# The Costs of Counterparty Risk in Long Term Contracts
# Code Guide - Section 8

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## Overview

The purpose of this analysis is to compare and quantify the economic and welfare impacts of different contracting schemes for renewable energy investments, specifically focusing on:

> **Regulator-Backed Contracts (RBC):** Contracts where a public entity (the regulator) guarantees the purchase of a certain quantity of renewable energy at a regulated price, thereby reducing risk for producers.

## Contents

# 1 Modeling Markets With Regulator-backed Contracts (RBC)

## 1.1 Conceptual Approach

We consider a renewable energy market with a **fixed total contract demand** of

$$\theta = 5000 \text{ MW}$$

split evenly between two contracting schemes:

$$\theta_{\text{private}} = 2500 \text{ MW} \quad \text{and} \quad \theta_{\text{RBC}} = 2500 \text{ MW}.$$

## 1.2 Numerical Methods

### 1.2.1 Objective

The goal is to understand how this division of demand between private PPAs and regulator-backed contracts (RBCs) influences investment decisions, contract prices, and overall welfare in the renewable energy sector.
We will finally compare RBC cases with other scenarios (public guarantees/subsidies schemes, baseline, *etc.*).

### 1.2.2 Methodology and Implementation

```
wind_solar_proj_2022_rbc_raw <- wind_solar_proj_2022 |>
  crossing(gamma = gamma_values) |>
  rowwise() |>
  mutate(
    # f_c_cpr --> find_f_root
    f_c_cpr = coalesce(
      find_f_root(q_i = q_i_mwh,
                  x = x,
                  gamma = gamma,
                  r_0 = r_0,
                  alpha = alpha,
                  beta = beta,
                  total_costs = total_cost,
                  T_values = 0),
      1),

    # f_spot_cpr : Pi_S - Pi_S0 = 0
    f_spot_cpr = coalesce(
      find_f_spot_root(q_i = q_i_mwh,
                       x = x,
                       gamma = gamma,
                       r_0 = r_0,
                       alpha = alpha,
                       beta = beta,
                       total_costs = total_cost,
                       expected_p = expected_p,
                       r = r,
                       T_values = 0),
      0),
    # f_upper_cpr : for \Pi_S that cross \Pi_S = 0 two times, find the
       second root.
    f_upper =
      find_upper_root(q_i = q_i_mwh,
                      x = x,
                      gamma = gamma,
                      r_0 = r_0,
                      alpha = alpha,
                      beta = beta,
                      total_costs = total_cost,
                      T_values = 0)
  ) |>
  ungroup() |>
  mutate(f_upper_message = if_else(
    !is.na(f_upper),
    if_else(f_upper > expected_p, "f_upper > E(p)", "f_upper <= E(p)"),
```

```
    NA_character_
  ),
  f_max_cpr = pmax(f_c_cpr, f_spot_cpr, na.rm = TRUE),
  xf_c_cpr = x * f_c_cpr,
  xf_spot_cpr = x * f_spot_cpr,
  xf_upper_cpr = x * f_upper,
  xf_max_cpr = x * f_max_cpr
  )

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc_raw |>
  arrange(gamma, xf_max_cpr) |>
  group_by(gamma) |>
  mutate(cumulative_production = cumsum(q_i_mwh),
         cumulative_capacity = cumsum(capacity),
         x_q_exp_p_total_costs = x * expected_p * q_i_mwh - total_cost
  ) |>
  ungroup()

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  mutate(theta = total_contract_demand,
         theta_private = private_demand,
         theta_rbc = rbc_demand
         ) |>
  arrange(theta, xf_max_cpr, gamma)
```

The code chunk above should look familiar, as it is essentially identical to the one presented in Section 4 (*cf.* Section 4 for more details on the functions used). The only difference here is the introduction of three new variables, which will be important for the following analysis:

1. `theta`: The total contract demand ($\theta_{total} = \theta_{private} + \theta_{rbc}$), set to 5,000.
2. `theta_private`: The demand allocated to private contracts ($\theta_{private}$), set to 2,500.
3. `theta_rbc`: The demand allocated to regulator-backed contracts ($\theta_{rbc}$), also set to 2,500.

### 1.2.3 Equilibrium Prices Dataset Creation ($\theta_{total}$ & $\theta_{private}$)

In this section, we compute the equilibrium contract prices and quantities for $\theta_{total} = 5000$ & $\theta_{private} = 2500$ . As before, for each value of $\gamma$, we determine the market-clearing price $f^*$ and quantity $q^*$. Specifically, we use the function `compute_equilibrium_prices`.

After computing the equilibrium prices for both demand scenarios, we combine the results into a single dataset (`all_equilibria`) for comparison and further analysis. We then extract the equilibrium values specifically for the total contract demand scenario by filtering on `demand_label == "theta"` (which is $\theta_{total}$). This provides the equilibrium prices and associated quantities for the case where the entire contract demand is set to 5,000.
The relevant code is as follows:

```
## Equilibrium Prices Dataset Creation
   -----------------------------------

equilibrium_theta <- compute_equilibrium_prices(wind_solar_proj_2022_
   rbc, "theta", expected_p, x)

equilibrium_theta_private <- compute_equilibrium_prices(wind_solar_proj
   _2022_rbc, "theta_private", expected_p, x)

# Combine if needed
all_equilibria <- bind_rows(equilibrium_theta, equilibrium_theta_
   private)

all_equilibria <- all_equilibria %>%
  arrange(demand_label, demand_value, gamma)

# View results
print(all_equilibria)

equilibrium_prices <- all_equilibria %>%
  mutate(theta = demand_value) %>%
  filter(demand_label == "theta") %>%
  select(-demand_value)
```

### 1.2.4 Welfare Dataset Creation - $\theta_{total} = 5000$

```r
## Welfare Dataset Creation
    -----------------------------------------------

# Join theta = 5000 and respective equilibria prices and quantities
    with main
# dataset.
theta_equilibrium <- all_equilibria %>%
  filter(demand_label == "theta") %>%
  select(
    gamma,
    theta = demand_value,
    theta_equilibrium_price = equilibrium_price,
    theta_equilibrium_quantity = equilibrium_quantity
  )


wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  left_join(theta_equilibrium, by = c("gamma", "theta"))


wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  mutate(f_equilibrium = theta_equilibrium_price / x,
         xf_equilibrium = theta_equilibrium_price,
         equilibrium_quantity = theta_equilibrium_quantity
         ) |>
  select(-theta_equilibrium_price, -theta_equilibrium_quantity)


wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  group_by(gamma) |>
  rowwise() |>
  mutate(R_f_equilibrium_cpr =
           compute_R_value_gamma(f_equilibrium, gamma, q_i_mwh, x, r_0,
               alpha, beta)) |>
  ungroup() |>
  mutate(
    x_q_exp_p_total_costs_R = x * expected_p * q_i_mwh - total_cost
    - R_f_equilibrium_cpr
  )

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  mutate(
    profit_cpr_private_contracts =
      vectorized_pi_s(
        f = f_equilibrium,
        q_i = q_i_mwh,
        x = x,
        gamma = gamma,
        r_0 = r_0,
        alpha = alpha,
        beta = beta,
        total_costs = total_cost,
        T_values = 0
      )
  ) |>
```

```
  arrange(theta, gamma, xf_max_cpr)


ordered_vars <- c(
  "theta", "gamma", "f_c_cpr", "f_spot_cpr", "f_upper", "f_upper_message",
  "f_max_cpr", "f_equilibrium", "R_f_equilibrium_cpr",
  "xf_c_cpr", "xf_spot_cpr", "xf_upper_cpr", "xf_max_cpr", "xf_equilibrium",
  "equilibrium_quantity", "x_q_exp_p_total_costs", "x_q_exp_p_total_costs_R",
  "cumulative_production", "cumulative_capacity", "profit_cpr_private_contracts"
)

# Reorder dataframe
wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  select(
    everything(),              # Keeps all variables in current order...
    -all_of(ordered_vars),     # ...but temporarily removes the ones you want to reorder
    -profits_sp_no_cpr,                # temporarily remove chosen_xf to place it explicitly
    profits_sp_no_cpr,                 # put chosen_xf in place
    all_of(ordered_vars)       # then add ordered vars in the desired order
  )

# STEP 1: Compute W^0 for gamma == 0
W_0_df <- wind_solar_proj_2022_rbc |>
  filter(gamma == 0, profits_sp_no_cpr >= 0) |>
  group_by(theta) |>
  summarise(W_0 = sum(x_q_exp_p_total_costs - r, na.rm = TRUE), .groups = "drop")

# STEP 2: Compute W(gamma) for each gamma
W_gamma_df <- wind_solar_proj_2022_rbc |>
  group_by(gamma, theta) |>
  summarise(
    welfare_gamma_eur = sum(
      if_else(xf_max_cpr <= xf_equilibrium & cumulative_capacity < equilibrium_quantity,
              x_q_exp_p_total_costs_R, 0),
      na.rm = TRUE
    )
  ) |>
  ungroup()

# STEP 3: Compute W(gamma) for each gamma == 0
W_gamma_0_df <- W_gamma_df %>%
  filter(gamma == 0) %>%
  rename(welfare_0_eur = welfare_gamma_eur) %>%
  select(theta, welfare_0_eur)


# STEP 4: Equilibrium prices for gamma == 0
```

```
eq_gamma_0 <- equilibrium_prices %>%
  filter(gamma == 0) %>%
  select(theta,
         equilibrium_quantity_gamma_0 = equilibrium_quantity,
         equilibrium_price_gamma_0 = equilibrium_price)


# STEP 5: Combine all metrics into one final table

welfare_dataset_wo_rbc_5000 <- equilibrium_prices |>
  left_join(W_gamma_df, by = c("gamma", "theta")) |>
  left_join(W_gamma_0_df, by = "theta") |>
  left_join(W_0_df, by = "theta") |>
  left_join(eq_gamma_0, by = "theta") |>
  mutate(
    eq_price = equilibrium_price,
    eq_quantity = equilibrium_quantity,

    welfare_ratio_percent       = (welfare_gamma_eur / welfare_0_eur) *
       100,
    welfare_gap_million_eur     = (welfare_0_eur - welfare_gamma_eur) /
       1e6,
    welfare_gain_million_eur    = (welfare_gamma_eur - W_0) / 1e6,

    eq_quantity_ratio_percent   = (eq_quantity / equilibrium_quantity_
       gamma_0) * 100,
    eq_price_ratio_percent      = (eq_price / equilibrium_price_gamma_0)
       * 100,

    W_0 = if_else(gamma == 0, W_0, NA_real_)  # Keep only at gamma = 0
       if needed
  ) |>
  select(
    gamma, theta,
    eq_price, eq_price_ratio_percent,
    eq_quantity, eq_quantity_ratio_percent,
    W_0, welfare_gamma_eur, welfare_ratio_percent,
    welfare_gap_million_eur, welfare_gain_million_eur
  ) |>
  arrange(theta, gamma)

welfare_dataset_wo_rbc_5000
```

In this section, we construct a comprehensive dataset that summarizes equilibrium prices, quantities, and welfare metrics for the scenario where the total contract demand is $\theta_{total} = 5000$, so without regulator-backed contracts. The steps are as follows:

1. **Join Equilibrium Prices and Quantities:**
   We merge the equilibrium prices and quantities (previously computed for $\theta_{total} = 5000$) with the main project dataset. This allows each project to be associated with the relevant market-clearing price and quantity for its value of $\gamma$.

2. **Compute Project-Level Equilibrium Variables:**
   For each project, we calculate:

   - The equilibrium contract price per contracted unit (`f_equilibrium`).
   - The equilibrium contract price scaled by $x$ (`xf_equilibrium`).

- The equilibrium quantity (`equilibrium_quantity`).
- The risk adjustment at the equilibrium price (`R_f_equilibrium_cpr`).
- The risk-adjusted net value (`x_q_exp_p_total_costs_R`).
- The risk-adjusted profit at the equilibrium price (`profit_cpr_private_contracts`).

3. **Reorder Dataset for Clarity:**
   The variables are reordered to facilitate subsequent analysis and reporting.

4. **Aggregate Welfare Computations:**

   - **Step 1:** Compute baseline welfare $W^0$ for the risk-neutral case ($\gamma = 0$), summing the net value of all profitable projects in the spot market.
   - **Step 2:** For each $\gamma$, compute total welfare $W(\gamma)$ by summing the risk-adjusted net value of all projects that are viable at the equilibrium price and within the equilibrium quantity.
   - **Step 3:** Extract $W(\gamma)$ for $\gamma = 0$ for later comparison.
   - **Step 4:** Extract equilibrium prices and quantities for $\gamma = 0$.

5. **Combine All Metrics:**
   We merge all computed metrics into a single summary table, `welfare_dataset_wo_rbc_5000`, which includes:

   - $\gamma$, $\theta$ (respectively opportunistic buyers and total demand)
   - Equilibrium price and quantity (and their ratios to the $\gamma = 0$ case)
   - Welfare $W(\gamma)$ and $W^0$
   - Welfare ratios and gaps (in percentage and million euros)

### 1.2.5 Profits Calculation

```
## Profits -----------------------------------

# Profits by gamma and theta

profits_by_gamma_theta_wo_rbc_5000 <- wind_solar_proj_2022_rbc |>
  group_by(gamma, theta) |>
  filter(xf_max_cpr <= xf_equilibrium & cumulative_capacity <
      equilibrium_quantity) |>
  summarise(
    seller_profits_eur  = sum(profit_cpr_private_contracts, na.rm =
       TRUE),
    .groups = "drop"
  ) |>
  ungroup() |>
  arrange(theta, gamma, seller_profits_eur)

profits_by_gamma_theta_wo_rbc_5000 <- profits_by_gamma_theta_wo_rbc_
    5000 |>
  left_join(welfare_dataset_wo_rbc_5000 |>
              select(gamma, theta, welfare_gamma_eur),
            by = c("gamma", "theta")) |>
  mutate(buyer_profits_eur = welfare_gamma_eur - seller_profits_eur) |>
  select(-welfare_gamma_eur)

welfare_with_profits <- welfare_dataset_wo_rbc_5000 %>%
  left_join(profits_by_gamma_theta_wo_rbc_5000, by = c("gamma", "theta"
     ))


welfare_with_profits <- welfare_with_profits %>%
  mutate(
    seller_profit_share_percent = round(
      (seller_profits_eur / welfare_gamma_eur) * 100, 2),
    buyer_profit_share_percent = round(
      (buyer_profits_eur / welfare_gamma_eur) * 100, 2),
  ) |>
  select(gamma, theta, seller_profits_eur,
         buyer_profits_eur, seller_profit_share_percent, buyer_profit_
            share_percent, welfare_gamma_eur) |>
  arrange(theta, gamma)
```

In this section, we compute and decompose the total welfare into seller and buyer profits for each value of $\gamma$ and for the fixed contract demand $\theta_{total} = 5000$.

1. **Compute Seller Profits:**
   For each combination of $\gamma$ and $\theta$, we sum (`profit_cpr_private_contracts`) for all plants that are viable at the equilibrium price and included within the equilibrium quantity. This gives the total profits accruing to sellers:

   where the selected projects satisfy as usual:

$$xf_{\max} \leq xf^* \quad \text{and} \quad \text{cumulative capacity} < \text{equilibrium quantity}$$

2. **Compute Buyer Profits:**
   We then merge the seller profits with the previously computed welfare for each $(\gamma, \theta)$

pair. The buyer profits are calculated as the difference between total welfare and seller profits:

$$\text{buyer\_profits\_eur} = \text{welfare\_gamma\_eur} - \text{seller\_profits\_eur}$$

This represents the surplus accruing to buyers (offtakers or the market/regulator).

3. **Calculate Profit Shares:**
For each $(\gamma, \theta)$, we compute the share of welfare going to sellers and buyers, respectively:

$$\text{seller\_profit\_share\_percent} = 100 \times \frac{\text{seller\_profits\_eur}}{\text{welfare\_gamma\_eur}}$$

$$\text{buyer\_profit\_share\_percent} = 100 \times \frac{\text{buyer\_profits\_eur}}{\text{welfare\_gamma\_eur}}$$

4. **Final Dataset:**
The final table (`welfare_with_profits`) summarizes, for each $(\gamma, \theta)$:

- Seller profits (in euros)
- Buyer profits (in euros)
- Seller and buyer profit shares (as percentages of total welfare)
- Total welfare

### 1.2.6 Exporting Results to Excel Workbook

```
# Save this in a separate workbook, for clarity
# Save everything

# Extract theta value
theta_value <- wind_solar_proj_2022_rbc$theta[1]

# Construct dynamic filename and output path
excel_filename_rbc <- paste0("01_wind_solar_projects_wo_rbc_theta_",
   theta_value, ".xlsx")
output_path_rbc <- file.path(with_rbc_path, excel_filename_rbc)

# Define dataset list
datasets_rbc <- list(
  `Wind_Solar_Projects`      = wind_solar_proj_2022_rbc,
  `Equilibrium P. & Q.`      = theta_equilibrium,
  `Welfare`                  = welfare_dataset_wo_rbc_5000,
  `Profits`                  = welfare_with_profits
)

# Filter all datasets by selected gamma values
filtered_rbc <- lapply(datasets_rbc, filter_by_gamma)

# Create workbook
wb_rbc <- createWorkbook()

# Add sheets dynamically
for (sheet in names(filtered_rbc)) {
  addWorksheet(wb_rbc, sheet)
  freezePane(wb_rbc, sheet, firstActiveRow = 2, firstActiveCol = 2)
  writeData(wb_rbc, sheet = sheet, x = filtered_rbc[[sheet]])
}

# Save workbook
saveWorkbook(wb_rbc, file = output_path_rbc, overwrite = TRUE)
```

In this final step, we export all key datasets to a single, well-organized Excel workbook for clarity and ease of analysis. The process is as follows:

1. **Dynamic File Naming:**
   We extract the value of the total contract demand (`theta`) from the dataset and use it to construct a descriptive filename (e.g., `01_wind_solar_projects_wo_rbc_theta_5000.xlsx`). This ensures that the output file is clearly labeled according to its scenario.

2. **Dataset Compilation:**
   We gather all relevant datasets into a named list, where each element will become a separate sheet in the Excel workbook:

   - `Wind_Solar_Projects`: The main dataset with all project-level variables.
   - `Equilibrium P. & Q.`: The equilibrium prices and quantities for $\theta_{total} = 5000$.
   - `Welfare`: The summary table of welfare metrics.
   - `Profits`: The table showing the breakdown of seller and buyer profits.

3. **Filtering by Gamma:**
   Each dataset is filtered to include only the selected values of the risk aversion parameter $\gamma$, ensuring that the exported results are focused and relevant.

4. **Workbook Creation and Sheet Organization:**
   We create a new Excel workbook and add each filtered dataset as a separate worksheet. For readability, panes are frozen at the top-left of each sheet.

5. **Saving the Workbook:**
   The completed workbook is saved to the specified output path, making all results easily accessible for further analysis, sharing, or reporting.

### 1.2.7 Computation of $f^R$ (Regulator-Backed Contract Price)

```
## f^R Computation -------------------------

# First we compute the f_rbc for each plant.

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  mutate(
    winning_plant = xf_max_cpr <= xf_equilibrium & cumulative_capacity
       <= equilibrium_quantity
  ) %>%
  filter(winning_plant) |>
  select(-winning_plant) |>
  mutate(
    f_rbc = (profit_cpr_private_contracts + total_cost) / (q_i_mwh * x)
       ,
    xf_rbc = x * f_rbc,
    # We can create a variable here in order to check if the profits
       are the same
    # as in private market. They should be equal for every line
    profits_f_rbc = xf_rbc * q_i_mwh - total_cost
  ) %>%
  ungroup()


wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  arrange(gamma, f_rbc) |>
  group_by(gamma) |>
  mutate(cumulative_production = cumsum(q_i_mwh),
         cumulative_capacity = cumsum(capacity)
  ) |>
  ungroup()
```

```
### P & Q for theta RBC
   --------------------------------------------------
# Be careful, those are not the equilibrium prices and quantitities per
    se.
# We just want to figure out which ones have private contracts, and
   each ones
# have regulator-backed contracts with theta_rbc.
# We subsequently compute the equilibrium prices/quantities.

# 1. For each gamma, get the last row before theta_val (preserving
   cumulative capacity)
before_theta_rbc <- wind_solar_proj_2022_rbc %>%
  group_by(gamma) %>%
  arrange(cumulative_capacity) %>%
  filter(cumulative_capacity < theta_rbc,
         xf_rbc < threshold_price) %>%
  slice_tail(n = 1) %>%
  ungroup()

# 2. For each gamma, get the first row at or after theta_val (to peek
   at the next price)
after_theta_rbc <- wind_solar_proj_2022_rbc %>%
  group_by(gamma) %>%
  arrange(cumulative_capacity) %>%
  filter(cumulative_capacity >= theta_rbc) %>%
```

```r
  slice_head(n = 1) %>%
  select(gamma, next_price = xf_rbc) %>%
  ungroup()

# 3. Join the two and update the price:
#    - Keep the cumulative capacity from before_theta
#    - Update the price to threshold_price only if the next row's price
     is >= threshold_price.
equilibrium_prices <- before_theta_rbc %>%
  left_join(after_theta_rbc, by = "gamma") |>
  mutate(
    equilibrium_price = if_else(
      !is.na(next_price) & next_price >= threshold_price,
      threshold_price,
      next_price
    ),
    equilibrium_quantity = cumulative_capacity
  ) %>%
  select(gamma, equilibrium_quantity, equilibrium_price, theta, theta_
     rbc)



# View the combined results
print(equilibrium_prices)

equilibrium_prices <- equilibrium_prices |>
  arrange(theta, gamma) %>%
  rename(xf_rbc_equilibrium = equilibrium_price,
         quantity_rbc = equilibrium_quantity) |>
  mutate(f_rbc_equilibrium = xf_rbc_equilibrium / x)

# Get all unique theta values
theta_values <- sort(unique(equilibrium_prices$theta_rbc))

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc |>
  left_join(
    equilibrium_prices |>
      select(gamma, theta_rbc, xf_rbc_equilibrium, f_rbc_equilibrium,
         quantity_rbc),
    by = c("gamma", "theta_rbc")
  )
```

In this section, we determine the contract price $f^R$ that would prevail in a market segment where a regulator guarantees contracts for a fixed quantity of renewable capacity ($\theta_{\text{rbc}}$). The process is as follows:

1. **Identify Eligible Projects:**
   We first select the set of projects that are built under the equilibrium for the total contract demand $\theta_{total} = 5000$. These are projects for which:

   $$xf_{\max} \leq xf^* \quad \text{and} \quad \text{cumulative capacity} \leq \text{equilibrium quantity}$$

   This ensures we only consider projects that are competitive at the prevailing market-clearing price and within the contracted capacity.

2. **Compute Plant-Specific RBC Price:**
   For each selected plant, we compute the price that would exactly cover its costs and risk-adjusted profit:

$$f_i^R = \frac{\Pi_i^{\theta_{total}} + C(k_i)}{q_i x}, \tag{1}$$

where $\Pi_i^{\theta_{total}} = q_i x \left[\gamma \int_0^{f^*} p\phi(p)\, dp + f^* \cdot \left(1 - \gamma\Phi(f^*)\right)\right] - R_i(f^*, \gamma) - C(k_i)$.

We used $f^*$ obtained with $\theta_{total} = 5000$. Profits under RBC are given by:

$$\begin{aligned} \Pi_i^R &= x f_i^R \cdot q_i - C(k_i) \\ &= \cancel{q_i x} \cdot \frac{\Pi_i^{\theta_{total}} + \cancel{C(k_i)}}{\cancel{q_i x}} - \cancel{C(k_i)} \\ &\Rightarrow \Pi_i^R = \Pi_i^{\theta_{total}} \end{aligned} \tag{2}$$

Consequently, individual profits for each plant $i$ should be the same.

3. **Aggregate and Sort Projects:**
   Projects are then sorted by $f_i^R$ for each value of $\gamma$, and cumulative production and capacity are recalculated. This allows us to build a supply curve for the RBC market segment.

4. **Determine RBC Market Clearing Price and Quantity:**

   (a) For each $\gamma$, we identify the last project included before reaching the RBC demand threshold ($\theta_{\text{rbc}}$), and the first project at or above this threshold.

   (b) The equilibrium quantity is the cumulative capacity up to the threshold.

   This procedure mirrors a uniform-price auction, where the marginal project determines the clearing price.

5. **Attach RBC Equilibrium Results:**
   The computed RBC equilibrium price ($f_*^R$), and ($x f_*^R$), and equilibrium quantity ($\text{quantity}_{\text{rbc}}$) are then joined back to the main project dataset for further analysis.

### 1.2.8 Profits Computation for the Regulator-Backed Contract Equilibrium ($f_R^*$)

```
### Profits for f_R^* ------------------------------------

# Now we define the f* and q* for each gamma. It is the marginal just
    below
# the RBC demand 2500.

marginal_f_rbc <- wind_solar_proj_2022_rbc %>%
  group_by(gamma, theta_rbc) %>%
  arrange(cumulative_capacity, .by_group = TRUE) %>%  # Important: sort
      within each gamma/theta_rbc
  filter(cumulative_capacity == quantity_rbc) %>%
  ungroup() %>%
  select(gamma, theta_rbc, f_rbc_equilibrium, xf_rbc_equilibrium)

#
marginal_flags <- wind_solar_proj_2022_rbc %>%
  group_by(gamma, theta_rbc) %>%
  mutate(
    f_rbc_equilibrium = (profit_cpr_private_contracts + total_cost) / (
       x * q_i_mwh),
    xf_rbc_equilibrium = x * f_rbc_equilibrium
  ) %>%
  group_by(gamma) %>%
  filter(
    near(xf_rbc_equilibrium, xf_rbc),
    near(cumulative_capacity, quantity_rbc)
  ) %>%
  slice(1) %>%
  mutate(is_marginal = TRUE) %>%
  ungroup()

# Profits computation for RBC cases
wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  mutate(
    profit_f_rbc = (xf_rbc_equilibrium * q_i_mwh) - total_cost
  ) %>%
  relocate(f_rbc_equilibrium, .before = xf_rbc_equilibrium)


wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  left_join(
    select(marginal_flags, gamma, theta_rbc, cumulative_capacity, is_
       marginal),
    by = c("gamma", "theta_rbc", "cumulative_capacity")
  ) %>%
  mutate(
    is_marginal = if_else(is.na(is_marginal), FALSE, is_marginal),
    cumulative_cutoff_rbc = cumulative_capacity <= quantity_rbc & xf_
       rbc <= xf_rbc_equilibrium
  )

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  mutate(
    profits = case_when(
```

```
      xf_max_cpr <= xf_equilibrium & cumulative_cutoff_rbc ~ profit_f_rbc,
      xf_equilibrium & xf_rbc >= xf_rbc_equilibrium & cumulative_capacity <= theta ~ profit_cpr_private_contracts,
      TRUE ~ NA
    ),
    contract_type = case_when(
      xf_max_cpr <= xf_equilibrium & cumulative_cutoff_rbc ~ "Regulated",
      xf_max_cpr <= xf_equilibrium & xf_rbc >= xf_rbc_equilibrium & cumulative_capacity <= theta ~ "Private",
      TRUE ~ "No Private/Regulated"
    )
  ) |>
  arrange(theta_rbc, gamma, xf_rbc) |>
  select(-is_marginal, -cumulative_cutoff_rbc)

# Calculate cumulative sums for private contract only for further use
private_cumsum <- wind_solar_proj_2022_rbc %>%
  filter(contract_type == "Private") %>%
  arrange(theta_rbc, gamma, xf_rbc) %>%
  group_by(gamma, theta_rbc) %>%
  mutate(
    cumulative_capacity_private = cumsum(capacity),
    cumulative_production_private = cumsum(q_i_mwh)
  ) %>%
  ungroup() |>
  group_by(theta_rbc, gamma) |>
  summarise(eq_quantity_private = last(cumulative_capacity_private), .groups = "drop") |>
  ungroup() |>
  select(-theta_rbc)

# We should have that profits under Regulated scheme should be >= profits under Private scheme
# some floating errors, no worries to have. Everything is fine!
violations <- wind_solar_proj_2022_rbc %>%
  filter(
    contract_type == "Regulated",
    profit_f_rbc < profit_cpr_private_contracts
  )
```

This section computes the profits for each project under the regulator-backed contract (RBC) equilibrium price, denoted $f_R^*$, and compares these to the profits under private contracts. The steps are as follows:

1. **Identify the Marginal Project for RBC:**
    - For each value of risk aversion ($\gamma$), we identify the project whose cumulative capacity exactly matches the RBC demand ($\theta_{\text{rbc}}$). This project determines the marginal price and quantity for the RBC segment.
    - The equilibrium price $f_R^*$ is the break-even price for this marginal project.
2. **Flag Marginal Projects:**
    - Projects are flagged as marginal if their contract value and cumulative capacity are (numerically) equal to the equilibrium values. This ensures precise identification of the marginal project even in the presence of floating-point errors.

3. **Compute Profits under RBC:**

   - For each project, we compute the profit under the RBC equilibrium price:

   $$\Pi_S(f_R^*) = x f_R^* \cdot q_i - C(k_i)$$

   - This profit is assigned to projects that are included in the RBC segment (i.e., those with contract values and cumulative capacity below or equal to the RBC equilibrium).

4. **Label Contract Type:**

   - Each project is labeled according to whether it is included under the "Regulated" (RBC) contract, the "Private" contract, or neither.
   - Profits are assigned accordingly:
     - **Regulated:** Projects included in the RBC segment receive $\Pi(f_R^*)$.
     - **Private:** Projects included only under the private contract equilibrium receive their private contract profit.
     - **No Private/Regulated:** All other projects.

5. **Cumulative Sums for Private Contracts:**

   - For projects under the private contract regime, cumulative capacity and production are calculated for further analysis and comparison.

### 1.2.9 Welfare Computation and Comparison

```
### Welfare -------------------------
# Create a table with eq_p and eq_q for each gamma

# Compute W^0 for gamma == 0
W_0_df <- wind_solar_proj_2022_rbc |>
  filter(gamma == 0, profits_sp_no_cpr >= 0) |>
  group_by(theta) |>
  summarise(theta_rbc = first(theta_rbc),
            W_0 = sum(x_q_exp_p_total_costs - r, na.rm = TRUE), .groups
              = "drop",
            )

# STEP 4: Compute W(gamma) for each gamma. We decide to do the sum for
    both
# Private and Regulated contracts. We also can just take the
# sum(x_q_exp_p_total_costs_R) for only "Private" contracts for
# W_gamma_private_c and the sum(x_q_exp_p_total_costs) for the W_gamma_
    rbc
# variable

W_gamma_private_c <- wind_solar_proj_2022_rbc %>%
  filter(contract_type == "Private") %>%
  group_by(gamma) %>%
  summarise(
    theta = first(theta),
    theta_rbc = first(theta_rbc),
    W_private_c = sum(x_q_exp_p_total_costs_R, na.rm = TRUE),
    .groups = "drop"
  )

W_gamma_rbc <- wind_solar_proj_2022_rbc %>%
  filter(
    contract_type == "Regulated"
  ) %>%
  group_by(gamma) %>%
  summarise(
    theta = first(theta),
    theta_rbc = first(theta_rbc),
    # We could also create W_rbc = sum(R_f_equilibrium_cpr), na.rm =
      TRUE),
    # .groups = "drop"
    # But if we do this, we should specify above in W_gamma_private_c:
    # filter(contract_type %in% c("Private", "Regulated"))
    W_rbc = sum(x_q_exp_p_total_costs, na.rm = TRUE),
    .groups = "drop"
  )

W_gamma_df <- W_gamma_private_c %>%
  left_join(W_gamma_rbc,
            by = c("gamma", "theta", "theta_rbc")) %>%
  mutate(
    W_gamma = W_private_c + W_rbc
  ) %>%
  arrange(gamma, theta)
```

```r
W_gamma_0_df <- W_gamma_df %>%
  filter(gamma == 0) %>%
  rename(W_gamma_0 = W_gamma) %>%
  select(theta, theta_rbc, W_gamma_0)


eq_gamma_0 <- equilibrium_prices %>%
  filter(gamma == 0) %>%
  select(theta, theta_rbc,
         quantity_gamma_0 = quantity_rbc,
         price_gamma_0 = xf_rbc_equilibrium
  )

equilibrium_prices

# STEP 5: Combine all metrics into one final table

welfare_dataset_rbc <- equilibrium_prices |>
  left_join(W_gamma_df |> select(-theta), by = c("gamma", "theta_rbc"))
    |>
  left_join(W_gamma_0_df |> select(-theta), by = "theta_rbc") |>
  left_join(W_0_df |> select(-theta), by = "theta_rbc") |>
  left_join(eq_gamma_0 |> select(-theta), by = "theta_rbc") |>
  mutate(
    eq_quantity_rbc = quantity_rbc,
    eq_price_rbc = xf_rbc_equilibrium,

    welfare_0_eur = if_else(gamma == 0, W_0, NA_real_),
    welfare_gamma_eur = W_gamma,
    welfare_gamma_ratio_percent = (W_gamma / W_gamma_0) * 100,
    welfare_gap_meur = (W_gamma_0 - W_gamma) / 1e6,
    welfare_gain_meur = (W_gamma - W_0) / 1e6
  ) |>

  select(
    gamma, theta_rbc, eq_price_rbc, eq_quantity_rbc,
    welfare_0_eur, welfare_gamma_eur, welfare_gamma_ratio_percent,
    welfare_gap_meur, welfare_gain_meur
  ) |>

  arrange(theta_rbc, gamma)


# For further use, we will merge dataset with theta = 5000 w/o RBC
# and also add the cumulative of private combtract
welfare_dataset_rbc <- welfare_dataset_rbc %>%
  left_join(
    welfare_dataset_wo_rbc_5000 %>%
      select(gamma, theta, eq_price_wo_rbc_5000 = eq_price, eq_quantity
        _total = eq_quantity),  # rename for clarity
    by = "gamma"
  ) |>
  left_join(private_cumsum |>
              select(gamma, eq_quantity_private), by = "gamma"
  ) |>
  select(-theta) |>
  relocate(eq_price_wo_rbc_5000, .after = eq_price_rbc) |>
  relocate(eq_quantity_private, .after = eq_quantity_rbc) |>
```

```
relocate(eq_quantity_total, .after = eq_quantity_private) |>
mutate(eq_price_rbc_vs_no_rbc_ratio_percent = (eq_price_rbc / eq_
   price_wo_rbc_5000) * 100,
       eq_quantity_rbc_vs_no_rbc_ratio_percent = (eq_quantity_rbc /
          eq_quantity_private) * 100) |>
relocate(eq_price_rbc_vs_no_rbc_ratio_percent, .after = eq_price_wo_
   rbc_5000) |>
relocate(eq_quantity_rbc_vs_no_rbc_ratio_percent, .after = eq_
   quantity_total)
```

This section calculates and compares welfare under different contract regimes (private, regulated, and combined) for each level of $\gamma$. The goal is to quantify the impact of regulator-backed contracts (RBC) on total welfare, and to benchmark these results against the private-only case.

1. **Baseline Welfare ($W^0$) for $\gamma = 0$:**

   - For the risk-neutral case ($\gamma = 0$), we sum the net values of all profitable projects (those with non-negative profits in the spot market).

2. **Welfare for Private and Regulated Contracts:**

   - For each $\gamma$, we separately sum the risk-adjusted net values for projects under:
     - **Private contracts** ($W_{\text{private}}$): sum over all winning plants of "Private" contracts. As before, it is $\sum_i xq_i \mathbb{E}(p) - C(k_i) - r_i$
     - **Regulated contracts** ($W_{\text{rbc}}$): sum over all winning plants that have "Regulated" contracts. It is $\sum_i xq_i \mathbb{E}(p) - C(k_i)$
   - The total welfare for each $\gamma$ is then $W(\gamma) = W_{\text{private}} + W_{\text{rbc}}$.

3. **Welfare for $\gamma = 0$:**

   - For comparison, we extract $W(\gamma)$ for $\gamma = 0$.

4. **Equilibrium Prices and Quantities for $\gamma = 0$:**

   - We also extract the equilibrium price and quantity for the regulated market segment ($f_*^R$ and $q_*^R$) when $\gamma = 0$.

5. **Combine Metrics into a Summary Table:**

   - All computed metrics are merged into a single summary dataset (`welfare_dataset_rbc`), which includes:
     - $\gamma$, $\theta_{\text{rbc}}$
     - Equilibrium price and quantity for the RBC segment
     - $W^0$ and $W(\gamma)$
     - Welfare ratios and gaps (in percent and million euros)

6. **Comparison with Private-Only and Total Contracting:**

   - The summary table is further augmented by merging with results without RBC ($\theta = 5000$) scenario and the respective cumulative contract quantity.
   - This allows for direct comparison of prices and quantities between the RBC and no-RBC regimes.
   - Relative ratios (in percent) are calculated for equilibrium prices and quantities between the RBC and no-RBC cases.

### 1.2.10 Profits Computation and Comparison for Private and Regulator-Backed Contracts

```r
### Profits ------------------------

# Profits by gamma and theta

# Firms with private contracts
profits_rbc <- wind_solar_proj_2022_rbc %>%
  filter(contract_type %in% c("Private", "Regulated")) %>%
  group_by(gamma) %>%
  summarise(
    theta_rbc = first(theta_rbc),
    profits_private = sum(
      if_else(contract_type == "Private", profits, 0),
      na.rm = TRUE
    ),
    profits_rbc = sum(
      if_else(contract_type == "Regulated", profits, 0),
      na.rm = TRUE
    ),
    seller_profits_eur_rbc = sum(profits, na.rm = TRUE),
    .groups = "drop"
  ) %>%
  arrange(gamma)

# Capture the demand value and the theta_rbc value you want to use

theta_equilibrium <- unique(equilibrium_theta$demand_value)
theta_rbc_value <- unique(profits_rbc$theta_rbc)

# Step 1: Merge welfare_dataset_rbc (for RBC equilibrium info)
profits_rbc <- profits_rbc %>%
  left_join(
    welfare_dataset_rbc %>%
      select(
        gamma,
        theta_rbc,
        welfare_gamma_eur,
        eq_price_rbc,
        eq_quantity_rbc
      ),
    by = c("gamma", "theta_rbc")
  ) %>%
  mutate(
    buyer_profits_eur_rbc = welfare_gamma_eur - seller_profits_eur_rbc
  ) %>%
  relocate(buyer_profits_eur_rbc, .after = seller_profits_eur_rbc)

# Dynamically rename the RBC columns
profits_rbc <- profits_rbc %>%
  rename_with(
    .fn = ~glue("Eq. Price (RBC, theta = {theta_rbc_value})"),
    .cols = eq_price_rbc
  ) %>%
  rename_with(
    .fn = ~glue("Eq. Quantity (RBC, theta = {theta_rbc_value})"),
    .cols = eq_quantity_rbc
  )
```

```r
# Step 2: Merge equilibrium_theta (external equilibrium info)
profits_rbc <- profits_rbc %>%
  left_join(
    equilibrium_theta %>%
      filter(demand_value == theta_equilibrium) %>%
      select(gamma,
             equilibrium_quantity,
             equilibrium_price),
    by = "gamma"
  ) %>%
  rename_with(
    ~glue("Eq. Quantity (theta = {theta_equilibrium})"),
    .cols = equilibrium_quantity
  ) %>%
  rename_with(
    ~glue("Eq. Price (theta = {theta_equilibrium})"),
    .cols = equilibrium_price
  )

profits_rbc <- profits_rbc %>%
  relocate(starts_with("Eq."), .after = gamma)

wind_solar_proj_2022_rbc <- wind_solar_proj_2022_rbc %>%
  relocate(profit_cpr_private_contracts, .before = profit_f_rbc) %>%
  relocate(f_rbc_equilibrium, xf_rbc_equilibrium, .after = cumulative_
     capacity) %>%
  relocate(xf_rbc_equilibrium, quantity_rbc, .after = xf_rbc) %>%
  arrange(theta, gamma, xf_rbc)
```

This section summarizes and compares the profits earned by sellers and buyers under both private and regulator-backed contract (RBC) regimes, for each level of $\gamma$. The resulting dataset is organized for easy reporting and policy analysis.

1. **Aggregate Seller Profits by Contract Type:**
   - For each value of $\gamma$, we sum the profits of all projects that are included under either "Private" or "Regulated" contracts.
   - Profits are split into two categories:
     - `profits_private`: Total profits from projects under private contracts.
     - `profits_rbc`: Total profits from projects under regulator-backed contracts.
   - The sum of these two gives the total seller profits for each $\gamma$ (`seller_profits_eur_rbc`).
2. **Merge with Welfare and Equilibrium Information:**
   - The profits data is merged with the welfare dataset (`welfare_dataset_rbc`), which provides:
     - Total welfare for each $\gamma$ (`welfare_gamma_eur`).
     - The equilibrium price and quantity for the RBC segment.
   - Buyer profits are computed as the difference between total welfare and seller profits:

$$\text{buyer\_profits\_eur\_rbc} = \text{welfare\_gamma\_eur} - \text{seller\_profits\_eur\_rbc}$$

3. **Dynamic Labeling for Reporting:**

- The equilibrium price and quantity columns are dynamically renamed to include the value of $\theta_{\text{rbc}}$, making the output tables self-explanatory and scenario-specific.

4. **Comparison with Total Contract Demand Equilibrium:**

    - The dataset is further merged with equilibrium price and quantity results for the total contract demand scenario ($\theta = 5000$), allowing direct comparison between the RBC and private-only regimes.
    - These columns are also dynamically labeled for clarity.

#### 1.2.11 Welfare Comparison Across Policy Scenarios

```
### Welfare Comparison----------------------

# Now we will create some tables that allows to compare the RBC with
    other
# cases, please. We will do that for theta = 2,500 and compare RBC with
    :

# i.   Public Subsidies
# ii.  Public Guarantees when T = G
# iii. Baseline Results

# We will compare welfare and seller/buyer profits

# Public Guarantees when T = G
welfare_with_profits_G_T <- welfare_with_profits_G_T |>
  filter(theta == theta_comparison_rbc) |>
  rename(welfare_gamma_eur_g_t  = welfare_gamma_eur,
         seller_profits_eur_g_t = seller_profits_eur,
         buyer_profits_eur_g_t  = buyer_profits_eur
  ) |>
  select(-seller_profit_share_percent, -buyer_profit_share_percent)

# Baseline
welfare_with_profits_baseline <- welfare_with_profits_baseline |>
  filter(theta == theta_comparison_rbc) |>
  rename(welfare_gamma_eur_b  = welfare_gamma_eur,
         seller_profits_eur_b = seller_profits_eur,
         buyer_profits_eur_b  = buyer_profits_eur
  ) |>
  select(-seller_profit_share_percent, -buyer_profit_share_percent)


welfare_dataset_pg <- welfare_dataset_pg |>
  filter(theta == theta_comparison_rbc) |>
  rename(welfare_gamma_eur_pg   = welfare_gamma_eur
  ) |>
  select(gamma, theta, buyer_profits_eur_pg, seller_profits_eur_pg,
     welfare_gamma_eur_pg)

profits_rbc <- profits_rbc |>
  rename(theta = theta_rbc,
         welfare_gamma_eur_rbc = welfare_gamma_eur)

combined_profits_welfare <- profits_rbc |>
  left_join(welfare_with_profits_G_T, by = c("gamma", "theta")) |>
  left_join(welfare_with_profits_baseline, by = c("gamma", "theta")) |>
  left_join(welfare_dataset_pg, by = c("gamma", "theta")) |>
  select(-T_star) |>
  relocate(theta, .before = gamma)

combined_profits_welfare_ratios <- combined_profits_welfare |>
  mutate(
    # Welfare ratios
    welfare_ratio_rbc_vs_g_t      = welfare_gamma_eur_rbc / welfare_
       gamma_eur_g_t,
```

```
    welfare_ratio_rbc_vs_baseline = welfare_gamma_eur_rbc / welfare_
       gamma_eur_b,
    welfare_ratio_rbc_vs_pg       = welfare_gamma_eur_rbc / welfare_
       gamma_eur_pg,

    # Seller profit ratios
    seller_profit_ratio_rbc_vs_g_t      = seller_profits_eur_rbc /
       seller_profits_eur_g_t,
    seller_profit_ratio_rbc_vs_baseline = seller_profits_eur_rbc /
       seller_profits_eur_b,
    seller_profit_ratio_rbc_vs_pg       = seller_profits_eur_rbc /
       seller_profits_eur_pg,

    # Buyer profit ratios
    buyer_profit_ratio_rbc_vs_g_t      = buyer_profits_eur_rbc / buyer_
       profits_eur_g_t,
    buyer_profit_ratio_rbc_vs_baseline = buyer_profits_eur_rbc / buyer_
       profits_eur_b,
    buyer_profit_ratio_rbc_vs_pg       = buyer_profits_eur_rbc / buyer_
       profits_eur_pg
  )

# Useful for plotting: from wide to long

combined_profits_ratios_long <- combined_profits_welfare_ratios |>
  select(gamma,
         welfare_ratio_rbc_vs_pg,
         welfare_ratio_rbc_vs_g_t,
         welfare_ratio_rbc_vs_baseline,
         seller_profit_ratio_rbc_vs_pg,
         seller_profit_ratio_rbc_vs_g_t,
         seller_profit_ratio_rbc_vs_baseline,
         buyer_profit_ratio_rbc_vs_pg,
         buyer_profit_ratio_rbc_vs_g_t,
         buyer_profit_ratio_rbc_vs_baseline) |>
  pivot_longer(
    cols = -gamma,
    names_to = c("type", "scenario"),
    names_pattern = "(welfare_ratio|seller_profit_ratio|buyer_profit_
       ratio)_rbc_vs_(pg|g_t|baseline)",
    values_to = "value"
  )
```

This section constructs summary tables to compare the welfare and profit outcomes of the Regulator-Backed Contract (RBC) regime with several alternative policy interventions, focusing on the case where contract demand $\theta = 2{,}500$. The alternative scenarios considered are:

- **Public Subsidies** (pg)
- **Public Guarantees** when optimal subsidy $T'*$ equals public guarantee $G$ (g_t)
- **Baseline Results**

The comparison is made for total welfare, seller profits, and buyer profits, for each value of the risk aversion parameter $\gamma$.

1. **Prepare Scenario-Specific Datasets:**

- For each alternative policy scenario, filter the results for the relevant contract demand ($\theta = 2{,}500$).
- Rename columns for clarity and remove unnecessary variables (such as profit shares).
- For the RBC scenario, ensure that variables are consistently named for joining.

2. **Merge All Scenarios into a Single Table:**

   - Combine the RBC, Public Guarantees, Public Subsidies, and Baseline datasets into a single summary table (`combined_profits_welfare`), matched by $\gamma$ and $\theta$.
   - This table contains, for each scenario and $\gamma$, the welfare, seller profits, and buyer profits.

3. **Compute Relative Ratios:**

   - For each $\gamma$, compute the ratios of welfare and profits in the RBC scenario relative to each alternative scenario:

$$\text{Welfare Ratio (RBC vs. X)} = \frac{\text{Welfare}_{\text{RBC}}}{\text{Welfare}_X}$$
$$\text{Seller Profit Ratio (RBC vs. X)} = \frac{\text{Seller Profits}_{\text{RBC}}}{\text{Seller Profits}_X}$$
$$\text{Buyer Profit Ratio (RBC vs. X)} = \frac{\text{Buyer Profits}_{\text{RBC}}}{\text{Buyer Profits}_X}$$

   - Where $X$ is one of: public guarantees (g_t), public subsidies (pg), or baseline (b).
   - These ratios allow for direct, quantitative comparison of the effectiveness and distributional consequences of each policy.

4. **Reshape for Visualization:**

   - The summary table is reshaped from wide to long format, with columns for the type of metric (welfare, seller profit, buyer profit), the comparison scenario, and the value.
   - This format is suitable for plotting or tabular reporting.

### 1.2.12 Visualization of Welfare and Profit Ratios Across Policy Scenarios

```r
#### Plots -------------------------------------

plot_ratio_by_type <- function(
    data_long,
    ratio_type,
    base_size = 25,
    filename = NULL,
    folder = NULL,
    base_palette = theme_palette_welfare,
    custom_labels = NULL
) {
  # Filter data
  df <- data_long |>
    dplyr::filter(type == ratio_type)

  # Handle custom label alignment
  if (!is.null(custom_labels)) {
    scenario_levels <- names(custom_labels)
    df <- df |>
      dplyr::mutate(scenario = factor(scenario, levels = scenario_levels))
    scenarios <- scenario_levels
    show_legend <- TRUE
    labels <- custom_labels
  } else {
    df <- df |>
      dplyr::mutate(scenario = as.factor(scenario))
    scenarios <- levels(df$scenario)
    show_legend <- FALSE
    labels <- scenarios
  }

  num_scenarios <- length(scenarios)

  # Aesthetic mappings
  color_values <- scales::gradient_n_pal(base_palette)(seq(0, 1, length.out = num_scenarios))
  names(color_values) <- scenarios

  linetypes <- setNames(rep(c("solid", "dashed", "dotted", "dotdash", "twodash"), length.out = num_scenarios), scenarios)
  shapes <- setNames(rep(16:20, length.out = num_scenarios), scenarios)
      # Solid shapes

  # Dynamic legend positioning
  gamma_cutoff <- quantile(df$gamma, 0.1, na.rm = TRUE)
  value_cutoff <- quantile(df$value, 0.5, na.rm = TRUE)

  top_left_density <- df |> filter(gamma <= gamma_cutoff, value >= value_cutoff) |> nrow()
  bottom_left_density <- df |> filter(gamma <= gamma_cutoff, value < value_cutoff) |> nrow()

  legend_at_top <- top_left_density < bottom_left_density
```

```
legend_position <- if (legend_at_top) c(0.05, 0.95) else c(0.05,
    0.05)
legend_just <- if (legend_at_top) c("left", "top") else c("left", "
    bottom")

# Build plot
p <- ggplot(df, ggplot2::aes(
  x = gamma,
  y = value,
  color = scenario,
  linetype = scenario,
  shape = scenario
)) +
  geom_line(linewidth = 1) +
  geom_point(size = 3) +
  scale_color_manual(values = color_values, labels = labels, name =
      NULL) +
  scale_linetype_manual(values = linetypes, labels = labels, name =
      NULL) +
  scale_shape_manual(values = shapes, labels = labels, name = NULL) +
  scale_y_continuous(labels = scales::label_number(accuracy = 0.01))
      +
  labs(
    x = expression(gamma),
    y = switch(
      ratio_type,
      "welfare_ratio" = "Welfare Ratio",
      "seller_profit_ratio" = "Seller Profit Ratio",
      "buyer_profit_ratio" = "Buyer Profit Ratio",
      ratio_type
    )
  ) +
  theme_minimal(base_size = base_size) +
  theme(
    legend.position = if (show_legend) legend_position else "none",
    legend.justification = legend_just,
    legend.box.just = "left",
    legend.background = element_rect(fill = scales::alpha("white",
        0.1), color = NA),
    legend.margin = margin(4, 4, 4, 4),
    legend.text = element_text(size = base_size * 0.6),
    legend.key.size = unit(0.4, "cm"),
    panel.grid.major = element_line(color = "grey90", size = 0.2),
    panel.grid.minor = element_line(color = "grey95", size = 0.1)
  )

# Legend override
if (show_legend) {
  p <- p + guides(
    color = guide_legend(
      override.aes = list(
        linetype = unname(linetypes),
        shape = unname(shapes),
        color = unname(color_values)
      )
    )
  )
}
```

```r
  # Save plot
  if (!is.null(filename) && !is.null(folder)) {
    path <- file.path(folder, filename)
    ggsave(path, plot = p, width = 16, height = 9, dpi = 300)
    message("Saved plot to: ", path)
  }

  print(p)
  invisible(p)
}



# Calls of functions
plot_ratio_by_type(
  combined_profits_ratios_long,
  ratio_type = "welfare_ratio",
  filename = "01_welfare_rbc_vs_others.pdf",
  folder = with_rbc_fig_path,
  custom_labels = c(
    pg       = expression(frac(W[RBC], W[PG])),
    g_t      = expression(frac(W[RBC], W["G=T"])),
    baseline = expression(frac(W[RBC], W[Baseline]))
  )
)


plot_ratio_by_type(
  combined_profits_ratios_long,
  ratio_type = "seller_profit_ratio",
  filename = "02_seller_profit_rbc_vs_others.pdf",
  folder = with_rbc_fig_path,
  custom_labels = c(
    pg       = expression(frac(Pi[RBC]^S, Pi[PG]^S)),
    g_t      = expression(frac(Pi[RBC]^S, Pi["G=T"]^S)),
    baseline = expression(frac(Pi[RBC]^S, Pi[Baseline]^S))
  )
)

plot_ratio_by_type(
  combined_profits_ratios_long,
  ratio_type = "buyer_profit_ratio",
  filename = "03_buyer_profit_rbc_vs_others.pdf",
  folder = with_rbc_fig_path,
  custom_labels = c(
    pg       = expression(frac(Pi[RBC]^B, Pi[PG]^B)),
    g_t      = expression(frac(Pi[RBC]^B, Pi["G=T"]^B)),
    baseline = expression(frac(Pi[RBC]^B, Pi[Baseline]^B))
  )
)
```

This section defines a flexible plotting function and uses it to visualize how the Regulator-Backed Contract (RBC) regime compares to alternative policy scenarios (public subsidies, public guarantees, and baseline) in terms of welfare, seller profits, and buyer profits, as a function of the risk aversion parameter $\gamma$.

1. **Plotting Function Definition (`plot_ratio_by_type`):**

- The function takes as input a long-format dataset of ratios (welfare, seller profit, or buyer profit), the type of ratio to plot, and various customization options (labels, color palettes, output file name, etc.).
- It filters the data for the selected ratio type and prepares the scenarios for plotting, optionally using custom mathematical labels for clarity.
- The function sets up color, linetype, and shape mappings for each scenario, ensuring that each policy comparison is visually distinct.
- It dynamically positions the legend to avoid overlapping with dense regions of the plot, improving readability.
- The resulting plot shows the ratio (e.g., $\frac{W_{\text{RBC}}}{W_{\text{PG}}}$) on the $y$-axis and the risk aversion parameter $\gamma$ on the $x$-axis, with each scenario represented by a different color, line, and symbol.
- If a filename and folder are provided, the plot is saved as a PDF for inclusion in reports or presentations.

2. **Plotting Calls:**

   - The function is called three times, once for each metric of interest:

     (a) **Welfare Ratio:** Plots the ratio of welfare under RBC to each alternative scenario:

     $$\frac{W_{\text{RBC}}}{W_{\text{PG}}}, \quad \frac{W_{\text{RBC}}}{W_{\text{G=T}}}, \quad \frac{W_{\text{RBC}}}{W_{\text{Baseline}}}$$

     (b) **Seller Profit Ratio:** Plots the ratio of seller profits under RBC to each alternative scenario:

     $$\frac{\Pi^S_{\text{RBC}}}{\Pi^S_{\text{PG}}}, \quad \frac{\Pi^S_{\text{RBC}}}{\Pi^S_{\text{G=T}}}, \quad \frac{\Pi^S_{\text{RBC}}}{\Pi^S_{\text{Baseline}}}$$

     (c) **Buyer Profit Ratio:** Plots the ratio of buyer profits under RBC to each alternative scenario:

     $$\frac{\Pi^B_{\text{RBC}}}{\Pi^B_{\text{PG}}}, \quad \frac{\Pi^B_{\text{RBC}}}{\Pi^B_{\text{G=T}}}, \quad \frac{\Pi^B_{\text{RBC}}}{\Pi^B_{\text{Baseline}}}$$

   - Each plot provides a clear, quantitative visualization of how the RBC regime compares to other policy options across the full range of risk aversion.

### 1.2.13 Welfare and Profits Analysis Without Regulator-Backed Contracts (RBC) at $\theta$ = 2,500

```
## Welfare w/o RBC (2500) --------------------------

wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_rbc_raw |>
  arrange(gamma, xf_max_cpr) |>
  group_by(gamma) |>
  mutate(cumulative_production = cumsum(q_i_mwh),
         cumulative_capacity = cumsum(capacity),
         x_q_exp_p_total_costs = x * expected_p * q_i_mwh - total_cost
  ) |>
  ungroup()


wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  mutate(theta = total_contract_demand,
         theta_private = private_demand,
         theta_rbc = rbc_demand
  ) |>
  arrange(theta, xf_max_cpr, gamma)

#  ------------------------ #
#  ------------------------ #

#  --------------------------------------------- #

## Equilibrium Prices Dataset Creation ----------

equilibrium_theta_private <- compute_equilibrium_prices(wind_solar_proj
   _2022_wo_rbc_2500, "theta_private", expected_p, x)

#  ------------------------ #
#  ------------------------ #

## Welfare Dataset Creation ----------------

# Join theta_private = 2500 and respective equilibria prices and
   quantities with main
# dataset.
theta_private_equilibrium <- equilibrium_theta_private %>%
  filter(demand_label == "theta_private") %>%
  select(
    gamma,
    theta_private = demand_value,
    private_equilibrium_price = equilibrium_price,
    private_equilibrium_quantity = equilibrium_quantity
  )


wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500
   %>%
  left_join(theta_private_equilibrium, by = c("gamma", "theta_private")
     )


wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
```

```r
  mutate(f_private_equilibrium = private_equilibrium_price / x,
         xf_private_equilibrium = private_equilibrium_price
  ) |>
  select(-private_equilibrium_price)


wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  arrange(theta_private, gamma, xf_max_cpr) |>
  group_by(gamma) |>
  rowwise() |>
  mutate(R_f_private_equilibrium_cpr =
           compute_R_value_gamma(f_private_equilibrium, gamma, q_i_mwh,
               x, r_0, alpha, beta)) |>
  ungroup() |>
  mutate(
    x_q_exp_p_total_costs_R = x * expected_p * q_i_mwh - total_cost
    - R_f_private_equilibrium_cpr
  )

wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  mutate(
    profit_cpr_private_contracts =
      vectorized_pi_s(
        f            = f_private_equilibrium,
        q_i          = q_i_mwh,
        x            = x,
        gamma        = gamma,
        r_0          = r_0,
        alpha        = alpha,
        beta         = beta,
        total_costs = total_cost,
        T_values     = 0
      )
  )

marginal_flags <- wind_solar_proj_2022_wo_rbc_2500 %>%
  group_by(gamma) %>%
  filter(
    near(xf_private_equilibrium, xf_max_cpr)
  ) %>%
  slice(1) %>%
  mutate(is_marginal = TRUE) %>%
  ungroup()



wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500
   %>%
  left_join(
    select(marginal_flags, gamma, theta_private, cumulative_capacity,
       is_marginal),
    by = c("gamma", "theta_private", "cumulative_capacity")
  ) %>%
  mutate(
    is_marginal = if_else(is.na(is_marginal), FALSE, is_marginal),
    cumulative_cutoff_private = cumulative_capacity <= private_
       equilibrium_quantity & xf_max_cpr <= xf_private_equilibrium
  )
```

```
ordered_vars <- c(
  "theta_private", "gamma", "f_c_cpr", "f_spot_cpr", "f_upper", "f_
     upper_message",
  "f_max_cpr", "f_private_equilibrium", "R_f_private_equilibrium_cpr",
  "xf_c_cpr", "xf_spot_cpr", "xf_upper_cpr", "xf_max_cpr", "xf_private_
     equilibrium",
  "private_equilibrium_quantity", "x_q_exp_p_total_costs", "x_q_exp_p_
     total_costs_R",
  "cumulative_production", "cumulative_capacity", "profit_cpr_private_
     contracts", "is_marginal",
  "cumulative_cutoff_private"
)

# Reorder dataframe
wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  select(
    everything(),              # Keeps all variables in current order
       ...
    -all_of(ordered_vars),     # ...but temporarily removes the ones
       you want to reorder
    -profits_sp_no_cpr,        # temporarily remove chosen_xf to place
       it explicitly
    profits_sp_no_cpr,         # put chosen_xf in place
    all_of(ordered_vars)       # then add ordered vars in the desired
       order
  )




# STEP 1: Compute W^0 for gamma == 0
W_0_df_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  filter(gamma == 0, profits_sp_no_cpr >= 0) |>
  group_by(theta_private) |>
  summarise(W_0 = sum(x_q_exp_p_total_costs - r, na.rm = TRUE), .groups
      = "drop")

# STEP 2: Compute W(gamma) for each gamma
W_gamma_df_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  group_by(gamma, theta_private) |>
  summarise(
    W_gamma = sum(
      if_else(cumulative_cutoff_private == TRUE, x_q_exp_p_total_costs_
         R, 0),
      na.rm = TRUE
    )
  ) |>
  ungroup()


# STEP 4: Compute W(gamma) for gamma = 0
W_gamma_0_df_2500 <- W_gamma_df_2500 %>%
  filter(gamma == 0) %>%
  rename(W_gamma_0 = W_gamma) %>%
  select(theta_private, W_gamma_0)
```

```r
eq_gamma_0_2500 <- theta_private_equilibrium %>%
  filter(gamma == 0) %>%
  select(theta_private,
         equilibrium_quantity_gamma_0 = private_equilibrium_quantity,
         equilibrium_price_gamma_0 = private_equilibrium_price)


# STEP 5: Combine all metrics into one final table

welfare_dataset_wo_rbc_2500 <- theta_private_equilibrium |>
  left_join(W_gamma_df_2500, by = c("gamma", "theta_private")) |>
  left_join(W_gamma_0_df_2500, by = "theta_private") |>
  left_join(W_0_df_2500, by = "theta_private") |>
  left_join(eq_gamma_0_2500, by = "theta_private") |>
  mutate(
    eq_quantity_private = private_equilibrium_quantity,
    eq_price_private = private_equilibrium_price,

    eq_quantity_ratio_percent = (eq_quantity_private / equilibrium_
       quantity_gamma_0) * 100,
    eq_price_ratio_percent = (eq_price_private / equilibrium_price_
       gamma_0) * 100,

    welfare_0_eur = if_else(gamma == 0, W_0, NA_real_),
    welfare_gamma_eur = W_gamma,
    welfare_gamma_ratio_percent = (W_gamma / W_gamma_0) * 100,
    welfare_gap_meur = (W_gamma_0 - W_gamma) / 1e6,
    welfare_gain_meur = (W_gamma - W_0) / 1e6
  ) |>
  select(
    gamma, theta_private,
    eq_price_private, eq_price_ratio_percent,
    eq_quantity_private, eq_quantity_ratio_percent,
    welfare_0_eur, welfare_gamma_eur, welfare_gamma_ratio_percent,
    welfare_gap_meur, welfare_gain_meur
  ) |>
  arrange(theta_private, gamma)



welfare_dataset_wo_rbc_2500

#  ----------------------- #
#  ----------------------- #

## Profits --------------------

# Profits by gamma and theta

profits_by_gamma_theta_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500
   |>
  group_by(gamma, theta_private) |>
  filter(cumulative_cutoff_private == TRUE) |>
  summarise(
    seller_profits_eur_wo_rbc = sum(profit_cpr_private_contracts, na.rm
       = TRUE),
    .groups = "drop"
```

```r
  ) |>
  ungroup() |>
  arrange(theta_private, gamma, seller_profits_eur_wo_rbc)


profits_by_gamma_theta_wo_rbc_2500 <- profits_by_gamma_theta_wo_rbc_
   2500 |>
  left_join(welfare_dataset_wo_rbc_2500 |>
              select(gamma, theta_private, welfare_gamma_eur),
            by = c("gamma", "theta_private")) |>
  mutate(buyer_profits_eur_wo_rbc = welfare_gamma_eur - seller_profits_
     eur_wo_rbc) |>
  rename(welfare_gamma_eur_wo_rbc = welfare_gamma_eur)


welfare_with_profits_2500_no_rbc <- welfare_dataset_wo_rbc_2500 %>%
  left_join(profits_by_gamma_theta_wo_rbc_2500, by = c("gamma", "theta_
     private"))

welfare_with_profits_2500_no_rbc <- welfare_with_profits_2500_no_rbc
   %>%
  mutate(
    buyer_profits_eur = welfare_gamma_eur - seller_profits_eur_wo_rbc,
    seller_profit_eur_wo_rbc_share_percent = round((seller_profits_eur_
       wo_rbc / welfare_gamma_eur) * 100, 2),
    buyer_profit_eur_wo_rbc_share_percent  = round((buyer_profits_eur_
       wo_rbc / welfare_gamma_eur) * 100, 2)
  ) %>%
  select(
    gamma, theta_private,
    welfare_gamma_eur_wo_rbc,
    seller_profits_eur_wo_rbc,
    buyer_profits_eur_wo_rbc,
    seller_profit_eur_wo_rbc_share_percent,
    buyer_profit_eur_wo_rbc_share_percent
  ) %>%
  arrange(theta_private, gamma)


## Welfare/Profits Comparison (RBC vs. No-RBC) --------------

comparison_rbc_vs_no_rbc <- welfare_with_profits_2500_no_rbc %>%
  left_join(profits_rbc, by = c("gamma" = "gamma", "theta_private" = "
     theta")) |>
  select(-theta_private) |>
  mutate(welfare_ratio        = welfare_gamma_eur_rbc  / welfare_gamma_
     eur_wo_rbc,
         seller_profit_ratio  = seller_profits_eur_rbc / seller_profits
            _eur_wo_rbc,
         buyer_profit_ratio   = buyer_profits_eur_rbc  / buyer_profits_
            eur_wo_rbc)

# Long format of dataset, to help with plotting
comparison_rbc_vs_no_rbc_long <- comparison_rbc_vs_no_rbc %>%
  select(gamma, welfare_ratio, seller_profit_ratio, buyer_profit_ratio)
      %>%
  pivot_longer(
    cols = c(welfare_ratio, seller_profit_ratio, buyer_profit_ratio),
```

```
    names_to = "type",
    values_to = "value") |>
  mutate(scenario = "ratio_comparison")


# Create a small table with Delta W, Reduced R and Increased Investment

welfare_differences_rbc_vs_no_rbc <- W_gamma_rbc %>%
  left_join(welfare_with_profits_2500_no_rbc, by = c("gamma" = "gamma",
      "theta_rbc" = "theta_private")) %>%
  left_join(profits_rbc, by = c("gamma" = "gamma", "theta_rbc" = "theta
     ")) |>
  select(gamma, welfare_gamma_eur_wo_rbc, welfare_gamma_eur_rbc, W_rbc)
      |>
  mutate(delta_W = welfare_gamma_eur_rbc - welfare_gamma_eur_wo_rbc,
         increased_investment = delta_W - W_rbc)
```

This section analyzes market outcomes and welfare in the scenario where only private contracts are available and the contract demand is fixed at 2,500 MW. The analysis proceeds as follows:

1. **Dataset Preparation and Supply Curve Construction:**
   - The wind and solar project dataset is arranged by risk aversion parameter ($\gamma$) and required contract price.
   - For each $\gamma$, cumulative production and capacity are computed to form a supply curve.
2. **Equilibrium Price and Quantity Calculation:**
   - The equilibrium price and quantity for the private contract demand ($\theta_{\text{private}} = 2{,}500$) are computed.
   - These values are joined back to the main dataset, and equilibrium contract prices per unit are calculated for each project.
3. **Risk Adjustment and Profits Calculation:**
   - For each project, risk adjustments are computed at the equilibrium price, and risk-adjusted net values are calculated.
   - Profits under private contracts are computed for each project.
4. **Marginal Project Identification:**
   - Projects at the margin of inclusion (where the equilibrium contract value matches the maximum contract price) are flagged for further analysis.
5. **Welfare Computation:**
   - For $\gamma = 0$ (risk-neutral case), welfare is computed as the sum of net values of all profitable projects.
   - For each $\gamma$, welfare is computed as the sum of risk-adjusted net values for projects within the equilibrium cutoff.
   - All metrics are combined into a summary table, including equilibrium prices, quantities, and welfare statistics for each $\gamma$.
6. **Profits Computation:**

- For each $\gamma$, seller profits are obtained by summing profits of projects included within the equilibrium cutoff.
- Buyer profits are then computed as the difference between total welfare and seller profits.
- The dataset is augmented with the shares of welfare allocated to sellers and buyers, and arranged for clarity and reporting.

7. **Comparison with RBC Scenario:**

   - The welfare and profits datasets for the no-RBC scenario are joined with the corresponding RBC results by $\gamma$ and demand.
   - Ratios of welfare, seller profits, and buyer profits are computed to quantify the relative performance of RBC versus private-only contracting:

$$\text{Welfare Ratio} = \frac{\text{Welfare}_{\text{RBC}}}{\text{Welfare}_{\text{No-RBC}}}$$
$$\text{Seller Profit Ratio} = \frac{\text{Seller Profits}_{\text{RBC}}}{\text{Seller Profits}_{\text{No-RBC}}}$$
$$\text{Buyer Profit Ratio} = \frac{\text{Buyer Profits}_{\text{RBC}}}{\text{Buyer Profits}_{\text{No-RBC}}}$$

   - The dataset is reshaped to long format for plotting and further analysis.
   - Additional metrics, such as welfare differences and changes in investment, are computed to provide deeper insights.

### 1.2.14 Plotting: Comparing RBC and No-RBC Scenarios

```
### Plotting ------------------------------------

# Fixed aesthetics for baseline (see previous graphs to take the
    corresponding one)

baseline_color <- theme_palette_welfare[3]  # Light green or blue
baseline_shape <- 18                        # Diamond
baseline_linetype <- "dotted"

# Welfare Ratio
df <- comparison_rbc_vs_no_rbc_long |>
  filter(type == "welfare_ratio")

ggplot(df, aes(x = gamma, y = value)) +
  geom_line(color = baseline_color, linetype = baseline_linetype,
      linewidth = 1) +
  geom_point(shape = baseline_shape, color = baseline_color, size = 3)
      +
  scale_y_continuous(labels = scales::label_number(accuracy = 0.01)) +
  labs(
    x = expression(gamma),
    y = "Welfare Ratio"
  ) +
  theme_minimal(base_size = base_s) +
  theme(
    legend.position = "none",
    panel.grid.major = element_line(color = "grey90", size = 0.2),
    panel.grid.minor = element_line(color = "grey95", size = 0.1)
  )

ggsave(
  filename = file.path(with_rbc_fig_path, "04_welfare_rbc_vs_no_rbc.pdf
      "),
  width = 16, height = 9, dpi = 300
)

# Seller Profit Ratio
df <- comparison_rbc_vs_no_rbc_long |>
  filter(type == "seller_profit_ratio")

ggplot(df, aes(x = gamma, y = value)) +
  geom_line(color = baseline_color, linetype = baseline_linetype,
      linewidth = 1) +
  geom_point(shape = baseline_shape, color = baseline_color, size = 3)
      +
  scale_y_continuous(labels = scales::label_number(accuracy = 0.01)) +
  labs(
    x = expression(gamma),
    y = "Seller Profit Ratio"
  ) +
  theme_minimal(base_size = base_s) +
  theme(
    legend.position = "none",
    panel.grid.major = element_line(color = "grey90", size = 0.2),
    panel.grid.minor = element_line(color = "grey95", size = 0.1)
  )
```

```r
ggsave(
  filename = file.path(with_rbc_fig_path, "05_seller_profit_ratio_rbc_
     vs_no_rbc.pdf"),
  width = 16, height = 9, dpi = 300
)

# Buyer Profit Ratio
df <- comparison_rbc_vs_no_rbc_long |>
  filter(type == "buyer_profit_ratio")

ggplot(df, aes(x = gamma, y = value)) +
  geom_line(color = baseline_color, linetype = baseline_linetype,
     linewidth = 1) +
  geom_point(shape = baseline_shape, color = baseline_color, size = 3)
     +
  scale_y_continuous(labels = scales::label_number(accuracy = 0.01)) +
  labs(
    x = expression(gamma),
    y = "Buyer Profit Ratio"
  ) +
  theme_minimal(base_size = base_s) +
  theme(
    legend.position = "none",
    panel.grid.major = element_line(color = "grey90", size = 0.2),
    panel.grid.minor = element_line(color = "grey95", size = 0.1)
  )

ggsave(
  filename = file.path(with_rbc_fig_path, "06_buyer_profit_ratio_rbc_vs
     _no_rbc.pdf"),
  width = 16, height = 9, dpi = 300
)
```

This section generates three publication-ready plots to visually compare the performance of the Regulator-Backed Contract (RBC) scenario versus the no-RBC (private contracts only) baseline, as a function of the risk aversion parameter $\gamma$.

1. **Consistent Aesthetics:**
   - A fixed color (light green or blue), diamond shape, and dotted line type are used for all baseline plots to ensure visual consistency across all figures.
2. **Data Preparation:**
   - For each plot, the data is filtered to include only the relevant ratio type:
     - `welfare_ratio`: Ratio of welfare under RBC to no-RBC.
     - `seller_profit_ratio`: Ratio of seller profits under RBC to no-RBC.
     - `buyer_profit_ratio`: Ratio of buyer profits under RBC to no-RBC.
3. **Plot Construction:**
   - Each plot uses $\gamma$ on the $x$-axis and the corresponding ratio on the $y$-axis.
   - Data are displayed as both a line and points for clarity.
   - The $y$-axis is formatted to show values with two decimal places.
   - A minimal theme is applied, with the legend hidden (since only one line is shown).

- Grid lines are styled in light grey for readability.

4. **Saving the Plots:**

   - Each plot is saved as a PDF with a descriptive filename in the specified output folder, ensuring reproducibility and easy inclusion in reports or presentations.

### 1.2.15 Exporting Results: Data Cleaning and Workbook Organization

```r
# Delete some useless variables

wind_solar_proj_2022_wo_rbc_2500 <- wind_solar_proj_2022_wo_rbc_2500 |>
  select(-is_marginal, -cumulative_cutoff_private)


# Keep useful variables, for further tables creation

profits_rbc <- profits_rbc |>
  select(theta, gamma, profits_private, profits_rbc, seller_profits_eur
    _rbc,
         buyer_profits_eur_rbc, welfare_gamma_eur_rbc)



#
   --------------------------------------------------------------------------
    #

# Save this in a separate workbook, for clarity

datasets_wo_rbc <- list(
  `Wind_Solar_Projects` = wind_solar_proj_2022_wo_rbc_2500,
  `Welfare wo RBC (theta = 2500)` = welfare_dataset_wo_rbc_2500,
  `Profits wo RBC (theta = 2500)` = profits_by_gamma_theta_wo_rbc_2500
)

filtered_wo_rbc <- lapply(datasets_wo_rbc, filter_by_gamma)

excel_filename_wo_rbc <- paste0("02_wind_solar_projects_wo_rbc_theta_",
    private_demand, ".xlsx")
output_path_wo_rbc <- file.path(with_rbc_path, excel_filename_wo_rbc)

wb_wo_rbc <- createWorkbook()

for (sheet in names(filtered_wo_rbc)) {
  addWorksheet(wb_wo_rbc, sheet)
  freezePane(wb_wo_rbc, sheet, firstActiveRow = 2, firstActiveCol = 2)
  writeData(wb_wo_rbc, sheet = sheet, x = filtered_wo_rbc[[sheet]])
}

saveWorkbook(wb_wo_rbc, file = output_path_wo_rbc, overwrite = TRUE)
#
   --------------------------------------------------------------------------
    #

# Save this in a separate workbook, for clarity
# We save in this file the case with RBC = 2500, and the comparison
# w/o RBC = 2500

# addWorksheet(wb, "W(gamma) - RBC")
# freezePane(wb, "W(gamma) - RBC", firstActiveRow = 2, firstActiveCol =
    2)
# writeData(wb, "W(gamma) - RBC", W_gamma_df)
```

```r
datasets_rbc <- list(
  `Wind_Solar_Projects`                    = wind_solar_proj_2022_rbc,
  `Welfare with RBC (theta = 2500)`        = welfare_dataset_rbc,
  `Welfare wo RBC (theta = 2500)`          = welfare_dataset_wo_rbc_
     2500,
  `Profits wo RBC (theta = 2500)`          = profits_by_gamma_theta_wo_
     rbc_2500,
  `Profits with RBC (theta = 2500)`        = profits_rbc,
  `Risk Reduction (theta = 2500)`          = welfare_differences_rbc_vs
     _no_rbc
)

filtered_rbc <- lapply(datasets_rbc, filter_by_gamma)

excel_filename_rbc <- paste0("03_wind_solar_projects_rbc_theta_", rbc_
   demand, ".xlsx")
output_path_rbc <- file.path(with_rbc_path, excel_filename_rbc)

wb_rbc <- createWorkbook()

for (sheet in names(filtered_rbc)) {
  addWorksheet(wb_rbc, sheet)
  freezePane(wb_rbc, sheet, firstActiveRow = 2, firstActiveCol = 2)
  writeData(wb_rbc, sheet = sheet, x = filtered_rbc[[sheet]])
}

saveWorkbook(wb_rbc, file = output_path_rbc, overwrite = TRUE)
```

This section finalizes the analysis by cleaning up datasets, selecting relevant variables, and exporting all key results to well-organized Excel workbooks for clarity, reproducibility, and further reporting.

1. **Data Cleaning and Variable Selection:**
   - Unnecessary intermediate variables (such as `is_marginal` and `cumulative_cutoff_private`) are removed from the main project dataset to streamline the data.
   - For the profits dataset (`profits_rbc`), only the variables relevant for reporting and further analysis are retained, such as contract demand, risk aversion, profits by contract type, and total welfare.
2. **Workbook Creation for the No-RBC Scenario:**
   - All key datasets for the scenario without regulator-backed contracts (RBC) and with $\theta = 2{,}500$ are compiled into a named list. This includes:
     - The main wind/solar project dataset,
     - The welfare summary,
     - The profits summary.
   - Each dataset is filtered by the selected $\gamma$ values as needed.
   - A new Excel workbook is created, with each dataset written to a separate worksheet. Panes are frozen for easier navigation.
   - The workbook is saved with a descriptive, scenario-specific filename.
3. **Workbook Creation for the RBC and Comparison Scenarios:**
   - All key datasets for the RBC scenario (with $\theta_{\text{rbc}} = 2{,}500$), as well as the comparison with the no-RBC case, are compiled into a comprehensive list. This includes:

  - Project-level results,
  - Welfare and profits with and without RBC,
  - Risk reduction metrics,
  - All relevant summary tables for direct comparison.
- As before, each dataset is filtered and written to its own worksheet in a new workbook, which is saved with an appropriate filename.

Each of these plots provides insight into the distributional and comparative effects of the policy instruments, highlighting how profits and welfare shares shift between market participants as risk aversion and plant size vary.

## 1.3 Created Tables

### 1.3.1 `01_wind_solar_projects_wo_rbc_theta_5000`

Table 1: Variables in `Wind Solar Projects` Sheet

| Variable | Description |
|---|---|
| projectname | Project name |
| capacity | Installed capacity (MW) |
| avgcapacityfactor | Average capacity factor |
| type | Technology type (Wind/Solar) |
| hours | Annual full-load hours |
| power_kw | Installed power (kW) |
| q_i_kwh | Annual generation (kWh) |
| q_i_mwh | Annual generation (MWh) |
| v_q_i_mwh | Consumer valuation (MWh) |
| c_inv | Investment cost per MW |
| c_om | O&M cost per MW |
| total_cost | Total cost |
| avg_cost_euro_kwh | Average cost (EUR/kWh) |
| avg_cost_euro_mwh | Average cost (EUR/MWh) |
| r_0 | $r_0$ |
| r | $r_i$ |
| theta_private | $\theta_{private}$ |
| theta_rbc | $\theta_{rbc}$ |
| profits_sp_no_cpr | $\Pi_S^0$ |
| theta | $\theta_{total}$ |
| gamma | Share of opportunistic buyers $\gamma$ |
| f_c_cpr | $f_c$ |
| f_spot_cpr | $f_{spot}$ |
| f_upper | Second root $f_{upper}$, if any |
| f_upper_message | Says if `f_upper`$> \mathbb{E}(p)$ or `f_upper`$\leq \mathbb{E}(p)$ |
| f_max_cpr | $f_{max}$ |
| f_equilibrium | $f^*$ |
| R_f_equilibrium_cpr | $R_i(f^*, \gamma)$ |
| xf_c_cpr | $xf_c$ |
| xf_spot_cpr | $xf_{spot}$ |
| xf_upper | Second root $xf_{upper}$, if any |
| xf_max_cpr | $xf_{max}$ |
| xf_equilibrium | $xf^*$ |
| equilibrium_quantity | $q^*$ |
| x_q_exp_p_total_costs | $xq_i \cdot \mathbb{E}(p) - C(k_i)$ |
| x_q_exp_p_total_costs_R | $xq_i \cdot \mathbb{E}(p) - C(k_i) - R_i(f^*, \gamma)$ |
| cumulative_production | Cumulative energy production (MWh) |
| cumulative_capacity | Cumulative capacity (MW) |
| profit_cpr_private_contracts | Profits under CPR contracts, using $f^*$ with $\theta_{total} = 5000$ |

Table 2: Variables in `Equilibrium P. & Q.` Sheet

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta | Demand scenario (MW) - $\theta_{total}$ |
| theta_equilibrium_quantity | Total contracted quantity at equilibrium (MW), $q^*$ |
| theta_equilibrium_price | Equilibrium contract price (EUR/MWh) |

Table 3: Variables in `Welfare` Sheet

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta | Demand scenario (MW) - $\theta_{total}$ |
| eq_price | Equilibrium contract price (EUR/MWh) |
| eq_price_ratio_percent | Price as % of $\gamma = 0$ baseline |
| eq_quantity_mw | Equilibrium contracted quantity (MW) |
| W_0 | Welfare $W^0$ |
| welfare_gamma_eur | Welfare $W(\gamma)$ (million EUR) |
| welfare_ratio_percent | Welfare as % of $W(\gamma = 0)$ baseline |
| welfare_gap_million_eur | Welfare gap vs. baseline $\Big[W(\gamma = 0) - W(\gamma)\Big]$ (million EUR) |
| welfare_gain_million_eur | Welfare gain vs. baseline $\Big[W(\gamma) - W^0\Big]$ (million EUR) |

Table 4: Variables in `Profits`

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta | Demand scenario (MW) - $\theta_{total}$ |
| seller_profits_eur | Seller profits (EUR) |
| buyer_profits_eur | Buyer profits (EUR) |
| seller_profit_share_percent | Seller share of welfare (%) |
| buyer_profit_share_percent | Buyer share of welfare (%) |
| welfare_gamma_eur | Welfare $W(\gamma)$ (EUR) |

### 1.3.2 02_wind_solar_projects_wo_rbc_theta_2500

Table 5: Variables in Wind_Solar_Projects Sheet

| Variable | Description |
|---|---|
| projectname | Project name |
| capacity | Installed capacity (MW) |
| avgcapacityfactor | Average capacity factor |
| type | Technology type (Wind/Solar) |
| hours | Annual full-load hours |
| power_kw | Installed power (kW) |
| q_i_kwh | Annual generation (kWh) |
| q_i_mwh | Annual generation (MWh) |
| v_q_i_mwh | Consumer valuation (MWh) |
| c_inv | Investment cost per MW |
| c_om | O&M cost per MW |
| total_cost | Total cost |
| avg_cost_euro_kwh | Average cost (EUR/kWh) |
| avg_cost_euro_mwh | Average cost (EUR/MWh) |
| r_0 | $r_0$ |
| r | $r_i$ |
| theta | $\theta_{total}$ |
| theta_rbc | $\theta_{rbc}$ |
| profits_sp_no_cpr | $\Pi_S^0$ |
| theta_private | $\theta_{private}$ |
| gamma | Share of opportunistic buyers $\gamma$ |
| f_c_cpr | $f_c$ |
| f_spot_cpr | $f_{spot}$ |
| f_upper | Second root $f_{upper}$, if any |
| f_upper_message | Says if `f_upper`$> \mathbb{E}(p)$ or `f_upper`$\leq \mathbb{E}(p)$ |
| f_max_cpr | $f_{max}$ |
| f_private_equilibrium | $f^*$ for $\theta_{private} = 2500$ |
| R_f_private_equilibrium_cpr | $R_i(f^*, \gamma)$ for $\theta_{private} = 2500$ |
| xf_c_cpr | $xf_c$ |
| xf_spot_cpr | $xf_{spot}$ |
| xf_upper | Second root $xf_{upper}$, if any |
| theta | Demand scenario $\theta$ (MW) |
| xf_max_cpr | $xf_{max}$ |
| xf_private_equilibrium | $xf^*$ |
| private_equilibrium_quantity | $q^*$ |
| x_q_exp_p_total_costs | $xq_i \cdot \mathbb{E}(p) - C(k_i)$ |
| x_q_exp_p_total_costs_R | $xq_i \cdot \mathbb{E}(p) - C(k_i) - R_i(f^*, \gamma)$ |
| cumulative_production | Cumulative energy production (MWh) |
| cumulative_capacity | Cumulative capacity (MW) |
| profit_cpr_private_contracts | Profits under CPR contracts, using $f^*$ |

Table 6: Variables in `Welfare wo RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta_private | Demand scenario (MW) - $\theta_{private}$ |
| eq_price_private | Equilibrium contract price (EUR/MWh) |
| eq_price_ratio_percent | Price as % of $\gamma = 0$ baseline |
| eq_quantity_private | Equilibrium contracted quantity (MW) |
| eq_quantity_ratio_percent | Quantity as % of $\gamma = 0$ baseline |
| welfare_0_eur | Welfare $W^0$ |
| welfare_gamma_eur | Welfare $W(\gamma)$ (million EUR) |
| welfare_gamma_ratio_percent | Welfare as % of $W(\gamma = 0)$ baseline |
| welfare_gap_meur | Welfare gap vs. baseline $\left[W(\gamma = 0) - W(\gamma)\right]$ (million EUR) |
| welfare_gain_meur | Welfare gain vs. baseline $\left[W(\gamma) - W^0\right]$ (million EUR) |

Table 7: Variables in `Profits wo RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta_private | Demand scenario (MW) - $\theta_{private}$ |
| seller_profits_eur_wo_rbc | Seller profits (EUR) |
| welfare_gamma_eur_wo_rbc | Welfare $W(\gamma)$ (EUR) |
| buyer_profits_eur_wo_rbc | Buyer profits (EUR) |

### 1.3.3 `03_wind_solar_projects_rbc_theta_2500`

Table 8: Variables in `Wind_Solar_Projects` Sheet

| Variable | Description |
|---|---|
| projectname | Project name |
| capacity | Installed capacity (MW) |
| avgcapacityfactor | Average capacity factor |
| type | Technology type (Wind/Solar) |
| hours | Annual full-load hours |
| power_kw | Installed power (kW) |
| q_i_kwh | Annual generation (kWh) |
| q_i_mwh | Annual generation (MWh) |
| v_q_i_mwh | Consumer valuation (MWh) |
| c_inv | Investment cost per MW |
| c_om | O&M cost per MW |
| total_cost | Total cost |
| avg_cost_euro_kwh | Average cost (EUR/kWh) |
| avg_cost_euro_mwh | Average cost (EUR/MWh) |
| r_0 | $r_0$ |
| r | $r_i$ |
| theta_private | $\theta_{private}$ |
| theta_rbc | $\theta_{rbc}$ |
| profits_sp_no_cpr | $\Pi_S^0$ |
| theta | $\theta_{total}$ |
| gamma | Share of opportunistic buyers $\gamma$ |
| f_c_cpr | $f_c$ |
| f_spot_cpr | $f_{spot}$ |
| f_upper | Second root $f_{upper}$, if any |
| f_upper_message | Says if `f_upper`$>\mathbb{E}(p)$ or `f_upper`$\leq \mathbb{E}(p)$ |
| f_max_cpr | $f_{max}$ |
| f_equilibrium | $f^*$ for $\theta_{total} = 5000$ |
| R_equilibrium_cpr | $R_i(f^*, \gamma)$ for $\theta_{total} = 5000$ |
| xf_c_cpr | $xf_c$ |
| xf_spot_cpr | $xf_{spot}$ |
| xf_upper | Second root $xf_{upper}$, if any |
| xf_max_cpr | $xf_{max}$ |
| xf_equilibrium | $xf^*$ for $\theta_{total} = 5000$ |
| equilibrium_quantity | $q^*$ for $\theta_{total} = 5000$ |
| x_q_exp_p_total_costs | $xq_i \cdot \mathbb{E}(p) - C(k_i)$ |
| x_q_exp_p_total_costs_R | $xq_i \cdot \mathbb{E}(p) - C(k_i) - R_i(f^*, \gamma)$ |
| cumulative_production | Cumulative energy production (MWh) |
| cumulative_capacity | Cumulative capacity (MW) |
| f_rbc_equilibrium | Equilibrium Price $f_*^R$ for each $\gamma$ |
| f_rbc | $f_i^R$ for each plant |
| xf_rbc | $xf_i^R$ for each plant |
| xf_rbc_equilibrium | $xf_*^R$ for each $\gamma$ |
| profit_cpr_private_contracts | Profits under CPR contracts, using $f^*$ for $\theta_{total} = 5000$ |
| profit_f_rbc | Profits from RBC, using $xf_*^R$ |
| profits | Either `profit_f_rbc` or `profit_cpr_private_contracts`, depending on which case |
| contract_type | Either `Regulated` or `Private`, depending on which case |

Table 9: Variables in `Welfare with RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| `gamma` | $\gamma$ |
| `theta_rbc` | $\theta_{rbc}$ |
| `eq_price_rbc` | Equilibrium contract price (EUR/MWh) in the RBC scenario. |
| `eq_price_wo_rbc_5000` | Equilibrium contract price (EUR/MWh) in the private-only (no-RBC) scenario. |
| `eq_price_rbc_vs_no_rbc_ratio_percent` | Ratio (%) of RBC equilibrium price to private-only equilibrium price. |
| `eq_quantity_rbc` | Equilibrium contracted quantity (MW) in the RBC scenario. |
| `eq_quantity_private` | Equilibrium contracted quantity (MW) in the private-only scenario. |
| `eq_quantity_total` | Total contracted quantity (MW) if both segments are combined. |
| `eq_quantity_rbc_vs_no_rbc_ratio_percent` | Ratio (%) of RBC equilibrium quantity to private-only equilibrium quantity. |
| `welfare_0_eur` | $W^0$ |
| `welfare_gamma_eur` | $W(\gamma)$ |
| `welfare_gamma_ratio_percent` | Welfare as a percentage of the baseline: $100 \times \frac{W(\gamma)}{W(\gamma=0)}$. |
| `welfare_gap_meur` | $W(\gamma = 0) - W(\gamma)$ (million EUR) |
| `welfare_gain_meur` | $W(\gamma) - W^0$ (million EUR) |

Table 10: Variables in `Welfare wo RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| `gamma` | $\gamma$ |
| `theta_private` | $\theta_{private}$ |
| `eq_price_private` | Equilibrium contract price (EUR/MWh) in the private scenario. |
| `eq_price_ratio_percent` | Ratio (%) of private-only equilibrium price to the case when $\gamma = 0$ |
| `eq_quantity_private` | Equilibrium contracted quantity (MW) in the private scenario. |
| `eq_quantity_ratio_percent` | Ratio (%) of private-only equilibrium quantity to the case when $\gamma = 0$ |
| `welfare_0_eur` | $W^0$ |
| `welfare_gamma_eur` | $W(\gamma)$ |
| `welfare_gamma_ratio_percent` | Welfare as a percentage of the baseline: $100 \times \frac{W(\gamma)}{W(\gamma=0)}$. |
| `welfare_gap_meur` | $W(\gamma = 0) - W(\gamma)$ (million EUR) |
| `welfare_gain_meur` | $W(\gamma) - W^0$ (million EUR) |

Table 11: Variables in `Profits wo RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| gamma | Share of opportunistic buyers $\gamma$ |
| theta_private | Demand scenario (MW) - $\theta_{private}$ |
| seller_profits_eur_wo_rbc | Seller profits (EUR) |
| welfare_gamma_eur_wo_rbc | Welfare $W(\gamma)$ (EUR) |
| buyer_profits_eur_wo_rbc | Buyer profits (EUR) |

Table 12: Variables in `Profits with RBC (theta = 2500)` Sheet

| Variable | Description |
|---|---|
| theta | Demand scenario (MW) - $\theta_{rbc}$ |
| gamma | Share of opportunistic buyers $\gamma$ |
| profits_private | Total profits per gamma for private contracts winning plants |
| profits_rbc | Total profits per gamma for regulator-backed contracts winning plants |
| seller_profits_eur_rbc | Seller profits (EUR) - sum of `profits_private` and `profits_rbc` |
| buyer_profits_eur_rbc | Buyer profits (EUR) - difference between `welfare_gamma_eur_rbc` and `seller_profits_eur_rbc` |
| welfare_gamma_eur_rbc | Welfare $W(\gamma)$ (EUR) |

Table 13: Variables in `Risk Reduction (theta = 2500)` Sheet

| Variable | Description |
| --- | --- |
| gamma | Share of opportunistic buyers $\gamma$ |
| welfare_gamma_eur_wo_rbc | Welfare $W(\gamma)$ without RBC (EUR) |
| welfare_gamma_eur_rbc | Welfare $W(\gamma) = W_{private} + W_{rbc}$ from RBC (EUR) |
| W_rbc | Welfare $W_{rbc}$ from RBC winning plants (EUR) |
| delta_W | welfare_gamma_eur_rbc - welfare_gamma_eur_wo_rbc |
| increased_investment | delta_W - W_rbc |