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COVID-19 containment policies, digitalization and sustainable development goals: evidence from Alibaba's administrative data

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The impact of digital platforms on the implementation of the United Nations' (UN) Sustainable Development Goals (SDGs), especially the business sustainability of micro, small and medium-sized enterprises (MSMEs), under different containment policies during and after the COVID-19 pandemic has not yet been studied in detail. Using detailed administrative data from Alibaba Group's online on-demand food delivery platform, we found that the digital platform contributed to the food security, wellbeing, employment and business sustainability of MSMEs both during and after the pandemic. We uncovered merchants' heterogeneous responses to the COVID-19 pandemic during and after the implementation of different containment policies in China. On the extensive margin, the period of complete lockdown left long-term scarring on online merchants by decreasing the number of entrants, especially in the cooked food industry. In contrast, on the intensive margin, chain stores, especially those with large chain networks or multiapp stores, exhibited stronger resilience than their counterparts during and after lockdown. Thus, specialization (at the outlet level) and wider coverage (at the network level) emerged as key factors that enable business sustainability under challenging economic circumstances.

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Introduction

In the last decade, the global economy has been characterized by unprecedented digitalization. Digital platforms are not only transforming the ways in which we interact, communicate and transact goods and services but also helping economies recover from unexpected negative shocks. The growing trend of e-commerce and the broader digitalization of economies has been accelerated by the global COVID-19 pandemic (ADB 2021a, b; Du et al. 2022). In late January 2020, the Chinese government imposed three stringent containment policies in various cities to prevent the rapid spread of the disease (Fang et al. 2020; Qiu et al. 2020), which considerably reduced the transmission rate and spread of COVID-19 (Alekseev et al. 2022; Bartik et al. 2020); prolonged the effects on the ecosystems of micro, small and medium-sized enterprises (MSMEs; Bartik et al. 2020; Bloom et al. 2020; Mathijs de et al. 2021; Cong et al. 2022; Dai et al. 2021a, b; Guo et al. 2022; Kong et al. 2021; Wang et al. 2020); and facilitated the digitization of MSMEs in China. However, the role played by digital platforms in supporting the United Nations (UN) Sustainable Development Goals (SDGs), the impact of different containment policies on digital merchants' business sustainability and the effectiveness of different business strategies on sustainable MSME resilience remain underinvested. To at least partly bridge this gap in the literature, this study employs large-scale administrative data from Alibaba Group's Ele.me in China, which is an online on-demand delivery service platform for food and nonfood groceries; most of the shops on Ele.me are MSMEs. This paper presents a quantitative evaluation of the impact of different containment policies on all selected shops on Ele.me, on shops in different product categories (e.g., cooked food, uncooked food, pharmacy), and on individual shops in sequence. We discuss the role of digital food delivery platforms in achieving the SDGs during and after the pandemic and then propose policy implications for policy-makers and merchants. This study shows that the digital food delivery platform has contributed not only to the food security, wellbeing, employment and business sustainability of MSMEs both during and after the pandemic but also to supporting the SDGs.

The contributions of this study are as follows. First, it examines sustainable development (SD) from the perspective of MSMEs; this focus is critical to the SD of China's economy because the proportion of persons employed by MSMEs in all enterprises was 79.4% in 2018 (NBS 2019). Furthermore, the SD of MSMEs is relevant to SDG target 8.3. The administrative data used herein, which is rarely accessible, provides a unique opportunity to quantitatively and comprehensively examine the long-term impact of different COVID-19 containment policies on the business sustainability of MSMEs and, hence, on SD in general. In addition to the number of orders or sales, which are usually examined, we construct proxies for product variety and price discounts. We employ quadratic time trends to track the potential nonlinearity of policy effects, while many previous studies have only adopted binary variables of different containment policies to estimate the average policy "treatment" effects (Raj et al. 2023; Han et al. 2022; Guo et al. 2022). Second, our case study is related to the food industry and pharmacy industry, where digitalization is seen through merchants' use of online delivery platforms; the findings can shed light on the role of digitalization in food security and health care issues during crises, which are related to SDG targets 2.c and 3.8, respectively. Our unique dataset allows us to derive one measure of the extent of digitalization driven by COVID-19, namely, the number of MSMEs in the food industry that entered one digital food delivery platform in China, which is linked to SDG target 8.3. Although this measure is limited to one platform, it can provide insights into the impact of containment policies on digitalization. Our finding is that these policies have

heterogeneous outcomes on different product categories, which are different when a longer time period is studied; therefore, the pandemic period has not had a straightforward relationship with digitalization, as it has been mediated by different containment policies. Third, we examine the impact of the two business strategies, i.e., chain stores and multiapp stores, on the resilience of sustainable MSMEs. For MSMEs that entered a platform (i.e., digitalized), we find that the effects of containment policies vary according to the merchant type. Chain stores are found to perform better than nonchain stores, suggesting that even when both store types are digitalized, a larger network of supply chains brings greater gains to digitalization. Similarly, multiapp stores (which indicate a higher level of digitalization than stores without multiple apps) are found to perform better.

The rest of this paper proceeds as follows. First, we provide a literature review focused on tackling the UN SDGs through digitalization and the impact of COVID-19 on the sustainability and resilience of MSMEs to exogenous shocks. Second, we illustrate the utilized materials and methods, including the evolution of COVID-19 in China, data, nonmodel facts, and empirical models. Third, we present empirical results on the impacts of various containment policies and two business strategies. Fourth, we summarize our findings and discuss implications for policy-makers and merchants. Fifth and finally, we close with recommendations for achieving the UN SDGs through digital food delivery platforms and the limitations of this study and future research.

Literature

Tackling the UN SDGs through digitalization. In 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, which established 17 SDGs and 169 targets (UN 2015a, b). The implementation of SDGs faces many challenges, such as localization and integration in governance. Digitalization is regarded as one of the most promising transformations for achieving the SDGs (Gouvea et al. 2018; Sachs et al. 2019; Seele and Lock 2017; Walker et al. 2019). Digital transformation and networking can help localize SDGs (ElMassah and Mohieldin 2020; Reuter 2023) and enhance governance toward the achievement of SD (Athey 2017; Lowman 2017). With the spread of big data and information and communication (ICT) technology in all areas of life, digitalization has dramatically increased in many scenarios, such as working from home, online education, digital health (Novillo-Ortiz et al. 2018; Asi and Williams 2020), smart cities (Jain et al. 2023), robotics, and emission reduction and other pro-environmental solutions (He et al. 2023), all of which have contributed to achieving the SDGs, especially during and after COVID-19 (Pan and Zhang 2020; Zhao et al. 2022). However, the relationship between digitalization and sustainability remains controversial (Castro et al. 2021; Vinuesa et al. 2020). Digitalization may undermine people's legal rights to privacy, lead to a misuse of data and political surveillance (Seele and Lock 2017), degrade natural ecosystems (Bekaroo et al. 2016) and negatively impact the environment and health (LaPointe 2018). Digitalization can alleviate income inequality (Yin and Choi 2022); however, whether digitalization reduces inequality also depends on how it is shaped (Asongu and Odhiambo 2019). Most of the extant studies have adopted a qualitative approach to analyze the impact of digitalization on the achievement of SDGs, while few studies have adopted a quantitative methodology. Most quantitative studies on SDGs examine the SDG index (SDGI) at the country level (Zhao et al. 2022). To the best of our knowledge, no study has focused on the mechanisms by which digital food delivery platforms have helped achieve the SDGs during and after the pandemic.

Impact of COVID-19 on the sustainability and resilience of MSMEs. Resilience refers to the economic system's ability to absorb shocks and reorganize in the face of socioeconomic changes. Sustainability is a broader concept than resilience and represents a long-term goal, which is the integration of social, environmental, and economic performance that benefits current and future generations (Geissdoerfer et al. 2017; Ranjbar et al. 2021; Elkington 1998). Exogenous shocks, such as natural disasters, usually propagate through supply chains or supplier-customer networks of firms (Brummitt et al. 2017; Inoue and Todo 2019; Carvalho et al. 2021). Studies focusing on COVID-19's impact on sustainability can be divided into three dimensions: environmental performance (Adelodun et al. 2020; Amankwah-Amoah 2020; Freire-González and Vivanco 2020), social performance (Anholon et al. 2020; Christoffel et al. 2020; Sharma et al. 2020; Ryan et al. 2020; Iyengar 2020), and economic performance (Pan and Zhang 2020). A considerable number of studies have adopted qualitative rather than quantitative approaches. However, many studies on the economic impact of COVID-19 on MSMEs have been based on surveys or transaction data from financial accounts (Bartik et al. 2020; Bloom et al. 2020; Mathijs de et al. 2021; Cong et al. 2022; Dai et al. 2021a, b; Guo et al. 2022; Kong et al. 2021; Wang et al. 2020), and they have examined various important topics, such as the revenue and costs of small businesses, business expectations, layoffs, closures, entry, number of firms, digitalization, financial crunches, and firms' factor productivity. However, detailed administrative data on MSMEs are either seldom available for research or have been reported at a low frequency (e.g., quarterly) in surveys (Guo et al. 2022; Kong et al. 2021). For the restaurant industry, some researchers have indirectly inferred restaurant visits or staffing from cell phone geolocation data, webpage views and reservations (Wang et al. 2022; Glaeser et al. 2021); only a small number of studies have employed the actual counts of orders obtained from an online platform (Raj et al. 2023). Additionally, the impact of COVID-19 on MSMEs varies considering the firm's location and characteristics, such as the area's income, whether a restaurant is a chain restaurant, whether the restaurant is located in the city center, or whether the state has different political preferences (Wang et al. 2022; Glaeser et al. 2021). To the best of our knowledge, no previous study has employed comprehensive high-frequency merchant-level administrative data to quantify the long-term impact of containment policies on merchants, users, delivery riders, product variety and price discounts on digital food delivery platforms. To bridge this important gap in the literature, we examine how shops in the food industry and pharmacy industry have responded to the different containment policies during and after lockdown.

Materials and methods

The evolution of COVID-19 in China. Table 1 shows the chronology of the COVID-19 pandemic in China starting from December 2019, when several cases of unexplained pneumonia were identified in Wuhan. Subsequently, the disease spread to the entire city, to Hubei Province, and to other parts of the country within a short period. On 23 January 2020, China took a pivotal step to curb the spread of the virus by completely shutting down movement out of Wuhan, followed by seven cities in Hubei. Partial shutdowns, checkpoints and quarantine zones were implemented in other Chinese cities. By mid-March, the number of new cases per day was contained within the single digits, and nationwide epidemic prevention and control measures had achieved considerable success. The lockdown in Wuhan was lifted on 8 April 2020. On 31 December 2020, the National Health Commission of the People's Republic of China announced that

the COVID-19 vaccine would be free for all citizens and that 300 million doses would be administered nationwide by 1 May 2021. As of 31 August 2021, more than 60% of China's population had full vaccine protection.

Data

Administrative data from Alibaba Group's Ele.me and Koubei. Ele.me offers different types of data: number of shops, active users, full-time and part-time delivery riders at the district-week level, operational data at the merchant-week level, and shop characteristics. Consumers can review menus and order food or other products for delivery or takeout from participating restaurants or stores using the Ele.me application, Ele.me's Alipay portal or Ele.me's web browser. Ele.me collects a commission on orders placed on the platform from restaurants or stores and delivery charges received from customers. Another application related to Ele.me is Koubei, which provides users with information and reviews of local lifestyle services. The takeaway services of Koubei shops are directed toward Ele.me through links on Koubei. Ele.me was combined with Koubei as a local life service company in October 2018, and its main competitor in China is Meituan, which is an app that focuses on local lifestyle services. In 2020 Q2, the nationwide market shares of Meituan and Ele.me were 68.2% and 25.4% (Trustdata 2020), respectively.

We employed 104-week-long detailed administrative data from Ele.me that ranged from the fifth week of 2019 to the fourth week of 2021, i.e., one year before and one year after the outbreak of the COVID-19 pandemic. Shops with at least one order during the entire sample period were randomly selected. An "effective" shop in a given week was defined as a shop with at least one order. Time-invariant shop characteristics included shop creation date and whether a shop is listed on Koubei, indicating the relative significance of the shop's offline presence and location at the city-district level. The time-varying data included shop operation data such as the number of orders, gross merchandise value (GMV), subsidies provided by a shop or the platform, number of Stock Keeping Units (SKUs), shop's rating score given by customers (0–5), categories of goods sold, whether a shop is a chain store, and a unique chain brand identification number. We used the ratio of subsidies to the GMV as a proxy for price discounts. Usually, the nominal or listed prices on Ele.me do not vary considerably over time, and the GMV is computed using nominal prices and delivery fees. Therefore, the ratio of subsidies to the GMV is a good proxy for price discounts. We further adopted the number of SKUs as a proxy for product variety.

These shops are classified into 204 "narrow" categories by Ele.me. We grouped these "narrow" categories into four mutually exclusive and exhaustive "broad" categories, as shown in Table 2: cooked food, uncooked food, pharmacy and others. Cooked food was the largest category in terms of the net GMV (GMV minus subsidies). The order of shares of the main categories from largest to smallest was cooked food, uncooked food, nonfood grocery store items, pharmacy and others.

We further augmented the Ele.me data with public information on the number of weekly confirmed COVID-19 cases and the start and end dates of policies for each city at different stringency levels (Du et al. 2022). For the former, we obtained the daily number of new cases from the National Health Commission at the city-day level and aggregated the number of new cases at the city-week level.

Lockdown. The stringency levels were threefold: complete, partial and checkpoint lockdowns. Under complete lockdowns, residents were prohibited from leaving the city and could only leave their homes for essential activities during limited periods; both public and private transportation were forbidden. Partial lockdowns

Table 1 The evolution of COVID-19 in China.

Stage	Date	Event
Stage I:		Swift Response to the Public Health Emergency (27 December 2019–19 January 2020)
Stage II:		Stage II: Initial Progress in Containing the Virus (20 January–20 February 2020)
Stage III:		Newly Confirmed Domestic Cases on the Chinese Mainland Drop to Single Digits (21 February–17 March 2020)
	Complete shutdown	Wuhan, Ezhou, Jingmen, Huangshi, Shiyan, Suizhou, Xiaogan, Yichang (24 January 2020–8 April 2020)
	Partial shutdown	Fuzhou in Fujian (4–10 February); Hangzhou in Zhejiang (4–26 February); Ningbo in Zhejiang (4–20 February); Zhenzhou in Henan (4–23 February); Zhumadian in Heilongjiang (4–23 February); Harbin in Heilongjiang (10 February–16 March)
	Checkpoint and quarantine zone	Twenty provinces or municipalities in China
	8 April 2020	Wuhan lifted the lockdown that lasted for 76 days.
Stage IV:		Wuhan and Hubei-An Initial Victory in a Critical Battle (18 March–28 April 2020)
Stage V:		Ongoing Prevention and Control (29 April 2020–30 January 2021)
	16 July 2020	New cases were reported in Urumqi, Xinjiang province; Xinjiang province went into complete lockdown.
	1 September 2020	Xinjiang province lifted the lockdown.
	30 December 2020	China's first COVID-19 vaccine was launched.
	1 May 2021	300 million doses of the COVID-19 vaccine had been administered nationwide.

Data source: A white paper titled "Fighting COVID-19: China in Action", published by the State Council Information Office of the People's Republic of China (http://english.www.gov.cn/news/topnews/202006/07/content_WS5edc559ac6d066592a449030.html); http://www.gov.cn/zhengce/2020-06/07/content_5517737.htm.

Table 2 Shop category.

Broad shop category	Narrow shop category
Cooked food	Sichuan and Hunan cuisine; barbecue; hamburger and fries, etc.
Uncooked food	Supermarkets; fruit stores; convenience stores; community fresh food stores, etc.
Pharmacy	Pharmacy.
Others	Beverage, dessert, cake, flower stores, etc.

were less stringent, and residents could leave the city. Although public transportation was shut down, private modes of travel were permitted. At the least stringent level, movement restrictions, such as checkpoints, were limited to localized pockets of disease outbreaks. Even in cities without any containment policy, at the start of the pandemic outbreak or in the early period of Wuhan's lockdown, people were strongly encouraged to obey the stay-at-home order. Usually, all delivered packages were left at the entrance of a community in cities with containment policies.

We focused on all seven cities for which data are available: Wuhan and Yichang in Hubei Province, Hangzhou in Zhejiang Province, Harbin in Heilongjiang Province, Suzhou in Jiangsu Province, and Chongqing and Xi'an in Shaanxi Province. These seven cities were selected for the following reasons. First, containment policies varied over time, and stringency levels varied across the seven cities. Wuhan and Yichang were under complete lockdown policies from 24 January 2020 to 7 April 2020. Partial lockdowns were experienced in Hangzhou from 4 February 2020 to 27 February 2020; and in Harbin from 4 February 2020 to 16 March 2020. Suzhou had checkpoints from 31 January 2020 to 23 March 2020, and Chongqing had checkpoints from 6 February 2020 to 19 February 2020. Xi'an never experienced containment policies during this period. Second, all cities except Yichang are provincial capitals or municipalities; Yichang is a small city. The six large cities are economically comparable in terms of population and GDP; the gross regional products of Wuhan, Yichang, Hangzhou, Harbin, Suzhou, Xi'an and Chongqing in 2021 were \$275, \$77.8, \$281, \$83, \$352, \$166 and \$432 billion (1.772, 0.502, 1.811, 0.535, 2.272, 1.069 and 2.789 trillion RMB) respectively. Third, these cities or municipalities do not share borders; therefore, the potential spillover effects are weak. We exploited the exogenous variations created by the pandemic to quantify its causal impact.

The market's geographical size is defined as a district in a city because the majority of orders are within a district. Consumers usually place orders from shops within three kilometers of their places. Very few shops provide citywide delivery services; moreover, these orders take much longer, charge much higher delivery fees and are often rejected by shops when they are busy.

Nonmodel facts

Entrants. The lockdown period witnessed a higher share of entrants listed on Koubei (defined as multiapp stores), chain stores and uncooked food (Fig. 1). On the supply side, shops listed on Koubei (most of which relied heavily on offline services before the pandemic and were better known to consumers due to their listing on Koubei) temporarily closed their brick-and-mortar stores because of stay-at-home orders and mandatory nonessential business closures and thus shifted toward multichannel retailing. Furthermore, shops listed on Koubei already had digitalization experience; therefore, it was easier for them to join another digital platform within the same company, namely, Ele.me. On the demand side, more consumers cooked at home and had to purchase uncooked food online during and after the pandemic. Even those who purchased online less often had to adapt to the online channel.

Overall operation performance by city. During the lockdown period, the overall operational performance (Fig. 2)—especially the net GMV—of uncooked food was rather different from that of cooked food. The total weekly net GMV of cooked food decreased, whereas that of uncooked food increased. Even when we took the Spring Festival into consideration, we observed that people stayed at home and cooked for themselves. The total weekly net GMV of pharmacies increased in Wuhan during the lockdown. For cities under complete lockdown, digital platforms became an important outlet for consumers to obtain medicines,

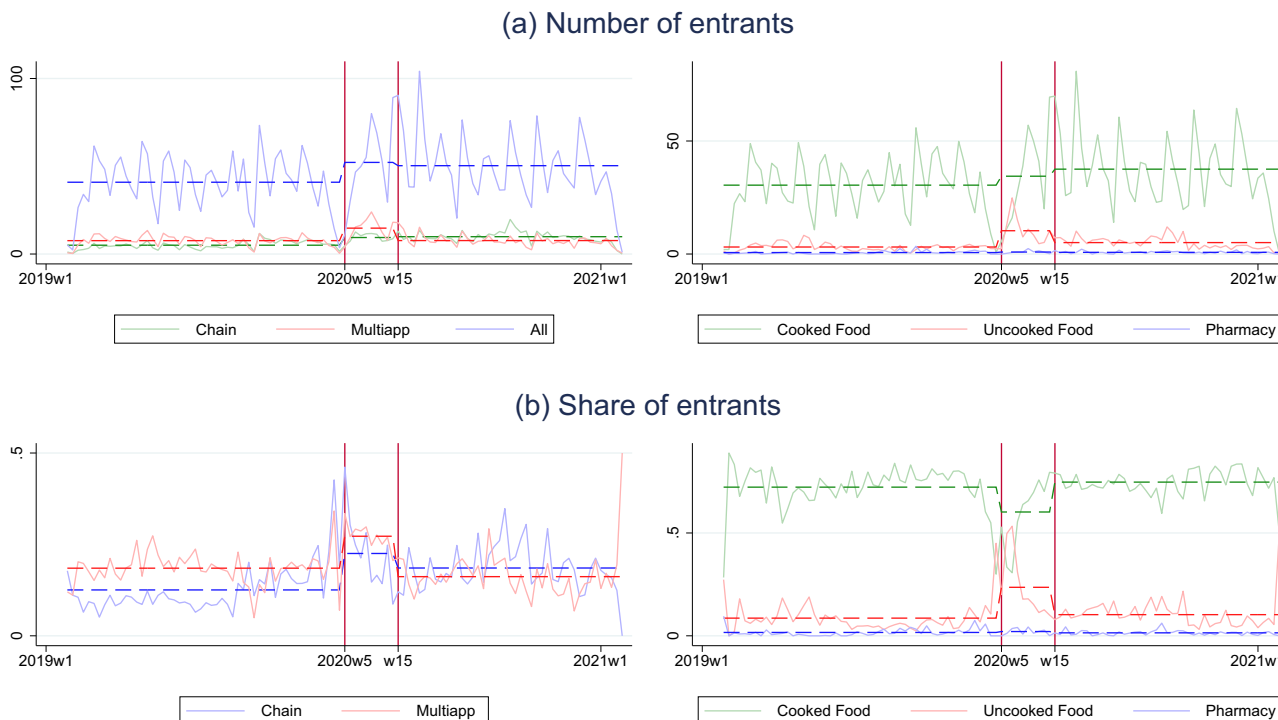


Fig. 1 Weekly number and share of entrants by shop type and product category. **a, b** display the number of entrants and share of entrants, respectively. The dashed lines represent the averages before, during and post-Wuhan-lockdown periods. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively.

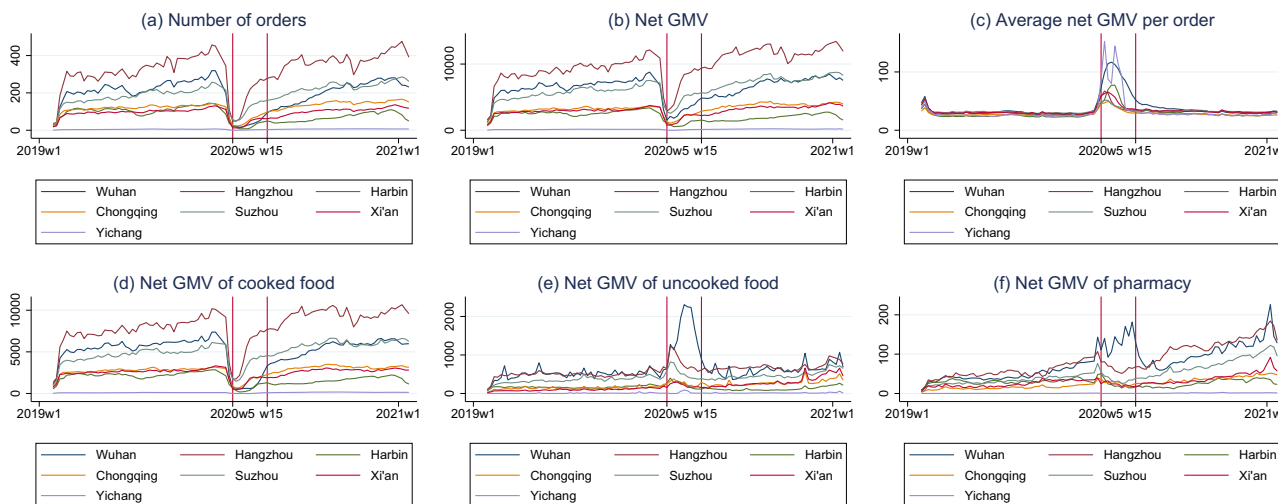


Fig. 2 Weekly overall operation performance by product category. **a-f** display the weekly overall operation performance for each city with measures such as number of orders, net GMV, average net GMV per order, net GMV of cooked food, net GMV of uncooked food, and net GMV of pharmacy. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively. The numbers of orders in **(a)** is given in 1000. The net GMVs in **(b), (d-f)** are given in 1000 RMB. The weekly overall operation performances in **(a-f)** are only for selected samples in each city.

which was a rather different situation than that in cities that were not under complete lockdown. In the postlockdown period, the net GMV of both uncooked food and pharmacy items continued to grow and exceeded prepandemic levels. The average GMV per order is a proxy for quantity per order because nominal prices are usually sticky in retail industries and GMV is measured by nominal value. The average GMV per order increased in all cities, indicating that consumers consolidated their orders.

Average individual shop operation performance. During Wuhan’s lockdown, the weekly average number of shop orders and the

weekly average ratio of subsidies to the GMV decreased (Fig. 3). In contrast, the weekly average shop net GMV, weekly average GMV per order and weekly average number of shop SKUs increased. Although consumers placed fewer orders, they received fewer price discounts, purchased more per order and spent more money on digital food delivery.

Business strategies of chain stores and multiapp stores. Figure 4 shows that average chain stores performed better than independent stores in terms of the number of orders, net GMV and average GMV per order, while multiapp stores performed better

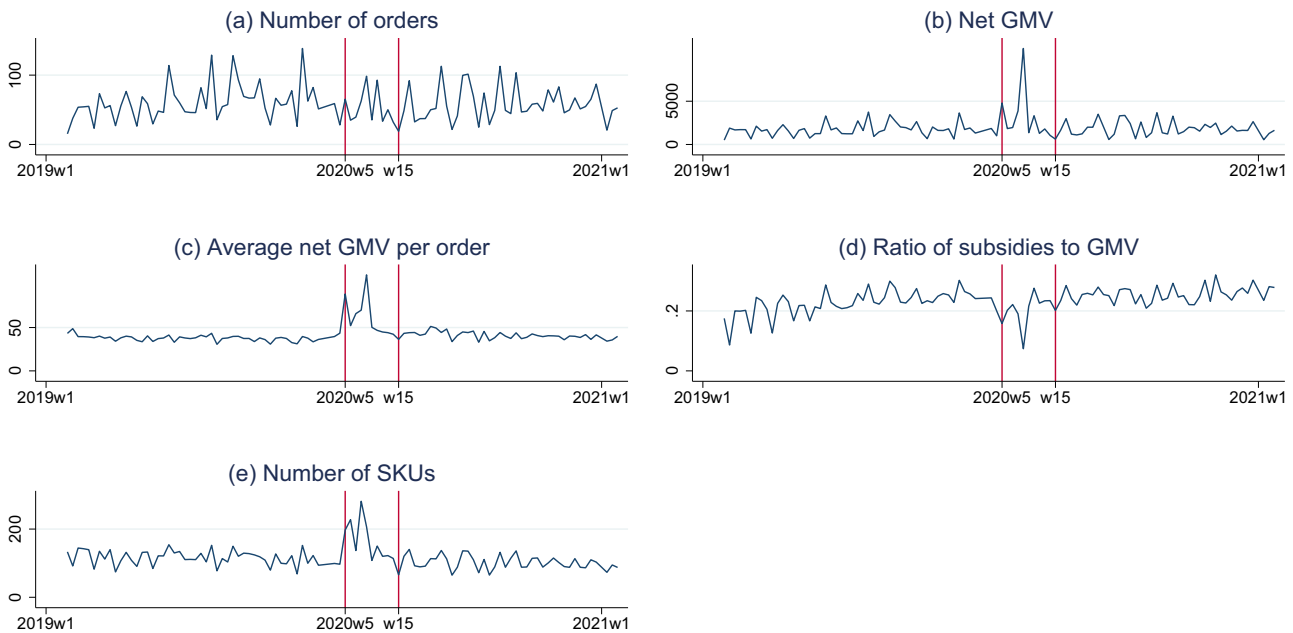


Fig. 3 Weekly average shop operation performance. a–e display the weekly average shop operation performance, with measures such as number of orders, net GMV, average net GMV per order, ratio of subsidies to GMV, and number of SKUs. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively.

than stores listed on Ele.me in terms of number of orders, net GMV and average GMV per order. Chain stores offered more price discounts (a higher ratio of subsidies to GMV) and more product variety (a higher number of SKUs) than independent stores, while multiapp stores offered fewer price discounts (a lower ratio of subsidies to GMV) and more product variety (a higher number of SKUs) than stores listed on Ele.me only.

Empirical models

Empirical analysis for entrants, number of agents, and overall performance. We postulated Eq. (1) to estimate the impact of the COVID-19 pandemic lockdown on shop entry and platform agents under different containment policies:

$$\begin{aligned}
 Y_{mt} = & \beta_{1m} \text{Lockdown}_{mt} + \beta_{2m} \text{Lockdown}_{mt} * \text{Time}_{mt} \\
 & + \beta_{3m} \text{Lockdown}_{mt} * \text{Time}_{mt}^2 + \beta_{4m} \text{Post}_{mt} \\
 & + \beta_{5m} \text{Post}_{mt} * \text{Time_post}_{mt} + \beta_{6m} \text{Post}_{mt} * \text{Time_post}_{mt}^2 \\
 & + \beta_7 \text{NewCase}_{mt} + \text{District}_m + \text{Week}_t + \varepsilon_{mt}
 \end{aligned}
 \tag{1}$$

where the subscripts *m* and *t* represent city-district and week, respectively. $Y_{m,t}$ is a set of proxy variables for platform entries, such as the logarithm of the number of entrants, the share of entrants of a given type (for example, being a chain store, being an independent store, being a multiapp store, being listed on Ele.me only, offering cooked food, offering uncooked food and offering pharmacy items), the logarithm of the number of agents (for example, shops, active users, and riders) in district *m* at time *t* and the share of a given type.

Lockdown_{mt} is a dummy variable that takes a value of 1 if city district *m* at time *t* is under a corresponding containment policy implemented in the city.

Time_{mt} is the number of weeks since a containment policy takes effect.

Post_{mt} takes a value of 1 if time *t* is in the postlockdown period.

Time_post_{mt} is the number of weeks since a containment policy is lifted.

NewCase_{mt} is the logarithm of the number of new COVID-19 infections in the city.

District_m is a vector of city-district fixed effects, controlling for time-invariant district-specific factors, such as districts with higher average income or population.

Week_t is a vector of weekly fixed effects, controlling for week-specific effects, such as holidays, when consumption patterns are considerably different from those of other weeks.

ε_{mt} is a random error component.

In Eq. (1), $\beta_{1m} \text{Lockdown}_{mt} + \beta_{2m} \text{Lockdown}_{mt} * \text{Time}_{mt} + \beta_{3m} \text{Lockdown}_{mt} * \text{Time}_{mt}^2 + \beta_{4m} \text{Post}_{mt} + \beta_{5m} \text{Post}_{mt} * \text{Time_post}_{mt} + \beta_{6m} \text{Post}_{mt} * \text{Time_post}_{mt}^2$ is the estimated containment policy time effect in city district *m* at time *t* for cities with a containment policy. For Xi’an, which has never experienced any containment policy, the estimated policy time effects are $\beta_{1m} \text{Lockdown}_{mt} + \beta_{2m} \text{Lockdown}_{mt} * \text{Time}_{mt} + \beta_{3m} \text{Lockdown}_{mt} * \text{Time}_{mt}^2$, where Lockdown_{mt} equals 1 during Wuhan’s lockdown. We used the interaction of containment-policy dummies with linear and quadratic time trends rather than containment-policy dummies to characterize the dynamic time evolution of policy effects. The control variables are the logarithm of the number of new cases in the city, city-district fixed effects and weekly fixed effects. We employed a quadratic time trend as a reasonably parsimonious parametric specification to track the potential nonlinearity contained in the variables. A quadratic time trend can capture that the value of a time series may rise or fall at a nonconstant rate. The impact of containment policies does not always increase or decrease over time. The marginal impact of containment policies is likely to attenuate, especially as merchants, consumers and the platform gradually adapt to containment policies. We also attempted to use the linear or cubic time trend to estimate policy effects. The linear time trend was not sufficient to display the complexity of the containment policies over time, and the results of the cubic time trend were very close to those of the quadratic time trend.

We estimated regression Eq. (1) using city-district-week-level data for each city and displayed the estimated policy-time effects and their corresponding 95% confidence intervals in Figs. 5 and 6.

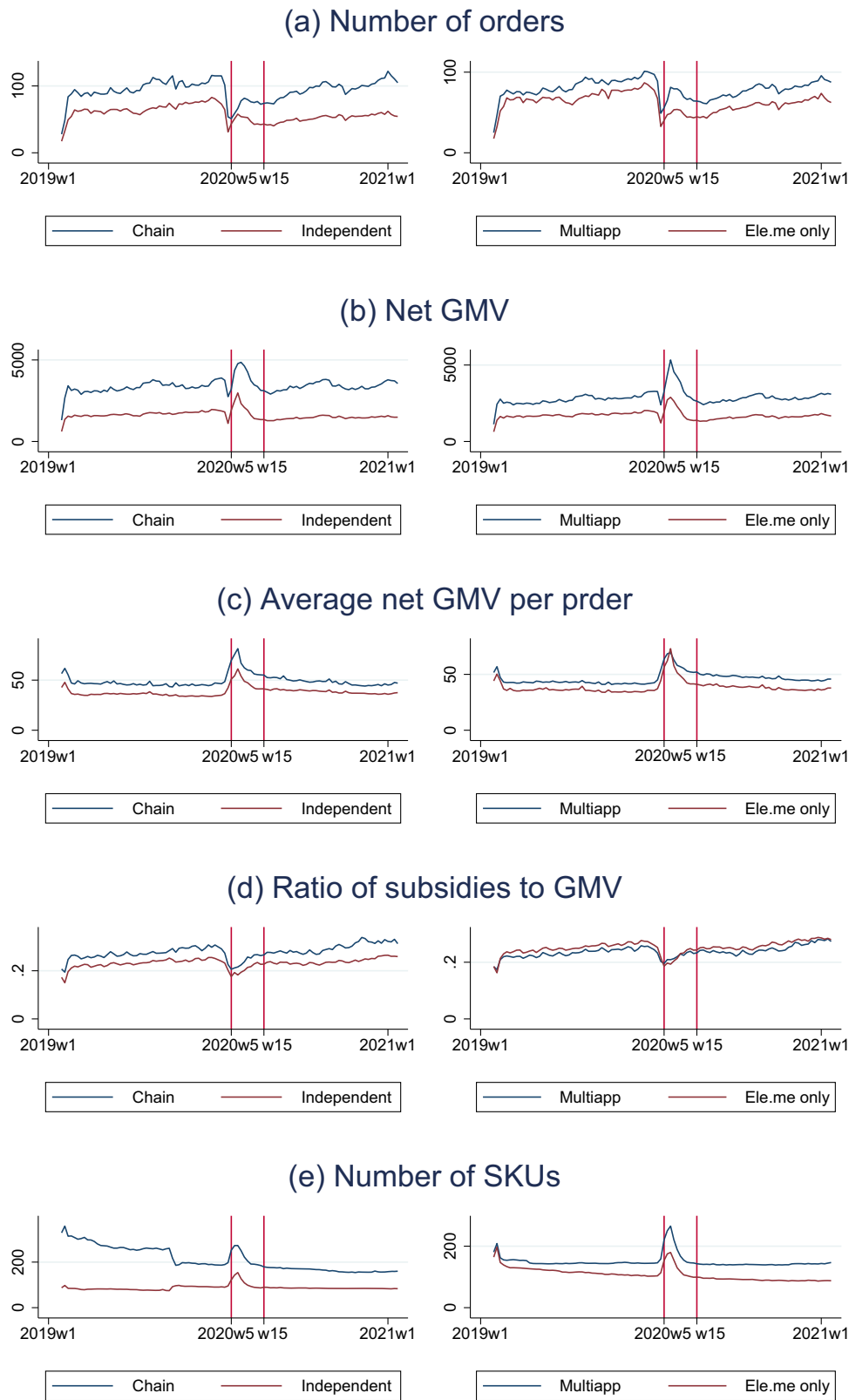


Fig. 4 Weekly average shop operation performance by shop type. a-e display the weekly average shop operation performance for different shop types, with measures such as number of orders, net GMV, average net GMV per order, ratio of subsidies to GMV, and number of SKUs. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively. “2019w1” and “2021w1” refer to the 1st week in 2019 and the 1st week in 2021, respectively.

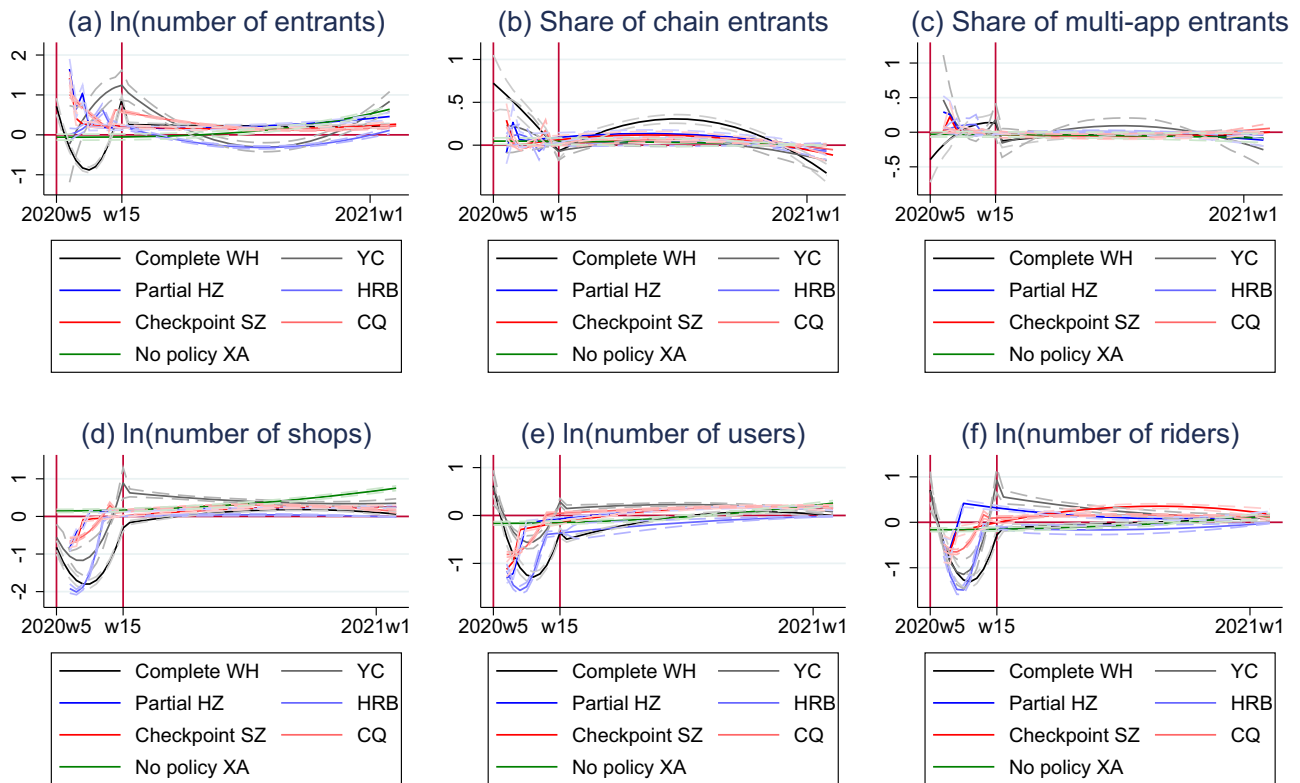


Fig. 5 Regression-estimated containment policy effects (solid lines) on shop entrants and number of shops, users and riders with 95% confidence intervals (dashed lines). a-f display the regression-estimated policy effects on the following dependent variables at the district-week level: logarithm of the number of entrants, the share of chain store entrants, the share of multiapp (Koubei) entrants, the logarithm of the number of active shops, active users, and delivery riders. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively. Complete WH and YC denote the policy effects of complete lockdown in Wuhan and Yichang, respectively. Partial HZ and HRB denote the policy effects of partial lockdown in Hangzhou and Harbin, respectively. Checkpoint SZ and CQ denote the policy effects of checkpoints in Suzhou and Chongqing, respectively. No policy XA denotes Xi’an which did not have any containment policy. Please refer to the “Materials and methods” section for policy and control variables and regression specifications.

We plotted the estimated policy effects rather than presenting the estimated parameters in tables because we included quadratic time trends, which made it difficult for the reader to determine the size and sign of policy effects for a given time period.

Empirical analysis for individual merchants. Using Eq. (2), we estimated the impact of the COVID-19 lockdown on individual merchants and how the impact varies with shop characteristics such as chain stores, the size of the network for chain stores and multiapp stores:

$$\begin{aligned}
 Y_{imt} = & \beta_{1m} \text{Lockdown}_{mt} + \beta_{2m} \text{Lockdown}_{mt} * \text{Time}_{mt} \\
 & + \beta_{3m} \text{Lockdown}_{mt} * \text{Time}_{mt}^2 + \beta_{4m} \text{Post}_{mt} \\
 & + \beta_{5m} \text{Post}_{mt} * \text{Time_post}_{mt} + \beta_{6m} \text{Post}_{mt} * \text{Time_post}_{mt}^2 \\
 & + \beta_7 \text{NewCase}_{mt} + \gamma_1 \text{ShopCharacteristics}_{imt} \\
 & + \gamma_2 \text{DNE}_{imt} + \gamma_4 \text{Lockdown}_{mt} * \text{Shop}_{imt} \\
 & + \gamma_5 \text{Post}_{mt} * \text{Shop}_{imt} + \text{Shop}_i + \text{Week}_t + \epsilon_{imt}
 \end{aligned}
 \tag{2}$$

where the subscripts i , m , and t represent shop, city district and week, respectively.

Y_{imt} is a set of proxy variables for shop operation performance entries, such as the logarithm of the number of orders, logarithm of net GMV, average net GMV per order, number of SKUs and ratio of subsidies to GMV. NewCase_{mt} is the logarithm of the number of new COVID-19 cases in a city. $\text{ShopCharacteristics}_{imt}$ is a vector of time-varying shop characteristics, including shop rating, which

ranges from 0 to 5; shop age in terms of weeks since the shop was listed on the platform; the size of a chain network if the shop is a chain store; and a dummy variable if the shop is a chain store. DNE_{imt} is the logarithm of the number of shops in the same city district as shop i , measuring the direct network effect, which is the difference between the spillover and competition effects. Shop_{imt} is a vector of shop characteristics such as a dummy variable for if the shop is a chain store, the size of a chain network if the shop is a chain store and a dummy variable for if the store is a multiapp store. Shop_i is a vector of shop fixed effects that controls for time-invariant shop-specific factors, such as shop location. Week_t is a vector of weekly fixed effects, controlling for week-specific effects, such as holidays, when consumption patterns are significantly different from those of weeks. ϵ_{imt} is a random error component.

We ran regressions using Eq. (2) with shop-week-level data for each city and displayed the estimated policy time effects and their corresponding 95% confidence intervals in Fig. 7.

Business strategies of chain stores and multiapp stores. Using Eq. (3), we estimated the impact of COVID-19 on individual merchants and how the impact varies with two business strategies, chain stores and multiapp stores, measured by an indicator of chain stores (or the size of the network for chain stores) and an indicator of multiapp stores, respectively:

$$\begin{aligned}
 Y_{imt} = & \gamma_1 \text{ShopCharacteristics}_{imt} + \gamma_2 \text{Post_WH}_{mt} * \text{Shop}_{imt} \\
 & + \gamma_3 \text{Lockdown_WH}_{mt} * \text{Shop}_{imt} + \text{Shop}_i \\
 & + \text{DistrictWeek}_{mt} + \epsilon_{imt}
 \end{aligned}
 \tag{3}$$

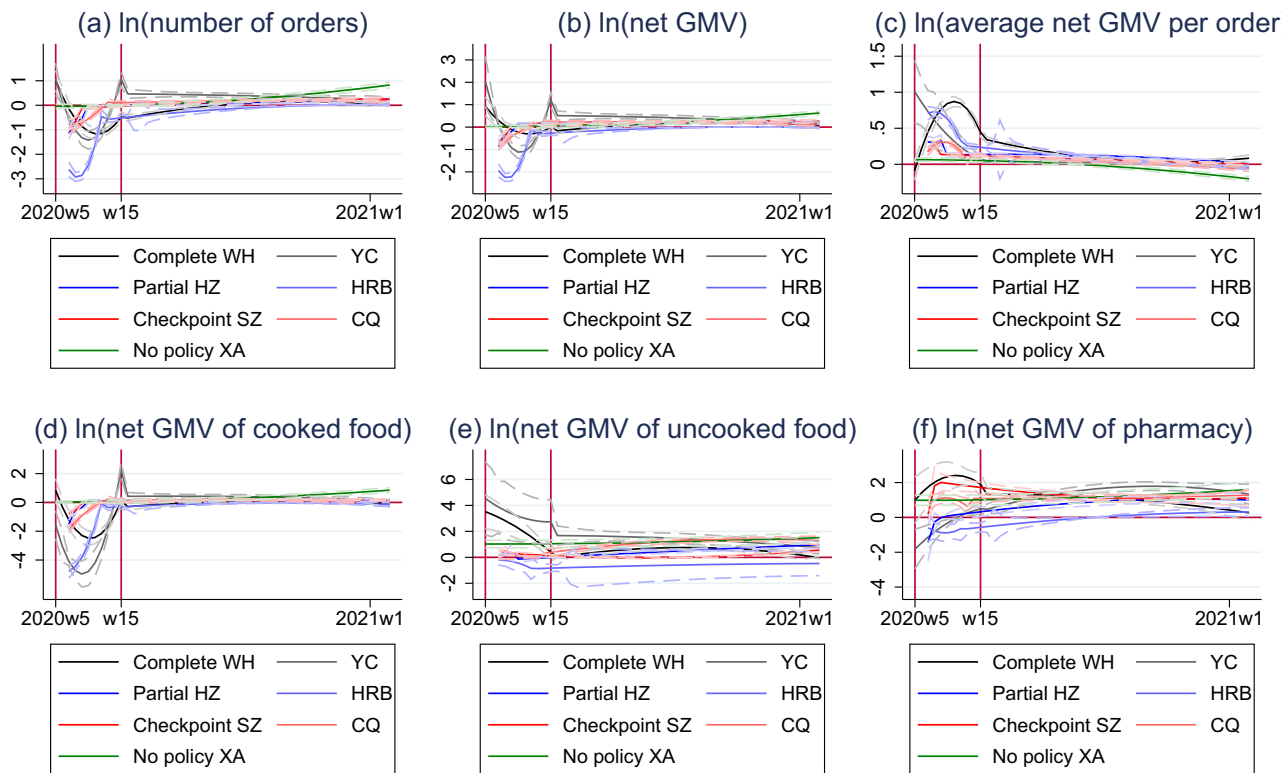


Fig. 6 Regression-estimated containment policy effects (solid lines) on overall operation performance with 95% confidence intervals (dashed lines). a–f display the regression-estimated policy effects on the respective dependent variables at the district-week level: logarithm of the number of orders, the logarithm of net GMV (Gross Merchandise Volume); logarithm of average GMV per order; and logarithm of net GMV of cooked food, uncooked food and nonfood grocery. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively. Complete WH and YC denote the policy effects of complete lockdown in Wuhan and Yichang, respectively. Partial HZ and HRB denote the policy effects of partial lockdown in Hangzhou and Harbin, respectively. Checkpoint SZ and CQ denote the policy effects of checkpoints in Suzhou and Chongqing, respectively. Please refer to the “Materials and methods” section for policy and control variables and regression specifications.

where the subscripts i , m , and t represent shop, city district, and week, respectively.

Lockdown_{WH_{mt}} is a dummy variable that takes a value of 1 if city district m at time t was during Wuhan’s lockdown period.

Post_{WH_{mt}} takes a value of 1 if time t is in the postlockdown period.

DistrictWeek_{mt} is a vector of district-week fixed effects, controlling for unobserved district-week-specific effects such as district-week-specific containment policies and temporary demand reduction in a central business district during holidays.

We ran regressions using Eq. (3) with shop-week-level data for all cities and displayed the results in Table 1.

Results

We examined the impact of various containment policies on the number of entrants, platform agents, overall operational performance in a market, operational performance of individual shops and the two business strategies in sequence. The cities under complete lockdown policies (i.e., Wuhan and Yichang), partial lockdown policies (i.e., Hangzhou and Harbin) or checkpoints (i.e., Suzhou and Chongqing) comprised the treatment group, and the remaining city (i.e., Xi’an) was considered the control group. Figures 5–7 display the estimated containment policy effects from Eqs. (1) and (2).

Impacts of containment policies on digitalization and platform agents. In Wuhan, which was under complete lockdown, the number of entrants (Fig. 5a) peaked immediately after the lockdown but plummeted by 58% in late February. This business shrinkage on the extensive margin (which refers to the

number of shops or entrants in this study) was due to the complete lockdown policy that ended all private and public transportation. In Yichang, which is a small city that was also under complete lockdown even though the pandemic situation was as not as serious as that in Wuhan, the number of entrants rose gradually during Wuhan’s lockdown. In cities under partial or checkpoint lockdowns, the number of entrants increased dramatically at the beginning of the lockdown and then declined gradually. This illustrates that only milder containment restrictions, i.e., partial or checkpoint lockdowns, helped accelerate digitalization. The share of chain entrants (Fig. 5b) increased most of the time in all cities, especially in those under complete lockdown. The economic advantages of such entrants, such as stable supply channels and discounts through centralized bulk purchases, make them less vulnerable than independent stores, as chain stores can quickly adapt to market disruptions. During lockdown, the share of multiapp entrants (Fig. 5c) increased (except at the beginning of the complete lockdown). Stores listed on Koubei, which were already digitalized or mainly focused on offline services, were more likely to become multiapp or multichannel shops to gain additional exposure to online consumers by joining Ele.me.

Figure 5d–f shows the comovements of shops, users and delivery riders on the Ele.me platform and show that the number of shops, active users, and delivery riders declined during lockdown. In particular, cities under complete lockdown took longer to recover than those under milder containment restrictions.

Impacts of containment policies on overall operation performance. The number of orders and the net GMV at the district

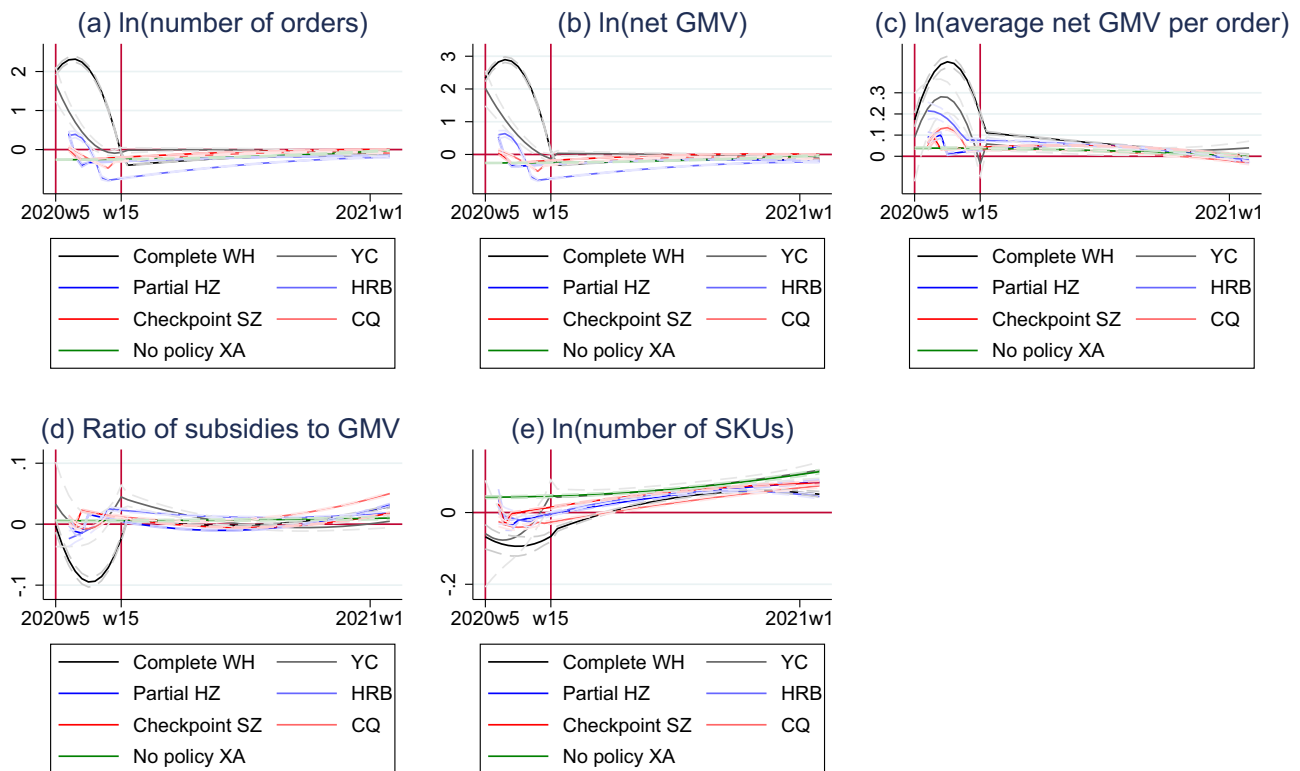


Fig. 7 Regression-estimated containment policy effects (solid lines) on individual shops with 95% confidence intervals (dashed lines). a–e display the regression-estimated policy effects on the respective dependent variables at the shop-week level: logarithm of the number of orders; the logarithm of net GMV; and logarithm of GMV per order, the ratio of subsidy to net GMV, the logarithm of the number of SKUs, the logarithm of the number of shops. “2020w5” and “w15” refer to the first and last week of the lockdown of Wuhan, which are the 5th week in 2020 and the 15th week in 2020, respectively. Complete WH and YC denote the policy effects of complete lockdown in Wuhan and Yichang, respectively. Partial HZ and HRB denote the policy effects of partial lockdown in Hangzhou and Harbin, respectively. Checkpoint SZ and CQ denote the policy effects of checkpoints in Suzhou and Chongqing, respectively. No policy XA denotes Xi’an which did not have any containment policy. Please refer to the “Materials and methods” section for policy and control variables and regression specifications.

level (Fig. 6a, b) in cities with partial or checkpoints recovered almost immediately after lockdowns. It took Wuhan city much longer to reach its pre-pandemic levels under complete lockdown, and it did not recover to the pre-pandemic net GMV until early May. The average net GMV per order (Fig. 6c) is a proxy for quantity per order, as explained in the “Nonmodel facts” section. The average net GMV per order during the complete lockdown was 195% of the pre-pandemic level. Consumers either combined orders or made large orders during lockdown, which may have been due to a decrease in offline logistics capacity (Han et al. 2022), caused by a reduction in the number of delivery riders (Fig. 5f) and consumers’ intention to reduce their level of physical contact with others and/or engage in stockpiling. As the GMV per order tends to be directly proportional to merchant profit, this increase during the lockdown period may have compensated for the decline in net GMV and orders. Stockpiling behavior was more pronounced in cities with stricter lockdown policies.

Under lockdown—especially complete lockdown—stay-at-home consumers tended to purchase less cooked food but more uncooked food and nonfood groceries (Fig. 6d–f). The sign of the estimated policy effects on the net GMV in the cooked food sector turned positive in Wuhan (a city with complete lockdown), Hangzhou (a city with partial lockdown) and Suzhou (a city with checkpoints) in the 27th, 10th and 14th weeks of 2020, respectively. However, it took longer for online services, particularly in the cooked food sector, to recover in cities under complete lockdown than in other cities (Fig. 6d). Therefore, lifting the lockdown immediately relieved the fear.

Impacts of containment policies on individual shops. Spikes in the number of orders, net GMV, and average net GMV per order of individual shops that remained open (Fig. 7a–c) indicate that average demand per seller rose sharply during the lockdown period on the intensive margin (which refers to the amount within a given extensive margin, i.e., an individual shop in this study), implying that the reduction in the number of shops within a district on the extensive margin (Fig. 5d) outweighed that in the net GMV (Fig. 6b). The high average net GMV per order (Fig. 6c) during lockdown was likely due to consumer consolidation of orders. Therefore, net GMV, which is the difference between total GMV and subsidies, is a better measure of operational performance than the number of orders. The ratio of subsidies to the GMV—which is a measure of price discounts—decreased in Wuhan during lockdown (Fig. 7d). Merchants who continued their operations faced cost escalations and weak competition (Raj et al. 2023). The number of SKUs (Fig. 7e) can be used to measure product variety or service quality, reflecting a shop’s willingness to meet the various demands of heterogeneous consumers. At the beginning of the pandemic, the number of SKUs dropped for almost all cities except for the city with no containment policy. This trend was particularly evident in cities with strict containment regulations. This was likely due to supply chain disruptions during the lockdown. The number of SKUs gradually increased after the lockdown, particularly in cities with no containment policies. While the number of SKUs dropped for the shops that remained open during Wuhan’s lockdown (Fig. 7e), those that remained open still offered an above-average number of SKUs

Table 3 Impact of two business strategies on operation performance of individual merchants coping with COVID-19.

Dependent variable	ln(number of orders) (1)	ln(net GMV) (2)	ln(average net GMV per order) (3)	The ratio of subsidies to GMV (4)	ln(number of SKUs) (5)
Panel A					
Business strategy 1: chain store					
Dummy of a chain store*Wuhan's lockdown	0.042*** (0.005)	0.073*** (0.006)	0.024*** (0.002)	-0.004*** (0.001)	0.041*** (0.002)
Dummy of a chain store*post Wuhan's lockdown	0.113*** (0.003)	0.123*** (0.004)	0.004*** (0.001)	0.001*** (0.000)	0.061*** (0.001)
Shop characteristics					
Shop rating score	0.127*** (0.001)	0.163*** (0.001)	0.005*** (0.000)	0.003*** (0.000)	0.007*** (0.000)
ln(shop age (weeks))	-0.077*** (0.001)	-0.067*** (0.001)	0.006*** (0.000)	-0.017*** (0.000)	0.031*** (0.000)
ln(number of chains in a district)	0.045*** (0.004)	0.053*** (0.005)	0.003* (0.001)	0.004*** (0.001)	0.012*** (0.001)
Dummy of a chain store	0.032*** (0.006)	0.027*** (0.007)	0.004*** (0.002)	0.007*** (0.001)	-0.025*** (0.002)
Robustness check for business strategy 1: chain store					
ln(number of chains in a district)*Wuhan's lockdown	0.045*** (0.005)	0.074*** (0.006)	0.029*** (0.002)	-0.001** (0.001)	0.035*** (0.002)
ln(number of chains in a district)*post-Wuhan's lockdown	0.091*** (0.003)	0.101*** (0.003)	0.008*** (0.001)	0.002*** (0.000)	0.045*** (0.001)
Panel B					
Business strategy 2: multi-app store					
Dummy of a multi-app store*Wuhan's lockdown	0.083*** (0.005)	0.097*** (0.006)	0.016*** (0.002)	0.007*** (0.001)	0.020*** (0.002)
Dummy of a multi-app store*post Wuhan's lockdown	0.118*** (0.003)	0.129*** (0.003)	0.005*** (0.001)	0.003*** (0.001)	0.055*** (0.001)
Shop fixed effects	Yes	Yes	Yes	Yes	Yes
District-week fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	≥1,000,000				

Standard errors are in parentheses. ***, ** and * represent significant at the 1%, 5% and 10% levels, respectively. Observations are at the shop-week level. Control variables include shop characteristics and the same-side network effects measured by the logarithm of the number of shops in a city-district.

compared with other shops that had closed (Fig. 3e). In other words, only some large stores offering various products remained open during Wuhan's lockdown, but they had to reduce their product variety, likely because of the disruption of supply chains.

Impacts of chain stores and multiapp stores' business strategies on business sustainability. Furthermore, we examined two business strategies related to a store's connectivity with other outlets within the economic ecosystem: chain stores (Glaeser et al. 2021) and multiapp stores (Table 3). Chain stores had a larger number of orders, a higher net GMV and larger GMV per order during and after lockdown, especially those with a large chain network, as measured by the number of shops of the same chain brand in a district. This finding indicates that chain stores showed stronger resilience and business sustainability than independent stores, aided by more robust supply chains and greater brand recognition. Specifically, joining a chain store raised a shop's net GMV by 7.6% during lockdown and by 13.1% after lockdown. Multiapp stores also showed greater business sustainability, as better access to another digital platform softened the adverse impacts of lockdown. Specifically, becoming a multiapp store

raised a shop's net GMV, on average, by 10.2% during lockdown and by 13.8% after it.

Table 4 shows how the effectiveness of chain stores' business strategy varied across broad shop categories. The chain store strategy significantly increased the number of orders and net GMV in most product categories, except for cooked food during Wuhan's lockdown and uncooked food postlockdown. One possible explanation is that the supply chain advantage of chain stores only comes into effect when the demand in a market reaches a certain threshold. For example, during Wuhan's lockdown, many consumers chose to cook at home; thus, the demand for cooked food became so low that chain stores had no cost advantage (Fig. 2). Similarly, after Wuhan's lockdown, many consumers returned to their workplaces, and the demand for uncooked food dropped sharply below the threshold (Fig. 2).

Table 5 shows how the effectiveness of the business strategy of multiapp stores varied across broad shop categories. For example, after Wuhan's lockdown, a multiapp store usually had a higher number of orders or a higher net GMV, except for uncooked food post-Wuhan's lockdown. One explanation is the 'revenge' consumption for in-person dining after 2 months of cooking at home, which was likely for Koubei stores.

Table 4 Impact of chain store strategy on operation performance of individual merchants coping with COVID-19 by product category.

Dependent variable	In(number of orders) (1)	In(net GMV) (2)	In(average net GMV per order) (3)	Ratio of subsidies to GMV (4)	In(number of SKUs) (5)
Dummy of cooked food*dummy of a chain store*Wuhan's lockdown	-0.058*** (0.007)	-0.042*** (0.008)	0.016*** (0.002)	0.003*** (0.001)	0.013*** (0.002)
Dummy of cooked food*dummy of a chain store*post Wuhan's lockdown	0.078*** (0.004)	0.073*** (0.004)	0.004*** (0.001)	0.009*** (0.000)	0.123*** (0.001)
Dummy of uncooked food*dummy of a chain store*Wuhan's lockdown	0.071*** (0.007)	0.169*** (0.008)	0.084*** (0.003)	-0.015*** (0.001)	0.050*** (0.002)
Dummy of uncooked food*dummy of a chain store*post Wuhan's lockdown	-0.045*** (0.004)	0.010* (0.005)	0.022*** (0.001)	-0.018*** (0.001)	-0.021*** (0.001)
Dummy of pharmacy*dummy of a chain store*Wuhan's lockdown	0.057*** (0.010)	0.079*** (0.012)	0.032*** (0.004)	-0.006*** (0.001)	-0.050*** (0.004)
Dummy of pharmacy*dummy of a chain store*post Wuhan's lockdown	0.172*** (0.006)	0.196*** (0.007)	0.036*** (0.002)	0.016*** (0.001)	-0.105*** (0.002)
Dummy of others*dummy of a chain store*Wuhan's lockdown	0.196*** (0.010)	0.124*** (0.011)	-0.055*** (0.003)	0.020*** (0.001)	0.083*** (0.003)
Dummy of others*dummy of a chain store*post Wuhan's lockdown	0.278*** (0.005)	0.274*** (0.006)	-0.028*** (0.002)	0.006*** (0.001)	0.091*** (0.002)
Shop fixed effects	Yes	Yes	Yes	Yes	Yes
District-week fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	≥1,000,000				

Standard errors are in parentheses. ***, **, * and * represent significant at the 1%, 5% and 10% levels, respectively. Observations are at the shop-week level. Control variables include shop characteristics and same-side network effects measured by the logarithm of the number of shops in a city-district.

Table 5 Impact of multi-app store strategy on operation performance of individual merchants coping with COVID-19 by product category.

Dependent Variable	In(number of orders) (1)	In(net GMV) (2)	In(average net GMV per order) (3)	Ratio of subsidies to GMV (4)	In(number of SKUs) (5)
Dummy of cooked food*dummy of a chain store*Wuhan's lockdown	0.039*** (0.006)	0.051*** (0.007)	0.013*** (0.002)	0.006*** (0.001)	-0.001 (0.002)
Dummy of cooked food*dummy of a chain store*post Wuhan's lockdown	0.103*** (0.003)	0.113*** (0.004)	0.007*** (0.001)	0.005*** (0.000)	0.058*** (0.001)
Dummy of uncooked food*dummy of a chain store*Wuhan's lockdown	0.122*** (0.010)	0.241*** (0.012)	0.104*** (0.004)	-0.015*** (0.001)	0.062*** (0.004)
Dummy of uncooked food*dummy of a chain store*post Wuhan's lockdown	-0.054*** (0.006)	0.002 (0.007)	0.030*** (0.002)	-0.029*** (0.001)	-0.028*** (0.002)
Dummy of pharmacy*dummy of a chain store*Wuhan's lockdown	0.260*** (0.046)	0.408*** (0.054)	0.111*** (0.016)	-0.014** (0.006)	-0.393*** (0.016)
Dummy of pharmacy*dummy of a chain store*post Wuhan's lockdown	0.807*** (0.028)	0.882*** (0.034)	0.043*** (0.010)	0.008** (0.004)	-0.486*** (0.010)
Dummy of others*dummy of a chain store*Wuhan's lockdown	0.200*** (0.009)	0.134*** (0.011)	-0.044*** (0.003)	0.024*** (0.001)	0.069*** (0.003)
Dummy of others*dummy of a chain store*post Wuhan's lockdown	0.270*** (0.005)	0.254*** (0.006)	-0.021*** (0.002)	0.010*** (0.001)	0.114*** (0.002)
Shop fixed effects	Yes	Yes	Yes	Yes	Yes
District-week fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	≥1,000,000				

Standard errors are in parentheses. ***, **, * and * represent significant at the 1%, 5% and 10% levels, respectively. Observations are at the shop-week level. Control variables include shop characteristics and same-side network effects measured by the logarithm of the number of shops in a city-district.

Discussion

Our findings show that a digital food delivery platform can help achieve the UN SDGs in the following ways. First, these digital platform support SDG target 2.c by ensuring the proper functioning of food commodity markets and stabilizing food prices. There was a significant increase in the total net GMV in the uncooked food sector both during and after lockdown. There was also a significant increase in the number of entrants listed on Koubei, which focused on dining services before lockdown but experienced an increase in the number of entrants in the uncooked food sector during and after lockdown. While most restaurants in the country were forced to pause their offline services during lockdown and for a short period afterwards, digital platforms assisted in the digitalization of MSMEs, ensuring the transactions of cooked and uncooked food. Second, such digital platforms contribute to SDG target 3.8 by expanding health coverage and facilitating access to quality essential health care services and medicines. There was a jump in the total net GMV in the pharmacy sector in Wuhan during the lockdown. Furthermore, digital platforms minimized the usage of bills and coins that were likely to carry the virus (Gardner 2020; Samantha 2020) by accepting only digital payments, thereby effectively preventing the spread of the virus. Third, such digital platforms are linked to SDG target 8.3, as they take advantage of big data technology, artificial intelligence and algorithms to improve productive activities, create decent jobs and encourage the formalization and growth of MSMEs. There was an increase in the number of shop entrants during, toward the end of, and after the lockdown. The shops present on such platforms provide jobs. The platforms themselves absorb a significant number of people who lost their jobs because of the pandemic.

Unlike other macroeconomic analyses that show or predict the overall damages under different policies across sectors and countries (Guan et al. 2020; Ludvigson et al. 2021), our analysis on containment policies is designed to identify the detailed impacts from the perspective of MSMEs, especially those in cooked food, uncooked food and pharmaceutical sectors.

Our study yields clear results and implications for policy-makers and merchants. First, our granular data from Ele.me highlight digitalization and heterogeneous industry dynamics during the pandemic. While the speed of digitalization before the pandemic was rather modest, after the immediate disruption caused by the pandemic, a sharp and full recovery to the level of the prepandemic period occurred within a year. The strictness of containment policies and sectors matters, which is consistent with the findings on pandemics and other shocks (Guan et al. 2020; Inoue and Todo 2019). A modest containment policy (i.e., partial or checkpoint lockdowns) may accelerate the digitalization of MSMEs; however, a complete lockdown policy is likely to cause a long-lasting negative impact on the economic ecosystem. Throughout the different phases of recovery, the observed data support the substantial benefits of digitalization among merchants, delivery riders and active users in the two-sided digital market. Digital takeout platforms helped stores (mainly offline) expand their online businesses during the epidemic. The online cooked food industry has been very slow to recover after lifting restrictions, partly because consumers have maintained their habit of buying uncooked food and nonfood groceries on the online platform during the epidemic recovery period. These findings suggest long-term scarring in the service sector and diminished business sustainability on the extensive margins (Guan et al. 2020).

Second, disruptions resulting from the pandemic have been more contagious than natural disasters such as earthquakes, floods and hurricanes (Brummitt et al. 2017; Inoue and Todo 2019; Carvalho et al. 2021) and have led to much larger negative

impacts. Governments could play a key role in internalizing contagious and spillover effects. The city with no containment policy, namely, Xi'an, was still substantially negatively affected, although it did not share borders with the other six examined cities. During lockdowns or other shocks, labor shortages, shortages in raw materials, supply chain interruptions, logistics disruptions, and transportation stoppages (Dai et al. 2021a, b) can spread contagiously from cities under the strictest containment policy to cities with less strict or no containment policy, even if these cities do not share borders.

Third, we emphasize sustainable development, especially the greater resilience of online MSMEs. On the intensive margin, specific business strategies, such as being a chain store or multiplatform go-live, could help online merchants—particularly MSMEs—remain sustainable and resilient in a world with large-scale aggregate shocks, such as lockdown risks arising from disasters. In addition, on the extensive margin, chain stores or multiapp stores were more likely to enter and survive on Alibaba's food delivery platform during lockdown. Chain stores, especially those with large networks, and multiplatform go-lives helped merchants effectively improve their business performance and contributed to postepidemic recovery.

Finally, governments can build a better ecosystem to incentivize firms to be more resilient. Resilience and sustainability are in line with International Standardization Organization (ISO) standards. For instance, governments should support the ISO standard for the business continuity management system (ISO 22301) to minimize the impact of disruptive incidents. To fully utilize the benefits of digitalization in the economy, the government should invest more in digital infrastructure, increase broadband and smartphone penetration and gain more experience in organizing transportation on the road for different digital transformations.

Conclusions

Our findings unveil diverse responses among merchants to the COVID-19 pandemic in relation to different containment policies in China. On the extensive side, stringent lockdown measures had a lasting impact on online merchants, resulting in a reduced number of new entrants, particularly in the cooked food industry. In contrast, on the intensive side, chain stores, particularly those with expansive network coverage or multiapp stores, displayed notable resilience compared to their counterparts both during and after lockdown. These outcomes highlight that specialization at the outlet level and broader network coverage are critical factors enabling business sustainability in challenging economic conditions.

Digital food delivery platforms help achieve the UN SDGs in middle-income countries by ensuring transactions of food commodities, facilitating access to quality health care services and essential medicines and creating jobs through technology. Better access to digital platforms with proper business strategies could help online merchants, especially MSMEs, survive in a world with lockdown risks. However, the government should be cautious about the strictest containment policies, the effects of which can be long-lasting and contagious.

This study has some limitations. First, we cannot compare the online economy with its offline counterpart. We do not have administrative data regarding the offline services provided by the merchants on this digital platform or those of other merchants who offer only offline services. Thus, it would be beneficial to observe and compare online services with offline services under proper controls. This issue should be addressed in future research. Second, we lack multihoming data because we only had access to the administrative data on Ele.me and could not access

the data of other digital food delivery platforms. Therefore, the issue of multihoming remains silent. Although our work has some inevitable limitations, we can promote greater usage of these administrative data and make them suitable for research on multiple platforms. In this regard, the government should promote data sharing for research purposes, conditional on proper management of individual information and confidentiality.

Data availability

The Alibaba datasets generated and analyzed during the current study are not publicly available due to the privacy laws of the People's Republic of China. However, Alibaba will maintain the original dataset in the server and provide access to the original dataset for those who apply. The datasets and all the programming codes used for this research are available through the corresponding author upon reasonable request, and after applying for permission to access Alibaba's server. To access the server, please follow the following two steps: write an email to the corresponding author, briefly stating your data request and proposing one or more time slots for server access; at the scheduled time, log in to the server via a temporary account provided by a server manager. The dataset on containment policies is included in this article as part of the Supplementary Information files.

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Author contributions

XZ, YS, MS and EST are all co-first authors. Conceptualization: XZ, YS, MS and EST; Methodology: XZ, YS, MS and EST; Investigation: XZ; Visualization: XZ; Project administration: EST; Supervision: YS and MS; Writing—original draft: XZ; Writing—review and editing: MS, YS, and EST.

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