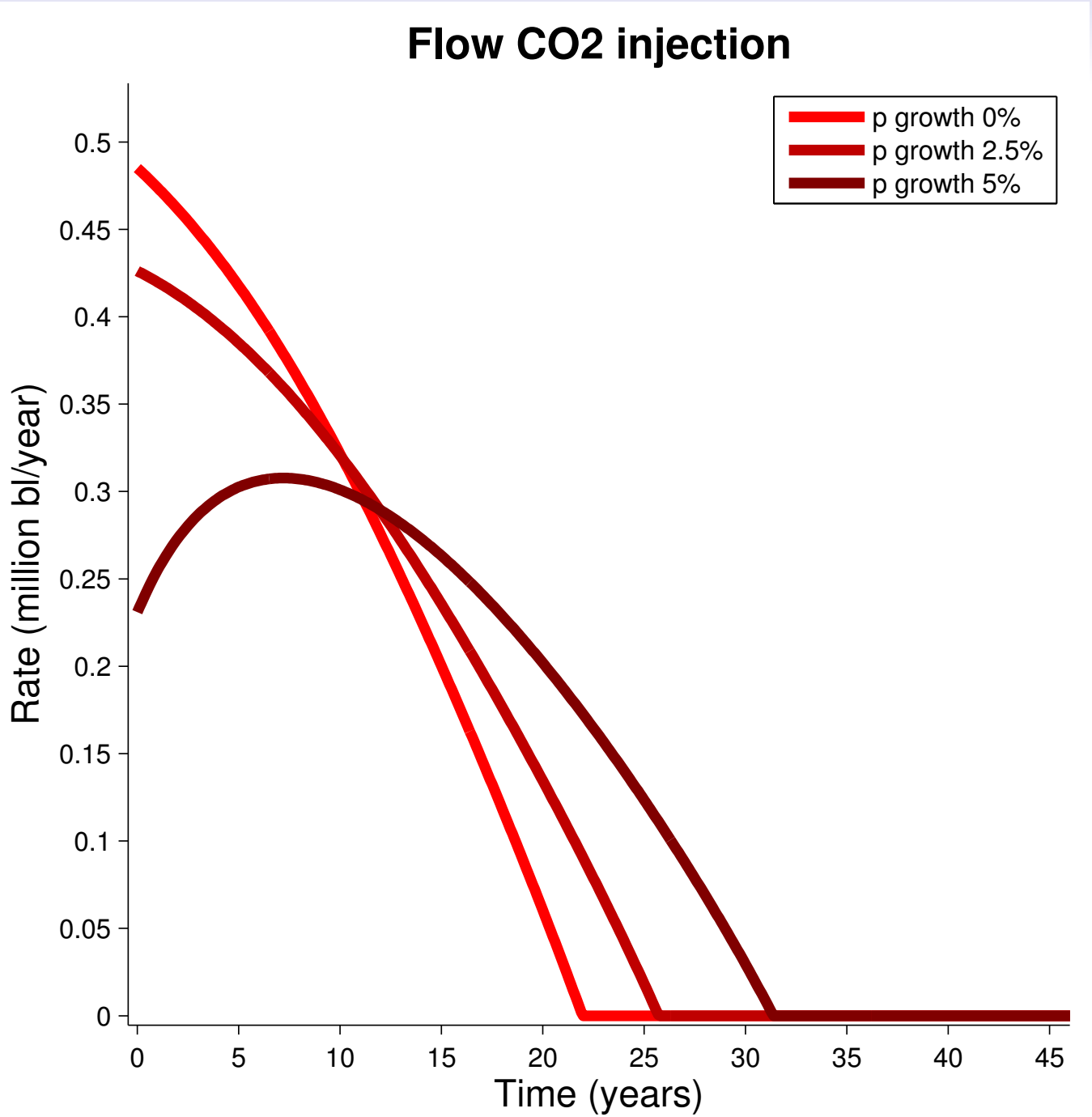
$$NPV = -\underbrace{I}_{\substack{\text{up-front}\\ \text{investment}\\ \text{cost}}} + \underbrace{p_{\text{oil}}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} Q_{\text{oil}}^{\text{prd}} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{\text{rec}})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} Q_{CO_2}^{\text{seq}} - \underbrace{c^{\text{rec}}}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{recycling}}} Q_{CO_2}^{\text{inj}} - \underbrace{C^{\text{oth}}}_{\substack{\text{other}\\ \text{costs}}}$$

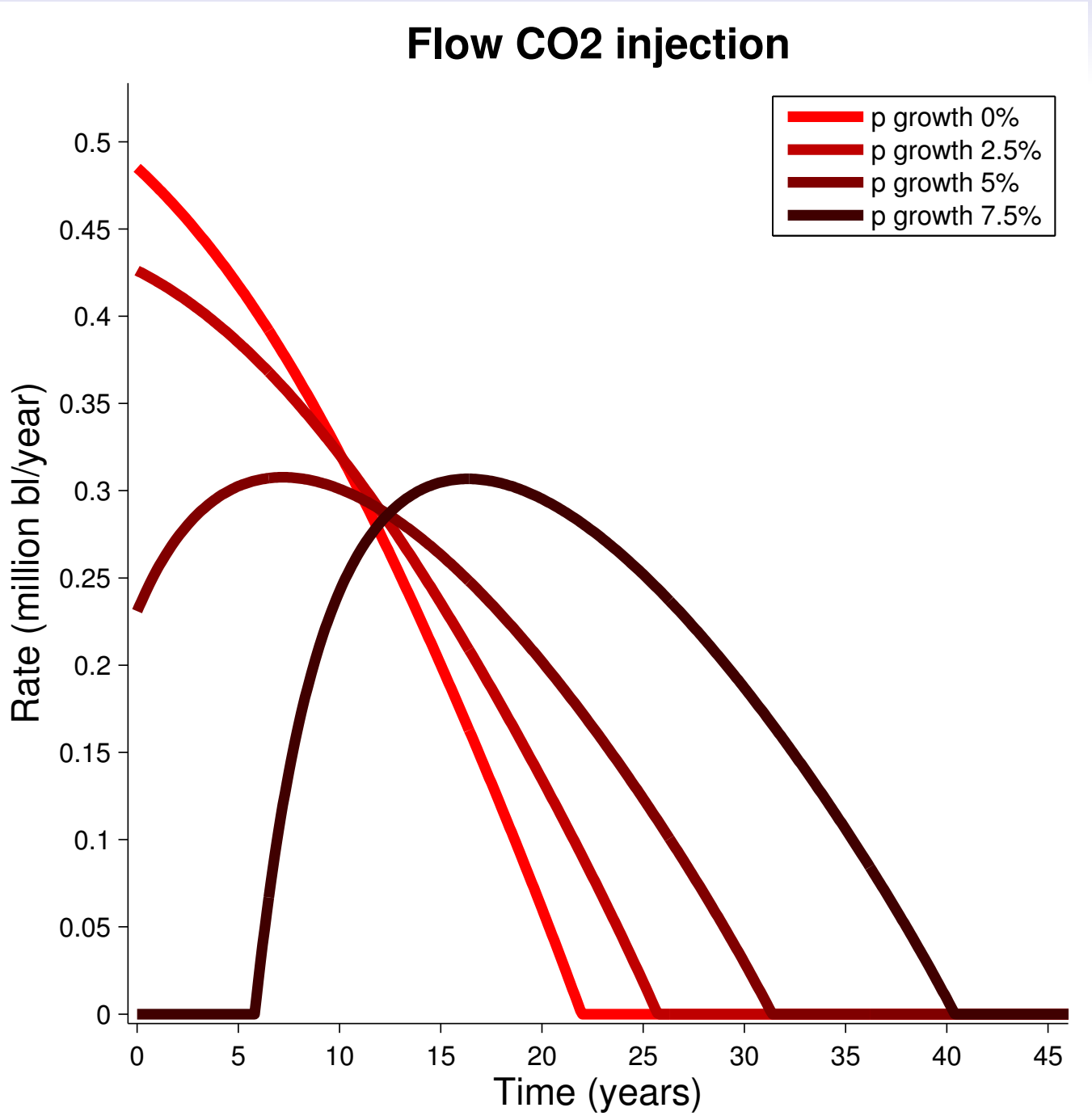
CO_2-EOR profits

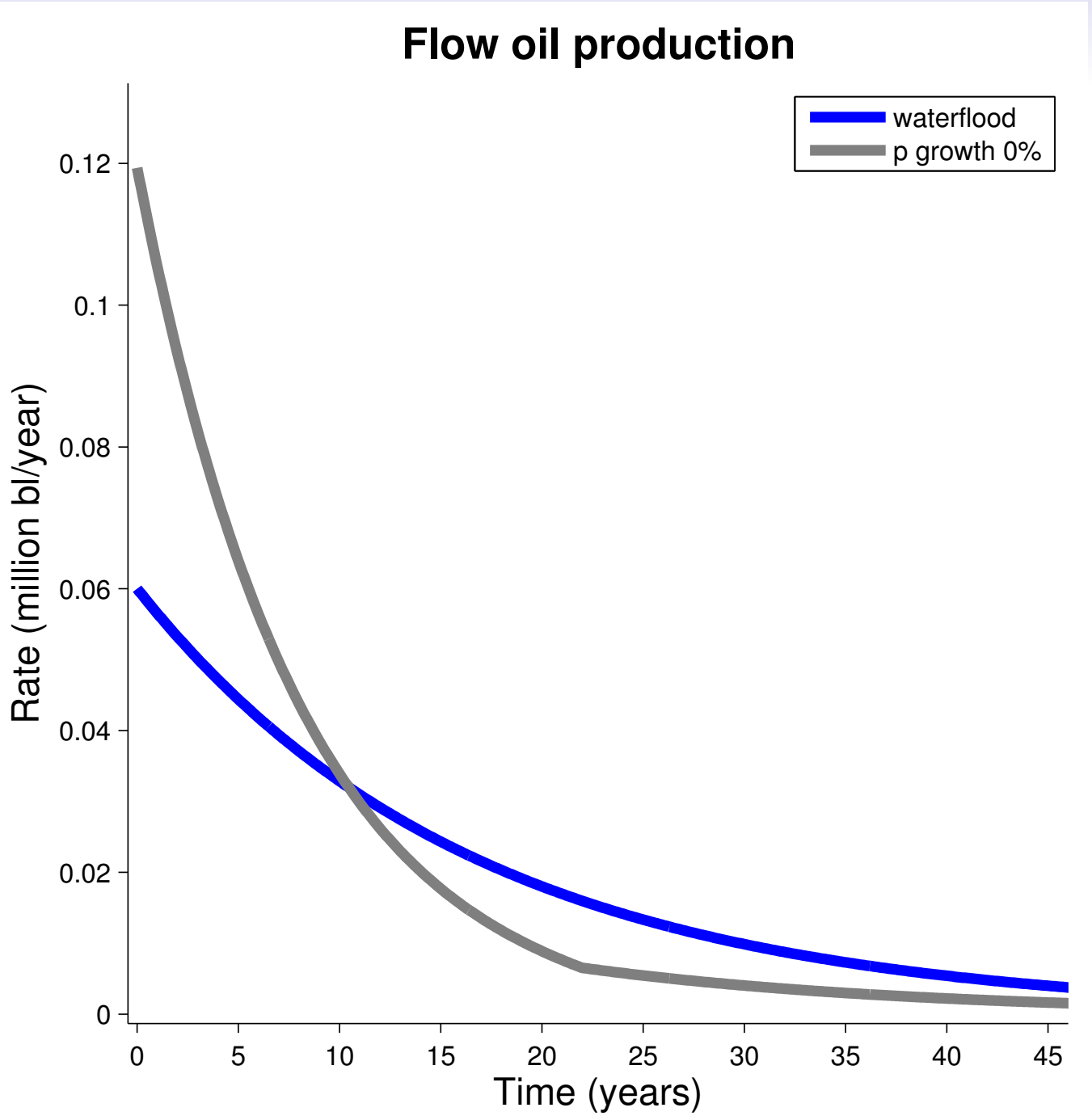
$$NPV = -\underbrace{I}_{\substack{\text{up-front}\\ \text{investment}\\ \text{cost}}} + \underbrace{p_{oil}}_{\substack{\text{weight}\\ \text{on oil}\\ \text{production}}} Q_{oil}^{prd} + \underbrace{(s_{CO_2} - p_{CO_2} + c^{rec})}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{sequestration}}} Q_{CO_2}^{seq} - \underbrace{c^{rec}}_{\substack{\text{weight}\\ \text{on } CO_2\\ \text{recycling}}} Q_{CO_2}^{inj} - \underbrace{C^{oth}}_{\substack{\text{other}\\ \text{costs}}}$$

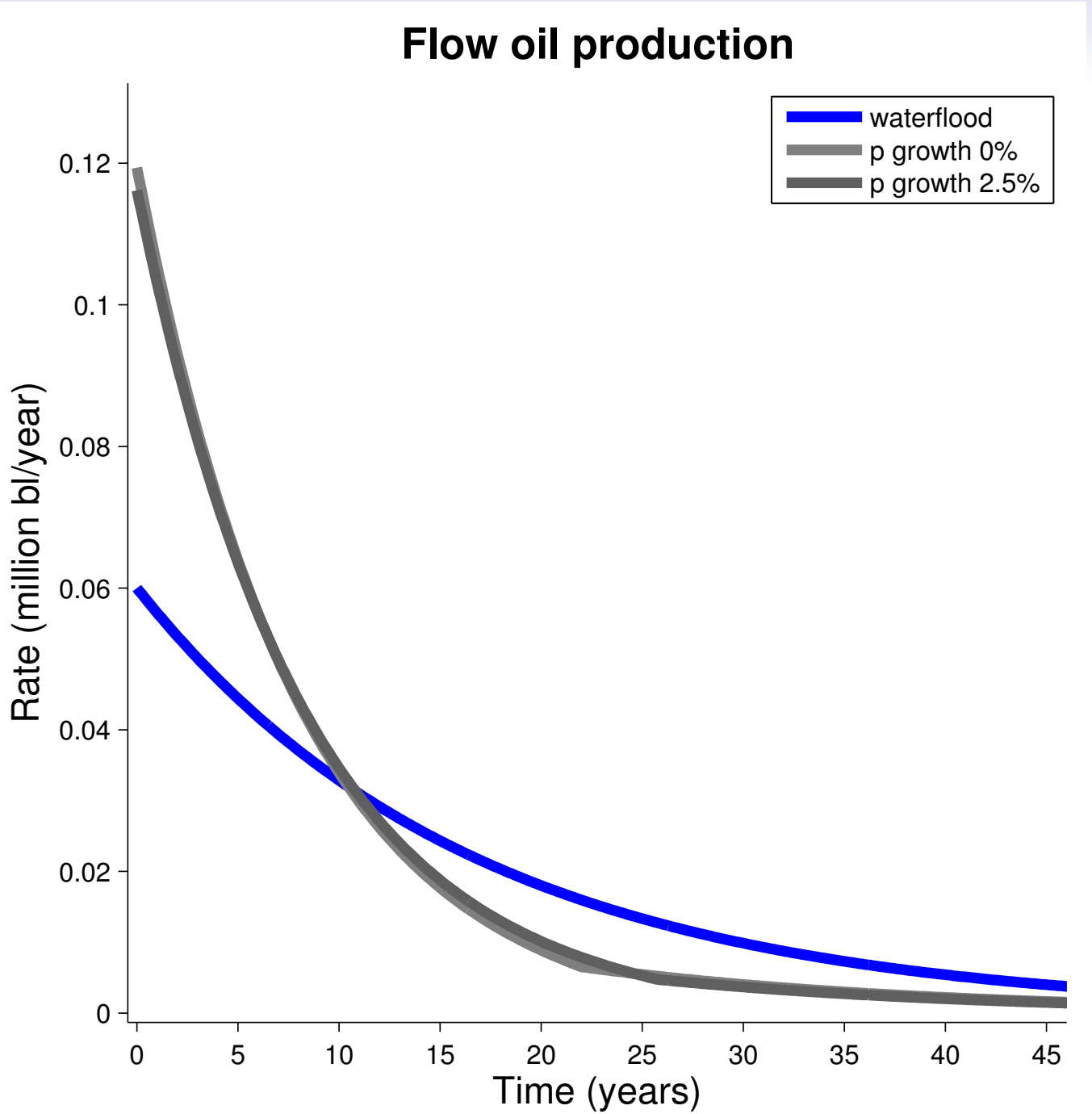

Flow CO2 injection
p growth 0%
Rate (million bl/year)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
5
10
15
20
25
30
35
40
45
Time (years)

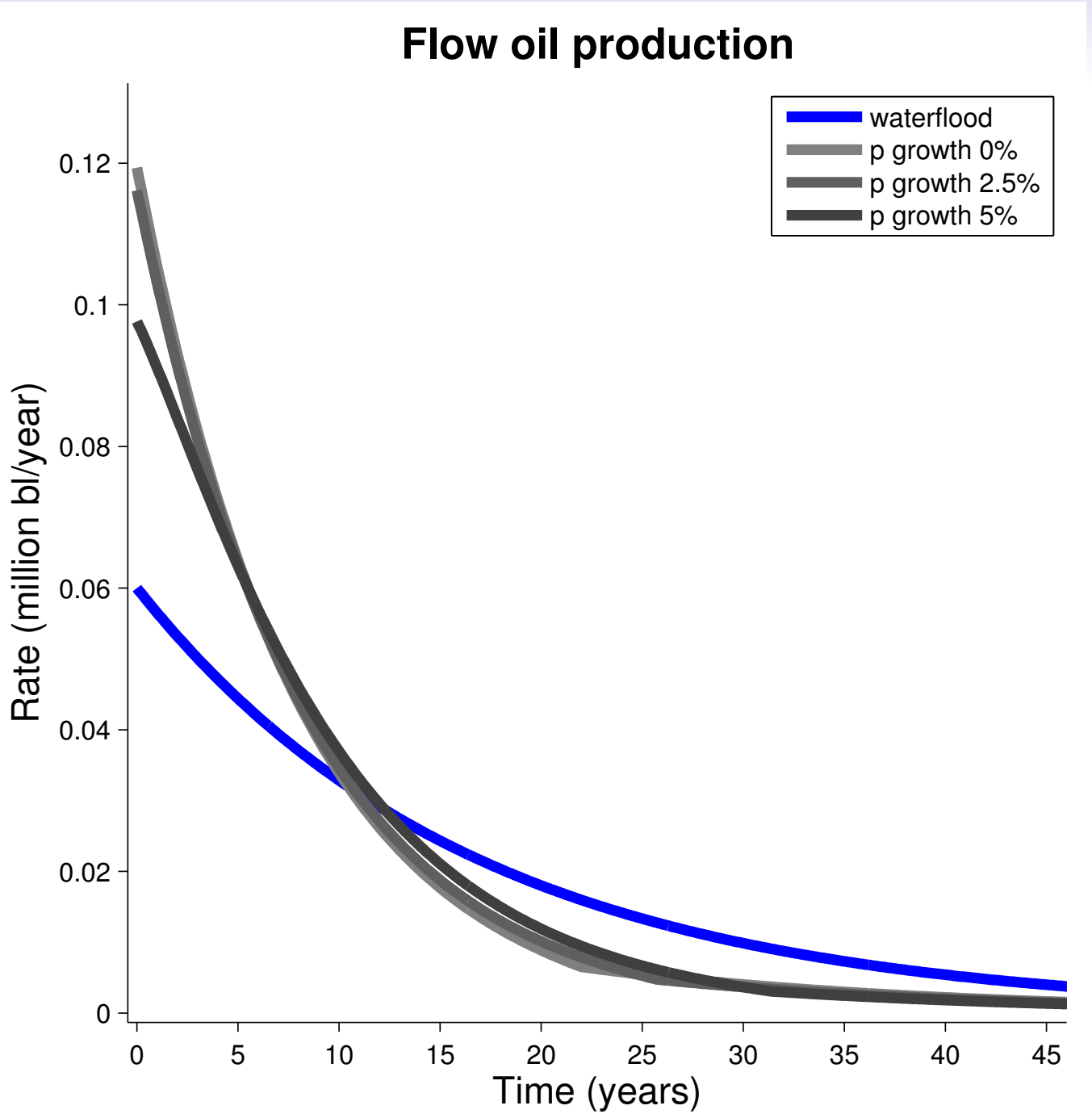

Flow CO2 injection
p growth 0%
p growth 2.5%
Rate (million bl/year)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
5
10
15
20
25
30
35
40
45
Time (years)

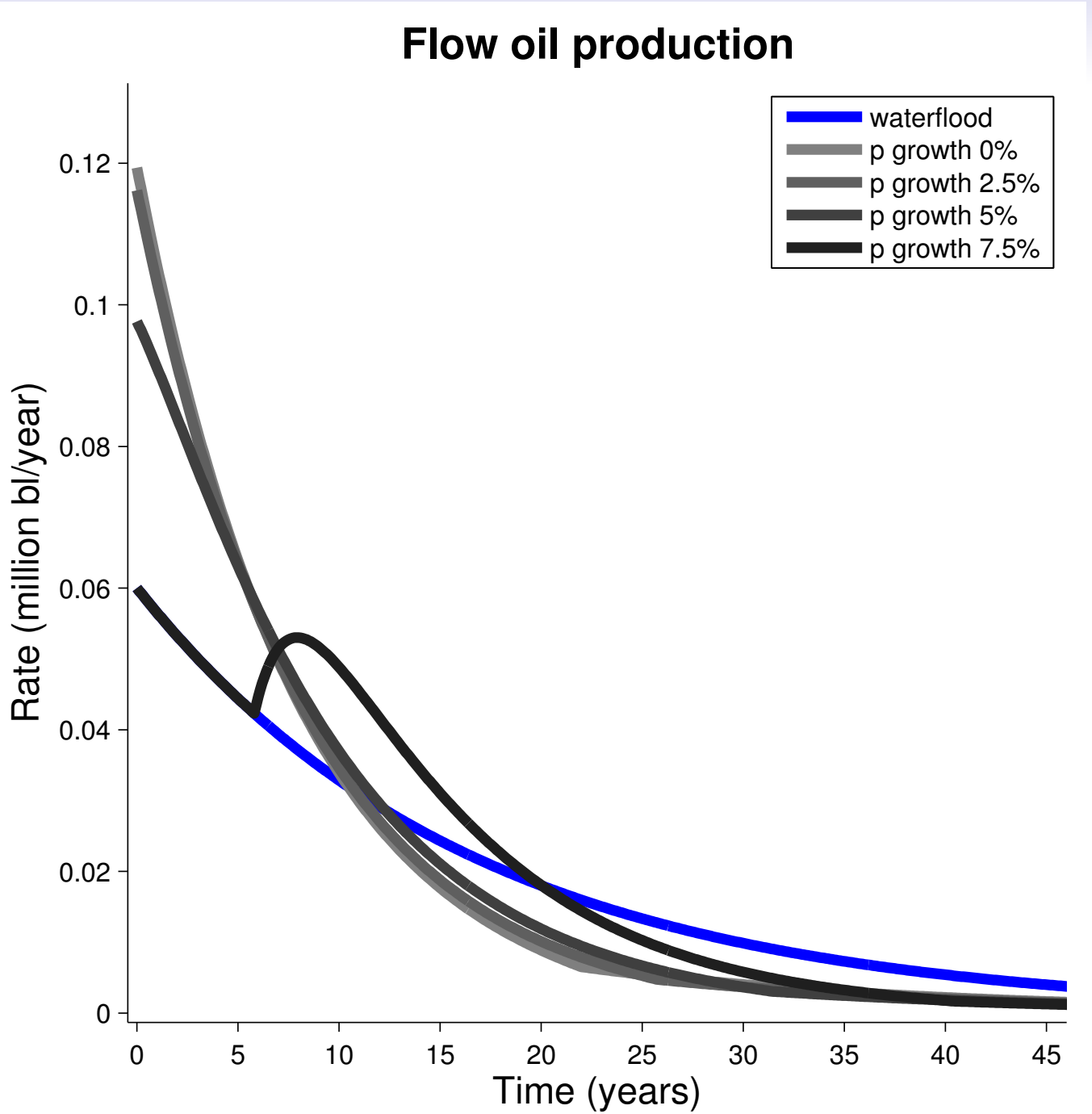

Flow CO2 injection
p growth 0%
p growth 2.5%
p growth 5%
Rate (million bl/year)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
5
10
15
20
25
30
35
40
45
Time (years)

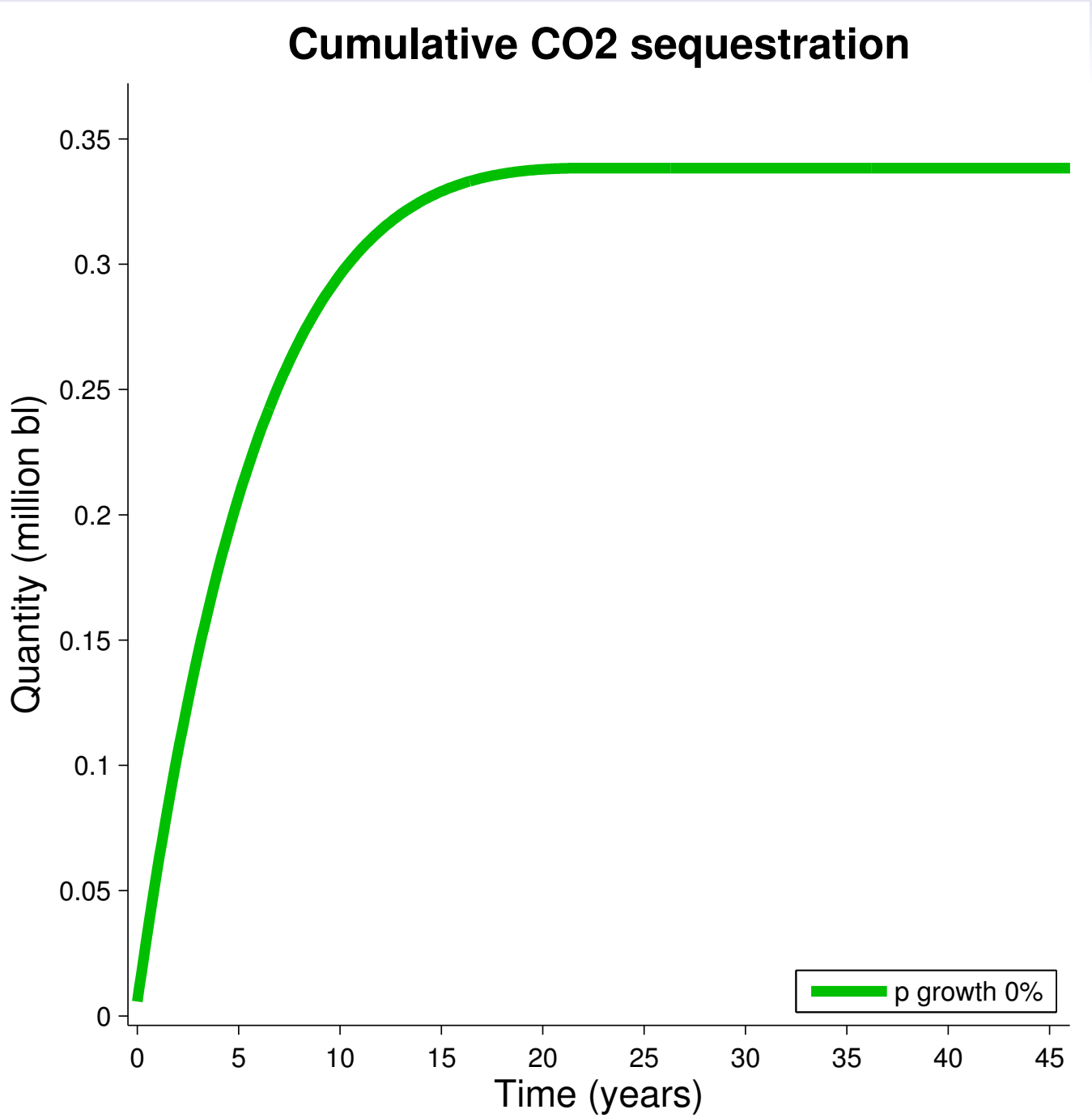

Flow CO2 injection
p growth 0%
p growth 2.5%
p growth 5%
p growth 7.5%
Rate (million bl/year)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)

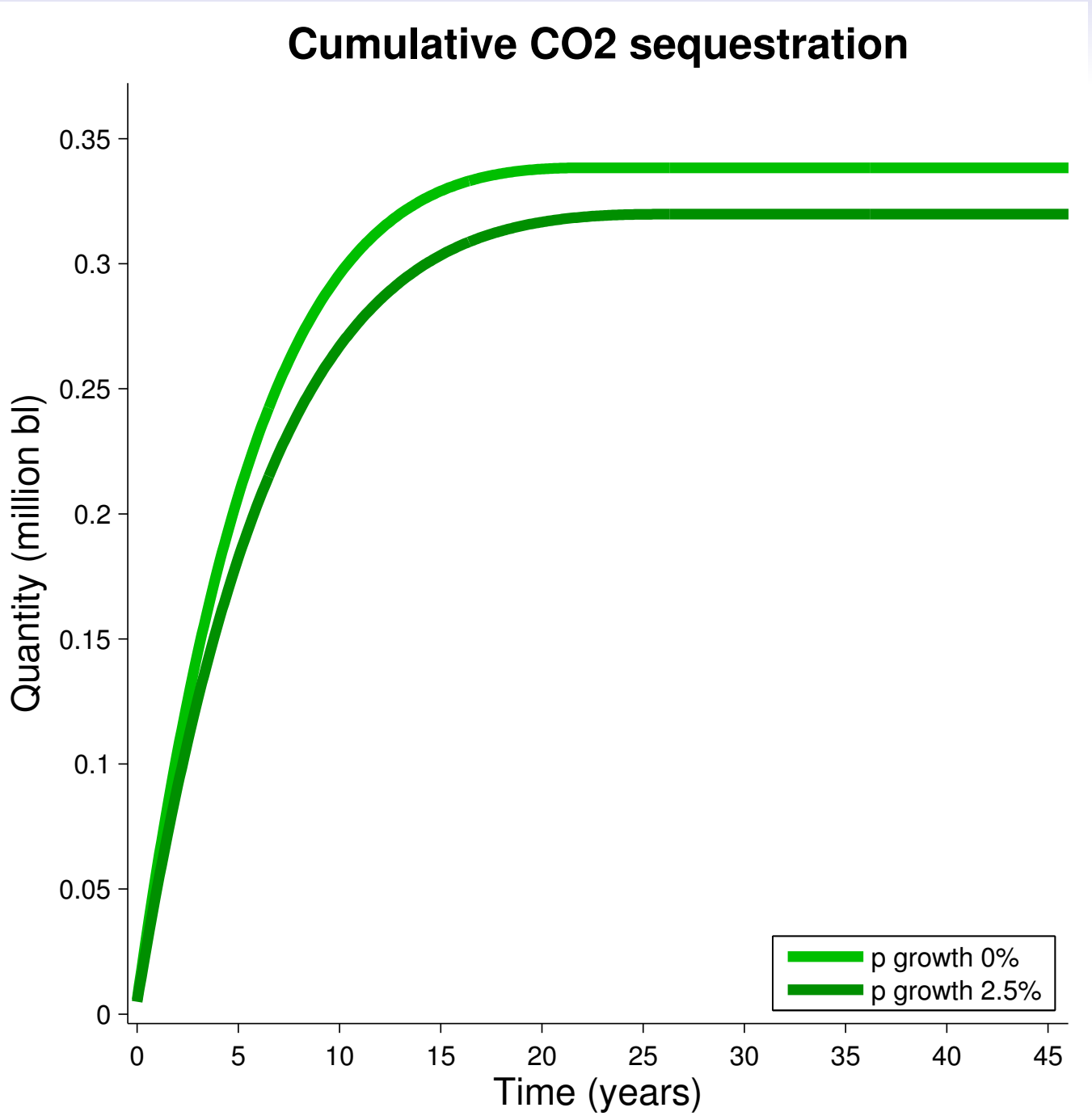

Flow oil production
waterflood
p growth 0%
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)

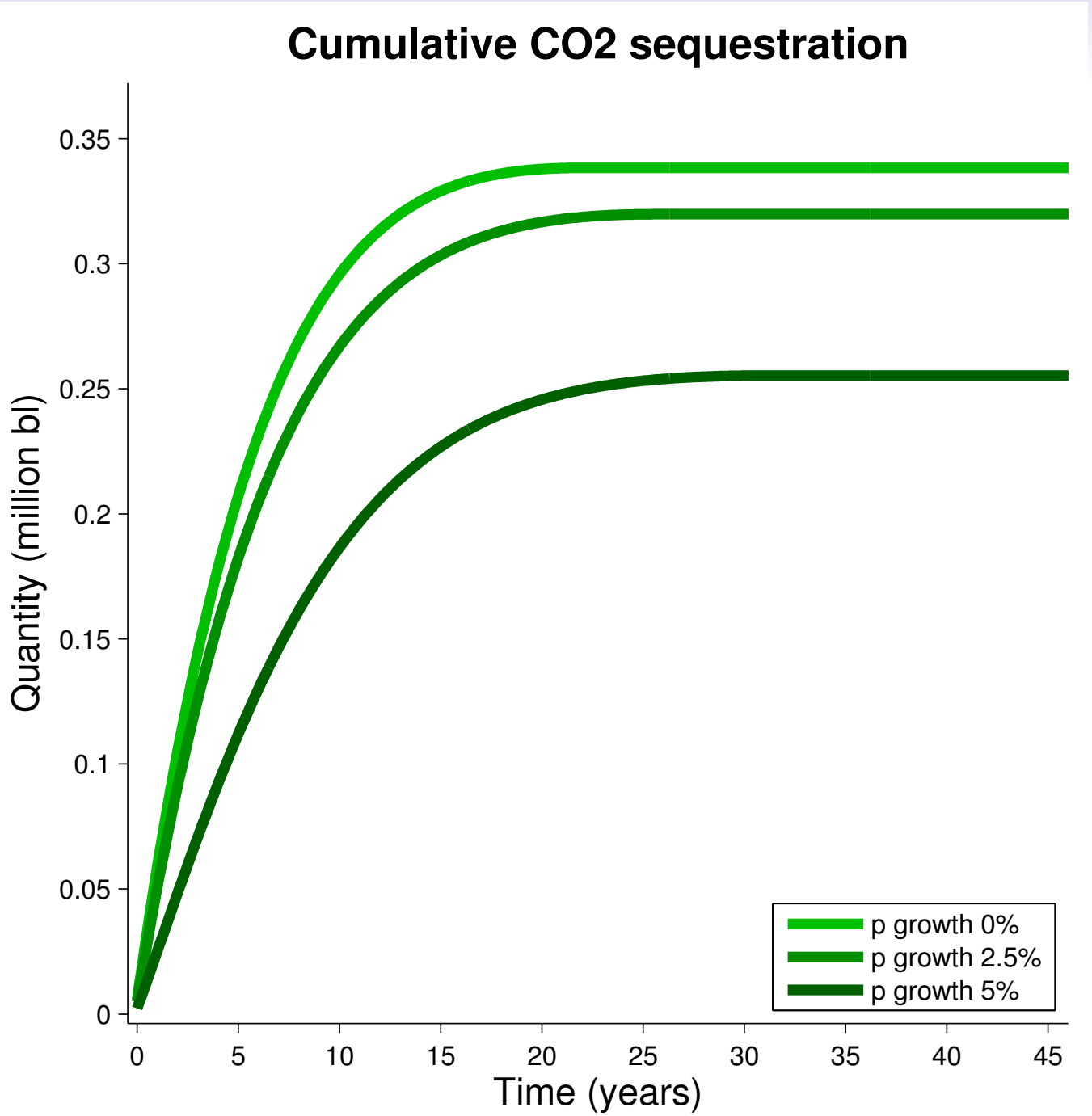

Flow oil production
waterflood
p growth 0%
p growth 2.5%
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)

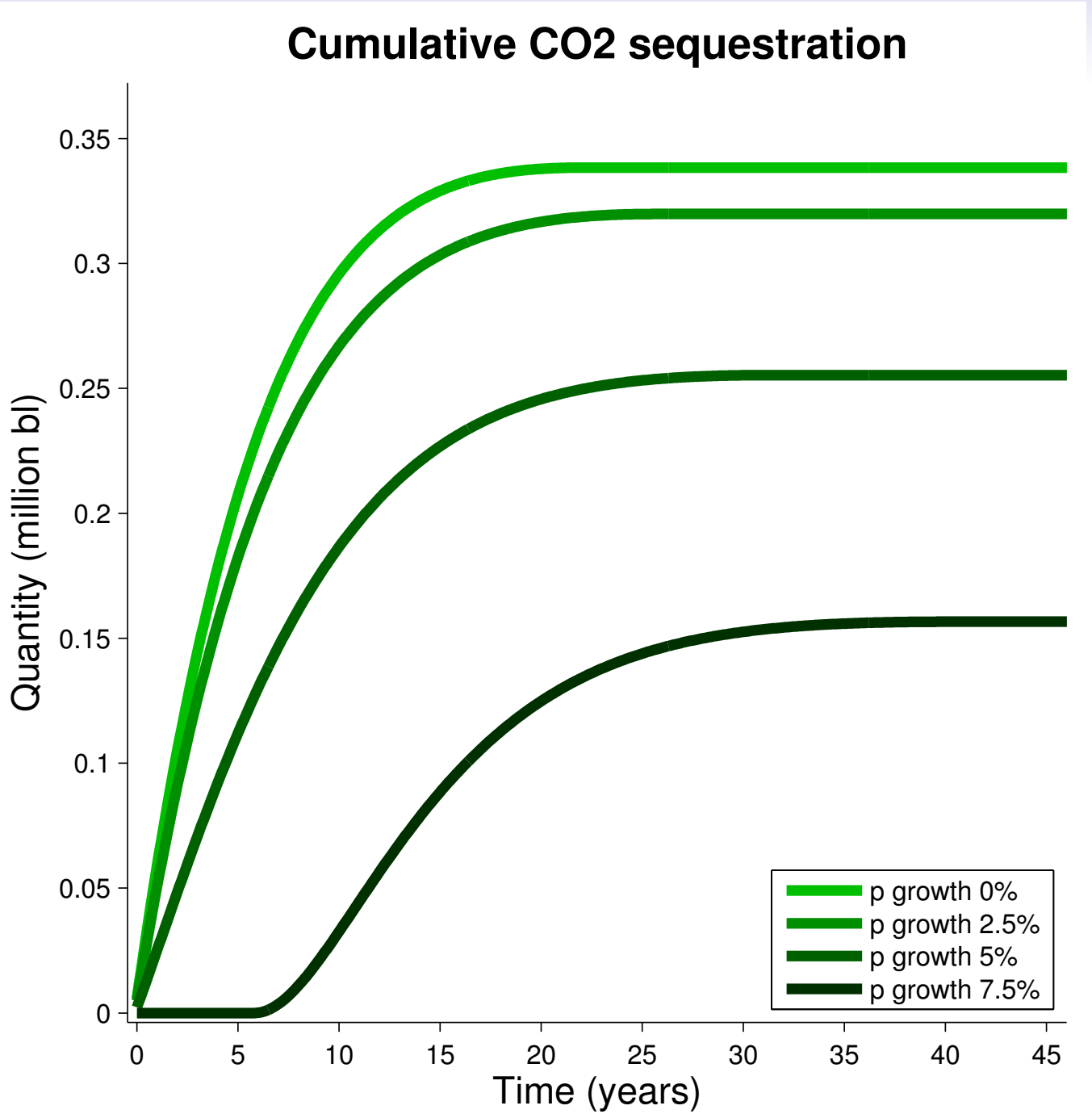

Flow oil production
waterflood
p growth 0%
p growth 2.5%
p growth 5%
Rate (million bl/year)
0
0.02
0.04
0.06
0.08
0.1
0.12
0
5
10
15
20
25
30
35
40
45
Time (years)


Flow oil production
waterflood
p growth 0%
p growth 2.5%
p growth 5%
p growth 7.5%
Rate (million bl/year)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
Time (years)


Cumulative CO2 sequestration
Quantity (million bl)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p growth 0%


Cumulative CO2 sequestration
Quantity (million bl)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p growth 0%
p growth 2.5%


Cumulative CO2 sequestration
Quantity (million bl)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p growth 0%
p growth 2.5%
p growth 5%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0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Time (years)
p growth 0%
p growth 2.5%
p growth 5%
p growth 7.5%

So . . .

. . . are high oil prices the environmentalist's best friend?

- On the demand side: discourage oil use
- On the supply side: promote CO_2 storage through EOR

Not necessarily, for two reasons:

- *Increasing* oil prices may *reduce* CO_2 storage through EOR
- Promoting CO_2-EOR may increase *net* CO_2 emissions

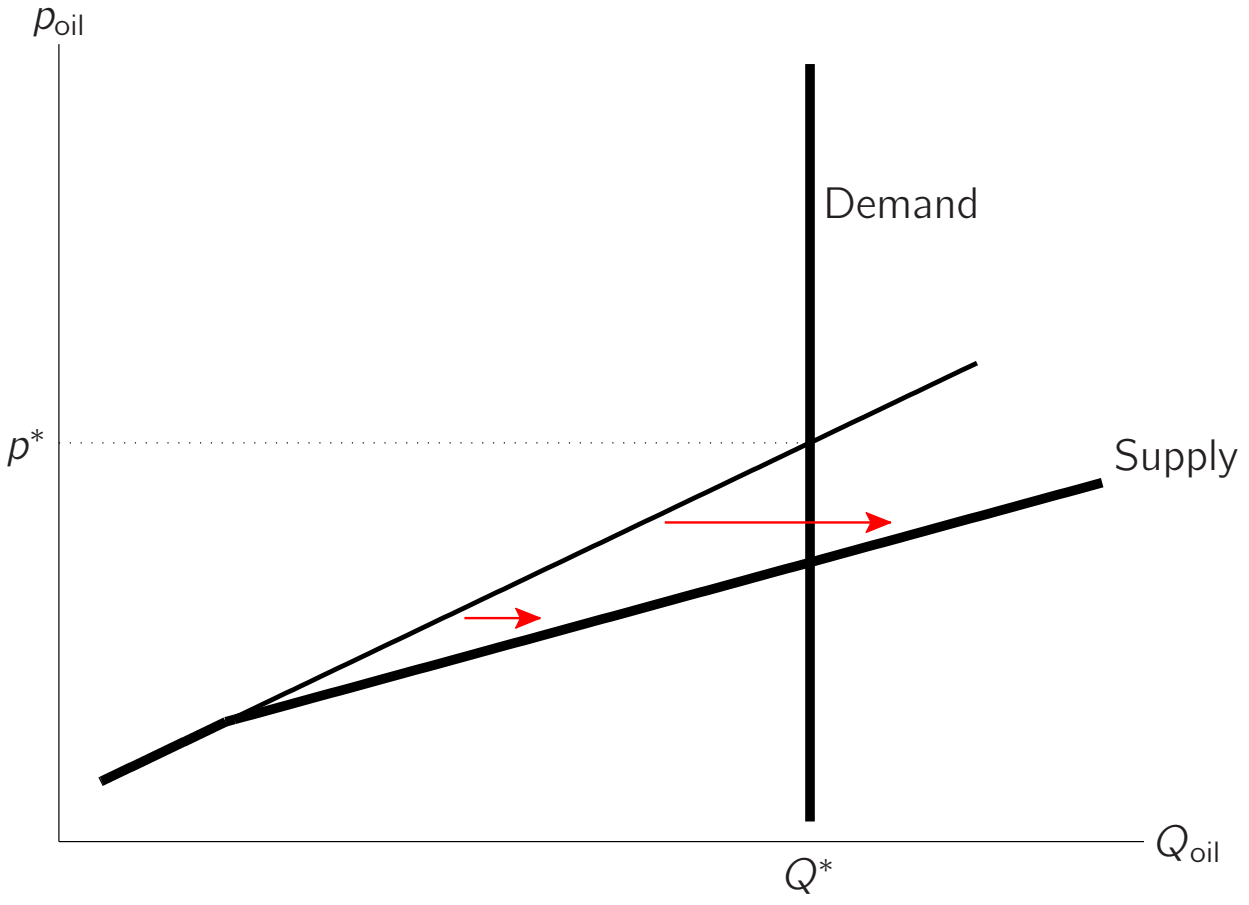
Common misconception

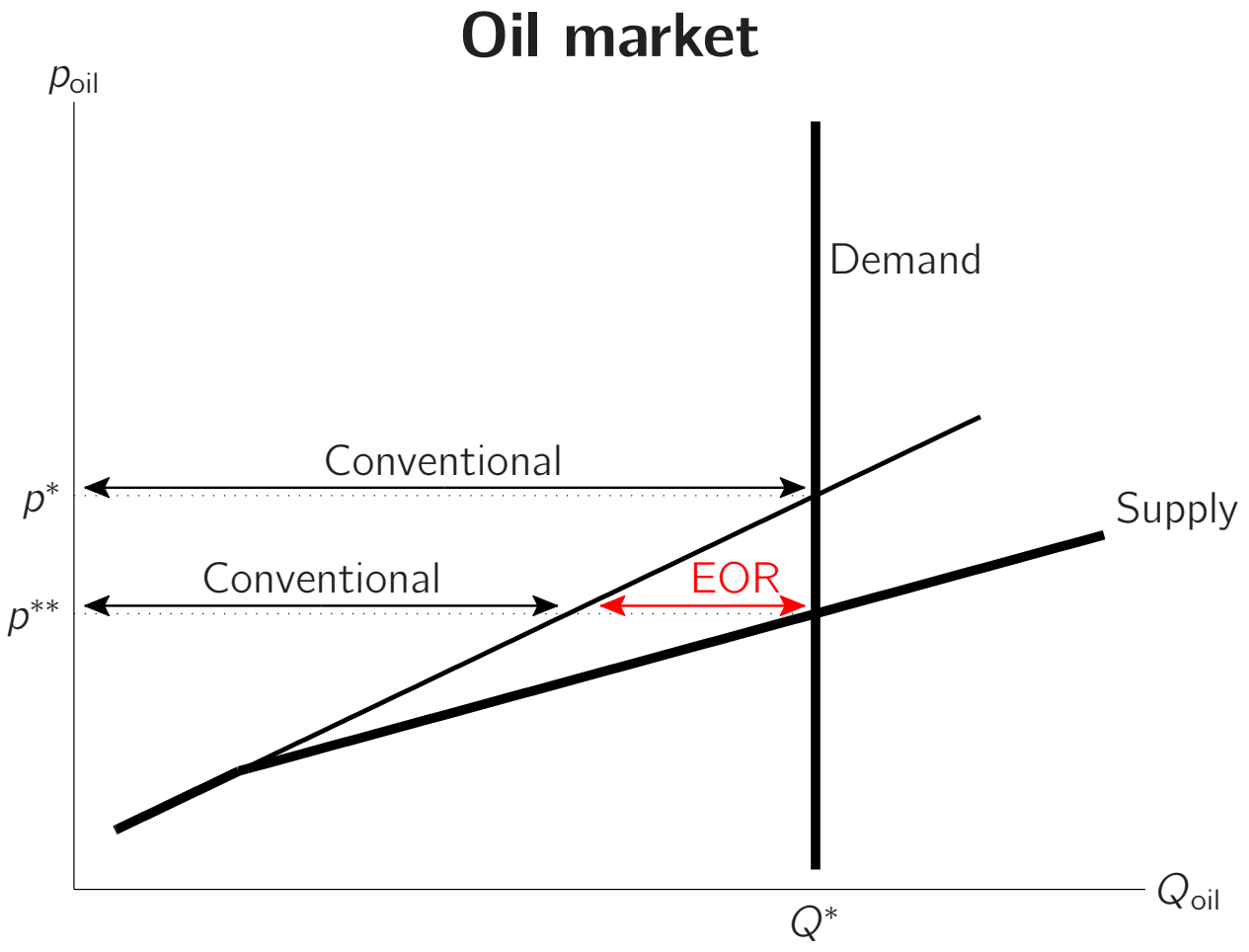
Emissions from incremental oil produced with CO_2-EOR don't matter.

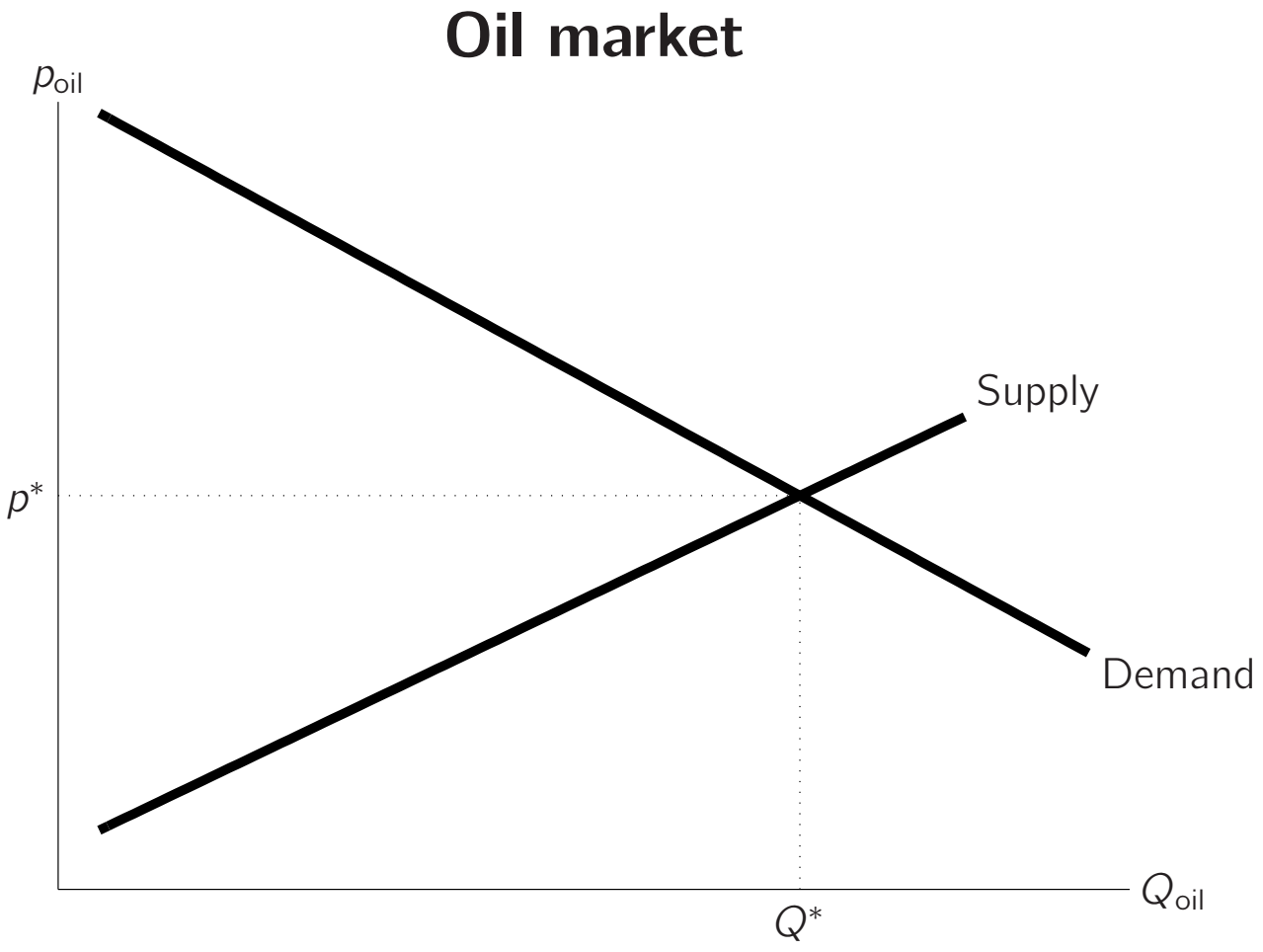
> *"World oil production is determined by world oil demand and if CO_2-EOR projects were not undertaken, some other source of oil would step forward and fill the gap. Therefore, executing CO_2-EOR projects will not result in incremental aggregate refining and consumption emissions."*

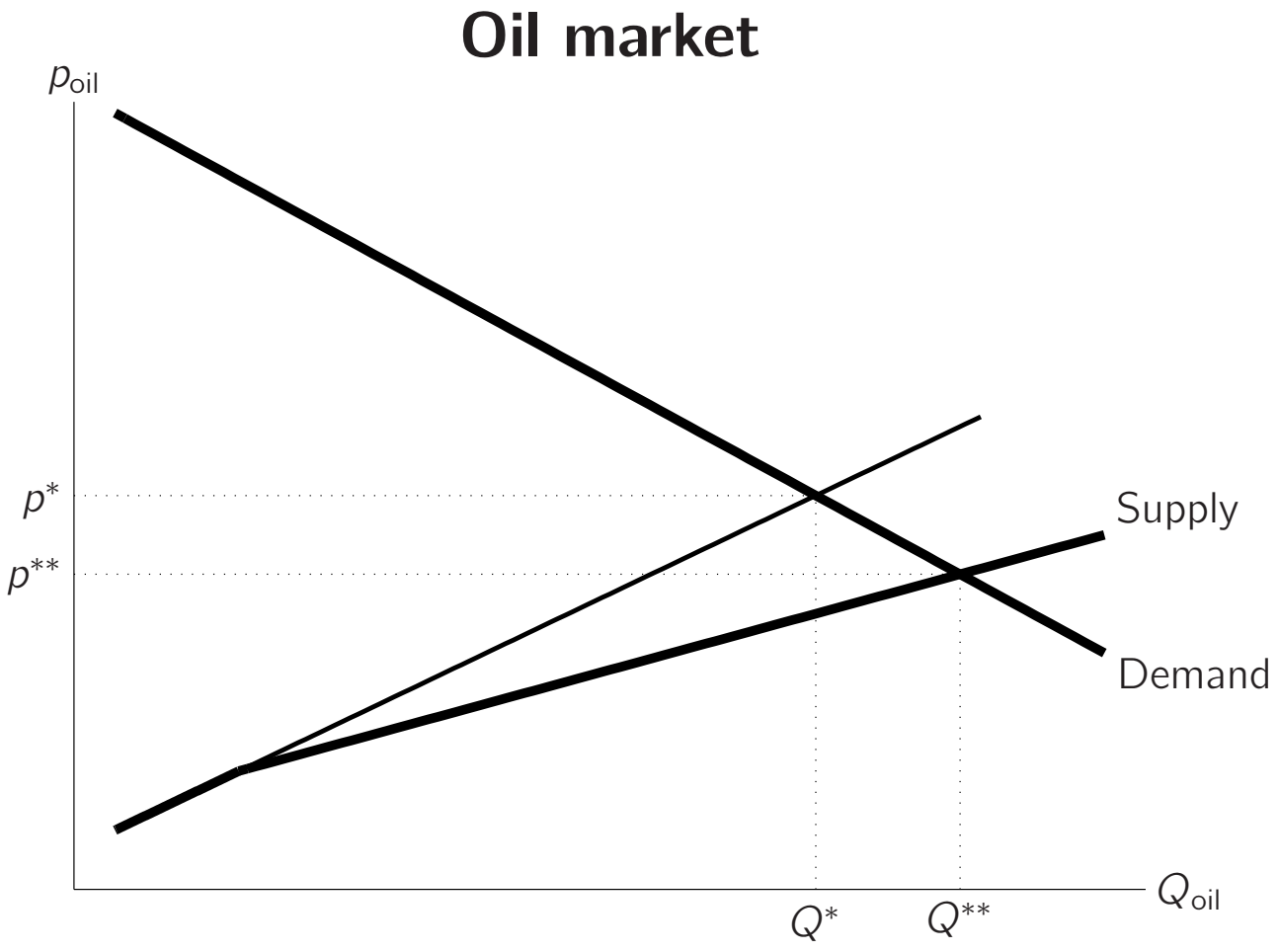
Faltinson, J. and Gunter, B. (2011). "Net CO_2 Stored in North American EOR Projects." *J. Can. Pet. Technol.* 50 (7/8): pp. 55–60.

Oil market

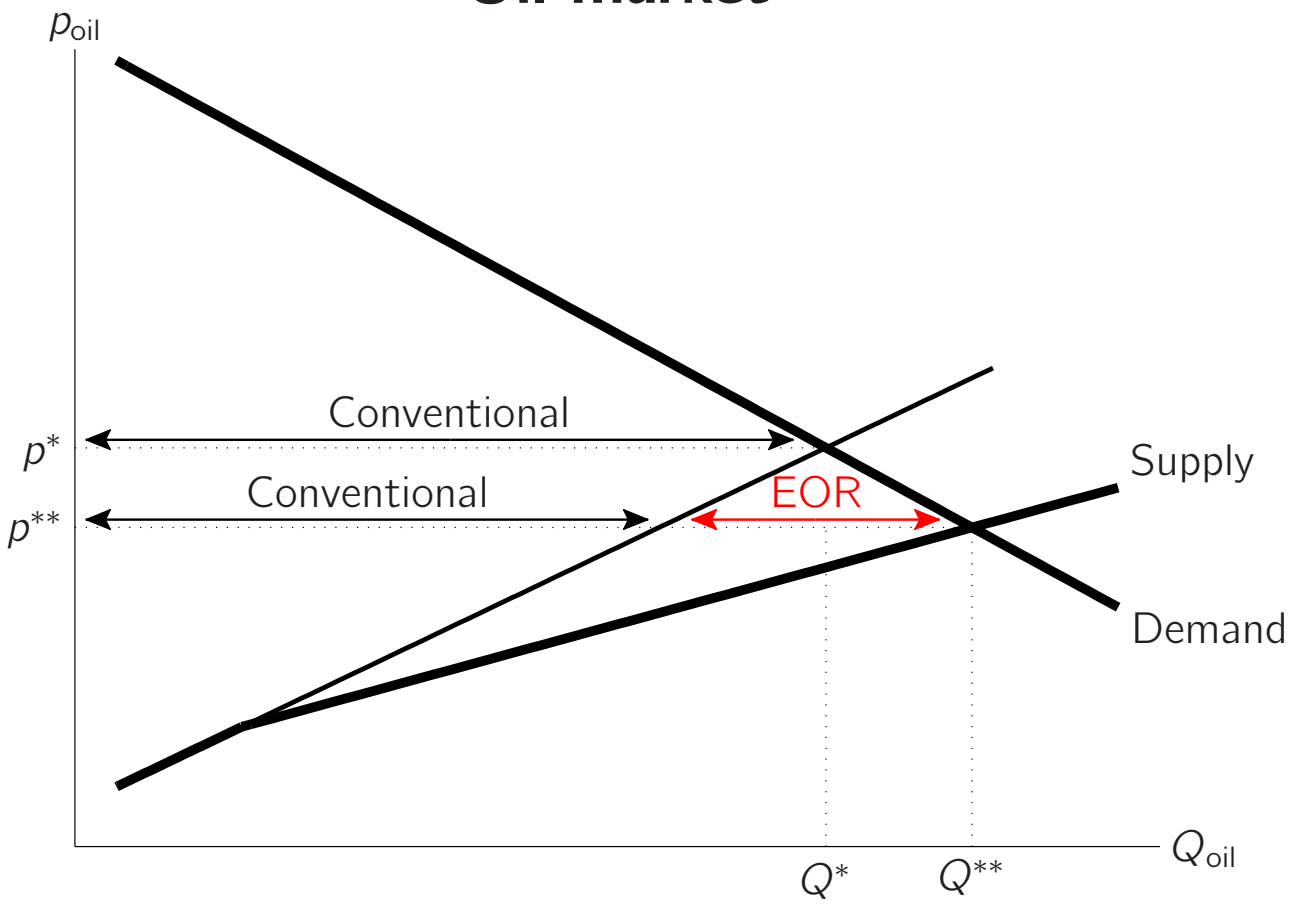


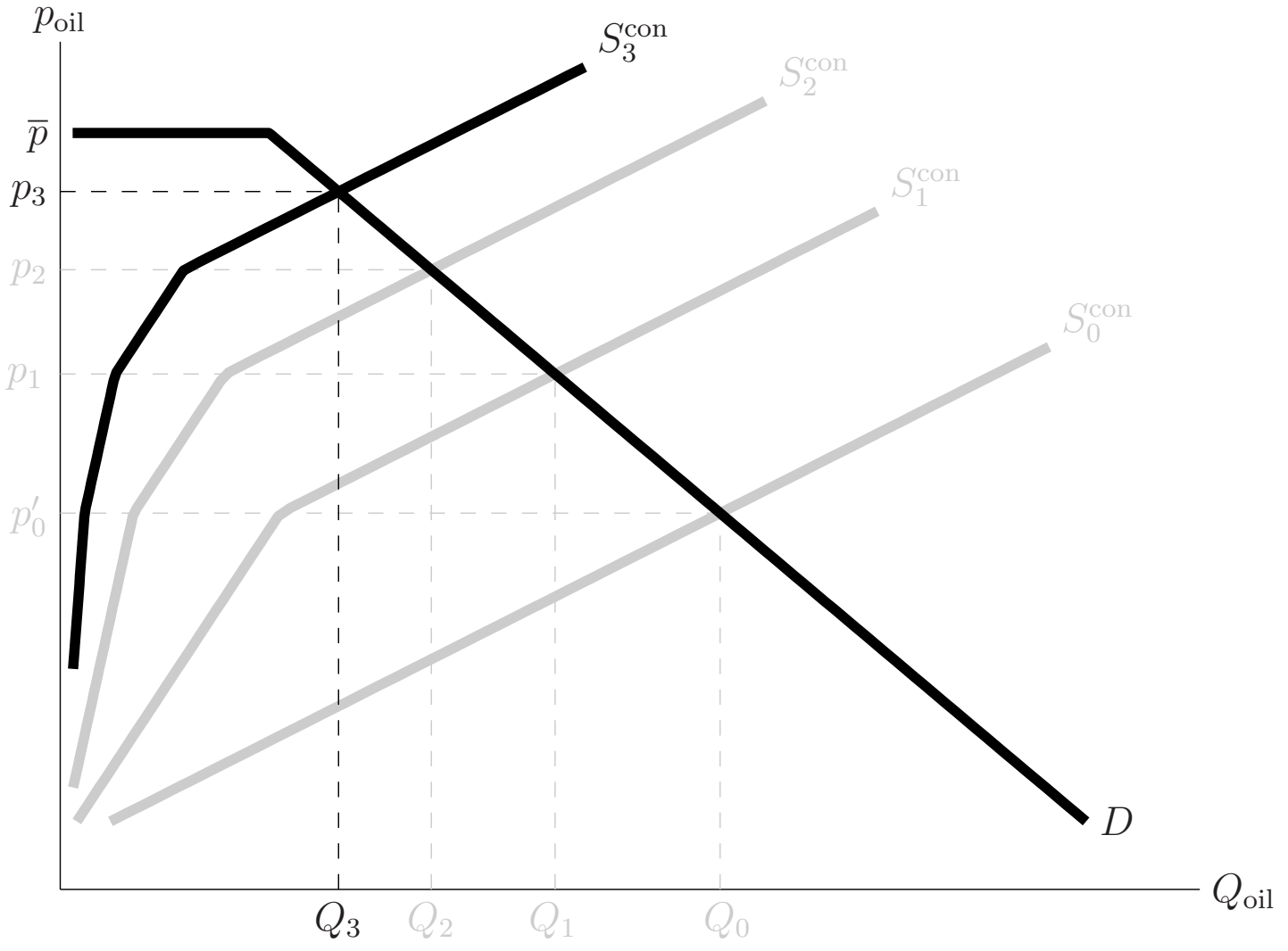

Oil market
p_{oil}
Demand
Conventional
p^*
Supply
Conventional
EOR
p^{**}
Q_{oil}
Q^*

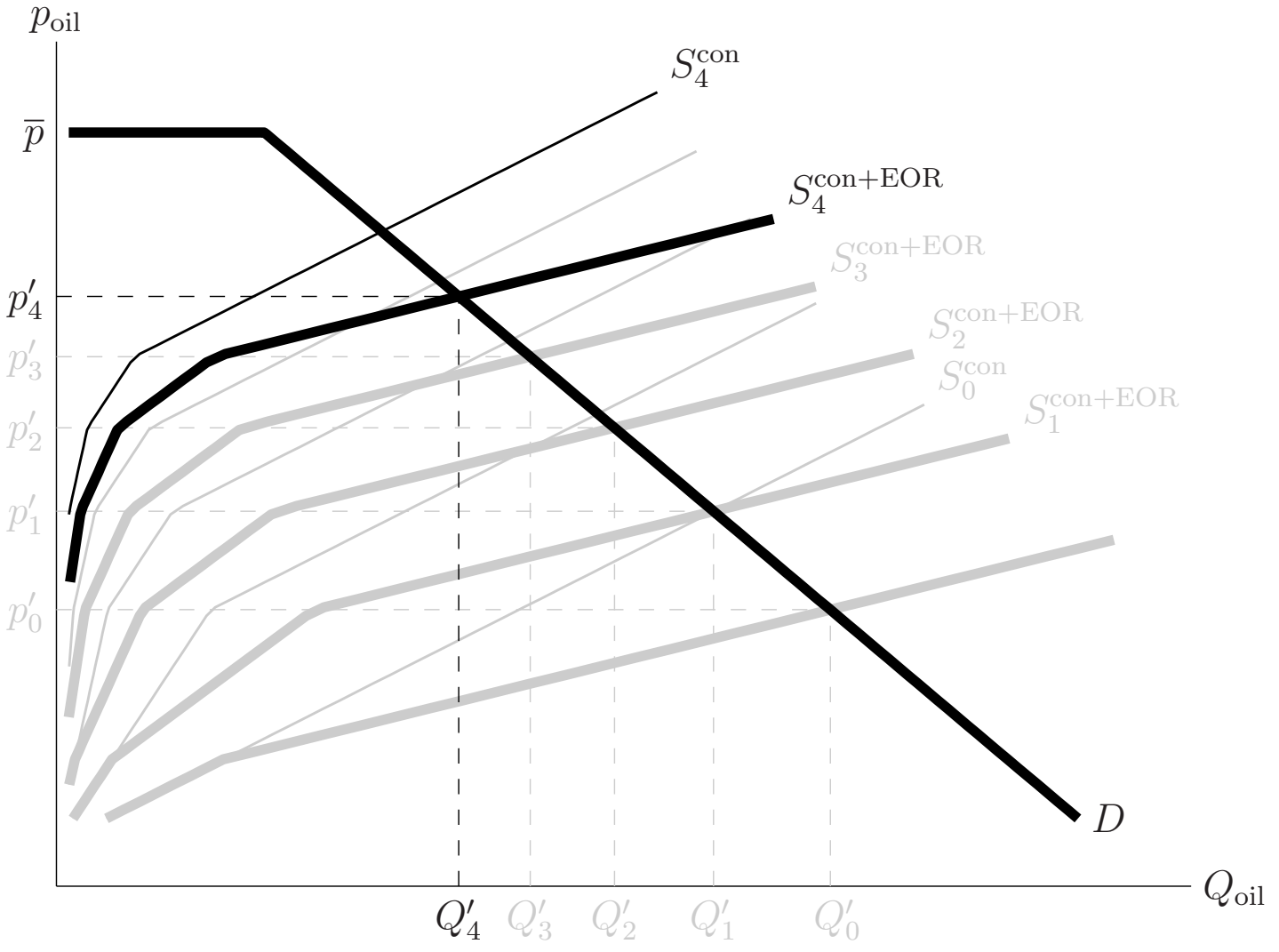

Oil market
p_{oil}
Supply
p^*
Demand
Q_{oil}
Q^*

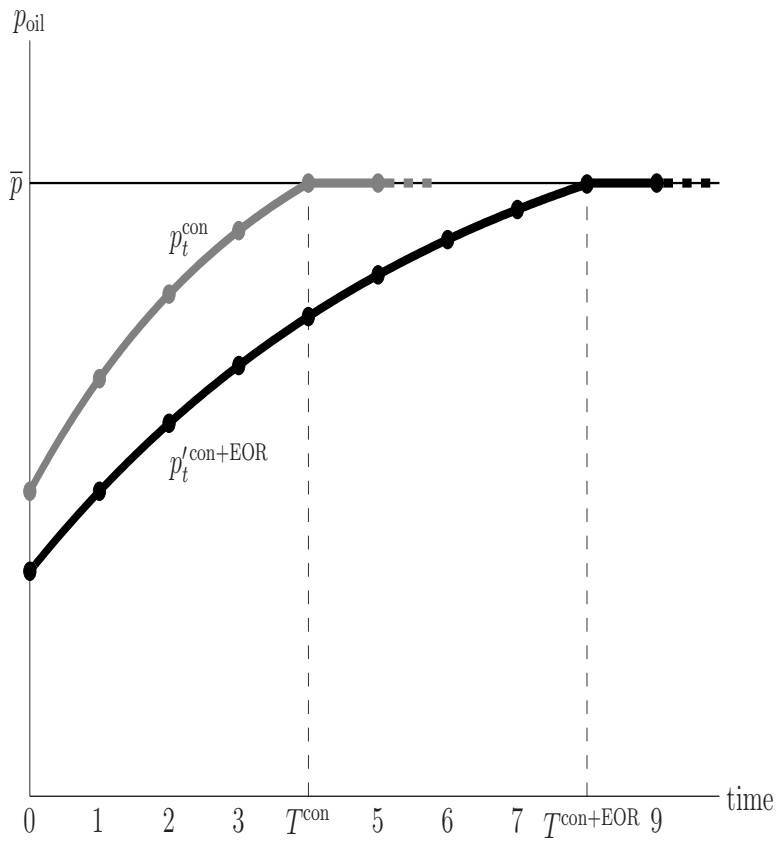

Oil market
p_{oil}
p^*
p^{**}
Supply
Demand
Q_{oil}
Q^*
Q^{**}

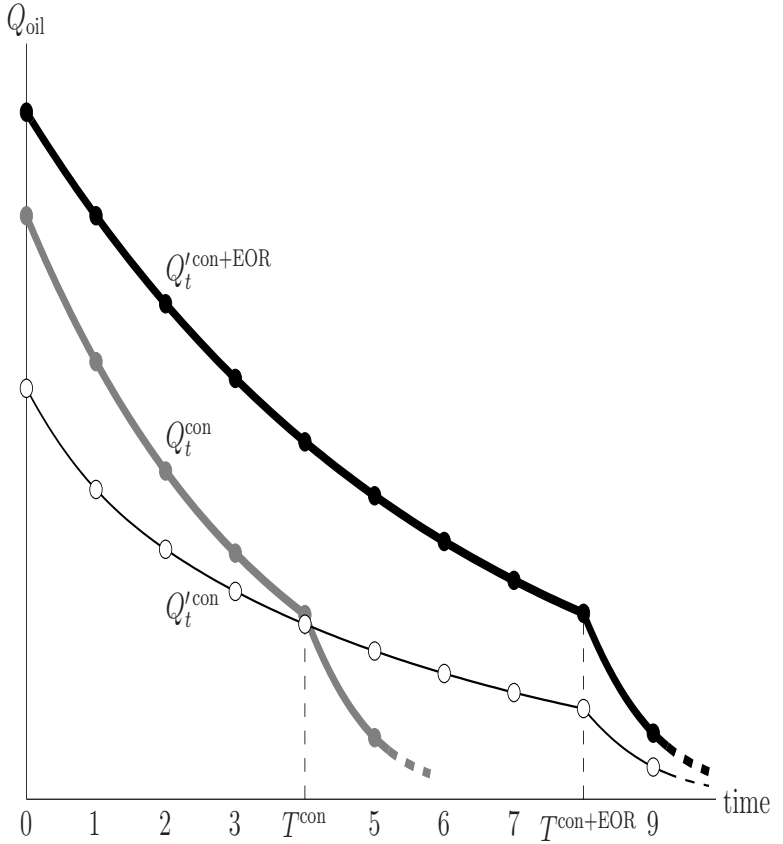
Oil market

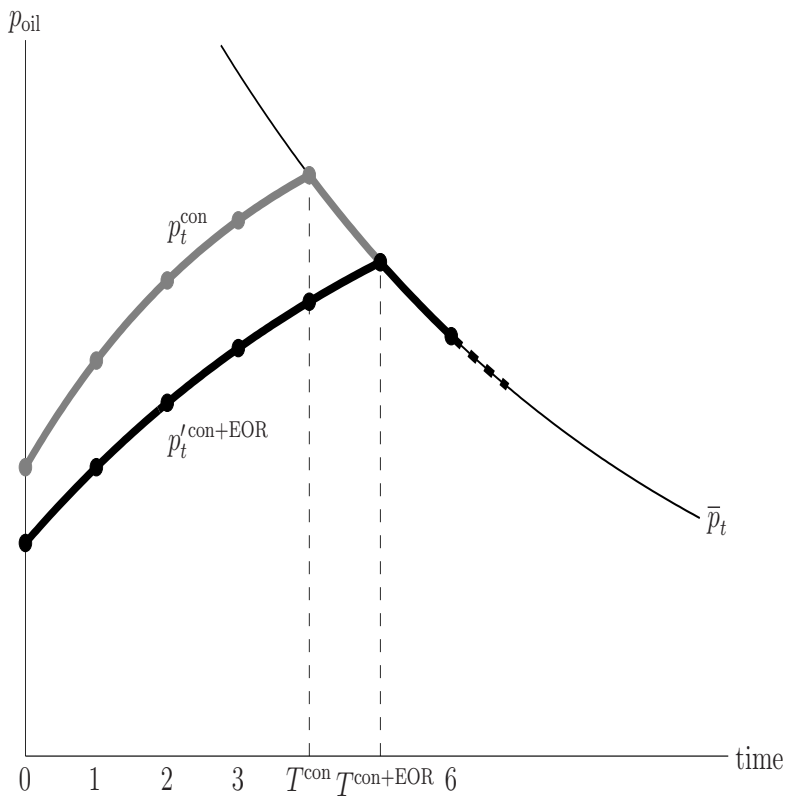

p_{oil}
Conventional
p^*
Conventional
p^{**}
EOR
Supply
Demand
Q_{oil}
Q^*
Q^{**}

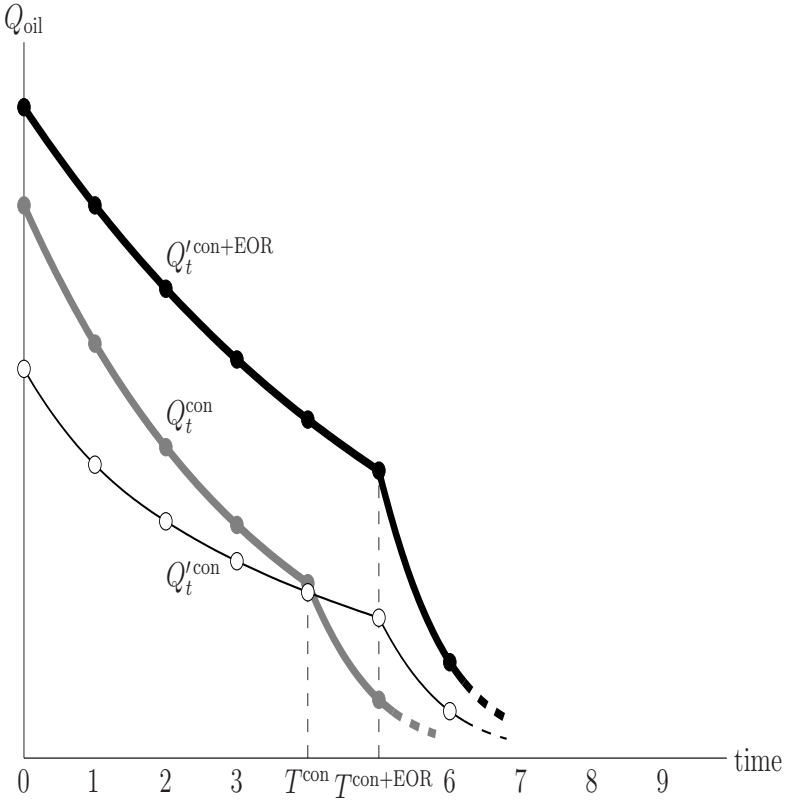

p_{oil}
S_3^{con}
S_2^{con}
S_1^{con}
S_0^{con}
$\overline{p}$
p_3
p_2
p_1
p_0'
D
Q_{oil}
Q_3
Q_2
Q_1
Q_0


p_{oil}
S_4^{con}
$\overline{p}$
$S_4^{\text{con+EOR}}$
$S_3^{\text{con+EOR}}$
p'_4
$S_2^{\text{con+EOR}}$
p'_3
S_0^{con}
$S_1^{\text{con+EOR}}$
p'_2
p'_1
p'_0
D
Q_{oil}
Q'_4
Q'_3
Q'_2
Q'_1
Q'_0


p_{oil}
$\overline{p}$
p_t^{con}
$p_t'^{\text{con+EOR}}$
time
0
1
2
3
T^{con}
5
6
7
$T^{\text{con+EOR}}$
9


Q_{oil}
$Q_t'^{\text{con+EOR}}$
Q_t^{con}
$Q_t'^{\text{con}}$
time
0
1
2
3
T^{con}
5
6
7
$T^{\text{con+EOR}}$
9


p_{oil}
p_t^{con}
$p_t'^{\text{con+EOR}}$
$\overline{p}_t$
time
0
1
2
3
T^{con}
$T^{\text{con+EOR}}$
6


Q_{oil}
$Q_t'^{\text{con+EOR}}$
Q_t^{con}
$Q_t'^{\text{con}}$
time
0
1
2
3
T^{con}
$T^{\text{con+EOR}}$
6
7
8
9

Common misconception

- So displacement of conventional oil is not one-for-one
- Moreover, conventional oil is also “displaced” by . . .
  - wind
  - solar
  - ethanol
  - nuclear
- Does that make their net CO_2 emissions *negative*?
- But if some CO_2-EOR projects generate positive net emissions, while others generate negative net emissions, what then is the optimal way of promoting EOR?
- Do we need taxes for some, and subsidies for others?

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  which for CO_2-EOR producers acts exactly like
  - a subsidy on CO_2 sequestration (i.e., on *avoided* CO_2 emissions)