main

May 17, 2023

1 Load and View Data

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

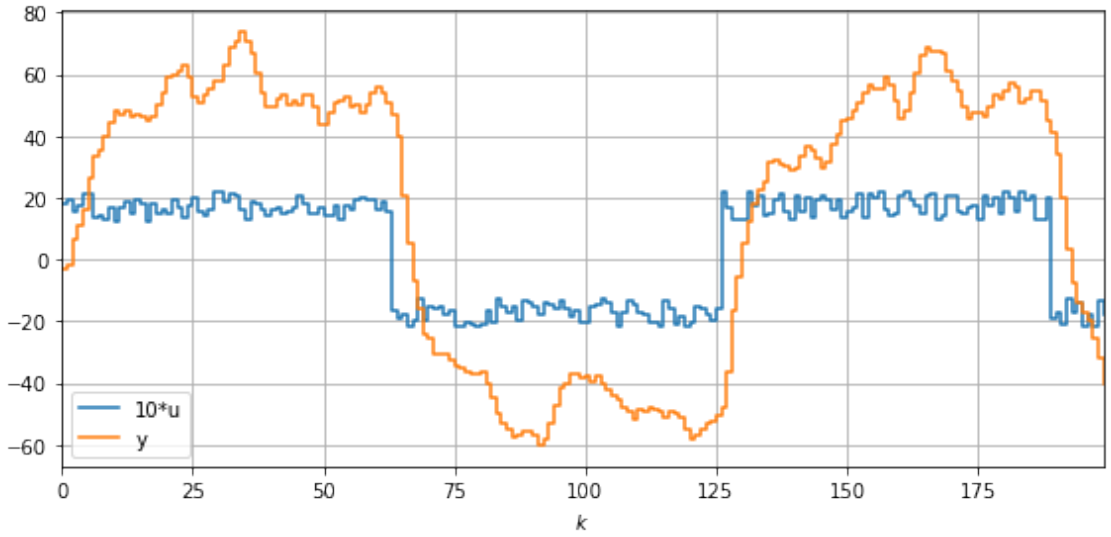
file = '../data.csv'
data = pd.read_csv(file, header=None, names=['u', 'y'])
N = len(data)

k = data.index.values
u = data.u.values
y = data.y.values

print('Number of data points:', N)
print(f'k in [{k[0]}, {k[-1]}]')

plt.figure(figsize=(8,4))
plt.plot(k, 10*u, label='10*u', drawstyle='steps-post')
plt.plot(k, y   , label='y'   , drawstyle='steps-post')
plt.xlim(k[0], k[-1])
plt.xlabel(r'$k$')
plt.grid()
plt.legend()
plt.tight_layout()
plt.show()
```

```
Number of data points: 200
k in [0, 199]
```



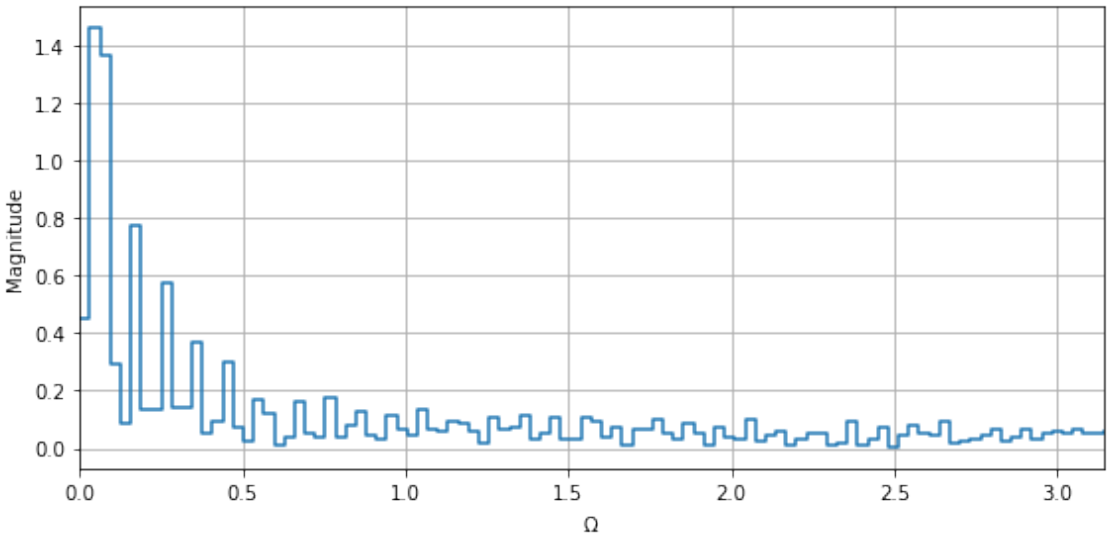
1.1 Input Fourier Transform

[ ]:
```
from scipy import fft

u_rfft = fft.rfft(u, norm='forward')
u_rfft[1:-1] = 2*u_rfft[1:-1]

u_rfft_mag = np.abs(u_rfft)
Omega = np.linspace(0, np.pi, len(u_rfft_mag))

plt.figure(figsize=(8,4))
plt.plot(Omega, u_rfft_mag, drawstyle='steps-post')
plt.xlim(Omega[0], Omega[-1])
plt.xlabel(r'$\Omega$')
plt.ylabel('Magnitude')
plt.grid()
plt.tight_layout()
plt.show()
```



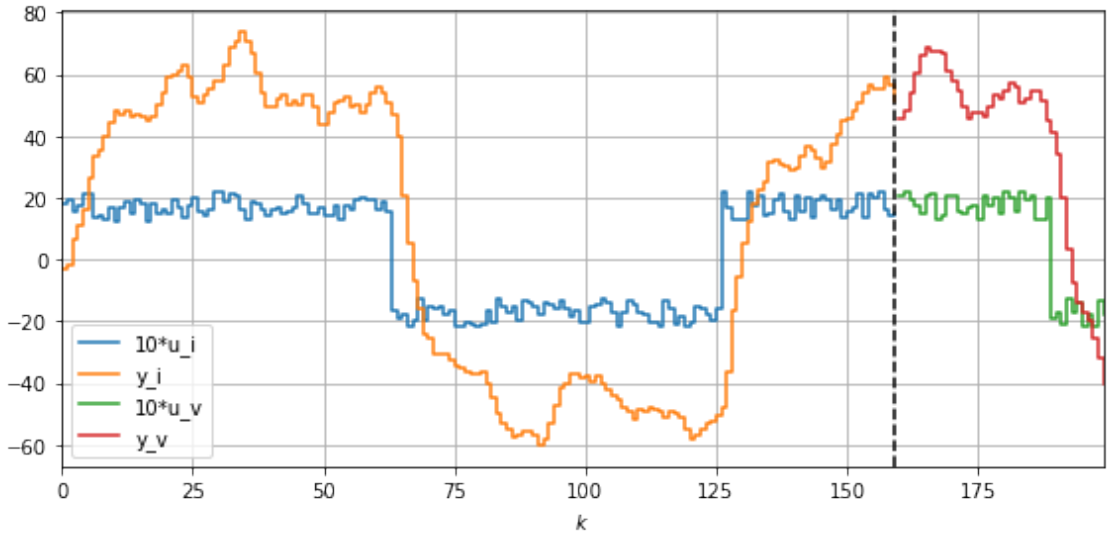
1.2 Separate Identification and Validation Data

[ ]:
```
N_fold = 160

k_i = k[:N_fold]
u_i = u[:N_fold]
y_i = y[:N_fold]

k_v = k[N_fold:]
u_v = u[N_fold:]
y_v = y[N_fold:]

plt.figure(figsize=(8,4))
plt.plot(k_i, 10*u_i, label='10*u_i', drawstyle='steps-post')
plt.plot(k_i, y_i   , label='y_i'   , drawstyle='steps-post')
plt.plot(k_v, 10*u_v, label='10*u_v', drawstyle='steps-post')
plt.plot(k_v, y_v   , label='y_v'   , drawstyle='steps-post')
plt.axvline(k[N_fold-1], color='black', linestyle='--')
plt.xlim(k[0], k[-1])
plt.xlabel(r'$k$')
plt.grid()
plt.legend()
plt.tight_layout()
plt.show()
```



2 Generic Model

$$A(q)\,y[k] = \frac{B(q)}{F(q)}\,u[k-n_k+1] + \frac{C(q)}{D(q)}\,e[k]$$
$$y[k] = G(q)\,u[k-n_k+1] + H(q)\,e[k]$$
$$G(q) = \frac{B(q)}{A(q)\,F(q)} \qquad H(q) = \frac{C(q)}{A(q)\,D(q)}$$
$$A(q) = 1 - a_1\,q^{-1} - \cdots - a_{n_a}\,q^{-n_a}$$
$$B(q) = b_1\,q^{-1} + \cdots + b_{n_b}\,q^{-n_b} + +b_{n_b+1}\,q^{-n_b-1}$$
$$C(q) = 1 + c_1\,q^{-1} + \cdots + c_{n_c}\,q^{-n_c}$$
$$D(q) = 1 + d_1\,q^{-1} + \cdots + d_{n_d}\,q^{-n_d}$$
$$F(q) = 1 + f_1\,q^{-1} + \cdots + f_{n_f}\,q^{-n_f}$$

[ ]:
```
from functions import models_frame

models = models_frame()
```

3 ARX

$$y[k] = G(q)\,u[k-n_k+1] + H(q)\,e[k]$$
$$G(q) = \frac{B(q)}{A(q)} \qquad H(q) = \frac{1}{A(q)}$$
$$A(q) = 1 - a_1\,q^{-1} - \cdots - a_{n_a}\,q^{-n_a}$$
$$B(q) = b_1\,q^{-1} + \cdots + b_{n_b}\,q^{-n_b} + +b_{n_b+1}\,q^{-n_b-1}$$

[ ]:
```
from functions import arx

na_range = range(0, 3 + 1)
nb_range = range(0, 2 + 1)
nk_range = range(0, 2 + 1)

models_arx = arx(u_i, y_i, u_v, y_v, na_range, nb_range, nk_range)

models = pd.concat([models, models_arx], ignore_index=True)
```

4 ARMAX

$$y[k] = G(q)\,u[k - n_k + 1] + H(q)\,e[k]$$
$$G(q) = \frac{B(q)}{A(q)} \qquad H(q) = \frac{C(q)}{A(q)}$$
$$A(q) = 1 - a_1\,q^{-1} - \cdots - a_{n_a}\,q^{-n_a}$$
$$B(q) = b_1\,q^{-1} + \cdots + b_{n_b}\,q^{-n_b} + +b_{n_b+1}\,q^{-n_b-1}$$
$$C(q) = 1 + c_1\,q^{-1} + \cdots + c_{n_c}\,q^{-n_c}$$

[ ]:
```
from functions import armax

na_range = range(0, 3 + 1)
nb_range = range(0, 2 + 1)
nc_range = range(0, 3 + 1)
nk_range = range(0, 2 + 1)

models_armax = armax(u_i, y_i, u_v, y_v, na_range, nb_range, nc_range, nk_range)

models = pd.concat([models, models_armax], ignore_index=True)
```

5 Output Error

$$y[k] = G(q)\,u[k - n_k + 1] + H(q)\,e[k]$$
$$G(q) = \frac{B(q)}{F(q)} \qquad H(q) = 1$$
$$B(q) = b_1\,q^{-1} + \cdots + b_{n_b}\,q^{-n_b} + +b_{n_b+1}\,q^{-n_b-1}$$
$$F(q) = 1 + f_1\,q^{-1} + \cdots + f_{n_f}\,q^{-n_f}$$

[ ]:
```
from functions import oe

nb_range = range(0, 2 + 1)
nf_range = range(1, 3 + 1) # nf = 0 causa erro no pysid!
```

```
nk_range = range(0, 2 + 1)

models_oe = oe(u_i, y_i, u_v, y_v, nb_range, nf_range, nk_range)

models = pd.concat([models, models_oe], ignore_index=True)
```

6 Box-Jenkins

$$y[k] = G(q)\,u[k - n_k + 1] + H(q)\,e[k]$$
$$G(q) = \frac{B(q)}{F(q)} \qquad H(q) = \frac{C(q)}{D(q)}$$
$$B(q) = b_1\,q^{-1} + \cdots + b_{n_b}\,q^{-n_b} + +b_{n_b+1}\,q^{-n_b-1}$$
$$C(q) = 1 + c_1\,q^{-1} + \cdots + c_{n_c}\,q^{-n_c}$$
$$D(q) = 1 + d_1\,q^{-1} + \cdots + d_{n_d}\,q^{-n_d}$$
$$F(q) = 1 + f_1\,q^{-1} + \cdots + f_{n_f}\,q^{-n_f}$$

[ ]:
```
from functions import bj

nb_range = range(0, 2 + 1)
nc_range = range(0, 3 + 1)
nd_range = range(0, 3 + 1)
nf_range = range(0, 3 + 1)
nk_range = range(0, 2 + 1)

models_bj = bj(u_i, y_i, u_v, y_v, nb_range, nc_range, nd_range, nf_range,␣
 ↪nk_range)

models = pd.concat([models, models_bj], ignore_index=True)
```

```
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:118:
RuntimeWarning: overflow encountered in multiply
  suf = s * uf
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\trf.py:513:
RuntimeWarning: invalid value encountered in double_scalars
  actual_reduction = cost - cost_new
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:112:
RuntimeWarning: overflow encountered in square
  denom = s**2 + alpha
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:113:
RuntimeWarning: invalid value encountered in true_divide
  p_norm = norm(suf / denom)
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
RuntimeWarning: invalid value encountered in true_divide
  phi_prime = -np.sum(suf ** 2 / denom**3) / p_norm
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  alpha = max(0.001 * alpha_upper, (alpha_lower * alpha_upper)**0.5)
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d:\ProgramData\Anaconda3\lib\site-packages\numpy\core\fromnumeric.py:1822:
VisibleDeprecationWarning: Creating an ndarray from ragged nested sequences
(which is a list-or-tuple of lists-or-tuples-or ndarrays with different lengths
or shapes) is deprecated. If you meant to do this, you must specify
'dtype=object' when creating the ndarray.
  return asanyarray(a).ravel(order=order)
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RuntimeWarning: divide by zero encountered in double_scalars
  alpha_lower = -phi / phi_prime
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RuntimeWarning: divide by zero encountered in double_scalars
  ratio = phi / phi_prime
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RuntimeWarning: divide by zero encountered in double_scalars
  ratio = phi / phi_prime
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RuntimeWarning: divide by zero encountered in double_scalars
  p *= Delta / norm(p)
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:154:
RuntimeWarning: divide by zero encountered in double_scalars
  ratio = phi / phi_prime
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RuntimeWarning: overflow encountered in multiply
  suf = s * uf
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:118:
RuntimeWarning: overflow encountered in multiply
  suf = s * uf
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RuntimeWarning: overflow encountered in square
  denom = s**2 + alpha
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:113:
RuntimeWarning: invalid value encountered in true_divide
  p_norm = norm(suf / denom)
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:161:
RuntimeWarning: overflow encountered in square
  p = -V.dot(suf / (s**2 + alpha))
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'dtype=object' when creating the ndarray.
  return asanyarray(a).ravel(order=order)
```

```
d:\ProgramData\Anaconda3\lib\site-packages\numpy\core\fromnumeric.py:1822:
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:141:
RuntimeWarning: invalid value encountered in double_scalars
  alpha = max(0.001 * alpha_upper, (alpha_lower * alpha_upper)**0.5)
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
RuntimeWarning: overflow encountered in square
  phi_prime = -np.sum(suf ** 2 / denom**3) / p_norm
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
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```
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
RuntimeWarning: overflow encountered in power
  phi_prime = -np.sum(suf ** 2 / denom**3) / p_norm
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:154:
RuntimeWarning: divide by zero encountered in double_scalars
  ratio = phi / phi_prime
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:141:
RuntimeWarning: invalid value encountered in double_scalars
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  ratio = phi / phi_prime
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:166:
RuntimeWarning: divide by zero encountered in double_scalars
  p *= Delta / norm(p)
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:166:
RuntimeWarning: invalid value encountered in multiply
  p *= Delta / norm(p)
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:141:
RuntimeWarning: invalid value encountered in double_scalars
  alpha = max(0.001 * alpha_upper, (alpha_lower * alpha_upper)**0.5)
```

```
d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
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d:\ProgramData\Anaconda3\lib\site-packages\scipy\optimize\_lsq\common.py:115:
RuntimeWarning: invalid value encountered in true_divide
  phi_prime = -np.sum(suf ** 2 / denom**3) / p_norm
```

7 Results

7.1 Sort by Prediction Cost

[ ]:
```
models.sort_values(by=['Jp'], inplace=True)
```

7.2 Display Predictions

[ ]:
```
for i, (index, model) in enumerate(models.iterrows()):
  if i > 20:
    break

  if np.isnan(model.yp).any():
    continue

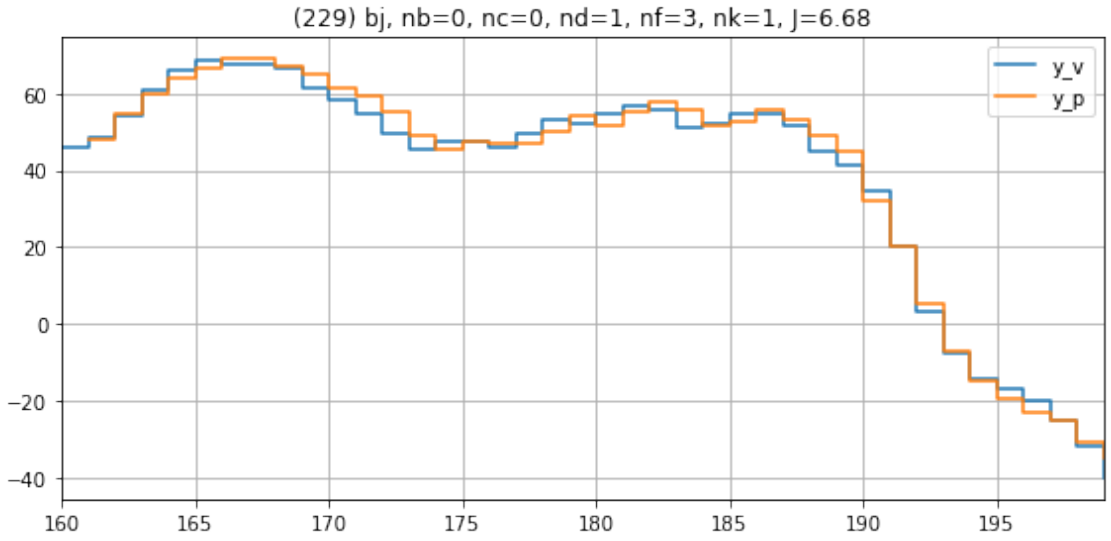
  if model.model == 'arx':
    title = f'({index}) {model.model}, na={model.na}, nb={model.nb}, nk={model.
↪nk}, J={model.Jp:.3g}'
  elif model.model == 'armax':
    title = f'({index}) {model.model}, na={model.na}, nb={model.nb}, nc={model.
↪nc}, nk={model.nk}, J={model.Jp:.3g}'
  elif model.model == 'oe':
    title = f'({index}) {model.model}, nb={model.nb}, nf={model.nf}, nk={model.
↪nk}, J={model.Jp:.3g}'
  elif model.model == 'bj':
    title = f'({index}) {model.model}, nb={model.nb}, nc={model.nc}, nd={model.
↪nd}, nf={model.nf}, nk={model.nk}, J={model.Jp:.3g}'
  else:
    assert(False)

  display(model.G)

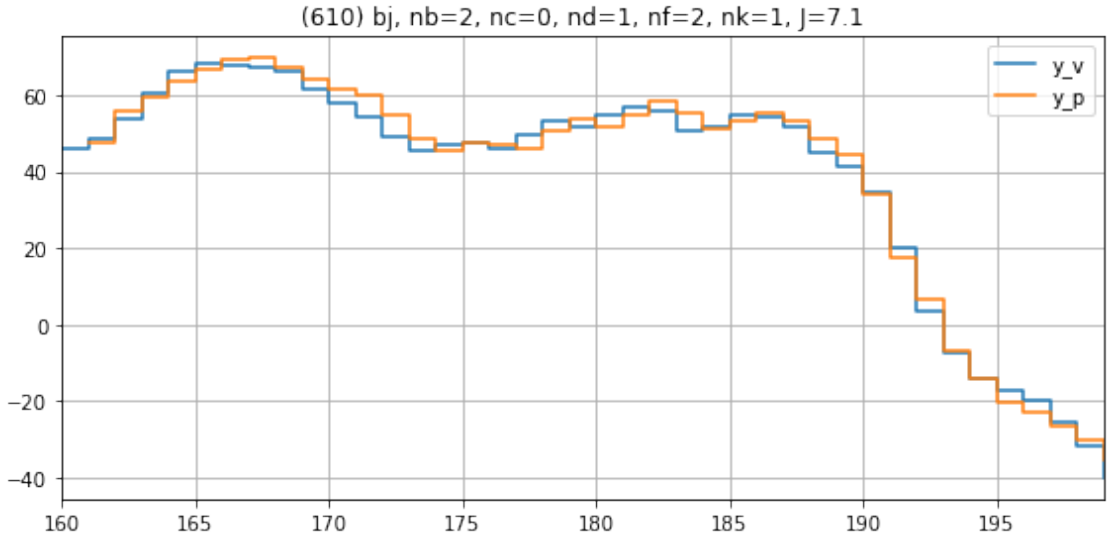
  plt.figure(figsize=(8,4))
  plt.title(title)
  plt.plot(k_v, y_v, label='y_v', drawstyle='steps-post')
  plt.plot(k_v[model.nk:], model.yp, label='y_p', drawstyle='steps-post')
  plt.xlim(k_v[0], k_v[-1])
  plt.grid()
  plt.legend()
  plt.tight_layout()
```

```
plt.show()
```

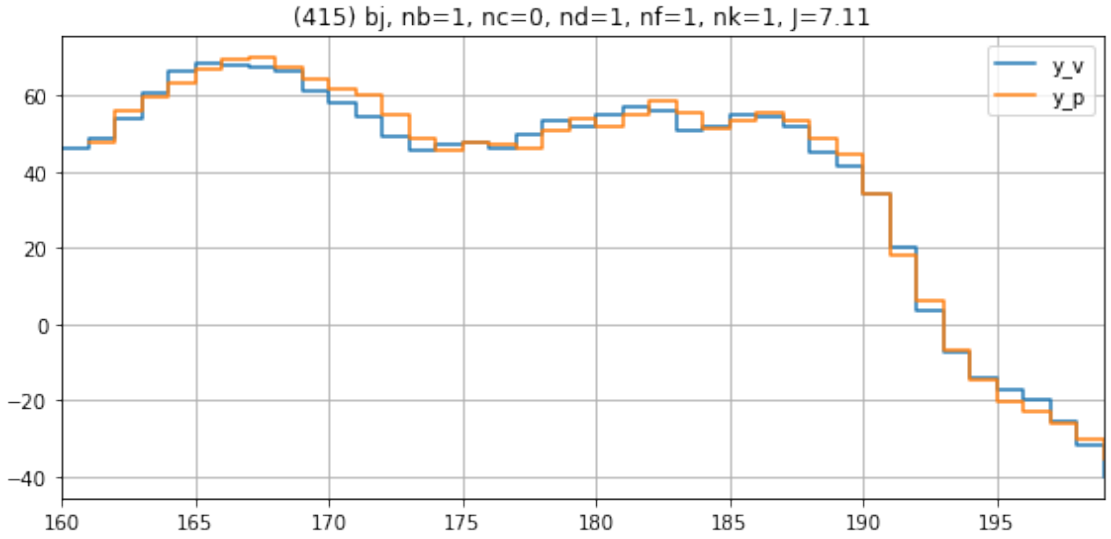
$$\frac{2.688z^2}{z^3 - 1.563z^2 + 0.8952z - 0.2373}$$



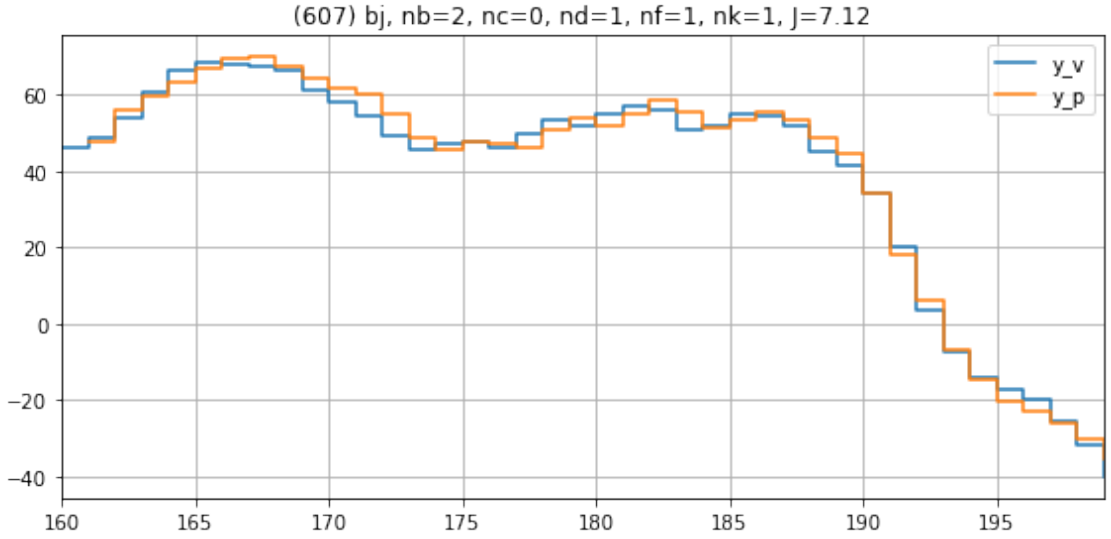
$$\frac{2.348z^2 + 5.097z + 2.657}{z^3 + 0.1443z^2 - 0.7839z}$$



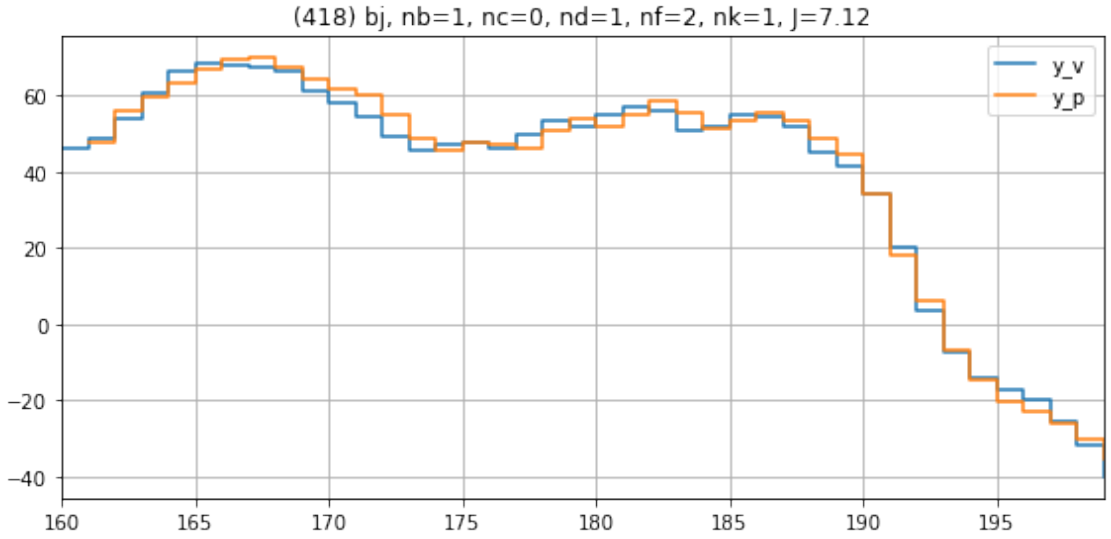
$$\frac{2.344z + 2.826}{z^2 - 0.8154z}$$



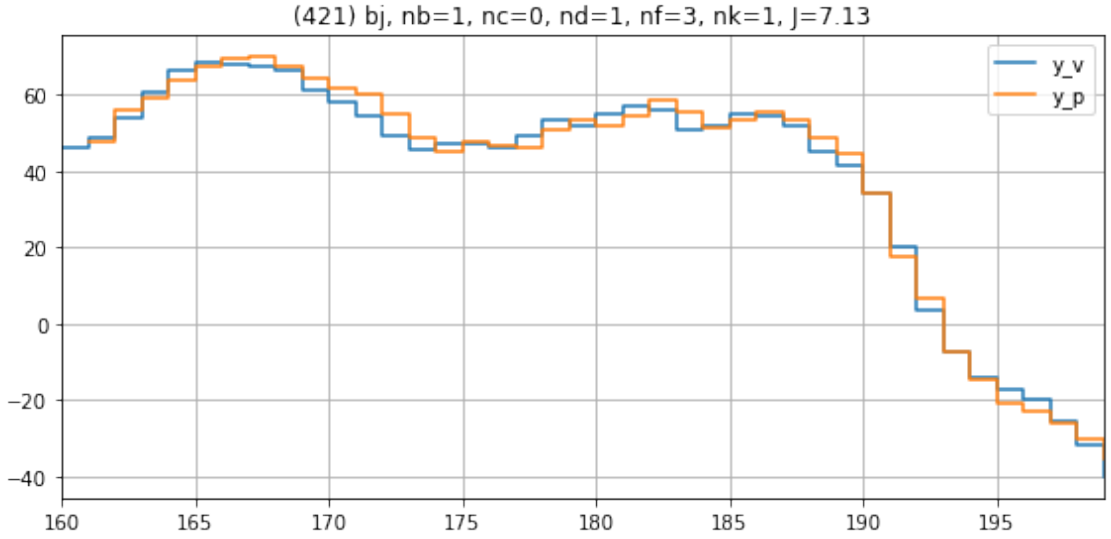
$$\frac{2.344z^2 + 2.832z - 0.01858}{z^3 - 0.8159z^2}$$



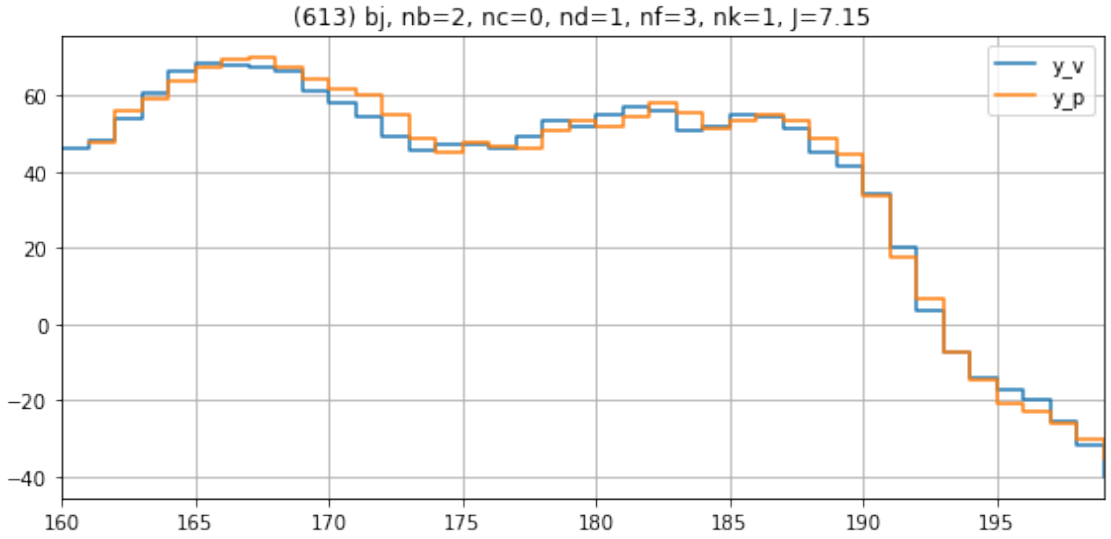
$$\frac{2.344z + 2.853}{z^2 - 0.8078z - 0.00669}$$



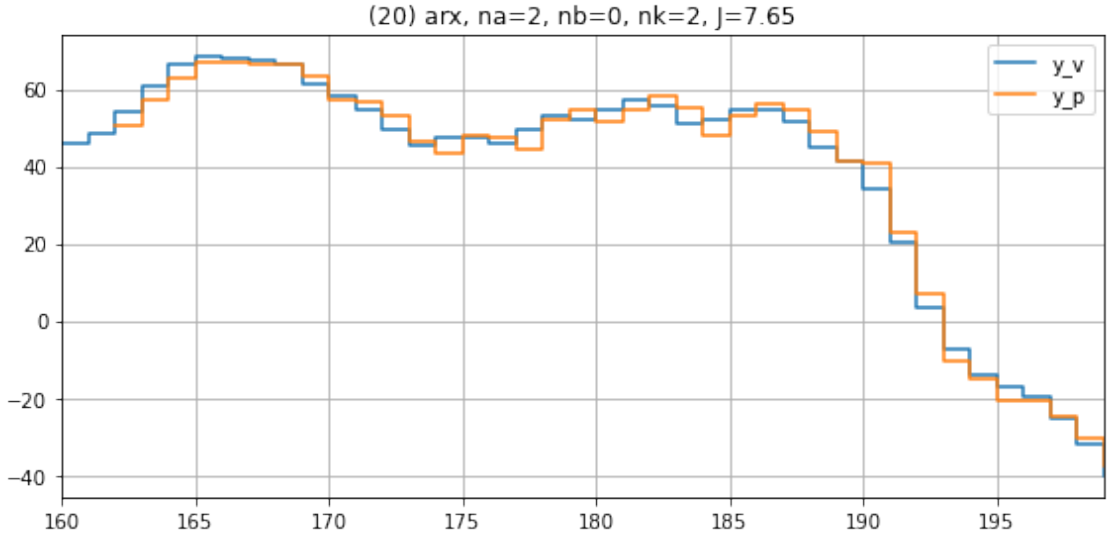
$$\frac{2.331z^2 + 3.04z}{z^3 - 0.7292z^2 - 0.1388z + 0.06155}$$



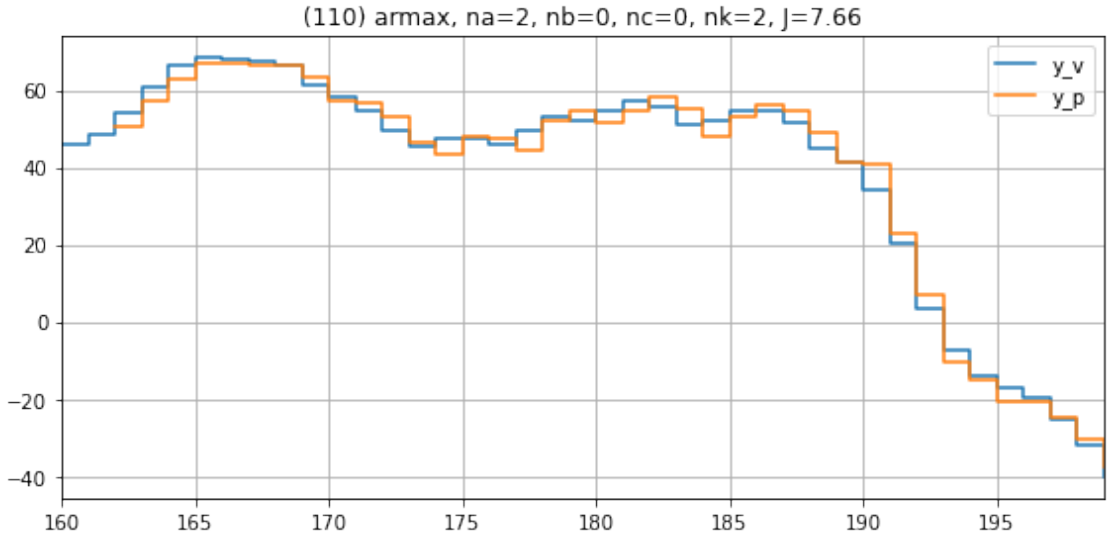
$$\frac{2.331z^2 + 2.839z - 0.2628}{z^3 - 0.8169z^2 - 0.06954z + 0.06343}$$



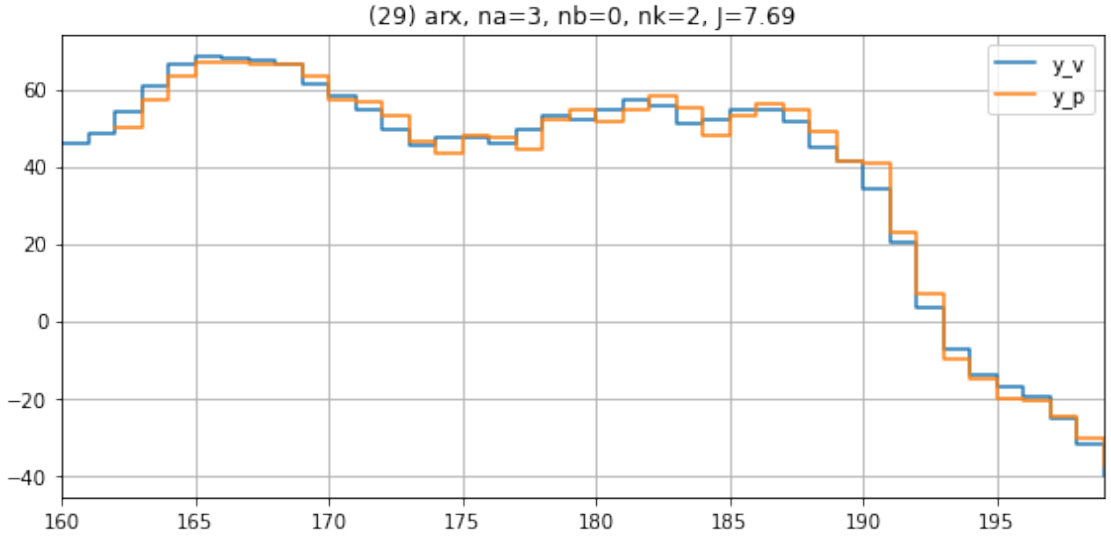
$$\frac{2.663}{z^2 - 1.366z + 0.4622}$$



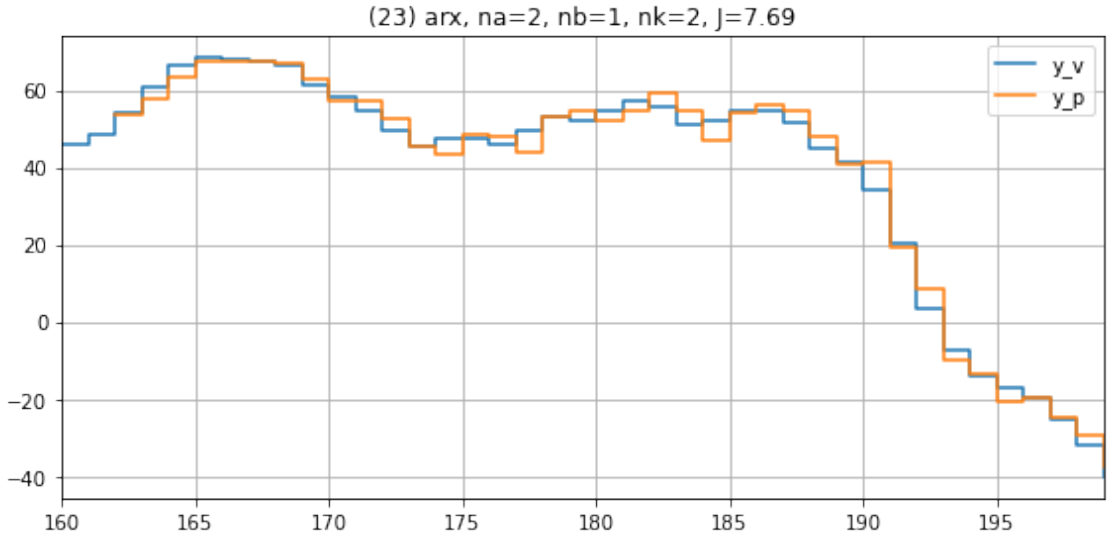
$$\frac{2.678}{z^2 - 1.362z + 0.4588}$$



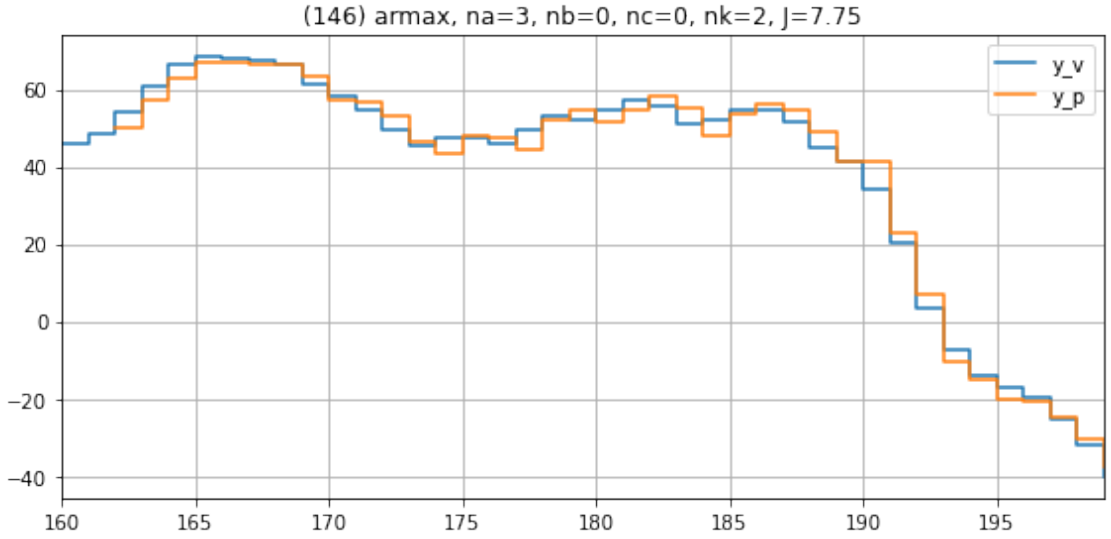
$$\frac{2.55z}{z^3 - 1.387z^2 + 0.4881z - 0.008455}$$



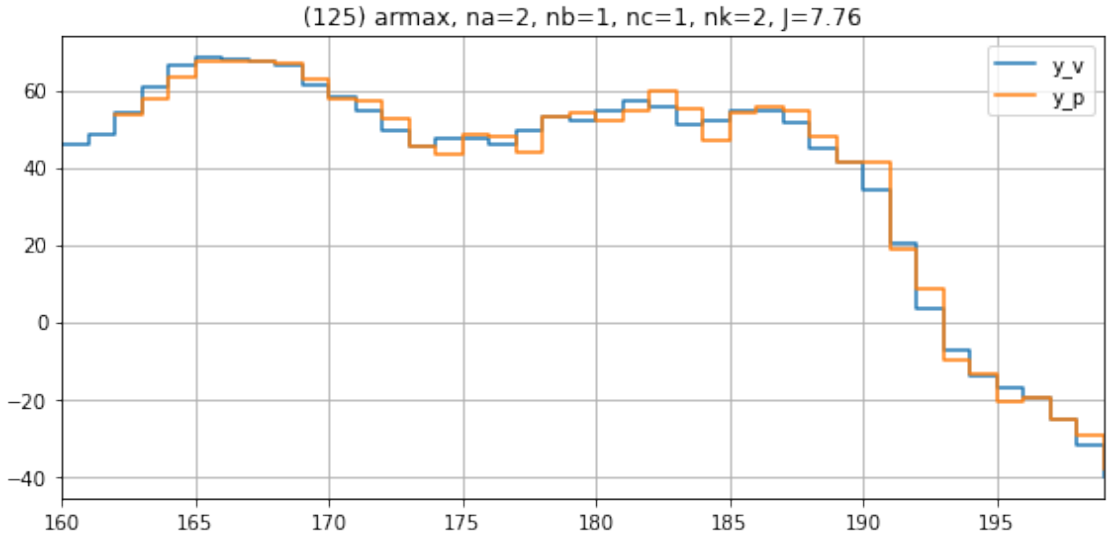
$$\frac{3.267z - 1.513}{z^3 - 1.464z^2 + 0.5285z}$$



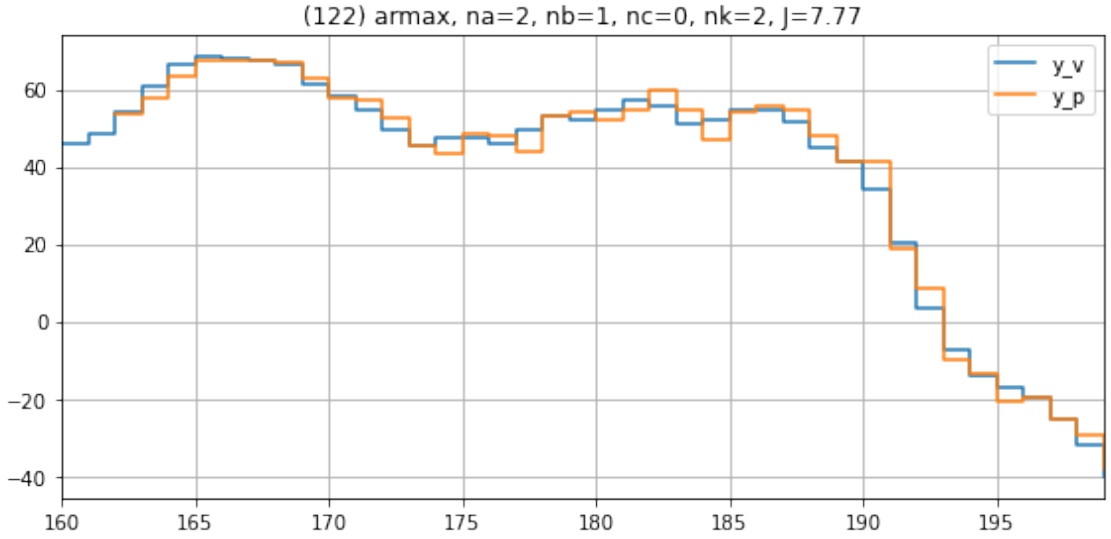
$$\frac{2.679z}{z^3 - 1.372z^2 + 0.4823z - 0.01372}$$



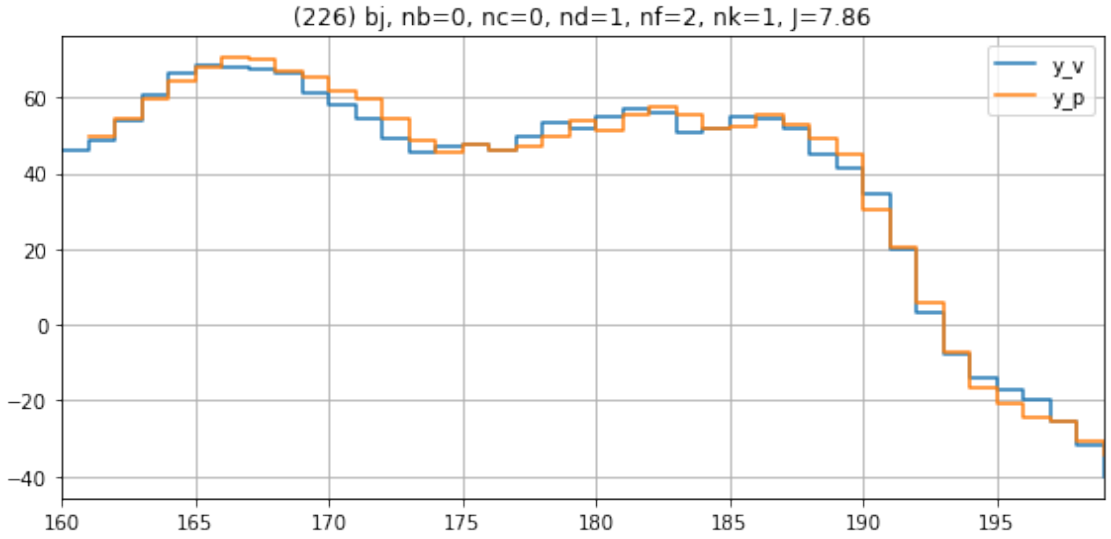
$$\frac{3.375z - 1.586}{z^3 - 1.46z^2 + 0.5255z}$$



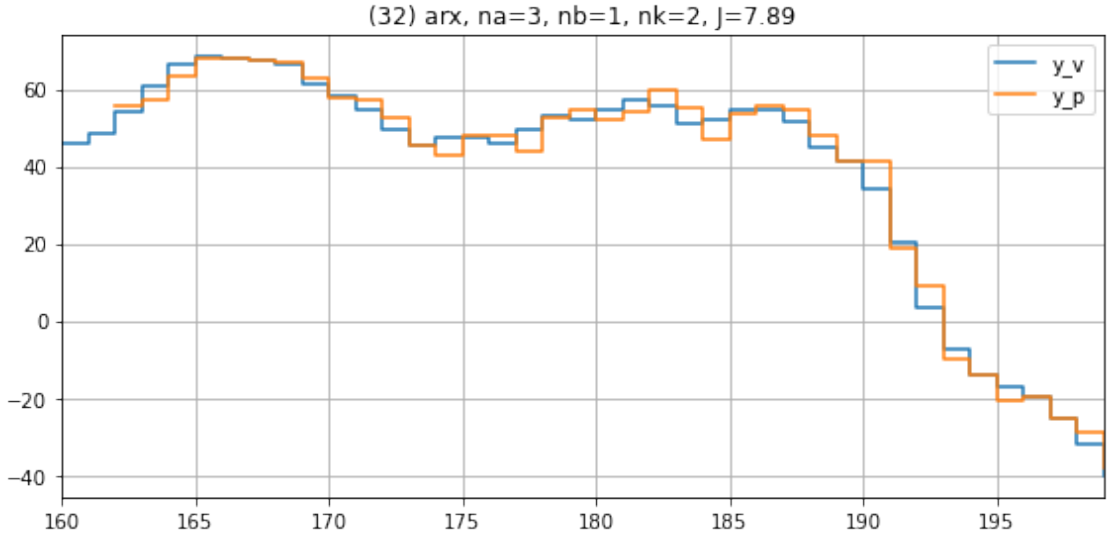
$$\frac{3.373z - 1.554}{z^3 - 1.453z^2 + 0.5193z}$$



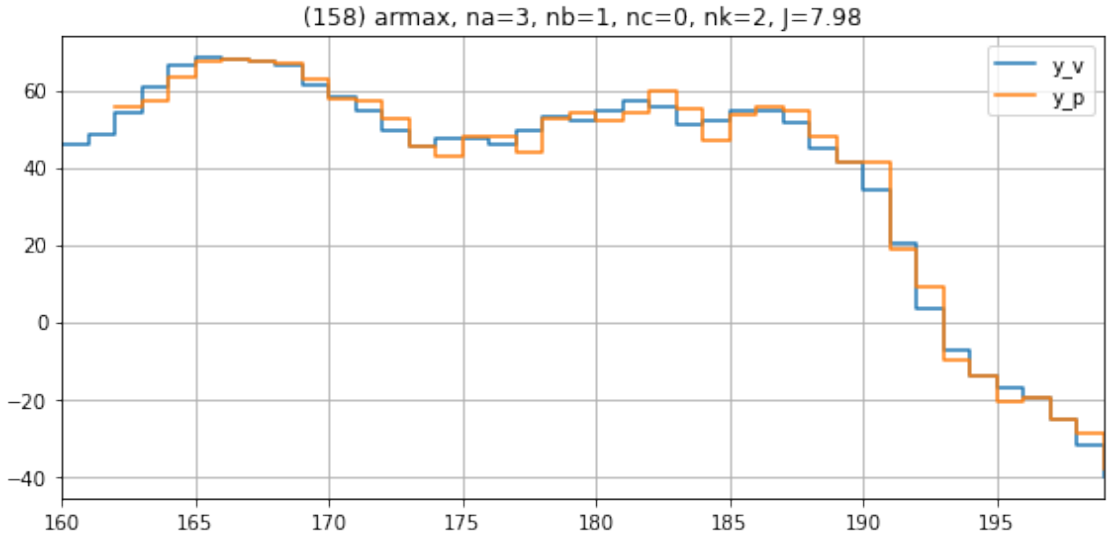
$$\frac{3.012z}{z^2 - 1.302z + 0.414}$$



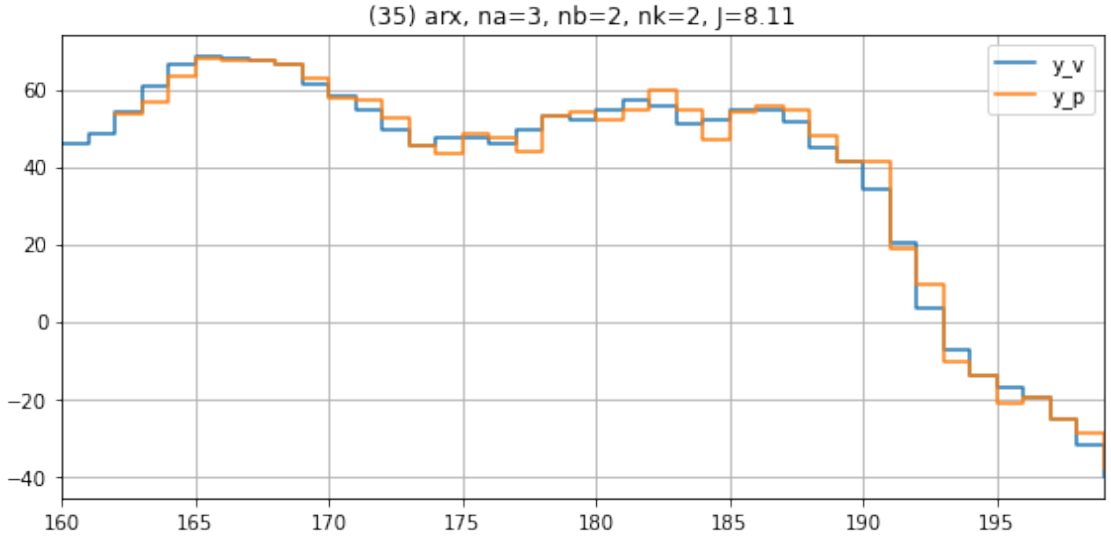
$$\frac{3.299z - 1.598}{z^3 - 1.434z^2 + 0.4481z + 0.04884}$$



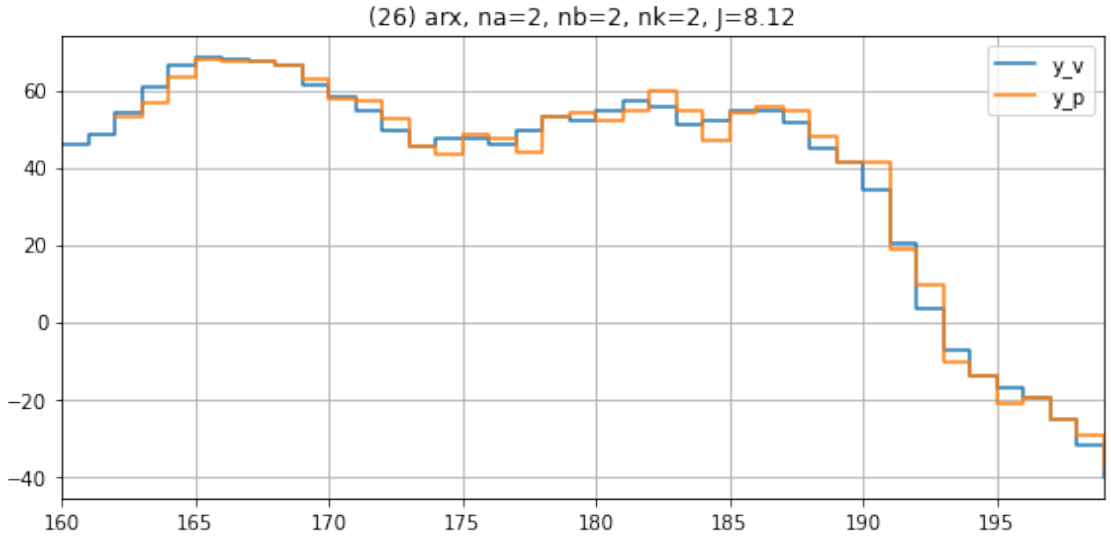
$$\frac{3.41z - 1.641}{z^3 - 1.423z^2 + 0.4397z + 0.04824}$$



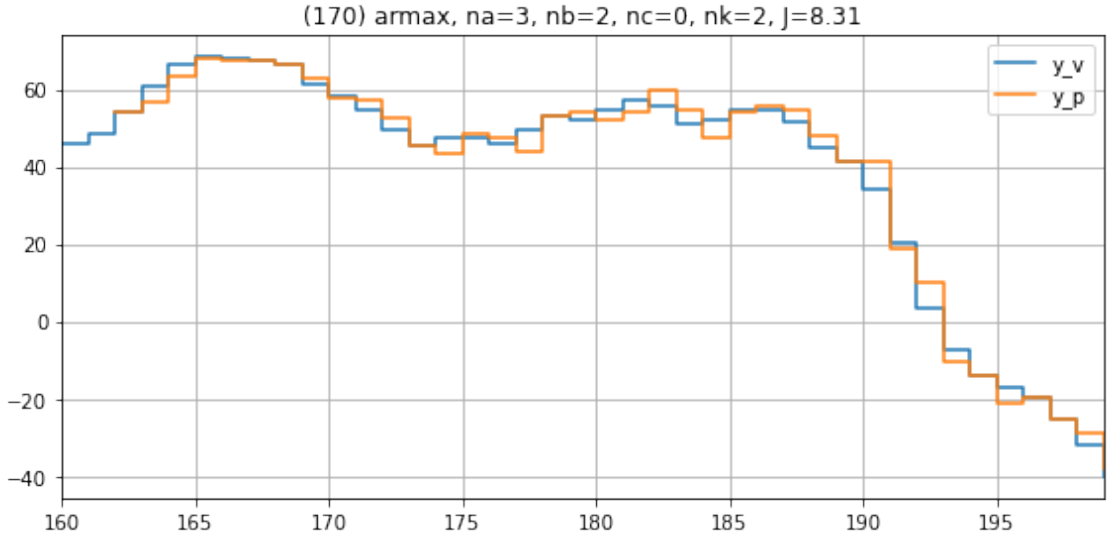
$$\frac{3.253z^2 - 1.771z + 0.4761}{z^4 - 1.465z^3 + 0.5281z^2 + 0.008387z}$$



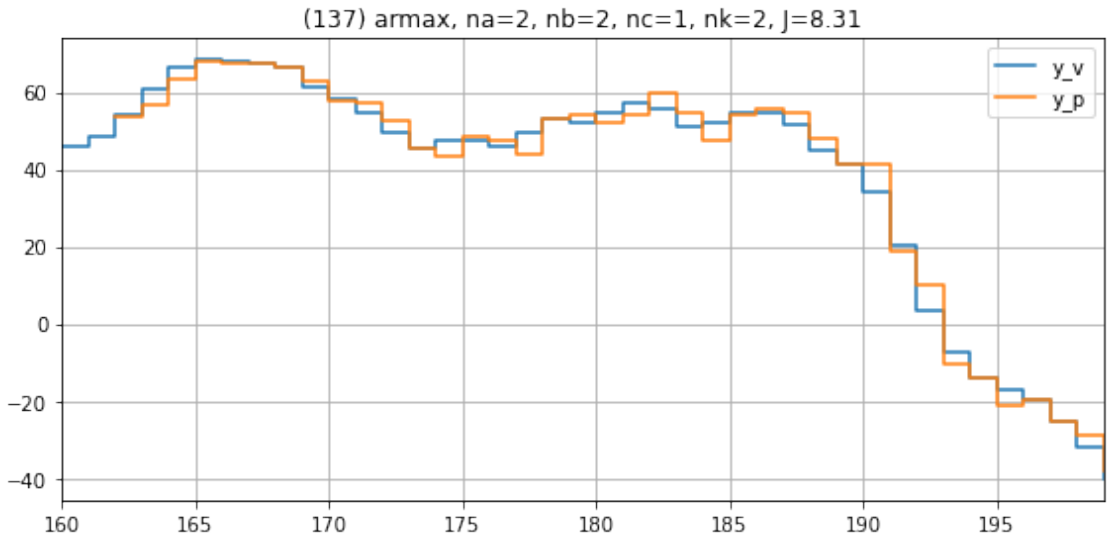
$$\frac{3.246z^2 - 1.767z + 0.4963}{z^4 - 1.47z^3 + 0.5425z^2}$$



$$\frac{3.339z^2 - 1.894z + 0.5276}{z^4 - 1.45z^3 + 0.5067z^2 + 0.01609z}$$



$$\frac{3.334z^2 - 1.968z + 0.5752}{z^4 - 1.476z^3 + 0.5469z^2}$$



[ ]:
```
model = models.loc[(models.model == 'arx') & (models.na == 2) & (models.nb ==␣
  ↪2) & (models.nk == 1)]
assert(len(model) == 1)
model = model.iloc[0]

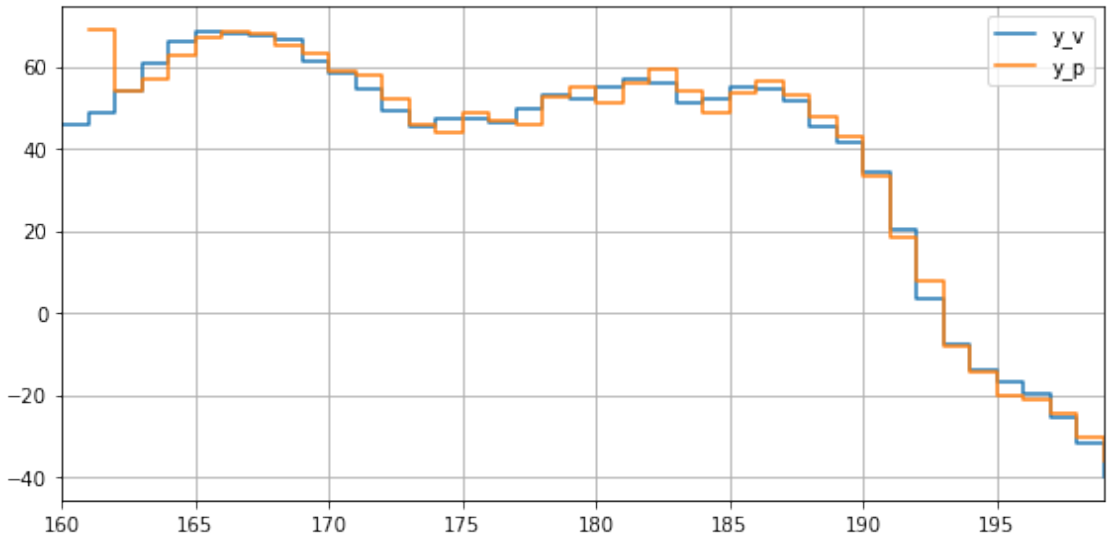
display(model.G)
display(model.H)
display(model.Jp)

plt.figure(figsize=(8,4))
plt.plot(k_v, y_v, label='y_v', drawstyle='steps-post')
plt.plot(k_v[model.nk:], model.yp, label='y_p', drawstyle='steps-post')
plt.xlim(k_v[0], k_v[-1])
plt.grid()
plt.legend()
plt.tight_layout()
plt.show()
```

$$\frac{2.162z^2 + 1.611z - 1.602}{z^3 - 1.407z^2 + 0.4826z}$$

$$\frac{z^2}{z^2 - 1.407z + 0.4826}$$

```
16.155434149353134
```


y_v
y_p
60
40
20
0
−20
−40
160
165
170
175
180
185
190
195