The influence of swine fever on China's pork market based on unit root tests

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Abstract. Swine fever was introduced into China in August 2018 and has influenced Chinese pork market to a large extent. Based on the law of one price (LOOP) theory, this article selects data from January 1, 2014 to November 30, 2019, using unit root test and OLS to examine the convergence in China’s pork market relative to Beijing. It turned out that LOOP did not hold in China before the swine fever but hold after; Only three provinces showed the same results as the national context, while the data of all the other provinces remained stable, and there was no swine fever. Factors influencing the existence of LOOP are analyzed based on the previous results. Therefore, the results show that population, the length of classified highway and the introduction of swine fever are the significant factors; while the introduction of swine fever exerts the largest impact on LOOP in Chinese pork market.

1. Introduction

Swine fever was introduced into Liaoning in August 2018 and then swept across 30 provinces in China. By April 2019, 123 cases had been reported in China, and China's hog stocks have halved since August 2018. The outbreak of swine fever has become a "black swan" event for the entire farming industry in China and influenced Chinese economy a lot [1-3]. The immediate effect is a surge in pork prices. Pork prices have been continuing to rise from March 2019 to now. According to the Ministry of Agriculture and Rural Affairs, the average price of pork in the wholesale market in June was 21.59 Yuan per kilogram, up by 4.7% month-on-month and 29.8% year-on-year. Production capacity of hogs and breeding sows has been declining since the fourth quarter of the year of 2018 [4]. In 2018, the inventory of breeding sows in 400 counties monitored by the Ministry of Agriculture dropped by 5.9% year-on-year, exceeding the warning line of 5% [5-6]. The production capacity of the pig base decreased in October 2018, which led to the decrease of pig supply from June and July 2019, and the price of hog continued to rise. Meanwhile China is the world's largest pork consumer, and Chinese eat half of the pork produced globally [7]. Analyzing the convergence of pork price in Chinese market is of great importance, especially under the impact of swine fever, which can help improve regional economic integration.

2. Literature review
Economists from all over the world have studied the law of one price for a long time. The law of one price (LOOP) states that, in an efficient market, the price of an identical good or asset must be the same at all locations. LOOP holds for most food products. Rumánková (2012) examines whether the LOOP holds at pork and beef markets in individual regions of Czech using bi-weekly data and shows that the wholesale prices are transmitted among the regions but they are not transmitted perfectly. Regarding China, Sun and Ren (2014) find that Chinese pork market has a high degree of integration, and the degree of long-term integration is higher than that of short-term integration. Pan and Li (2016) believe that the integration of pig production and marketing market in China is gradually improving and has reached a high level [8-9]. Yin and Bai (2017) use the price method to measure the degree of integration of China's pork market, result shows that there is a long-term and short-term market integration relationship of the pork prices in China, and the integration degree of pork market space was high. Huang, ZhengChen (2019) use the revised LOOP to measure the aquatic product market of 29 provinces, cities and autonomous regions in China [10]. It is found that China's aquatic products market is only highly integrated in the central region, Inner Mongolia, Heilongjiang and Jilin provinces. Ying Tan and Xuning Wang (2020) used cointegration test to find that African plague will significantly affect the fluctuation of pork price in the short term. Qi Xiao and Yang Zhou (2019) used multiple linear models to analyze the impact of African plague on pork prices. Wenbin Cao and Wei Zhang(2015) used CHOW test to point out the important factors that unexpected events affect the pork market [11-12].

There are few studies concerning China’s regional price differences, but the research on this problem has important significance (Liu, 2013; Wang, 2012). Also, even though there are many studies focusing on LOOP and numerous news about pork price changes, few have noticed that the outbreak of swine fever may affect the the existence of LOOP in Chinese pork market. The paper investigates the case of China between 2014 and 2018 [13]. The significant variations in pork price allow us to test whether LOOP is persistent throughout the swine fever.

Evidence on this question is provided by developing and implementing a two-stage approach. In the first stage, we adopt a standard test in the LOOP literature which is to examine the price differences over China for stationarity by LLC and ADF tests. Our intention is to test the persistency of LOOP before and after the introduction of swine fever. Then, the same methodology as the first stage is used for the province data. In the second stage, we look into the factors influencing the existence of LOOP by running ordinary least square (OLS) regression many times. By developing this empirical study connecting LOOP and pork price, this paper provides suggestions about policies towards regulation of agricultural products. Furthermore, the paper attributes to the literature on LOOP, in particular the more recent work that tries to test the absolute/relative version of LOOP with unit root tests and that which looks to test if LOOP applies for intra-national context.

3. Data source
This paper uses daily data of the white pork price for 18 provinces in China (within mainland) from January 1, 2014 to November 30, 2019 to examine the convergence in China’s pork market relative to Beijing. The daily white pork prices of several wholesale markets of all provinces in China are collected from BRK agricultural data terminal. After deleting the provinces with large numbers of missing data, the final available observations are 18 provinces.

For the further analysis of factors that affect the LOOP of China's pork market, we conclude four variables: GDP, Population, Imports, Exports and the length of classified highway, each of them can be collected from National Bureau of Statistics of China. To find the specific level of GDP, Population, Imports, Exports and the length of classified highway, we use annual data from 2014 to 2018 to calculate the average level of these five variables.

4. Methodology
There are two stages in the whole analysis. This paper decides to use unit root test and OLS estimation. The use of unit root test in the first stage is to test whether the law of one price holds in Chinese pork
market before and after the introduction of swine fever. In the second stage, the OLS is for the analysis of the factors influencing the law of one price in Chinese pork market.

4.1. Stage one
In the first stage, we use unit root test to examine the stationarity of pork price to see if LOOP holds. The date when the first case of swine fever broke out in Liaoning Province --- August 1st, 2018 is chosen as the dividing point. So, two time periods are defined --- before the swine fever and after the swine fever. In both time periods, this paper uses the daily pork price to test the LOOP of pork in the whole country, and then test it in each province, both using Beijing as the base province.

Learning from the relevant researches, this paper chooses LLC and ADF test to finish it. Table 1 shows the null hypothesis and the alternative hypothesis of these two methods. After comparing the difference, it is found that LLC test is more suitable for panel data. If using LLC test to do unit root test of panel data, it can be concluded that no panel contains unit root when the null hypothesis is rejected; while if using ADF test, under the same circumstance, it can be only concluded that at least one panel does not contain unit root but cannot get a definite answer whether all the panels are stationary. Combined with the purpose of the analysis, this paper chooses LLC test to test whether the price of pork in all provinces in China is consistent with the LOOP, and use the ADF test to test whether the price of pork in each province relative to Beijing is consistent with the LOOP.

Table 1. The Comparison of the Hypotheses of ADF and LLC Test.

| Augmented Dicky-Fuller test | Levin-Lin-Chu unit-root test |
|-----------------------------|------------------------------|
| $H_0$: All panels contain unit roots | $H_0$: Panels contain unit roots |
| $H_a$: At least one panel is stationary | $H_a$: Panels are stationary |

ADF test model:

$$
\Delta q_{nt} = \alpha_n + \varphi q_{nt-1} + \rho \Delta q_{nt-1} + \varepsilon_{nt} \quad (17 \geq n \geq 1)
$$

where $n$ represents province and $t$ represents time.

$q_{nt}$: $q_{nt} = \frac{p_{nt}}{p_{bt}}$, the relative price of province $n$ compared with Beijing at time $t$.

$\Delta q_{nt}$: $\Delta q_{nt} = q_{nt} - q_{nt-1}$, the difference of relative price between time $t$ and $t - 1$.

$\Delta q_{nt-1}$: the lagged difference. After using Stata, the model may choose the optimal lag length it provides since the lag length always depends on data frequency and sample size.

$\varphi$: the null hypothesis is $\varphi = 0$, so the relative prices have a unit root and LOOP does not hold. If $\varphi < 0$, the null hypothesis can be rejected and LOOP holds. As the data of 17 provinces are finally obtained, 17 corresponding $\varphi$ at each time period would be obtained.

$\alpha_n$: According to the model, the constant terms $\alpha_n$ represents the distance between the converging relative price and one, so it can give the information of converging relative price. If the LOOP holds, constant term $\alpha_n$ equals zero then absolute LOOP holds; and if $\alpha_n$ is positive then relative LOOP holds, as table 2 shows. From the empirical results below, it is known that all the LOOP tested in the following is based on relative LOOP.

Table 2. The Information Conveyed by Constant Terms.

|                | $\alpha_n = 0$ | $\alpha_n > 0$ |
|----------------|----------------|----------------|
| $\varphi \neq 0$ | Absolute LOOP holds. | Relative LOOP holds. |
| $\varphi = 0$   | LOOP does not hold. | LOOP does not hold. |

LLC test model:

$$
\Delta q_{nt} = \alpha_n + \varphi q_{nt-1} + \rho \Delta q_{nt-1} + \varepsilon_{nt} \quad (17 \geq n \geq 1)
$$

It is observed that the model is the same as that of ADF. It is because the main idea of LLC test is to first perform ADF regression for each vertical section time series, then construct two sets of orthogonal residual series, and finally use the t statistic value of the combined regression coefficient of the orthogonal residual series to get the adjusted t statistic value. LLC test is not able to give a specific value.
of \( \varphi \), it can be inferred whether there is a unit root, that is whether LOOP holds, from the adjusted t-statistic and P-value.

4.2. Stage two

In the second stage, we proceed to look into the possible determinants that affect the persistency of LOOP. To do this, the regression model is constructed:

\[
\varphi_{iT} = \beta_0 + \beta_1 SF_{iT} + \beta_2 Len_{iT} + \beta_3 Pop_{iT} + \beta_4 TIX_{iT} + \beta_5 GDP_{iT} + \epsilon_{iT}
\]

(3)

\( \varphi_{iT} \): the coefficient \( \varphi_1 \) that is drawn from (4) representing the Province i’s accordance with LOOP in period T

\( SF_{iT} \): the dummy variable whether the province is influenced by swine fever

\( SF_{iT} = 0 \): the province is not influenced; \( SF_{iT} = 1 \): the province is influenced

\( Len_{iT} \): the average length of classified highway in Province i in period T

\( Pop_{iT} \): the average populations of Province i in period T

\( TIX_{iT} \): the average total imports and exports of Province i in period T

\( GDP_{iT} \): the average yearly GDP of Province i in period T

Considering the fact that LOOP did not hold before introduction of swine fever but holds after, we suspect that swine fever may be a factor affect the holding of LOOP. It is believed that the length of classified highway is likely to be correlated with the transporting cost. As the length of classified highway increases, the transporting cost changes, which influence the pork price. What’s more, among all the meats, pork is consumed the most. If supply remains unchanged, an increase in population will inevitably lead to a rise in pork prices. The price changes cause price convergence or divergence and eventually influence LOOP. As demand for pork outstrips supply, imports of pork and its substitutes increase, and exports of related commodities are also adjusted with the purpose to meet domestic demand first. GDP, as one of the most frequently used macro indicators, exerts the influence on most of commodities, including pork as well as its complements and substitutes. It is suspected that GDP is likely to impact the existence of LOOP.

If there are insignificant independent variables, the one with the biggest P-value would be eliminated and regress on the rest independent variables. We keep doing this until all the independent variables are significant, which are believed to be the most possible factors affecting the existence of LOOP.

5. Empirical results

5.1. Description of analyzed data
**Figure 1.** Changes of Pork Price in Area 1.

![Changes of Pork Price in Area 1](image1)

**Figure 2.** Changes of Pork Price in Area 2.

![Changes of Pork Price in Area 2](image2)

**Figure 3.** Changes of Pork Price in Area 3.

![Changes of Pork Price in Area 3](image3)
Figure 4. Changes of Pork Price in Area 4.

First is to describe the development of the wholesale price of pork in provinces in period from January 2014 to November 2019. Since it is not clear to present 18 lines into one figure to compare the development trend of pork prices across the country, they are divided into the following four figures according to the geographical area, and Beijing is chosen as the base province in each figure. It can be seen that in no matter which area, there is a certain gap between the pork price in each province and the pork price in Beijing. And the development trends are not quite uniform. However, after 2018, the figures show great increasing tendency of all provinces, and the trend in each province and that in Beijing has become similar.

5.2. The result of the first stage

Table 3. The Result of LLC Test before the Swine Fever.

| Levin-Lin-Chu unit-root test for relative price |
|------------------------------------------------|
| \( H_0 \): Panels contain unit roots | Number of panels = 17 |
| \( H_a \): Panels are stationary | Number of periods = 1561 |
| Adjusted \( t^* \) | Statistic | P-value |
| 0.6808 | 0.7520 |

Table 3 shows the result of LLC test before the swine fever. The adjusted \( t \)-statistic is 0.6808, which is in the confidence interval and the P-value is 0.7520, higher than the value of 5% significance level. Thus, the null hypothesis cannot be rejected. For total 17 panels, there exists unit root test, which means the LOOP does not hold before the swine fever period.

In order to investigate which provinces’ pork price break the LOOP at national level, next we use ADF test to test the LOOP of each province, and finally get 17 corresponding results.

Table 4. The Result of ADF Test before the Swine Fever.

| Provinces | \( \varphi \) | t-statistic of \( \varphi \) | p-value of \( \varphi \) | \( \alpha \) |
|-----------|--------------|-----------------|----------------|--------|
| Tianjin   | -0.014       | -2.062          | 0.039           | 0.016  |
| Hebei     | -0.048       | -3.847          | 0.000           | 0.054  |
| Inner Mongolia | -0.042 | -3.393          | 0.001           | 0.047  |
| Shanxi    | -0.032       | -2.937          | 0.003           | 0.036  |
| Liaoning  | -0.053       | -3.967          | 0.000           | 0.060  |
| Shanghai  | -0.031       | -2.824          | 0.005           | 0.033  |
Table 4 shows the corresponding results of each province. According to t-statistic and p-value of $\varphi$ at 5% significance level, we are able to find that Tianjin, Fujian and Ningxia fail to reject the null hypothesis, which means all panels contain unit roots. So the pork price of Tianjin, Fujian and Ningxia is not stationary, that is to say, LOOP does not hold in these 3 provinces, and it holds for other 14 provinces. For provinces that consistent with the LOOP, $\alpha_n$ does not equal to zero. Combined with previous analysis, this paper concludes that the relative LOOP holds for other 14 provinces.

To test the impact of swine fever on the existence of Law of one price, this paper uses the LLC test to test it after the swine fever.

### Table 5. The Result of LLC Test after the Swine Fever.

| Provinces | $\varphi$ | t-statistic | p-value of $\varphi$ | $\alpha$ |
|-----------|-----------|-------------|----------------------|----------|
| Tianjin   | -0.239    | -5.518      | 0.000                | 0.252    |
| Hebei     | -0.266    | -6.091      | 0.000                | 0.296    |
| Inner Mongolia | -0.317   | -7.579      | 0.000                | 0.349    |
| Shanxi    | -0.230    | -5.689      | 0.000                | 0.261    |
| Liaoning  | -0.238    | -5.395      | 0.000                | 0.268    |
| Shanghai  | -0.240    | -5.260      | 0.000                | 0.276    |
| Jiangsu   | -0.198    | -4.677      | 0.000                | 0.231    |
| Zhejiang  | -0.222    | -5.147      | 0.000                | 0.262    |
| Anhui     | -0.242    | -5.841      | 0.000                | 0.276    |
| Fujian    | -0.355    | -7.947      | 0.000                | 0.370    |
| Shandong  | -0.167    | -3.921      | 0.000                | 0.181    |
| Hunan     | -0.221    | -4.857      | 0.000                | 0.239    |
| Sichuan   | -0.369    | -6.604      | 0.000                | 0.399    |
| Shaanxi   | -0.496    | -10.183     | 0.000                | 0.540    |
| Gansu     | -0.236    | -5.838      | 0.000                | 0.252    |
| Ningxia   | -0.302    | -6.719      | 0.000                | 0.316    |
| Xinjiang  | -0.538    | -10.249     | 0.000                | 0.555    |

This table shows the result that the adjusted t-statistic is -23.4108, which is not in the confidence interval. The corresponding P-value is 0.0000. So, the null hypothesis can be rejected at 5% significance level, which means the LOOP holds after the swine fever at national level.

### Table 6. The Result of ADF Test after the Swine Fever.

| Provinces | $\varphi$ | t-statistic of $\varphi$ | p-value of $\varphi$ | $\alpha$ |
|-----------|-----------|---------------------------|----------------------|----------|
| Tianjin   | -0.239    | -5.518                    | 0.000                | 0.252    |
| Hebei     | -0.266    | -6.091                    | 0.000                | 0.296    |
| Inner Mongolia | -0.317   | -7.579                    | 0.000                | 0.349    |
| Shanxi    | -0.230    | -5.689                    | 0.000                | 0.261    |
| Liaoning  | -0.238    | -5.395                    | 0.000                | 0.268    |
| Shanghai  | -0.240    | -5.260                    | 0.000                | 0.276    |
| Jiangsu   | -0.198    | -4.677                    | 0.000                | 0.231    |
| Zhejiang  | -0.222    | -5.147                    | 0.000                | 0.262    |
| Anhui     | -0.242    | -5.841                    | 0.000                | 0.276    |
| Fujian    | -0.355    | -7.947                    | 0.000                | 0.370    |
| Shandong  | -0.167    | -3.921                    | 0.000                | 0.181    |
| Hunan     | -0.221    | -4.857                    | 0.000                | 0.239    |
| Sichuan   | -0.369    | -6.604                    | 0.000                | 0.399    |
| Shaanxi   | -0.496    | -10.183                   | 0.000                | 0.540    |
| Gansu     | -0.236    | -5.838                    | 0.000                | 0.252    |
| Ningxia   | -0.302    | -6.719                    | 0.000                | 0.316    |
| Xinjiang  | -0.538    | -10.249                   | 0.000                | 0.555    |

In addition, from the ADF test of each province, the P-values of $\varphi$ of each province equals 0.000, and the t-value of $\varphi$ are higher than the 5% significance level. So, the alternative hypothesis can be
accepted. That is to say, the relative pork price of each province is stationary after the swine fever, which support the result we get from LLC test. As the positive $\alpha_n$ term of each province, the relative LOOP can be concluded.

Figure 5 highlights the only three provinces (Tianjin, Fujian and Ningxia) confirm to the law of one price after swine fever while not before the swine fever. It can be seen that they have no common characteristics in geographical location. Although Fujian is far away from Beijing, Tianjin is just the neighbor of Beijing. In stage two, this paper figure outs the factors influencing the existence of LOOP.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Tianjin, Fujian, Ningxia and the Base Province---Beijing.}
\end{figure}

5.3. The result of the second stage

First, following regression is constructed:

$$\varphi_{IT} = \beta_0 + \beta_1 SF_{IT} + \beta_2 Len_{IT} + \beta_3 Pop_{IT} + \beta_4 TIX_{IT} + \beta_5 GDP_{IT} + \varepsilon_{IT}$$

(4)

It turned out that $GDP_{IT}$ is the most insignificant independent variable, so this variable was eliminated, then we ran the following regression:

$$\varphi_{IT} = \beta_0 + \beta_1 SF_{IT} + \beta_2 Len_{IT} + \beta_3 Pop_{IT} + \beta_4 TIX_{IT} + \varepsilon_{IT}$$

(5)

It turned out that $TIX_{IT}$ is the most insignificant independent variable, so this variable was eliminated, then we ran the following regression:

$$\varphi_{IT} = \beta_0 + \beta_1 SF_{IT} + \beta_2 Len_{IT} + \beta_3 Pop_{IT} + \varepsilon_{IT}$$

(6)

It turned out that all the independent variables in (III) are significant.

\begin{table}[h]
\centering
\caption{The Results of Statistical Analysis.}
\begin{tabular}{lccc}
\hline
& I & II & III \\
\hline
SF & -0.232*** & -0.231*** & -0.232*** \\
& (0.026) & (0.024) & (0.024) \\
Len & -0.756* & -0.751* & -0.625** \\
& (0.399) & (0.392) & (0.254) \\
Pop & 0.199 & 0.229* & 0.189** \\
& (0.166) & (0.120) & (0.075) \\
TIX & -0.090 & -0.046 & — \\
& (0.199) & (0.106) & — \\
\hline
\end{tabular}
\end{table}
| Variable | Coefficient | Standard Error | \( R^2 \) |
|----------|-------------|----------------|---------|
| GDP      | 0.006       | (0.024)        | 0.780   |

Notes: Dependent variable is \( \varphi \) value. Standard errors in parentheses; *p<0.1, **p<0.05, *** p<0.01.

\( R^2 \) being over 0.77 means that the existence of LOOP at Chinese pork market is largely explained by the independent variables above. The results indicate that GDP and total import and export exert little effect on the persistency of LOOP, while the variables of population, the length of classified highway and SF are all significant at 5% level.

Population has a negative effect on the persistency of LOOP, for different consumers have different consumption behaviors. The likelihood that the presence of more consumers causes market disorder is quite high. The length of classified highway, however, exerts a positive influence on LOOP. The increase in the length of highway implies the improvement of infrastructures, reduces transporting cost, diminishes trade barriers and leads to price convergence or at least to the stabilization of regional price differences.

Throughout all the three regressions, SF always remains significant at 1% level. So, it is believed that it is the introduction of swine fever that is the main factor influencing the existence of LOOP. Furthermore, the \( \beta_1 \) being negative indicates that swine fever pushed Chinese pork market forward towards the persistency of LOOP since the absolute value of \( \beta_1 \) is larger. Also, swine fever has a so large impact on pork supply that non-official pork suppliers cannot handle this problem properly on their own, even if the demand of pork stays the same. A policy regulation will certainly be promoted at this special time. Considering that fact that LOOP did not hold before the introduction of swine fever but holds after, it is likely that policy has been playing a major role in keeping the existence of LOOP. With swine fever spreading almost throughout the country, even though the policy is wanted to be implemented according to the different situation in different provinces, it will still be enacted on a national level. This national policy may promote LOOP in a national context.

### 6. Conclusions

To some degree, the swine fever has greatly influenced the LOOP in Chinese pork market. To begin with, in stage one, the results showed that pork prices in the three provinces did not conform to LOOP before, but conform to that after the introduction of swine fever, which probably due to the implement of local policies. This is consistent with the situation of the whole country. It illustrates that the situation of each province will have a certain impact on that of the whole country. Therefore, each province should pay attention to it, and the local governments should make policies according to their own conditions.

However, the results obtained in stage two show that the swine fever has led to the implement of national policies, which contributes to the existence of LOOP in the whole country. Under the influence of swine fever, it is difficult to achieve the law of one price by relying solely on the market itself. At this time, the national government should give a hand to it, which means In addition to local policy, national governments need to formulate national policies to make the local policy-making move toward to an orderly efficient trend.

Besides, in stage two, the length of classified highway has a positive correlation with LOOP. It illustrates that it plays a vital role in the existence of LOOP in Chinese pork market. In other words, the government should attach great importance on that and invest more in improving the transportation system in order to promote the LOOP.

In summary, although swine fever has a negative impact on people's lives, it can contribute to promoting the national market unification. It illustrates that emergencies are not only harmful to country, they can sometimes bring benefits. Actually, it depends on the measures the government did to deal with it. Therefore, the country should summarize the experiences from swine fever, so as to be able to solve it calmly in the next outbreak and turn the disadvantages into advantages as much as possible.
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