Green Transition Driven Carbon Trading Mechanism and Design Based on Urban Vehicle Trajectory Data

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Abstract. As the fastest growing source of carbon emissions in the world, road traffic must carry out green transformation in order to achieve carbon neutrality, it is one of the feasible ways to establish private car carbon trading market and carry out personal carbon trade. Based on the big data of urban vehicle trajectory, this paper uses BP neural network to predict the carbon emissions of urban vehicles. Next, the total carbon emission cap is set by combining the predicted amount with the emission reduction, and the carbon consumers of private cars will be equally distributed free of charge based on the total emissions quota. In addition, this paper introduces block chain technology into the carbon trading system and designs a main-side block chain architecture to isolate the data business and financial business of carbon trade. Next, this paper establishes a transaction matching strategy to maximize the overall benefit. Finally, this paper verifies the proposed carbon-trading mechanism for private car through simulation design, and the results show that carbon-trading mechanism for private cars driven by green transition designed in this paper is feasible. It can play a certain role in emission reduction and market guidance.

Keywords: Green transition · Carbon trading · Carbon emission prediction · Carbon quota allocation

1 Introduction

Mitigation of climate warming has been a major problem for human beings. As early as 1992, the United Nations Conference on Environment and Development adopted the Framework and Convention on Climate Change to discuss climate issues in Rio. The Paris Agreement proposed to keep the temperature rise within 1.5 °C in 2015. At the United Nations General Assembly in 2020, China made it clear that it would strive to achieve a peak in carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 [1].

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The Energy Foundation released China's Carbon Neutral Comprehensive Report 2020 in December 2020, it pointed out that the carbon emission of China's transportation industry in 2050 should be reduced by 80% compared with that in 2015 [2]. According to the International Energy Agency in 2019, the transportation industry accounts for 24.6% of global carbon emissions and road traffic accounts for 73.8% of carbon dioxide emissions from transportation industry. As for China, China's carbon dioxide emissions were 10.2 billion tonnages; the transportation industry accounts for about 10%, and road traffic accounts for 84.1% of carbon dioxide emissions from the transportation industry [3]. Carbon emissions from road traffic have become the largest sector of the transportation industry, which is mainly due to the large increase in the number of cars in China. The rapid growth of private car ownership poses a huge challenge for China to achieve carbon peak by 2030, how to reduce carbon dioxide emission of private cars in China, it is of great significance to study the feasible carbon emission trade for private cars.

At present, the research on individual carbon trading mainly focuses on two aspects. The first aspect is the allocation of carbon quota. The fair allocation of carbon quota is the premise of carbon trade, and it is the main research direction. Some scholars have suggested that all adults should regularly receive an equal share of domestically free tradable quotas [4]. Fleming et al. proposed giving 40% of the cap to individuals for free and selling the remaining 60% to other energy users through bidding; equal distribution can provide incentives for every energy user, forcing them to make low-carbon behaviour [5]. However, Biran et al. believed that equal distribution is not absolutely fair, and subjective happiness is a better measure [6]. Therefore, Barns et al. proposed to auction 100% of the carbon quota to energy suppliers and distributed part of the auction revenue equally to individuals [7]. At present, the same level of fairness cannot be found. Whether it is equal distribution or auction, the policy implementation of different schemes varies greatly. For transportation, Fawcett et al. have proposed giving 50% of the carbon quota to individuals for free (including children) [8]. Wadud et al. also found that the social benefit of distribution by adults was the largest, followed by the number of cars, and the social benefit of distribution by the natural population was the worst [9]. It can be seen that the allocation of carbon quotas involving the transport sector is similar to the appeal, which is mainly free. The second aspect is the trading of carbon emission quota. It mainly revolves around carbon trade price and carbon trade mode. For carbon pricing, the Grantham Institute for Climate Change and the Environment's policy brief suggests two ways to set a carbon price. One was to consider the marginal cost of carbon emission reduction; the second was to consider the social cost of carbon [10]. For the first way, Creti et al. believed that the cost of carbon emission reduction was the least and the effect of emission reduction was the best when the carbon trade price was the same as the marginal cost of emission reduction [11]. For the second way, Wong et al. put forward the ratio of carbon emission quota to the total cost of carbon trading as a unit of carbon emission price [12]. As for carbon trade mode, Raux et al. proposed that participants bought and sold licenses through banks and other intermediary institutions or bought licenses at gas stations for carbon emissions [13]. Harwatt also proposed tradable transport carbon emission certificates to examine the carbon emissions generated by private transport in France [14].

Recently, Pan et al. proposed applying block chain technology to carbon trading to reduce the entry threshold of carbon trading market [15]. With the launch of the first block chain-based carbon exchange in Singapore, the carbon-trading model based on block chain technology has sparked a research boom among scholars. In addition, many scholars believe that carbon trading can drive the green transition. In essence, green transition is the transition of sustainable development mode oriented by ecological civilization construction [16]. For the objective, green transition is to solve the problem of harmonious coexistence between human and nature [17]. Cheng et al. showed that carbon trading cannot only reduce carbon dioxide emissions, but also has the synergistic effect of reducing SO2 and NOx emissions [18]. Through experimental research, Li et al. found that the implementation of individual carbon trading has a significant positive impact on people's use of battery electric vehicles [19]. Raux et al. has demonstrated that personal carbon trading can effectively change travel behaviour and thus reduce transport emissions from personal travel [20]. At present, personal carbon trading based on block chain has a good development prospect. Some scholars proposed the combination of block chain and micro-grid energy market, indicating that block chain is a qualified technology to operate a decentralized energy trading market [21]. In addition, the EU Scanergy project proposed a trade model combining block chain and personal carbon trade. The model can support distributed person-to-person direct transactions, and made it possible for small users to trade green energy directly [22]. Lu et al. believed that the unique decentralized transaction of block chain can realize the direct peer-to-peer transaction, reduced the cost of transaction subject, and improved the efficiency of carbon trade market [23]. Hua et al. proposed a block chain-based peer-to-peer trading framework, which provides potential design ideas for carbon-emission reduction policies by designing smart contracts and introducing distributed low-carbon incentive mechanisms [24]. Existing studies mainly focus on the theoretical application of block chain technology in carbon trading, and there are few studies on quantitative analysis of carbon trading. This paper conducts carbon trading simulation experiment based on big data of urban vehicle trajectory. The purpose is to quantitatively analyse the effect of carbon trading and provide ideas for the construction of private car carbon trading market.

The remainder of this paper is organized as follows. Section 2 proposes the application design of carbon trading based on block chain and establishes the allocation and trading model of private car carbon trading. Section 3 is the simulation result analysis of private car carbon trading. The conclusion and policy proposal are presented in Sect. 4.

2 Materials and Methods

2.1 Block Chain-Based Carbon Trading Application Design

Block chain technology has the characteristics of decentralization, collective maintenance, timestamp, open source programming, security and trust, quasi-anonymous transactions and so on. It can effectively solve these problems such as the lack of transparency in the early stage of carbon trading, the security of data storage, the excessive dependence on centralized management, and the information asymmetry between the two sides [25]. Based on the principle of "who emits, who pays", this paper establishes a carbon trading market to guide private car consumers to reduce emissions and obtain green benefits.

Block Chain-Based Carbon Trading Chain Architecture. In order to solve the problem of data storage, business isolation and transaction security in the transaction process, and ensure efficient operation of the block chain, this paper designs a main-side block chain architecture. Through the side chain protocol, the docking between the side chain of carbon trading financial business and the main chain of carbon trading data business is realized, which enables data clearance and financial transactions to be accounted separately, improves transaction efficiency, achieves automatic currency settlement, and ensures the security and stability of the main chain.

The data business chain of carbon trading is the main chain of blocks, on which user nodes, audit nodes and supervision nodes are created. The user node is the main body of carbon trading, which is mainly involved in sending and receiving trading information and recording trading matters. The audit node is an officially certified third-party audit institution that mainly participates in the audit of trading information. The regulatory node mainly participates in the policy formulation and compliance supervision in the process of carbon trading. The data service chain is mainly used for the clearing and storage of trading data. The financial business chain of carbon trading is a side chain, on which user nodes, financial nodes and regulatory nodes are created. The financial node mainly involves auditing the account information and payment for goods of the user node, while the financial business chain is mainly used to obtain the clearing data of the data business chain through the side chain protocol for currency settlement. Through two-way anchoring, the seller realizes the conversion of carbon credit into currency, and the buyer realizes the conversion of currency into carbon credit [26].

Framework of Carbon Trading System Based on Block Chain Technology.
Step 1. Monitor and record the driving time, mileage and fuel consumption of private cars through the Internet of Vehicles technology. Step 2. The big data of private car trajectory collected and recorded are used for deep learning through BP neural network to predict their carbon emissions and put them on the block chain platform. Step 3. By combining the recorded carbon emission forecast with the government's emission reduction ratio, the block chain distributes the set total carbon quota to each private car carbon consumer equally. Step 4. Private car carbon consumers accept carbon quotas and enter the trade based on the carbon emissions already used. The transaction nodes (sellers) with the remaining amount of carbon emissions release the transaction information (minimum selling price, expected rate of return) to the block chain platform; transaction nodes with excess carbon emissions (buyers) release transaction information (highest purchase price, expected rate of return) to the block chain platform; the two parties make matching trades. The first stage is the price determination stage (the seller's lowest selling price and the buyer's highest purchase price). The second stage is the bargaining stage (the seller's expected sell price and the buyer's expected purchase price). Step 5. Transaction match successfully; the main chain of data service connects the side chain of financial service through side chain protocol; the financial nodes push payment information to buyers and payment successes. The transaction node keep accounts for the transaction data and broadcasts the whole network; the third party audit institution checks the transaction data. If the audit is successful, the transaction completes. If the buyer fails to pay within the specified time, the transaction will be cancelled. Step 6. If transaction settlement is successful, the block chain platform stores the transaction and

other relevant data, the transaction node maintains the account book and the supervision node supervises it. Due to the storage and delay problems of block chain at the present stage, it is necessary to set iteration times and time limit when matching user carbon transactions. Upon completion of the specified time and number of iterations, the failed match is returned to the user node, and the seller can declare the price and expected rate of return again before the closing date of the trade to match again. Based on block chain, this paper constructs a carbon trading mechanism for private car use supplemented by government supervision and third-party auditing institutions. The specific process is shown in Fig. 1.

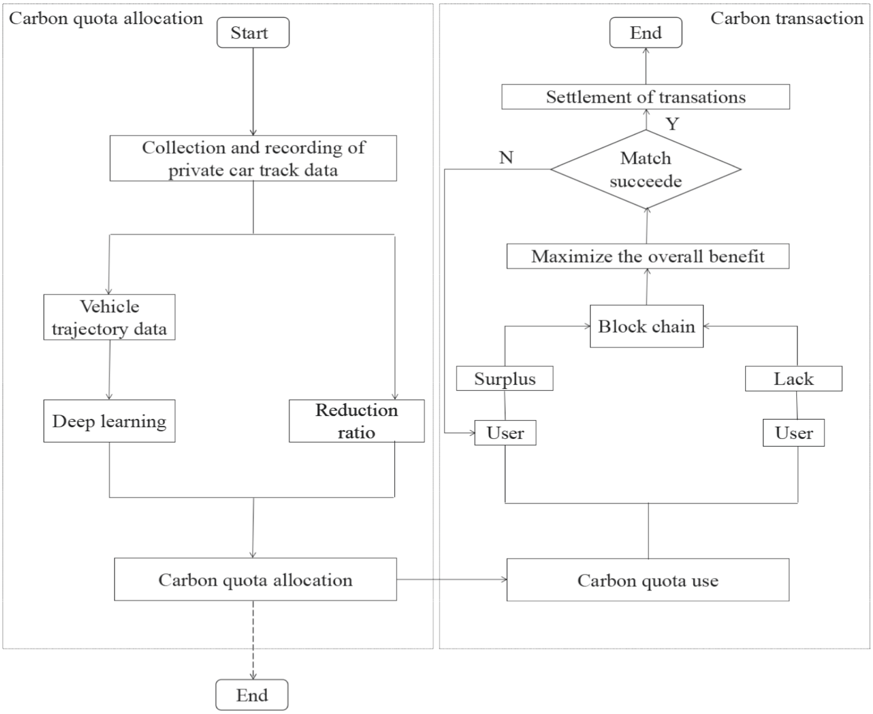

Fig. 1. Carbon trading flow chart based on block chain

2.2 Prediction of Carbon Emission and Allocation of Carbon Quota

BP Neural Network Algorithm. BP neural network is a multi-layer feed-forward network trained by error back propagation algorithm proposed by Rumelhart and McCelland in 1986. The main idea is: input learning samples and use error back propagation algorithm to adjust the weights and deviations of the network repeatedly, which makes the expected value as close as possible to the actual output value [27]. The learning rule of BP neural network is the steepest descent method. The weights and thresholds are adjusted by back propagation to minimize the sum of square error. Because BP neural network can approximate any function and has strong nonlinear mapping ability, it has become one of the most widely used artificial neural network algorithms [28]. The driving distance, driving time and driving fuel consumption in the traveling track of private cars are taken as the input layer of BP neural network, the carbon emissions of private cars are taken as the network output layer, this paper establishes a three-layer BP neural network structure to predict the carbon emissions based on private car trajectory data.

BP Neural Network Prediction Model. The number of neurons in the input layer is m, the number of neurons in the hidden layer is n, and the number of neurons in the output layer is p. The output of hidden layer neurons is:

$$X_{ij} = f(\sum\nolimits_{i=1}^{m} W_{ij}X_i + b_j)\ \ j = 1, 2, 3, \ldots\ldots n \tag{1}$$

where X_{ij} is the output of hidden layer neurons, X_i is the input value of initial mileage, time and fuel consumption, W_{ij} is the weight from the input layer to the hidden layer, b_j is the threshold of hidden layer. The output of neurons in output layer is:

$$T_k = t(\sum\nolimits_{1}^{n} \left(W_{jk}X_j + b_k\right)\ \ k = 1, 2, 3 \ldots\ldots p \tag{2}$$

where T_k Is the output of neuron in the output layer, X_j is the input value calculated by the hidden layer, W_{jk} is the weight from hidden layer to output layer, b_k is the threshold of output layer, t is the output layer function. The calculation error of the quadratic cost function between the expected output and the actual output is:

$$E = \frac{1}{2}\sum\nolimits_{k=1}^{p} (Y_k - T_k)^2 \tag{3}$$

where Y_k is the actual output value. After the BP neural network simulation, the error between the predicted value and the actual output value should be evaluated to evaluate the reliability of the model, this paper uses MSE, MAE and RMSE as indicators, the smaller each index, the better the model performance. The actual carbon emissions of private cars are calculated by IPCC calculation method, the calculation formula of CO_2 provided in the IPCC Guidelines for Greenhouse Gas Emission Inventory is as follows:

$$T_{CO2} = \sum\nolimits_{i=1}^{n} EF_i Q_i \tag{4}$$

where T_{co2} is the total carbon dioxide emission, Q_i is the consumption of fuel i and EF_i is the emission factor of fuel i.

Allocation of Carbon Quotas. Based on the carbon emission forecast and the government's emission reduction ratio, the total amounts of carbon quota will be equally distributed to each private car carbon consumer, this paper establishes the following model:

$$S_i = \frac{\sum_{i=1}^{m} P_{yi}}{m} \times B \tag{5}$$

where S_i is the carbon quota of the i-th private car carbon consumer, Pyi is the carbon emission forecast of the i-th private car carbon consumer, m is the number of people who get carbon quota, B is the proportion of government emission reduction. Combined with the carbon emission forecast and the government's emission reduction ratio, the period-by-period adjustment of carbon quota allocation can meet the carbon emission space required by economic growth and development, and avoid the use of constraints. In addition, the government sets the emission reduction proportion to limit the total amount of carbon emissions. Consumers with low carbon emissions can obtain relatively abundant carbon emission credits and make profits by trading abundant carbon emission credits in the market. The proportion of emission reduction set by the government is constantly adjusted with the level of economic development to meet the consumption demand of residents' daily travel.

Matching Strategy of Carbon Trading. The principle is to maximize the total profit of the transaction. The seller's lowest selling price is C_i; the buyer's highest willing purchase price is M_i. The transaction is as follows: when $C_i > M_i$, the highest willing price of the buyer is not enough to meet the price demand of the seller, and the seller refuses to trade; when $C_i \leq M_i$, the buyer's highest willing price is higher than the seller's minimum price demand, the two parties match the transaction, and transaction price $C_i \leq P_i \leq M_i$. When $P_i \leq C_i$ or $P_i \geq M_i$, the transaction fails. When the transaction matches successfully, both sides enter the bargaining stage. In essence, it is a zero sum game to divide the total transaction profit. The seller gains $P_i - C_i$ and the buyer gains $M_i - P_i$. The profit ratio of both parties to the transaction is as follows:

$$X_1 = \frac{P_i - C_i}{M_i - C_i} \tag{6}$$

$$X_2 = \frac{M_i - P_i}{M_i - C_i} \tag{7}$$

where X_1 is the return ratio of the seller, X_2 is the return ratio of the buyer ($0 \leq X_1 \leq 1$, $0 \leq X_2 \leq 1$). Because the buyer and the seller have different expectations for the division of the total transaction return, X_1 is not necessarily the same as X_2. There are two cases: when $0 \leq X_1 + X_2 \leq 1$, the match is successful; when $X_1 + X_2 > 1$, the match fails. Based on the maximization of the total benefits of the transaction, this paper carries out the transaction matching according to the principle of $X_1 + X_2 = 1$. The pricing strategies of both parties are as follows:

$$P_i = C_i + X_1(M_i - C_i) \tag{8}$$

$$P_j = M_i - X_2(M_i - C_i) \tag{9}$$

$$P_n = X_1 M_i + X_2 C_i \tag{10}$$

where P_i is the seller's pricing strategy, P_j is the buyer's pricing strategy, and P_n is the successful matching transaction price. The actual benefits of carbon emissions trading between the two parties are as follows:

$$r_i = \frac{P_{max} - P_i}{P_{max}} \tag{11}$$

$$r_j = \frac{p_i - p_{min}}{p_i} \tag{12}$$

where ri is the buyer's actual rate of return, rj is the seller's actual rate of return, P_{max} is the buyer's repurchase price, and P_{min} is the seller's recovery price. In order to ensure an orderly transaction, the matching constraints during the transaction are as follows:

Carbon market trade balance can be expressed as:

$$\sum\nolimits_{i=1}^{n} S_{B,i} = \sum\nolimits_{j=1}^{m} S_{B,j} \tag{13}$$

where $S_{B,i}$ is the amount of carbon emissions sold by the i-th trading entity, and $S_{B,j}$ is the carbon emissions purchased by the j-th trading entity.

Carbon trading volume constraints of trading entities:

$$S_{B,i} \leq S_{Q,i} \tag{14}$$

where $S_{Q,i}$ is the total ownership of carbon emissions of the i-th trading entity.

Transaction price constraints can be expressed as:

$$C_i \leq P_i \leq M_i \tag{15}$$

$$0 \leq X_1 + X_2 \leq 1 \tag{16}$$

3 Results and Discussion

3.1 Parameter Selection

This paper selects 100000 private car trajectory data for deep learning of BP neural network. 70000 pieces of data are used to form the training set [29]. 15000 pieces of data are used to form the test set and 15000 pieces of data are used to form the validation set. The driving time, mileage and fuel consumption of private cars are taken as input variables [30]. The carbon dioxide emissions are regarded as the network output layer variable. The activation function is Sigmoid, output function is Softmax, training cycle are 1000 times, learning rate is 0.01, and training error is 10^{-6}.

3.2 Analysis of Fitting Effect

The simulation results are regressed to the real value, and the closer R is to 1, the better the fitting effect is. As can be seen from Fig. 2, training sample R = 0.99982, validation sample R = 0.99994, test sample R = 0.99989, total sample R = 0.99985. The R of all samples is greater than 0.999, and the effect is excellent [31].

As can be seen from Fig. 3, the mean square error of training set, test set and validation set converge to 10^{-6}. The error results are as follows: the mean absolute error MAE is 0.06947; the mean square error MSE is 0.01745; the root mean square error RMSE is 0.1321; the error of each sample is very small. It can be seen from the comparison

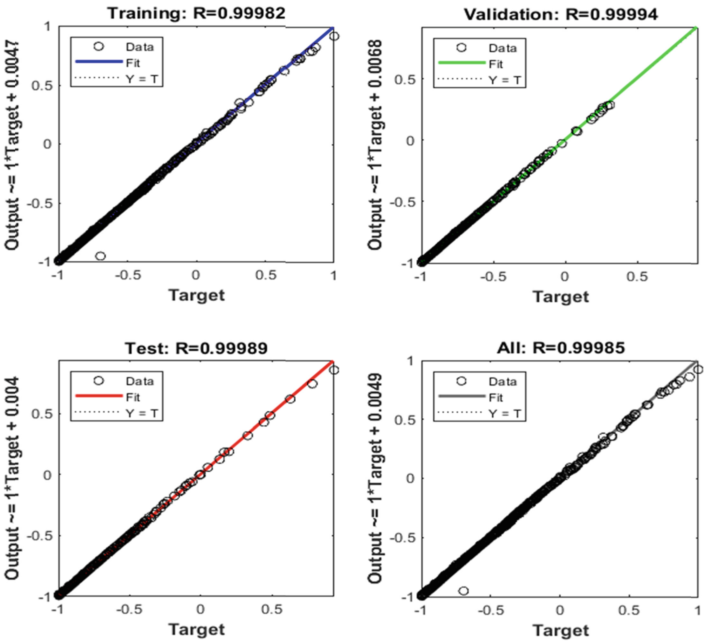

Fig. 2. Training set, validation set, test set and full sample regression curve.

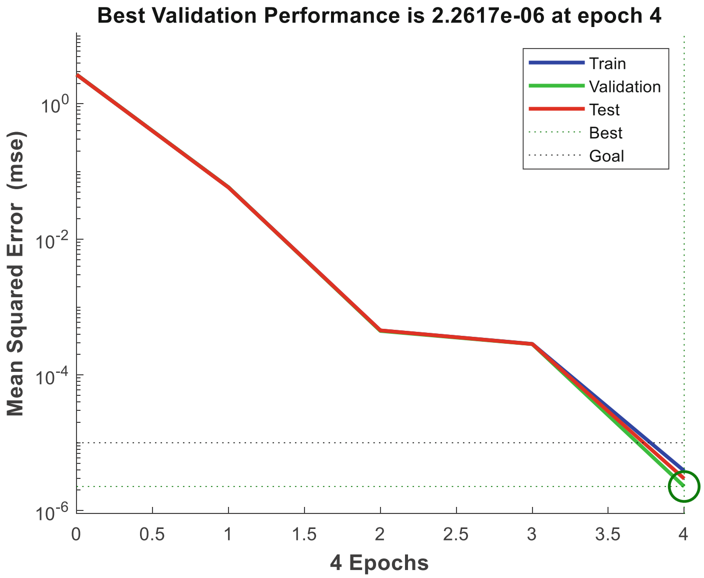

Fig. 3. Mean square error of training set, validation set and test set.

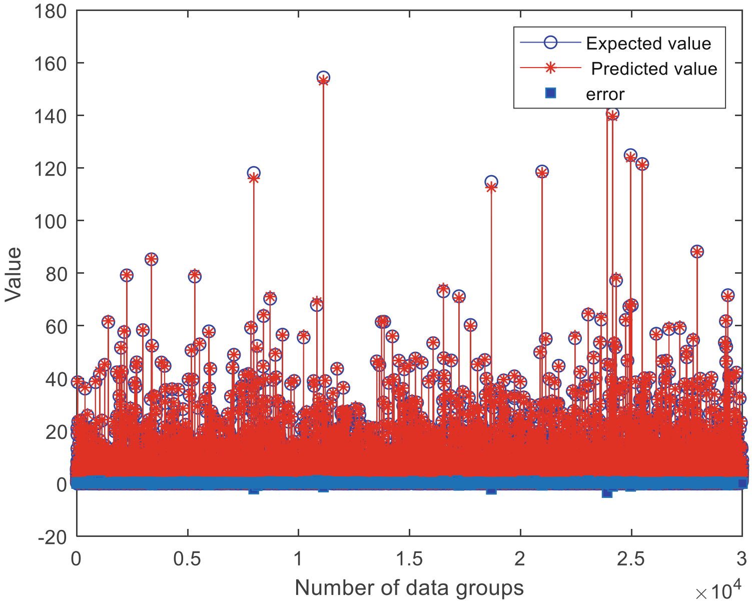

Fig. 4. Comparison of predicted value and expected value.

between the predicted value and the real value in Fig. 4, the BP neural network has excellent prediction effect. This paper takes the sum of the predicted carbon emissions of 30000 output samples multiplied by the government's emission reduction ratio as the upper limit, then it will be equally distributed to each private car carbon consumer (the government emission reduction ratio adopted in this paper is 100%).

The average quota in Table 1 represents the free carbon quota that individual private car carbon consumers can get. According to Eq. (5), through simulation calculation, each consumer can get 3.30 kg free carbon quota. The surplus of private car carbon consumers represents the difference value between the actual carbon emissions and the equalization quota. The positive value represents the balance and the negative value represents the vacancy. The specific distribution is shown in Table 1.

At present, China's carbon trading price fluctuates widely and falls year by year. The emission cost of 30–40 yuan per tonnage is too low. In order to create effective emission reduction pressure, this paper sets the guiding carbon-trading price at 250 yuan per tonnage, the recovery subsidy with a surplus is 200 yuan per tonnage at the end of the trading period, and the repurchase price of the shortage is 300 yuan per tonnage.

In 30000 samples, 21171 consumers have balance and need to sell carbon quota, 21 consumers just do not need to buy or sell, 8809 consumers need to buy carbon quota, it is estimated that the total amount of carbon sold is 43864.75 kg, the total amount of carbon quota is expected to buy 43101.55 kg. Among 30000 samples, 21171 consumers have surplus and need to sell carbon quotas, 21 consumers just do not need to buy and sell, and 8809 consumers need to buy carbon quota. It is estimated that the total amount of carbon quota sold is 43864.75 kg, and the total amount of carbon quota bought is 43101.55 kg. In this paper, normrnd function in Matlab program is used to randomly give

Table 1. Distributions and surpluses

S/N	Actual carbon emissions [kg]	Forecast carbon emissions [kg]	Quota sharing [kg]	Gap (−)/Balance (+) [kg]
1	5.07	5.05	3.30	−1.76
2	3.81	3.93	3.30	−0.50
3	5.74	5.67	3.30	−2.44
4	4.17	4.30	3.30	−0.86
5	1.20	1.23	3.30	2.11
6	0.38	0.39	3.30	2.92
7	0.34	0.35	3.30	2.97
8	1.16	1.20	3.30	2.14
9	0.12	0.11	3.30	3.18
10	0.99	1.02	3.30	2.32
11	0.67	0.69	3.30	2.64
12	2.85	2.92	3.30	0.45
…	…	…	…	…
…	…	…	…	…
30000	0.62	0.64	3.30	2.68

consumers the expected price of transaction. The mean value of the given normal distribution function is 0.25, the variance is 0.01, and the expected rate of return of consumers is Yi ∈ [0, 1] with 100 iterations. According to the transaction matching strategy in this paper, in this round of carbon trading, 3336 simulated transactions are matched, with a total transaction volume of 11000.62 kg. Among them, the actual transaction matching volume of seller accounted for 25.08% of the total expected sales matching volume, and the actual transaction matching volume of buyer accounted for 25.52% of the total expected purchase matching volume. A total of 29979 pieces of data are matched, and 100 iterations are performed, which take only 0.05 s. The matching strategy designed in this paper can greatly shorten the carbon trading time and improve the trading efficiency. In addition, by setting the repurchase and subsidy prices in the carbon trading market, users' trading prices will not be lower than 0.2 yuan per kg or higher than 0.3 yuan per kg. Therefore, the market can control the equilibrium of carbon trading price from the macro level, regulate the price range according to supply and demand, and guide users to recognize the deviation of price, which is conducive to the stability of carbon trading market in the early stage. The trading results are shown in Table 2.

In Table 2, the seller's lowest price (S.L) and the buyer's highest purchase price (B.H) are the upper and lower limits of the purchase price of both parties, within which the transaction can proceed. The buyer's expected price (B.E) and the seller's expected price (S.E) are the expected selling prices of both parties. The buyer's rate of return (B.R) and the seller's rate of return (S.R) are the actual rates of return obtained by both parties

Table 2. Transaction quantity table

S/N	S.L [yuan]	B.H [yuan]	S.E [yuan]	B.E [yuan]	S.R [%]	B.R [%]	T.P [yuan]	T.N [kg]	D.N [kg]	T.E [yuan]
1	0.228	0.237	0.23	0.231	13.14	23.25	0.23	172.61	80	39.74
2	0.233	0.246	0.24	0.242	16.94	19.73	0.241	147.8	40	35.53
3	0.234	0.245	0.235	0.24	15.72	20.9	0.237	508.5	247	120.67
4	0.235	0.261	0.238	0.24	16.28	20.37	0.239	566.64	189	135.37
5	0.236	0.25	0.237	0.246	17.22	19.47	0.242	595.67	305	143.91
6	0.237	0.258	0.239	0.248	17.8	18.9	0.243	769.52	248	187.2
7	0.24	0.269	0.257	0.266	23.59	12.75	0.262	416.14	77	108.92
8	0.24	0.248	0.241	0.243	17.36	19.33	0.242	671.37	332	162.47
9	0.244	0.246	0.245	0.245	18.4	18.3	0.245	1543.51	290	378.31
10	0.245	0.262	0.248	0.255	20.57	16.07	0.252	1054.53	108	265.53
11	0.245	0.254	0.248	0.253	20.13	16.53	0.25	571.26	339	143.04
12	0.247	0.249	0.248	0.249	19.42	17.27	0.248	1570.07	354	389.69
13	0.248	0.26	0.258	0.259	22.54	13.93	0.258	1144.98	213	295.63
14	0.248	0.253	0.249	0.25	19.76	16.92	0.249	587.6	364	146.46
15	0.248	0.25	0.249	0.249	0	0	0.249	0	0	0
16	0.257	0.263	0.258	0.262	23.08	13.33	0.26	680.68	150	176.98

in a transaction when they directly purchase or sell to the government or institutions. Transaction price (T.R) is the price at which both parties conclude a transaction and sell it. Transaction number (T.N) is the transaction matching quantity. Deal number (D.N) is the number of transactions successfully matched. Transaction expense (T.E) is the cost paid by the buyer to conclude the transaction.

It can be concluded from Table 2, the matching quantity of seller's transaction is 13838.7 kg, the successful matching quantity is 11000.62 kg, and the turnover rate is 79.49%. The matching quantity of buyer's transaction is 19197.19 kg, and the turnover rate is 57.3%. The market is in short supply and the carbon trading market is the seller's market. It can be seen that the transaction price of this round is distributed between 0.23 yuan per kg and 0.262 yuan per kg, which is in line with the price constraint of the market. Moreover, the price fluctuation trend does not exceed 12.21%, and the transaction price is stable. When a round of matching is completed, the failed matching can be matched on the trading deadline again. Therefore, the carbon trading based on block-chain can timely feedback market information, guide users to reasonably declare price and yields, promote the maximum trading volume of the carbon trading market, stabilize the market price and protect the marketization process.

The total return of the trading matching strategy in this paper is certain, both sides of the transaction declare the price and yield to enter the market and the actual profit depends on their expected yield, the transaction price is calculated in Eq. (10). The general trend is that the higher the minimum price a seller declares, the higher the actual return. The seller's declared price of group 7 was only 0.24 yuan per kg, lower than that of group 8 to 16. However, since the buyer's declared price was 0.269 yuan per kg, the transaction price of both parties was higher and the actual profit obtained was larger than that of the other groups. The lowest selling price of the seller and the highest buying price of the buyer can reasonably ensure that the transaction price is in an expected price range. In addition, both sides of the transaction enter the market according to their expected rate of return and match with the principle of maximizing the overall income. If the transaction is successful, both parties can obtain the expected profit.

According to the carbon trading data of both sides, all the matching groups gained certain gains except the 14th group, which failed to gain gains due to seller's insufficient supply quantity. In addition, from the perspective of the return rate of both buyers and sellers, the return rate declared by sellers is superior, which conforms to the seller's market principle and verifies that the market environment of this round of carbon trading is a seller's market.

From the perspective of a single buyer, when the seller offers 0.24 yuan per kg and the buyer offers 0.269 yuan per kg, the buyer's actual return rate is 12.75%, and when the buyer offers 0.248 yuan per kg, the buyer's actual return rate is 19.33%. The increase of buyer's rate of return is mainly due to the decrease of buyer's quotation. Therefore, when buying the same carbon price, the higher the quotation, the lower the actual yield. The match failure of the 15th group is mainly due to the seller gives priority to match the party with high quotation, and the buyer's quotation does not meet the market demand. If the seller does not enter the next round of matching before the trading day ends, it cannot obtain profits.

In Fig. 5, the buyer's actual rate of return is the rate of return that the buyer can get from participating in the carbon trading, compared with the buyer's direct repurchase from the government or institutions. The seller's actual rate of return is the rate of return that the seller can get from participating in the carbon trading, compared with the seller's direct sell from the government or institutions. The buyer's declared rate of return and the seller's declared rate of return are the rate of return that both parties intend to obtain in carbon price declaration based on the maximization of their own interests.

In terms of the actual return rate obtained by both sides of this round of transaction, except for the failure of the 15th group, both parties of the remaining groups obtain certain benefits. When the seller's quotation increases, the actual rate of return obtained by the seller generally increases. When the buyer's quotation decreases, the buyer's actual rate of return generally increases. It can be seen that the actual rate of return obtained by both parties is directly related to the declared price. The transaction cost of this round is 2729.49 yuan, compared with the direct repurchase carbon quota of 0.3 yuan per kg, the transaction cost decrease by 570.7 yuan, actual transaction costs are reduced by 17.29%, compared with the direct purchase of 0.25 yuan per kg, the carbon emission can be reduced by 2,282.8 kg. Therefore, according to the market principle of "who emits, who pays", the trading match between the two parties can reduce carbon-trading costs, reduce carbon emissions, and reflect the guiding role of carbon trading on carbon emission reduction.

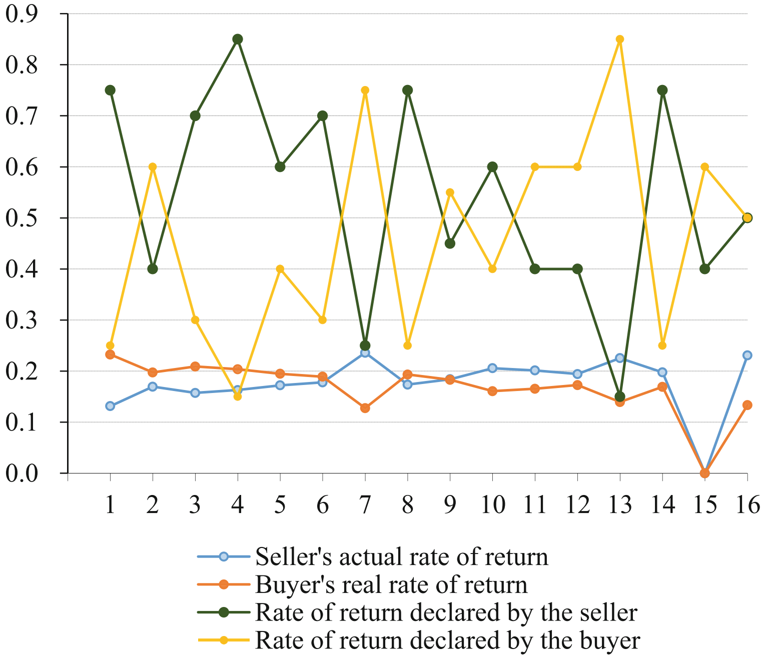

Fig. 5. Rate of return on both sides of the transaction.

In general, the buyer will lower the maximum purchase price and the seller will raise the minimum purchase price, assuming both parties want to make more profit. The zero-sum game between the two parties based on the principle of profit maximization will inevitably lead the transaction price to the market-guiding price. The transaction matching strategy in this paper can reasonably guide the transaction main body to make market offer and stabilize the market price. In addition, users can carry out multiple rounds of matching and declare the price within the trading deadline, which can reasonably guarantee the trading volume of the carbon market and stabilize the operation of the carbon trading market.

Block chain is a shared ledger of distributed data storage, characterized by decentralization, traceability and open transaction data, which can provide an open and transparent trading environment for participants in the carbon trading market [32]. This paper builds green transition driven carbon trading based on the block chain technology, embeds rules such as carbon quota allocation and carbon emissions trading into the block chain platform in the form of smart contract and provides open and transparent trading process to promote the establishment of carbon trade market.

4 Conclusions

Based on the big data of urban vehicle trajectory and combined with block chain technology, this paper proposes a carbon trading market mechanism for private cars that maximizes the benefits of both sides of the transaction, and uses the decentralized and traceable characteristics of block chain to build an open and transparent carbon trading market. It can guide private car carbon consumers to enter the market, reduce carbon dioxide emissions, and advocate green travel. In addition, through the simulation of private car consumers' personal trading, it is verified that the personal carbon trading method proposed in this paper can bring benefits to low-carbon emitters and reduce carbon emissions at the same time.

In this paper, the block chain is incorporated into the whole system of personal carbon quota allocation and carbon emission trading, and the simulation design is carried out to quantitatively analyze the emission reduction effect of carbon trading, which provides some ideas for the establishment of individual carbon trading market.

The green and low-carbon transition strategy needs to be implemented in order to achieve carbon neutralization in 2060. Based on the carbon trading mechanism proposed in this paper, relevant policy proposals can start from the following aspects. First, set higher targets for carbon emission reduction. Based on limiting the total amount of carbon emissions, per capita carbon quota should be reduced to increase the cost of carbon emissions, so as to encourage people to carry out green travel and reduce carbon emissions. Second, promote the construction of private car carbon trading market and clear private car carbon trading market positioning. The establishment of private automobile carbon trading market can stimulate the development of new energy automobile industry, restrain the negative externalities of carbon emissions of traditional fossil energy industry, thus adjust the energy structure and improve energy efficiency. In addition, we should define the positioning of the carbon trading market for private cars, build a unified carbon trading market for private cars, and make systematic arrangements in carbon quota allocation and trading to reduce carbon emissions with high efficiency. Third, formulate relatively balanced carbon emission reduction measures. Different regions in China differ greatly in economic development and energy structure, so relevant policies and measures should be formulated in light of local conditions.

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