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_21496\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_21496\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
2025-09-07	40.8645	41.0020	41.0055	40.7565	-0.34
2025-09-08	41.3550	41.0050	41.6750	40.5132	1.20
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	42.6165	42.2050	42.7656	41.9966	1.22
2025-09-16	42.5295	42.6175	42.7525	42.3505	-0.20

[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	\
2025-09-05	4.42	115	41.005	41.552	
2025-09-08	4.40	112	41.355	41.902	
2025-09-09	4.40	111	40.905	41.341	
2025-09-10	4.39	110	41.170	41.600	
2025-09-11	4.41	109	41.585	42.149	
2025-09-12	4.41	108	42.195	42.830	

	Theoretical Price	Difference	Risk Premium
2025-09-05	41.575504	-0.023504	0.013340
2025-09-08	41.912764	-0.010764	0.013227
2025-09-09	41.451737	-0.110737	0.010659
2025-09-10	41.714067	-0.114067	0.010444
2025-09-11	42.131967	0.017033	0.013563
2025-09-12	42.744866	0.085134	0.015049

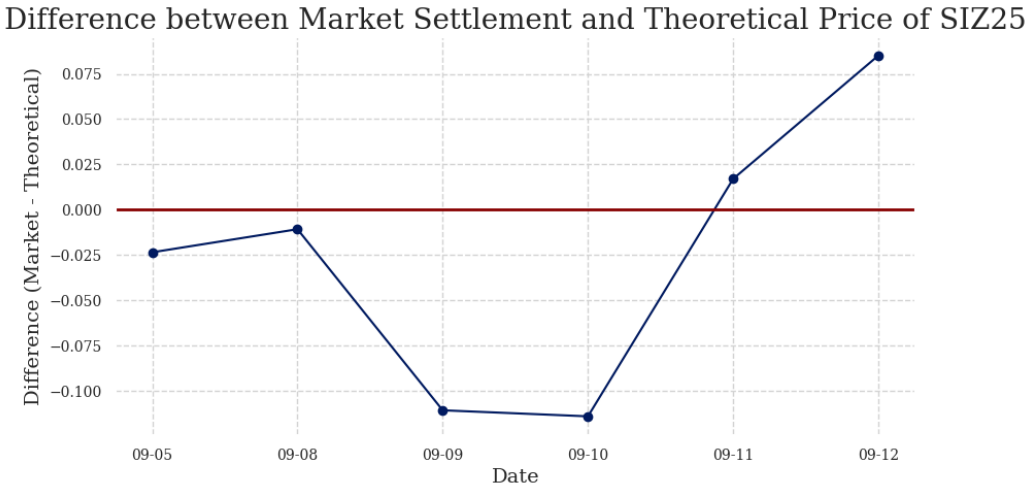
Plot the table for LaTeX

[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

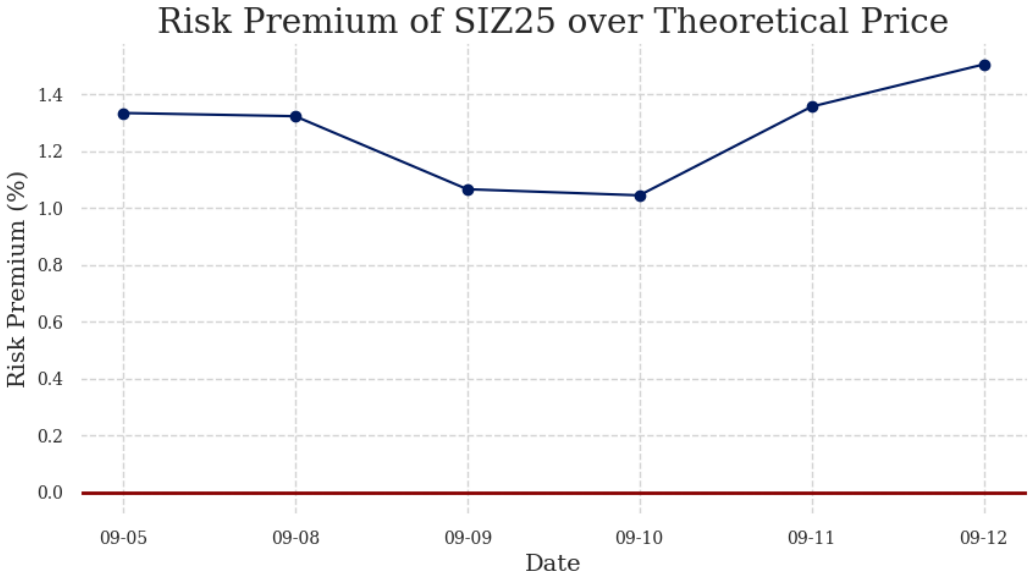
Plot the difference between Theoretical and Market Price

[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(True)
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_21496\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
2025-09-07	0.05339	0.05344	0.05349	0.05337	-0.07
2025-09-08	0.05359	0.05343	0.05371	0.05336	0.37
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	0.05448	0.05446	0.05449	0.05443	0.06

Pricing

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

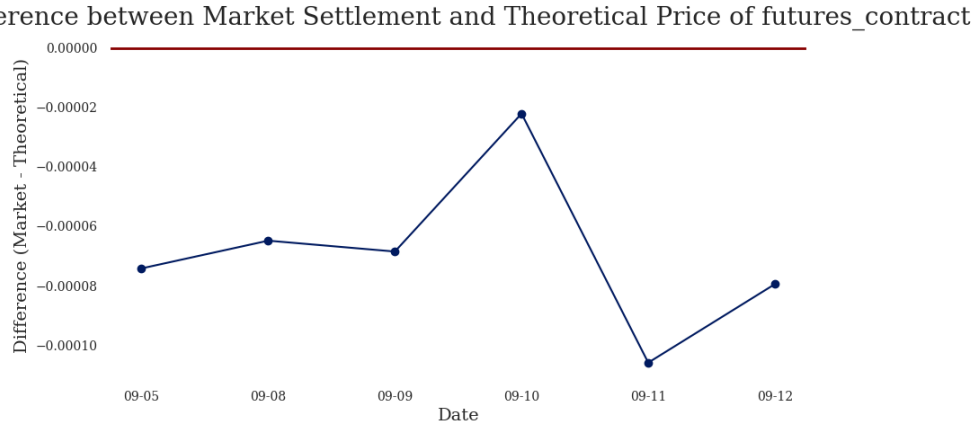
[26]:

	SOFR Rate	Horizon (days)	mxnusd Price	Market Settlement	\
2025-09-05	4.42	10	0.05343	0.05342	
2025-09-08	4.40	7	0.05359	0.05357	
2025-09-09	4.40	6	0.05370	0.05367	
2025-09-10	4.39	5	0.05377	0.05378	
2025-09-11	4.41	4	0.05417	0.05409	
2025-09-12	4.41	3	0.05427	0.05421	

	Theoretical Price	Difference	Risk Premium
2025-09-05	0.053494	-0.000074	-0.000187
2025-09-08	0.053635	-0.000065	-0.000373
2025-09-09	0.053739	-0.000069	-0.000559
2025-09-10	0.053802	-0.000022	0.000186
2025-09-11	0.054196	-0.000106	-0.001477
2025-09-12	0.054290	-0.000080	-0.001106

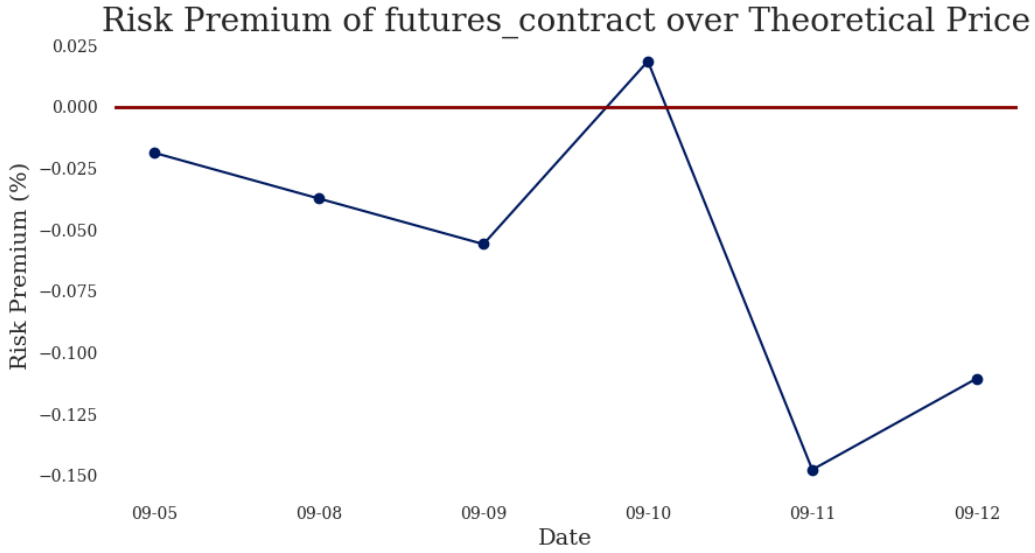
Difference between Theoretical and Market Price

[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_21496\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
2025-09-07	62.23	62.34	62.34	61.87	0.58
2025-09-08	62.26	62.00	63.34	61.85	0.05
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	63.33	63.32	63.67	62.52	1.04
2025-09-16	63.43	63.32	63.52	63.31	0.16

Pricing

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

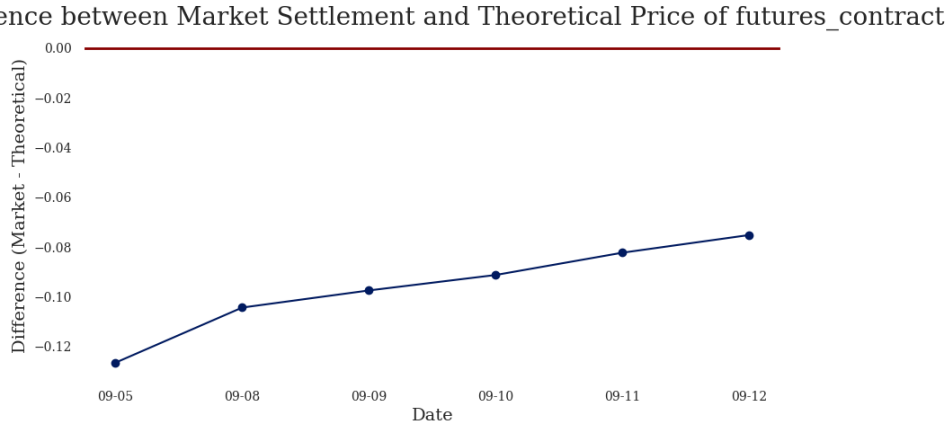
[31]:

	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

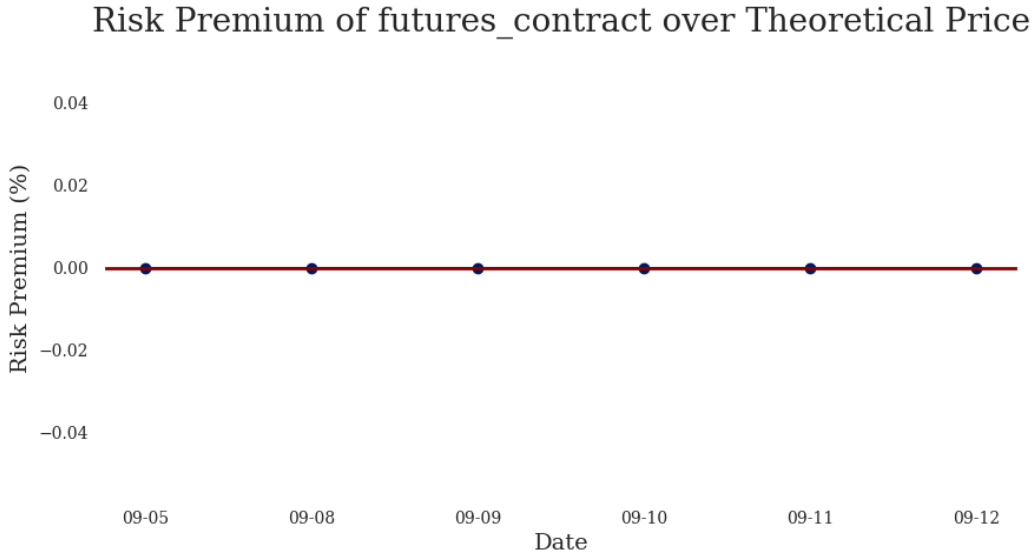
Difference between Theoretical and Market Price

[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_21496\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	62252.128906	61730.359375	61894.851562	134046507

[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
```

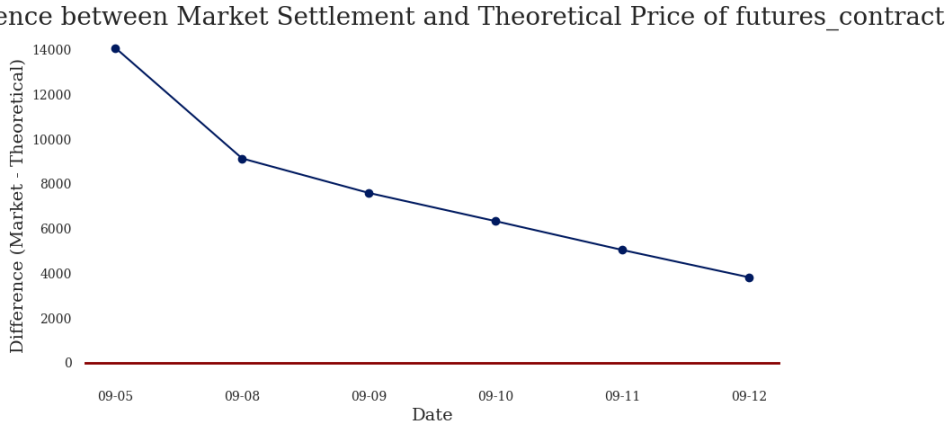
[39]:

	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

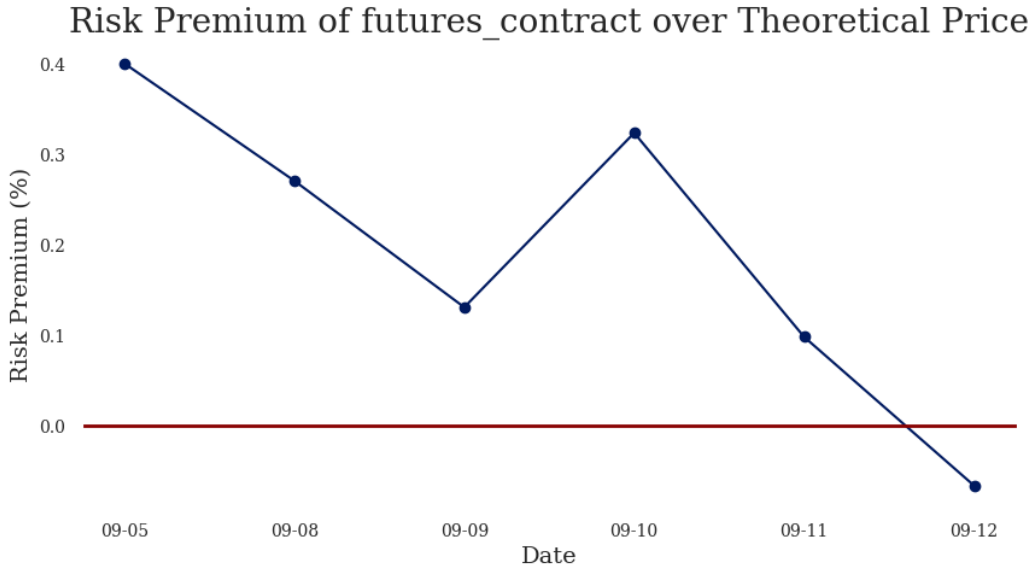
Difference between Theoretical and Market Price

[40]:
```
plot_difference(IPC, "ipc")
```



Premium Risk

[41]:
```
plot_risk_premium(IPC, "ipc")
```



CORN

Futures Contract Price

[42]:
```
# 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
```

[42]:
```
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

[43]:
```
# 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
```

[43]:
```
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
```

[44]:
```
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
```

[44]:
```
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

[45]:
```
# read the Sheet1 from tiie.xlsx
tiie = pd.read_excel("tiie.xlsx", sheet_name="Sheet1", index_col=0, parse_dates=True)
tiie
```

[45]:
```
            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]
```

[46]:
```
tiie = tiie[tiie.index.isin(dates)]
tiie = pd.Series(tiie.iloc[:,0], index=tiie.index)
tiie
```

[46]:
```
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

[47]:
```
theoretical_price_tiie = 100 - 100*((1 + tiie/100/360) ** days_for_expiration-1)*360/days_for_expiration
theoretical_price_tiie
```

[47]:
```
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
```

[48]:
```
difference_tiie = TIEU26 - theoretical_price_tiie
difference_tiie
```

[48]:
```
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
```

[49]:
```
TIIE = pd.DataFrame({
    "SOFR Rate": SOFR,
    "Horizon (days)": days_for_expiration,
    "TIIE Rate": tiie,
    "Market Settlement": TIEU26,
    "Theoretical Price": theoretical_price_tiie,
    "Difference": difference_tiie
})
TIIE
```

[49]:
```
            SOFR Rate  Horizon (days)  TIIE Rate  Market Settlement  \
2025-09-05       4.42             390     8.0226             92.855
2025-09-08       4.40             387     8.0226             92.925
2025-09-09       4.40             386     8.0126             92.955
2025-09-10       4.39             385     8.0126             92.930
2025-09-11       4.41             384     8.0126             92.965
2025-09-12       4.41             383     8.0126             93.035

            Theoretical Price  Difference
2025-09-05          91.619424    1.235576
2025-09-08          91.622265    1.302735
2025-09-09          91.634107    1.320893
2025-09-10          91.635051    1.294949
2025-09-11          91.635995    1.329005
2025-09-12          91.636939    1.398061
```

[50]:
```
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')
```

[51]:
```
tiie_pricing_derivatives_over_time(TIIE, "tiie")
```

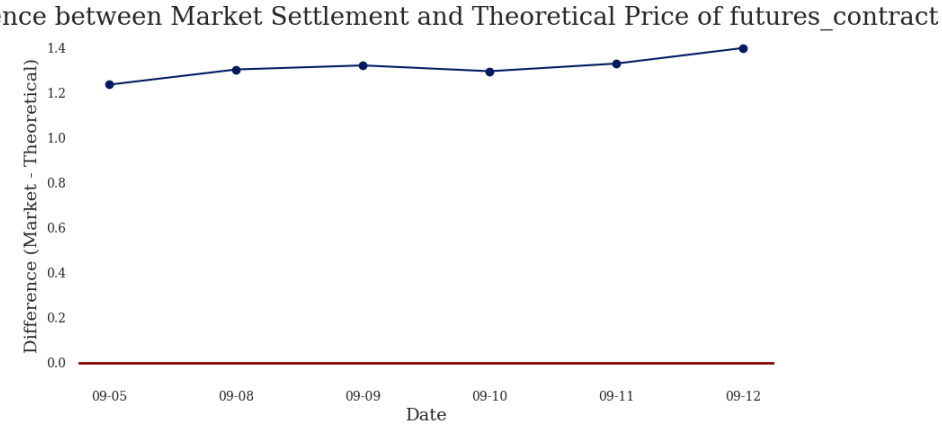
Date	SOFR Rate	Horizon (days)	TIIE Rate	Market Settlement	Theoretical Price	Difference
2025-09-05	4.42	390	8.0226	92.855	91.6194	1.2356
2025-09-08	4.4	387	8.0226	92.925	91.6223	1.3027
2025-09-09	4.4	386	8.0126	92.955	91.6341	1.3209
2025-09-10	4.39	385	8.0126	92.93	91.6351	1.2949
2025-09-11	4.41	384	8.0126	92.965	91.636	1.329
2025-09-12	4.41	383	8.0126	93.035	91.6369	1.3981

[52]:
```
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
```

Difference between Theoretical and Market Price

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

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



[53]:

	SOFR Rate	Horizon (days)	TIIE Rate	Market Settlement	Theoretical Price	Difference
2025-09-05	4.42	390	8.0226	92.855	91.619424	1.235576
2025-09-08	4.40	387	8.0226	92.925	91.622265	1.302735
2025-09-09	4.40	386	8.0126	92.955	91.634107	1.320893
2025-09-10	4.39	385	8.0126	92.930	91.635051	1.294949
2025-09-11	4.41	384	8.0126	92.965	91.635995	1.329005
2025-09-12	4.41	383	8.0126	93.035	91.636939	1.398061