Appendices

Draft version

Appendix A: Code

All code underlying DBAFS is bundled in the R package dockless, available on github through the following link: https://github.com/luukvdmeer/dockless. For now, the code is optimized for the case study in San Francisco, but can easily be generalized to be used in any dockless bike sharing system.

Appendix B: Models

```
## Loading required package: forecast
## Series: x
## ARIMA(0,1,5)
##
## Coefficients:
##
             ma1
                     ma2
                              ma3
                                        ma4
                                                 ma5
##
         -0.1618 0.0033
                          -0.0429
                                    -0.0678
                                             -0.0228
## s.e.
          0.0112
                  0.0113
                            0.0115
                                     0.0114
##
## sigma^2 estimated as 0.03256:
                                   log likelihood=2349.34
## AIC=-4686.68
                  AICc=-4686.67
                                   BIC=-4644.75
## Series: x
## ARIMA(0,1,5)
##
## Coefficients:
##
             ma1
                      ma2
                                ma3
                                         ma4
                                                  ma5
         -0.3572
                  -0.1328
                           -0.0581
                                     -0.0770
                                              -0.0936
##
## s.e.
          0.0112
                   0.0119
                             0.0122
                                      0.0123
##
## sigma^2 estimated as 0.1635: log likelihood=-4105.57
## AIC=8223.13
                 AICc=8223.14
                                 BIC=8265.05
## Series: x
## ARIMA(2,1,1)
##
## Coefficients:
##
            ar1
                    ar2
                             ma1
##
         0.5906 0.0876
                         -0.9179
## s.e. 0.0206 0.0161
                          0.0166
## sigma^2 estimated as 0.124: log likelihood=-3000.02
## AIC=6008.05
                 AICc=6008.05
                                 BIC=6035.99
```

```
## Series: x
## ARIMA(1,1,1)
## Box Cox transformation: lambda= 0
##
## Coefficients:
## ar1 ma1
## 0.831 -0.9285
## s.e. 0.042 0.0306
##
## sigma^2 estimated as 0.013: log likelihood=5444
## AIC=-10882.01 AICc=-10882 BIC=-10861.04
```

Appendix C: Test points

```
time
                                          location cluster
## 54381 2018-12-07 04:07:00 -122.42064, 37.77994
## 111719 2018-12-08 10:03:00 -122.4009, 37.7663
                                                         2
## 207864 2018-12-04 01:03:00 -122.40465, 37.77197
## 225706 2018-12-06 05:08:00 -122.39988, 37.76512
                                                         3
## 45951 2018-12-08 23:28:00 -122.45842, 37.79226
                                                         4
## 19014 2018-12-04 19:12:00 -122.39896, 37.79543
## 215470 2018-12-04 20:15:00 -122.40842, 37.77884
## 241305 2018-12-05 04:52:00 -122.40464, 37.78504
                                                         2
## 209366 2018-12-04 17:56:00 -122.41799, 37.77716
                                                         2
## 190904 2018-12-07 20:34:00 -122.39821, 37.78672
## 139948 2018-12-07 06:01:00 -122.38811, 37.75664
                                                         2
## 235558 2018-12-04 23:04:00 -122.42493, 37.77087
                                                         3
## 147066 2018-12-08 17:03:00 -122.44152, 37.76019
                                                         3
## 51241 2018-12-05 18:53:00 -122.43135, 37.80177
## 26546 2018-12-05 00:24:00 -122.40334, 37.76335
                                                         3
## 93582 2018-12-04 05:56:00 -122.40527, 37.75257
                                                         3
## 200322 2018-12-04 22:35:00 -122.39311, 37.77558
                                                         2
## 133848 2018-12-09 19:38:00 -122.44664, 37.77495
## 117560 2018-12-08 02:03:00 -122.40380, 37.77243
                                                         2
## 79620 2018-12-09 04:21:00 -122.41187, 37.78788
                                                         3
## 223114 2018-12-05 17:11:00 -122.39163, 37.77335
                                                         2
## 204664 2018-12-03 00:59:00 -122.45875, 37.80303
## 124028 2018-12-04 22:11:00 -122.42127, 37.75925
                                                         3
## 88236 2018-12-04 02:18:00 -122.42131, 37.75825
                                                         3
## 78690 2018-12-06 00:41:00 -122.39145, 37.77771
                                                         2
## 128217 2018-12-06 03:46:00 -122.43457, 37.77833
                                                         3
## 151791 2018-12-06 04:41:00 -122.45253, 37.76827
                                                         3
## 134571 2018-12-04 12:08:00 -122.42634, 37.76933
                                                         3
## 107840 2018-12-04 16:36:00 -122.39509, 37.79417
## 26241 2018-12-09 04:53:00 -122.42237, 37.79901
                                                         3
## 229686 2018-12-05 01:43:00 -122.39774, 37.79573
                                                         2
                                                         2
## 175998 2018-12-07 06:29:00 -122.40841, 37.79583
## 99266 2018-12-09 18:23:00 -122.43039, 37.76045
         2018-12-04 15:46:00 -122.40409, 37.78456
                                                         2
## 169757 2018-12-07 23:59:00 -122.41391, 37.78118
                                                         2
## 71862 2018-12-06 14:21:00 -122.42083, 37.75385
                                                         3
## 51983 2018-12-06 22:23:00 -122.40556, 37.78879
## 104403 2018-12-03 14:40:00 -122.42467, 37.76319
```

```
## 128940 2018-12-09 17:48:00 -122.41263, 37.78489
## 201514 2018-12-03 02:44:00 -122.42256, 37.77492
## 208458 2018-12-06 19:46:00 -122.4349, 37.7878
## 64115 2018-12-04 19:12:00 -122.41728, 37.77679
## 161285 2018-12-08 05:10:00 -122.38564, 37.74941
                                                         2
## 42130 2018-12-08 04:27:00 -122.4330, 37.7642
                                                         3
## 35368 2018-12-05 18:10:00 -122.39237, 37.79064
## 167286 2018-12-08 19:36:00 -122.41864, 37.78411
                                                         3
## 62667 2018-12-07 02:01:00 -122.39902, 37.78676
                                                         2
## 108122 2018-12-07 15:53:00 -122.46584, 37.78362
## 139380 2018-12-07 16:15:00 -122.4597, 37.7997
## 44941 2018-12-09 10:43:00 -122.4125, 37.7781
                                                         2
## 158447 2018-12-07 07:17:00 -122.43668, 37.75109
                                                         3
## 128930 2018-12-08 03:40:00 -122.39529, 37.79422
## 70012 2018-12-04 01:04:00 -122.42417, 37.76666
## 56956 2018-12-08 00:49:00 -122.41832, 37.77609
## 111697 2018-12-07 02:23:00 -122.42557, 37.80118
                                                         3
## 36142 2018-12-05 16:32:00 -122.39841, 37.77454
## 203876 2018-12-03 04:05:00 -122.45313, 37.76938
## 73205 2018-12-06 19:57:00 -122.43140, 37.78591
## 53083 2018-12-08 02:00:00 -122.45348, 37.77766
                                                         3
## 155915 2018-12-06 23:59:00 -122.43254, 37.78548
## 76996 2018-12-03 15:47:00 -122.43049, 37.76647
                                                         3
## 4702 2018-12-08 06:40:00 -122.43712, 37.80076
                                                         3
## 85370 2018-12-06 16:44:00 -122.42259, 37.79495
## 10172 2018-12-04 02:52:00 -122.41275, 37.76865
## 89004 2018-12-06 22:30:00 -122.40531, 37.78572
## 136150 2018-12-09 06:03:00 -122.42277, 37.76486
                                                         3
## 25916 2018-12-07 23:09:00 -122.42193, 37.76532
                                                         3
## 117278 2018-12-09 01:05:00 -122.42060, 37.78995
## 122282 2018-12-09 20:34:00 -122.42395, 37.76346
                                                         3
## 11732 2018-12-05 02:10:00 -122.38628, 37.73904
                                                         1
## 118705 2018-12-06 23:23:00 -122.42109, 37.75572
## 90721 2018-12-09 00:01:00 -122.46256, 37.79604
## 99567 2018-12-05 01:39:00 -122.44354, 37.77899
## 162467 2018-12-08 22:07:00 -122.41823, 37.78422
                                                         3
## 83994 2018-12-03 15:57:00 -122.42388, 37.77139
## 30247 2018-12-06 16:09:00 -122.43081, 37.78058
                                                         3
## 156476 2018-12-05 20:03:00 -122.39316, 37.77594
                                                         2
## 236292 2018-12-04 08:02:00 -122.42011, 37.76176
## 213262 2018-12-09 21:06:00 -122.43501, 37.76187
## 27322 2018-12-03 01:36:00 -122.40684, 37.76941
## 184264 2018-12-08 07:45:00 -122.43028, 37.76638
                                                         3
## 194190 2018-12-04 20:26:00 -122.41946, 37.76535
                                                         3
## 10094 2018-12-03 22:56:00 -122.42350, 37.80418
## 58276 2018-12-09 20:21:00 -122.42128, 37.75818
                                                         3
## 240506 2018-12-05 06:52:00 -122.42691, 37.76455
                                                         3
## 142482 2018-12-07 19:29:00 -122.41067, 37.76702
## 209485 2018-12-07 00:07:00 -122.39235, 37.78254
## 174388 2018-12-09 03:41:00 -122.4472, 37.8049
## 114258 2018-12-04 02:24:00 -122.46262, 37.77914
                                                         3
## 167707 2018-12-08 10:56:00 -122.41436, 37.78862
                                                         3
## 36175 2018-12-04 15:14:00 -122.39968, 37.77477
                                                         2
## 65888 2018-12-08 01:31:00 -122.41723, 37.77669
```

```
## 187737 2018-12-06 19:34:00 -122.41389, 37.76917
## 16306 2018-12-05 00:12:00 -122.38653, 37.76966
## 59226 2018-12-04 20:38:00 -122.40820, 37.78448
## 65882 2018-12-06 05:21:00 -122.41978, 37.76534
## 63542 2018-12-03 17:49:00 -122.42813, 37.76118
                                                         3
## 211257 2018-12-06 03:59:00 -122.47170, 37.78052
                                                         3
## 201100 2018-12-08 19:24:00 -122.40021. 37.76727
## 202859 2018-12-03 16:59:00 -122.38975, 37.78471
                                                         2
## 233245 2018-12-04 22:43:00 -122.40543, 37.78887
                                                         2
## 136453 2018-12-03 20:42:00 -122.40412, 37.77037
## 91288 2018-12-05 02:26:00 -122.42431, 37.79937
## 184448 2018-12-07 15:11:00 -122.46870, 37.80385
## 100341 2018-12-06 08:14:00 -122.43344, 37.78627
                                                         3
## 155809 2018-12-03 00:05:00 -122.39381, 37.72664
## 46946 2018-12-08 05:39:00 -122.42073, 37.76022
## 31213 2018-12-04 01:03:00 -122.39453, 37.77684
## 172488 2018-12-09 09:47:00 -122.42074, 37.76111
                                                         3
## 134200 2018-12-04 17:02:00 -122.40229, 37.77138
## 120334 2018-12-08 12:14:00 -122.40014, 37.79352
## 164535 2018-12-08 23:04:00 -122.44692, 37.77015
## 190786 2018-12-05 02:08:00 -122.43232, 37.79763
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## 80715 2018-12-07 16:40:00 -122.43043, 37.79572
## 231913 2018-12-05 23:57:00 -122.40050, 37.78959
                                                         2
## 89666 2018-12-08 03:49:00 -122.39741, 37.76058
                                                         3
## 133719 2018-12-03 22:06:00 -122.41981, 37.77642
## 104954 2018-12-03 05:18:00 -122.44997, 37.76537
## 70927 2018-12-03 14:48:00 -122.46487, 37.77511
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## 113353 2018-12-08 05:10:00 -122.45332, 37.77698
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## 11571 2018-12-06 01:17:00 -122.39135, 37.77298
## 66315 2018-12-07 21:24:00 -122.4077, 37.7711
## 161845 2018-12-09 18:57:00 -122.42922, 37.78561
## 139484 2018-12-03 05:25:00 -122.45193, 37.76848
                                                         3
## 195102 2018-12-09 01:21:00 -122.44682, 37.80333
## 78660 2018-12-03 18:15:00 -122.41521, 37.77575
        2018-12-04 23:18:00 -122.44167, 37.78133
## 137645 2018-12-08 21:31:00 -122.45912, 37.78354
                                                         3
## 235118 2018-12-09 21:50:00 -122.4053, 37.7837
## 154209 2018-12-09 00:55:00 -122.43322, 37.78565
                                                         3
## 159437 2018-12-05 01:15:00 -122.39122, 37.78013
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## 169336 2018-12-07 17:54:00 -122.42106, 37.75215
## 122854 2018-12-05 19:57:00 -122.39037, 37.76696
## 185336 2018-12-07 03:04:00 -122.41783, 37.78897
## 105242 2018-12-09 18:33:00 -122.40488, 37.77096
                                                         2
## 49583 2018-12-07 07:15:00 -122.40560, 37.78588
## 46992 2018-12-06 22:20:00 -122.40045, 37.78737
## 110811 2018-12-05 08:26:00 -122.4447, 37.7693
                                                         3
## 74244 2018-12-04 20:09:00 -122.40434, 37.79402
                                                         2
## 79852 2018-12-07 01:48:00 -122.38787, 37.78323
## 186645 2018-12-04 16:26:00 -122.4416, 37.7775
## 154502 2018-12-06 00:34:00 -122.42149, 37.79427
## 163574 2018-12-03 17:39:00 -122.38657, 37.77113
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## 238343 2018-12-03 22:43:00 -122.41923, 37.78885
                                                         3
## 165401 2018-12-06 17:24:00 -122.39324, 37.77747
                                                         2
## 111749 2018-12-04 17:49:00 -122.46200, 37.79719
```

```
## 135625 2018-12-09 00:46:00 -122.4256, 37.7936
## 109527 2018-12-08 05:39:00 -122.44734, 37.78332
## 77828 2018-12-09 23:36:00 -122.40434, 37.77211
## 106442 2018-12-04 01:24:00 -122.39345, 37.79318
## 16456 2018-12-07 00:10:00 -122.41302, 37.78025
                                                         2
## 115793 2018-12-08 02:37:00 -122.38868, 37.76345
## 15385 2018-12-06 16:06:00
                               -122.443, 37.784
## 199084 2018-12-09 00:38:00 -122.40726, 37.77076
                                                         2
## 59798 2018-12-08 20:21:00 -122.42158, 37.76065
                                                         3
## 178363 2018-12-06 20:45:00 -122.39155, 37.77979
        2018-12-05 06:08:00 -122.44983, 37.76535
## 172799 2018-12-07 22:04:00 -122.41268, 37.76096
                                                         2
## 190712 2018-12-03 01:44:00 -122.42835, 37.79751
                                                         3
## 125849 2018-12-06 01:48:00 -122.39558, 37.77652
## 18249 2018-12-08 20:24:00 -122.41391, 37.77099
## 83279 2018-12-04 19:07:00 -122.39401, 37.77796
## 211042 2018-12-07 03:46:00 -122.44886, 37.80109
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## 94646 2018-12-06 01:09:00 -122.41001, 37.75965
         2018-12-05 02:48:00 -122.39745, 37.76062
                                                         3
## 190144 2018-12-08 22:58:00 -122.45196, 37.80447
## 20024 2018-12-08 02:42:00 -122.42655, 37.79264
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## 65286 2018-12-08 02:30:00 -122.40855, 37.79577
## 160439 2018-12-09 11:18:00 -122.43869, 37.75905
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## 150632 2018-12-09 22:59:00 -122.39906, 37.77905
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## 212960 2018-12-04 19:53:00 -122.40086, 37.78946
## 41089 2018-12-06 22:44:00 -122.41084, 37.76301
## 194697 2018-12-08 01:17:00 -122.40929, 37.78419
## 172686 2018-12-08 20:23:00 -122.44506, 37.80159
                                                         3
## 185234 2018-12-08 05:27:00 -122.46103, 37.76597
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## 231993 2018-12-09 07:49:00 -122.43159, 37.76929
## 231738 2018-12-09 02:41:00 -122.41599, 37.78818
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## 171406 2018-12-04 20:39:00 -122.40230, 37.79019
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## 230447 2018-12-07 00:34:00 -122.41533, 37.78534
## 228672 2018-12-08 04:32:00 -122.40494, 37.78156
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## 213110 2018-12-09 08:57:00 -122.4111, 37.7880
                                                         2
## 243313 2018-12-04 04:25:00 -122.40076, 37.77472
                                                         2
          2018-12-08 01:13:00 -122.42199, 37.76573
## 64787 2018-12-08 21:55:00 -122.42525, 37.77511
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## 113257 2018-12-07 00:47:00 -122.40000, 37.78979
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## 22163 2018-12-08 20:17:00 -122.42714, 37.76874
## 18724 2018-12-06 21:05:00 -122.44106, 37.78797
## 56748 2018-12-04 19:27:00 -122.38251, 37.73313
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## 93506 2018-12-04 04:46:00 -122.41744, 37.77668
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## 108208 2018-12-06 08:39:00 -122.3912, 37.7667
## 187746 2018-12-07 01:55:00 -122.42042, 37.78889
## 81174 2018-12-09 00:15:00 -122.40070, 37.77499
                                                         2
## 75394 2018-12-08 23:58:00 -122.4214, 37.7733
                                                         2
## 57126 2018-12-06 01:38:00 -122.42840, 37.79756
                                                         3
## 67017 2018-12-08 23:36:00 -122.4308, 37.7659
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## 23543 2018-12-05 17:34:00 -122.4033, 37.7883
                                                         2
## 80053 2018-12-06 18:37:00 -122.39592, 37.78505
                                                         2
## 14762 2018-12-07 16:59:00 -122.42298, 37.75527
                                                         3
## 128266 2018-12-05 07:40:00 -122.42100, 37.75449
                                                         3
## 141917 2018-12-04 06:43:00 -122.42175, 37.76354
```

```
## 196382 2018-12-08 00:57:00 -122.42914, 37.76726
## 32414 2018-12-08 07:38:00 -122.41372, 37.77945
## 45768 2018-12-04 23:04:00 -122.39954, 37.78852
## 30776 2018-12-03 18:12:00 -122.43001, 37.79782
## 55500 2018-12-04 19:44:00 -122.42105, 37.78133
## 153576 2018-12-08 23:18:00 -122.38841, 37.74183
## 208833 2018-12-06 16:43:00 -122.41296. 37.76092
## 47176 2018-12-07 17:40:00 -122.41844, 37.77578
                                                         2
## 219263 2018-12-09 04:39:00 -122.43492, 37.80298
                                                         3
## 181085 2018-12-04 11:46:00 -122.42085, 37.75553
## 118666 2018-12-04 23:55:00 -122.41021, 37.78245
## 123811 2018-12-09 20:32:00 -122.40135, 37.75451
## 112094 2018-12-08 23:33:00 -122.43196, 37.77083
                                                         3
## 73773 2018-12-03 17:25:00 -122.42876, 37.76627
## 82358 2018-12-04 03:46:00 -122.40903, 37.77916
## 161026 2018-12-09 23:20:00 -122.42135, 37.75819
## 174438 2018-12-04 19:33:00 -122.45153, 37.79868
## 241145 2018-12-07 01:51:00 -122.40862, 37.78442
## 113434 2018-12-05 00:46:00 -122.39848, 37.78932
## 67260 2018-12-08 00:00:00 -122.45440, 37.77721
## 162962 2018-12-04 12:08:00 -122.44327, 37.79424
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## 85783 2018-12-04 20:01:00 -122.40316, 37.79499
## 42898 2018-12-04 21:55:00 -122.41878, 37.77545
                                                         2
## 10627 2018-12-06 11:15:00 -122.43446, 37.80116
                                                         3
## 67365 2018-12-04 20:12:00 -122.39426, 37.77991
## 212441 2018-12-03 01:46:00 -122.43196, 37.77119
## 50428 2018-12-06 19:36:00 -122.40151, 37.79008
## 9395 2018-12-07 07:32:00 -122.4665, 37.7641
                                                         3
## 30050 2018-12-09 01:36:00 -122.4684, 37.8042
## 141286 2018-12-05 20:52:00 -122.40209, 37.79664
## 153928 2018-12-04 19:07:00 -122.46686, 37.78296
## 68960 2018-12-04 01:24:00 -122.39834, 37.78872
                                                         2
## 144781 2018-12-08 04:49:00 -122.45839, 37.79224
## 86923 2018-12-06 00:02:00 -122.39275, 37.76773
## 187962 2018-12-07 15:43:00 -122.42093, 37.75492
## 221452 2018-12-06 01:18:00 -122.40078, 37.77747
                                                         2
## 230743 2018-12-04 16:08:00 -122.43338, 37.75145
## 160519 2018-12-09 20:45:00 -122.39442, 37.77631
                                                         2
## 54656 2018-12-08 05:24:00 -122.42855, 37.75225
                                                         3
## 190890 2018-12-06 17:24:00 -122.39674, 37.77694
## 186983 2018-12-04 04:00:00 -122.41849, 37.77911
## 50327 2018-12-08 21:55:00 -122.43443, 37.80127
## 196203 2018-12-08 01:54:00 -122.41710, 37.78815
                                                         3
                                                         2
## 186673 2018-12-07 20:48:00 -122.41060, 37.78239
## 167578 2018-12-06 02:42:00 -122.40023, 37.79023
## 156169 2018-12-07 04:29:00 -122.42206, 37.76328
## 158036 2018-12-04 19:53:00 -122.39574, 37.77888
                                                         2
## 112239 2018-12-07 18:31:00 -122.41039, 37.77694
## 192445 2018-12-06 08:33:00 -122.40327, 37.77213
## 138386 2018-12-08 01:47:00 -122.41759, 37.77646
## 221446 2018-12-04 21:17:00 -122.39375, 37.79022
                                                         2
## 139984 2018-12-06 22:37:00 -122.3951, 37.7941
## 224707 2018-12-08 05:05:00 -122.4331, 37.7641
                                                         3
## 239329 2018-12-04 05:07:00 -122.45134, 37.76554
```

```
## 185754 2018-12-03 21:43:00 -122.42072, 37.76011
## 115381 2018-12-04 18:31:00 -122.39178, 37.79289
## 220331 2018-12-03 01:38:00 -122.4392, 37.7734
## 216862 2018-12-07 15:32:00 -122.43176, 37.77762
                                                         3
## 188450 2018-12-08 05:13:00 -122.42259, 37.75524
                                                         3
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