In [10]:
```python
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import datetime as dt
import warnings

# Disable SettingWithCopyWarning
warnings.filterwarnings('ignore')
```

In [11]:
```python
# IMPORT DATA SETS
# 'm' = monthly data
# 'w' = weekly data
df_consumption_m = pd.read_excel('data/NG_CONS.xls', sheet_name='Data 1', header=2)
df_production_m = pd.read_excel('data/NG_PROD.xls', sheet_name='Data 1', header=2)
df_storage_w = pd.read_excel('data/NG_STOR.xls', sheet_name='Data 1', header=2)
df_price_m = pd.read_excel('data/NG_PRI_FUT_S1.xls', sheet_name='Data 1', header=2)
df_import_m = pd.read_excel('data/NG_MOVE_IMP.xls', sheet_name='Data 1', header=2)
df_export_m = pd.read_excel('data/NG_MOVE_EXP.xls', sheet_name='Data 1', header=2)
df_exportprice_m = pd.read_excel('data/NG_MOVE_EXP.xls', sheet_name='Data 2', header=2)
df_gdp_m = pd.read_excel('data/US-Monthly-GDP-History-Data.xlsx', sheet_name= 'Data')
```

In [12]:
```python
# ! Long processing time !

#https://www.cftc.gov/MarketReports/CommitmentsofTraders/HistoricalCompressed/index.htm

# Import Commitment of traders data from 2006-2016
df_cot_2006_2015_w = pd.read_excel('data/F_DisAgg06_15.xls')

# Import data from 2016-2024 in individual excel sheets
df_cot_2016_w = pd.read_excel('data/COT_2016.xls')
df_cot_2017_w = pd.read_excel('data/COT_2017.xls')
df_cot_2018_w = pd.read_excel('data/COT_2018.xls')
df_cot_2019_w = pd.read_excel('data/COT_2019.xls')
df_cot_2020_w = pd.read_excel('data/COT_2020.xls')
df_cot_2021_w = pd.read_excel('data/COT_2021.xls')
df_cot_2022_w = pd.read_excel('data/COT_2022.xls')
df_cot_2023_w = pd.read_excel('data/COT_2023.xls')
df_cot_2024_w = pd.read_excel('data/COT_2024.xls')
```

In [13]:
```python
# Join all COT data frames
df_cot_w = pd.concat([df_cot_2006_2015_w, df_cot_2016_w, df_cot_2017_w, df_cot_2018_w, df_cot_2019_w, df_cot_2020_w, df_cot_2021_w, df_cot_2022_w, df_cot_2023_w ,df_cot_
# Select only Henry Hub nat gas data
df_cot_w = df_cot_w.loc[df_cot_w['Market_and_Exchange_Names'] == 'HENRY HUB LAST DAY FIN - NEW YORK MERCANTILE EXCHANGE']
```

In [14]:
```python
#https://www.eia.gov/naturalgas/data.php

# Convert weekly storage to monthly
df_storage_w['Month'] = df_storage_w['Date'].dt.month
df_storage_w['Year'] = df_storage_w['Date'].dt.year
df_storage_m = df_storage_w.groupby(['Year', 'Month']).mean()

# Convert weekly COT to monthly
df_cot_w['Month'] = df_cot_w['Report_Date_as_MM_DD_YYYY'].dt.month
df_cot_w['Year'] = df_cot_w['Report_Date_as_MM_DD_YYYY'].dt.year
df_cot_m = df_cot_w.groupby(['Year', 'Month']).mean()

# Separate month and year from date in the rest of the dataframes to allow easy merging
df_consumption_m['Month'] = df_consumption_m['Date'].dt.month
df_consumption_m['Year'] = df_consumption_m['Date'].dt.year
df_consumption_m = df_consumption_m.groupby(['Year', 'Month']).mean()

df_production_m['Month'] = df_production_m['Date'].dt.month
df_production_m['Year'] = df_production_m['Date'].dt.year
df_production_m = df_production_m.groupby(['Year', 'Month']).mean()

df_price_m['Month'] = df_price_m['Date'].dt.month
df_price_m['Year'] = df_price_m['Date'].dt.year
df_price_m = df_price_m.groupby(['Year', 'Month']).mean()

df_import_m['Month'] = df_import_m['Date'].dt.month
df_import_m['Year'] = df_import_m['Date'].dt.year
df_import_m = df_import_m.groupby(['Year', 'Month']).mean()

df_export_m['Month'] = df_export_m['Date'].dt.month
df_export_m['Year'] = df_export_m['Date'].dt.year
df_export_m = df_export_m.groupby(['Year', 'Month']).mean()

df_exportprice_m['Month'] = df_exportprice_m['Date'].dt.month
df_exportprice_m['Year'] = df_exportprice_m['Date'].dt.year
df_exportprice_m = df_exportprice_m.groupby(['Year', 'Month']).mean()

#https://www.spglobal.com/marketintelligence/en/mi/products/us-monthly-gdp-index.html
df_gdp_m['Month'] = df_gdp_m['Date'].dt.month
df_gdp_m['Year'] = df_gdp_m['Date'].dt.year
df_gdp_m = df_gdp_m.groupby(['Year', 'Month']).mean()
```

In [15]:
```python
# Merge all data frames on Month and Year
df_full = df_cot_m.merge(df_production_m, on=['Month', 'Year']).merge(df_storage_m, on=['Month', 'Year']).merge(df_consumption_m, on=['Month', 'Year']).merge(df_price_m,

# Create new data frame of only desired columns from full data frame
df = df_full[['U.S. Natural Gas Imports (MMcf)', 'U.S. Natural Gas Exports (MMcf)', 'Weekly Lower 48 States Natural Gas Working Underground Storage (Billion Cubic Feet)'
#Add date column to data frame
df['Date'] = [dt.datetime(year, month, 1) for month, year in df['U.S. Natural Gas Imports (MMcf)'].index]

# Calculate net imports, actual storage change and estimated storage change based on values in data frame
df['Net_Imports_MMcf'] = df['U.S. Natural Gas Imports (MMcf)'] - df['U.S. Natural Gas Exports (MMcf)']
df['Storage_Change_MMcf'] = (df['Weekly Lower 48 States Natural Gas Working Underground Storage (Billion Cubic Feet)'].diff())*1000
df['Estimated_Storage_Change_MMcf'] = df['Net_Imports_MMcf'] + df['U.S. Natural Gas Marketed Production (MMcf)'] - df['U.S. Natural Gas Total Consumption (MMcf)']
```

In [16]:
```python
#Retrieve Temperature Data
from meteostat import Point, Daily
#Set start and end date for temperature data
start = dt.datetime(2011, 11, 1)
end = dt.datetime(2024, 1, 1)

# Create Point for Cities
newyork = Point(40.7143, -74.006)
chicago = Point(41.85, -87.65)
orlando = Point(28.5383, -81.3792)
denver = Point(39.7392, -104.9847)
oklahomacity = Point(35.4676, -97.5164)
knoxville = Point(35.9606, -83.9207)
losangeles = Point(34.0522, -118.2437)
seattle = Point(47.6062, -122.3321)
lasvegas = Point(36.175, -115.1372)
houston = Point(29.7633, -95.3633)

tempdf = pd.DataFrame()
# Get monthly data since 2011 and add to tempdf data frame
tempdf['new_york_t'] = Daily(newyork, start, end).fetch()['tavg']
tempdf['chicago_t'] = Daily(chicago, start, end).fetch()['tavg']
tempdf['orlando_t'] = Daily(orlando, start, end).fetch()['tavg']
tempdf['denver_t'] = Daily(denver, start, end).fetch()['tavg']
tempdf['oklahoma_city_t'] = Daily(oklahomacity, start, end).fetch()['tavg']
tempdf['knoxville_t'] = Daily(knoxville, start, end).fetch()['tavg']
tempdf['los_angeles_t'] = Daily(losangeles, start, end).fetch()['tavg']
tempdf['seattle_t'] = Daily(seattle, start, end).fetch()['tavg']
tempdf['las_vegas_t'] = Daily(lasvegas, start, end).fetch()['tavg']
tempdf['houston_t'] = Daily(houston, start, end).fetch()['tavg']


# Seperate month and year from date value for easy manipulation
tempdf['Month'] = tempdf.index.month
tempdf['Year'] = tempdf.index.year
```

In [17]:
```python
# Heating degree day function (HDD)
def hdd(x):
    hdd = (18 - x)
    if hdd < 0:
        hdd = 0
    return hdd
# Cooling degree day function (CDD)
def cdd(x):
    cdd = (x - 18)
    if cdd < 0:
        cdd = 0
    return cdd

# Apply functions to get daily HDD and CDD dataframes (excluding applying function to month and year)
daily_hdd = tempdf.iloc[:, :-2].applymap(hdd)
daily_cdd = tempdf.iloc[:, :-2].applymap(cdd)

# Add back month and year values to allow grouping by year and month
daily_hdd[['Month', 'Year']] = tempdf[['Month', 'Year']]
daily_cdd[['Month', 'Year']] = tempdf[['Month', 'Year']]

# Calculate monthly sums of EDD and CDD
monthly_hdd = daily_hdd.groupby(['Year', 'Month']).sum()
monthly_cdd = daily_cdd.groupby(['Year', 'Month']).sum()

# Rename columns appropiately adding _hdd and _cdd to allow for merging
monthly_hdd.columns = [col + '_hdd' for col in monthly_hdd.columns]
monthly_cdd.columns = [col + '_cdd' for col in monthly_cdd.columns]

# Merge two data frames into joint energy degree day data frame
edd_m = monthly_cdd.merge(monthly_hdd, on=['Year', 'Month'])

# Finally merge to dataframe containg rest of data
df = df.merge(edd_m, on=['Year', 'Month'])
```

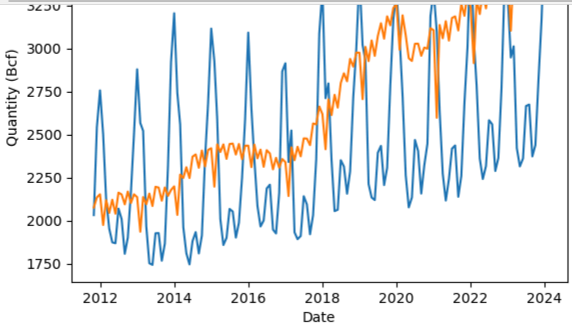
In [19]:
```python
# Retrieve US Population data set
#https://fred.stlouisfed.org/series/POPTHM
df_population_m = pd.read_excel('data/US_POP.xls', header=10)
# Seperate month and year from date value for easy manipulation
df_population_m['Month'] = df_population_m['observation_date'].dt.month
df_population_m['Year'] = df_population_m['observation_date'].dt.year
# Drop date to avoid unnecessary merging
df_population_m = df_population_m.drop(columns=['observation_date'])
df = df.merge(df_population_m, on=['Year', 'Month'])
```

In [20]:
```python
#Send all data to CSV
df.to_csv('output/clean_dataset.csv')
```

Summary

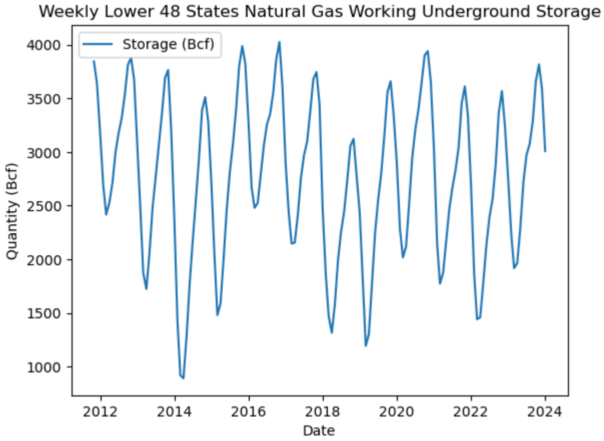
In [21]:

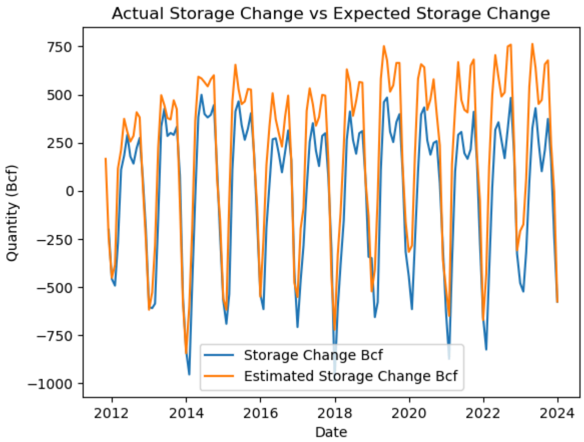
```
#Net exports as % of domestic production
plt.plot(df['Date'], (df['U.S. Natural Gas Exports (MMcf)'].values - df['U.S. Natural Gas Imports (MMcf)'].values)/df['U.S. Natural Gas Marketed Production (MMcf)'].valu
plt.xlabel('Date')
plt.ylabel('Proportion of Domestic Production')
plt.title('U.S. Natural Gas Net Exports Over Time as Proportion of Domestic Production')
plt.show()

#Spread between international and domestic price
plt.plot(df['Date'], df['Price of U.S. Natural Gas Exports (Dollars per Thousand Cubic Feet)'] - df['Henry Hub Natural Gas Spot Price (Dollars per Million Btu)'])
plt.xlabel('Date')
plt.ylabel('($) Per Thousand Cubic Feet')
plt.title('Price Spread Between International and Domestic Natural Gas')
plt.show()

#12 month average consumption index vs population index
plt.plot(df['Date'], (df['U.S. Natural Gas Total Consumption (MMcf)'].rolling(window=12).mean())/df['U.S. Natural Gas Total Consumption (MMcf)'][0], label = 'Natural Gas
plt.plot(df['Date'], (df['POPTHM'])/df['POPTHM'][0], label = 'US Population Index')
plt.plot(df['Date'], (df['Monthly Real GDP Index'])/df['Monthly Real GDP Index'][0], label = 'US Real GDP Index')

plt.xlabel('Date')
plt.ylabel('Index Value')
plt.title('U.S. Natural Gas Consumption 12-Month Average, Population, Real GDP Indexes')
plt.legend()
plt.show()

#Production vs consumption
plt.plot(df['Date'], df['U.S. Natural Gas Total Consumption (MMcf)']/1000, label = 'Natural Gas Total Consumption')
plt.plot(df['Date'], df['U.S. Natural Gas Marketed Production (MMcf)']/1000, label = 'Natural Gas Marketed Production')
plt.xlabel('Date')
plt.ylabel('Quantity (Bcf)')
plt.title('U.S. Natural Gas Total Consumption vs Production')
plt.legend()
plt.show()
```

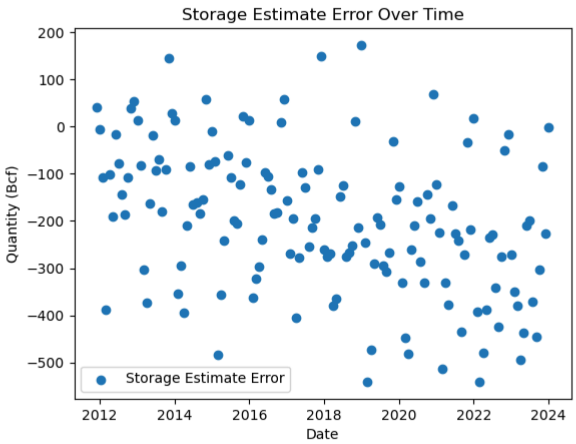


Storage

In [22]:
```python
# Regress predicted storage on actual storage and check that error term is mean zero homoskedastic
# Or just plot the difference between the two and check its mean zero homoskedastic
#Production vs consumption


plt.plot(df['Date'], df['Weekly Lower 48 States Natural Gas Working Underground Storage (Billion Cubic Feet)'], label = 'Storage (Bcf)')
plt.xlabel('Date')
plt.ylabel('Quantity (Bcf)')
plt.title('Weekly Lower 48 States Natural Gas Working Underground Storage')
plt.legend()
plt.show()

plt.plot(df['Date'], df['Storage_Change_MMcf']/1000, label = 'Storage Change Bcf')
plt.plot(df['Date'], df['Estimated_Storage_Change_MMcf']/1000, label = 'Estimated Storage Change Bcf')
plt.xlabel('Date')
plt.ylabel('Quantity (Bcf)')
plt.title('Actual Storage Change vs Expected Storage Change')
plt.legend()
plt.show()

plt.scatter(df['Date'], (df['Storage_Change_MMcf'] - df['Estimated_Storage_Change_MMcf'])/1000, label = 'Storage Estimate Error')
plt.xlabel('Date')
plt.ylabel('Quantity (Bcf)')
plt.title('Storage Estimate Error Over Time')
plt.legend()
plt.show()
```

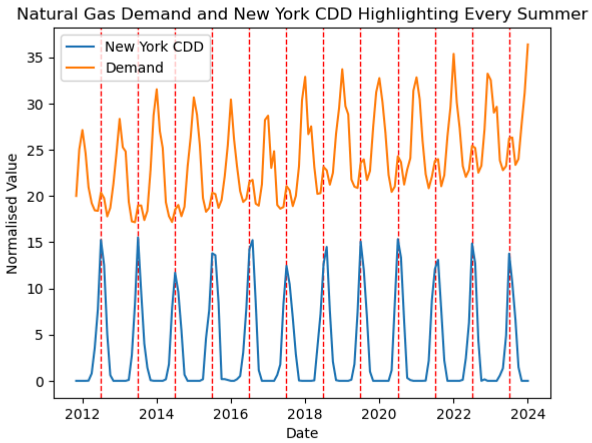


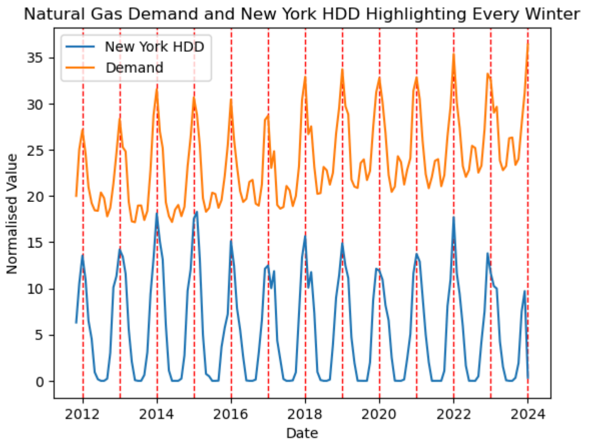




Temperature

In [23]:
```
import matplotlib.dates as mdates

plt.gca().xaxis.set_major_formatter(mdates.DateFormatter('%Y'))

# Add vertical lines every 6 months
for date in pd.date_range(start='2012-06-01', end='2024-01-01', freq='12M'):
    plt.axvline(x=date, color='r', linestyle='--', linewidth=1)

plt.plot(df['Date'], monthly_cdd['new_york_t_cdd'].values/18, label='New York CDD')
plt.plot(df['Date'], df['U.S. Natural Gas Total Consumption (MMcf)']*20/df['U.S. Natural Gas Total Consumption (MMcf)'][0], label='Demand')
plt.xlabel('Date')
plt.ylabel('Normalised Value')
plt.title('Natural Gas Demand and New York CDD Highlighting Every Summer')
plt.legend()
plt.show()

plt.gca().xaxis.set_major_formatter(mdates.DateFormatter('%Y'))

# Add vertical lines every 6 months
for date in pd.date_range(start='2011-12-01', end='2024-01-01', freq='12M'):
    plt.axvline(x=date, color='r', linestyle='--', linewidth=1)

plt.plot(df['Date'],monthly_hdd['new_york_t_hdd'].values/35, label='New York HDD')
plt.plot(df['Date'], df['U.S. Natural Gas Total Consumption (MMcf)']*20/df['U.S. Natural Gas Total Consumption (MMcf)'][0], label='Demand')
plt.xlabel('Date')
plt.ylabel('Normalised Value')
plt.title('Natural Gas Demand and New York HDD Highlighting Every Winter')
plt.legend()
plt.show()
```





COT

In [24]:
```
# Regress price on net COT positions, what is the relationship, what is the inference
# Done in stata or python_regression.jpynb
```

Full Model

In [26]:
```
# Full regression model output completed in stata or python_regression.jpynb
df_regression = pd.read_excel('output/regression_output.xlsx')

plt.plot(df['Date'], df_regression['lnprice'], label = 'ln(Price)')
plt.plot(df['Date'], df_regression['lnpred_price'], label = 'ln(Predicted Price)')

plt.xlabel('Date')
plt.ylabel('ln(Price) $')
plt.title('Regression Predicted Natural Log Price vs Natural Log Actual Price')
plt.legend()
plt.show()
```