國立臺灣大學電機資訊學院資訊工程學系

碩士論文

Department of Computer Science and Information Engineering

College of Electrical Engineering and Computer Science

National Taiwan University

Master Thesis

以基於時間比重之回歸預測電視收視率

TV Ratings Prediction with Time Weighting Based Regression

顧廷緯

Ting-Wei Ku

指導教授：林守德 博士

Advisor: Shou-De Lin, Ph.D.

中華民國104年1月  
Jan 2015

側邊

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國立臺灣大學（碩）博士學位論文

# 口試委員會審定書

以基於時間比重之回歸預測電視收視率  
TV Ratings Prediction with Time Weighting Based Regression

本論文係顧廷緯君（r01922060）在國立臺灣大學資訊工程學系、所完成之碩士學位論文，於民國104年1月30日承下列考試委員審查通過及口試及格，特此證明

口試委員：

　　　　　　　　　　　　　　　　（簽名）  
（指導教授）

系主任、所長 　　　　　　　　　　　（簽名）

（是否須簽章依各院系所規定）

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# 中文摘要

此論文主要貢獻為提出一個簡單且實驗結果準確的電視收視率預測方法，名為 Time Weighting Regression (TWR)。基於「越新的資料對預測接下來的收視率越重要」的假設，TWR 主要做的事情為：根據資料的時間賦予權重，再以帶有權重的資料建立回歸模型，最後用建立的模型預測接下來的收視率。我們以真實世界的電視收視率資料進行實驗，結果顯示它的預測比知名的時間序列模型（例如 Exponential Smoothing 和 ARIMA）和回歸模型（類神經網路）還準。

關鍵詞：時間序列預測、電視收視率預測、回歸。

# 英文摘要

In this thesis, the primary contribution is proposing a simple and experimentally accurate solution, named Time Weighting Regression (TWR), to the problem of TV ratings prediction. Based on the assumption that newer data are more important for predicting upcoming ratings, what TWR does is: weighing data based on time, and then using weighted data to build regression model for predicting upcoming ratings. In the experiments on a real-world TV ratings data set, it outperforms well-known time series models (e.g., Exponential Smoothing and ARIMA) and regression model (neural network).

Keywords: time series prediction, TV ratings prediction, regression.

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# 第一章 Introduction

1.1 Contribution

The main contributions of the thesis are summarized as below:

* A solution named Time Weighting Regression (TWR) is proposed to improve the results of TV ratings prediction.
* Experiments on a real-world TV ratings data set are conducted to show that our solution really gives us better results.

1.2 Background and importance of TV ratings prediction

Why is TV ratings prediction important? In TV industry, because the price of advertising time is mainly defined as ratings, predicting ratings accurately is very important to broadcasters and advertisers. Accurate predictions help them make money, while inaccurate predictions cause money loss.

How complex is TV ratings prediction? First, it is complex because TV ratings is an aggregated measurement of a lot of people’s watching choices. Second, generally speaking, TV is competing with every other platform/service that tries to grab eyeballs. As more such platforms/services appear and grow, the competition becomes more complex, which probably makes accurately predicting TV ratings increasingly difficult. For example, we may need to consider whether people prefer watching YouTube videos via mobile to watching programs via TV.

Although TV ratings prediction seems important and complex, it may become less and less important and complex. In [1], it argues that TV industry is dying because people are switching from TV to other devices such as mobile which provides content via the Internet. If TV is no longer a popular media, it is not important to predict TV ratings accurately.

1.3 Overview of the problem and solution

In this thesis, our goal is to accurately predict the ratings of an upcoming episode. Because ratings of a TV program is a time series, the problem can be viewed as one-step time series forecasting. When it comes to solutions to time series forecasting, commonly used models can be divided into two main categories: time series models (e.g., ARIMA) and regression models (e.g., regression tree), where our proposed solution (TWR) falls into the latter. In addition to model, features used by model also largely affects prediction, but we choose to only use historical ratings of a TV program as features to avoid losing focus because our focus is models not features, and TWR can be used with any features, which is superior to some time series models (e.g., Exponential Smoothing) since they are not able to incorporate external features except historical time series values.

How does TWR work? Briefly speaking, it weighs training instances for regression analysis based on time, and then uses weighted instances to build regression model for predicting upcoming ratings. Thus, what makes TWR special is the idea of weighs training instances for regression analysis based on time before training. For building a base model with weighted instances, it can use any regression model, but among the models we have tried, regression tree gives us the best results. Details of how TWR works are described in section 3.

Why TWR works? That is, why the step of weighing training instances based on time in TWR gives us better predictions? We think it is because the following assumption holds: newer training instances are more important for predicting upcoming ratings. This assumption comes from our own experience on watching TV programs (especially dramas because our data set is ratings of dramas). When watching dramas, I don’t watch them due to past episodes long time ago, but I do watch them due to their recent episodes. For example, I may watch a drama because I hear that it is hot recently.

1.4 Motivation of solution

TWR is motivated by a well-known time series model called Simple Exponential Smoothing (SES). SES’s idea is that forecast is the weighted average of all past observations, and the weights decay exponentially as observations get older. The key difference is that TWR weighs training instances by time, while SES weighs training features (past observations) by time. Another difference is that TWR automatically tries different types of growth functions and decides the best one, not only the exponential function, which is the case of SES.

# 第二章 Related Work

In [2, 3], eight different models and one novel logit model for predicting TV ratings are studied, but we do not consider them in our study due to different characteristic of data set in terms of type of programs. Concretely, in their data set, many TV programs are broadcast only once, which is largely different from our problem of predicting ratings for weekly dramas.

In [4, 5, 6], their data sets are similar to ours in terms of type of programs, but we do not rely on any web or social info as features as they did, which makes our solution more general and easily applied to new dramas.

In [7], its data set only consists of one TV program with ten weekly ratings, which is too small to be compared with ours.

# 第三章 Method

In this section, we describe our proposed solution (TWR) in detail. As every learning algorithm, TWR consists of two stages: fitting and predicting, i.e., building model with training data and making prediction on testing data with trained model.

For fitting, it consists of three main steps: (1) transforming a time series into a set of training instances with a window size (this step is known as windowing transformation), (2) weighing training instances with a time-based growth function, and finally (3) building a model for one-step forecasting with a base learning algorithm (like decision tree) and weighted training instances.

For predicting, it makes a one-step forecast by providing trained model with input features from training data. Multi-step forecasts are computed recursively, e.g., taking one-step forecast as input to make the second-step forecast.

In the following sub-sections, we provide pseudo-code and describe each stage and step in detail.

3.1 Pseudo-code of Time Weighting Algorithm

Input data: A time series **x** with length **t**

Parameter: Window size **w**, growth function **f**, a base algorithm **Learner** with its parameters **p**

(For illustration, let **n** = 5, **w** = 3, **f** = ex, where ex is the exponential function.)

Fitting process:

1. Windowing transformation with window size **w**:  
   **x** = { x1, x2,..., x5 } 🡪 **X** = { **w1**= (x1, x2, x3=y3), (x2, x3, x4=y4), (x3, x4, x5=y5) }  
   We get 3 training instances, with each having 2 input features and 1 label.
2. Weighing training instances with growth function **f**: **W** = { e, e2, e3 }
3. Building a base model with weighted instances: **m** = **Learner.Fit**(**X**, **W**, **p**)

Output: base model **m**

Predicting process: Input data **w4** = (x4, x5, x6=y6), where x6=y6 is the unknown label to predict.

Output: one-step forecast **x­6’** = **Learner.Predict**(**m**, **w4**)

3.2 Fitting step 1: Windowing transformation

Windowing transformation is needed to apply regression models to time series forecasting. This process has 1 parameter: window size. It can be decided either by user or model-selection techniques such as AIC (Akaike information criterion) or cross-validation.

3.3 Fitting step 2: Weighing training instances

Mathematically speaking, because there are infinite “strictly increasing” functions, there are infinite growth functions that match our assumption, i.e., the newer, the more important. Take illustration in 3.1 for example, importance order is w1 < w2 < w3. So, what is the best growth function and how to find it from infinite possibilities? We define the best growth function as the one that minimizes the testing error of one-step forecast, and we start from studying some well-known types of growth functions: **linear** (x = { 2, 4, 6,… }), **exponential** (ex ), and **cubic exponential** (e3x) growth. Because testing data/error is unknown during training, we choose the growth function that minimizes the validation error of one-step forecast.

Although other growth functions should be considered, there is a technique that can narrow down the search space: resampling. By resampling training instances with given weights as probability (sampling with replacement), many weights assignments actually produce the same resampling result in most cases. For example, 10x and 11x produces probability p10 = { 0.09%, 0.9%, 9%, 90% }, p11 = { 0.06%, 0.75%, 8.26%, 90.9% }, respectively. For a time series of length 20 (average of our data set for experiment), the maximum number of training instances is 19. By resampling them with p10 and p11, it is very likely that their results have little or no difference (sample the last instance with over 90%).

Resampling implements weighting step at data level instead of learning algorithm level, which has the benefit of combing with any base algorithm. However, it introduces randomness, so reduce the variance by applying bagging, i.e., we repeat the iteration of this step and step of building a base model over many runs (20 times in our experiment).

3.4 Fitting step 3: Building a base model

We choose regression tree (regression version of decision tree) as our base model because it is sensitive to different data distribution.

3.5 Predicting stage of TWR

Taking average of predictions from multiple base models.

# 第四章 Experiments

In this section, we describe data set, evaluation metric, models, and results.

4.1 Data set

Our data set contains 8 weekly Idol dramas broadcasting in Taiwan. They are so-called Nielsen ratings, which is the most frequently used ratings in TV industry. Normally, the ratings are only available for Nielsen’s customers. Fortunately, some of them are announced in news and organized into Wikipedia, which is the case of all the dramas in our data set.

Simple data analysis results are presented via Table 1 and Figure 1 – 2. From the time series plot (Figure 1), the following things are observed:

* D2 and D7 have clear increasing trend, while all the others don’t have any obvious increasing or decreasing trend.
* There is no obvious seasonal or periodic component for ratings of all dramas, so there is no need to consider modeling ratings via seasonal decomposition or any seasonal models such as Triple Exponential Smoothing (also known as Holt-Winter’s seasonal method).
* D1 has the lowest ratings over the time. In fact, its ratings are close to zero.

From the box plots (Figure 2), the following things are observed:

* D2 and D7 has much wider ranges of ratings than all the other dramas. This is also reflected from the standard deviation of ratings in Table 1. It is likely that the wider the range of ratings, the more complex to predict ratings accurately.
* There is only 1 outlier in D4 (the 5th episode).

Table . Basic information about dramas

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 |
| Name | 大紅帽 | 小資女孩 | 向前走 | 金大花 | 真愛黑白 | 國民英雄 | 犀利人妻 | 螺絲小姐 |
| # Episode | 16 | 25 | 22 | 21 | 21 | 19 | 23 | 23 |
| Start(Y/M/D) | 13/2/28 | 11/8/21 | 12/2/19 | 13/1/6 | 13/6/9 | 10/12/5 | 10/11/5 | 12/7/22 |
| Avg – ratings | 0.21 | 5.12 | 2.38 | 1.57 | 2.16 | 1.10 | 3.36 | 3.47 |
| Std – ratings | 0.08 | 1.09 | 0.16 | 0.23 | 0.30 | 0.21 | 2.75 | 0.56 |

Figure . Time series plot for ratings of dramas

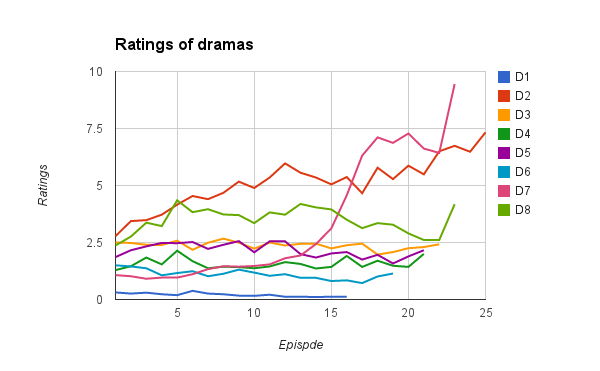
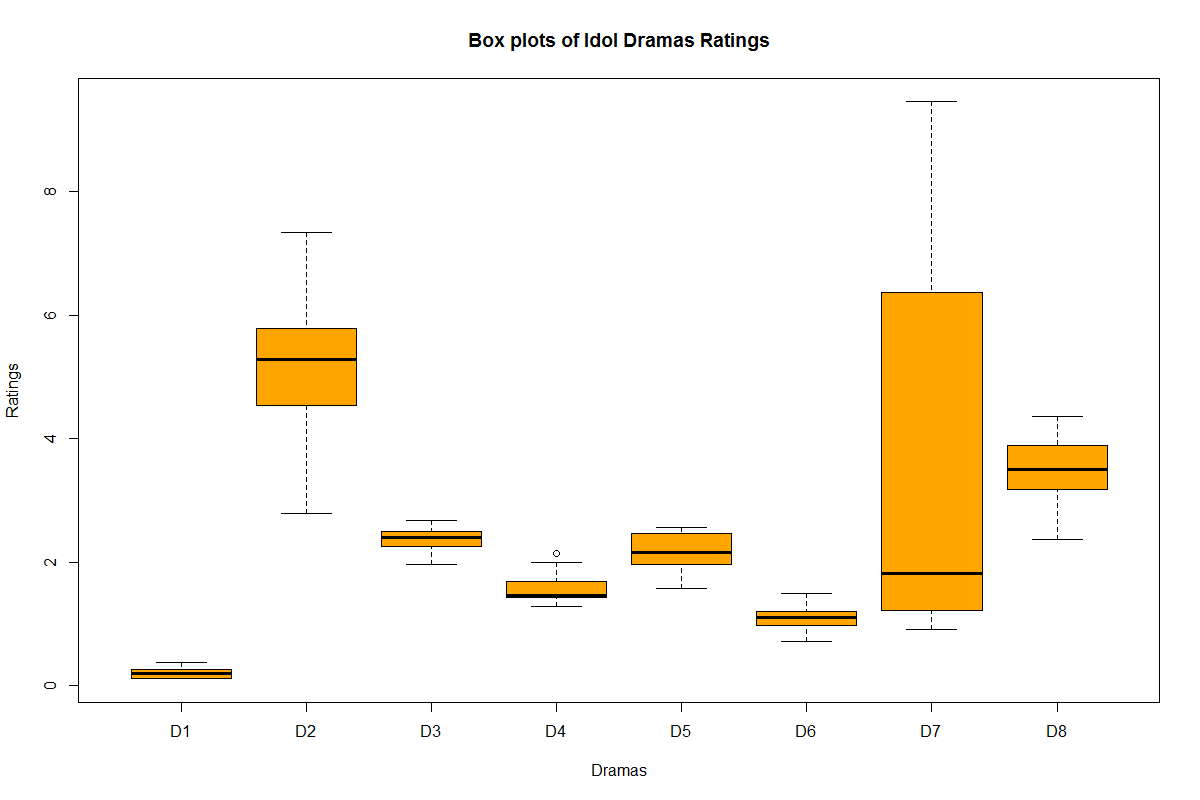


Figure . Box plots for ratings of dramas



In our experiments, each drama is treated independently, i.e., ratings from other dramas are not considered and only historical ratings of the drama itself are used to predict its future ratings. For each drama, only 1 rating is predicted at one time, a.k.a., one-step forecast. Ratings are predicted from the 6th episode. For each rating to be predicted, say kth episode, ratings ranging from the 1st episode to the k-2th episode are for training, and the k-1th episode for performing validation to choose the parameter growth function. For example, for testing the 10th episode, the first 8 episodes are for training, and the 9th episode for validation. We call this experiment scenario “sequential one-step forecast”. In this scenario, a model is trained for testing each episode.

4.2 Evaluation metric

We evaluate performance via 2 commonly used metrics in literature: mean absolute percentage error (MAPE) and mean absolute error (MAE). It is worth noting that by MAPE alone the result probably is somewhat misleading for programs of small ratings. For small ratings, it is easier to get bad MAPE, but probably by MAE the predictions are only a bit different from the actual.

In fact, In TV industry, programs of higher ratings are more valuable. Thus, we should focus on how accurate the predictions are in terms of the programs of higher ratings.

4.3 Models

We compare our solution with 7 competitors which can be categorized into 3 categories: (1) naïve guess, (2) well-known time series models, and (3) advance regression model. All the competitors along with our solution are summarized in Table 2. In Table 2, the 4th category is our solution with different growth functions.

We choose language R as our implementation platform. For most models, we just use the published packages in the official R repository, so-called Comprehensive R Archive Network, CRAN. For example, as we said in the previous section, we choose regression tree as the base model for our solution, so package rpart, a well-known R implementation of decision tree that supports regression, is used. For models that don’t have published packages, they are implemented by ourselves.

Table . List of models

|  |  |  |  |
| --- | --- | --- | --- |
| # | Category | Name | Summary |
| 1 | 1 | Last period (LP) | Guess value of the last period |
| 2 | 1 | Past average (PA) | Guess average of all the previous |
| 3 | 2 | Simple Exponential Smoothing (SES) | Package: HoltWinters {stats} |
| 4 | 2 | Double Exponential Smoothing (DES) | Package: HoltWinters {stats} |
| 5 | 2 | Exponential Smoothing State Space (ETS) | Package: ets {forecast} |
| 6 | 2 | ARIMA | Package: auto.arima {forecast} |
| 7 | 3 | Neural network auto-regression (NNA) | Package: nnetar {forecast} |
| 8 | 4 | TWR with no growth (TWR.N) | It equals to no TWR at all. |
| 9 | 4 | TWR with linear growth (TWR.L) | g(x) = x |
| 10 | 4 | TWR with exponential growth (TWR.E) | g(x) = ex |
| 11 | 4 | TWR with e3x growth (TWR.E3) | g(x) = e3x |
| 12 | 4 | TWR with auto-selected growth (TWR.A) | Pick growth with min validation err. |

4.4 Results

In this section, we show how well the models predict ratings in terms of MAPE and MAE.

Surprisingly, the most naïve and simplest model, LP, already performs pretty well. Among all competitors, it has the lowest overall MAPE of 0.1218, which sets a very challenging baseline. On the other hand, another naïve baseline, PA, perform pretty bad. It has much larger MAPE and MAE than all the other models. From results of two baselines, we can infer that value of next ratings has much to do with recent ratings, while has little or nothing to do with older ratings. This observation is very similar to the idea of Simple Exponential Smoothing: forecast is the weighted average of past observations, and the weights decay exponentially as observations get older.

As for the models of the 2nd category, SES has the best overall performance in this category. Among all competitors, it has the 2nd lowest overall MAPE of 0.1222 and the lowest overall MAE of 0.2893. Because SES is suitable for data with no trend or seasonal pattern, this result is as expected because from Figure 1 we already know that all dramas have no seasonal pattern, while only 2 out of 8 have trend pattern.

As for NNA, the only model of the 3rd category, its performance is neither very good nor very bad. However, it is worth noting that it has the lowest MAPE and MAE for D7, probably the most difficult drama to be predicted well due to its widest range of ratings.

Now it comes to the results of our solution. First, let’s compare the performance among 3 different growth functions: no growth (TWR.N), linear growth (TWR.L), and exponential growth (TWR.E). TWR.E has the best performance, followed by TWR.L and TWR.N. It shows that as more weights are put on the more recent training instances, the better performance we get. This evidence supports that our idea is valid. However, TWR has its limitation because TWR.E3 has mixed performance, i.e., performance of some dramas are improved, while some become worse. Thus, in order to automatically choose the best growth function, TWR.A is implemented. The results show that TWR.A outperforms all the other models in terms of overall MAPE and MAE among all dramas, which gives us more confidence that our idea is valid.

Table . MAPE of TV ratings predictions

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| M↓D→ | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | All |
| LP | 0.2427 | 0.0853 | 0.0859 | 0.1395 | 0.1265 | 0.1263 | 0.1307 | 0.0898 | 0.1218 |
| PA | 0.6017 | 0.1937 | 0.0647 | 0.1072 | 0.1398 | 0.2077 | 0.4609 | 0.1375 | 0.2248 |
| SES | 0.3247 | 0.0821 | 0.0633 | 0.1194 | 0.1235 | 0.1257 | 0.1307 | 0.0890 | 0.1222 |
| DES | 0.3016 | 0.0841 | 0.0688 | 0.1859 | 0.1515 | 0.1266 | 0.1215 | 0.1322 | 0.1377 |
| ETS | 0.4039 | 0.0912 | 0.0649 | 0.1067 | 0.1222 | 0.1350 | 0.1330 | 0.0894 | 0.1302 |
| ARIMA | 0.3412 | 0.0834 | 0.0718 | 0.1072 | 0.1302 | 0.1301 | 0.1358 | 0.0958 | 0.1264 |
| NNA | 0.5536 | 0.0922 | 0.0765 | 0.1252 | 0.1246 | 0.1378 | 0.1171 | 0.1081 | 0.1478 |
| TWR.N | 0.5693 | 0.1475 | 0.0649 | 0.1282 | 0.1343 | 0.1761 | 0.3659 | 0.1151 | 0.1972 |
| TWR.L | 0.4423 | 0.1130 | 0.0661 | 0.1188 | 0.1241 | 0.1543 | 0.2751 | 0.1112 | 0.1635 |
| TWR.E | 0.2560 | 0.0765 | 0.0791 | 0.1193 | 0.1122 | 0.1269 | 0.1588 | 0.0852 | 0.1197 |
| TWR.E3 | 0.2428 | 0.0839 | 0.0842 | 0.1358 | 0.1255 | 0.1263 | 0.1334 | 0.0884 | 0.1209 |
| TWR.A | 0.2547 | 0.0786 | 0.0759 | 0.1081 | 0.1211 | 0.1167 | 0.1344 | 0.0897 | **0.1154** |

Table . MAE of TV ratings predictions

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| M↓D→ | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | All |
| LP | 0.0518 | 0.4775 | 0.1965 | 0.2250 | 0.2569 | 0.1286 | 0.5950 | 0.3272 | 0.3044 |
| PA | 0.0882 | 1.1048 | 0.1439 | 0.1681 | 0.2764 | 0.1900 | 2.3341 | 0.4646 | 0.6589 |
| SES | 0.0598 | 0.4604 | 0.1410 | 0.1909 | 0.2520 | 0.1280 | 0.5950 | 0.3202 | 0.2893 |
| DES | 0.0627 | 0.4644 | 0.1589 | 0.2880 | 0.3158 | 0.1370 | 0.5679 | 0.4904 | 0.3331 |
| ETS | 0.0686 | 0.5068 | 0.1447 | 0.1675 | 0.2504 | 0.1381 | 0.6249 | 0.3213 | 0.3000 |
| ARIMA | 0.0576 | 0.4573 | 0.1608 | 0.1681 | 0.2628 | 0.1318 | 0.6124 | 0.3412 | 0.2955 |
| NNA | 0.0955 | 0.5232 | 0.1731 | 0.1943 | 0.2442 | 0.1348 | 0.5031 | 0.3669 | 0.3002 |
| TWR.N | 0.0836 | 0.8287 | 0.1444 | 0.1973 | 0.2644 | 0.1606 | 1.6678 | 0.3880 | 0.5122 |
| TWR.L | 0.0695 | 0.6435 | 0.1480 | 0.1854 | 0.2458 | 0.1441 | 1.1960 | 0.3714 | 0.4099 |
| TWR.E | 0.0510 | 0.4335 | 0.1800 | 0.1915 | 0.2286 | 0.1283 | 0.6919 | 0.3035 | 0.2979 |
| TWR.E3 | 0.0515 | 0.4699 | 0.1928 | 0.2190 | 0.2550 | 0.1288 | 0.6055 | 0.3208 | 0.3023 |
| TWR.A | 0.0497 | 0.4429 | 0.1712 | 0.1756 | 0.2440 | 0.1173 | 0.6094 | 0.3248 | **0.2883** |

# 第五章 Conclusion

In this thesis, we present a novel solution called TWR to the problem of TV ratings prediction problem. Experiment results show that the auto-selected growth version of TWR outperforms all the other models in terms of overall MAPE and MAE among all dramas.

# 第六章 Future Work

When applying TWR to our data set, experimental results show that different dramas need different growth functions to result in good prediction accuracy, so it is worth extending the search space of growth functions and choosing it with a better way.

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# 附錄

N/A