# Appendix B: Notebook Code

Course: Productos Derivados: O25 LAT4012 2

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# Contents

# Import necessary libraries

[1]:
```
import numpy as np
import pandas as pd
import requests
import re
import matplotlib.pyplot as plt

import style
style.mpl_apply()
```

# Fetching data from Investing.com

[2]:
```
def fetch_from_investing(URL):


    HDRS = {
        "User-Agent": "Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko)␣
↪Chrome/122.0 Safari/537.36",
        "Accept-Language": "en-US,en;q=0.9",
    }

    def parse_investing_hist(url=URL, headers=HDRS):
        html = requests.get(url, headers=headers, timeout=30).text
        tables = pd.read_html(html, flavor="lxml")  # all tables, any locale
        # column name normalizer
        def norm_cols(df):
            # flatten MultiIndex if present
            if isinstance(df.columns, pd.MultiIndex):
                df.columns = [" ".join([str(x) for x in tup if str(x)!='nan']).strip()
                              for tup in df.columns]
            df.columns = [c.strip().lower().replace("%","%").replace(" ", "_") for c in df.columns]
            return df

        # candidate header translations
        name_map = {
            "fecha":"date", "date":"date",
            "precio":"price", "price":"price",
            "apertura":"open", "open":"open",
            "máximo":"high", "maximo":"high", "high":"high",
            "mínimo":"low", "minimo":"low", "low":"low",
            "volumen":"volume", "volume":"volume",
```

```
            "var._%":"change_%", "variación_%":"change_%", "change_%":"change_%", "chg_%":"change_%"
        }

        for t in tables:
            t = norm_cols(t.copy())
            # try to rename known headers
            for k,v in list(name_map.items()):
                if k in t.columns and v not in t.columns:
                    t = t.rename(columns={k:v})

            # fallback: detect a date-like first column
            if "date" not in t.columns:
                first = t.columns[0]
                # keep only rows that look like dates
                mask = t[first].astype(str).str.contains(r"\d{1,2}/\d{1,2}/\d{2,4}", na=False)
                if mask.any():
                    t = t.loc[mask].rename(columns={first:"date"})

            if "date" not in t.columns:
                continue  # not the right table

            # keep plausible price table (has at least price/open/high/low or price+change)
            if not ({"price","open","high","low"} & set(t.columns)):
                continue

            # clean rows with actual dates
            t = t[t["date"].astype(str).str.contains(r"\d", na=False)].copy()

            # types
            t["date"] = pd.to_datetime(t["date"], errors="coerce", dayfirst=False)
            num_cols = [c for c in ["price","open","high","low","volume","change_%"] if c in t.columns]
            for c in num_cols:
                s = t[c].astype(str)
                # remove thousands separators and percent signs
                s = s.str.replace("%","", regex=False)
                s = s.str.replace(",","").str.replace("\u202f","")
                # handle suffixes like 'K','M'
                def to_num(x):
                    m = re.fullmatch(r"(-?\d+(?:\.\d+)?)([KkMmBb])?", x.strip())
                    if not m:
                        return pd.to_numeric(x, errors="coerce")
                    val, suf = m.groups()
                    val = float(val)
                    mult = {"K":1e3,"k":1e3,"M":1e6,"m":1e6,"B":1e9,"b":1e9}.get(suf,1.0)
                    return val*mult
                t[c] = s.map(to_num)

            t = t.sort_values("date").reset_index(drop=True)
            # standardize column order
            want = [c for c in ["date","price","open","high","low","volume","change_%"] if c in t.columns]
            return t[want]

        raise RuntimeError("Historical table not found. Page structure or consent wall blocked parsing.")

    df = parse_investing_hist()
    # make date the index
    df = df.set_index("date").sort_index()
```

```
    return df
```

# SOFR

[3]:
```
SOFR_rate = [4.34, 4.34, 4.39, 4.39, 4.41, 4.42, 4.40, 4.40, 4.39, 4.41, 4.41]

# Remove the non-bank day 2025-09-01
non_bank_day = ['2025-09-01']

dates = pd.date_range(start='2025-08-28', periods=len(SOFR_rate) + len(non_bank_day), freq='B')

# Filter out the non-bank day from dates and SOFR
dates = dates[~dates.isin(non_bank_day)]
SOFR_rate = [rate for date, rate in zip(dates, SOFR_rate) if date != non_bank_day]

# Update SOFR_series
SOFR = pd.Series(SOFR_rate, index=dates)
```

```
C:\Users\herie\AppData\Local\Temp\ipykernel_27404\2588569263.py:9:
FutureWarning: The behavior of 'isin' with dtype=datetime64[ns] and castable
values (e.g. strings) is deprecated. In a future version, these will not be
considered matching by isin. Explicitly cast to the appropriate dtype before
calling isin instead.
  dates = dates[~dates.isin(non_bank_day)]
```

[4]:
```
SOFR
```

[4]:
```
2025-08-28    4.34
2025-08-29    4.34
2025-09-02    4.39
2025-09-03    4.39
2025-09-04    4.41
2025-09-05    4.42
2025-09-08    4.40
2025-09-09    4.40
2025-09-10    4.39
2025-09-11    4.41
2025-09-12    4.41
dtype: float64
```

[5]:
```
start_date = SOFR.index[0]
end_date = SOFR.index[-1]
```

[6]:
```
# keep the SOFR from 5sep until max
SOFR = SOFR[(SOFR.index >= '2025-09-05')]
```

[7]:
```
SOFR
```

[7]:
```
2025-09-05    4.42
2025-09-08    4.40
2025-09-09    4.40
2025-09-10    4.39
2025-09-11    4.41
2025-09-12    4.41
dtype: float64
```

[8]:
```
dates = SOFR.index
```

[9]:
```
SOFR_daily = (1 + SOFR/100)**(1/360) - 1  # daily compounding
SOFR_daily
```

[9]:
```
2025-09-05    0.000120
2025-09-08    0.000120
2025-09-09    0.000120
2025-09-10    0.000119
2025-09-11    0.000120
2025-09-12    0.000120
dtype: float64
```

# Silver

# Stock Price

[10]:
```
silver = fetch_from_investing("https://www.investing.com/currencies/xag-usd-historical-data")
```

```
C:\Users\herie\AppData\Local\Temp\ipykernel_27404\338722890.py:11:
FutureWarning: Passing literal html to 'read_html' is deprecated and will be
removed in a future version. To read from a literal string, wrap it in a
'StringIO' object.
  tables = pd.read_html(html, flavor="lxml")  # all tables, any locale
```

[11]:
```
silver
```

[11]:

| date | price | open | high | low | change_% |
|---|---|---|---|---|---|
| 2025-08-18 | 38.0350 | 38.0350 | 38.2850 | 37.8176 | 0.05 |
| 2025-08-19 | 37.3950 | 38.0357 | 38.1750 | 37.2665 | -1.68 |
| 2025-08-20 | 37.9087 | 37.3495 | 37.9650 | 36.9556 | 1.37 |
| 2025-08-21 | 38.1900 | 37.8729 | 38.2550 | 37.5262 | 0.74 |
| 2025-08-22 | 38.8475 | 38.1456 | 39.0950 | 37.6868 | 1.72 |
| 2025-08-25 | 38.5750 | 38.9319 | 39.0250 | 38.5222 | -0.70 |
| 2025-08-26 | 38.6150 | 38.5811 | 38.8850 | 38.3275 | 0.10 |
| 2025-08-27 | 38.6385 | 38.5839 | 38.7249 | 38.0774 | 0.06 |
| 2025-08-28 | 39.0950 | 38.5767 | 39.1467 | 38.5404 | 1.18 |
| 2025-08-29 | 39.6950 | 39.0361 | 40.0050 | 38.7090 | 1.53 |
| 2025-09-01 | 40.6996 | 39.7050 | 40.7850 | 39.5160 | 2.53 |
| 2025-09-02 | 40.9150 | 40.7542 | 40.9750 | 40.1307 | 0.53 |
| 2025-09-03 | 41.2150 | 40.8735 | 41.4850 | 40.6171 | 0.73 |
| 2025-09-04 | 40.6950 | 41.1801 | 41.2431 | 40.3947 | -1.26 |
| 2025-09-05 | 41.0050 | 40.6890 | 41.4350 | 40.5497 | 0.76 |
| 2025-09-08 | 41.3550 | 41.0050 | 41.6750 | 40.5132 | 0.85 |
| 2025-09-09 | 40.9050 | 41.3382 | 41.4984 | 40.7728 | -1.09 |
| 2025-09-10 | 41.1700 | 40.9085 | 41.3150 | 40.7155 | 0.65 |
| 2025-09-11 | 41.5850 | 41.1929 | 41.7850 | 40.8810 | 1.01 |
| 2025-09-12 | 42.1950 | 41.5695 | 42.4950 | 41.3931 | 1.47 |
| 2025-09-14 | 42.1035 | 42.2325 | 42.2425 | 42.0705 | -0.22 |
| 2025-09-15 | 42.7350 | 42.2050 | 42.7656 | 41.9966 | 1.50 |
| 2025-09-16 | 42.6245 | 42.6850 | 42.9950 | 42.2511 | -0.26 |
| 2025-09-17 | 42.0055 | 42.6235 | 42.6325 | 41.7955 | -1.45 |

[12]:
```
silver_price = silver.iloc[:,0]
silver_price = silver_price[silver_price.index.isin(dates)]
silver_price
```

[12]:
```
date
2025-09-05    41.005
2025-09-08    41.355
2025-09-09    40.905
2025-09-10    41.170
2025-09-11    41.585
2025-09-12    42.195
Name: price, dtype: float64
```

# Futures Contract Price

[13]:
```
SIZ25_settle = [41.902-.35, 41.902, 41.341, 41.6, 42.149, 42.83]
SIZ25_expiration_date = pd.to_datetime("2025-12-29")
SIZ25_days_to_exp = (SIZ25_expiration_date - dates[-1]).days
SIZ25 = pd.Series(SIZ25_settle, index=dates)
SIZ25
```

[13]:
```
2025-09-05    41.552
2025-09-08    41.902
2025-09-09    41.341
2025-09-10    41.600
2025-09-11    42.149
2025-09-12    42.830
dtype: float64
```

# Horizon

[14]:
```
SIZ25_days_to_exp = []

for day in range(len(dates)):
    SIZ25_days_to_exp.append((SIZ25_expiration_date - dates[day]).days)

SIZ25_days_to_exp = pd.Series(SIZ25_days_to_exp, index=dates)
SIZ25_days_to_exp
```

[14]:
```
2025-09-05    115
2025-09-08    112
2025-09-09    111
2025-09-10    110
2025-09-11    109
2025-09-12    108
dtype: int64
```

# Dividens

[15]:
```
silver_dividends = pd.Series(np.zeros(len(dates)), index=dates)
silver_dividends
```

[15]:
```
2025-09-05    0.0
2025-09-08    0.0
2025-09-09    0.0
2025-09-10    0.0
2025-09-11    0.0
2025-09-12    0.0
dtype: float64
```

# Theoretical Futures Price

[16]:
```
theoretical_price = silver_price * np.exp((SOFR_daily-silver_dividends) * SIZ25_days_to_exp)
theoretical_price
```

[16]:
```
date
2025-09-05    41.575504
2025-09-08    41.912764
2025-09-09    41.451737
2025-09-10    41.714067
2025-09-11    42.131967
2025-09-12    42.744866
dtype: float64
```

# Difference between Theoretical and Market Price

[17]:
```
SIZ25_difference = SIZ25 - theoretical_price
SIZ25_difference
```

[17]:
```
2025-09-05   -0.023504
2025-09-08   -0.010764
2025-09-09   -0.110737
2025-09-10   -0.114067
2025-09-11    0.017033
2025-09-12    0.085134
dtype: float64
```

# Risk Premium

[18]:
```
SIZ25_risk_premium = SIZ25_settle / silver_price - 1
SIZ25_risk_premium
```

[18]:
```
date
2025-09-05    0.013340
2025-09-08    0.013227
2025-09-09    0.010659
2025-09-10    0.010444
2025-09-11    0.013563
2025-09-12    0.015049
Name: price, dtype: float64
```

# Create a DataFrame with all the information

[19]:
```
SILVER = pd.DataFrame({
    "SOFR Rate": SOFR,
    "Horizon (days)": SIZ25_days_to_exp,
    "Silver Price": silver_price,
    "Market Settlement": SIZ25,
    "Theoretical Price": theoretical_price,
    "Difference": SIZ25_difference,
    "Risk Premium": SIZ25_risk_premium
})
SILVER
```

[19]:

| | SOFR Rate | Horizon (days) | Silver Price | Market Settlement | Theoretical Price | Difference | Risk Premium |
|---|---|---|---|---|---|---|---|
| 2025-09-05 | 4.42 | 115 | 41.005 | 41.552 | 41.575504 | -0.023504 | 0.013340 |
| 2025-09-08 | 4.40 | 112 | 41.355 | 41.902 | 41.912764 | -0.010764 | 0.013227 |
| 2025-09-09 | 4.40 | 111 | 40.905 | 41.341 | 41.451737 | -0.110737 | 0.010659 |
| 2025-09-10 | 4.39 | 110 | 41.170 | 41.600 | 41.714067 | -0.114067 | 0.010444 |
| 2025-09-11 | 4.41 | 109 | 41.585 | 42.149 | 42.131967 | 0.017033 | 0.013563 |
| 2025-09-12 | 4.41 | 108 | 42.195 | 42.830 | 42.744866 | 0.085134 | 0.015049 |

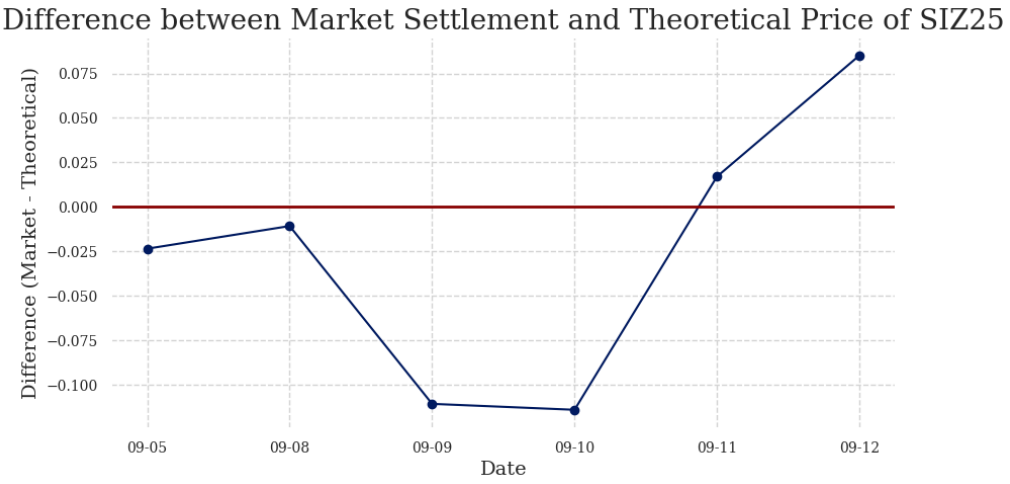
# Plot the table for LaTeX

[20]:
```
fig, ax = plt.subplots(figsize=(12, 6))
ax.axis('tight')
ax.axis('off')

# Include the index in the table
table_data = SILVER.reset_index()  # Reset index to include it as a column

# Rename the index column
table_data = table_data.rename(columns={"index": "Date"})
# show only the days, not the time
table_data['Date'] = table_data['Date'].dt.date

cell_text = table_data.round(4).values
col_labels = table_data.columns

the_table = ax.table(
    cellText=cell_text,
    colLabels=col_labels,
    loc='center',
    cellLoc='center'
)
the_table.auto_set_font_size(True)
the_table.set_fontsize(10)
the_table.scale(1.2, 1.8)

# Apply styles to the table
for key, cell in the_table.get_celld().items():
    cell.set_facecolor('#001a60')  # Set background color to blue
    cell.set_edgecolor('white')  # Set border color to white
    cell.set_text_props(color='white')  # Set font color to white

    # Make the Date and first column bold
    if key[1] == 0:  # Date column
        cell.set_text_props(weight='bold')
    # Make the first row (header) bold
    if key[0] == 0:  # Header row
        cell.set_text_props(weight='bold')

# Adjust layout to reduce margins
plt.tight_layout(pad=0.1)

plt.savefig("latex/figures/silver__pricing_over_the_week.pdf", bbox_inches='tight', pad_inches=0.2)
plt.show()
```

| Date | SOFR Rate | Horizon (days) | Silver Price | Market Settlement | Theoretical Price | Difference | Risk Premium |
|---|---|---|---|---|---|---|---|
| **2025-09-05** | 4.42 | 115 | 41.005 | 41.552 | 41.5755 | -0.0235 | 0.0133 |
| **2025-09-08** | 4.4 | 112 | 41.355 | 41.902 | 41.9128 | -0.0108 | 0.0132 |
| **2025-09-09** | 4.4 | 111 | 40.905 | 41.341 | 41.4517 | -0.1107 | 0.0107 |
| **2025-09-10** | 4.39 | 110 | 41.17 | 41.6 | 41.7141 | -0.1141 | 0.0104 |
| **2025-09-11** | 4.41 | 109 | 41.585 | 42.149 | 42.132 | 0.017 | 0.0136 |
| **2025-09-12** | 4.41 | 108 | 42.195 | 42.83 | 42.7449 | 0.0851 | 0.015 |

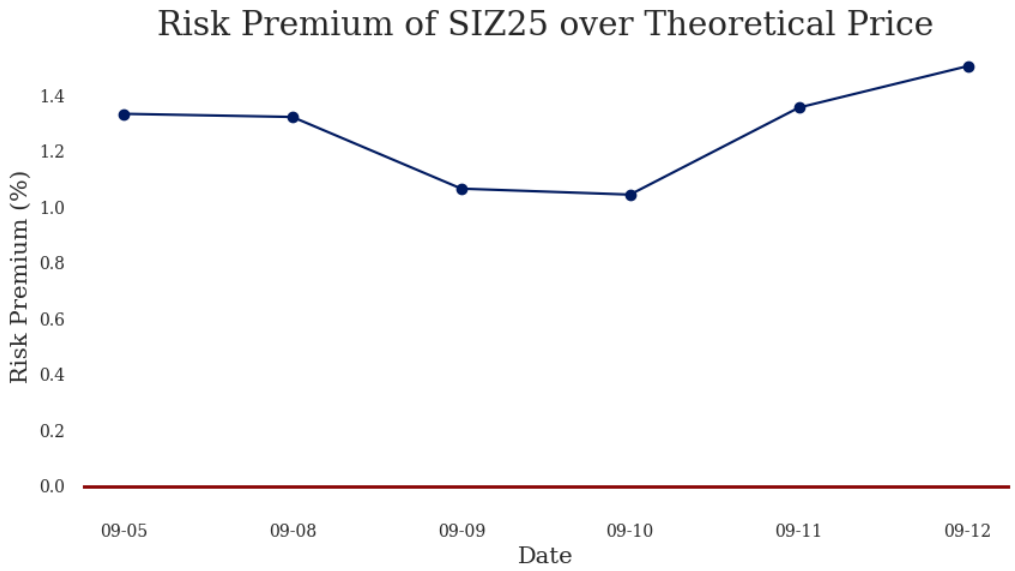
# Plot the difference between Theoretical and Market Price

[21]:
```
# plot a bar chart of the difference between theoretical and market price
plt.figure(figsize=(10, 5))
plt.plot(SILVER.index.strftime('%m-%d'), SILVER['Difference'], color='#001a60', marker='o')
plt.xlabel('Date')
plt.ylabel('Difference (Market - Theoretical)')
plt.title('Difference between Market Settlement and Theoretical Price of SIZ25')
plt.axhline(0, color='#880000', linestyle='-', linewidth=2)
plt.grid(True)
plt.savefig("latex/figures/silver_difference.pdf", bbox_inches='tight', pad_inches=0.2)
plt.show()
```



# Plot the risk premium

[22]:
```
# plot the risk premium
plt.figure(figsize=(10, 5))
plt.plot(SILVER.index.strftime('%m-%d'), SILVER['Risk Premium']*100, color='#001a60', marker='o')
plt.xlabel('Date')
plt.ylabel('Risk Premium (%)')
plt.title('Risk Premium of SIZ25 over Theoretical Price')
plt.axhline(0, color='#880000', linestyle='-', linewidth=2)
plt.grid(False)
plt.savefig("latex/figures/silver_risk_premium.pdf", bbox_inches='tight', pad_inches=0.2)
plt.show()
```



# Generalize the function for other derivatives

[23]:
```
def pricing_derivatives_over_time(SOFR, spot, name, futures_contract_settle,␣
↪futures_contract_expiration_date,
                                  spot_dividends=None):
    """
    futures_contract_settle = [41.902-.35, 41.902, 41.341, 41.6, 42.149, 42.83]
    futures_contract_expiration_date = pd.to_datetime("2025-12-29")
    """

    dates = SOFR.index

    SOFR_daily = (1 + SOFR/100)**(1/360) - 1
    SOFR_daily

    spot_price = spot.iloc[:,0]
    spot_price = spot_price[spot_price.index.isin(dates)]

    futures_contract_expiration_date = pd.to_datetime(futures_contract_expiration_date)
    futures_contract_days_to_exp = (futures_contract_expiration_date - dates[-1]).days
    futures_contract = pd.Series(futures_contract_settle, index=dates)


    futures_contract_days_to_exp = []
    for day in range(len(dates)):
        futures_contract_days_to_exp.append((futures_contract_expiration_date - dates[day]).days)
    futures_contract_days_to_exp = pd.Series(futures_contract_days_to_exp, index=dates)

    if spot_dividends is None:
        spot_dividends = pd.Series(np.zeros(len(dates)), index=dates)
    else :
```

```
        spot_dividends = spot_dividends[spot_dividends.index.isin(dates)]

    theoretical_price = spot_price * np.exp((SOFR_daily-spot_dividends) * futures_contract_days_to_exp)

    futures_contract_difference = futures_contract - theoretical_price
    futures_contract_risk_premium = futures_contract_settle / spot_price - 1

    spot = pd.DataFrame({
        "SOFR Rate": SOFR,
        "Horizon (days)": futures_contract_days_to_exp,
        f"{name} Price": spot_price,
        "Market Settlement": futures_contract,
        "Theoretical Price": theoretical_price,
        "Difference": futures_contract_difference,
        "Risk Premium": futures_contract_risk_premium
    })

    return spot

def plot_table(spot, name):
    # plot the table for LaTeX
    fig, ax = plt.subplots(figsize=(12, 6))
    ax.axis('tight')
    ax.axis('off')

    table_data = spot.reset_index()
    table_data = table_data.rename(columns={"index": "Date"})
    table_data['Date'] = table_data['Date'].dt.date

    cell_text = table_data.round(4).values
    col_labels = table_data.columns

    the_table = ax.table(
        cellText=cell_text,
        colLabels=col_labels,
        loc='center',
        cellLoc='center'
    )
    the_table.auto_set_font_size(True)
    the_table.set_fontsize(10)
    the_table.scale(1.2, 1.8)

    # Apply styles to the table
    for key, cell in the_table.get_celld().items():
        cell.set_facecolor('#001a60')  # Set background color to blue
        cell.set_edgecolor('white')  # Set border color to white
        cell.set_text_props(color='white')  # Set font color to white

        # Make the Date and first column bold
        if key[1] == 0:  # Date column
            cell.set_text_props(weight='bold')
        # Make the first row (header) bold
        if key[0] == 0:  # Header row
            cell.set_text_props(weight='bold')

    # Adjust layout to reduce margins
    plt.tight_layout(pad=0.1)
```

```
    plt.savefig(f"latex/figures/{name}_pricing_over_the_week.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()
    return spot

def plot_difference(spot, name):
    # plot a bar chart of the difference between theoretical and market price
    plt.figure(figsize=(10, 5))
    plt.plot(spot.index.strftime('%m-%d'), spot['Difference'], color='#001a60', marker='o')
    plt.xlabel('Date')
    plt.ylabel('Difference (Market - Theoretical)')
    plt.title('Difference between Market Settlement and Theoretical Price of futures_contract')
    plt.axhline(0, color='#880000', linestyle='-', linewidth=2)
    plt.grid(False)
    plt.savefig(f"latex/figures/{name}_difference.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()

def plot_risk_premium(spot, name):
    # plot the risk premium
    plt.figure(figsize=(10, 5))
    plt.plot(spot.index.strftime('%m-%d'), spot['Risk Premium']*100, color='#001a60', marker='o')
    plt.xlabel('Date')
    plt.ylabel('Risk Premium (%)')
    plt.title('Risk Premium of futures_contract over Theoretical Price')
    plt.axhline(0, color='#880000', linestyle='-', linewidth=2)
    plt.grid(False)
    plt.savefig(f"latex/figures/{name}_risk_premium.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()
```

# MXN/USD

# Futures Contract Price

[24]:
```
# MXN/USD (MPU25)
MPU25_settle = [.05357 - .00015, .05357, .05367, .05378, .05409, .05421]
MPU25 = pd.Series(MPU25_settle, index=dates)
MXNUSD_expiration_date = "2025-09-15"
MPU25
```

[24]:
```
2025-09-05    0.05342
2025-09-08    0.05357
2025-09-09    0.05367
2025-09-10    0.05378
2025-09-11    0.05409
2025-09-12    0.05421
dtype: float64
```

# Spot Price

[25]:
```
mxnusd = fetch_from_investing("https://www.investing.com/currencies/mxn-usd-historical-data")
mxnusd
```

```
C:\Users\herie\AppData\Local\Temp\ipykernel_27404\338722890.py:11:
FutureWarning: Passing literal html to 'read_html' is deprecated and will be
removed in a future version. To read from a literal string, wrap it in a
'StringIO' object.
  tables = pd.read_html(html, flavor="lxml")  # all tables, any locale
```

[25]:

| date | price | open | high | low | change_% |
|---|---|---|---|---|---|
| 2025-08-18 | 0.05323 | 0.05343 | 0.05345 | 0.05299 | -0.22 |
| 2025-08-19 | 0.05314 | 0.05324 | 0.05332 | 0.05299 | -0.17 |
| 2025-08-20 | 0.05328 | 0.05314 | 0.05341 | 0.05305 | 0.26 |
| 2025-08-21 | 0.05332 | 0.05321 | 0.05340 | 0.05314 | 0.08 |
| 2025-08-22 | 0.05375 | 0.05335 | 0.05386 | 0.05322 | 0.81 |
| 2025-08-25 | 0.05355 | 0.05381 | 0.05391 | 0.05347 | -0.37 |
| 2025-08-26 | 0.05358 | 0.05355 | 0.05372 | 0.05345 | 0.06 |
| 2025-08-27 | 0.05358 | 0.05357 | 0.05364 | 0.05319 | 0.00 |
| 2025-08-28 | 0.05361 | 0.05358 | 0.05376 | 0.05350 | 0.06 |
| 2025-08-29 | 0.05360 | 0.05363 | 0.05370 | 0.05341 | -0.02 |
| 2025-09-01 | 0.05362 | 0.05362 | 0.05376 | 0.05354 | 0.04 |
| 2025-09-02 | 0.05340 | 0.05364 | 0.05366 | 0.05299 | -0.41 |
| 2025-09-03 | 0.05346 | 0.05342 | 0.05361 | 0.05323 | 0.11 |
| 2025-09-04 | 0.05337 | 0.05345 | 0.05349 | 0.05317 | -0.17 |
| 2025-09-05 | 0.05343 | 0.05337 | 0.05382 | 0.05334 | 0.11 |
| 2025-09-08 | 0.05359 | 0.05343 | 0.05371 | 0.05336 | 0.30 |
| 2025-09-09 | 0.05370 | 0.05359 | 0.05381 | 0.05356 | 0.21 |
| 2025-09-10 | 0.05377 | 0.05369 | 0.05387 | 0.05360 | 0.13 |
| 2025-09-11 | 0.05417 | 0.05377 | 0.05421 | 0.05356 | 0.74 |
| 2025-09-12 | 0.05427 | 0.05416 | 0.05429 | 0.05399 | 0.18 |
| 2025-09-14 | 0.05420 | 0.05424 | 0.05424 | 0.05416 | -0.13 |
| 2025-09-15 | 0.05445 | 0.05421 | 0.05456 | 0.05416 | 0.46 |
| 2025-09-16 | 0.05468 | 0.05443 | 0.05474 | 0.05435 | 0.41 |
| 2025-09-17 | 0.05465 | 0.05467 | 0.05467 | 0.05464 | -0.04 |

# Pricing

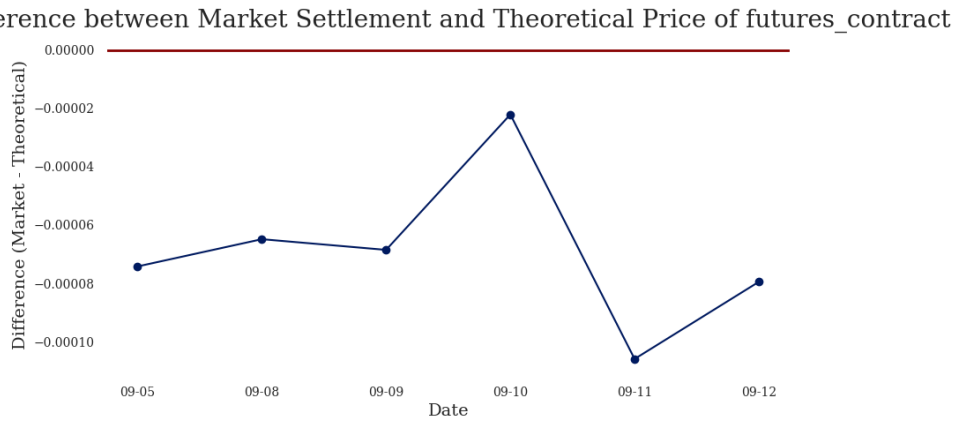
[26]:
```
MXNUSD = pricing_derivatives_over_time(SOFR, mxnusd, "mxnusd", MPU25_settle, MXNUSD_expiration_date)
MXNUSD
```

[26]:

| | SOFR Rate | Horizon (days) | mxnusd Price | Market Settlement | Theoretical Price | Difference | Risk Premium |
|---|---|---|---|---|---|---|---|
| 2025-09-05 | 4.42 | 10 | 0.05343 | 0.05342 | 0.053494 | -0.000074 | -0.000187 |
| 2025-09-08 | 4.40 | 7 | 0.05359 | 0.05357 | 0.053635 | -0.000065 | -0.000373 |
| 2025-09-09 | 4.40 | 6 | 0.05370 | 0.05367 | 0.053739 | -0.000069 | -0.000559 |
| 2025-09-10 | 4.39 | 5 | 0.05377 | 0.05378 | 0.053802 | -0.000022 | 0.000186 |
| 2025-09-11 | 4.41 | 4 | 0.05417 | 0.05409 | 0.054196 | -0.000106 | -0.001477 |
| 2025-09-12 | 4.41 | 3 | 0.05427 | 0.05421 | 0.054290 | -0.000080 | -0.001106 |

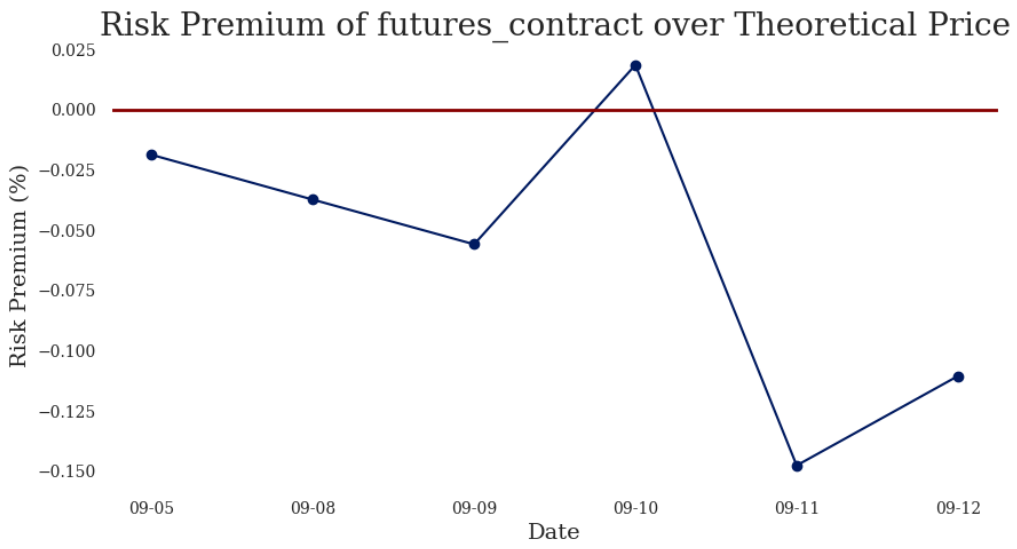
# Difference between Theoretical and Market Price

[27]:
```
plot_difference(MXNUSD, "mxnusd")
```



# Premium Risk

[28]:
```
plot_risk_premium(MXNUSD, "mxnusd")
```



# Crude Oil

# Futures Contract Price

[29]:
```
# Crude Oil Futures (CLV25)
CLV25_settle = [62.26-.39, 62.26, 62.63, 63.67, 62.37, 62.69]
CLV25_expiration_date = "2025-09-22"
CLV25 = pd.Series(CLV25_settle, index=dates)
CLV25
```

[29]:
```
2025-09-05    61.87
2025-09-08    62.26
2025-09-09    62.63
2025-09-10    63.67
2025-09-11    62.37
2025-09-12    62.69
dtype: float64
```

# Spot Price

[30]:
```
wti = fetch_from_investing("https://www.investing.com/commodities/crude-oil-historical-data")
wti
```

```
C:\Users\herie\AppData\Local\Temp\ipykernel_27404\338722890.py:11:
FutureWarning: Passing literal html to 'read_html' is deprecated and will be
removed in a future version. To read from a literal string, wrap it in a
'StringIO' object.
  tables = pd.read_html(html, flavor="lxml")  # all tables, any locale
```

[30]:

| date | price | open | high | low | change_% |
|---|---|---|---|---|---|
| 2025-08-18 | 63.42 | 63.00 | 63.79 | 62.18 | 0.99 |
| 2025-08-19 | 62.35 | 63.27 | 63.39 | 62.25 | -1.69 |
| 2025-08-20 | 63.21 | 62.60 | 63.55 | 62.39 | 1.38 |
| 2025-08-21 | 63.52 | 62.85 | 63.67 | 62.52 | 0.49 |
| 2025-08-22 | 63.66 | 63.50 | 63.93 | 63.31 | 0.22 |
| 2025-08-25 | 64.80 | 63.88 | 65.10 | 63.53 | 1.79 |
| 2025-08-26 | 63.25 | 64.75 | 64.76 | 63.13 | -2.39 |
| 2025-08-27 | 64.15 | 63.31 | 64.23 | 62.95 | 1.42 |
| 2025-08-28 | 64.60 | 63.87 | 64.70 | 63.35 | 0.70 |
| 2025-08-29 | 64.01 | 64.26 | 64.55 | 63.88 | -0.91 |
| 2025-08-31 | 63.96 | 63.98 | 64.01 | 63.92 | -0.08 |
| 2025-09-01 | 64.64 | 64.61 | 64.88 | 63.67 | 1.06 |
| 2025-09-02 | 65.59 | 63.95 | 66.03 | 63.66 | 1.47 |
| 2025-09-03 | 63.97 | 65.62 | 65.72 | 63.72 | -2.47 |
| 2025-09-04 | 63.48 | 63.82 | 63.84 | 62.72 | -0.77 |
| 2025-09-05 | 61.87 | 63.33 | 63.49 | 61.45 | -2.54 |
| 2025-09-08 | 62.26 | 62.00 | 63.34 | 61.85 | 0.63 |
| 2025-09-09 | 62.63 | 62.43 | 63.67 | 62.37 | 0.59 |
| 2025-09-10 | 63.67 | 62.74 | 64.08 | 62.72 | 1.66 |
| 2025-09-11 | 62.37 | 63.80 | 63.80 | 62.21 | -2.04 |
| 2025-09-12 | 62.69 | 62.27 | 63.98 | 61.69 | 0.51 |
| 2025-09-14 | 62.68 | 62.32 | 62.71 | 62.26 | -0.02 |
| 2025-09-15 | 63.30 | 62.97 | 63.67 | 62.52 | 0.99 |
| 2025-09-16 | 64.64 | 63.31 | 64.76 | 62.89 | 2.12 |
| 2025-09-17 | 64.39 | 64.63 | 64.64 | 64.39 | -0.39 |

# Pricing

[31]:
```
CRUDE_OIL = pricing_derivatives_over_time(SOFR, wti, "crude_oil", CLV25_settle, CLV25_expiration_date)
CRUDE_OIL
```

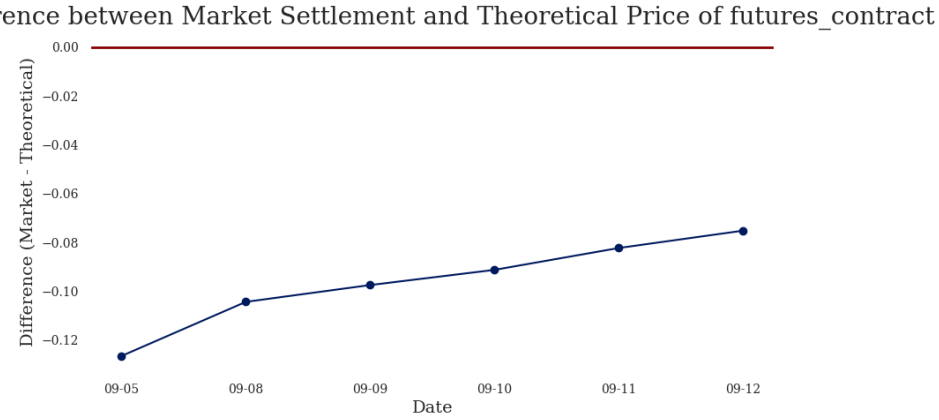
[31]:

| | SOFR Rate | Horizon (days) | crude_oil Price | Market Settlement | \ |
|---|---|---|---|---|---|
| 2025-09-05 | 4.42 | 17 | 61.87 | 61.87 | |
| 2025-09-08 | 4.40 | 14 | 62.26 | 62.26 | |
| 2025-09-09 | 4.40 | 13 | 62.63 | 62.63 | |
| 2025-09-10 | 4.39 | 12 | 63.67 | 63.67 | |
| 2025-09-11 | 4.41 | 11 | 62.37 | 62.37 | |
| 2025-09-12 | 4.41 | 10 | 62.69 | 62.69 | |

| | Theoretical Price | Difference | Risk Premium |
|---|---|---|---|
| 2025-09-05 | 61.996501 | -0.126501 | 0.0 |
| 2025-09-08 | 62.364350 | -0.104350 | 0.0 |
| 2025-09-09 | 62.727467 | -0.097467 | 0.0 |
| 2025-09-10 | 63.761254 | -0.091254 | 0.0 |
| 2025-09-11 | 62.452302 | -0.082302 | 0.0 |
| 2025-09-12 | 62.765200 | -0.075200 | 0.0 |

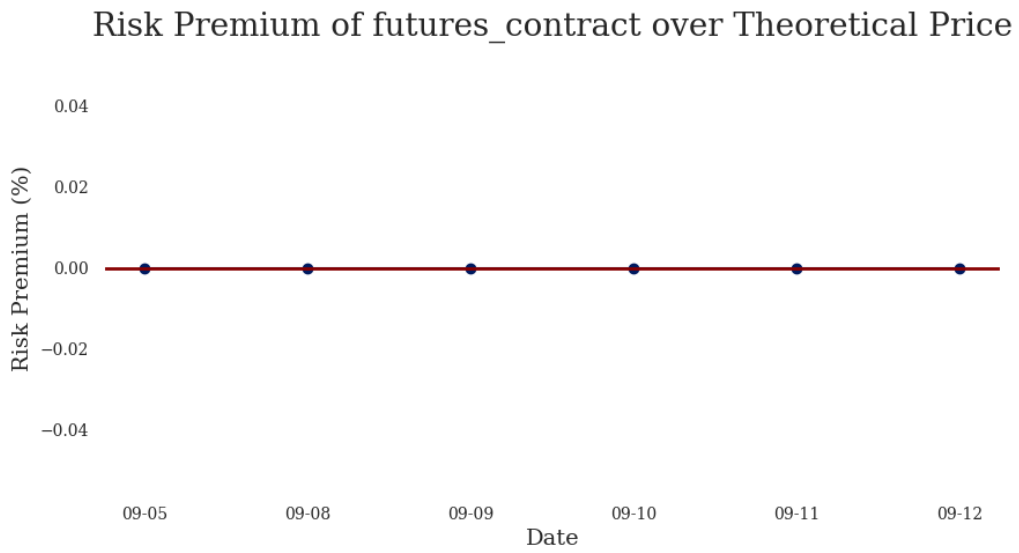
# Difference between Theoretical and Market Price

[32]:
```
plot_difference(CRUDE_OIL, "crude_oil")
```



# Premium Risk

[33]:
```
plot_risk_premium(CRUDE_OIL, "crude_oil")
```



# IPC

# Futures Contract Price

[34]:
```
# IPC Futures (IPCU25)
IPCU25_settle = [60814-92, 60814, 60759, 60685, 61614, 61758]
IPCU25_expiration_date = "2025-09-19"
IPCU25 = pd.Series(IPCU25_settle, index=dates)
IPCU25
```

[34]:
```
2025-09-05    60722
2025-09-08    60814
2025-09-09    60759
2025-09-10    60685
2025-09-11    61614
2025-09-12    61758
dtype: int64
```

# Stock Price

[35]:
```
import yfinance as yf


ipc = yf.download('^MXX', start='2020-01-01', end='2025-12-31')
ipc
```

```
C:\Users\herie\AppData\Local\Temp\ipykernel_27404\2632186628.py:4:
FutureWarning: YF.download() has changed argument auto_adjust default to True
  ipc = yf.download('^MXX', start='2020-01-01', end='2025-12-31')
[**********************100%**********************]  1 of 1 completed
```

[35]:

| Price | Close | High | Low | Open | Volume |
|---|---|---|---|---|---|
| Ticker | ^MXX | ^MXX | ^MXX | ^MXX | ^MXX |
| Date | | | | | |
| 2020-01-02 | 44437.230469 | 44521.519531 | 43716.488281 | 43739.519531 | 95180400 |
| 2020-01-03 | 44624.851562 | 44742.980469 | 44177.910156 | 44355.210938 | 103484500 |
| 2020-01-06 | 44495.300781 | 44571.738281 | 44287.128906 | 44489.968750 | 86928400 |
| 2020-01-07 | 44157.808594 | 44588.269531 | 44018.058594 | 44522.359375 | 137546300 |
| 2020-01-08 | 44470.910156 | 44515.988281 | 44078.410156 | 44160.550781 | 144629400 |
| … | … | … | … | … | … |
| 2025-09-09 | 60679.531250 | 60820.859375 | 60447.128906 | 60688.058594 | 172272600 |
| 2025-09-10 | 60489.191406 | 60987.351562 | 60431.628906 | 60643.140625 | 156040900 |
| 2025-09-11 | 61553.578125 | 61886.121094 | 60605.320312 | 60686.628906 | 201091300 |
| 2025-09-12 | 61798.941406 | 61941.988281 | 61535.960938 | 61596.890625 | 157237100 |
| 2025-09-15 | 62102.128906 | 0.000000 | 0.000000 | 0.000000 | 0 |

[1437 rows x 5 columns]

[36]:
```
monthly_dividends_expected = 0.04
```

[37]:
```
# Ensure IPCU25_expiration_date is a datetime object
IPCU25_expiration_date = pd.to_datetime(IPCU25_expiration_date)

# U in futures stands for the month of September

# Calculate days for expiration
days_for_expiration = (IPCU25_expiration_date - dates).days
days_for_expiration
```

[37]:
```
Index([14, 11, 10, 9, 8, 7], dtype='int64')
```

[38]:
```
expected_dividends = monthly_dividends_expected / 30 * days_for_expiration
expected_dividends = pd.Series(expected_dividends, index=dates)
```

[39]:
```
IPC = pricing_derivatives_over_time(SOFR, ipc, "ipc", IPCU25_settle, IPCU25_expiration_date,␣
 ↪expected_dividends)
IPC
```

[39]:

| | SOFR Rate | Horizon (days) | ipc Price | Market Settlement | \ |
|---|---|---|---|---|---|
| 2025-09-05 | 4.42 | 14 | 60479.761719 | 60722 | |
| 2025-09-08 | 4.40 | 11 | 60649.761719 | 60814 | |
| 2025-09-09 | 4.40 | 10 | 60679.531250 | 60759 | |
| 2025-09-10 | 4.39 | 9 | 60489.191406 | 60685 | |
| 2025-09-11 | 4.41 | 8 | 61553.578125 | 61614 | |
| 2025-09-12 | 4.41 | 7 | 61798.941406 | 61758 | |

| | Theoretical Price | Difference | Risk Premium |
|---|---|---|---|
| 2025-09-05 | 46649.282408 | 14072.717592 | 0.004005 |
| 2025-09-08 | 51681.410836 | 9132.589164 | 0.002708 |
| 2025-09-09 | 53168.667423 | 7590.332577 | 0.001310 |
| 2025-09-10 | 54355.122058 | 6329.877942 | 0.003237 |
| 2025-09-11 | 56573.106082 | 5040.893918 | 0.000982 |
| 2025-09-12 | 57939.078173 | 3818.921827 | -0.000662 |

[40]:
```
## add expected dividends to the dataframe on the 3 column
IPC['Expected Dividends'] = expected_dividends
```

[41]:
```
IPC
```

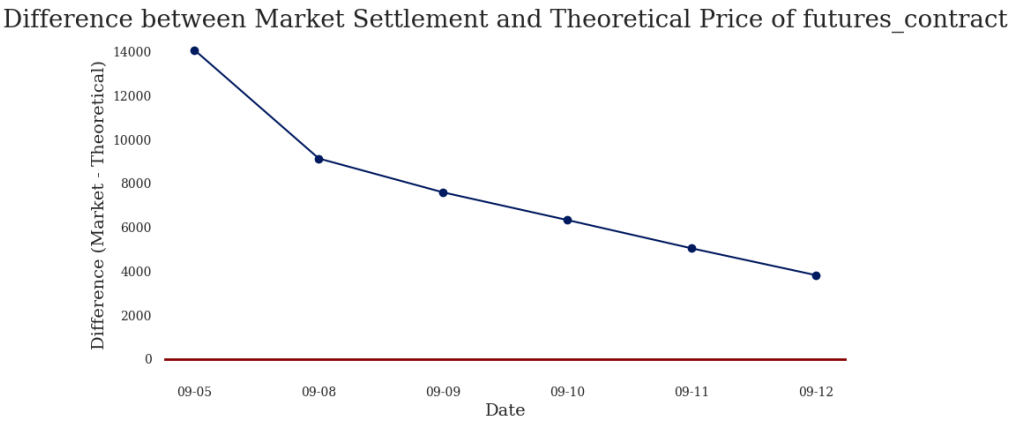
[41]:

| | SOFR Rate | Horizon (days) | ipc Price | Market Settlement | \ |
|---|---|---|---|---|---|
| 2025-09-05 | 4.42 | 14 | 60479.761719 | 60722 | |
| 2025-09-08 | 4.40 | 11 | 60649.761719 | 60814 | |
| 2025-09-09 | 4.40 | 10 | 60679.531250 | 60759 | |
| 2025-09-10 | 4.39 | 9 | 60489.191406 | 60685 | |
| 2025-09-11 | 4.41 | 8 | 61553.578125 | 61614 | |
| 2025-09-12 | 4.41 | 7 | 61798.941406 | 61758 | |

| | Theoretical Price | Difference | Risk Premium | Expected Dividends |
|---|---|---|---|---|
| 2025-09-05 | 46649.282408 | 14072.717592 | 0.004005 | 0.018667 |
| 2025-09-08 | 51681.410836 | 9132.589164 | 0.002708 | 0.014667 |
| 2025-09-09 | 53168.667423 | 7590.332577 | 0.001310 | 0.013333 |
| 2025-09-10 | 54355.122058 | 6329.877942 | 0.003237 | 0.012000 |
| 2025-09-11 | 56573.106082 | 5040.893918 | 0.000982 | 0.010667 |
| 2025-09-12 | 57939.078173 | 3818.921827 | -0.000662 | 0.009333 |

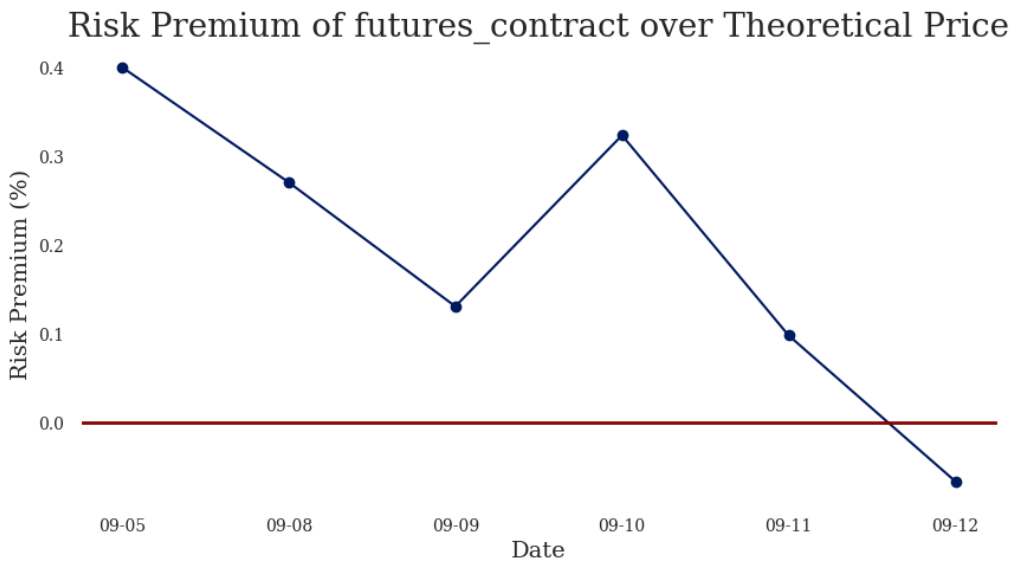
# Difference between Theoretical and Market Price

[42]:
```
plot_difference(IPC, "ipc")
```



# Premium Risk

[43]:
```
plot_risk_premium(IPC, "ipc")
```



# CORN

# Futures Contract Price

[44]:
```
# Corn Futures (CZ25)
CZ25_settle = [4216-36, 4216, 4196, 4170, 4196, 4300]
CZ25_expiration_date = "2025-12-12"
CZ25 = pd.Series(CZ25_settle, index=dates)
CZ25
```

[44]:
```
2025-09-05    4180
2025-09-08    4216
2025-09-09    4196
2025-09-10    4170
2025-09-11    4196
2025-09-12    4300
dtype: int64
```

# Spot Price

It is difficult to get reliable data for the spot price of corn.

# TIIE

# Futures Contract Price

[45]:
```
# TIIE Futures (TIEU26)
TIEU26_settle = [92.925-.07, 92.925, 92.955, 92.93, 92.965, 93.035]
TIEU26 = pd.Series(TIEU26_settle, index=dates)
TIEU26
```

[45]:
```
2025-09-05    92.855
2025-09-08    92.925
2025-09-09    92.955
2025-09-10    92.930
2025-09-11    92.965
2025-09-12    93.035
dtype: float64
```

[46]:
```
TIEU26_expiration_date = "2026-09-30"
TIEU26_expiration_date = pd.to_datetime(TIEU26_expiration_date)
days_for_expiration = (TIEU26_expiration_date - dates).days
days_for_expiration = pd.Series(days_for_expiration, index=dates)
days_for_expiration
```

[46]:
```
2025-09-05    390
2025-09-08    387
2025-09-09    386
2025-09-10    385
2025-09-11    384
2025-09-12    383
dtype: int64
```

# Spot Price

[47]:
```
# read the Sheet1 from tiie.xlsx
tiie = pd.read_excel("tiie.xlsx", sheet_name="Sheet1", index_col=0, parse_dates=True)
tiie
```

[47]:
```
            TIIE a 28 días, Tasa de interés en por ciento anual
Fecha
2006-01-02                                             8.5700
2006-01-03                                             8.5650
2006-01-04                                             8.5500
2006-01-05                                             8.5650
2006-01-06                                             8.5750
…                                                       …
2025-09-09                                             8.0126
2025-09-10                                             8.0126
2025-09-11                                             8.0126
2025-09-12                                             8.0126
2025-09-15                                             8.0126

[4955 rows x 1 columns]
```

[48]:
```
tiie = tiie[tiie.index.isin(dates)]
tiie = pd.Series(tiie.iloc[:,0], index=tiie.index)
tiie
```

[48]:
```
Fecha
2025-09-05    8.0226
2025-09-08    8.0226
2025-09-09    8.0126
2025-09-10    8.0126
2025-09-11    8.0126
2025-09-12    8.0126
Name: TIIE a 28 días, Tasa de interés en por ciento anual, dtype: float64
```

# Pricing

[49]:
```
theoretical_price_tiie = 100 - 100*((1 + tiie/100/360) ** days_for_expiration-1)*360/days_for_expiration
theoretical_price_tiie
```

[49]:
```
Fecha
2025-09-05    91.619424
2025-09-08    91.622265
2025-09-09    91.634107
2025-09-10    91.635051
2025-09-11    91.635995
2025-09-12    91.636939
dtype: float64
```

[50]:
```
difference_tiie = TIEU26 - theoretical_price_tiie
difference_tiie
```

[50]:
```
2025-09-05    1.235576
2025-09-08    1.302735
2025-09-09    1.320893
2025-09-10    1.294949
2025-09-11    1.329005
2025-09-12    1.398061
dtype: float64
```

[51]:
```
TIIE = pd.DataFrame({
    "Horizon (days)": days_for_expiration,
    "TIIE Rate": tiie,
    "Market Settlement": TIEU26,
    "Theoretical Price": theoretical_price_tiie,
    "Difference": difference_tiie
})
TIIE
```

[51]:
```
            Horizon (days)  TIIE Rate  Market Settlement  Theoretical Price  \
2025-09-05             390     8.0226             92.855          91.619424
2025-09-08             387     8.0226             92.925          91.622265
2025-09-09             386     8.0126             92.955          91.634107
2025-09-10             385     8.0126             92.930          91.635051
2025-09-11             384     8.0126             92.965          91.635995
2025-09-12             383     8.0126             93.035          91.636939

            Difference
2025-09-05    1.235576
2025-09-08    1.302735
2025-09-09    1.320893
2025-09-10    1.294949
2025-09-11    1.329005
2025-09-12    1.398061
```

[52]:
```
def tiie_pricing_derivatives_over_time(spot, name):
    # plot the table for LaTeX
    fig, ax = plt.subplots(figsize=(12, 6))
    ax.axis('tight')
    ax.axis('off')

    table_data = spot.reset_index()
```

```
    table_data = table_data.rename(columns={"index": "Date"})
    table_data['Date'] = table_data['Date'].dt.date

    cell_text = table_data.round(4).values
    col_labels = table_data.columns

    the_table = ax.table(
        cellText=cell_text,
        colLabels=col_labels,
        loc='center',
        cellLoc='center'
    )
    the_table.auto_set_font_size(True)
    the_table.set_fontsize(10)
    the_table.scale(1.2, 1.8)

    # Apply styles to the table
    for key, cell in the_table.get_celld().items():
        cell.set_facecolor('#001a60')  # Set background color to blue
        cell.set_edgecolor('white')  # Set border color to white
        cell.set_text_props(color='white')  # Set font color to white

        # Make the Date and first column bold
        if key[1] == 0:  # Date column
            cell.set_text_props(weight='bold')
        # Make the first row (header) bold
        if key[0] == 0:  # Header row
            cell.set_text_props(weight='bold')

    # save
    plt.tight_layout(pad=0.1)
    plt.savefig(f"latex/figures/{name}_pricing_over_the_week.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()
```

# Difference between Theoretical and Market Price

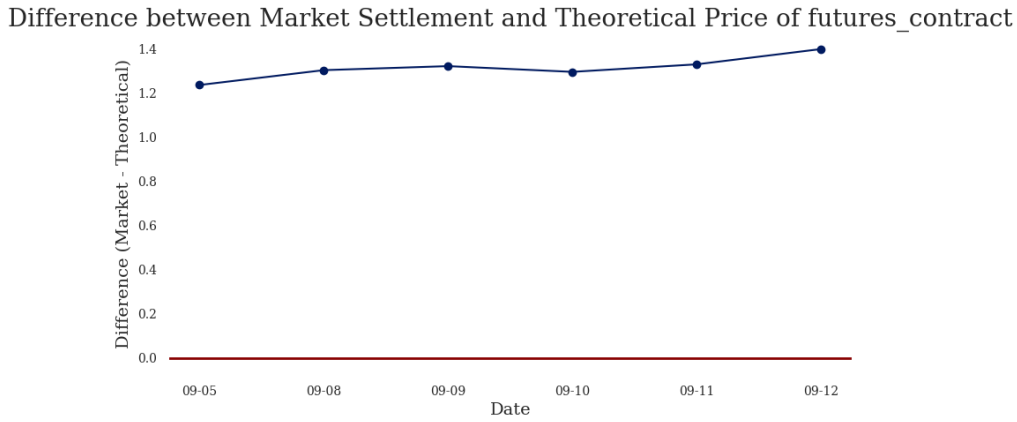
[53]:
```
tiie_pricing_derivatives_over_time(TIIE, "tiie")
```

| Date | Horizon (days) | TIIE Rate | Market Settlement | Theoretical Price | Difference |
|---|---|---|---|---|---|
| **2025-09-05** | 390 | 8.0226 | 92.855 | 91.6194 | 1.2356 |
| **2025-09-08** | 387 | 8.0226 | 92.925 | 91.6223 | 1.3027 |
| **2025-09-09** | 386 | 8.0126 | 92.955 | 91.6341 | 1.3209 |
| **2025-09-10** | 385 | 8.0126 | 92.93 | 91.6351 | 1.2949 |
| **2025-09-11** | 384 | 8.0126 | 92.965 | 91.636 | 1.329 |
| **2025-09-12** | 383 | 8.0126 | 93.035 | 91.6369 | 1.3981 |

[54]:
```
def plot_difference(spot, name):
    # Adjust layout to reduce margins
    plt.tight_layout(pad=0.1)

    plt.savefig(f"latex/figures/{name}_pricing_over_the_week.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()

    # plot a bar chart of the difference between theoretical and market price
    plt.figure(figsize=(10, 5))
    plt.plot(spot.index.strftime('%m-%d'), spot['Difference'], color='#001a60', marker='o')
    plt.xlabel('Date')
    plt.ylabel('Difference (Market - Theoretical)')
    plt.title('Difference between Market Settlement and Theoretical Price of futures_contract')
    plt.axhline(0, color='#880000', linestyle='-', linewidth=2)
    plt.grid(False)
    plt.savefig(f"latex/figures/{name}_difference.pdf", bbox_inches='tight', pad_inches=0.2)
    plt.show()
    return spot
```

[55]:
```
plot_difference(TIIE, "tiie")
```

```
<Figure size 800x800 with 0 Axes>
```




[55]:

| | Horizon (days) | TIIE Rate | Market Settlement | Theoretical Price | Difference |
|---|---|---|---|---|---|
| 2025-09-05 | 390 | 8.0226 | 92.855 | 91.619424 | 1.235576 |
| 2025-09-08 | 387 | 8.0226 | 92.925 | 91.622265 | 1.302735 |
| 2025-09-09 | 386 | 8.0126 | 92.955 | 91.634107 | 1.320893 |
| 2025-09-10 | 385 | 8.0126 | 92.930 | 91.635051 | 1.294949 |
| 2025-09-11 | 384 | 8.0126 | 92.965 | 91.635995 | 1.329005 |
| 2025-09-12 | 383 | 8.0126 | 93.035 | 91.636939 | 1.398061 |