Regime Modeling with NLP

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Install External Modules

[1]:
```
# !pip install finbert-embedding
# !pip install gensim
# !pip install hmmlearn
# !pip install numpy==1.21.4
# !pip install pandas==1.5.1
# !pip install pyldavis
# !pip install seaborn
# !pip install torch torchvision torchaudio
# !pip install transformers
# !pip install yahoofinance
```

Imports/Settings

Macro Variables

[2]:
```
# Set LDA_IMPORT flag to True only if you have the correct version of Pandas␣
 ↪installed!
LDA_IMPORT = False
```

Import External Modules

[3]:
```
import warnings
warnings.filterwarnings('ignore')
```

[4]:
```
from datetime import datetime
from finbert_embedding.embedding import FinbertEmbedding
import matplotlib.cm as cm
import matplotlib.patches as mpatches
import matplotlib.pyplot as plt
from matplotlib.ticker import PercentFormatter
import nltk
nltk.download("stopwords")
from nltk.corpus import stopwords
```

```
import numpy as np
import os
import pandas as pd
if LDA_IMPORT:
    import pyLDAvis
import seaborn as sns
from sklearn import preprocessing
from sklearn.cluster import KMeans
from sklearn.feature_extraction.text import CountVectorizer, ENGLISH_STOP_WORDS
import sys
```

```
[nltk_data] Downloading package stopwords to
[nltk_data]     C:\Users\dhruv\AppData\Roaming\nltk_data…
[nltk_data]   Package stopwords is already up-to-date!
```

Import Internal Modules

[5]:

```
sys.path.append(os.getcwd() + '/modules')
from modules.cross_validation import Pipeline, CustomCrossValidation
from modules.data import *
from modules.directional_change import *
from modules.hidden_markov_model import make_regime_plots, fit_hmm
from modules.kmeans import *
from modules.logistic_regression import do_all_LR
from modules.NaiveBayesClassifier import *
from modules.svm import do_all_SVM
from modules.text_preprocessing import *
from modules.topic_modeling import *
from modules.trading_strategy import *
from modules.visualization import *
```

```
[nltk_data] Downloading package stopwords to
[nltk_data]     C:\Users\dhruv\AppData\Roaming\nltk_data…
[nltk_data]   Package stopwords is already up-to-date!
```

[6]:

```
plt.style.use('seaborn')
sns.set_theme()
```

Assign Train/Test Dates

[7]:

```
period_start = datetime(1985, 1, 1)
period_end = datetime(2023, 6, 30)

train_start = datetime(1985, 1, 1)
train_end = datetime(2019, 12, 31)
test_start = datetime(2020, 1, 1)
test_end = datetime(2023, 6, 30)
```

Unsupervised Learning

Natural Language Processing

Text Data - Reading

[8]:

```
FOMC_FPATH = '../fomc_documents/fomc_documents.csv'
# FOMC_PATH = 'data/fomc_documents.csv'
```

[ ]:

```
fomc_data = get_text_data(fpath=FOMC_FPATH)
fomc_data
```

Text Data - Pre-Processing

[ ]:

```
# Remove names
fomc_data.text = fomc_data.text.apply(remove_names_from_minutes)

# Remove stop-words
fomc_data.text = fomc_data.text.apply(tokenizer_wo_stopwords)

# Set index as meeting_date
fomc_data.set_index('meeting_date', inplace=True)

fomc_data
```

[11]:

```
# Define train and test data
train_data = fomc_data[(fomc_data.index >= train_start) & (fomc_data.index <=␣
 ↪train_end)]
test_data = fomc_data[(fomc_data.index >= test_start) & (fomc_data.index <=␣
 ↪test_end)]
```

Label Generation

TF-IDF Values Computation

[12]:

```
# Compute TF-IDF values
tfidf_class = TF_IDF(X_train=train_data.text, X_test=test_data.text)

tfidf_class.fit_manual()
tfidf_class.fit_gensim()
```

K-Means Clustering on TF-IDF Values

[13]:

```
# Train KMeans Clustering
model_kmeans = KMeansCluster(
    k=2,
    X_train=preprocessing.normalize(tfidf_class.tfidf_gensim_train),
    X_test=preprocessing.normalize(tfidf_class.tfidf_gensim_test),
)
model_kmeans.fit()
model_kmeans.predict()
```

[14]:

```
display(pd.merge(
    left=model_kmeans.sizes_train_df,
    right=model_kmeans.sizes_test_df,
    left_index=True,
    right_index=True,
    suffixes=('_TRAIN', '_TEST'),
)['CLUSTER_SIZE_TRAIN'])
```

```
CLUSTER
0    177
1    104
Name: CLUSTER_SIZE_TRAIN, dtype: int32
```

[ ]:

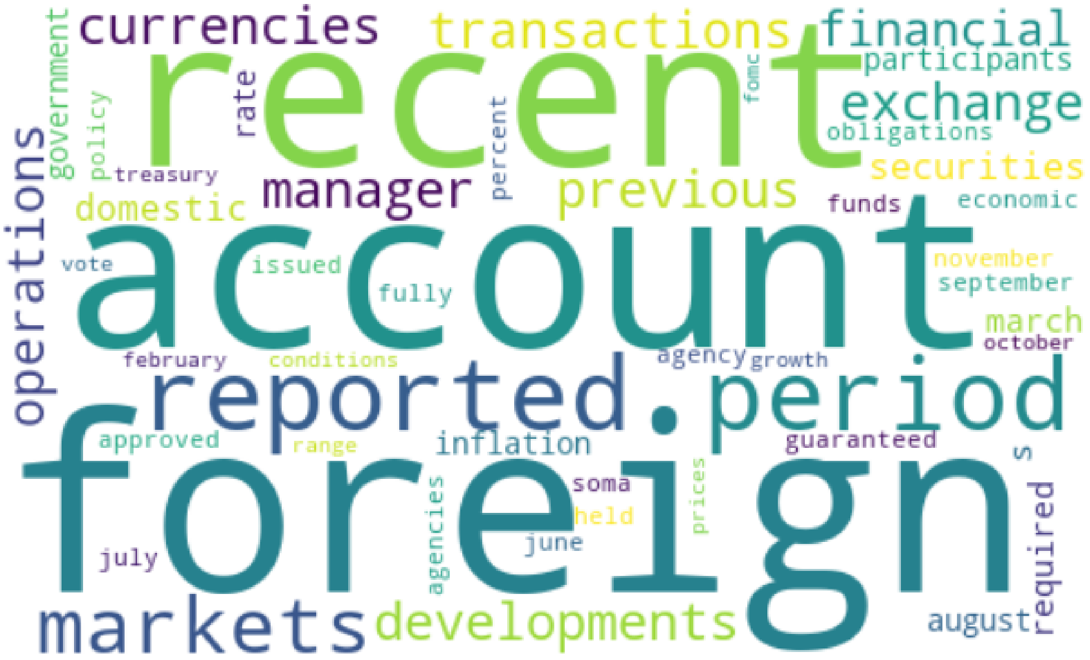
```
assert model_kmeans.labels_.shape[0] == train_data.shape[0]
assert model_kmeans.y_test_pred.shape[0] == test_data.shape[0]

nlp_regimes_train = pd.DataFrame.from_dict({
    'NLP_Regimes': model_kmeans.labels_
}).set_index(train_data.index)
nlp_regimes_test = pd.DataFrame.from_dict({
    'NLP_Regimes': model_kmeans.y_test_pred
}).set_index(pd.to_datetime(test_data.index))

display(nlp_regimes_train)
# display(nlp_regimes_test)
```

Wordclouds using Training Labels

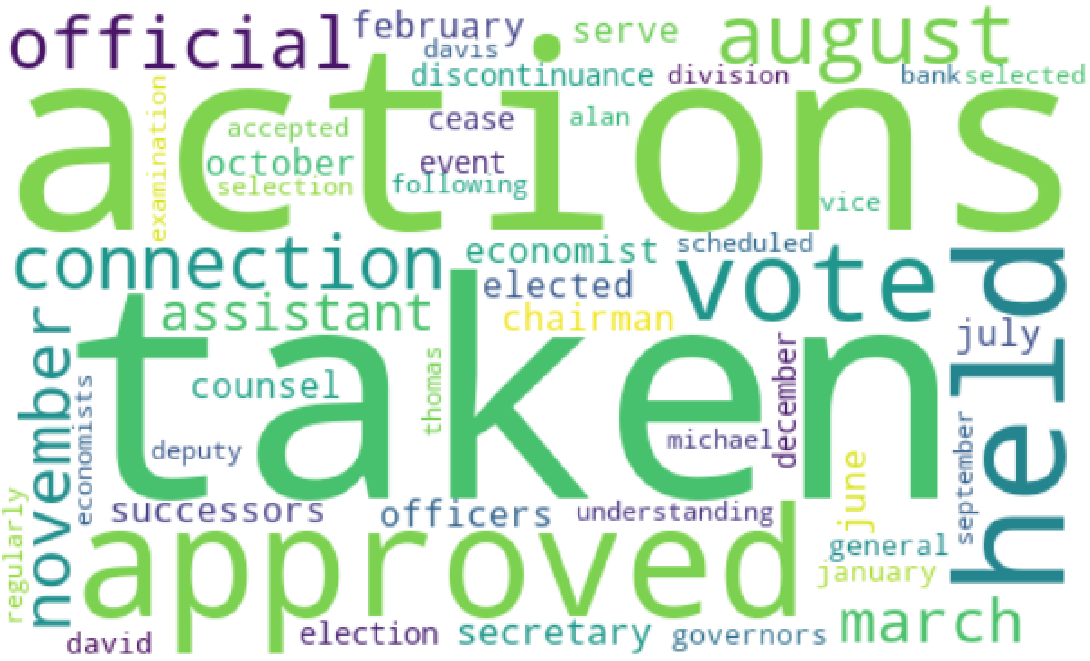
[16]:

```
wordcloud_clusters(
    model_kmeans.model,
    preprocessing.normalize(tfidf_class.tfidf_gensim_train),
    tfidf_class.dict_gensim_statements,
)
```

Cluster = 0



Cluster = 1



Feature Generation

Topic Modeling (CV Scoring)

[17]:

```
X_test = tfidf_class.X_test.apply(tokenizer_wo_stopwords).apply(lambda x: x.
  ↪split(" "))
bow_test = [tfidf_class.dict_gensim_statements.doc2bow(text) for text in X_test]

topicmod = TopicModel(
    tfidf_class.tfidf_statements_train,
    tfidf_class.dict_gensim_statements,
    tfidf_class.X_train.apply(tokenizer_wo_stopwords).apply(lambda x: x.split("␣
  ↪")).tolist(),
    bow_test,
)

topicmod.fit_predict()
```

[18]:

```
topicmod.num_topic
```

[18]:

```
10
```

[19]:

```
topicmod.cv_topics_list
```

[19]:

```
[(10, 0.4962291321541573),
 (5, 0.48200517385359387),
 (7, 0.45150784480669054),
 (2, 0.3560655730463756)]
```

[20]:

```
# pdf_test = topicmod.pdf_test
print(topicmod.pdf_test.shape)
```

```
(28, 10)
```

[21]:

```
topic_models_train = pd.DataFrame(
    topicmod.doc_mat,
    columns=[f"Topic_{i}" for i in range(10)],
    index=tfidf_class.X_train.index
)

topic_models_test = pd.DataFrame(
    topicmod.pdf_test,
    columns=[f"Topic_{i}" for i in range(10)],
    index=tfidf_class.X_test.index
)
```

Top 10 Words by Topic

[22]:

```
print("Top 10 words for topics")
topicmod.cv_model.show_topics(num_words=10)
```

```
Top 10 words for topics
```

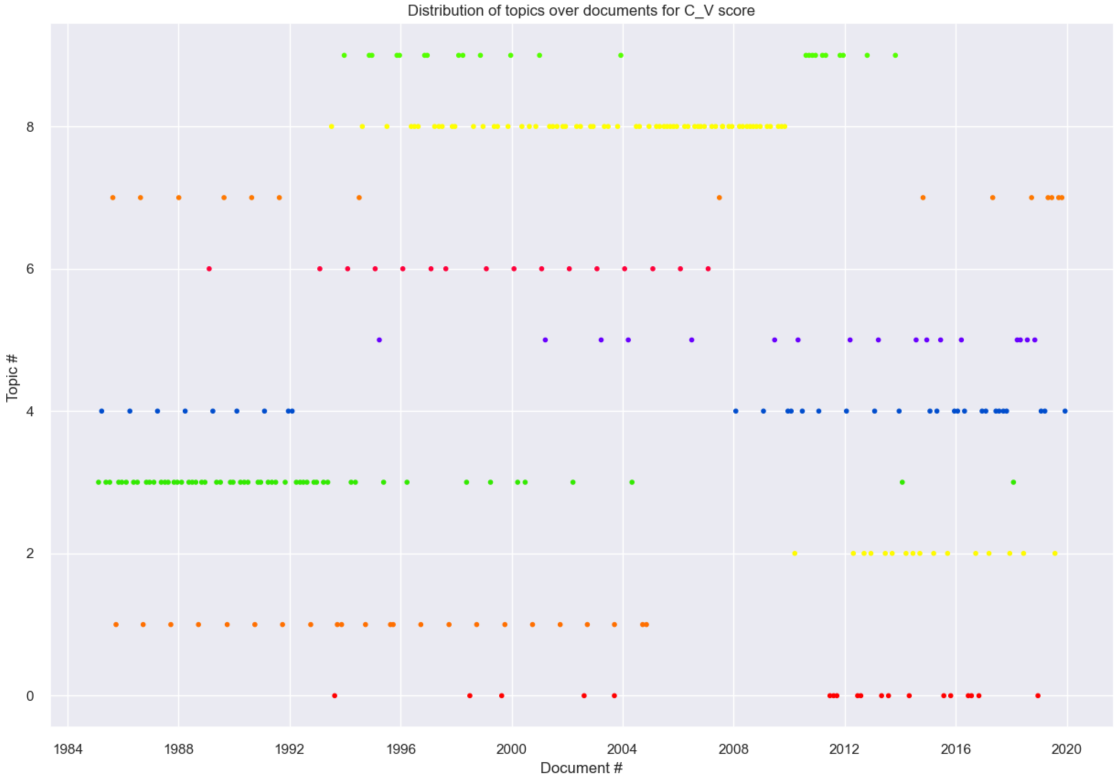
[22]:

```
[(0,
  '0.031*"june" + 0.011*"inflation" + 0.009*"economic" + 0.009*"labor" +
0.008*"policy" + 0.007*"pace" + 0.007*"conditions" + 0.006*"participants" +
0.006*"growth" + 0.006*"quarter"'),
 (1,
  '0.067*"august" + 0.036*"september" + 0.018*"april" + 0.013*"s" +
0.009*"inflation" + 0.009*"participants" + 0.008*"business" + 0.008*"selection"
+ 0.008*"agency" + 0.007*"obligations"'),
 (2,
  '0.027*"participants" + 0.021*"projections" + 0.018*"financial" + 0.017*"rate"
+ 0.017*"percent" + 0.016*"inflation" + 0.014*"domestic" + 0.011*"october" +
0.010*"appropriate" + 0.009*"unemployment"'),
 (3,
  '0.089*"taken" + 0.081*"actions" + 0.064*"march" + 0.057*"february" +
0.056*"approved" + 0.052*"held" + 0.033*"vote" + 0.021*"chairman" +
0.018*"required" + 0.016*"august"'),
 (4,
  '0.014*"deputy" + 0.011*"secretary" + 0.011*"assistant" + 0.011*"counsel" +
0.010*"economist" + 0.010*"rate" + 0.009*"general" + 0.009*"rates" +
0.008*"continued" + 0.008*"policy"'),
 (5,
  '0.018*"soma" + 0.013*"inflation" + 0.013*"january" + 0.011*"participants" +
0.011*"rate" + 0.010*"economic" + 0.008*"policy" + 0.007*"financial" +
0.007*"growth" + 0.007*"guaranteed"'),
 (6,
  '0.039*"connection" + 0.037*"official" + 0.020*"discontinuance" +
0.019*"officers" + 0.019*"cease" + 0.019*"successors" + 0.019*"event" +
0.018*"elected" + 0.017*"election" + 0.016*"governors"'),
 (7,
  '0.022*"taken" + 0.020*"actions" + 0.020*"july" + 0.016*"november" +
0.014*"rate" + 0.009*"participants" + 0.009*"economic" + 0.009*"funds" +
0.008*"policy" + 0.007*"range"'),
 (8,
  '0.074*"foreign" + 0.060*"account" + 0.055*"previous" + 0.052*"exchange" +
0.052*"currencies" + 0.050*"recent" + 0.048*"period" + 0.046*"reported" +
0.044*"operations" + 0.044*"markets"'),
 (9,
  '0.050*"november" + 0.033*"september" + 0.019*"securities" +
0.017*"transactions" + 0.017*"treasury" + 0.016*"july" + 0.015*"desk" +
0.013*"met" + 0.013*"fomc" + 0.013*"required"')]
```

Topic Distribution by Time

[23]:

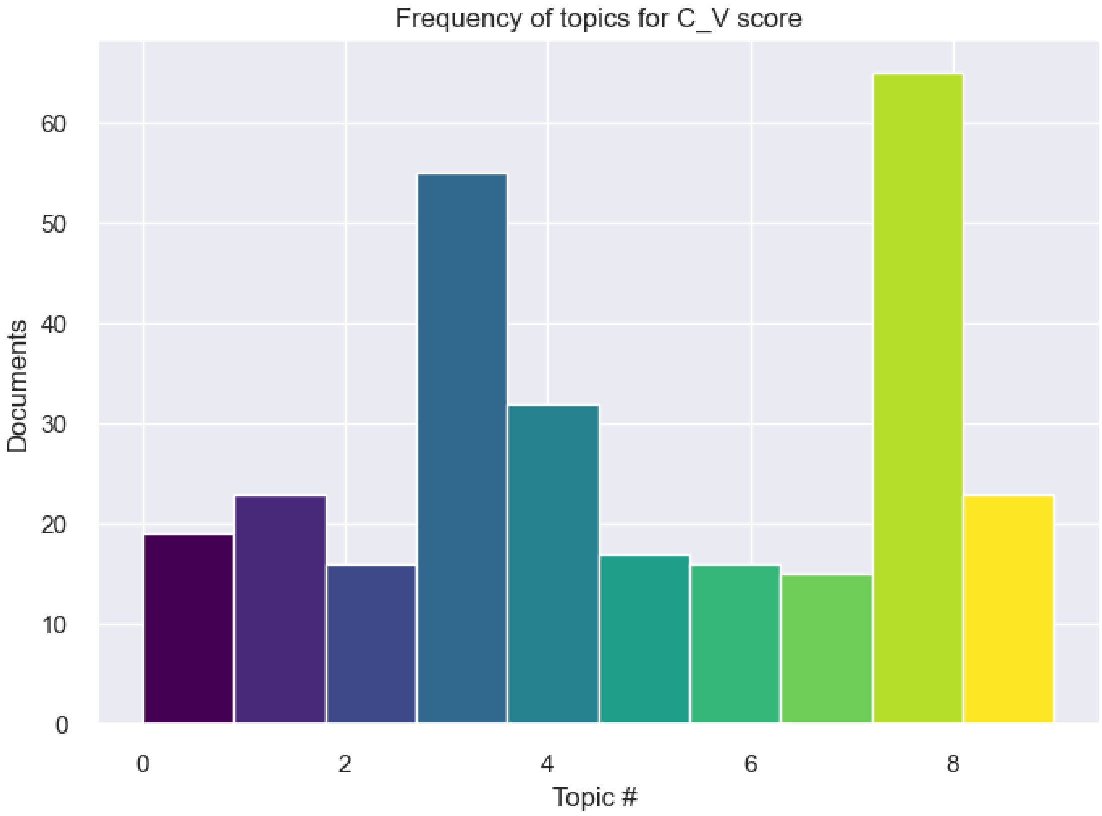
```
fig, ax =plt.subplots(1, figsize=(15, 10))
ax.scatter(y=topicmod.topic_mat, x=train_data.index, marker=".", c=topicmod.
  ↪topic_mat, cmap="prism")
ax.set_xlabel("Document #")
ax.set_ylabel("Topic # ")
plt.title("Distribution of topics over documents for C_V score")
plt.show()
```



Topic Frequency across Documents

[24]:

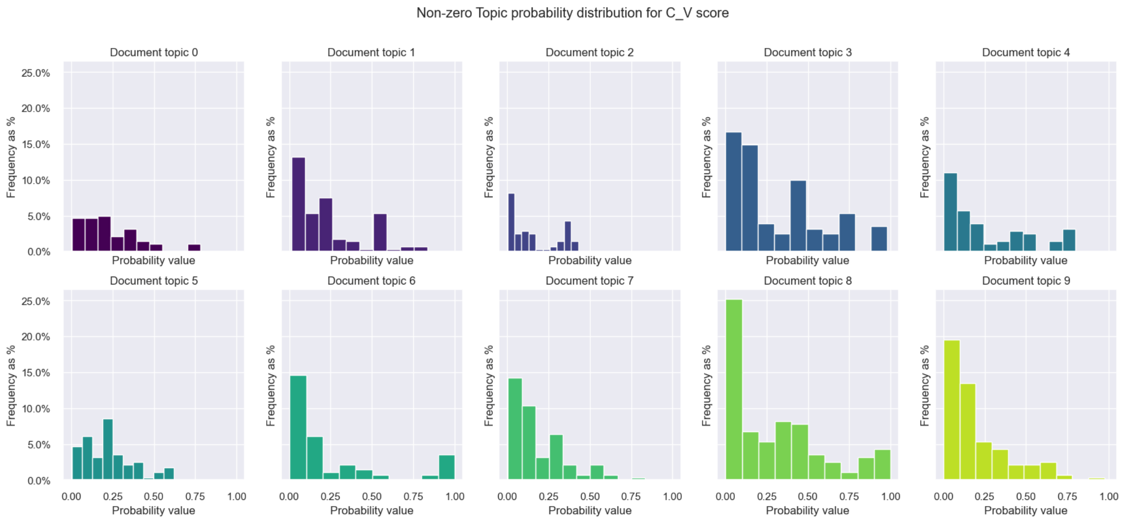
```
fig, ax = plt.subplots()
counts, bins, patches = ax.hist(topicmod.topic_mat, bins=10)

# Use a colormap
cmap = plt.get_cmap('viridis')
colors = cmap(np.linspace(0, 1, len(patches)))

for i, patch in enumerate(patches):
    patch.set_facecolor(colors[i])
ax.set_ylabel("Documents")
ax.set_xlabel("Topic # ")
plt.title("Frequency of topics for C_V score")
plt.show()
```



Probability Distributions by Topic

[25]:

```
fig, ax = plt.subplots(2, 5, figsize=(20, 8),sharey=True, sharex=True)
k = 0
cmap = cm.get_cmap('viridis')
for i in range(2):
    for j in range(5):
        df = topicmod.doc_mat[:, k][topicmod.doc_mat[:, k].nonzero()]
        ax[i, j].hist(df, weights= np.ones_like(df)/len(topicmod.doc_mat[:,k]),␣
 ↪color=cmap(k/10))
        ax[i, j].set_title("Document topic " + str(k))
        ax[i, j].set_xlabel("Probability value")
        ax[i, j].set_ylabel("Frequency as %")
        k=k+1
        ax[i, j].yaxis.set_major_formatter(PercentFormatter(1))
plt.suptitle("Non-zero Topic probability distribution for C_V score")
plt.show()
```



LDA Visualization

```
[26]: if LDA_IMPORT:
          topic_term_dists = topicmod.cv_model.get_topics()  # transpose to make␣
       ↪shape (num_terms, num_topics)
          doc_topic_dists = topicmod.doc_mat # cv_model.get_document_topics(topicmod.
       ↪tfidf_mat, minimum_probability=0)
          # doc_topic_dists = [[tup[1] for tup in lst] for lst in doc_topic_dists]  #␣
       ↪convert list of tuples to just list
          doc_lengths = [len(doc) for doc in gensim_statements]
          vocab = list(dict_gensim_statements.token2id.keys())
          term_frequency = dict_gensim_statements.cfs

          # Use pyLDAvis
          vis_data = pyLDAvis.prepare(
              topic_term_dists=topic_term_dists,
              doc_topic_dists=doc_topic_dists,
              doc_lengths=doc_lengths,
              vocab=vocab,
              term_frequency=list(term_frequency.values())
          )

          print("Intertopic distance map for C_V Score\n\n")
          pyLDAvis.display(vis_data)
      else:
          print(f"Please see attached PDF for LDA Visualization!")
```

```
Please see attached PDF for LDA Visualization!
```

Topic Modeling (UMass Scoring)

[27]:

```
um_topicmod = TopicModel(
    tfidf_class.tfidf_statements_train,
    tfidf_class.dict_gensim_statements,
    tfidf_class.X_train.apply(tokenizer_wo_stopwords).apply(lambda x: x.split("␣
 ↪")).tolist(),
    cv_score="u_mass",
)

um_topicmod.fit()
```

Top 10 Words by Topic

[28]:

```
um_topicmod.cv_model.show_topics(num_words=10)
```

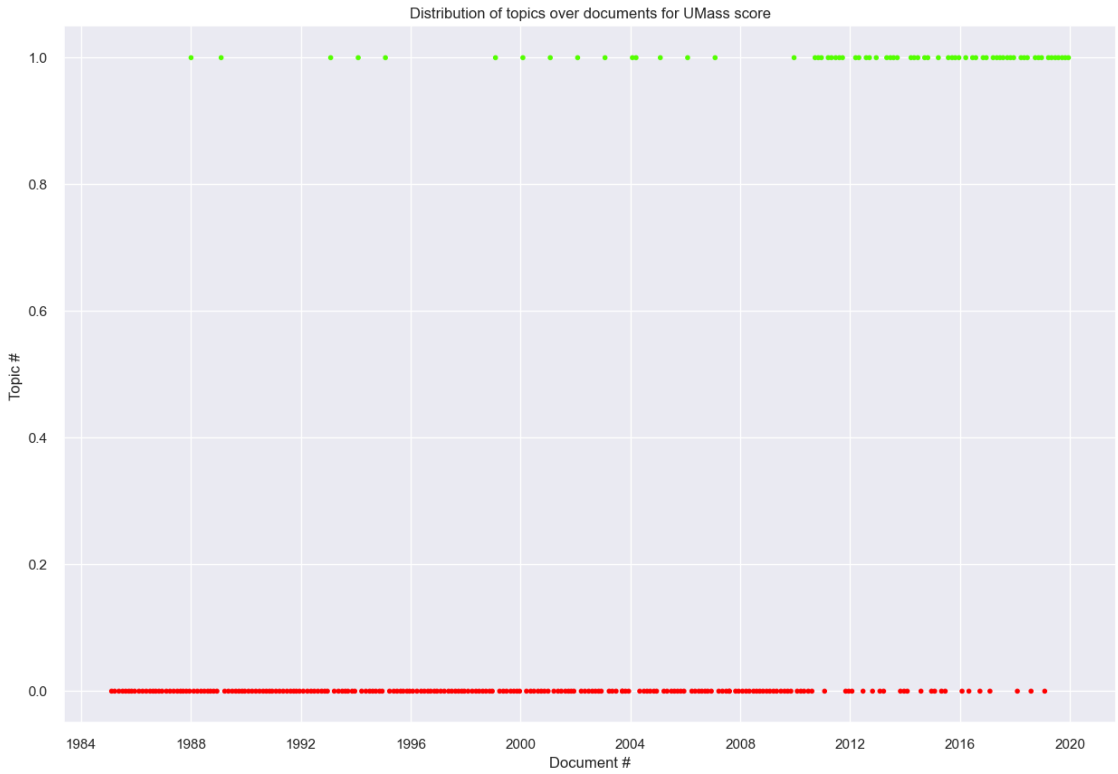
[28]:

```
[(0,
  '0.017*"foreign" + 0.014*"recent" + 0.014*"account" + 0.012*"taken" +
0.012*"reported" + 0.012*"markets" + 0.011*"actions" + 0.011*"developments" +
0.011*"period" + 0.010*"approved"'),
 (1,
  '0.012*"participants" + 0.012*"inflation" + 0.011*"rate" + 0.009*"s" +
0.009*"economic" + 0.008*"policy" + 0.007*"securities" + 0.007*"percent" +
0.005*"funds" + 0.005*"growth"')]
```

Topic Distribution by Time

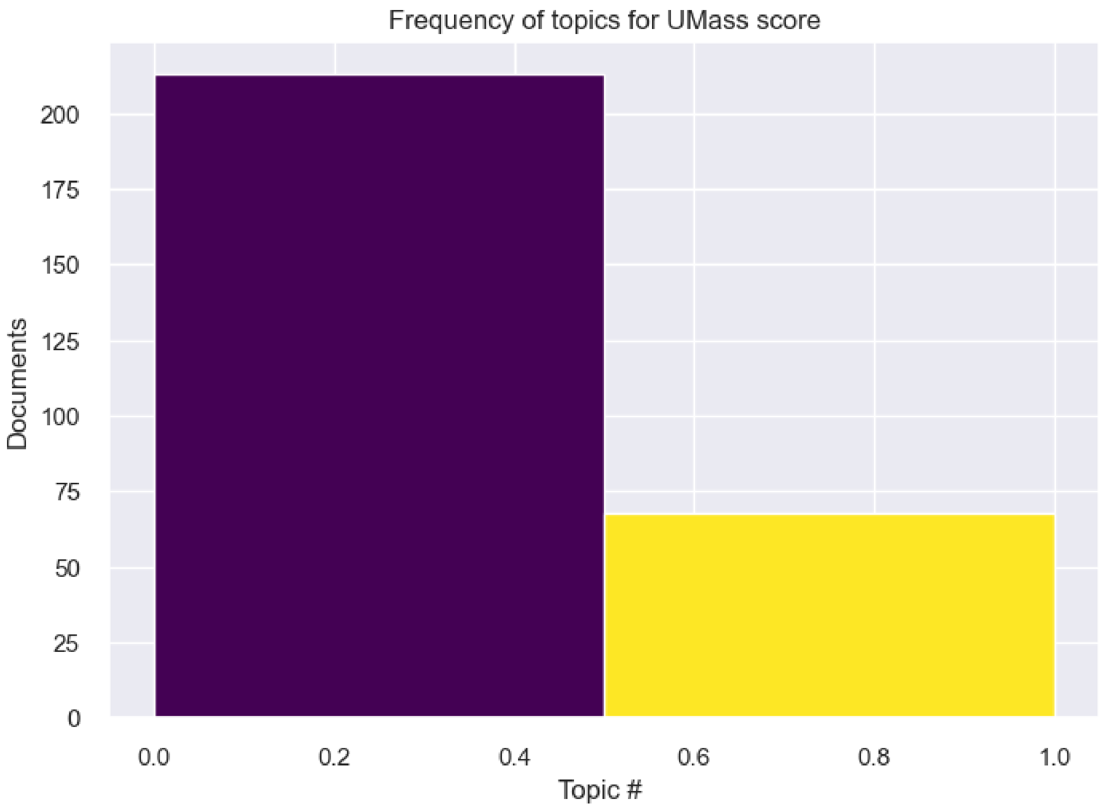
[29]:

```
fig, ax =plt.subplots(1, figsize=(15, 10))
ax.scatter(y=um_topicmod.topic_mat, x=train_data.index, marker=".
 ↪",c=um_topicmod.topic_mat, cmap="prism")
ax.set_xlabel("Document #")
ax.set_ylabel("Topic # ")
plt.title("Distribution of topics over documents for UMass score")
plt.show()
```



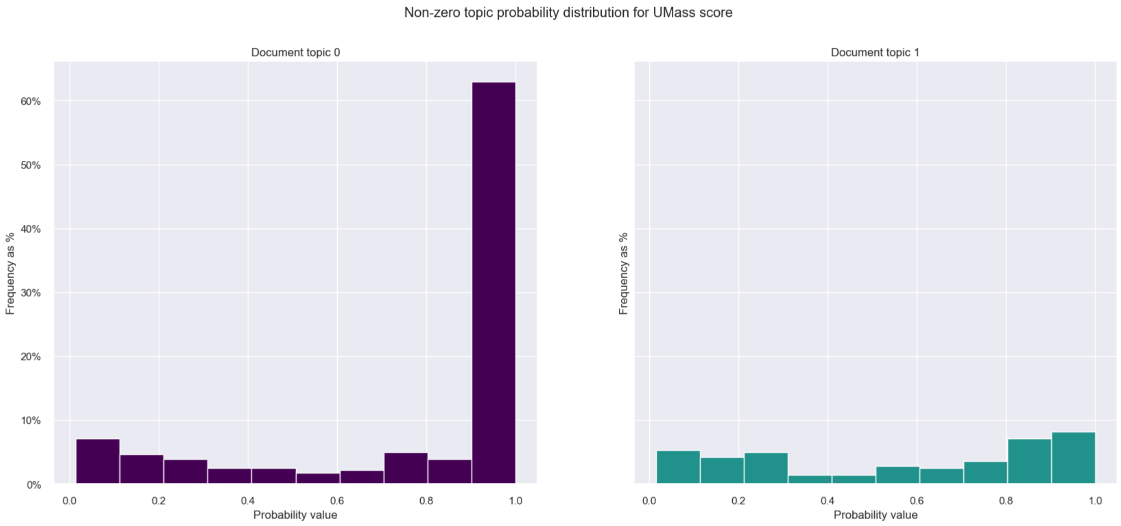
Topic Frequency across Documents

[30]:
```
fig, ax = plt.subplots()
counts, bins, patches = ax.hist(um_topicmod.topic_mat, bins=2)

# Use a colormap
cmap = plt.get_cmap('viridis')
colors = cmap(np.linspace(0, 1, len(patches)))

for i, patch in enumerate(patches):
    patch.set_facecolor(colors[i])
ax.set_ylabel("Documents")
ax.set_xlabel("Topic # ")
plt.title("Frequency of topics for UMass score")
plt.show()
```



Probability Distributions by Topic

```
[31]: fig, ax = plt.subplots(1, 2, figsize=(20, 8), sharey=True, sharex=True)
cmap = cm.get_cmap('viridis')
k = 0
for j in range(2):
        df = um_topicmod.doc_mat[:, k][um_topicmod.doc_mat[:, k].nonzero()]
        ax[j].hist(df, weights= np.ones_like(df)/len(um_topicmod.doc_mat[:,k]),␣
 ↪color=cmap(k/2))
        ax[j].set_title("Document topic " + str(k))
        ax[j].set_xlabel("Probability value")
        k=k+1
        ax[j].yaxis.set_major_formatter(PercentFormatter(1))
        ax[j].set_ylabel("Frequency as %")
plt.suptitle("Non-zero topic probability distribution for UMass score")
plt.show()
```



LDA Visualization

[32]:

```python
if LDA_IMPORT:
    topic_term_dists = um_topicmod.cv_model.get_topics() # transpose to make shape (num_terms, num_topics)
    doc_topic_dists = um_topicmod.doc_mat # cv_model.get_document_topics(topicmod.tfidf_mat, minimum_probability=0)
    # doc_topic_dists = [[tup[1] for tup in lst] for lst in doc_topic_dists]  # convert list of tuples to just list
    doc_lengths = [len(doc) for doc in gensim_statements]
    vocab = list(dict_gensim_statements.token2id.keys())
    term_frequency = dict_gensim_statements.cfs

    # Use pyLDAvis
    vis_data = pyLDAvis.prepare(
        topic_term_dists=topic_term_dists,
        doc_topic_dists=doc_topic_dists,
        doc_lengths=doc_lengths,
        vocab=vocab,
        term_frequency=list(term_frequency.values())
    )
    print("Intertopic distance map for UMass score\n\n")
    pyLDAvis.display(vis_data)
else:
    print(f"Please see attached PDF for LDA Visualization!")
```

```
Please see attached PDF for LDA Visualization!
```

FinBERT Word Embeddings

[33]:

```python
finbert = FinbertEmbedding()
```

[34]:
```
def word_embedding_to_np(text: str):
    sentence_embedding = finbert.sentence_vector(text)
    res = np.array(list(map(lambda x: x.detach().numpy(), sentence_embedding)))
    return res
```

[35]:
```
finbert_embeddings_train = train_data.text.apply(word_embedding_to_np)
finbert_embeddings_test = test_data.text.apply(word_embedding_to_np)
```

[36]:
```
finbert_embeddings_train = pd.DataFrame(
    np.array(list(map(lambda x: list(x), finbert_embeddings_train.values))),
    columns=[f"Word {i}" for i in range(len(finbert_embeddings_train.
 ↪values[0]))],
    index=train_data.index,
)

finbert_embeddings_test = pd.DataFrame(
    np.array(list(map(lambda x: list(x), finbert_embeddings_test.values))),
    columns=[f"Word {i}" for i in range(len(finbert_embeddings_test.
 ↪values[0]))],
    index=test_data.index,
)
```

Hidden Markov Models

Price Data - Reading

[37]:
```
epsilon = 0.5
theta = 0.01
trading_day = {'equity':12, 'fx':12,'bond':12}
```

[38]:
```
df_ts = get_ts_data(
    '^GSPC',
    start_date=period_start,
    end_date=period_end,
    delta=trading_day['equity']
)
```

```
[*********************100%%**********************]  1 of 1 completed
```

Price Data - Pre-Processing

[ ]:
```
df_ts_train = df_ts[(df_ts.index.date >= train_start.date()) & (df_ts.index.
 ↪date <= train_end.date())]
df_ts_test = df_ts[(df_ts.index.date >= test_start.date()) & (df_ts.index.date␣
 ↪<= test_end.date())]

df_ts_train
```

[40]:

```
def get_r_values(data):
    r_values = get_R(
        get_TMV(get_DC_data_v2(data, theta), theta),
        get_T(get_DC_data_v2(data, theta)),
        theta
    )
    return r_values

r_values_train = get_r_values(df_ts_train)
r_values_test = get_r_values(df_ts_test)
```

Label Generation

[41]:

```
hmm_regimes_train, hmm_model = fit_hmm(
    2,
    df_ts_train,
    r_values_train,
    '^GSPC',
    plot=False,
    verbose=False
)

hmm_regimes_test = hmm_model.predict(r_values_test.values.reshape(-1, 1))
```

[42]:

```
hmm_regimes_train = pd.DataFrame.from_dict({
    'HMM_Regimes': list(hmm_regimes_train.values),
}).set_index(r_values_train.index)

hmm_regimes_test = pd.DataFrame.from_dict({
    'HMM_Regimes': hmm_regimes_test,
}).set_index(r_values_test.index)
```

[ ]:

```
display(hmm_regimes_train)
```

Supervised Learning

Fill Labels Across Entire Time Period

[ ]:

```
train_regimes = pd.DataFrame(index=pd.date_range(
    start=period_start,
    end=train_end + timedelta(1),
    freq='12H'
)[:-1])

train_regimes = pd.merge(
    left=train_regimes,
    right=nlp_regimes_train,
    how="left",
    left_index=True,
    right_index=True,
).bfill()

train_regimes = pd.merge(
    left=train_regimes,
    right=hmm_regimes_train,
    how="left",
    left_index=True,
    right_index=True,
).bfill()

train_regimes.NLP_Regimes = train_regimes.NLP_Regimes.ffill()
train_regimes.HMM_Regimes = train_regimes.HMM_Regimes.ffill()

train_regimes
```

Equalize Indexes for Features

[45]:

```
index_train = r_values_train.index
X_train = pd.DataFrame(index=index_train)

# ffill() topic model PDFs to account for dates on which we have text data but␣
 ↪no DC data
topic_models_train_new = pd.merge(
    left=X_train,
    right=topic_models_train,
    how='outer',
    left_index=True,
    right_index=True
).ffill()
topic_models_train_new = topic_models_train_new[topic_models_train_new.index.
 ↪isin(index_train)]

# ffill() word embeddings to account for dates on which we have text data but␣
 ↪no DC data
finbert_embeddings_train_new = pd.merge(
    left=X_train,
    right=finbert_embeddings_train,
    how='outer',
    left_index=True,
    right_index=True
).ffill()
finbert_embeddings_train_new =␣
 ↪finbert_embeddings_train_new[finbert_embeddings_train_new.index.
 ↪isin(index_train)]
```

```
# Add name to R Values Series
r_values_train.name = 'R_Values_Train'
```

[46]:

```
index_test = r_values_test.index
X_test = pd.DataFrame(index=index_test)

# ffill() topic model PDFs to account for dates on which we have text data but␣
 ↪no DC data
topic_models_test_new = pd.merge(
    left=X_test,
    right=topic_models_test,
    how='outer',
    left_index=True,
    right_index=True
).ffill()
topic_models_test_new = topic_models_test_new[topic_models_test_new.index.
 ↪isin(index_test)]

# ffill() word embeddings to account for dates on which we have text data but␣
 ↪no DC data
finbert_embeddings_test_new = pd.merge(
    left=X_test,
    right=finbert_embeddings_test,
    how='outer',
    left_index=True,
    right_index=True
).ffill()
finbert_embeddings_test_new =␣
 ↪finbert_embeddings_test_new[finbert_embeddings_test_new.index.
 ↪isin(index_test)]

# Add name to R Values Series
r_values_test.name = 'R_Values_Test'
```

Construct Covariates and Labels

[47]:

```
# Flags to change covariates used in NB Classifier
USE_TOPIC_MODEL_PDF = True
USE_WORD_EMBEDDINGS = True
USE_R_VALUES = True
```

[48]:

```
def make_X(
    train: bool = True,
    topic_model: bool = USE_TOPIC_MODEL_PDF,
    word_embeddings: bool = USE_WORD_EMBEDDINGS,
    price_data: bool = USE_R_VALUES,
):
    """
    This function creates a new DataFrame of covariates based on the flags which
    determine specifically which covariates will be included.

    @param train: flag for deciding if making train or test data
    @param topic_model: flag for including NMF Topic Models (loadings)
    @param word_embeddings: flag for including Finbert Word Embeddings
    @param topic_model: flag for including R Indicator Values (price data)
    @return X: pd.DataFrame indexed by DC Indicators containing specified␣
 ↪covariates
    """
    if train:
        index = r_values_train.index
        topic_models_df = topic_models_train_new.copy()
        word_embeddings_df = finbert_embeddings_train_new.copy()
        r_values_df = r_values_train.copy()
    else:
        index = r_values_test.index
        topic_models_df = topic_models_test_new.copy()
        word_embeddings_df = finbert_embeddings_test_new.copy()
        r_values_df = r_values_test.copy()

    X = pd.DataFrame(index=index)

    # Add topic model PDFs to covariates DataFrame
    if topic_model:
        X = pd.merge(
            left=X,
            right=topic_models_df,
            how='inner',
            left_index=True,
            right_index=True
        )

    # Add word embeddings to covariates DataFrame
    if word_embeddings:
        X = pd.merge(
            left=X,
            right=word_embeddings_df,
            how='inner',
            left_index=True,
            right_index=True
        )

    # Add DC Indicator (price data) to covariates DataFrame
    if USE_R_VALUES:
        X = pd.merge(
            left=X,
            right=r_values_df,
            how='inner',
            left_index=True,
            right_index=True
        )

    # TODO: either bfill() here, or remove the NA rows from y_train and X_train
    X = X.bfill()

    if train:
        print(f"X_train: {X.shape}")
    else:
        print(f"X_test: {X.shape}")

    return X
```

[49]:

```
def make_Y(
    train: bool = True,
):
    """
    This function constructs the NLP and HMM y-labels.

    @param train: flag for deciding if making train or test data
    @return (y_nlp, y_hmm): tuple containing NLP and HMM y-labels
    """
    if train:
        regimes = train_regimes.copy()
        index = index_train.copy()
    else:
        regimes = test_regimes.copy()
        index = index_test.copy()

    regimes = regimes[regimes.index.isin(index)]

    y_nlp = regimes.NLP_Regimes
    y_hmm = regimes.HMM_Regimes

    if train:
        print(f"y_train_nlp: {y_nlp.shape}")
        print(f"y_train_hmm: {y_hmm.shape}")
    else:
        print(f"y_test_nlp: {y_nlp.shape}")
        print(f"y_test_hmm: {y_hmm.shape}")

    return y_nlp, y_hmm
```

[50]:

```
def make_data(
    topic_model: bool = USE_TOPIC_MODEL_PDF,
    word_embeddings: bool = USE_WORD_EMBEDDINGS,
    price_data: bool = USE_R_VALUES,
):
    """
    This function creates all X and y data for the classification model.

    @param topic_model: flag for including NMF Topic Models (loadings)
    @param word_embeddings: flag for including Finbert Word Embeddings
    @param topic_model: flag for including R Indicator Values (price data)
    @return (X_train, X_test, y_train_nlp, y_train_hmm, y_test_nlp, y_test_nlp):
 ↪ tuple containing all train and test data
    """
    X_train = make_X(
        train=True,
        topic_model=topic_model,
        word_embeddings=word_embeddings,
        price_data=price_data
    )
    X_test = make_X(
        train=False,
        topic_model=topic_model,
        word_embeddings=word_embeddings,
        price_data=price_data
    )
    y_train_nlp, y_train_hmm = make_Y(train=True)
    # y_test_nlp, y_test_hmm = make_Y(train=False)
    return X_train, X_test, y_train_nlp, y_train_hmm
```

[51]:

```
X_train, X_test, y_train_nlp, y_train_hmm = make_data()
```

```
X_train: (4932, 779)
X_test: (563, 779)
y_train_nlp: (4932,)
y_train_hmm: (4932,)
```

Classification and Performance on Trading Strategies

[67]:

```
def make_test_regimes(X_train, X_test, do_all_func):
    test_regimes = pd.DataFrame(index=pd.date_range(
        start=test_start,
        end=period_end + timedelta(1),
        freq='12H'
    )[:-1])

    def add_to_regime_dataframe(X_train, y_train, X_test, label, test_regimes):
```

```
    y_pred = pd.DataFrame.from_dict({
        label: do_all_func(
            X_train.values,
            y_train.values,
            X_test.values,
        )
    }).set_index(index_test)

    test_regimes = pd.merge(
        left=test_regimes,
        right=y_pred,
        how="left",
        left_index=True,
        right_index=True,
    ).bfill()

    test_regimes[label] = test_regimes[label].ffill()
    return test_regimes

test_regimes = add_to_regime_dataframe(
    X_train.iloc[:,-1:],
    pd.DataFrame(y_train_nlp),
    X_test.iloc[:,-1:],
    'Kmeans_labels_DC_indicators',
    test_regimes
)
test_regimes = add_to_regime_dataframe(
    X_train.iloc[:,:10],
    pd.DataFrame(y_train_nlp),
    X_test.iloc[:,:10],
    'Kmeans_labels_NMF_loadings',
    test_regimes
)
test_regimes = add_to_regime_dataframe(
    X_train.iloc[:,10:-1],
    pd.DataFrame(y_train_nlp),
    X_test.iloc[:,10:-1],
    'Kmeans_labels_finBERT_embeddings',
    test_regimes
)
test_regimes = add_to_regime_dataframe(
    X_train.iloc[:,-1:],
    pd.DataFrame(y_train_hmm),
    X_test.iloc[:,-1:],
    'HMM_labels_DC_indicators',
    test_regimes
)
```

```
    test_regimes = add_to_regime_dataframe(
        X_train.iloc[:,:10],
        pd.DataFrame(y_train_hmm),
        X_test.iloc[:,:10],
        'HMM_labels_NMF_loadings',
        test_regimes
    )
    test_regimes = add_to_regime_dataframe(
        X_train.iloc[:,10:-1],
        pd.DataFrame(y_train_hmm),
        X_test.iloc[:,10:-1],
        'HMM_labels_finBERT_embeddings',
        test_regimes
    )

    return test_regimes
```

[68]:

```
result_labels = [
    'Control 1',
    'Control 2',
    'K-means labels, only DC covariates',
    'K-means labels, NMF loading covariates',
    'K-means labels, FinBERT embeddings',
    'HMM labels, only DC covariates',
    'HMM labels, NMF loading covariates',
    'HMM labels, FinBERT embeddings'
]

def make_results(test_regimes):
    results = []

    strat_test = Pipeline(
        df_ts=df_ts,
        to_test=True,
        strat='control',
        start_date=str(train_start)[:10],
        train_end=str(train_end)[:10],
        test_start=str(test_start)[:10],
        theta=theta,
        epsilon=0.5,
        provide_labels=True,
        labels=test_regimes[test_regimes.columns[0]] # labels are a placeholder␣
 ↪for control
    )
    strat_test.fit(verbose=False)
    results.append(strat_test.trading_metrics_test)
    strat_test = Pipeline(
        df_ts=df_ts,
        to_test=True,
        strat='control2',
        start_date=str(train_start)[:10],
        train_end=str(train_end)[:10],
        test_start=str(test_start)[:10],
        theta=theta,
        epsilon=0.5,
        provide_labels=True,
        labels=test_regimes[test_regimes.columns[0]]
    )
    strat_test.fit(verbose = False)
    results.append(strat_test.trading_metrics_test)

    for label, column in zip(result_labels[2:], test_regimes.columns):
        strat_test = Pipeline(
            df_ts=df_ts,
            to_test=True,
            start_date=str(train_start)[:10],
            train_end=str(train_end)[:10],
            test_start=str(test_start)[:10],
            theta=theta,
            epsilon=0.5,
            provide_labels=True,
            labels=test_regimes[column]
        )
        strat_test.fit(verbose = False)
        results.append(strat_test.trading_metrics_test)

    return results
```

[69]:

```
do_all_map = {
    'nbc': do_all_NBC,
    'svm': do_all_SVM,
    'lr': do_all_LR,
}

def train_predict_eval(classifier):
    assert classifier in list(do_all_map.keys())
    do_all_func = do_all_map[classifier]
    test_regimes = make_test_regimes(X_train, X_test, do_all_func)
    results = make_results(test_regimes)
    results = pd.DataFrame(
        results,
        index=result_labels
    ).round(8).sort_values('sharpe')
    return test_regimes, results
```

Naive Bayes Classifier

```
[70]: test_regimes_nbc, results_nbc = train_predict_eval('nbc')
```

```
[71]: results_nbc
```

```
[71]:                                         drawdown    profit    sharpe
      K-means labels, NMF loading covariates  0.154341  0.530849  0.540878
      Control 1                               0.154341  0.530849  0.541172
      K-means labels, only DC covariates      0.154341  0.530849  0.541172
      K-means labels, FinBERT embeddings      0.154341  0.530849  0.541172
      HMM labels, FinBERT embeddings          0.154341  0.530849  0.541172
      Control 2                               0.154564  0.529506  0.616659
      HMM labels, NMF loading covariates      0.158274  0.530849  0.618412
      HMM labels, only DC covariates          0.222633  0.901848  0.710041
```

Support Vector Machine Classifier

```
[72]: test_regimes_svm, results_svm = train_predict_eval('svm')
```

```
[ ]: results_svm
```

Logistic Regression Classifier

```
[74]: test_regimes_lr, results_lr = train_predict_eval('lr')
```

```
[ ]: results_lr
```

Additional Visualizations

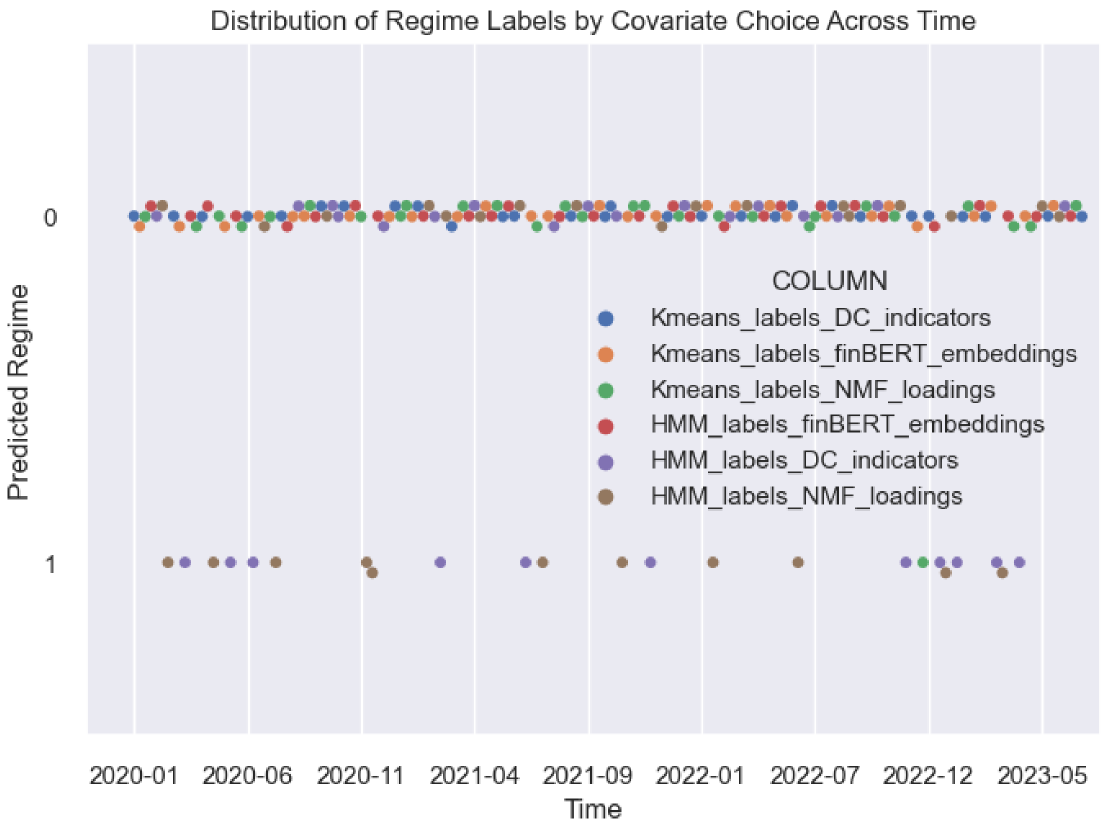
```
[ ]: test_regimes_nbc_plot = test_regimes_nbc[pd.DatetimeIndex(test_regimes_nbc.
      ↪index.date).isin(test_data.index)]
```

```
[ ]: label_list = []
     column_list = []
     date_list = []
     test_regimes = test_regimes_nbc_plot

     for i, col in enumerate(test_regimes.columns):
         col_vals = test_regimes.loc[:, test_regimes.columns[i]]
         label_list += list(col_vals.values)
         column_list += [col for _ in range(col_vals.shape[0])]
         date_list += list(test_regimes.index.date)
```

```
df = pd.DataFrame.from_dict({
    'LABEL': label_list,
    'COLUMN': column_list,
    'DATE': date_list,
}).sort_values(by='DATE')

df['LABEL'] = df['LABEL'].astype("int").astype("category")
df.DATE = pd.to_datetime(df.DATE)
df = df.drop_duplicates(subset=('COLUMN', 'DATE'))

df.reset_index(inplace=True)
df['x'] = df.index.astype("int")

df
```

[246]:

```
ax = sns.swarmplot(
    data=df.drop_duplicates(subset=('COLUMN', 'DATE')),
    x="x",
    y="LABEL",
    hue="COLUMN"
)

labels = ax.get_xticklabels()

def get_date(label):
    txt = str(label)
    if '-' in txt or '-' in txt:
        return txt
    txt = int(txt)
    if txt > max(df.x.astype("int")):
        return str(txt)
    my_date = pd.to_datetime(df[df.x == txt].DATE.values[0]).date()
    return f"{my_date.year}-{'0' + str(my_date.month) if my_date.month < 10␣
 ↪else my_date.month}"

ax.set_xticklabels(list(map(get_date, [-20] + [i * 20 for i in range(9)])))

xlim = ax.get_xlim()
ax.set_xlim(xlim[0], xlim[1] - 5)

ax.set_xlabel('Time')
ax.set_ylabel('Predicted Regime')
ax.set_title('Distribution of Regime Labels by Covariate Choice Across Time')

plt.show()
```


Distribution of Regime Labels by Covariate Choice Across Time
Predicted Regime
0
1
COLUMN
Kmeans_labels_DC_indicators
Kmeans_labels_finBERT_embeddings
Kmeans_labels_NMF_loadings
HMM_labels_finBERT_embeddings
HMM_labels_DC_indicators
HMM_labels_NMF_loadings
2020-01
2020-06
2020-11
2021-04
2021-09
2022-01
2022-07
2022-12
2023-05
Time