Market Power and Incentive-Based Capacity Payment Mechanisms

Shaun McRae[1] and Frank Wolak[2]

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[1]ITAM

[2]Stanford University and NBER

How should electricity markets be designed to keep the lights on in a world with a large share of intermittent renewables?

- Common belief that paying generators for the energy they produce is insufficient to ensure a reliable electricity supply
  - Demand does not respond to price in the short-run
  - Price caps in the short-term market
  - Generators may not earn sufficient revenue to recover fixed costs
- **Capacity payment mechanisms** pay plants for "being available", even if they do not produce any output
  - Comprise an increasing share of generator revenue in electricity markets around the world (about 20% in the U.S.)
  - Popular with generation firms and regulators

We study an incentive-based capacity mechanism based on payments to generators for their "firm energy"

- Traditional capacity payments using regulatory mechanisms have been costly for consumers... but with few benefits
- Firm energy mechanism is the best-practice design for capacity payments because it solves the "being available" problem
  - Wholesale price provides signal to generators for when their firm energy should be available
  - Wholesale price sets the "punishment" for not being available
- Adopted in Colombia, New England ISO, and Ireland—and under consideration in many other markets
- Various names for the mechanism we study: reliability option, peak energy rent, pay-for-performance, firm energy refund

Firm energy mechanism is based on the idea of a "scarcity period" that creates an obligation for sellers of firm energy

- Scarcity periods occur when the wholesale market price exceeds an administrative "scarcity price"
- During scarcity periods:
  - The price that electricity purchasers pay is capped at the scarcity price
  - Generators have an obligation to make or pay the difference between the market price and the scarcity price, for the quantity of firm energy they sold
- This gives generators an incentive to supply at least their firm energy quantity during the scarcity period
- No obligations for generators during non-scarcity periods

We show that the interaction between firm energy and forward contracts creates perverse incentives for generators

- Large generators can **choose** whether or not a scarcity condition exists
- In markets with intermittent renewables, it can be optimal for generation firms to withhold generation and create scarcity
- For the example of the Colombian wholesale market, we show that generators recognize and respond to these incentives
- As a result, the "gold standard" firm energy mechanism may lead to lower reliability, higher generation costs, and higher prices
- We suggest an alternative based on modifications to the existing forward contract design

What are forward contracts for energy?

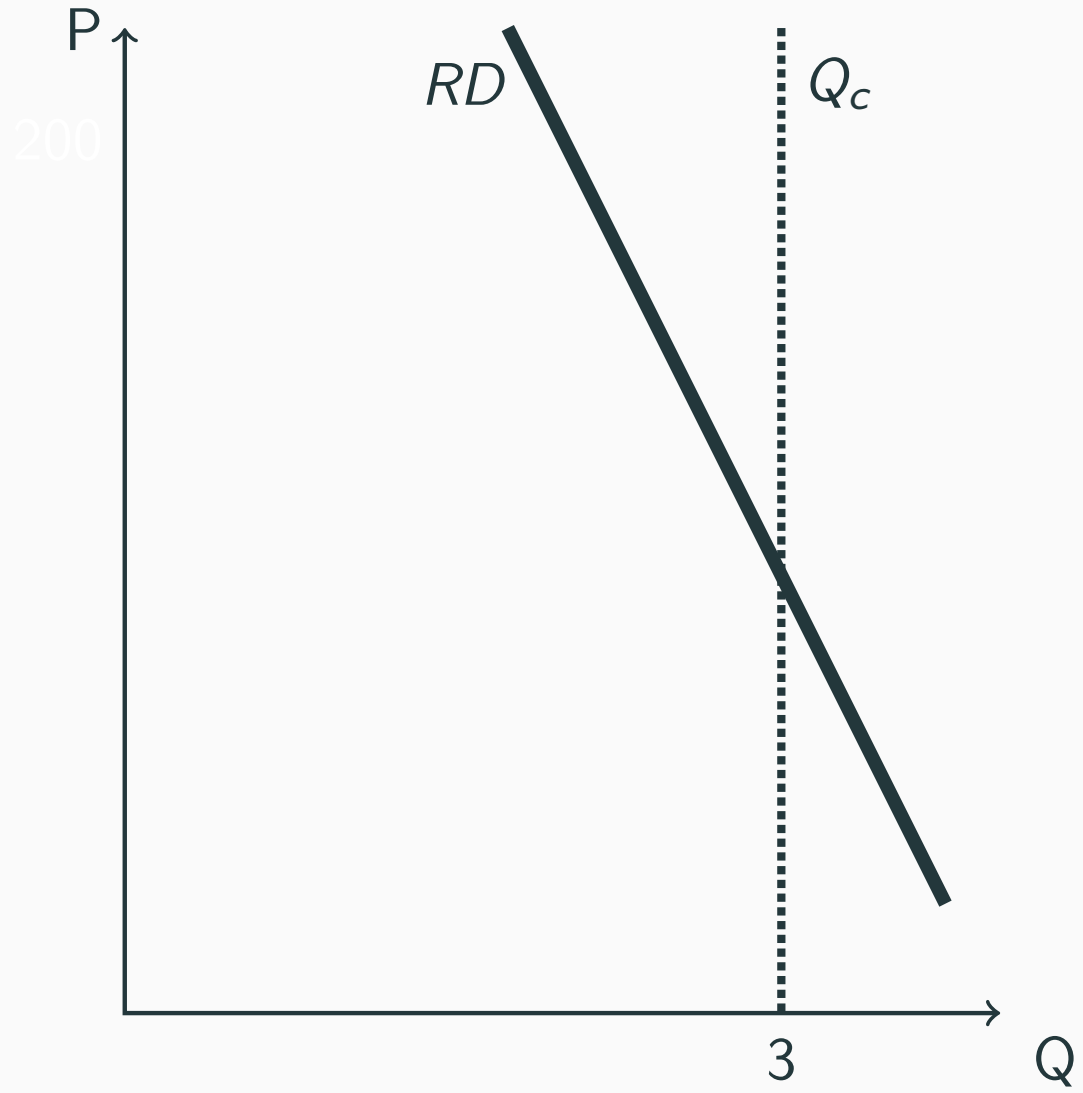
First study the incentives for a generation firm after signing fixed-price forward contracts for energy

- Firm faces a linear inverse residual demand curve:

$$P = 400 - 100Q$$

- Firm sells $Q_c = 3$ forward contracts for a fixed price of \$50
  - Constant revenue of \$150
  - Firm has to make or buy $Q_c = 3$ at the market price to fulfill its contract obligations
- Assume generation costs are zero

Firm has the ability to choose any price and quantity along its residual demand curve



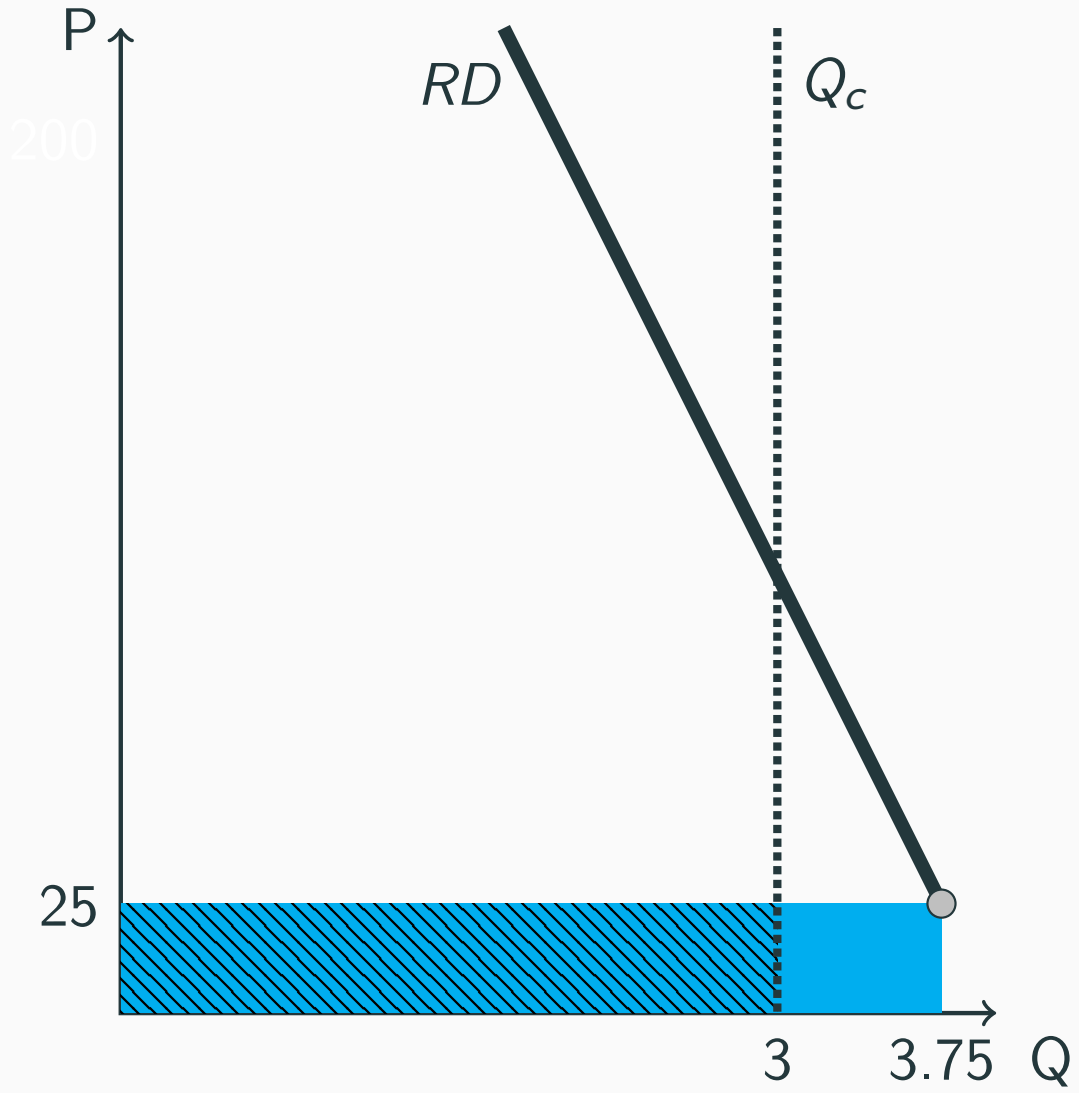
Contract revenue
+150.0

Generation revenue

Forward obligation

NET REVENUE

Firm receives wholesale market revenue equal to the generation quantity times the wholesale price



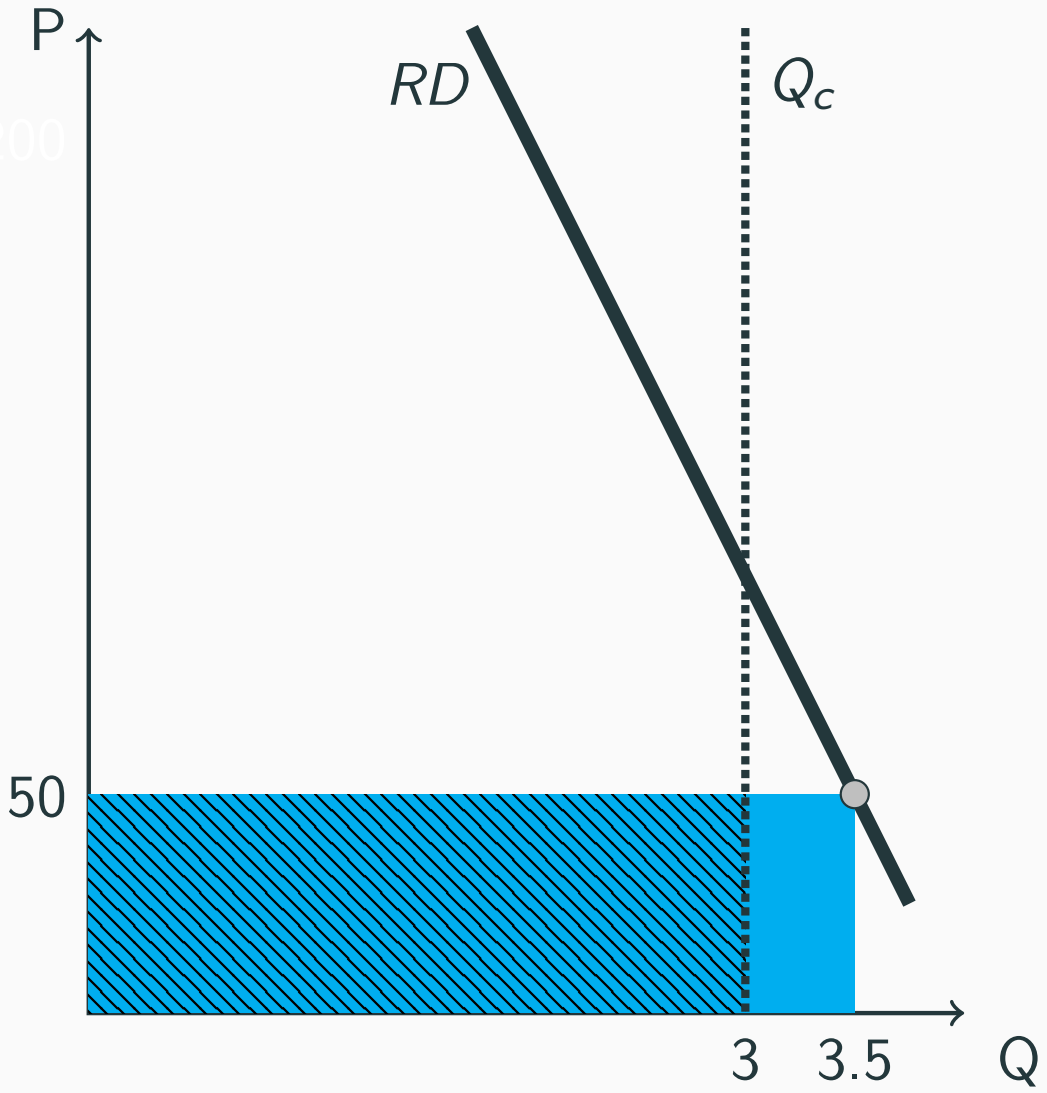
Contract revenue
+150.0

Generation revenue
+93.75

Forward obligation
−75.0

NET REVENUE
168.75

Firm fulfills its forward contract obligation by buying $Q_c = 3$ at the wholesale price



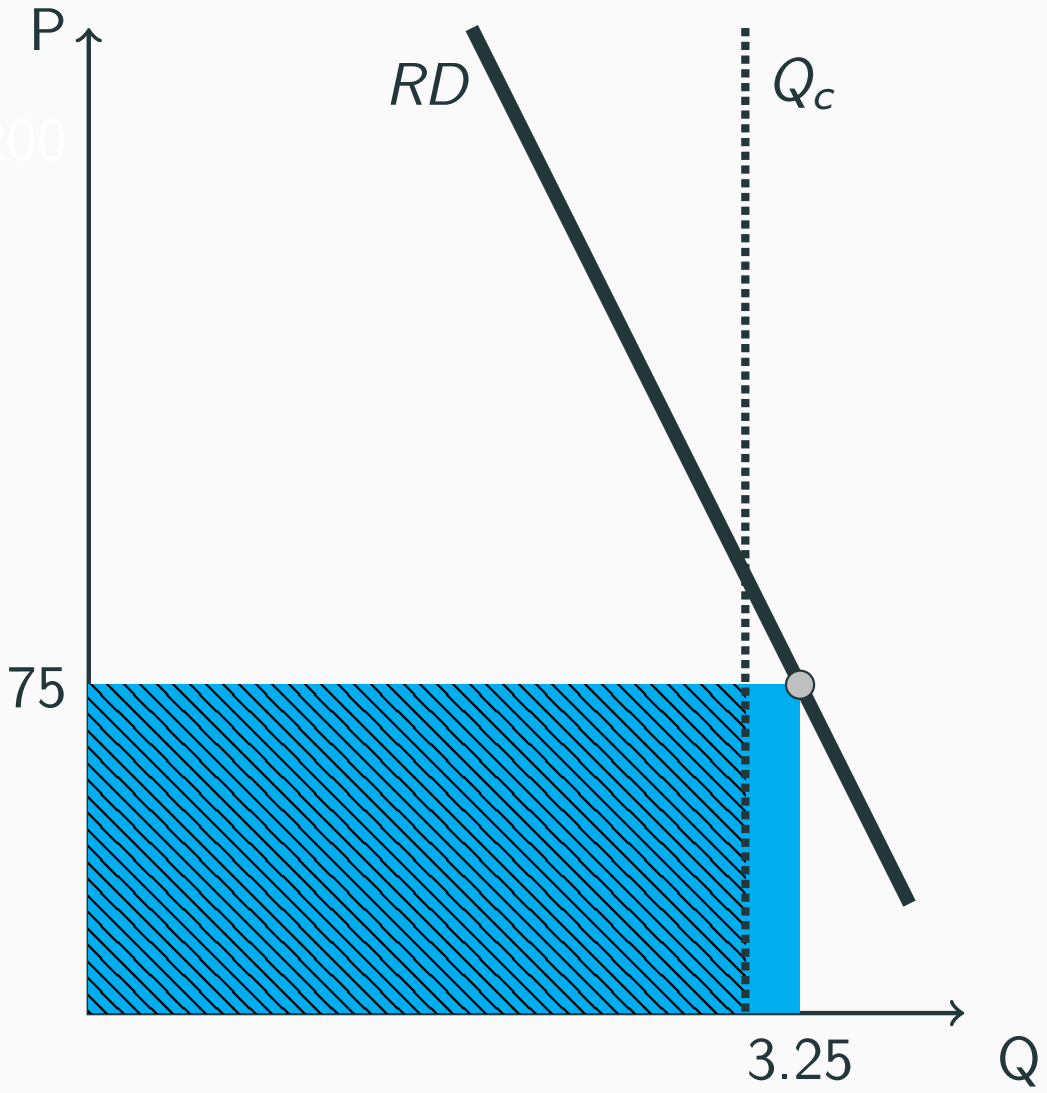
Contract revenue
+150.0

Generation revenue
+175.0

Forward obligation
−150.0

NET REVENUE
175.0

Increasing the price will increase the generation revenue but also increase the forward contract obligation



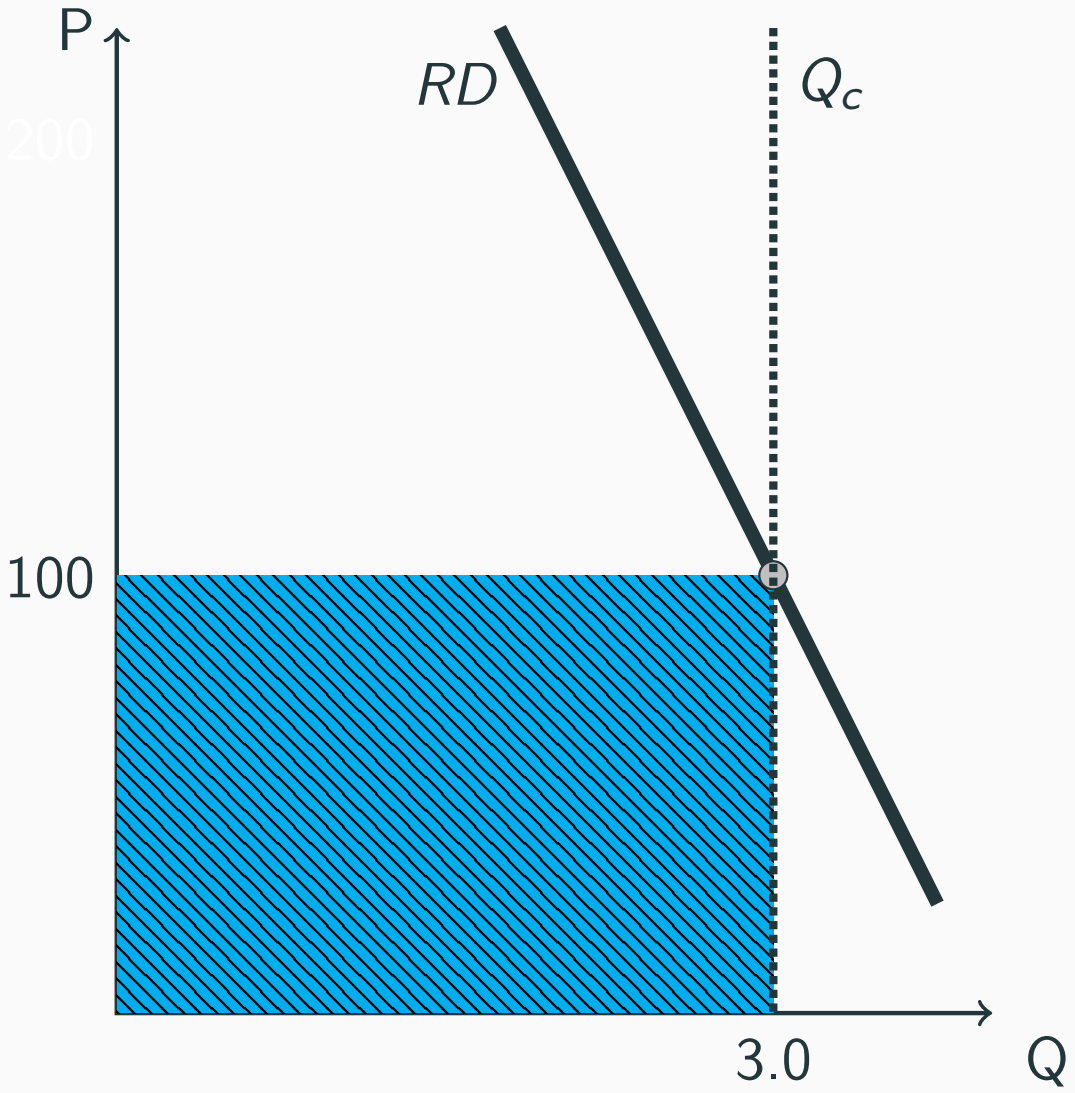
Contract revenue
+150.0

Generation revenue
+243.75

Forward obligation
−225.0

NET REVENUE
168.75

If the firm produces exactly its forward contract quantity, then the net revenue will be the revenue from contract sales



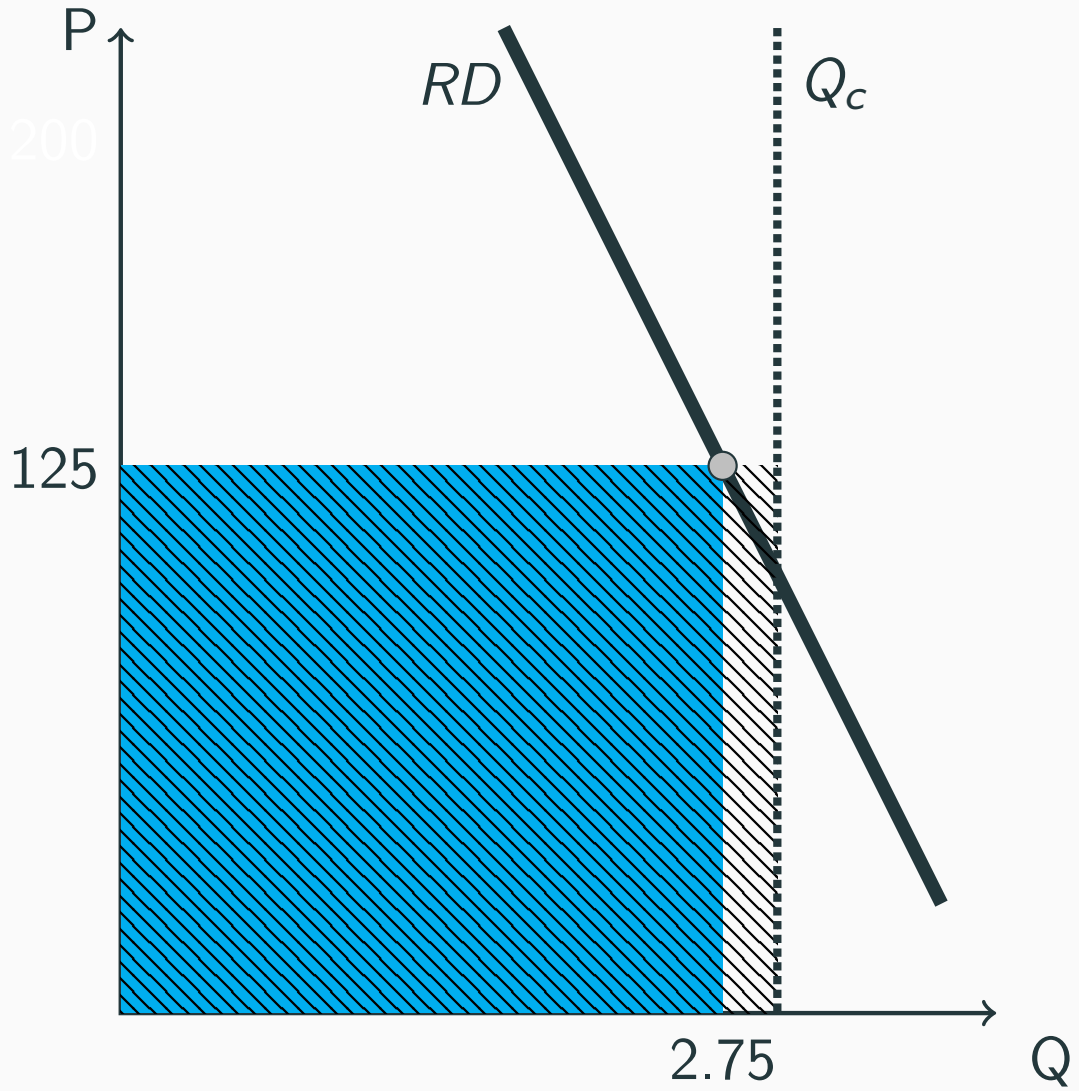
Contract revenue
+150.0

Generation revenue
+300.0

Forward obligation
−300.0

NET REVENUE
150.0

Reducing the generation quantity further means that the firm is a net buyer—at a price that continues to increase



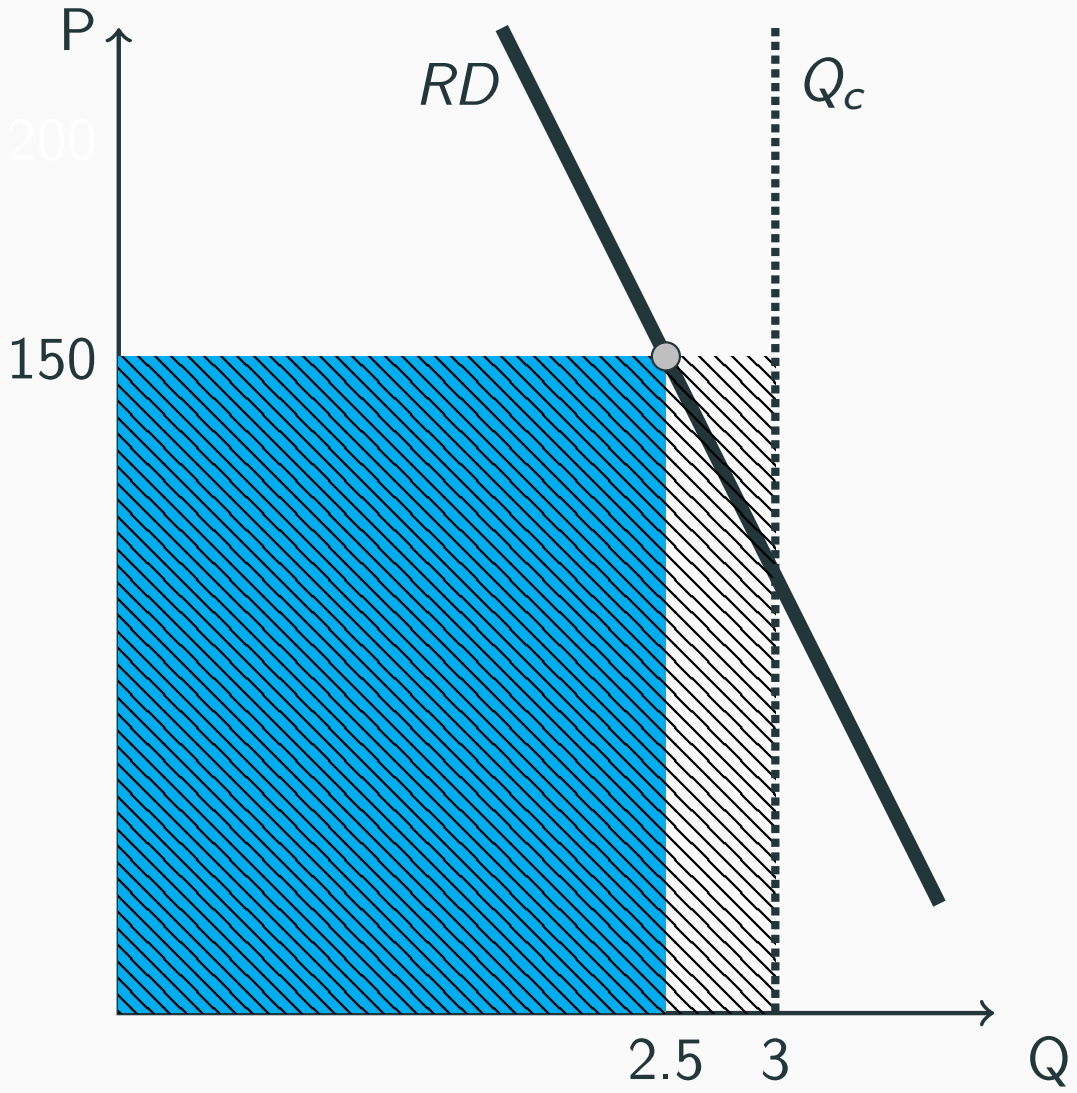
Contract revenue
+150.0

Generation revenue
+343.75

Forward obligation
−375.0

NET REVENUE
118.75

Reducing the generation quantity further means that the firm is a net buyer—at a price that continues to increase



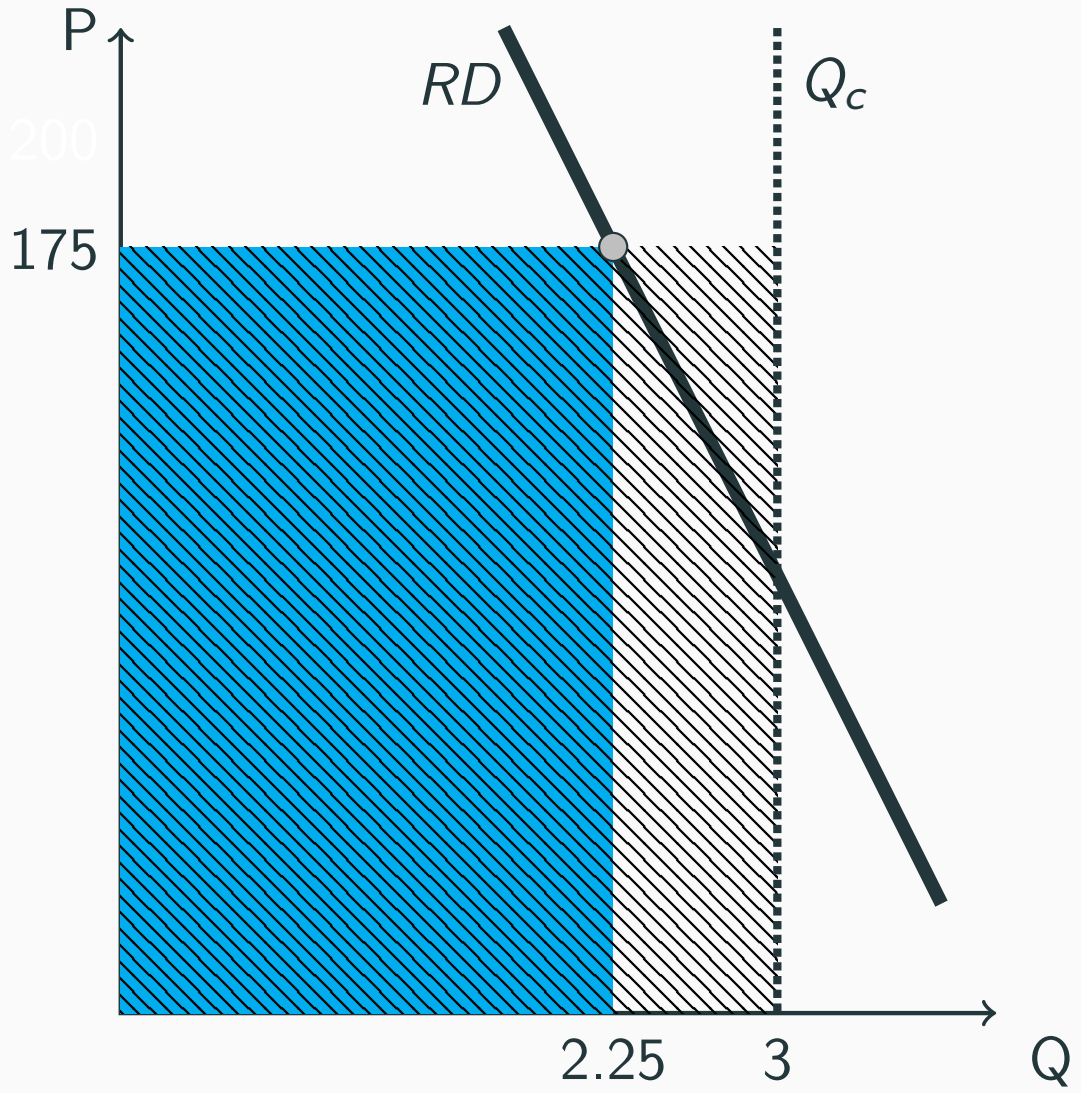
Contract revenue
+150.0

Generation revenue
+375.0

Forward obligation
−450.0

NET REVENUE
75.0

Reducing the generation quantity further means that the firm is a net buyer—at a price that continues to increase



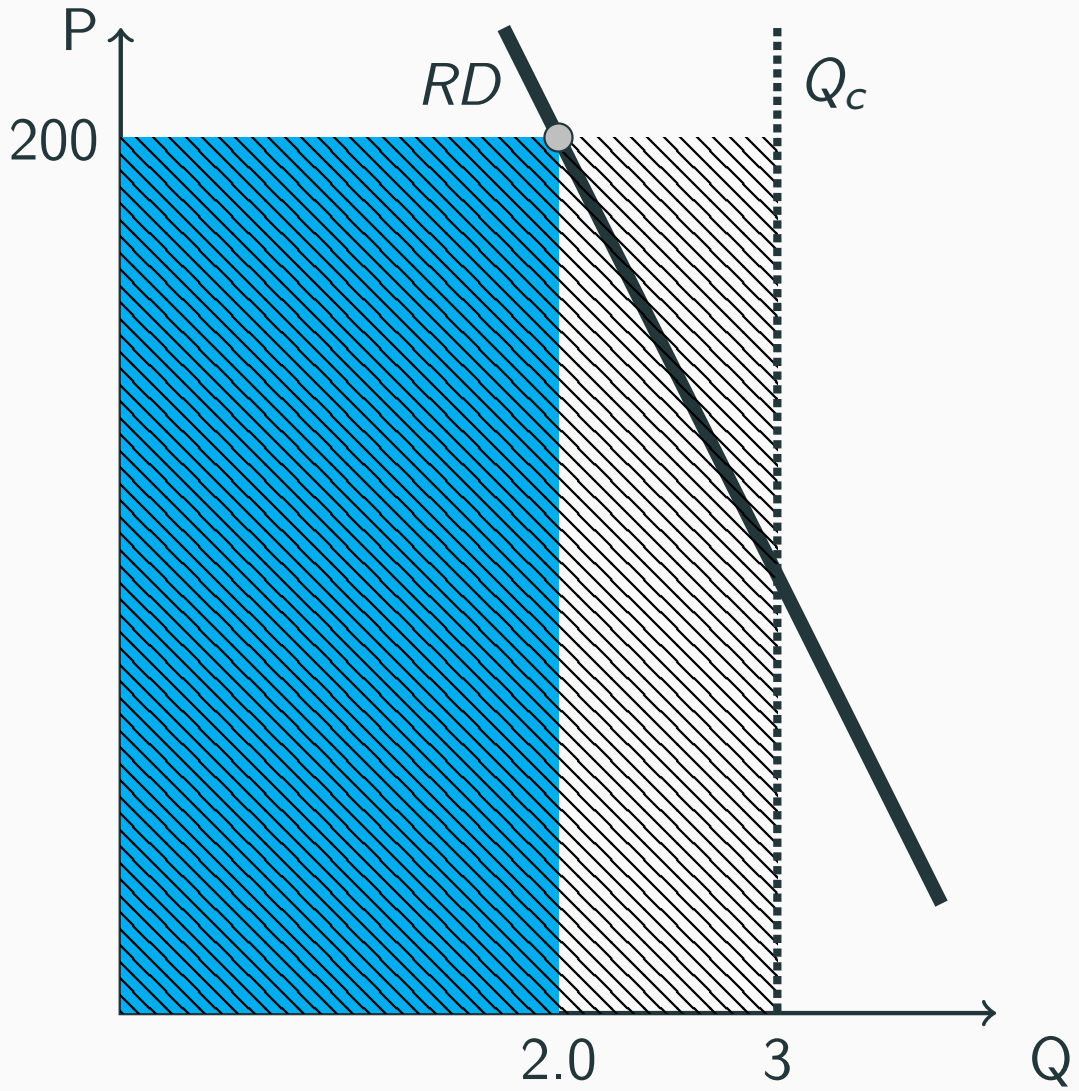
Contract revenue
+150.0

Generation revenue
+393.75

Forward obligation
−525.0

NET REVENUE
18.75

Net revenue can even go negative, if the firm has to buy a sufficiently large quantity to cover its forward obligations



Contract revenue
+150.0

Generation revenue
+400.0

Forward obligation
−600.0

NET REVENUE
−50.0

Selling forward contracts gives a powerful incentive to the firm not to withhold generation and push up the market price

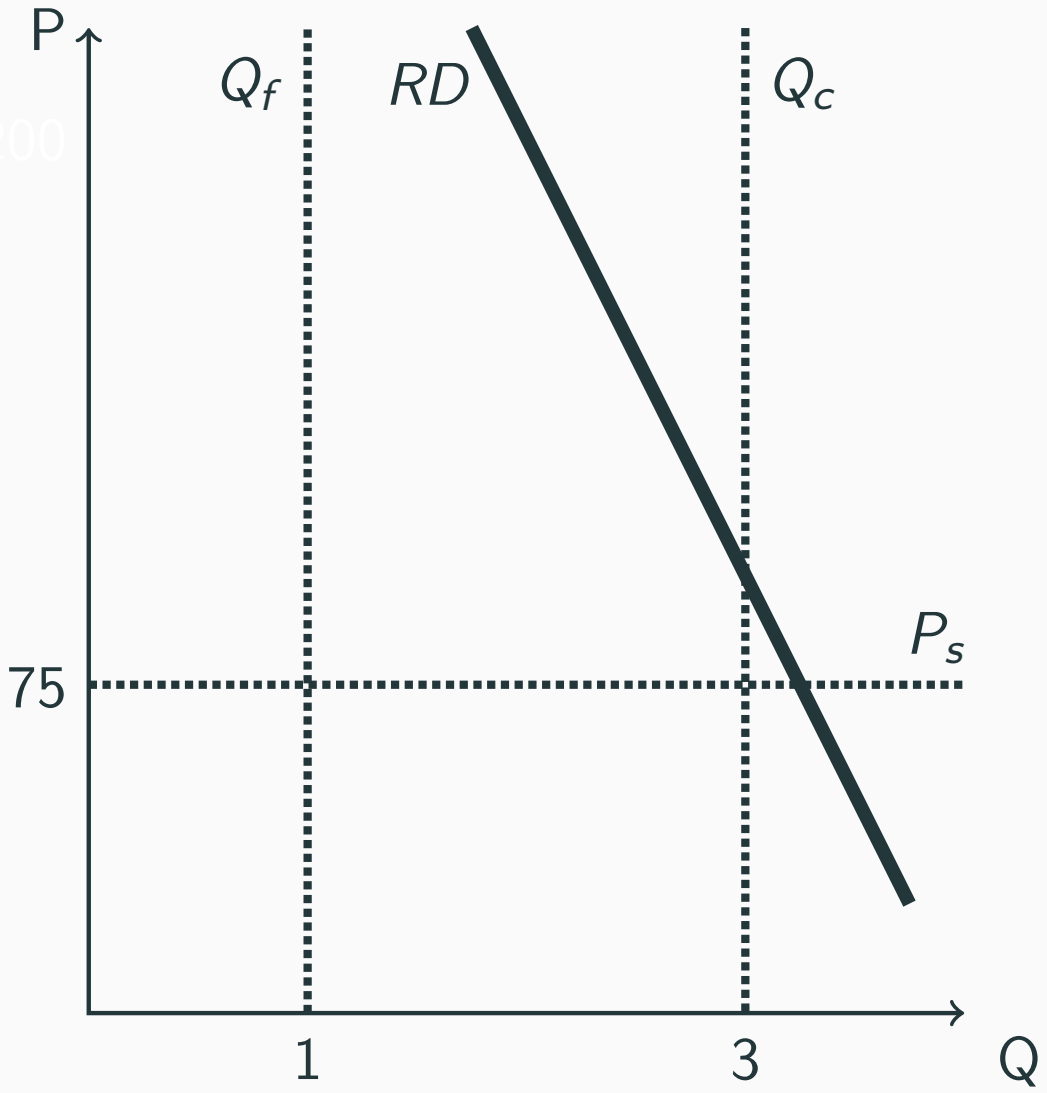
- In this example, profits are highest when the firm generates a quantity of 3.5 GW
- Firm does not have an incentive to withhold generation and increase the market price—because this will also increase the size of its forward contract obligation

What will change when we introduce firm energy contracts?

In addition to the forward contracts, we introduce firm energy contracts to see how incentives will change

- Generator **also** sells $Q_f = 1$ firm energy contract at price of \$20
- System operator sets a **scarcity price** of \$75
- Firm energy contracts create two changes:
  - Price to fulfill forward contract obligation is capped at \$75
  - When the market price exceeds \$75, the generator has to fulfill its firm energy obligation for the difference between the market price and the scarcity price

Setting is identical to the previous setup, with addition of scarcity price and firm energy obligation



Contract revenue

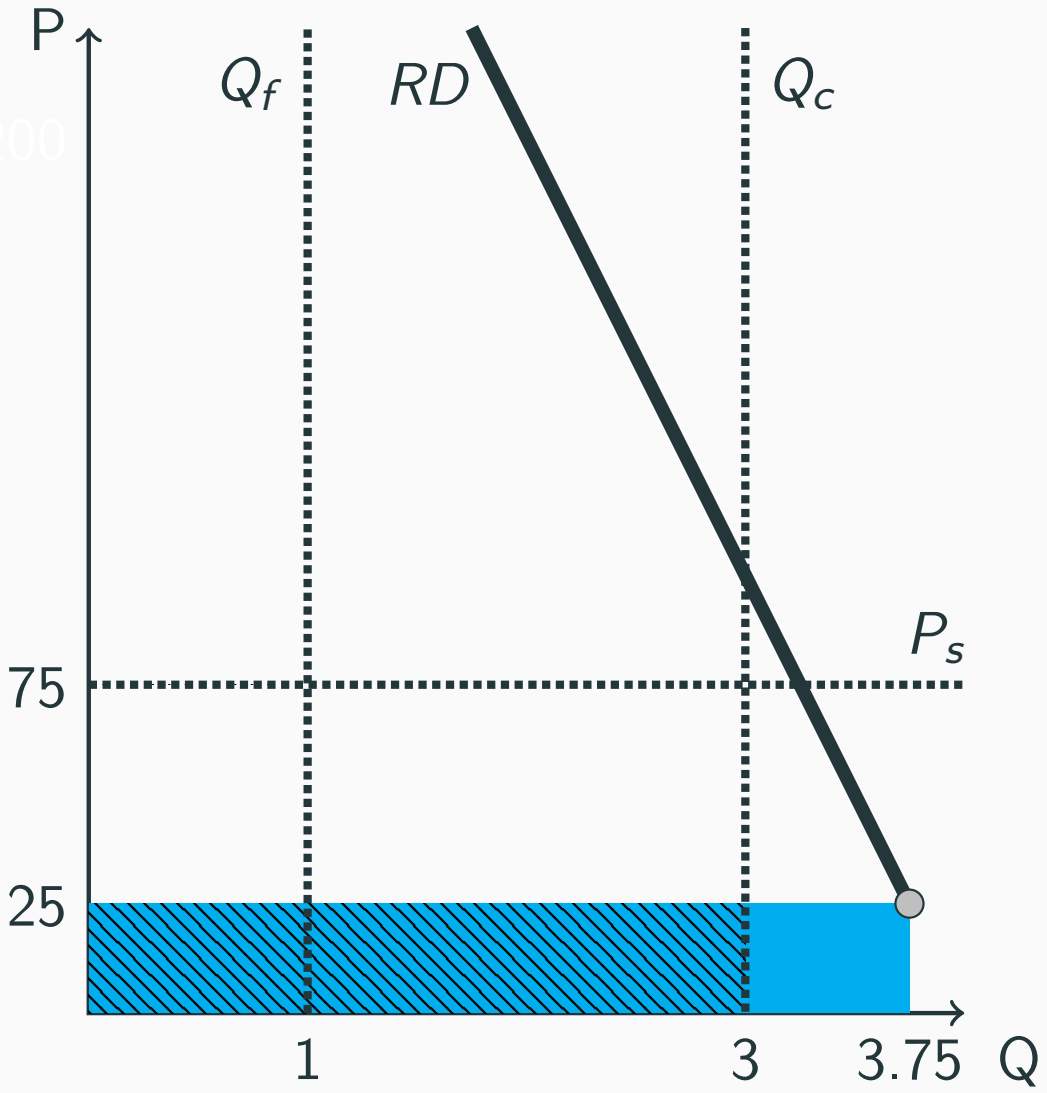
$+150 + 20$

Generation revenue

Forward obligation

NET REVENUE

If market price is below the scarcity price, net revenue is same as before, with addition of the firm energy contract revenue



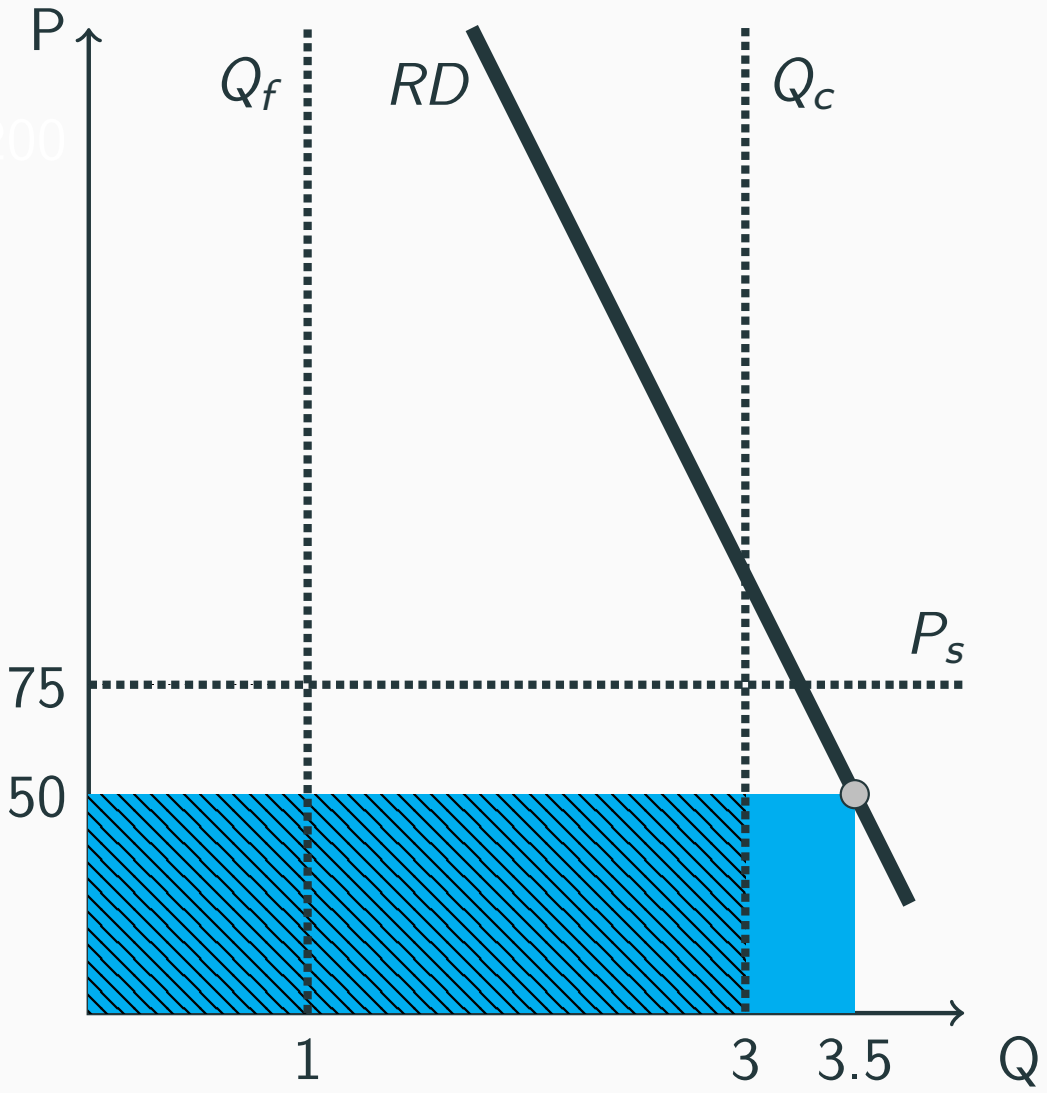
Contract revenue
+150 + 20

Generation revenue
+93.75

Forward obligation
−75.0

NET REVENUE
188.75

If market price is below the scarcity price, net revenue is same as before, with addition of the firm energy contract revenue



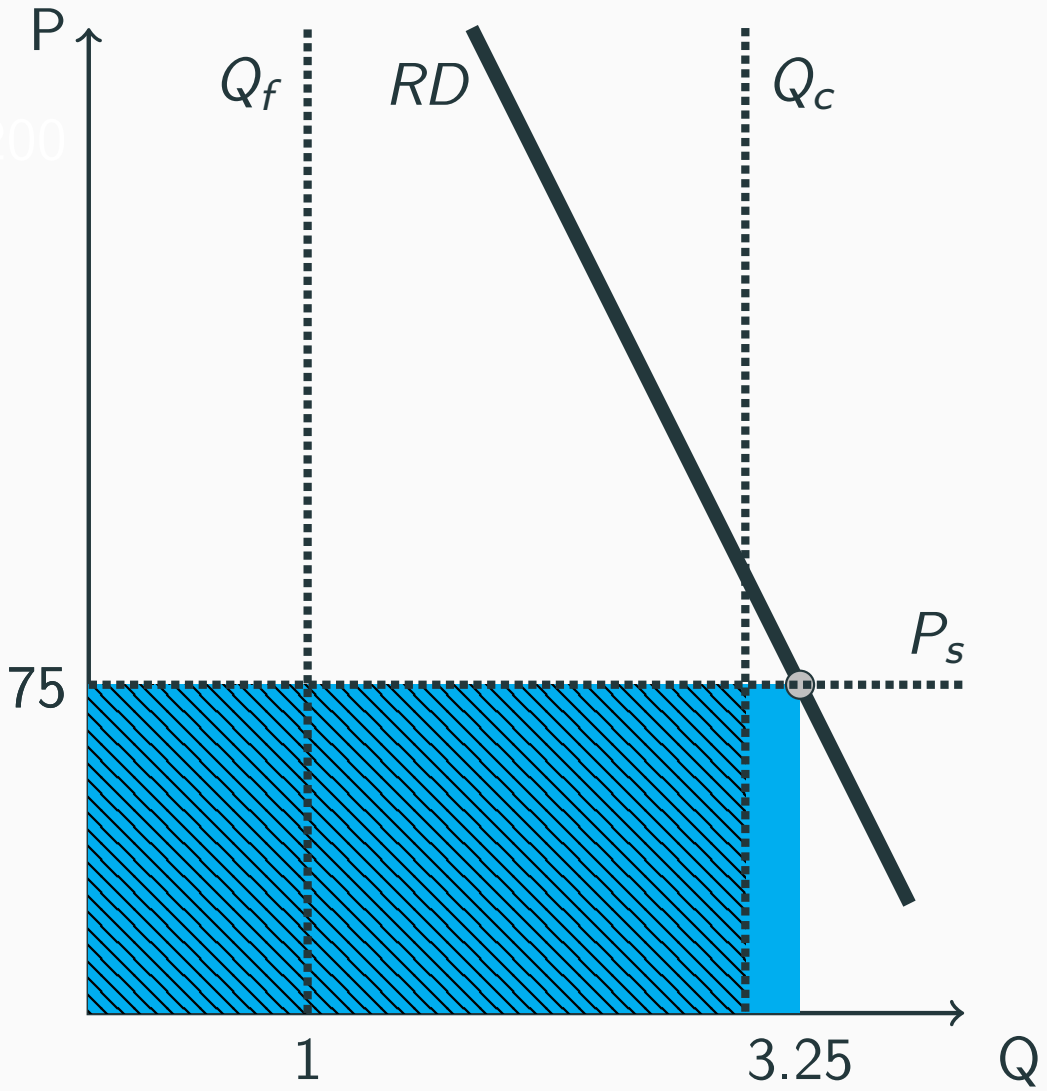
Contract revenue
+150 + 20

Generation revenue
+175.0

Forward obligation
−150.0

NET REVENUE
195.0

If market price is below the scarcity price, net revenue is same as before, with addition of the firm energy contract revenue



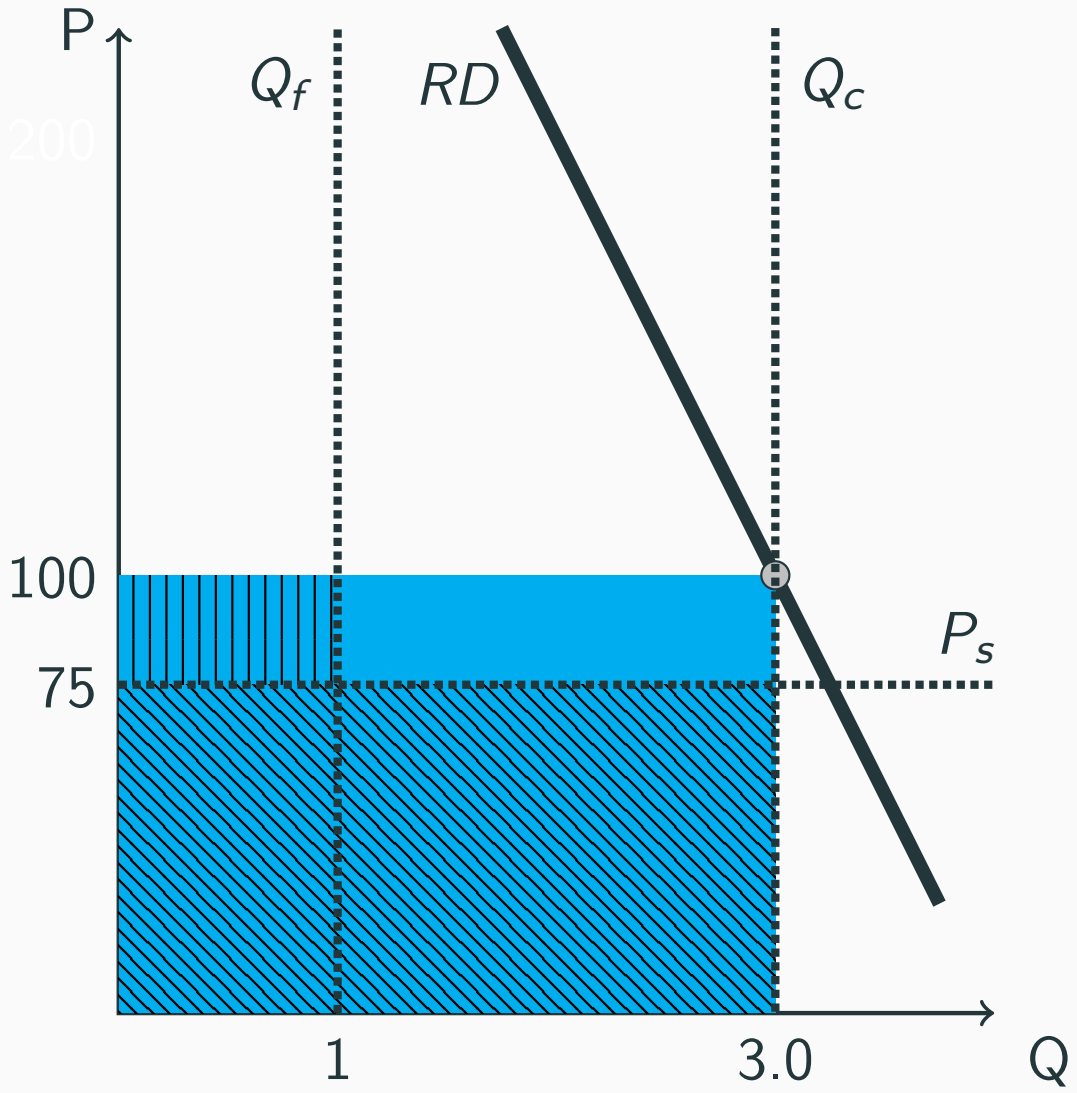
Contract revenue
+150 + 20

Generation revenue
+243.75

Forward obligation
−225.0

NET REVENUE
188.75

When the price is above the scarcity price, the firm must pay the price difference on its firm energy quantity



Contract revenue
+150 + 20

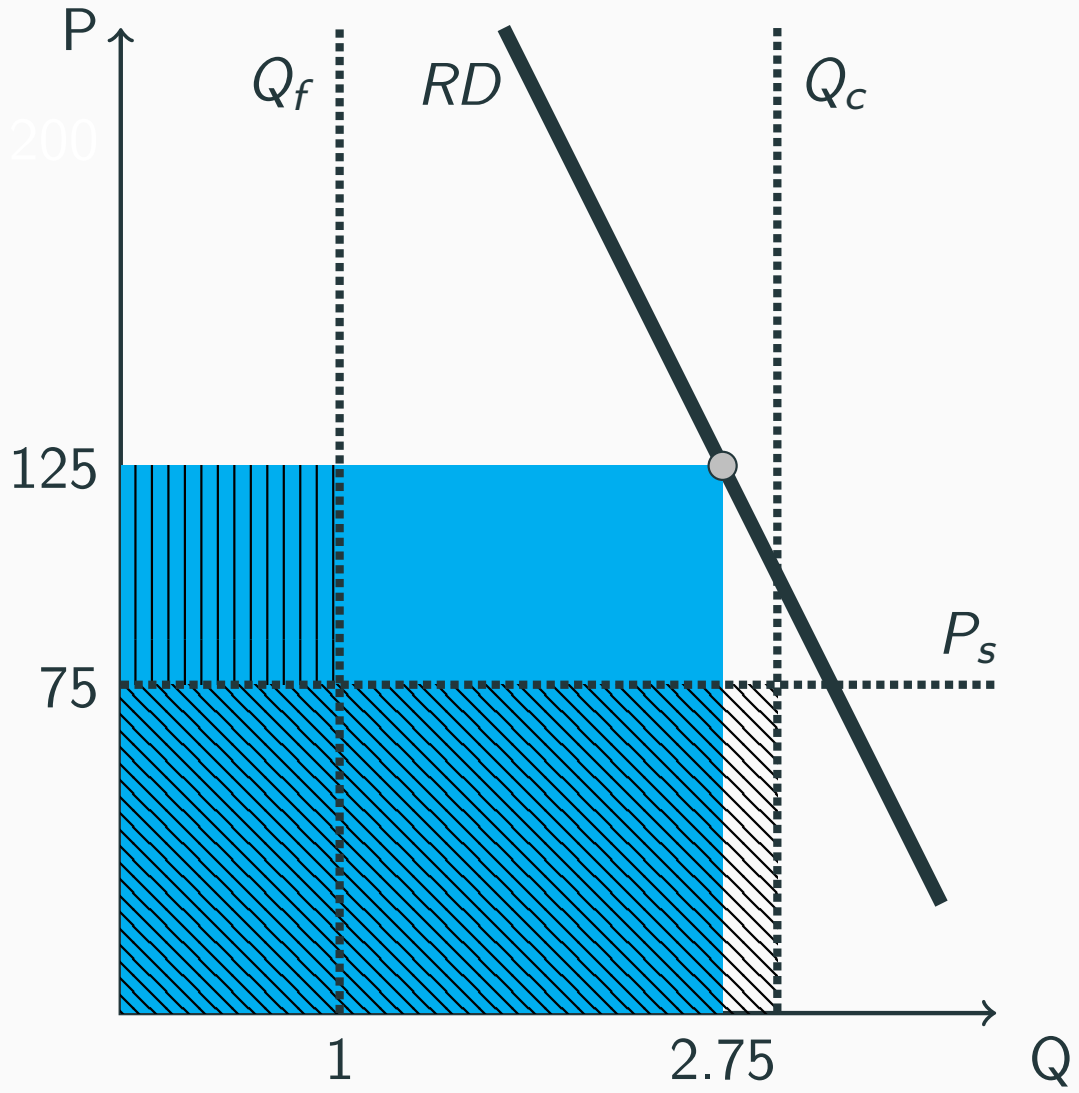
Generation revenue
+300.0

Forward obligation
−225.0

Firm obligation
−25.0

NET REVENUE
220.0

The forward contract obligation is capped at the scarcity price, reducing the disincentive to push up the market price



Contract revenue
+150 + 20

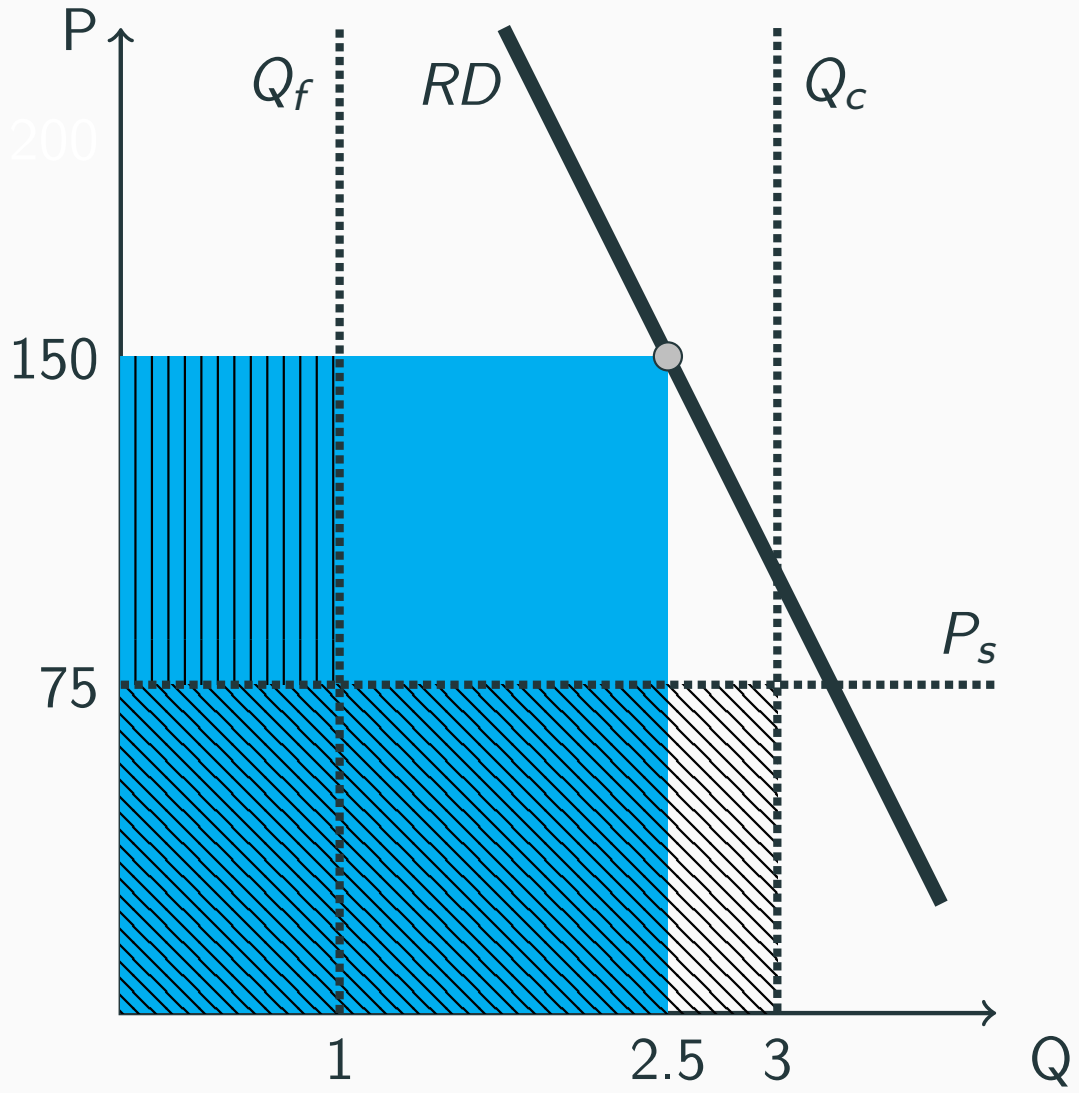
Generation revenue
+343.75

Forward obligation
−225.0

Firm obligation
−50.0

NET REVENUE
238.75

With firm energy, the generator finds it optimal to withhold generation to below the forward contract quantity



Contract revenue
+150 + 20

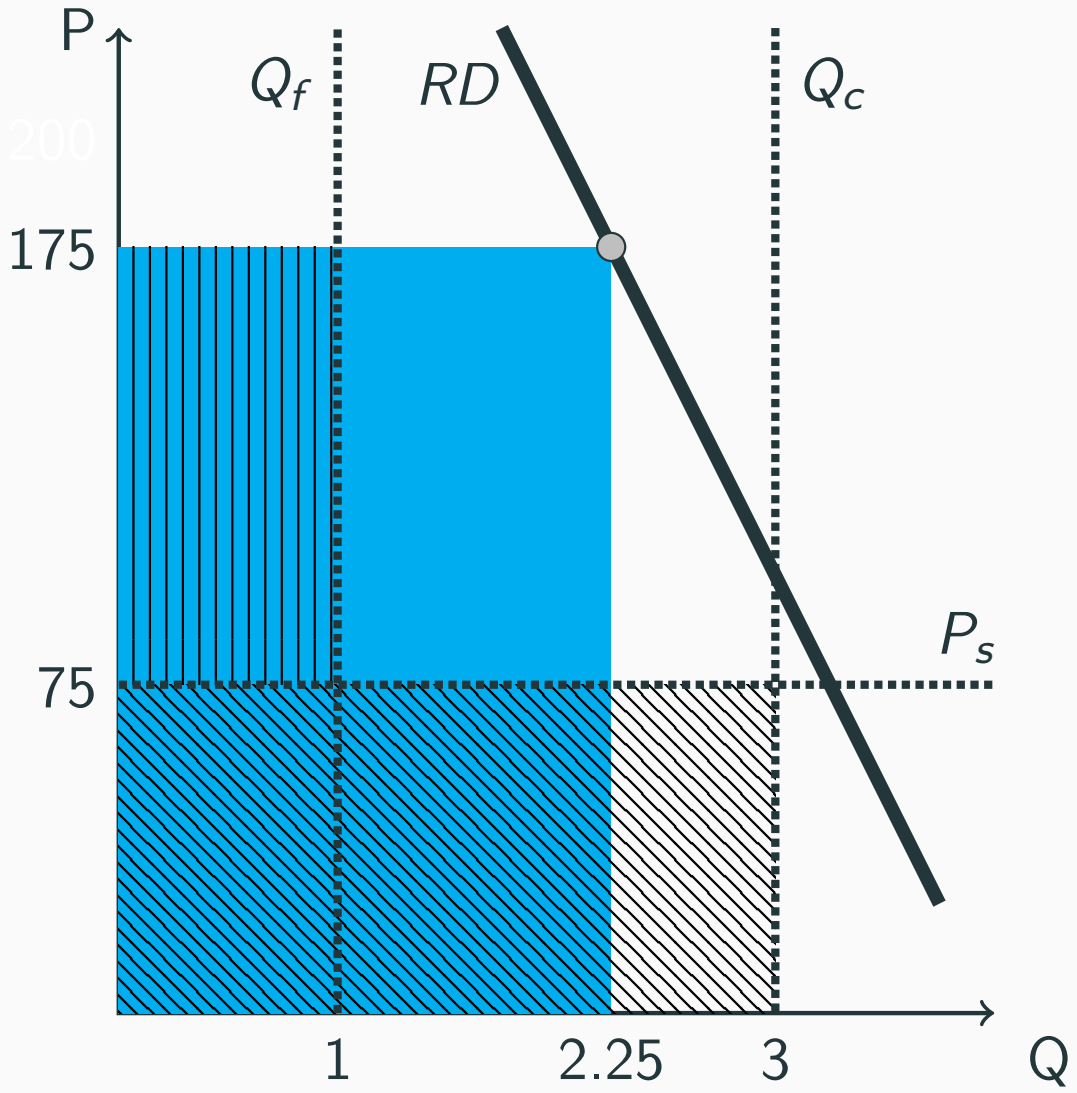
Generation revenue
+375.0

Forward obligation
−225.0

Firm obligation
−75.0

NET REVENUE
245.0

With firm energy, the generator finds it optimal to withhold generation to below the forward contract quantity



Contract revenue
+150 + 20

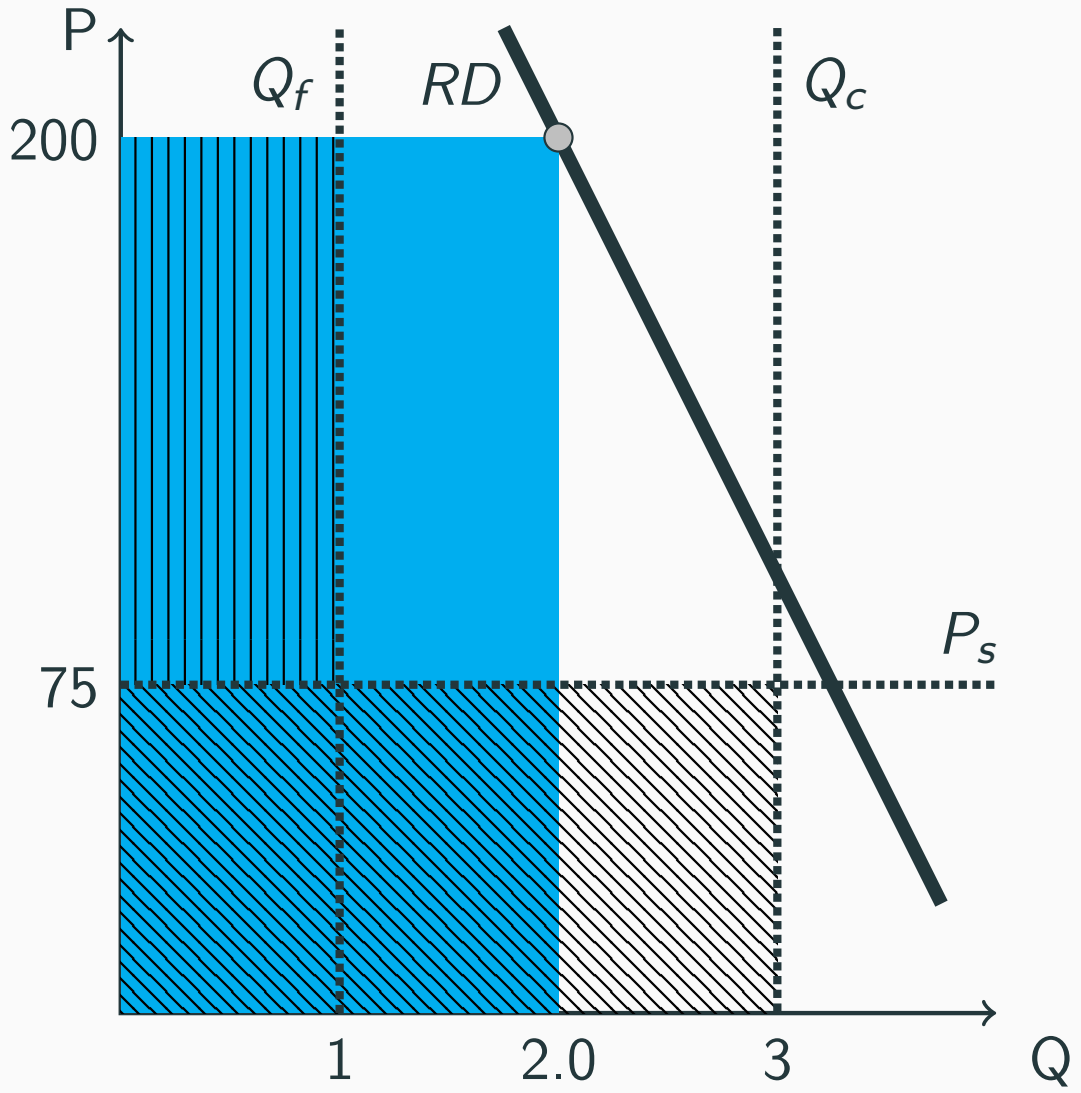
Generation revenue
+393.75

Forward obligation
−225.0

Firm obligation
−100.0

NET REVENUE
238.75

With firm energy, the generator finds it optimal to withhold generation to below the forward contract quantity



Contract revenue
+150 + 20

Generation revenue
+400.0

Forward obligation
−225.0

Firm obligation
−125.0

NET REVENUE
220.0

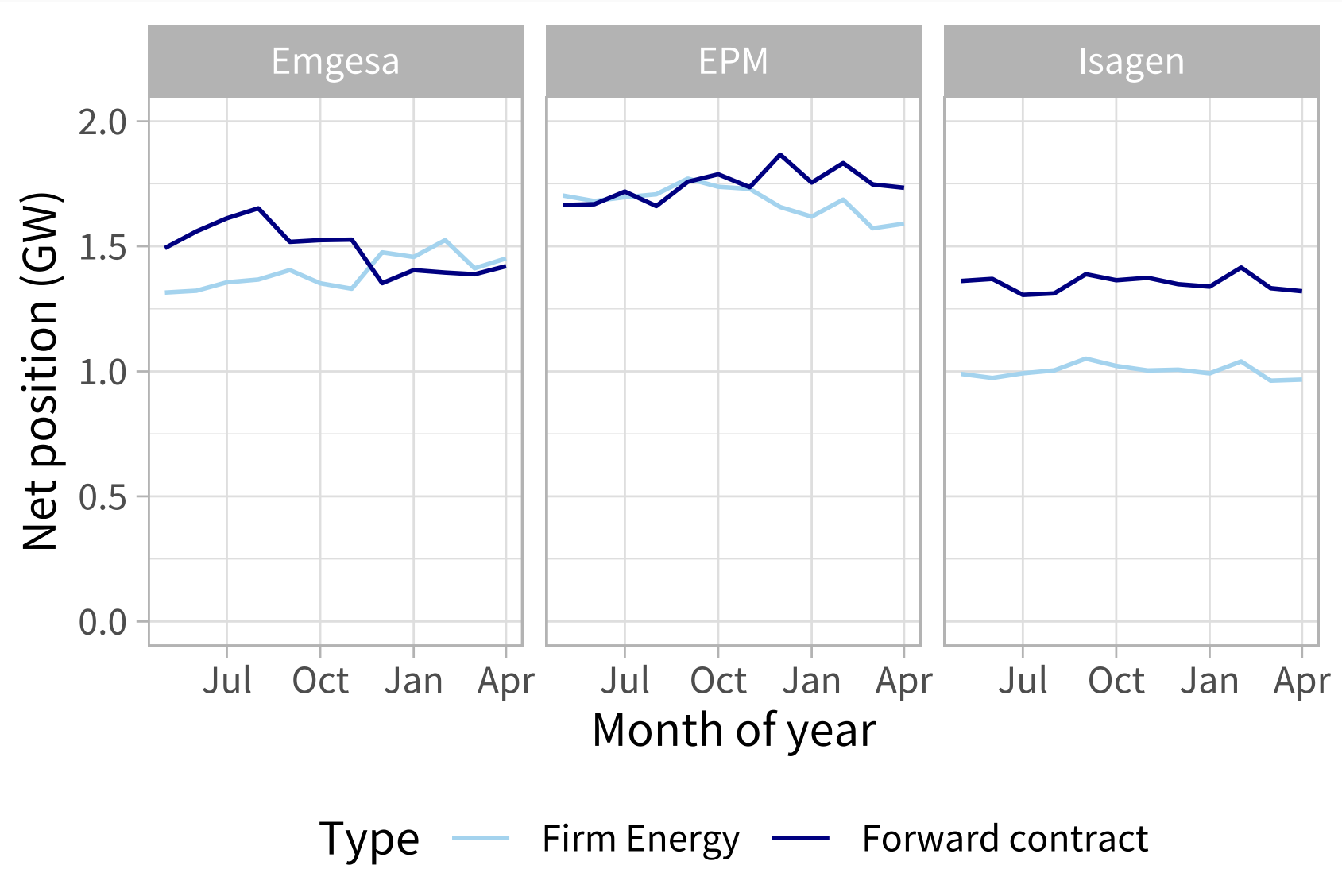
Compared to the case with forward contracts only, firm energy contracts provide incentive to withhold generation capacity

- In the example with forward contracts **and** firm energy, optimal generation quantity was 2.5 GW
- With only forward contracts, the optimal generation quantity was 3.5 GW
- Although consumers pay for the firm energy contracts, they receive higher prices and lower generation availability

Is it realistic to assume that the firm energy contract quantity is below the forward contract quantity?

- Math relies on firm energy quantity being lower than forward contract quantity
- With intermittent renewable generation, this will usually be the case
- System operator assumes a "worst case" scenario for calculating firm energy

Largest generators usually have firm energy obligations that are lower than their net forward contracts for energy

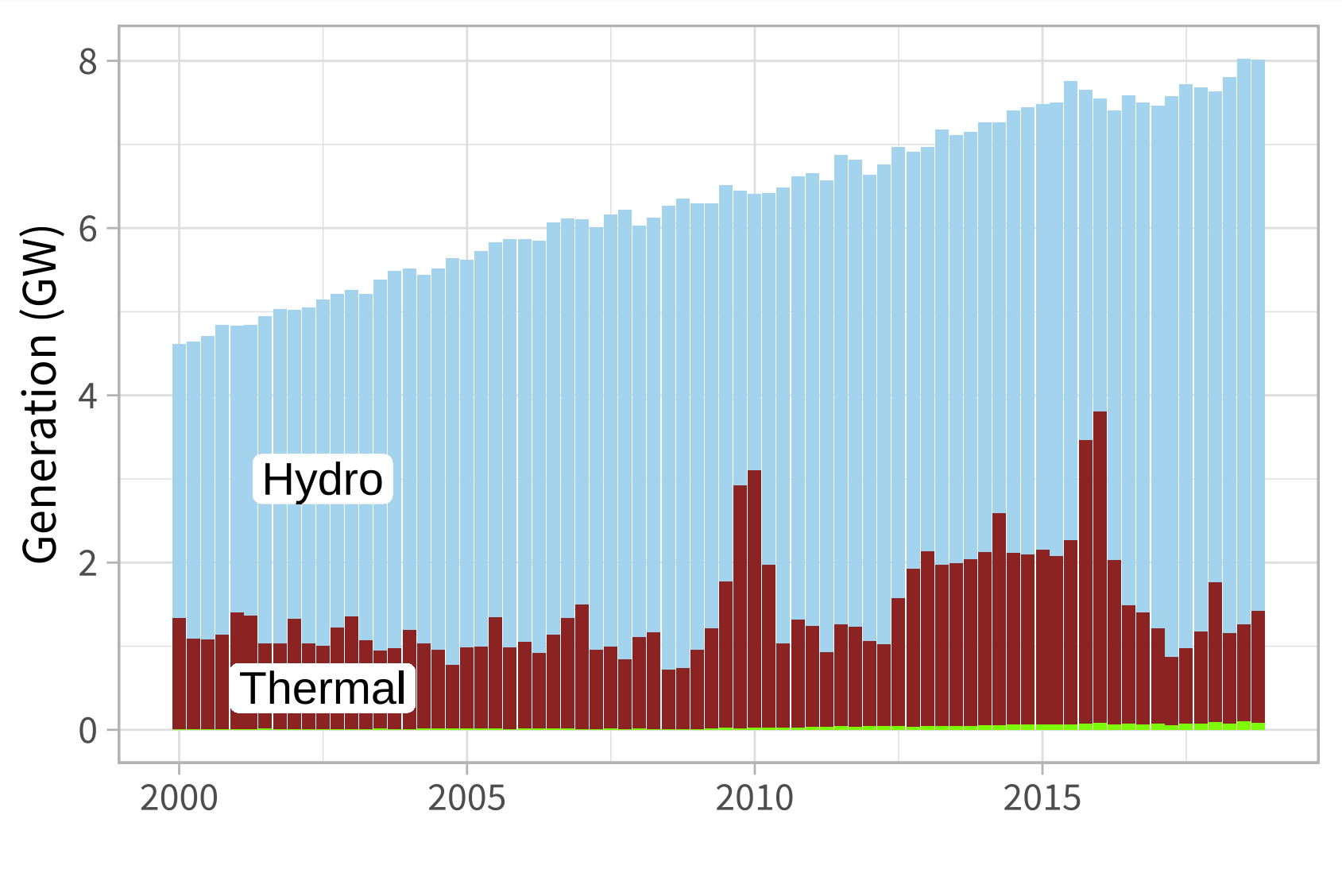


Do generators recognize the firm energy incentive?

We study the performance of the firm energy mechanism in Colombia, where it was introduced in 2006

- Colombian wholesale market is bid-based (similar to U.S. market design)
  - Generation firms bid hourly quantities and daily prices into the wholesale market
- In addition, there are long-term auctions for firm energy every 4 or 5 years
- Price in this auction sets the price that all plants (not just new ones) receive for their firm energy

Hydro is the dominant form of generation in Colombia but is subject to periodic shortfalls due to El Niño climate pattern



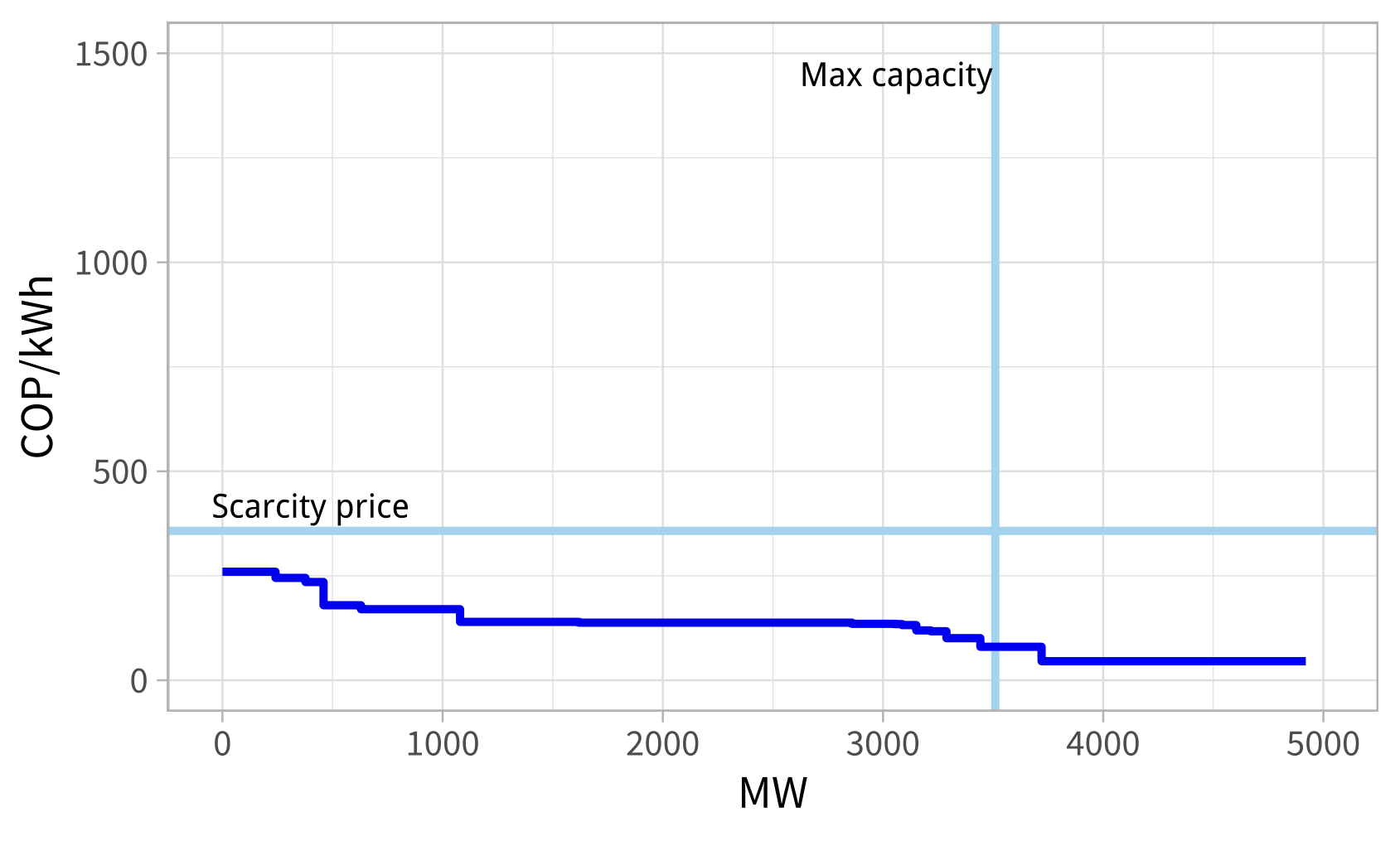
We use hourly data from the Colombian system operator XM to study the performance of the firm energy mechanism

- We have data on plant-level generation, bids, fuel prices, and contract positions
- Focus on three largest firms: EPM, Emgesa, Isagen
  - These firms own more than 60% of the system capacity
  - Most of their generation is hydro
- Many small owners of thermal generation plants—we treat these as competitive

We first show that the large generation firms have the ability to choose whether there is a scarcity condition

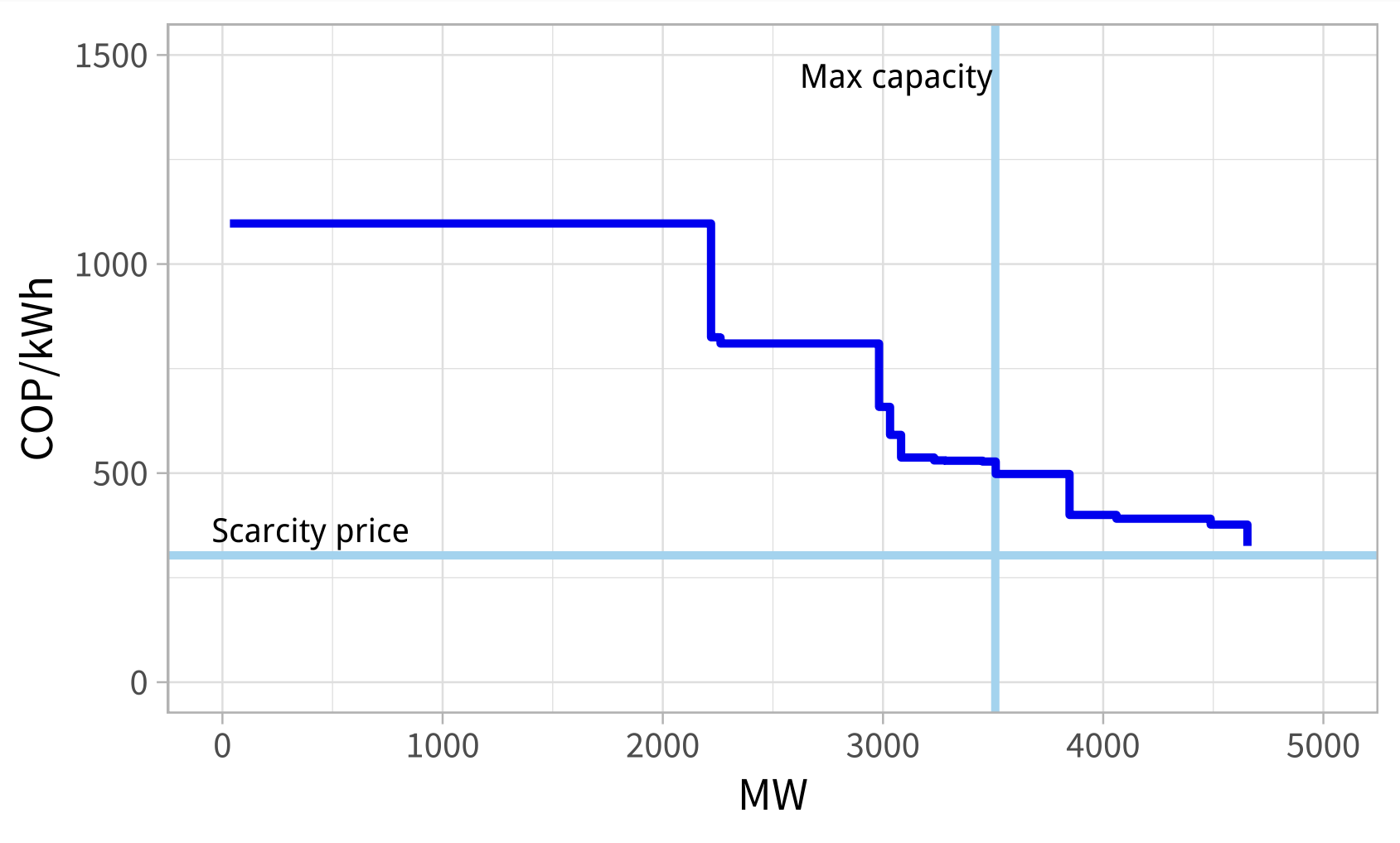
- We calculate the residual demand for each firm and hour
  - Market demand, less the bids of all other firms
- Firms can choose combinations of price and quantity along their residual demand curve
- Firms do not observe their residual demand at the time they submit their price and quantity bids

When residual demand lies below the scarcity price, generator does not have ability to create scarcity condition



Residual demand for EPM on 25 July 2015, at 6:00 PM.

When residual demand lies completely above the scarcity price, scarcity condition will occur for any generation quantity

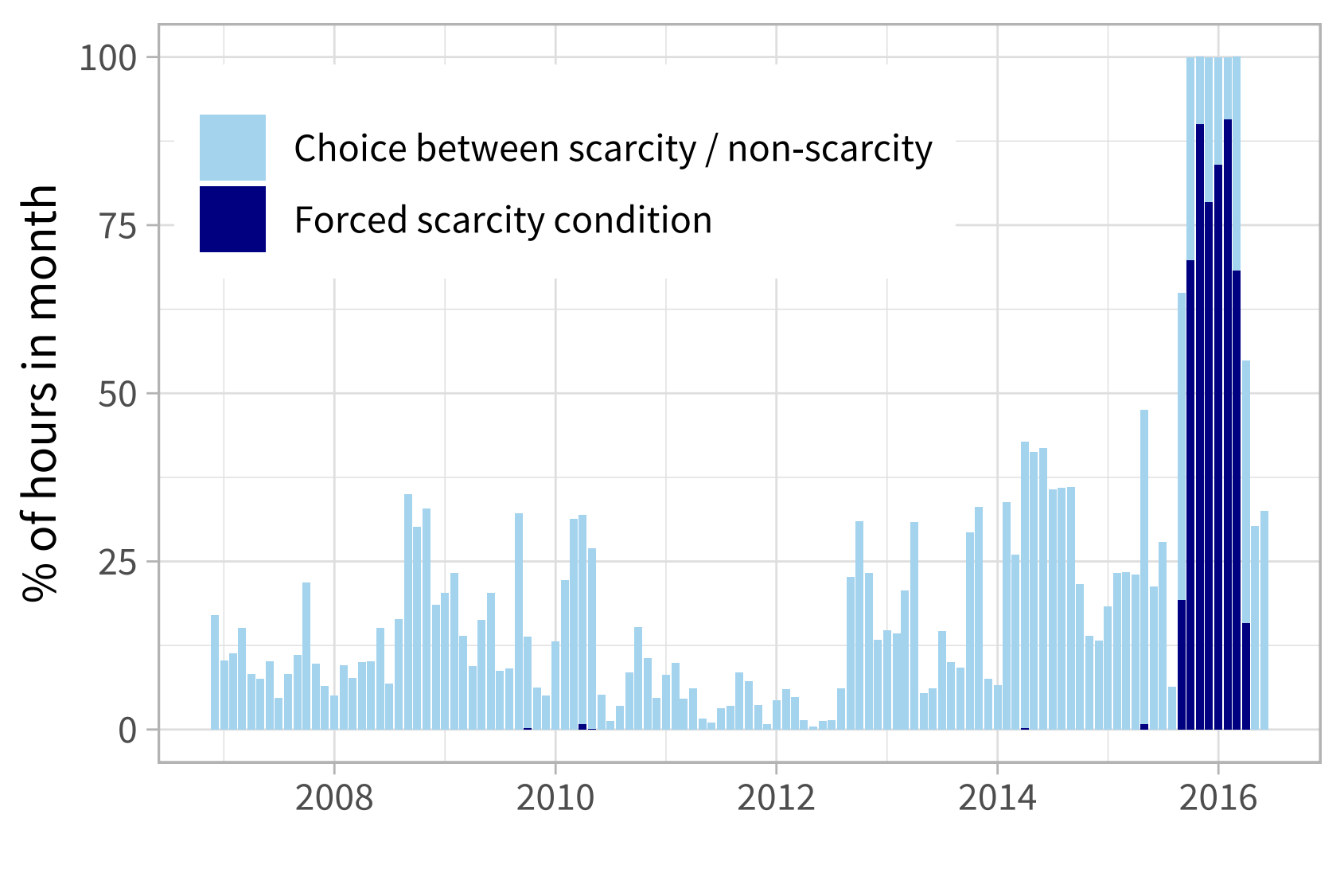


Residual demand for EPM on 25 November 2015, at 6:00 PM.

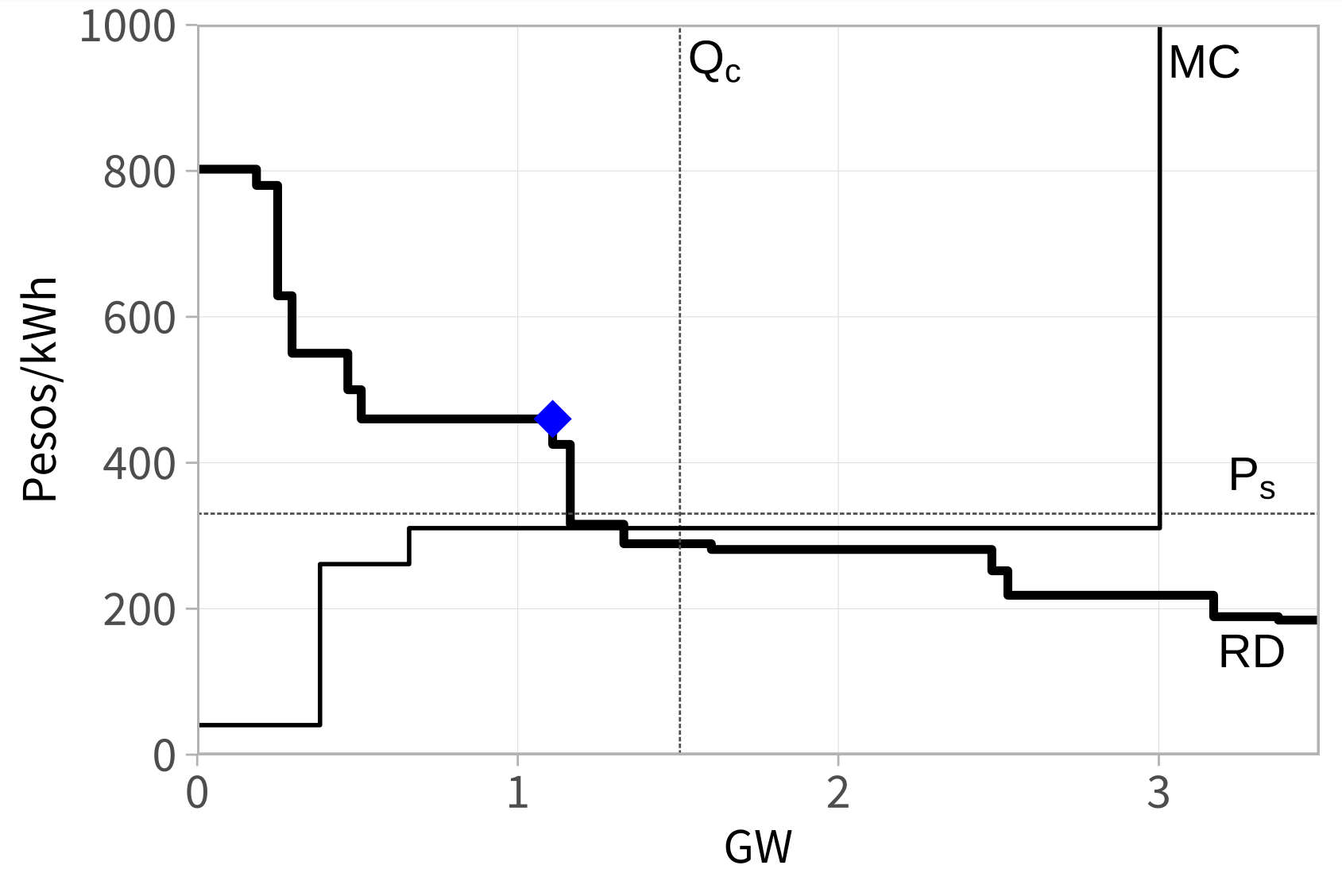
When residual demand crosses the scarcity price, then the firm can choose to induce scarcity condition or not

Residual demand for EPM on 25 May 2015, at 6:00 PM.

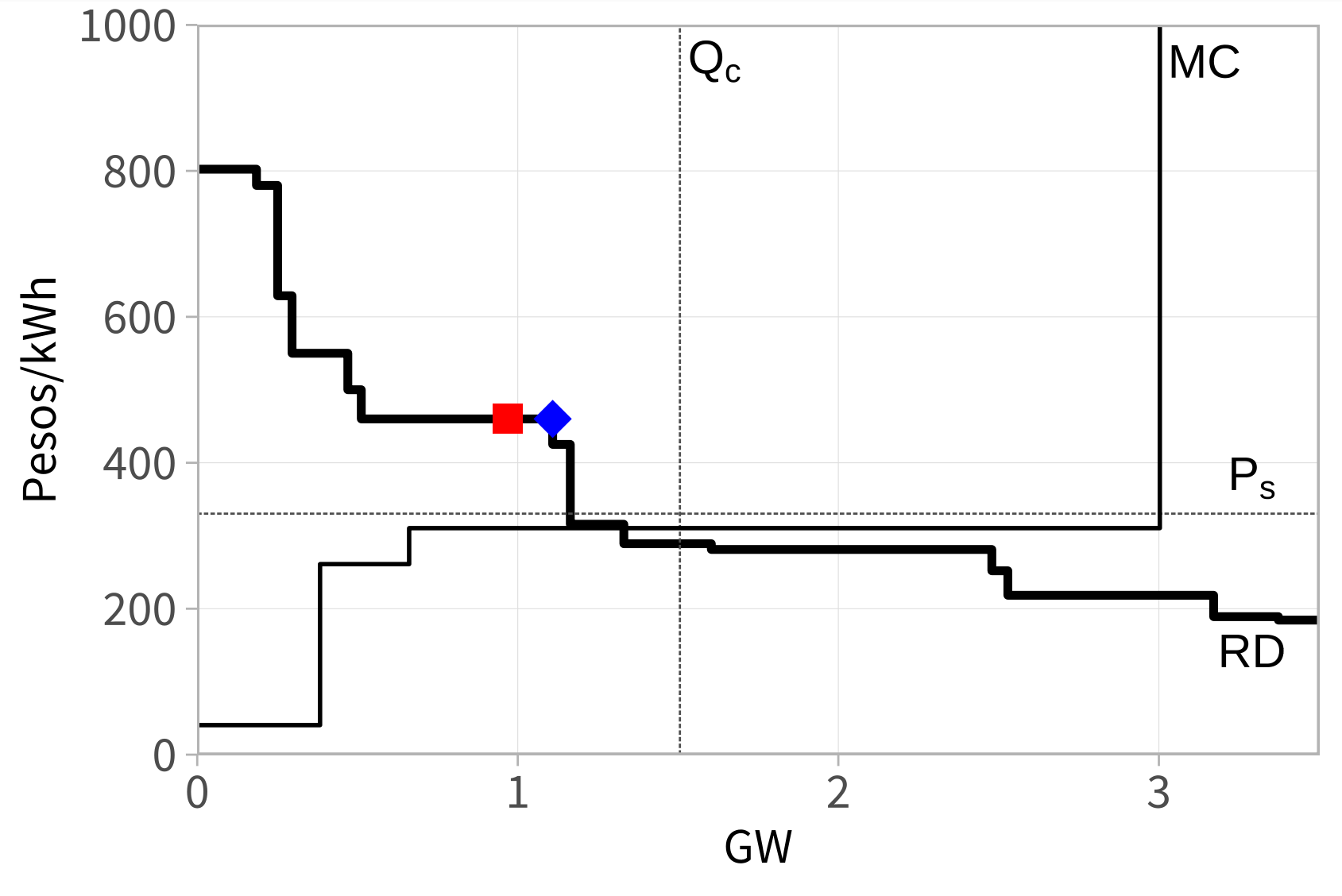
For EPM, in 16% of hours in the sample it had the ability to choose between scarcity and non-scarcity



In this hour, profits for Isagen would be maximized by restricting generation below Q_c and inducing scarcity condition



Actual generation for Isagen in this hour was below Q_c and the price was above the scarcity price

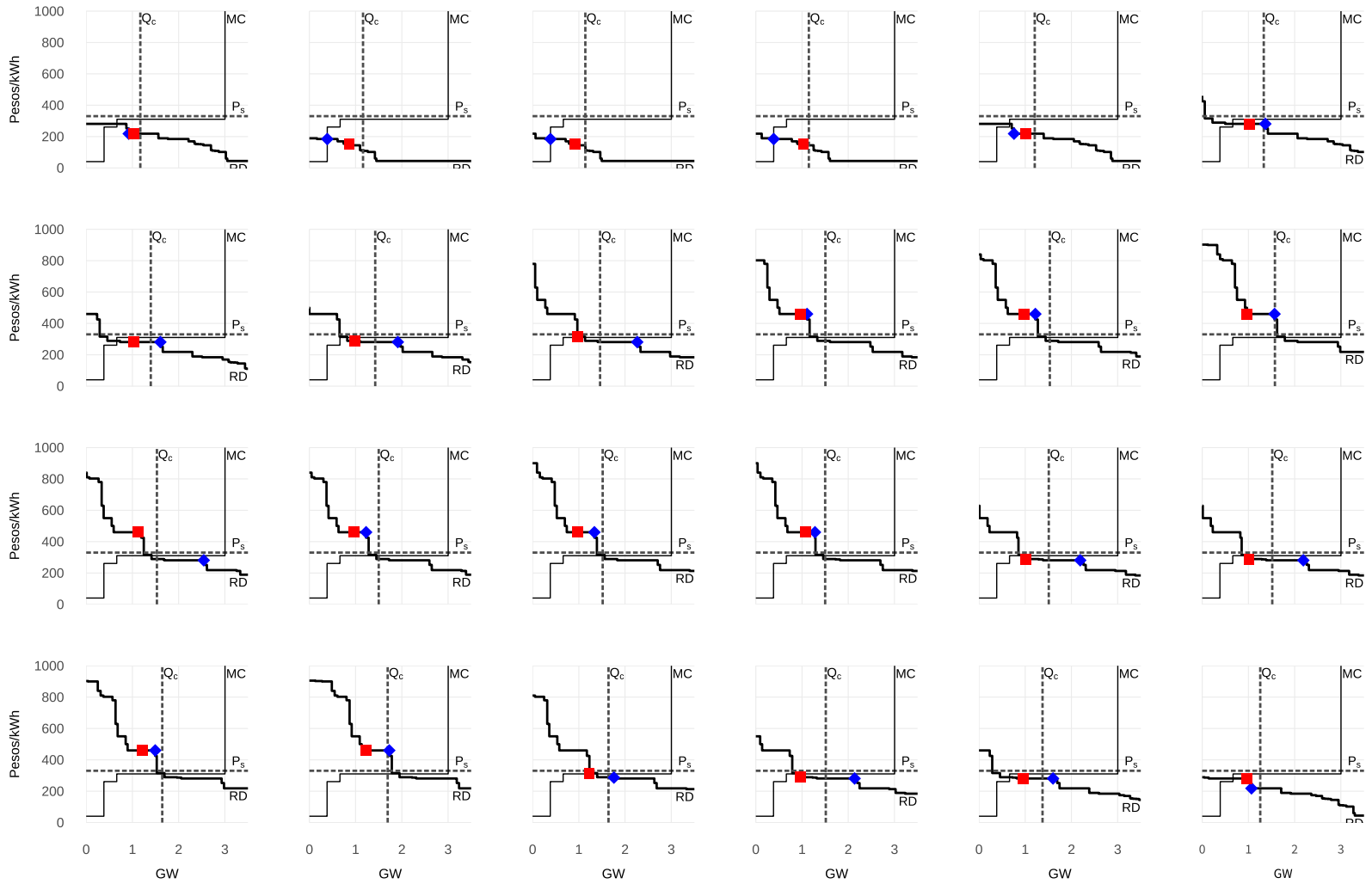


We repeat this analysis for the three major firms over the ten-year period from December 2006 to June 2016

Two complications for determining optimal best reply:

1. Net firm energy position is determined at a daily level based on total generation and daily firm energy
    - Firm energy obligation affected by generation in every hour (both scarcity and non-scarcity)
    - We solve simultaneously for the optimal generation in every hour of the day using a variant on the Nelder-Mead algorithm

Solve simultaneously for profit-maximizing quantity in each hour of the day, accounting for calculation of firm energy refunds

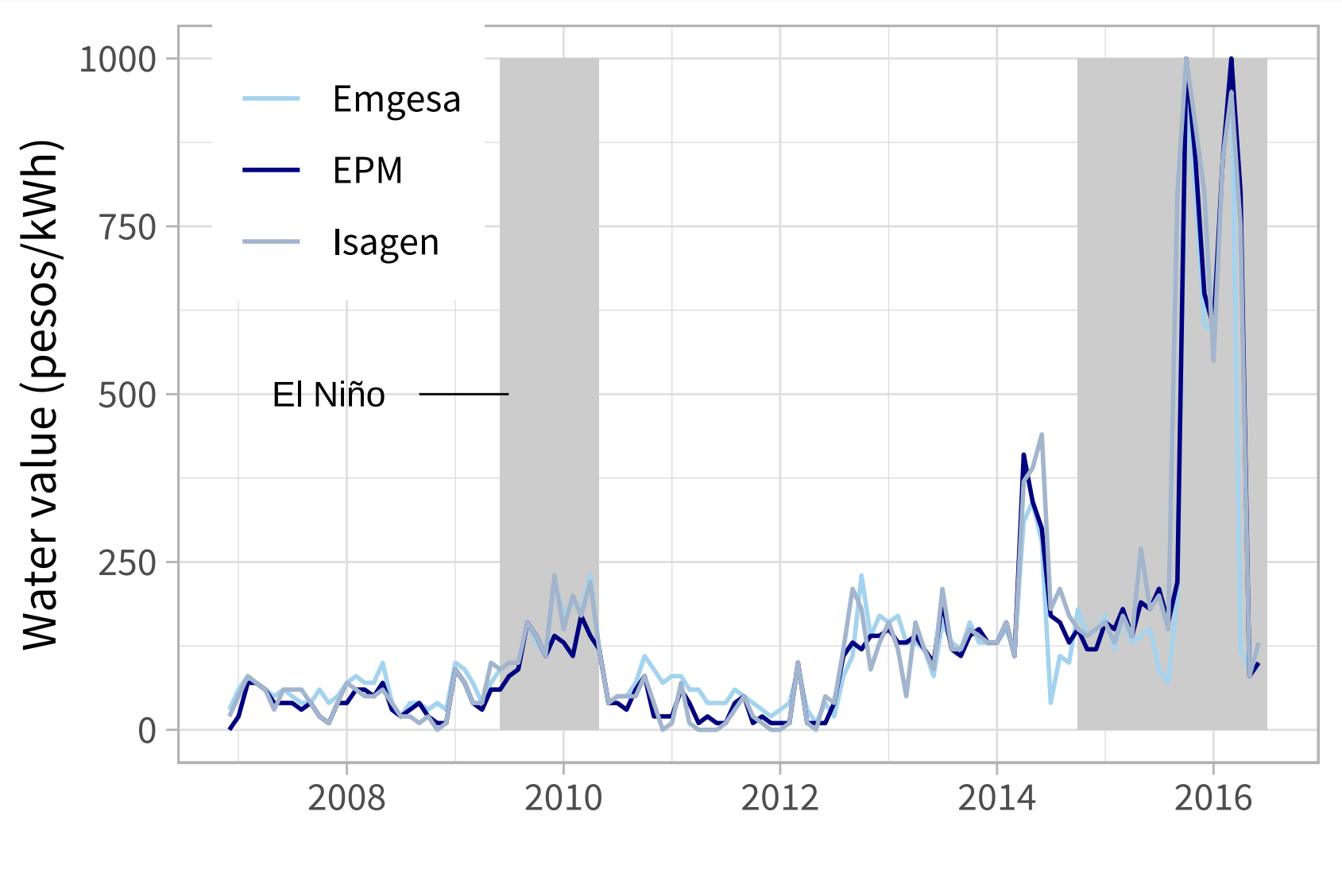


We repeat this analysis for the three major firms over the ten-year period from December 2006 to June 2016

Two complications for determining optimal best reply:

2. We observe the thermal generation cost but not the opportunity cost of water for hydro generation
    - Solve the daily problem for a grid of water values
    - For each month and firm, pick the water value that minimizes the squared deviation between actual and optimal hydro and thermal generation

Monthly opportunity cost of water is highest during drought conditions and in periods with unusually low reservoir levels



Optimal choice for the firm between scarcity and non-scarcity periods predicts the observed market outcomes

- Focus on the hours when generators can choose to trigger the scarcity condition
- For EPM: 1,274 hours when choosing scarcity was **optimal**

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    - Scarcity condition triggered in **90.1%** of these

Optimal choice for the firm between scarcity and non-scarcity periods predicts the observed market outcomes

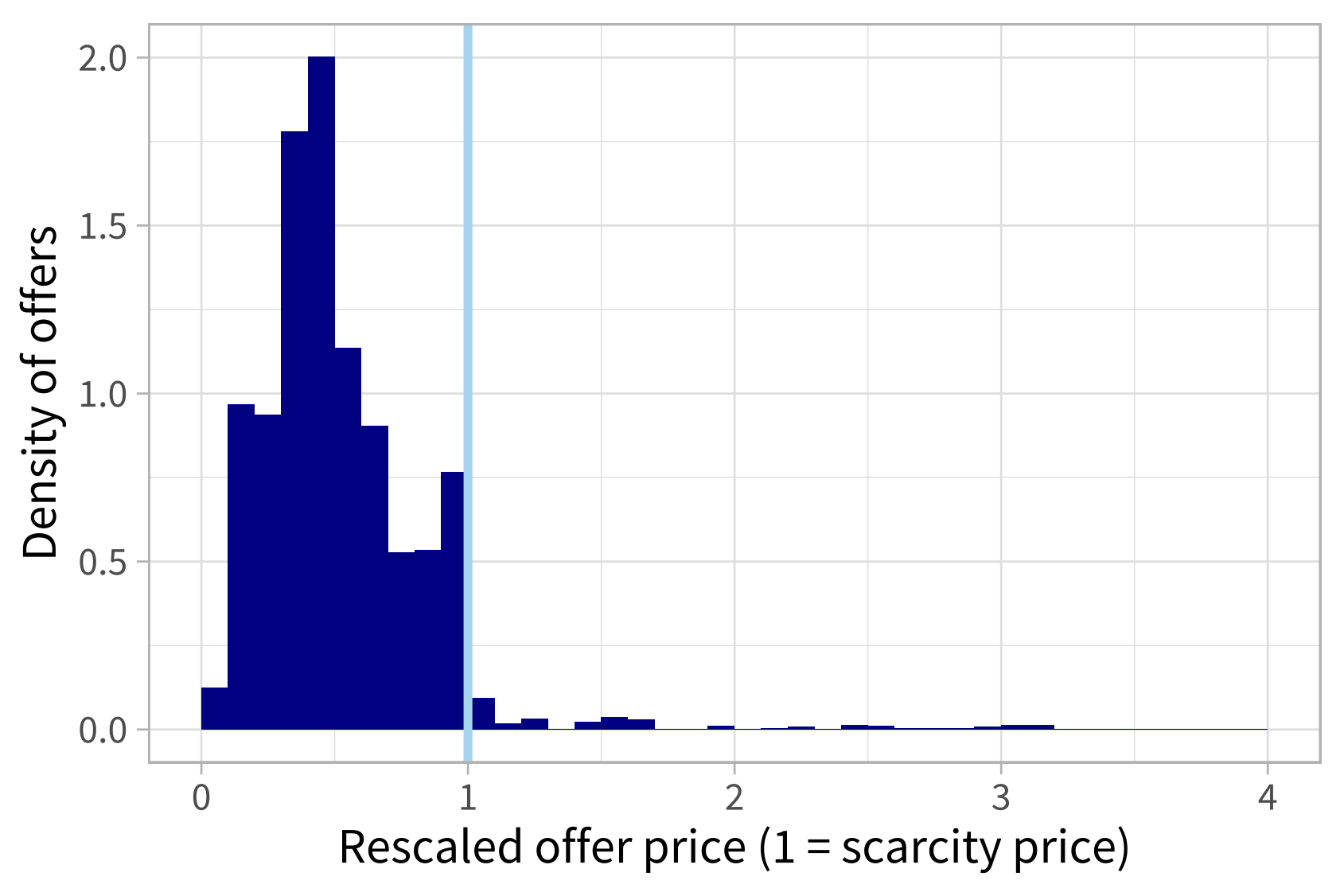
- Focus on the hours when generators can choose to trigger the scarcity condition
- For EPM: 1,274 hours when choosing scarcity was **optimal**
  - Scarcity condition triggered in **90.1%** of these
- For EPM: 12,301 hours when scarcity was **not optimal**

Optimal choice for the firm between scarcity and non-scarcity periods predicts the observed market outcomes

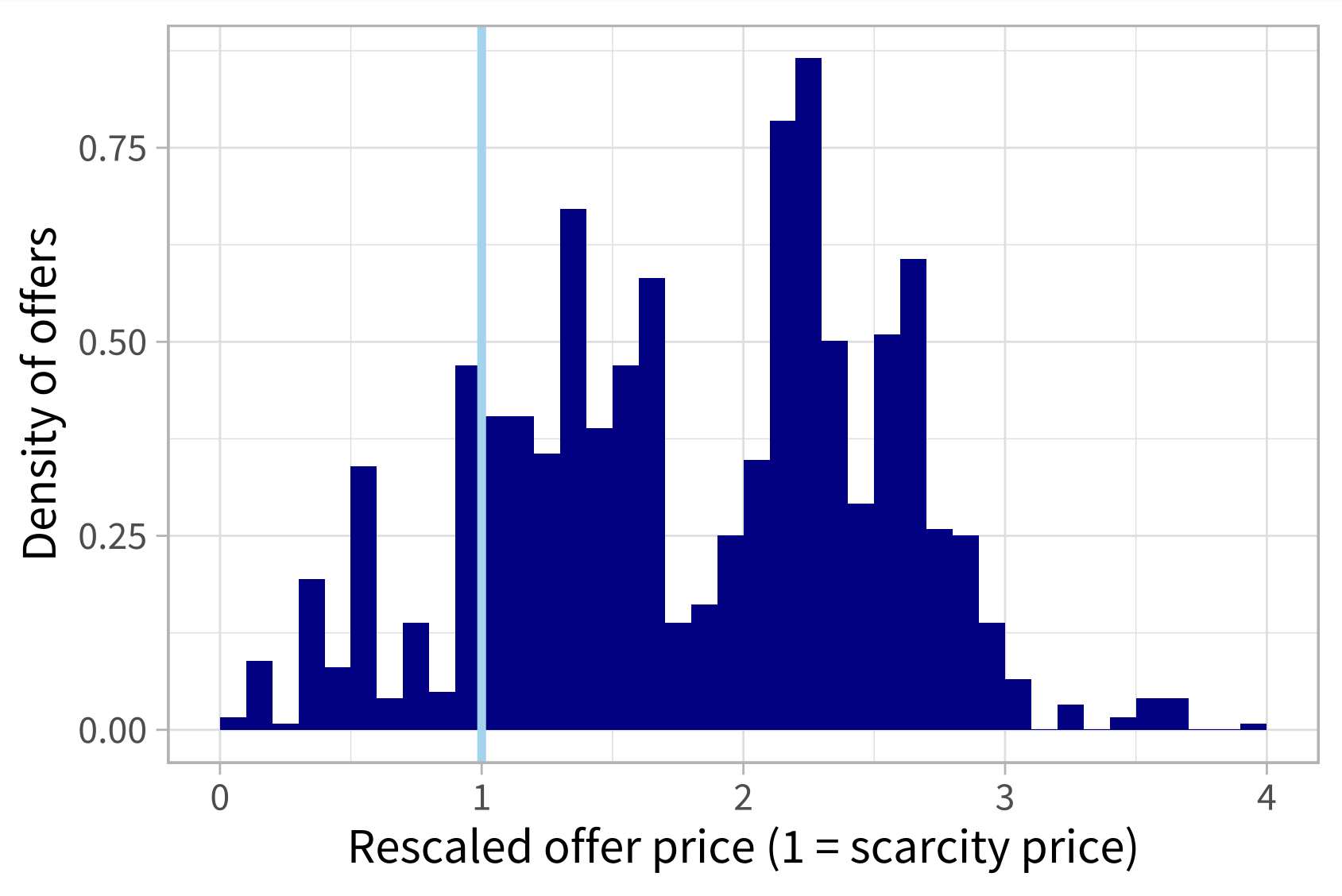
- Focus on the hours when generators can choose to trigger the scarcity condition
- For EPM: 1,274 hours when choosing scarcity was **optimal**
  - Scarcity condition triggered in **90.1%** of these
- For EPM: 12,301 hours when scarcity was **not optimal**
  - Scarcity condition was **not** triggered in **97.6%** of these
- We see similar results for Isagen and Emgesa
- Note that the firms **do not observe** their residual demand at the time they are making their price and quantity bids

Do the firms bid differently on the days when it would be optimal for them not to trigger the scarcity condition?

For hours when non-scarcity is optimal, highest accepted generation price offers for EPM bunch below scarcity price



For hours when scarcity is optimal, highest accepted generation price offers for EPM lie above scarcity price

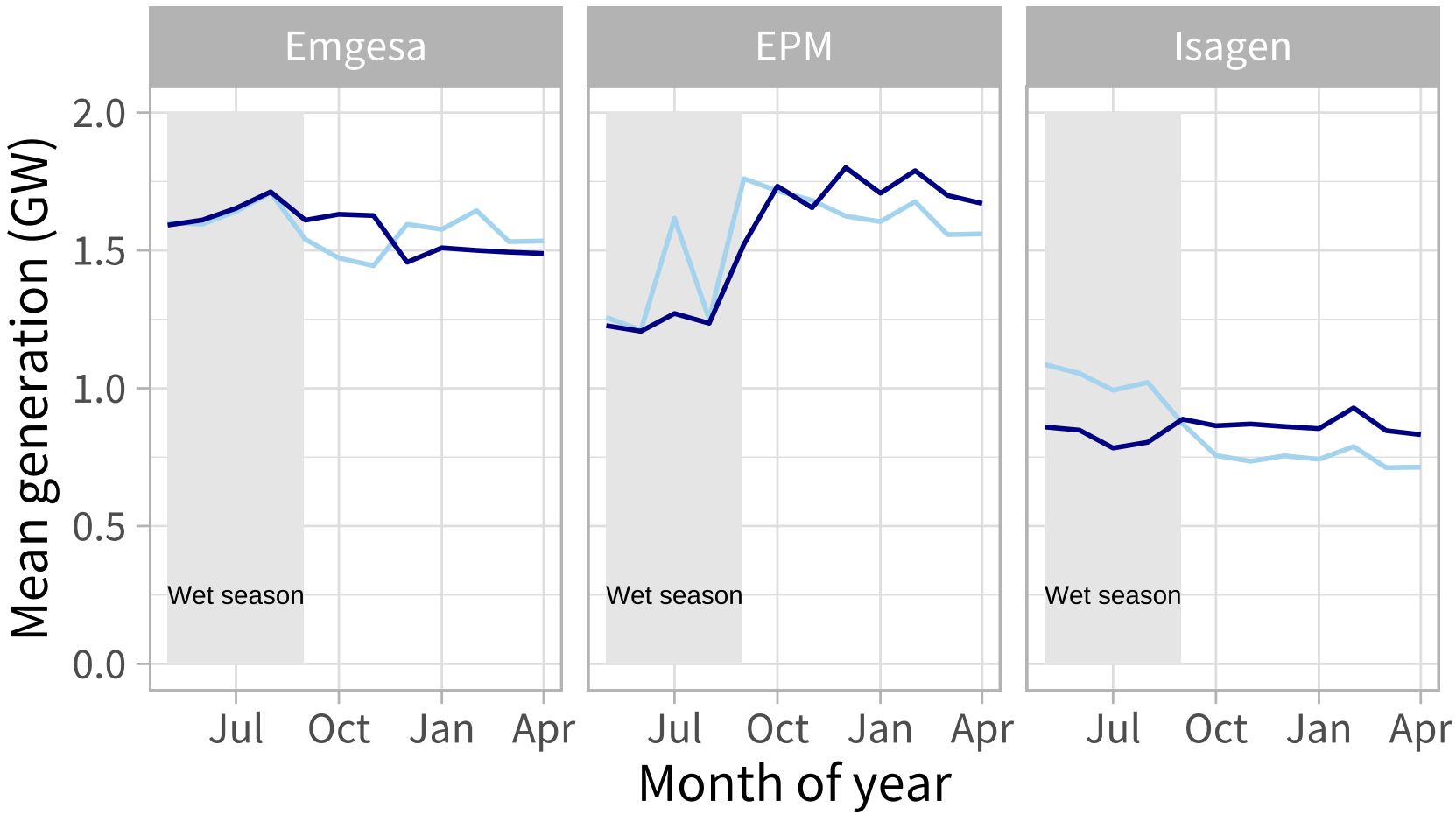


How does the firm energy mechanism affect market outcomes?

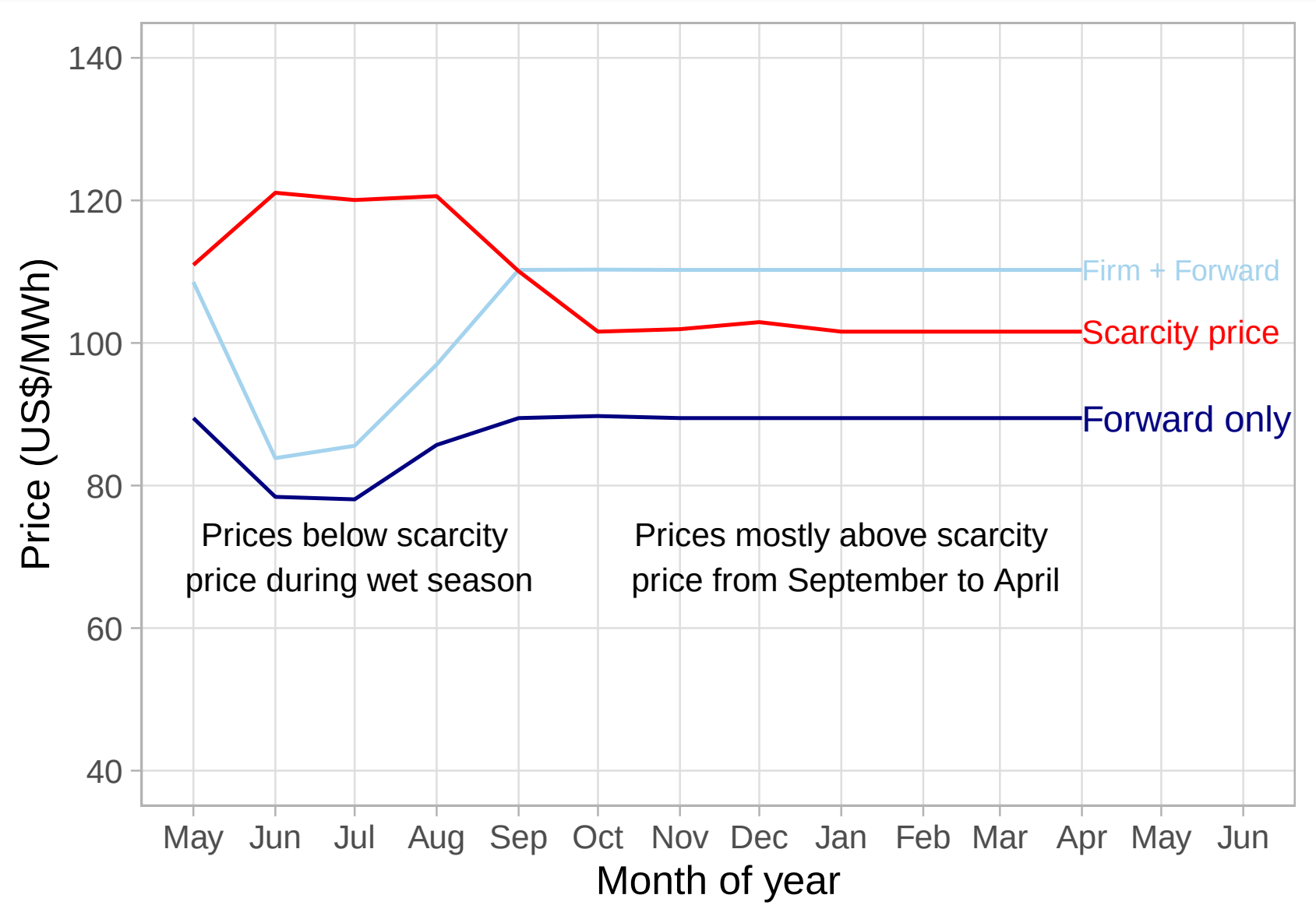
We simulate a counterfactual world without the firm energy mechanism to show why this matters

- Our analysis of the bidding and generation data show that the firms respond to the incentives created by the mechanism
- But we do not know what outcomes would look like in the absence of the firm energy mechanism
- We construct a simplified model of the Colombian market over a one-year period to compare two sets of outcomes:
  - Existing market structure with forward contracts and firm energy
  - Counterfactual market structure with only forward contracts
- Model is based on the three large firms choosing an optimal allocation of their scarce hydro resources (Bushnell, 2003)

With the firm energy mechanism, firms restrict generation in shortage periods when their residual demands are steepest



Wholesale prices are lower for the counterfactual without firm energy, mostly due to removal of firm energy charge



Hydro and thermal generation resources used more efficiently in the counterfactual simulation without firm energy

	Firm + Forward	Forward only
Mean price (US$/MWh)	104.73	87.30
Max hydro storage	80%	86%
Max thermal generation (GW)	1.54	1.49

- Firm energy mechanism creates incentive for hydro operators to save less water during wet season
  - Lower storage raises the risk of a supply shortfall
  - More expensive thermal units are required to run during the dry season

What is an alternative to the firm energy mechanism?

Do forward contracts provide an alternative to meet the objectives of the firm energy mechanism?

- Three objectives of the firm energy mechanism (Fabra, 2018):
  1. Provide incentives to invest in generation
  2. Mitigate market power
  3. Provide incentives for plants to be available
- We saw that **forward contracts** already achieve (2) and (3)
  - Results suggest that combination of firm energy with forward contracts performs worse than forward contracts alone

Can forward contracting mechanism be adjusted to provide incentives for generation investment?

- Existing forward contracts are signed months to (at most) one or two years in advance
  - This does not give enough time to bring new generation resources on line
- Regulators could mandate that retailers purchase forward contracts **three to five years** in advance
  - This would provide wholesale price certainty for consumers and a revenue stream for generators
  - Sufficient time to build new generation units if required
- McRae and Wolak (2016) and Wolak (2020) provide additional details about our proposed mechanism

Concluding remarks

Details of market design matter a lot in a setting where firms have substantial market power

- Firm energy mechanism is regarded as the best-practice design for capacity markets
- We show that firm energy can interact with existing forward contracts to **reduce** generation availability
- Generation firms in the longest-running firm energy market recognize and respond to these incentives
- Firm energy may lead to higher prices, higher generation costs, and lower reliability in markets with intermittent renewables
- Modifications to the forward contracting mechanism could achieve the same objectives at a lower cost

Thank you!