Research Article

Prediction of Farmers’ Income in Hebei Province Based on the Fractional Grey Model (1,1)

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The problem of increasing farmers’ income has been a hot issue of social concern. Understanding the farmers’ income and the overall development trend is conducive to the rational layout of the social economy and promotes the steady development of a well-off society. Based on this, the paper selects the per capita disposable income (PCDI) of farmers’ households from 2012 to 2019 in 11 cities of Hebei Province as the research object and applies the fractional grey model (FGM (1,1)) to predict farmers’ income from 2020 to 2024. The results show that the farmers’ income will increase in the next five years. However, the growth rate of farmers’ income is slow in the areas with a large base of farmers’ income and strong in the areas with a small base of farmers’ income. The area with the highest trend in the growth rate of farmers’ income is Zhangjiakou and the lowest place is Handan. Only Shijiazhuang’s income growth rate is on the rise. Finally, suggestions are given to promote farmers’ income in Hebei Province.

1. Introduction

In recent years, the government has been focusing on “three rural issues: agriculture, rural areas, and farmers” in rural work and “how to increase farmers’ income” has been a long-term work to tread. Only by understanding the development trend of farmers’ income can the government better formulate economic plans and achieve a well-off society [1]. Hebei, as a province in China, should also consider the importance of predicting farmers’ income to promote the rural economy. As of 2020, the urbanization level of Hebei Province was 45%. It means that the rural population still has an absolute advantage. The precondition for the rapid economic development of Hebei Province is that farmers’ income needs to increase substantially. Meanwhile, some studies expressed that increasing farmers’ income is also the key step in solving the urbanization and the dual economy between urban and rural areas. In Hebei, farmers’ absolute income is increasing, but at a slower rate, wage income is the main income factor. In addition, the PCDI of farmers’ households in Hebei Province has no advantage across the country. So, it was necessary to evaluate and predict the future farmers’ income, investigate the income channels, and formulate relevant rural policies. The paper takes Hebei farmers’ income as the research object, the basic data are obtained from the PCDI of farmers in different cities from 2012 to 2019, and FGM (1,1) is used to predict the farmers’ income from 2020 to 2024. Then, the paper analyses the results and gives suggestions of promoting farmers’ income in Hebei Province. Meanwhile, the prediction model of farmers’ income and the experience of increasing farmers’ income also have some guiding significance for other provinces in China.

2. Literature Review

There have been many related studies on farmers’ income, which can be divided into the analysis of factors influencing farmers’ income and the prediction research of farmers’ income. In terms of influencing factors of farmers’ income, the agricultural industrial structure had an impact on farmers’ income and not all agricultural structures were useful to the growth of farmers’ income [2, 3]. In addition, agricultural technology and the degree of agricultural
intensification also affected farmers’ income; advanced agricultural technology saved resources and reduced costs, which increased farmers’ income [4]. The scale of the agricultural industry and agricultural mechanization would also raise farmers’ income [5]. Some researchers introduced the quality of farmers in their studies and found that there was a positive relationship between income and education years, so it was necessary to guide farmers to receive vocational skills training [6]. And, the government support and urbanization development levels had a certain influence on farmers’ income [7]. Both national policies and measures to support agriculture could affect farmers’ income. The development of industries increased the level of nonagricultural employment and directly promoted the increase of farmers’ income [8, 9].

Researchers have also devoted a lot of work on income prediction. Backpropagation neural network has strong nonlinear mapping ability, and it has high accuracy in farmers’ income prediction [10]. The autoregressive integrated moving average model was applied to time-series data, which could accurately reflect the interdependence of dynamic data and provide an effective reference for the prediction of farmers’ income in the short term [11]. The “quasi-stepwise regression” method had high accuracy, and the average relative error of farmers’ income obtained was around 1%, which had a good validity [12]. Compared with the previous model, the support vector machine model, which had the nonlinear time-series prediction characteristic, greatly improved the prediction accuracy of farmers’ income [13]. The advantage of the grey theory [14] was that the model was able to reduce the influence of redundant factors on farmers’ income prediction and screen the main factors. The fuzzy set theory and rough set theory were widely applied in many fields [18]. The grey model GM (1,1) was a basic predictive model [19, 20]. The advantage of the GM (1,1) model was that it can deal with grey information and poor data, but the model was mainly applicable to the sequence with strong exponential law and could only describe the monotone change process, and it had a big error in some specific fields [21]. In view of the shortcomings of the traditional GM (1,1) model, the fractional grey model (FGM (1,1)) was proposed [22]. In the process of FGM (1,1), the matrix perturbation theory was used to prove that the traditional integer-order cumulative generating operator violated the new information priority principle of grey system theory. Under certain conditions, the FGM (1,1) had a higher accuracy than the GM (1,1) model [23]. The FGM (1,1) was able to effectively reduce the error and obtain a better prediction by choosing the appropriate fractional order. Therefore, in this paper, the PCDI of farmers’ households in various cities of Hebei Province from 2012 to 2019 was used as the measurement of farmers’ income, the FGM (1,1) model was used to predict farmers’ income, and suggestions were put forward to promote farmers’ income.

3. Model Introduction of FGM (1,1)

The sequence with the nonnegative samples is \( X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\} \). The FGM (1,1) model is constructed as follows.

**Step 1.** The R-order accumulation generation sequence is

\[
X^{(r)} = \{x^{(r)}(1), x^{(r)}(2), \ldots, x^{(r)}(n)\},
\]

Among them,

\[
x^{(r)}(k) = \sum_{i=1}^{k} C_{k-i}^{k-i} x^{(0)}(i), \quad k = 1, 2, \ldots, n,
\]

\[
C_{r-1}^{0} = 1, C_{k-1}^{k} = 0,
\]

\[
C_{k-i}^{k-i+1} = \frac{(k-i+1)(k-i+r-2)\cdots(r+1)}{(k-i)!}.
\]

We establish the average generation sequence of \( X^{(r)} \):

\[
Z^{(r)} = \{z^{(r)}(2), z^{(r)}(3), \ldots, z^{(r)}(n)\},
\]

Among them,

\[
z^{(r)}(k) = \frac{1}{2} (x^{(r)}(k) + x^{(r)}(k-1)), \quad k = 2, 3, \ldots, n.
\]

**Step 2.** We establish the whitening differential equation:

\[
\frac{dx^{(r)}(t)}{dt} + ax^{(r)}(t) = b,
\]

where \( a \) is the developmental grey number and \( b \) is the grey action.

Since the least squares method can minimize the error of the solution, we use the least squares method to solve \( \tilde{a} \) and \( \tilde{b} \):

\[
\begin{bmatrix}
\tilde{a} \\
\tilde{b}
\end{bmatrix} = (B^TB)^{-1}B^TY.
\]

Among them,

\[
B = \begin{bmatrix}
-z^{(r)}(2) & 1 \\
-z^{(r)}(3) & 1 \\
\vdots & \vdots \\
-z^{(r)}(n) & 1
\end{bmatrix},
\]

\[
Y = \begin{bmatrix}
x^{(r)}(2) - x^{(r)}(1) \\
x^{(r)}(3) - x^{(r)}(2) \\
\vdots \\
x^{(r)}(n) - x^{(r)}(n-1)
\end{bmatrix}.
\]

The time response formula is as follows:
\begin{equation}
\hat{x}^{(r)}(t) = \left( x^{(0)}(1) - \frac{\hat{b}}{\tilde{a}} \right) \cdot e^{-\hat{a}(t-1)} + \frac{\hat{b}}{\tilde{a}} \tag{8}
\end{equation}

Using the time response formula, \( \hat{x}^{(r)} \) is solved:
\begin{equation}
\hat{x}^{(r)} = \{ \hat{x}^{(r)}(1), \hat{x}^{(r)}(2), \ldots, \hat{x}^{(r)}(n) \}. \tag{9}
\end{equation}

**Step 3.** The inverse accumulation generating operator is used to obtain
\begin{equation}
\hat{x}^{(1)} = x^{(r)} x^{(1-r)} = \{ \hat{x}^{(r)} x^{(1-r)}(1), \hat{x}^{(r)} x^{(1-r)}(2), \ldots, \hat{x}^{(r)} x^{(1-r)}(n) \}. \tag{10}
\end{equation}

Then, the predicted value can be obtained by the following reduction formula:
\begin{equation}
\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k - 1), \quad k = 2, 3, \ldots, n. \tag{11}
\end{equation}

**Step 4. Model Testing.** There are many testing methods for grey prediction models. And, the average absolute percentage is a commonly used testing method in grey prediction. The paper uses this method for model testing. Grey systems are often evaluated by using the mean absolute percentage error (MAPE).
\begin{equation}
\text{MAPE} = \frac{1}{n} \sum_{k=1}^{n} \left| \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \right| \times 100\%. \tag{12}
\end{equation}

The evaluation criteria of MAPE are shown in Table 1. When MAPE < 10%, it means that the model fitting effect is better and the prediction result is more reliable. When 10% < MAPE < 20%, the model fit has a certain degree of credibility. When MAPE > 20%, the fitting effect of the model is average and the prediction result has little reference value.

Especially in the FGM (1,1), when \( r = 1 \), the FGM (1,1) is equivalent to the GM (1,1). The GM (1,1) can be regarded as a special case of the fractional grey model.

### 4. Prediction and Result Analysis of Farmers’ Income

**4.1. Data Sources.** The data came from Hebei Statistical Yearbook from 2013 to 2020. From Table 2, the PCDI of farmers in all cities showed an upward trend from 2012 to 2019. In combination with the trend chart of farmers’ income in Figure 1 and the average growth rate in Figure 2, it can be concluded that there is a large gap in the income level of farmers in the different areas of Hebei Province. The PCDI of Tangshan farmers is twice that of Chengde farmers. From the average growth rate of farmers’ income in different cities, the growth rate of farmers’ income in Hebei Province is more than 8%. In addition, income in Zhangjiakou, Hengshui, Chengde, Xingtai, Cangzhou, and Baoding all grew by more than 10% and even income in Zhangjiakou and Hengshui both grew by almost 12%. However, it cannot be ignored that the average growth rate is relatively low in areas with higher farmers’ incomes, such as Tangshan and Langfang. This might have a certain relationship with the economic background of the new normal of China’s economic growth rate from high-speed growth to medium-high growth [24]. But overall, under the premise of stable development of the economic environment, the slowdown of farmers’ income growth in some cities is temporary and it will still keep the rising trend in the future.

**4.2. Testing the Validity of FGM (1,1).** The FGM (1,1) was established according to the PCDI of farmers’ households in different cities of Hebei Province from 2012 to 2019. The FGM (1,1) process was as follows.

Due to the duplication and similarity of calculations, the paper only gives the process of predicting farmers’ income in Handan City from 2020 to 2024. The income prediction process of farmers in other cities is omitted.

PCDI of farmers’ households in Handan City from 2012 to 2019 as follows:
\begin{equation}
X^{(0)} = (8447, 9307, 10343, 11247, 12153, 13151, 14307, 15695). \tag{13}
\end{equation}

In MATLAB software, particle swarm optimization was used to calculate the optimal order \( r \) of the prediction model, \( r = 0.95 \), and then the 0.95-order accumulation generation sequence was

\begin{equation}
X^{(0.95)} = (8447.0, 17336.5, 27021.1, 37409.3, 48526.2, 60474.4, 73412.8, 87566.3). \tag{14}
\end{equation}

We established a first-order one-variable differential equation about \( t \) for \( X^{(0.95)} \):
\begin{equation}
\frac{dx^{(0.95)}}{dt} + ax^{(0.95)} = b. \tag{15}
\end{equation}

Then, the least squares method was used to solve \( a \) and \( b \):
\begin{equation}
\begin{bmatrix} a \\ b \end{bmatrix} = \left( B^T B \right)^{-1} B^T Y = \begin{bmatrix} -0.076 \\ 7914.332 \end{bmatrix}, \tag{16}
\end{equation}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
MAPE (%) & Predictive performance \\
\hline
<10 & Excellent \\
10–20 & Good \\
20–50 & General \\
>50 & Difference \\
\hline
\end{tabular}
\caption{MAPE evaluation criteria.}
\end{table}
Table 2: PCDI of farmers’ households in various cities of Hebei Province from 2012 to 2019 (unit: yuan).

<table>
<thead>
<tr>
<th></th>
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<td>14854</td>
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<td>10782</td>
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<td>12563</td>
<td>13719</td>
<td>15035</td>
</tr>
</tbody>
</table>

Figure 1: The farmers’ income trend of Hebei Province from 2012 to 2019.

Figure 2: Average growth rate of farmers’ income in Hebei Province from 2012 to 2019.
where

\[
B = \begin{bmatrix}
-12891.8 & 1 \\
-22178.8 & 1 \\
-32215.2 & 1 \\
-42967.8 & 1 \\
-54500.3 & 1 \\
-66943.6 & 1 \\
-80489.6 & 1 \\
8889.53 & \\
9684.61 & \\
10388.20 & \\
11116.89 & \\
11948.18 & \\
12938.40 & \\
14153.53 & \\
\end{bmatrix}
\]

\[
Y_n = \begin{bmatrix}
8447.0 \\
9307.0 \\
10249.6 \\
11202.5 \\
12197.0 \\
13249.0 \\
14370.0 \\
15570.0 \\
\end{bmatrix}
\]

The predicted value sequence of \( X^{(0)} \) is

\[
\{ 8447.0, 9307.0, 10249.6, 11202.5, 12197.0, 13249.0, 14370.0, 15570.0 \}.
\]

When \( r = 1 \), the FGM (1,1) model became the GM (1,1) model. The MAPE of the GM (1,1) model and FGM (1,1) model is shown in Table 3. It can be found that the MAPE of the FGM (1,1) model and GM (1,1) model both meet the requirements, but the MAPE of the FGM (1,1) model was significantly lower than that of the GM (1,1) model. In other words, the FGM (1,1) model had a higher accuracy than the GM (1,1) model. Excluding the second data, the growth rate of GM (1,1) is a constant. But, the growth rate of FGM (1,1) is mutable and data-driven. The growth rate of FGM (1,1) is very consistent with the actual situation. This is an important property. Thus, we used FGM (1,1) to fit the other data. The results are listed in Table 4; the FGM (1,1) model and GM (1,1) model both meet the requirements, but the MAPE of the FGM (1,1) model was significantly lower than or equal to that of the GM (1,1) model. In other words, the FGM (1,1) model had a higher accuracy than the GM (1,1) model.

### 4.3 Prediction Results of Farmers’ Income in Different Cities

Based on the data of farmers’ income from 2012 to 2019, the FGM (1,1) model was used to predict farmers’ income from 2020 to 2024. The predicted results are shown in Table 5.

![Table 3: Prediction results of the GM (1,1) model and FGM (1,1) model for Handan data.](image)

\[ \begin{array}{cccc}
\text{Year} & \text{PCDI} & \text{GM (1,1)} & \text{FGM (1,1)} \\
2012 & 8447 & 8447 & 8447 \\
2013 & 9307 & 9417 & 9307 \\
2014 & 10343 & 10246 & 10250 \\
2015 & 11247 & 11149 & 11203 \\
2016 & 12153 & 12132 & 12197 \\
2017 & 13151 & 13201 & 13249 \\
2018 & 14307 & 14364 & 14370 \\
2019 & 15695 & 15630 & 15570 \\
\hline
\text{MAPE} & 0.52 & 0.87 & 0.83 \\
\end{array} \]

We used the corresponding formula of time, and we obtained

\[
\tilde{X}^{(0.95)} = \left( \tilde{x}^{(0.95)}(1), \tilde{x}^{(0.95)}(2), \ldots, \tilde{x}^{(0.95)}(13) \right) = \left( \begin{array}{c}
8447.0, 17336.5, 26927.8, 37326.1, 48444.4, 60488.0, 73485.5, \\
87509.0, 102639.5, 118964.4, 136577.9, 155581.8, 176085.9 \\
\end{array} \right).
\] (18)

Then, the 0.95-order reverse accumulation generation operation was performed on \( \tilde{X}^{(0.95)} \) to obtain \( \tilde{X}^{(1)} \):

\[
\tilde{X}^{(1)} = \alpha^{(0.95)} X^{(0)} = \left( \begin{array}{c}
8447.0, 17754.0, 28003.6, 39206.2, 51403.1, 64652.3, 79022.5, \\
94952.3, 111448.5, 129686.8, 149411.2, 170735.1, 193781.4 \\
\end{array} \right).
\] (19)

Finally, the fitting value sequence and the predicted value sequence of \( X^{(0)} \) were obtained.

The fitted value sequence of \( X^{(0)} \) is

\[
\{8447.0, 9307.0, 10249.6, 11202.5, 12197.0, 13249.1, 14370.3, 15569.8\}.
\] (20)
### Table 4: Prediction results of the GM (1,1) model and FGM (1,1) model.

<table>
<thead>
<tr>
<th>Year</th>
<th>PCDI</th>
<th>Shijiazhuang GM (1,1)</th>
<th>FGM (1,1)</th>
<th>Tangshan GM (1,1)</th>
<th>FGM (1,1)</th>
<th>Qinhuangdao GM (1,1)</th>
<th>FGM (1,1)</th>
<th>MAPE (%)</th>
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<td>8993</td>
<td>10698</td>
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<th>FGM (1,1)</th>
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### Table 5: Prediction results of farmers’ income from 2020 to 2024.

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<tr>
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<th>Tangshan</th>
<th>Handan</th>
<th>Baoding</th>
<th>Cangzhou</th>
<th>Xingtai</th>
<th>Langfang</th>
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4.4. Result Analysis. The farmers’ income has been predicted, combining the actual values of farmers’ income from 2012 to 2019 and the predicted values from 2020 to 2024 (as shown in Figure 3); obviously, farmers’ income in Hebei Province is generally increasing by years and the growth rate of farmers’ income in cities with a small income base is higher than that in cities with a large income base (as shown in Figure 4). In particular, 2021 is a turning point for farmers’ income. Later, the growth rate tends to stabilize, which is closely related to the economic environment such that the whole country enters a well-off society and the productive forces are fully released. For the convenience of analysis, the farmers’ income in 11 cities is divided into three ranges based on the income growth rate. The first growth range: Zhangjiakou and Hengshui (income growth rate > 11%), the second growth range: Baoding, Xingtai and Chengde (10% < income growth rate < 11%), and the third growth range: Shijiazhuang, Tangshan, Handan, Cangzhou, Langfang, and Qinhuangdao (income growth rate < 10%).

In the first range, as shown in Figure 5, the income growth rate of Zhangjiakou and Hengshui is in the leading position in the province. This is inseparable from the local government support and farmers’ motivation. In particular, Zhangjiakou’s growth rate is the first; it takes the “2022 Winter Olympics” as an opportunity to increase the “ice and snow economy,” promoting the development of tertiary industries. Meanwhile, Zhangjiakou actively guides the transfer of rural surplus labor to cities, creates a lot of rural wealth, and increases the farmers’ income. Hengshui takes advantage of its proximity to the Xiong’an New District, and it develops characteristic agriculture, such as pears and peaches, uses modern science and technology, optimizes the structure of agricultural industries, and builds modern agricultural parks. At the same time, Hengshui relies on the advantages of the Internet to carry out e-commerce cooperation with large agricultural enterprises. All these have laid a solid foundation for increasing farmers’ incomes.

Baoding, Xingtai, and Chengde are in the second range (as shown in Figure 6), where farmers’ incomes are growing at a medium speed. Based on the actual situation, Baoding cultivates characteristic and advantageous agricultural products, builds industry-leading enterprises, helps agricultural product clusters, mixes the development of primary, secondary, and tertiary industries in rural areas, and promotes “agriculture and industry,” “agriculture and Internet,” “agriculture and tourism,” and other models to increase farmers’ employment and income. While increasing the development of agricultural planting industries in Chengde and Xingtai, two cities take advantage of geographical and labor cost advantages to export rural surplus labor to Beijing and Tianjin, the purpose of which is to increase farmers’ income through multiple channels.

The third range is the slower increase in farmers’ income, as shown in Figure 7, including Shijiazhuang, Tangshan, Handan, Cangzhou, Langfang, and Qinhuangdao. From the existing statistical yearbook of Hebei Province, it can be found that the farmers’ income in the six cities is higher than that in the other five cities, but the growth rate is slow. In particular, Handan and Xingtai have the slowest income growth rates in the province. They are both heavy industrial cities, and their development models are in a transitional period; this influences economic development, but the impact is temporary. Langfang is next to Beijing, and its economic development is inseparable from Beijing. However, the phenomenon of economic and talent “siphoning” is inevitable. Although Qinhuangdao has increased its
investment in rural infrastructure construction, the unreasonable structure of agricultural industrialization, backward education, and ecological environmental governance still disturb farmers’ income. Cangzhou promotes the cultivation of characteristic agriculture and strengthens the construction of the fruit market such that behaviors have been useful in promoting farmers’ income. Shijiazhuang is the capital of Hebei Province, and it is the only city where farmers’ income growth rate has been growing steadily. However, it has a slow growth rate, which is completely inconsistent with the characteristics of capital cities. It also proves that the development of urban and rural areas is relatively unbalanced, the economic growth force is still focused on cities, and there is lack of management of rural development.

5. Conclusions and Suggestions

By using the FGM (1,1) model to predict the farmers’ income in Hebei province, it can be concluded that the FGM (1,1) model can better predict farmers’ income and the FGM (1,1) model has certain advantages over the GM (1,1) model in predicting accuracy. The prediction results show that the farmers’ income in Hebei province will continue to increase in the next five years, and from the perspective of the growth rate of farmers’ income, the growth rate is slow in the areas with a large base of farmers’ income and strong in the areas with a small base of farmers’ income. The area with the highest trend growth rate of farmers’ income is Zhangjiakou, and the lowest place is Handan. Only Shijiazhuang’s income growth rate is on the rise.

According to the prediction results of farmers’ income in Hebei Province, combined with national policies, the core of solving the rural issue is to increase farmers’ income. Meanwhile, increasing farmers’ income is also the basic requirement of a well-off society [25]. Hence, the paper makes the following suggestions for increasing farmers’ income:

1. Strengthen rural infrastructure construction and improve rural production efficiency.

Rural infrastructure is an important material foundation for enhancing rural productivity, developing modern agriculture, increasing farmers’ income, and building a new socialist countryside. The government needs to increase capital investment in rural infrastructure. Farmers are the main body of new rural construction, and the government should take various measures to mobilize farmers’ enthusiasm, initiative, and creativity so that farmers consciously participate in rural construction.
(2) Improve the quality of farmers and guide the transfer of rural surplus labor.

The low quality and ability of the farmers are the main factors affecting the increase in income. The government has the responsibility to improve the quality of farmers in rural areas. In addition, it is necessary to strengthen rural vocational and technical education based on market demand and promote the transfer of rural labor to cities, to ensure stable employment for farmers and increase income.

(3) Promote the combined development of rural revitalization strategy and new urbanization.

The coupled development of rural revitalization and new urbanization is conducive to promoting the extension of urban public resources and public services to the rural areas, encouraging the flow of urban capital, technology, and talents to the rural areas. Then, the new industrialization, information technology, urbanization, and agricultural modernization are developed simultaneously.

Finally, the prediction of farmers’ income is a complex issue. In the next step, the paper will analyze the influencing factors of farmers’ income in Hebei Province, establish the GM (1,N) model, and put forward more targeted methods to increase farmers’ income.

Data Availability

The research data come from Hebei Statistical Yearbook from 2013 to 2020, available at (http://tjj.hebei.gov.cn/hetj/tjsj/jjnj/).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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