WERE BORDER CONTROL MEASURES HELPFUL FOR CONTAINING COVID-19? A TIME-SERIES ANALYSIS

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ABSTRACT

This study aims to explore the impacts of COVID-19 border control policy on the number of confirmed imported and local cases in Taiwan. Poisson regression models were applied with the standard errors corrected through the Newey-West estimators for the weekly time series data from January 22, 2020, to April 1, 2022. The measurement of the stringency of border control measures was from the Oxford COVID-19 Government Response Tracker (OxCGRT). A structural break analysis was also conducted on time-series data to evaluate the relationship between border control measures and COVID-19 confirmed cases. The results show that stringent border control measures were associated with a reduction in imported COVID-19 cases. However, there was insufficient evidence to demonstrate the relationship between border control measures and the spread of local cases. Instead, this study found a lagged negative association between the stringency of the overall COVID-19 containment measures and the number of confirmed local cases, highlighting the importance of implementing additional community-level interventions after a local outbreak begins. The findings suggest that although border control measures were associated with the mitigation of cross-border viral transmission, particularly in

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geographically isolated places or countries like Taiwan, border control measures should be adopted proactively before the community transmission occurs. Once local transmission commenced, other community control measures are necessary alongside border control measures to prevent the spread of the pandemic locally.

KEYWORDS: *COVID-19, longitudinal studies, Taiwan, health policy, Poisson distribution*

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I. INTRODUCTION

The novel coronavirus pneumonia (hereinafter "SARS-CoV-2", or "COVID-19") pandemic has been a major focus globally since 2020. Taiwan stands out internationally for its pandemic prevention measures, resulting in a 253-day record of zero confirmed cases, and daily life remained relatively normal for residents,[1] despite Taiwan's frequent commercial trade with and location across the strait from China.

Before the Omicron variant of the virus entered Taiwan in early 2022, the pandemic remained stable in Taiwan. The number of confirmed cases per capita was much lower in Taiwan compared with the global average. As of April 1, 2022, the number of accumulated confirmed cases in Taiwan was 23,629,[2] accounting for about one-thousandth of the total Taiwanese population.[3] At the same time, the number of accumulated confirmed cases worldwide was 485 million,[4] accounting for about 6% of the global population.[5]

Some commentators have attributed Taiwan's epidemic prevention

[1] Li-Wei Huang & Lung-Hsiang Chiang, *Taiwan's Streak of Zero Local COVID-19 Cases Broken; Chen Shih-Chung Admits Feeling Disappointed in Interview*, PTS NEWS (Dec. 24, 2020), https://news.pts.org.tw/article/505789; Raymond Zhong, *How Taiwan Plans to Stay (Mostly) Covid-Free*, N.Y. TIMES (Aug. 23, 2021), https://www.nytimes.com/2021/01/02/world/asia/taiwan-coronavirus-health-minister.html.

[2] *Crucial Policies for Combating COVID-19*, MINISTRY OF HEALTH & WELFARE (Aug. 1, 2022), https://covid19.mohw.gov.tw/ch/sp-timeline0-205.html.

[3] *Overall Statistics Database*, NAT'L STAT. OF TAIWAN (2022), https://nstatdb.dgbas.gov.tw/dgbasall/webMain.aspx?k=dgmain.

[4] MINISTRY OF HEALTH & WELFARE, *supra* note 2.

[5] *World Population Dashboard*, U.N. POPULATION FUND (June 10, 2022), https://www.unfpa.org/data/world-population-dashboard.

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outcomes to the implementation of stricter border control measures.[6] However, no analysis has provided concrete empirical evidence to support whether the border control measures have led to the success of the pandemic control on this island. The impact of border control measures in controlling the pandemic is still understudied. Although a few studies mentioned the effects of border control, many indicated that the border control was ineffective or only effective if implemented at the initial stage.[7]

This study goes a step further to explain why border control measures were effective during the initial stage but had no impact later on by separating the COVID-19 confirmed cases into confirmed imported cases and local cases, and showing that border control was associated with a reduction in imported cases from abroad; however, similar patterns were not observed for local cases within communities. The aim of this study was to quantitatively analyze the relationship between the COVID-19 border control measures and the number of confirmed imported and local cases in order to provide empirical evidence of the impacts of the border control measures for policymakers.

Although the literature has indicated the importance of earlier and stronger border control measures to prevent COVID-19,[8] it has been challenging for studies to evaluate policies in the absence of suitable counterfactuals, particularly in exceptional cases like Taiwan's success in preventing COVID-19. This study addresses this limitation by employing a time-series approach, which offers a viable method for evaluating the border control policy in the absence of a counterfactual.

II. EVALUATIONS OF COVID-19 PREVENTION MEASURES

Numerous studies have evaluated the effects of government COVID-19 prevention measures. Studies have shown that stricter coercive measures are more effective in mitigating the spread of local epidemics.[9] Among all the

[6] Zhong, *supra* note 1.

[7] Jacqueline Cumming, *Going Hard and Early: Aotearoa New Zealand's Response to COVID-19*, 17(1) HEALTH ECON. POL'Y & L. 107, 107-08, 116 (2022); Karen Ann Grépin et al., *Effectiveness of International Border Control Measures During the COVID-19 Pandemic: A Narrative Synthesis of Published Systematic Reviews*, 381(2257) PHIL. TRANSACTION ROYAL SOC'Y A 1, 1-2 (2023); Mary A. Shiraef et al., *Did Border Closures Slow SARS-CoV-2?*, 12 SCI. REP. 1, 1 (2022).

[8] Cumming, *supra* note 7, at 107, 116-17; Jennifer Summers et al., *Potential Lessons from the Taiwan and New Zealand Health Responses to the COVID-19 Pandemic*, 4 LANCET REG'L HEALTH W. PAC. 1, 1-2 (2020).

[9] Ashwin Aravindakshan et al., *Preparing for a Future COVID-19 Wave: Insights and Limitations from a Data-Driven Evaluation of Non-Pharmaceutical Interventions in Germany*, 10 SCI. REP. 1, 1 (2020); Liana R. Woskie et al., *Early Social Distancing Policies in Europe, Changes in Mobility & COVID-19 Case Trajectories: Insights from Spring 2020*, 16(6) PLOS ONE 1, 1 (2021); Zongfeng Xiu et al., *Are Stringent Containment and Closure Policies Associated with a Lower COVID-19 Spread Rate? Global Evidence*, 19(3) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 1 (2022).

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policy measures, lockdown is thought to be the most significant measure.[10] However, citizens will sacrifice their freedom and economy during lockdown, and the effects are usually short-term and weaken in the long run.[11]

Mandatory wearing of masks and vaccination have, in contrast, long-term impacts in preventing and reducing the spread of the pandemic of COVID-19,[12] where mandatory wearing of masks and vaccination are more effective three weeks after policy implementation.[13]

However, the effects of policy measures mentioned in the literature are not necessarily consistent. For example, the implementation of home orders in the United States and California may be effective,[14] but had no significant effect across other countries.[15] Previous literature pointed out that better and cost-effective epidemic prevention outcomes can be achieved if different measures can be complemented with each other, including population-based measures (such as maintaining social distance or wearing masks) and case-based measures (contact tracing and quarantine).[16]

In addition to domestic measures, border control measures were frequently adopted in 2020 and 2021 to prevent confirmed cases from crossing the borders, as contact with overseas confirmed cases is the initial

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[10] Lucas Silva et al., *The Effect of Lockdown on the COVID-19 Epidemic in Brazil: Evidence from an Interrupted Time Series Design*, 36(10) CAD. SAÚDE PÚBLICA 1, 1 (2020); Winter M. Thayer et al., *An Interrupted Time Series Analysis of the Lockdown Policies in India: A National-Level Analysis of COVID-19 Incidence*, 36(5) HEALTH POL'Y & PLAN. 620, 621, 626 (2021); Rosario Megna, *Inferring a Cause-Effect Relationship Between Lockdown Restrictions and COVID-19 Pandemic Trend During the First Wave*, 125(11) HEALTH POL'Y 1,441, 1,441, 1,445 (2021).

[11] Steven R. Kraaijeveld, *COVID-19: Against a Lockdown Approach*, 13(2) ASIAN BIOETHICS REV. 195, 204 (2021); Siqin Wang et al., *Examining the Change of Human Mobility Adherent to Social Restriction Policies and Its Effect on COVID-19 Cases in Australia*, 17(21) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 1 (2020); Luca Bonacini et al., *Identifying Policy Challenges of COVID-19 in Hardly Reliable Data and Judging the Success of Lockdown Measures*, 34(1) J. POPULATION ECON. 275, 293, 295 (2021).

[12] Dhaval Adjodah et al., *Association Between COVID-19 Outcomes and Mask Mandates, Adherence, and Attitudes*, 16(6) PLOS ONE 1, 1 (2021); Wei Lyu & George L. Wehby, *Community Use of Face Masks and COVID-19: Evidence from a Natural Experiment of State Mandates in the US*, 39(8) HEALTH AFF. 1,419, 1,419 (2020); Chiara Reno et al., *The Impact of Health Policies and Vaccine Rollout on the COVID-19 Pandemic Waves in Italy*, 11(2) HEALTH POL'Y & TECH. 1, 6-7 (2022).

[13] Lyu & Wehby, *supra* note 12, at 1,419; Yun Li et al., *Phased Implementation of COVID-19 Vaccination: Rapid Assessment of Policy Adoption, Reach and Effectiveness to Protect the Most Vulnerable in the US*, 18(14) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 1 (2021).

[14] James H. Fowler et al., *Stay-at-Home Orders Associate with Subsequent Decreases in COVID-19 Cases and Fatalities in the United States*, 16(6) PLOS ONE 1, 1 (2021); Fatemeh Navazi et al., *The Effect of the Ontario Stay-at-Home Order on COVID-19 Third Wave Infections Including Vaccination Considerations: An Interrupted Time Series Analysis*, 17(4) PLOS ONE 1, 1 (2022).

[15] Seung-Hun Hong et al., *Effect of COVID-19 Non-Pharmaceutical Interventions and the Implications for Human Rights*, 18(1) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 6, 9 (2021).

[16] Ta-Chou Ng et al., *Comparison of Estimated Effectiveness of Case-Based and Population-Based Interventions on COVID-19 Containment in Taiwan*, 181(7) JAMA INTERNAL MED. 913, 913-14, (2021); Hong et al., *supra* note 15, at 1, 9.

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stage of local transmissions in countries without existing COVID-19 cases.[17] Studies have pointed out that strict early limitations on movement and high epidemic detection capabilities were associated with a reduction in pandemic infections and the delay of community spread.[18] On the contrary, the increase in the number of imported cases may cause the local outbreak.[19]

Although the literature has pointed out the importance of strict border control in containing the COVID-19 pandemic at the initial stage, border control measures are not necessarily always effective across countries. For example, Shiraef et al. found no evidence that border closures contributed to the spread of COVID-19 cases across 185 countries.[20] Why international travel bans have no significant impact in many countries was discussed,[21] but not fully explained. By taking advantage of disguising imported confirmed cases and local confirmed cases in the data, this study provides empirical evidence to explain why border control could be effective if implemented at the beginning of the pandemic in some places, but was not influential in other countries. This study evaluates the impact of border control by reasoning that international movement restrictions are associated with a reduction in imported confirmed cases, but this pattern was not evident for local cases. Thus, once local transmission begins, the government should adopt additional community prevention measures to contain the spread of the pandemic.

III. METHODS

A. Data

In this study, data on the number of confirmed COVID-19 cases in Taiwan were obtained from the Open Data Platform of the Centers for Disease Control and Prevention, Ministry of Health and Welfare.[22] The data analysis period was from January 22 (the 4th week), 2020, to April 1 (the 13th week), 2022, a total of 802 days (114 weeks). This study did not include data after April 2022 because the Omicron variant, which became

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[17] Yazhen Li et al., *Epidemiological Characteristics of COVID-19 Resurgence in Areas Initially Under Control*, 9 FRONTIERS IN PUB. HEALTH 1, 1-3 (2021).

[18] Timokleia Kousi et al., *COVID-19 Pandemic in Africa's Island Nations During the First 9 Months: A Descriptive Study of Variation in Patterns of Infection, Severe Disease, and Response Measures*, 7(3) BMJ GLOB. HEALTH 1, 1 (2022).

[19] Chuanliang Han et al., *Mechanisms of Recurrent Outbreak of COVID-19: A Model-Based Study*, 106(2) NONLINEAR DYNAMICS 1,169, 1,169 (2021).

[20] Shiraef et al., *supra* note 7, at 1, 4.

[21] Hong et al., *supra* note 15, at 10.

[22] *CDC Open Data Platform: COVID-19 (SARS-CoV-2) Dataset*, TAIWAN CTR. FOR DISEASE CONTROL (2022), https://data.cdc.gov.tw/dataset/?_tags_limit=0&tags=%E5%9A%B4%E9%87%8D%E7%89%B9%E6%AE%8A%E5%82%B3%E6%9F%93%E6%80%A7%E8%82%BA%E7%82%8E.

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predominant after 2022, is distinct from previous variants of the virus. Specifically, the Omicron variant is characterized by strong infectivity and a short incubation period, engendering difficulties in eliminating it from the community.[23] Therefore, instead of implementing the border control measures, the government of Taiwan claimed to incrementally co-exist with the virus and sought to control its spread through vaccination and herd immunity.[24] Thus, the strict border control measures were no longer enforced after the early months of 2022, rendering the inclusion of such period cases unnecessary in this study, which targets to evaluate the impacts of border control measures.

B. Poisson Regression Models

This study aims to estimate the relationship between the stringency of border control measures and the confirmed COVID-19 cases. Because the weekly number of confirmed COVID-19 cases constitutes countable data and contains numerous values of 0 (especially for confirmed local cases), Poisson regression models were applied.[25] Newey-West standard errors were applied to mitigate autocorrelation and heteroscedasticity arising from the error term of time series data.[26] The Poisson regression model applied to examine the strength of the border control measures on the number of confirmed imported cases is expressed as follows:

$$Y_t = \beta_0 + \alpha Y_{t-j} + \delta_t I_t + X_t \beta + \varepsilon_t \quad (1)$$

Y_t is the dependent variable, representing the number of confirmed imported cases. *t* indicates the time periods in weeks. The lagged dependent variables Y_{t-j} are also controlled for autocorrelation with the coefficient α. *j* denotes the order of the lagged variable, with *t-1* represents the first-order

[23] Hideo Tanaka et al., *Shorter Incubation Period Among COVID-19 Cases with the BA.1 Omicron Variant*, 19(10) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 1 (2022).

[24] Ping-Xi Liu, *Lee Ping-ying: Coexisting with the Virus Should Be Gradual; Experts Agree the Time Is Not Now*, LINE TODAY (Feb. 10, 2022, 10:53 AM), https://today.line.me/tw/v2/article/8n6DvWZ; Jun Qiu Zeng, *From "Zero COVID" to "Coexistence"?*, NEWTALK (May 16, 2022, 3:15 PM), https://newtalk.tw/news/view/2022-05-16/755617.

[25] Hye Won Chung et al., *Effects of Government Policies on the Spread of COVID-19 Worldwide*, 11 SCI. REP. 1, 1 (2021); Gyujin Heo et al., *Statistical Estimation of Effects of Implemented Government Policies on COVID-19 Situation in South Korea*, 18(4) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 5 (2021).

[26] Yousef Alimohamadi et al., *Effect of Social Distancing on COVID-19 Incidence and Mortality in Iran Since February 20 to May 13, 2020: An Interrupted Time Series Analysis*, 13 RISK MGMT. & HEALTHCARE POL'Y 1,695, 1,696 (2020); Jienchi Dorward et al., *The Impact of the COVID-19 Lockdown on HIV Care in 65 South African Primary Care Clinics: An Interrupted Time Series Analysis*, 8(3) LANCET HIV e158, e160 (2021); Adriana Poppe, *Impact of the Healthcare System, Macro Indicator, General Mandatory Quarantine, and Mask Obligation on COVID-19 Cases and Death in Six Latin American Countries: An Interrupted Time Series Study*, 8 FRONTIERS PUB. HEALTH 1, 4 (2020).

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lagged variable, and *t-2* represents the second-order lagged variable, and so on. I_t indicates the strength of the border control measures with coefficient δ, evaluated according to the C8 "International travel controls" variable of the Oxford COVID-19 Government Response Tracker (hereinafter "OxCGRT"; Hale et al., 2021). In this study, lagged independent variables were included in the regression model to control for the delayed times of the border control measures. Because the lagged effects of COVID-19 prevention measures may persist for up to four weeks,[27] the analysis controlled for policy measures up to the previous three weeks (I_{t-1} to I_{t-3}).

X_t denotes the control variables that may affect the number of confirmed cases, including data on new confirmed cases globally, the number of inbound arrivals, and temperature.[28] Data on confirmed cases globally were obtained from the Our World in Data (2022);[29] the number of inbound arrivals data were obtained from the Taoyuan Airport Website;[30] and the temperature data were obtained from city-level information on AccuWeather's, which is used to control for temperature trends in Taiwan based on the temperature data for Taipei City.[31]

The Poisson regression model used for confirmed local cases was largely the same as that used for confirmed imported cases, but additionally controlled for the stringency of domestic pandemic prevention measures by using the Containment and Health Index as expressed in formula (2):

$$Y_t = \beta_0 + \alpha Y_{t-j} + \delta I_t + X_t\beta + \varepsilon_t \quad (2)$$

Y_t represents the number of confirmed local cases. Y_{t-j} indicates the lagged variables of the confirmed local and imported cases to control for the effect of the pandemic severity that occurred in the previous time periods.[32] I_t represents the policy measures, including the OxCGRT border control indicator (C8) and the Containment and Health Index, which ranges from 0 to 100 (higher values indicate stricter policies). The Containment and Health Index is measured on the basis of fourteen policy indicators, such as

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[27] Megna, *supra* note 10, at 1,441.

[28] Pierre Nguimkeu & Sosson Tadadjeu, *Why Is the Number of COVID-19 Cases Lower Than Expected in Sub-Saharan Africa? A Cross-Sectional Analysis of the Role of Demographic and Geographic Factors*, 138(2) WORLD DEV. 1, 4 (2021).

[29] *COVID-19 Dataset by Our World in Data - GitHub*, GITHUB (Sep. 3, 2022), https://github.com/owid/covid-19-data.

[30] *Passenger Volume*, TAOYUAN INT'L AIRPORT CORP. LTD. (2025), https://www.taoyuanairport.com.tw/passengervolume.

[31] *Taiwan Monthly Weather*, ACCUWEATHER (Aug. 24, 2022), https://www.accuweather.com/zh/tw/taipei-city/315078/january-weather/315078.

[32] Yaset Caicedo-Ochoa et al., *Effective Reproductive Number Estimation for Initial Stage of COVID-19 Pandemic in Latin American Countries*, 95 INT'L J. INFECTIOUS DISEASES 316, 317 (2020); Peter Congdon, *A Spatio-Temporal Autoregressive Model for Monitoring and Predicting COVID Infection Rates*, 24(4) J. GEOGRAPHICAL SYS. 583, 586, 597 (2022).

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school closures, contact tracing, and vaccination.[33] The fourteen policy indicators included in the Containment and Health Index are listed in Appendix Table 1. X_t denotes the control variables, as in the formula (1), but the number of inbound arrivals is not included in the Poisson regression due to convergence issues with Maximum likelihood estimation (MLE), which could possibly be due to limited sample size. As an alternative, this study includes the number of inbound arrivals in the regression for local cases using daily data, which provides a larger sample size, as a sensitivity analysis. The results remain robust regardless of whether the number of arrivals is included, as shown in Appendix Table 4-1 to Table 5-2.

C. Structural Break Analysis

To ensure the credibility of the Poisson regression models, structural break (structural change) analyses were constructed for triangulation.[34] Structural break analysis is one kind of time series analysis, which can be applied without a control group.[35] A structural break occurs when the entire time series does not have the same time series underlying features, but instead has two or more distinct subsamples with unique underlying series. A structural break may result from some endogenous reasons or from an exogenous shock, such as a historical event or a policy intervention, which can persistently affect the series of the data for a nontrivial amount of time.[36]

A structural break is related to a nonstationary series that has a unit root—a time series that does not return to a mean value. When the impact of an exogenous shock does not dissipate from the time series, a unit root occurs, and the series never reverts to a mean.[37] The time series of this study was tested by the Augmented Dickey-Fuller (hereinafter "ADF"), and the null hypothesis of having a unit root was not rejected. This represents the possibility of having structural changes.[38]

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[33] Toby Phillips, *Methodology for Calculating Indices*, OXCGRT (July 27, 2022), https://github.com/OxCGRT/covid-policy-tracker/blob/b051d4ae9878573a3ad8bd57540e64eab036aa56/documentation/index_methodology.md.

[34] Pei-Shan Liao et al., *Subjective Quality of Community Life: An Example of Data Triangulation*, 11 SURVEY RSCH.—METHOD & APPLICATION 105, 107 (2002); *An Introduction to Triangulation*, JOINT U.N. PROGRAMME ON HIV & AIDS [hereinafter UNAIDS] 14-15 (2010), https://www.unaids.org/sites/default/files/sub_landing/files/10_4-Intro-to-triangulation-MEF.pdf.

[35] James Lopez Bernal et al., *The Use of Controls in Interrupted Time Series Studies of Public Health Interventions*, 47(6) INT'L J. EPIDEMIOLOGY 2082, 2082 (2018); Ijeoma Edoka et al., *Free Health Care for Under-Fives, Expectant and Recent Mothers? Evaluating the Impact of Sierra Leone's Free Health Care Initiative*, 6(1) HEALTH ECON. REV. 1, 4, 12 (2016).

[36] JANET M. BOX-STEFFENSMEIER ET AL., TIME SERIES ANALYSIS FOR THE SOCIAL SCIENCES 65 (2014); Jonas Dehning et al., *Inferring Change Points in the Spread of COVID-19 Reveals the Effectiveness of Interventions*, 369(6500) SCI. 1, 1 (2020).

[37] BOX-STEFFENSMEIER ET AL., *supra* note 36, at 128-31.

[38] *Id*. at 132-33; SHIU-SHENG CHEN, TIME SERIES ANALYSIS: APPLICATIONS IN MACROECONOMICS AND FINANCIAL FINANCE 143, 169, 182 (2d ed. 2013).

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Similar to the ADF test that tests the existence of a unit root in the time series, the structural break analysis is used to test for the presence of a structural break in time-series data. Traditionally, scholars use the Chow test when a breakpoint is known by examining the null hypothesis of whether coefficients remain constant across subsamples of the time series before and after the breakpoint. If the null hypothesis is rejected, the existence of a structural break, which divides the subsamples to be characterized by different underlying time series, is supported.[39] Previous studies in health have applied the structural break analysis to test the impacts of policies, such as the effects of a free health care initiative,[40] COVID-19 outbreak containment interventions,[41] or an opioid abuse-deterrent formulation.[42]

In recent years, scholars have developed an alternative way of conducting structural break analysis. Instead of using the Chow test for a known structural break to compare the trends of the time series before and after the break, Bai and Perron (1998, 2003) use the Wald test and least squares to detect unknown breaks and determine the breakpoints in the time series to let the data speak for itself.[43] Several studies have used this technique to detect the breakpoints and examine the change in outcome before and after the breakpoints. The detected breakpoints can then be related to specific policy interventions so as to infer the effects of the policy interventions.[44] For example, Edoka et al. (2016) used the structural break analysis and found a shift in the intercept for key outcome variables around 2 months after the implementation of the free health care policy, suggesting the existence of the lagged effects of the policy.

This study applied structural break analysis to identify the breakpoints in the time series data by using a Wald test with the *estat sbsingle* command in STATA 15 software. The STATA command *estat sbsingle* can identify only one unknown breakpoint at a time, although more than one breakpoint may exist in the time series data. Therefore, this study adopts a sequential testing procedure, which firstly identifies one optimal breakpoint in the data. The second procedure is searching for the next optimal two breakpoints in the two partitions divided by the first breakpoint. Third, continuing to search for the next optimal breakpoints in the existing petitions until no breaks can be found.[45]

In this study, the time series was first split at the initially identified

[39] BOX-STEFFENSMEIER ET AL., *supra* note 36, at 66.
[40] Edoka et al., *supra* note 35, at 1.
[41] Dehning et al., *supra* note 36, at 1.
[42] William N. Evans et al., *How the Reformulation of OxyContin Ignited the Heroin Epidemic*, 101(1) REV. ECON. & STAT. 1, 1 (2019).
[43] BOX-STEFFENSMEIER ET AL., *supra* note 36, at 206-11.
[44] Edoka et al., *supra* note 35, at 4; Dehning et al., *supra* note 36, at 1, 2.
[45] Jushan Bai & Pierre Perron, *Computation and Analysis of Multiple Structural Change Models*, 18(1) J. APPLIED ECONOMETRICS 1, 2, 5-6 (2003); CHEN, *supra* note 38, at 179-80.

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breakpoint, and the procedure was subsequently repeated on each resulting segment to identify additional breakpoints within the two divided time segments. This process continued until the segments contained insufficient observations to detect additional breakpoints or the null hypothesis of no change was not rejected by the Wald test. Finally, the identified structural breaks were related to the key border control measures (Table 4) to infer the impacts of border control measures based on weekly data.[46] If the time point at which the breakpoint occurs overlaps with the time point at which a given policy measure was implemented, the change in the time trend of the number of confirmed cases is likely to be attributed to the policy measure, allowing inferences to be drawn regarding the effects of policy measure implementation on the number of confirmed cases.

As noted in the literature, the influence of COVID-19 containment policy measures typically appears after an incubation period of 1 to 4 weeks after policy implementation.[47] Considering this delay, this study examines the policy measures one month before the emergence of each structural breakpoint to relate the impacts of border control measures to the number of confirmed cases.

IV. RESULTS

A. Poisson Regression Results

Table 1 demonstrates the Poisson regression results. The results show that the second-order lagged international travel control variable was significantly negatively associated with the confirmed imported cases ($p < 0.01$), revealing a significant lagged negative correlation between the number of imported cases and the strictness of border control measures in the preceding three weeks. This finding suggests that stricter "international travel control" measures contribute to the reduction of the confirmed imported cases in the subsequent three weeks.

Regarding the containment of COVID-19 local cases, border control measures exhibit a time lag in reducing local cases in the following week, as indicated by the significant negative coefficient ($p < 0.001$) of the first-order lagged international travel control variable in Table 2. However, when the overall pandemic control measures (Containment and Health Index) were controlled, as shown in Table 3, the magnitude of the negative border control coefficient was reduced. In addition, although the first-order lagged internal

[46] Shiraef et al., *supra* note 7, at 3.

[47] Fowler et al., *supra* note 14, at 1; Maria Michela Gianino et al., *Evaluation of the Strategies to Control COVID-19 Pandemic in Four European Countries*, 9 FRONTIERS PUB. HEALTH 1, 1 (2021); Jessica N. Sanchez et al., *Impact of Social Distancing on Early SARS-CoV-2 Transmission in the United States*, 69(6) ZOONOSES & PUB. HEALTH 746, 746-47 (2022).

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travel control variable remained significantly negative with or without controlling for the Containment and Health Index, as shown in both Table 2 and Table 3, the second-order lagged internal travel control variable turned significantly positive, thereby obscuring the effect of the border control measures on local cases.

In contrast, the significant negative time lag of the Containment and Health Index variable in Table 3 suggests that comprehensive community-based pandemic prevention measures played an essential role in curbing the spread of domestic confirmed cases in the subsequent week. Additionally, the first-order lagged imported and local case variables in Table 3 demonstrated a positive association with current local cases, indicating that the number of confirmed imported and local cases in the previous week was related to continued local transmissions.

Furthermore, Tables 2 and 3 reveal a positive relationship between local cases and both the current week's international travel control variable and the Containment and Health Index variable. This positive relationship between the stringent policy measures and the confirmed local cases may reflect a reversed causality, where governments are more likely to intensify control measures in response to worsening local outbreaks.

B. Results of the Structural Break Detection

This study further employs structural break analysis to identify the breakpoints of the time series and relate the detected breakpoints to the timing of border control measure implementations, so as to infer the effects of border control measures as adopted in prior literature.[48] The key breakpoints identified by structural break analysis are demonstrated in Table 4 and Figure 1. The first two columns of Table 4 list the major border control measures implemented in Taiwan, while the last two columns present the breakpoints identified in the time series of imported and local cases during the first three rounds of the sequential testing procedure. These breakpoints are listed near the weeks of the border control implementations to facilitate the inference of a potential relationship between the breakpoints and the border control measures. Detailed information on all identified breakpoints is provided in Appendix Table 2 and Appendix Figure 1.

The thick black lines in Figure 1 indicate the major breakpoints identified during the first three rounds of the sequential testing procedure in the structural break analysis. The red dashed lines indicate the weeks when the government implemented stringent border control measures, while the green dashed lines mark the weeks when border control was relaxed. The structural break analysis results, as shown in Table 4 and Figure 1, clearly

[48] Edoka et al., *supra* note 35, at 4; Dehning et al., *supra* note 36, at 1, 2.

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demonstrate that the stringency of the border control measures was negatively correlated with the number of confirmed imported cases, suggesting the association between the border control policy and the reduction in imported COVID-19 cases in Taiwan. As illustrated in the upper panel of Figure 1, the number of confirmed imported cases decreased immediately after implementing stringent border control measures (e.g., the overlap of the first red dashed line and the first breakpoint) or remained unchanged without increasing thereafter. By contrast, after the border control policy was relaxed (e.g., the last two green dashed lines), the number of imported cases increased (the last three breakpoints). This result was in line with the results of the Poisson regression model in Table 1, which shows a negative relationship between border control measures and confirmed imported cases.

Regarding confirmed local cases, although a negative relationship with border control measures was observed, the relationship was not definitive. Notably, as appeared around the third thick breakpoint line, local cases increased immediately after implementing a stringent border control measure and then began to decline about three weeks later. This time lag of border control policy further obscures the impact of border control measures on local case numbers.

C. Sensitivity Analysis and Robustness Check

To examine the robustness of the results, this study re-estimated the Poisson regression models using daily data instead of weekly data. As presented in Appendix Table 3 to 5-2, the results remained consistent across both weekly data and daily data. Likewise, Appendix Figure 2, which depicts the structural break analysis based on daily data, exhibits results consistent with those shown in Figure 1 using weekly data. The identified breakpoints were located at the same positions on Figure 1 and Appendix Figure 2.

However, Appendix Figure 2, which provides detailed information on the daily time-series patterns, suggests a potential endogeneity issue that policy measures may have been implemented in response to the worsening pandemic situation. As shown in Appendix Figure 2, the first strict border control measure (the first dashed red line in the upper panel) was introduced two days after the 1st breakpoint (the first solid dark line in the upper panel), which represents the turning point of rising confirmed cases. Similarly, in the lower panel of Appendix Figure 2, the third strict border control measure (the third dashed red line) was implemented after two breakpoints, both of which suggest an upward trend in local confirmed cases.

As this endogeneity issue may yield a biased positive relationship between the policy measures and the outcomes of interest, such a biased relationship appears to be reflected in the Poisson regression results for local

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cases. This potential endogeneity problem helps explain why the local confirmed cases are positively correlated with the current week's border control measures and the Containment and Health Index in the Poisson regressions (Tables 2 and 3). It likely results from reverse causality, whereby COVID-19 prevention measures were more likely to be implemented when the pandemic became severe.

In addition, this study further employs a regression discontinuity design (hereinafter "RDD") with multiple cutoffs as an alternative approach to confirm the robustness of the structural break findings.[49] The bandwidths are set to include thirty days before and after each cutoff. As demonstrated in Appendix Figures 3 and 4, the RDD results are consistent with the structural break findings, suggesting a downward pattern following the implementation of stringent border control measures and an upward pattern following the relaxation of border control measures.

V. DISCUSSION

This study aims to explore the impacts of border control measures on COVID-19 containment and finds that stringent border control measures contribute to a reduction in imported cases approximately two weeks after their implementation. The aforementioned finding is consistent across both the Poisson regression models and structural break analysis, highlighting the robustness of the results.

However, once community transmission began, border control measures became limited in curbing local spread. In contrast, the comprehensive community prevention measures were essential for containing the local cases for the following weeks. This result aligns with Yu et al. (2021),[50] who found that contact tracing and the subsequent rapid isolation of contacts can reduce over 90% of domestic confirmed cases. It is also consistent with prior literature highlighting the time lags of policy interventions.[51]

The aforementioned findings also help explain why previous studies, such as Grépin et al. (2023),[52] concluded that border control measures are effective only when implemented during the initial stage of an outbreak. That is because once community transmission has begun, border controls alone are insufficient and must be complemented by other community containment measures to substantially control the spread, as found in this study. Taiwan's success in preventing COVID-19 in 2020 further supports the conclusion that

[49] Matias D. Cattaneo et al., *Analysis of Regression-Discontinuity Designs with Multiple Cutoffs or Multiple Scores*, 20(4) STATA J. 866, 866-88 (2020).
[50] Zidong Yu et al., *Reopening International Borders Without Quarantine: Contact Tracing Integrated Policy Against COVID-19*, 18(14) INT'L J. ENV'T RSCH. & PUB. HEALTH 1, 10 (2021).
[51] Fowler et al., *supra* note 14, at 1; Gianino et al., *supra* note 47, at 1; Sanchez et al., *supra* note 47, at 1-2.
[52] Grépin et al., *supra* note 7, at 16.

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the stringent border controls at the onset of the global pandemic successfully prevented the virus from crossing the border.

This study implies that strict border control is a possible anti-transmission strategy for policymakers, particularly when the global epidemic is raging. Border control measures are especially impactful in geographically isolated regions like Taiwan and New Zealand, where natural oceanic barriers help prevent the intrusion of external disease, as echoed in the results of studying the case in New Zealand.[53]

The limitations of this study are as follows. First, the limitation of applying the structural break analysis is that the identification of significant breakpoints alone is not sufficient for researchers to draw causal inferences between policy measures and the outcomes of interest, as the analysis does not control for other factors that may also result in the breakpoints. Therefore, Poisson regression models were applied. Although Poisson regressions alone can only provide observational associations and may suffer from reverse causality, the structural break analysis can complement the regression results by revealing the temporal sequence between the policy interventions and the outcomes of interest. This study thus combines both methods to enhance the robustness of the findings.

Second, this study did not include data after April 2022. Given that the Omicron and other COVID-19 variants may differ from the previous versions of the virus, whether the study findings can be fully extrapolated to later variants of the virus requires future exploration.

VI. CONCLUSIONS

This study uses time-series structural break analysis and Poisson regression models to evaluate the impacts of border control measures on COVID-19 confirmed imported and local cases to determine whether Taiwan's salient success in controlling the COVID-19 pandemic can be attributed to its stringent border control measures. Both analyses yield consistent results supporting the negative association between the confirmed imported cases and the stringent border control measures, such as a ban on the entry of noncitizens.

However, for the existing domestic pandemic, implementing strict border control measures alone is insufficient to curb the epidemic in communities. Border control measures must be combined with other community epidemic prevention measures to achieve better outcomes.

By including both the COVID-19 imported and local cases in the data, this study is able to distinguish the relationship between border control measures and confirmed cases acquired abroad versus those transmitted

[53] Cumming, *supra* note 7, at 116.

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locally, thereby contributing to the literature by providing empirical evidence to support the impacts of border control measures in preventing the spread of the virus from different sources.

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TABLE 1: Impacts of Border Control Measures on Imported Cases

	Model 1	Model 2	Model 3	Model 4
C8_International Travel Controls	0.120 (0.215)	0.677 (0.448)	0.128 (0.900)	0.217 (0.833)
C8_International Travel Control (t-1)		-1.111** (0.420)	0.636 (0.895)	0.106 (0.569)
C8_International Travel Control (t-2)			**-1.261***** (0.220)	**-0.352**** (0.114)
C8_International Travel Control (t-3)				-0.389 (0.382)
Global confirmed cases (per million)	0.877 *** (0.137)	0.426*** (0.065)	1.129* (0.492)	1.205*** (0.309)
Global confirmed cases (per million, t-1)		-0.202** (0.0729)	-1.685* (0.833)	-1.060** (0.403)
Global confirmed cases (per million, t-2)			0.975* (0.405)	-0.254 (0.139)
Global confirmed cases (per million, t-3)				0.586*** (0.110)
# of Arrival (per 1000)	-0.036 ** (0.011)	-0.073 (0.115)	0.013 (0.061)	-0.085 (0.070)
# of Arrival (per 1000, t-1)		0.033 (0.087)	0.024 (0.048)	0.226*** (0.050)
# of Arrival (per 1000, t-2)			-0.042* (0.020)	-0.179*** (0.045)
# of Arrival (per 1000, t-3)				0.042 (0.030)
Temperature (˚C)	-0.071 *** (0.019)	-0.027* (0.012)	-0.029 (0.017)	-0.041** (0.014)
Temperature (˚C, t-1)		-0.004 (0.011)	0.038 (0.032)	0.015 (0.034)
Temperature (˚C, t-2)			0.015 (0.020)	0.082 (0.044)
Temperature (˚C, t-3)				0.019 (0.013)
Imported cases (per 1000, t-1)		34.19*** (1.541)	44.50*** (3.486)	32.70*** (4.726)
Imported cases (per 1000, t-2)			-17.21** (5.240)	-11.79* (5.540)
Imported cases (per 1000, t-3)				13.13 (8.087)
Constant	2.915 *** (0.495)	3.276*** (0.404)	3.047*** (0.685)	2.394*** (0.672)

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N	114	113	112	111
AIC	1404.2	633.6	571.5	555.9
BIC	1417.9	660.9	612.3	610.1

NOTE: The values in brackets are standard errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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TABLE 2: Impacts of Border Control Measures on Local Cases

	Model 5	Model 6	Model 7	Model 8
C8_International Travel Controls	2.827***	3.015***	3.280***	2.281***
	(0.526)	(0.314)	(0.299)	(0.338)
C8_International Travel Control (t-1)		-1.894***	-3.295***	-1.939***
		(0.121)	(0.353)	(0.374)
C8_International Travel Control (t-2)			0.911	1.364*
			(0.533)	(0.628)
C8_International Travel Control (t-3)				-0.673*
				(0.305)
Global confirmed cases (per million)	2.140**	-2.696**	1.228	-1.617
	(0.692)	(0.858)	(0.951)	(0.920)
Global confirmed cases (per million, t-1)		4.151***	-1.725	3.885*
		(0.904)	(1.206)	(1.737)
Global confirmed cases (per million, t-2)			3.465***	-1.136
			(0.507)	(1.216)
Global confirmed cases (per million, t-3)				2.868***
				(0.704)
Temperature (℃)	0.115*	0.253***	0.255***	0.321***
	(0.052)	(0.026)	(0.013)	(0.037)
Temperature (℃, t-1)		-0.009	0.183***	0.249***
		(0.010)	(0.046)	(0.017)
Temperature (℃, t-2)			-0.087*	0.067***
			(0.041)	(0.018)
Temperature (℃, t-3)				-0.303***
				(0.019)
Local cases (per 1000, t-1)		6.599***	7.355***	7.074***
		(0.493)	(1.131)	(0.946)
Local cases (per 1000, t-2)			1.869	2.703
			(1.106)	(1.445)
Local cases (per 1000, t-3)				1.327
				(0.684)
Imported cases (per 1000, t-1)		24.14***	125.3***	109.1***
		(2.477)	(14.62)	(9.418)
Imported cases (per 1000, t-2)			-136.3***	16.78
			(23.26)	(10.91)
Imported cases (per 1000, t-3)				-194.3***
				(27.68)
Constant	-11.56**	-10.42***	-14.07***	-15.06***
	(3.846)	(1.758)	(1.037)	(1.860)
N	114	113	112	111
AIC	5955.1	1543.4	1168.1	613.1

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BIC	5966.0	1567.9	1206.2	664.5

NOTE: The values in brackets are standard errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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TABLE 3: Impacts of Border Control and Containment Measures on Local Cases

	Model 1	Model 2	Model 3	Model 4
C8_International Travel Controls	0.530	0.612***	0.347	1.070**
	(0.296)	(0.090)	(0.216)	(0.403)
C8_International Travel Control (t-1)		-0.0146	-0.355*	-1.537***
		(0.105)	(0.138)	(0.395)
C8_International Travel Control (t-2)			0.855*	1.931***
			(0.356)	(0.377)
C8_International Travel Control (t-3)				-0.817
				(0.548)
Containment and Health Index	0.215***	0.259***	0.245***	0.203***
	(0.013)	(0.017)	(0.014)	(0.030)
Containment and Health Index (t-1)		**-0.136****	**-0.120****	**-0.111****
		(0.007)	(0.005)	(0.011)
Containment and Health Index (t-2)			-0.020*	0.023
			(0.009)	(0.016)
Containment and Health Index (t-3)				-0.013
				(0.029)
Global confirmed cases (per million)	0.836***	-0.263	1.037	-0.389
	(0.110)	(0.200)	(0.888)	(1.472)
Global confirmed cases (per million, t-1)		1.054***	-1.119	-0.014
		(0.208)	(1.361)	(1.003)
Global confirmed cases (per million, t-2)			1.431	2.411
			(0.827)	(1.596)
Global confirmed cases (per million, t-3)				-0.751
				(1.070)
Temperature (˚C)	-0.224***	0.018	0.046*	0.057
	(0.036)	(0.027)	(0.022)	(0.086)
Temperature (˚C, t-1)		-0.055***	0.019	0.024
		(0.005)	(0.031)	(0.027)
Temperature (˚C, t-2)			-0.077***	-0.009
			(0.022)	(0.064)
Temperature (˚C, t-3)				-0.121*
				(0.057)
Local cases (per 1000, t-1)		5.710***	6.946***	8.661***
		(0.135)	(0.537)	(1.666)
Local cases (per 1000, t-2)			-0.006	-3.488**
			(0.520)	(1.188)
Local cases (per 1000, t-3)				3.053***
				(0.865)
Imported cases		30.09***	67.31***	58.89***

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(per 1000, t-1)		(1.244)	(6.757)	(12.14)
Imported cases			-49.27***	-18.09*
(per 1000, t-2)			(8.072)	(7.673)
Imported cases				-47.47*
(per 1000, t-3)				(20.08)
Constant	-5.894***	-7.448***	-8.504***	-6.442***
	(0.625)	(0.478)	(1.537)	(1.499)
N	114	113	112	111
AIC	2762.2	487.9	459.3	393.4
BIC	2775.9	517.9	505.6	455.8

NOTE: The values in brackets are standard errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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TABLE 4: Dates of Major Border Control Measures and the Identified Breakpoints

Date	Border control measures	Breakpoints (Import)	Breakpoints (Local)
2020/3/19 (Week 12)	Ban on the entry of noncitizens (+)	2020 week 12 (↓) 2020 week 19	2020 week 15
2020/6/29 (Week 26)	Reopening the entry of noncitizens (−)		
2021/1/1 (Week 1)	Ban on the entry of noncitizens (+)		
2021/3/1 (Week 9)	Reopening the entry of noncitizens (−)		2021 week 10
2021/5/19 (Week 20)	Ban on the entry of noncitizens (+)	2021 week 22 (↓)	2021 week 20 (↓) 2021 week 28 (↓)
2021/11/11 (Week 45)	Allowing the entry of foreign workers (−)	2021 week 48 (↑)	2021 week 43
2022/3/7 (Week 10)	Allowing the entry of noncitizens for business (−)	2022 week 3 2022 week 10 (↑)	

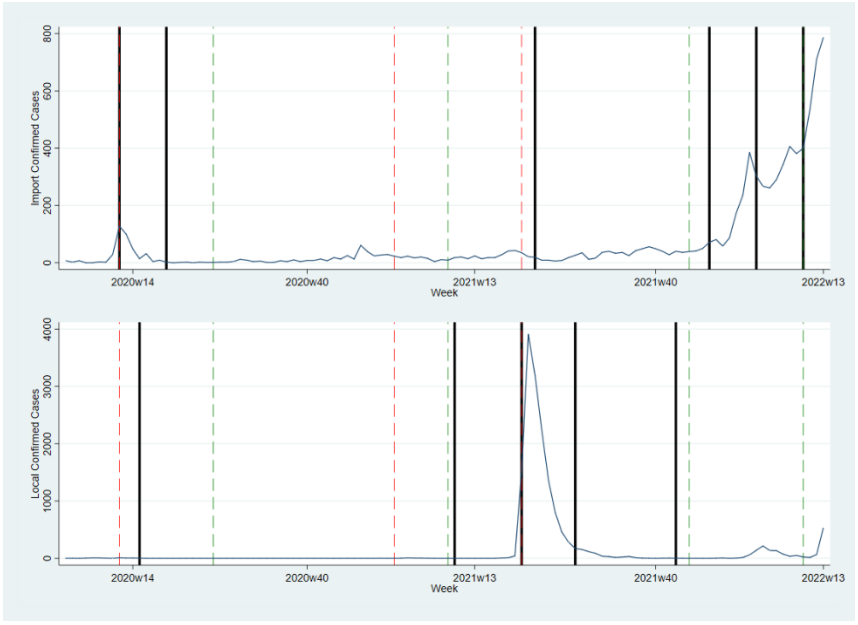
NOTE: + represents a stringency of a border control measure; − represents a relaxation of a border control measure. ↑ represents an increase in confirmed imported cases after the breakpoint; ↓ represents a decrease after the breakpoint; no sign represents no trend changes.

SOURCE: The source of the major border control measures is from the Ministry of Health and Welfare (2022)[54]

[54] MINISTRY OF HEALTH & WELFARE, *supra* note 2.

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FIGURE 1: Identified Major Breakpoints of Imported and Local Confirmed Cases



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Appendix

APPENDIX TABLE 1: Policy Indicators Comprised in the OxCGRT Containment and Health Index

ID	Indicator Name	Coding
C1	School closing	0 - no measures 1 - recommend closing or all schools open with alterations resulting in significant differences compared to non-COVID-19 operations 2 - require closing (only some levels or categories, eg just high school, or just public schools) 3 - require closing all levels Blank - no data
C2	Workplace closing	0 - no measures 1 - recommend closing (or recommend work from home) or all businesses open with alterations resulting in significant differences compared to non-COVID-19 operation 2 - require closing (or work from home) for some sectors or categories of workers 3 - require closing (or work from home) for all-but-essential workplaces (eg grocery stores, doctors) Blank - no data
C3	Cancel public events	0 - no measures 1 - recommend cancelling 2 - require cancelling Blank - no data
C4	Restrictions on gatherings	0 - no restrictions 1 - restrictions on very large gatherings (the limit is above 1000 people) 2 - restrictions on gatherings between 101-1000 people 3 - restrictions on gatherings between 11-100 people 4 - restrictions on gatherings of 10 people or less Blank - no data

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C5	Close public transport	0 - no measures 1 - recommend closing (or significantly reduce volume/route/means of transport available) 2 - require closing (or prohibit most citizens from using it) Blank - no data
C6	Stay at home requirements	0 - no measures 1 - recommend not leaving house 2 - require not leaving house with exceptions for daily exercise, grocery shopping, and 'essential' trips 3 - require not leaving house with minimal exceptions (eg allowed to leave once a week, or only one person can leave at a time, etc.) Blank - no data
C7	Restrictions on internal movement	0 - no measures 1 - recommend not to travel between regions/cities 2 - internal movement restrictions in place Blank - no data
C8	International travel controls	0 - no restrictions 1 - screening arrivals 2 - quarantine arrivals from some or all regions 3 - ban arrivals from some regions 4 - ban on all regions or total border closure Blank - no data
H1	Public information campaigns	0 - no Covid-19 public information campaign 1 - public officials urging caution about Covid-19 2- coordinated public information campaign (eg across traditional and social media) Blank - no data
H2	Testing policy	0 - no testing policy 1 - only those who both (a) have symptoms AND (b) meet specific criteria (eg key workers, admitted to hospital, came into contact with a known case, returned from overseas) 2 - testing of anyone showing Covid-19 symptoms 3 - open public testing (eg “drive through” testing available to asymptomatic people) Blank - no data
H3	Contact tracing	0 - no contact tracing 1 - limited contact tracing; not done for all cases 2 - comprehensive contact tracing; done for all identified cases

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H6	Facial coverings	0 - no policy 1 - recommended 2 - required in some specified shared/public spaces outside the home with other people present, or some situations when social distancing not possible 3 - required in all shared/public spaces outside the home with other people present or all situations when social distancing not possible 4 - required outside the home at all times regardless of location or presence of other people
H7	Vaccination policy	0 - no availability 1 - availability for ONE of following: key workers/ clinically vulnerable groups (non elderly) / elderly groups 2 - availability for TWO of following: key workers/ clinically vulnerable groups (non elderly) / elderly groups 3 - availability for ALL of following: key workers/ clinically vulnerable groups (non elderly) / elderly groups 4 - availability for all three plus partial additional availability (select broad groups/ages) 5 - universal availability
H8	Protection of elderly people	0 - no measures 1 - recommended isolation, hygiene, and visitor restriction measures in LTCFs and/or elderly people to stay at home 2 - narrow restrictions for isolation, hygiene in LTCFs, some limitations on external visitors and/or restrictions protecting elderly people at home 3 - extensive restrictions for isolation and hygiene in LTCFs, all non-essential external visitors prohibited, and/or all elderly people required to stay at home and not leave the home with minimal exceptions, and receive no external visitors Blank - no data

SOURCE: Oxford COVID-19 Government Response Tracker Index

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Codebook[55]

[55] Toby Phillips, *Codebook for the Oxford COVID-19 Government Response Tracker*, OXCGRT (July 27, 2022), https://github.com/OxCGRT/covid-policy-tracker/blob/b051d4ae9878573a3ad8bd57540e64eab036aa56/documentation/codebook.md.

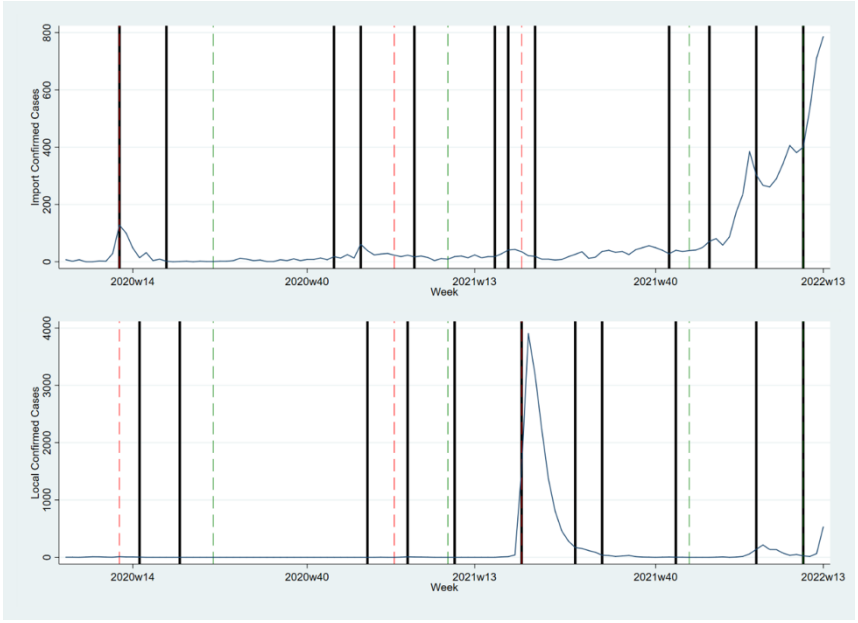
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APPENDIX TABLE 2: All Breakpoints Identified Through the Sequential Testing Procedure

Sequential identification	Breakpoints (Import)	Breakpoints (Local)
1st round	2021 week 48 (↑)	2021 week 20 (↓)
2nd round	2020 week 19, 2022 week 10 (↑),	2021 week 10, 2021 week 28 (↓)
3rd round	2020 week 12 (↓), 2021 week 22 (↓), 2022 week 3,	2020 week 15, 2021 week 43
4th round	2021 week 4, 2021 week 42	2021 week 3, 2021 week 32, 2022 week 10 (↑)
5th round	2020 week 48 (↓), 2021 week 18 (↓)	2020 week 49, 2022 week 3 (↓)
6th round	2020 week 44 (↑), 2021 week 16 (↑)	2020 week 21

NOTE: ↑ represents an increase in confirmed imported cases after the breakpoint; ↓ represents a decrease after the breakpoint.

APPENDIX FIGURE 1: Breakpoints Detected by Structural Break Analysis



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APPENDIX TABLE 3: Impacts of Border Control Measures on Imported Cases (Daily Data)

	(1) import	(2) import	(3) import	(4) import
C8_International travel controls	-0.040	0.542	0.241	0.295
	(0.169)	(0.340)	(0.477)	(0.430)
C8_International Travel Control (w-1)		-0.991**	0.473	0.151
		(0.309)	(0.422)	(0.167)
C8_International Travel Control (w-2)			**-1.289***	**-0.630****
			(0.200)	(0.205)
C8_International Travel Control (w-3)				-0.323
				(0.285)
Global confirmed cases (per million)	0.799***	0.300***	0.369***	0.384***
	(0.114)	(0.040)	(0.071)	(0.057)
Global confirmed cases (per million, w-1)		-0.072	-0.516***	0.058
		(0.049)	(0.107)	(0.182)
Global confirmed cases (per million, w-2)			0.446***	-0.595
			(0.054)	(0.408)
Global confirmed cases (per million, w-3)				0.531**
				(0.194)
# of Arrival (per 1000)	-0.030***	0.008	0.078	0.064
	(0.008)	(0.094)	(0.073)	(0.083)
# of Arrival (per 1000, w-1)		-0.028	-0.048	0.076
		(0.076)	(0.061)	(0.073)
# of Arrival (per 1000, w-2)			-0.025	-0.106
			(0.018)	(0.083)
# of Arrival (per 1000, w-3)				0.007
				(0.057)
Temperature (˚C)	-0.045***	-0.009	-0.009	-0.014**
	(0.010)	(0.005)	(0.006)	(0.004)
Temperature (˚C, w-1)		-0.016	0.018	-0.005
		(0.015)	(0.018)	(0.019)
Temperature (˚C, w-2)			-0.036***	-0.014
			(0.009)	(0.008)
Temperature (˚C, w-3)				0.016
				(0.010)
Imported cases (per 1000, w-1)		34.19***	46.58***	36.91***
		(1.505)	(4.601)	(5.188)
Imported cases (per 1000, w-2)			-19.47**	-12.05***
			(6.183)	(3.346)
Imported cases (per 1000, w-3)				5.643
				(8.548)

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Constant	2.781***	3.153***	3.511***	2.873***
	(0.353)	(0.361)	(0.414)	(0.627)
N	801	794	787	780
AIC	11521.5	5498.9	5014.1	4883.1
BIC	11544.9	5545.7	5084.1	4976.3

NOTE: The values in brackets are standard errors; w-1, w-2, and w-3 represent controls for the mean values of the previous 1, 2, and 3 weeks, respectively; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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APPENDIX TABLE 4-1: Impacts of Border Control Measures on Local Cases (Daily Data)

	(1) local	(2) local	(3) local	(4) local
C8_International travel controls	2.740***	3.306***	3.499***	2.307***
	(0.529)	(0.339)	(0.305)	(0.280)
C8_International Travel Control (w-1)		-2.060***	-3.191***	-2.781***
		(0.161)	(0.330)	(0.243)
C8_International Travel Control (w-2)			0.650	2.520***
			(0.364)	(0.374)
C8_International Travel Control (w-3)				-1.655***
				(0.247)
Global confirmed cases (per million)	1.761**	-0.880**	0.003	-0.235
	(0.588)	(0.307)	(0.181)	(0.141)
Global confirmed cases (per million, w-1)		2.285***	0.192	1.029
		(0.399)	(0.353)	(0.585)
Global confirmed cases (per million, w-2)			2.123**	0.504
			(0.668)	(0.961)
Global confirmed cases (per million, w-3)				2.002***
				(0.412)
Temperature (°C)	0.073*	0.069***	0.061***	0.046***
	(0.033)	(0.007)	(0.007)	(0.009)
Temperature (°C, w-1)		0.091***	0.195***	0.281***
		(0.019)	(0.057)	(0.030)
Temperature (°C, w-2)			-0.011	0.164***
			(0.045)	(0.021)
Temperature (°C, w-3)				-0.247***
				(0.029)
Local cases (per 1000, w-1)		6.093***	6.112***	8.509***
		(0.407)	(0.834)	(0.652)
Local cases (per 1000, w-2)			1.810*	-2.734***
			(0.868)	(0.526)
Local cases (per 1000, w-3)				5.784***
				(0.559)
Imported cases (per 1000, w-1)		13.18***	96.85***	70.60***
		(2.914)	(13.71)	(14.81)
Imported cases (per 1000, w-2)			-112.6***	47.07***
			(20.05)	(9.643)
Imported cases				-197.1***

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(per 1000, w-3)				(40.43)
Constant	-9.769**	-8.051***	-10.35***	-9.297***
	(3.317)	(1.767)	(1.468)	(0.946)
N	801	794	787	780
AIC	46178.6	15316.9	12439.5	8118.5
BIC	46197.4	15359.0	12504.9	8207.0

NOTE: The values in brackets are standard errors; w-1, w-2, and w-3 represent controls for the mean values of the previous 1, 2, and 3 weeks, respectively; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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APPENDIX TABLE 4-2: Impacts of Border Control Measures on Local Cases (Daily Data, Controlling for the Number of Inbound Arrivals)

	(1) local	(2) local	(3) local	(4) local
C8_International travel controls	2.428***	3.155***	3.391***	2.115***
	(0.532)	(0.357)	(0.369)	(0.332)
C8_International Travel Control (w-1)		-2.013***	-3.176***	-2.686***
		(0.171)	(0.397)	(0.334)
C8_International Travel Control (w-2)			0.709*	3.057***
			(0.334)	(0.791)
C8_International Travel Control (w-3)				-2.040***
				(0.566)
Global confirmed cases (per million)	1.749**	-0.791**	0.068	-0.220
	(0.548)	(0.275)	(0.166)	(0.137)
Global confirmed cases (per million, w-1)		2.102***	0.065	0.967
		(0.405)	(0.427)	(0.794)
Global confirmed cases (per million, w-1)			2.166**	0.594
			(0.725)	(1.270)
Global confirmed cases (per million, w-2)				2.010**
				(0.656)
# of Arrival (per 1000)	-1.002**	-0.264**	-0.179**	-0.079
	(0.329)	(0.088)	(0.057)	(0.065)
# of Arrival (per 1000, w-1)		0.112*	-0.057	0.543*
		(0.044)	(0.181)	(0.217)
# of Arrival (per 1000, w-2)			0.158	-0.363*
			(0.111)	(0.148)
# of Arrival (per 1000, w-3)				0.047
				(0.086)
Temperature (˚C)	0.066	0.070***	0.063***	0.047***
	(0.034)	(0.007)	(0.007)	(0.010)
Temperature (˚C, t-7)		0.085***	0.200**	0.289***
		(0.019)	(0.065)	(0.033)
Temperature (˚C, t-14)			-0.013	0.172***
			(0.044)	(0.021)
Temperature (˚C, t-21)				-0.251***
				(0.030)
Local cases (per 1000, w-1)		6.090***	5.898***	9.550***
		(0.451)	(0.692)	(0.864)
Local cases (per 1000, t-14)			1.979**	-4.371**
			(0.760)	(1.413)
Local cases (per 1000, t-21)				6.722***
				(1.135)

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Imported cases (per 1000, w-1)		15.37*** (2.839)	96.98*** (13.31)	54.42*** (13.45)
Imported cases (per 1000, t-14)			-110.5*** (18.43)	69.12*** (16.06)
Imported cases (per 1000, t-21)				-199.3*** (47.63)
Constant	-7.515* (3.516)	-7.323*** (1.784)	-10.33*** (1.767)	-10.16*** (1.419)
N	801	794	787	780
AIC	42521.0	15022.9	12279.7	7914.9
BIC	42544.4	15074.3	12359.0	8022.1

NOTE: The values in brackets are standard errors; w-1, w-2, and w-3 represent controls for the mean values of the previous 1, 2, and 3 weeks, respectively;* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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APPENDIX TABLE 5-1: Impacts of Border Control and Containment Measures on Local Cases (Daily Data)

	(1) local	(2) local	(3) local	(4) local
C8_International travel controls	0.415**	0.779***	-0.866***	-0.735**
	(0.155)	(0.196)	(0.251)	(0.225)
C8_International Travel Control (w-1)		-0.672**	1.308*	1.151*
		(0.221)	(0.610)	(0.500)
C8_International Travel Control (w-2)			-0.038	0.567
			(0.595)	(0.323)
C8_International Travel Control (w-3)				-0.677**
				(0.239)
Containment and Health Index	0.163***	0.143***	0.169***	0.121***
	(0.007)	(0.013)	(0.014)	(0.013)
Containment and Health Index (w-1)		-0.044***	0.005	**-0.044****
		(0.008)	(0.006)	(0.009)
Containment and Health Index (w-2)			**-0.107*****	**-0.134*****
			(0.006)	(0.016)
Containment and Health Index (w-3)				0.117***
				(0.034)
Global confirmed cases (per million)	0.791***	-0.441	0.150*	-0.085
	(0.070)	(0.246)	(0.075)	(0.081)
Global confirmed cases (per million, w-1)		1.090***	0.026	0.022
		(0.177)	(0.230)	(0.777)
Global confirmed cases (per million, w-2)			0.807**	1.480
			(0.289)	(1.331)
Global confirmed cases (per million, w-3)				0.533
				(0.716)
Temperature (˚C)	-0.087***	0.042***	0.018**	0.019*
	(0.019)	(0.011)	(0.006)	(0.007)
Temperature (˚C, w-1)		0.001	0.071	0.206***
		(0.013)	(0.040)	(0.033)
Temperature (˚C, w-2)			-0.024	0.080*
			(0.018)	(0.034)
Temperature (˚C, w-3)				-0.235***
				(0.028)
Local cases (per 1000, w-1)		5.570***	2.904*	11.01***
		(0.209)	(1.269)	(1.216)
Local cases (per 1000, w-2)			4.252***	-0.773
			(1.241)	(0.631)
Local cases (per 1000, w-3)				1.302*
				(0.589)

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Imported cases (per 1000, w-1)		26.00*** (2.023)	52.25*** (5.633)	57.44*** (5.252)
Imported cases (per 1000, w-2)			-33.32*** (7.816)	15.90* (7.508)
Imported cases (per 1000, w-3)				-105.9*** (15.59)
Constant	-6.225*** (0.503)	-6.217*** (0.525)	-6.347*** (0.408)	-6.671*** (1.083)
N	801	794	787	780
AIC	23838.9	9301.7	6597.8	5318.1
BIC	23862.3	9353.1	6677.2	5425.2

NOTE: The values in brackets are standard errors; w-1, w-2, and w-3 represent controls for the mean values of the previous 1, 2, and 3 weeks, respectively; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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APPENDIX TABLE 5-2: Impacts of Border Control and Containment Measures on Local Cases (Daily Data, Controlling for the Number of Inbound Arrivals)

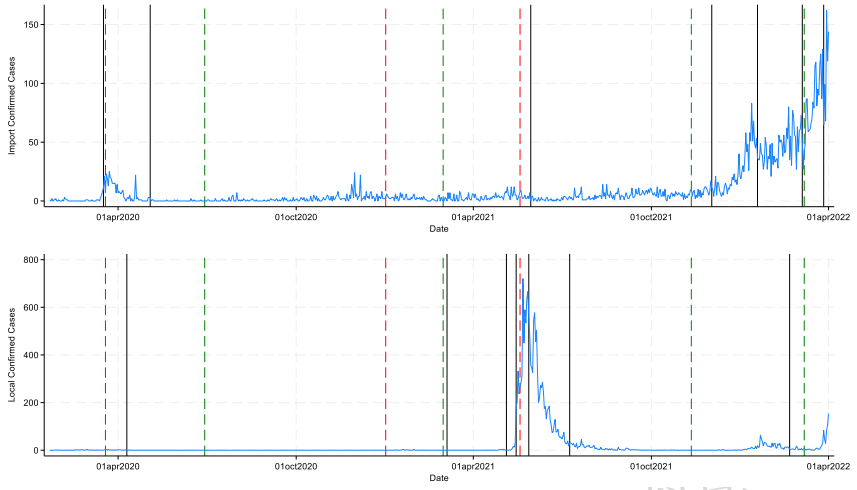
	(1) local	(2) local	(3) local	(4) local
C8_International travel controls	0.413*	0.667***	-0.867***	-0.719**
	(0.163)	(0.188)	(0.255)	(0.220)
C8_International Travel Control (w-1)		-0.570***	1.313*	1.196*
		(0.169)	(0.628)	(0.554)
C8_International Travel Control (w-2)			-0.070	0.664
			(0.595)	(0.341)
C8_International Travel Control (w-3)				-0.805**
				(0.271)
Containment and Health Index	0.157***	0.143***	0.171***	0.121***
	(0.011)	(0.013)	(0.015)	(0.013)
Containment and Health Index (w-1)		-0.043***	0.001	**-0.043***
		(0.007)	(0.006)	(0.010)
Containment and Health Index (w-2)			**-0.109***	**-0.139***
			(0.005)	**(0.013)**
Containment and Health Index (w-3)				0.121***
				(0.033)
Global confirmed cases (per million)	0.802***	-0.424*	0.170**	-0.044
	(0.074)	(0.204)	(0.062)	(0.081)
Global confirmed cases (per million, w-1)		1.084***	0.036	0.149
		(0.151)	(0.247)	(0.663)
Global confirmed cases (per million, w-2)			0.827*	1.272
			(0.324)	(1.199)
Global confirmed cases (per million, w-3)				0.725
				(0.529)
# of Arrival (per 1000)	-0.177	-0.178**	0.065	0.086
	(0.348)	(0.059)	(0.092)	(0.090)
# of Arrival (per 1000, w-1)		0.162***	-0.174	0.294
		(0.037)	(0.112)	(0.234)
# of Arrival (per 1000, w-2)			0.121**	-0.389**
			(0.040)	(0.121)
# of Arrival (per 1000, w-3)				0.153***
				(0.025)
Temperature (°C)	-0.083***	0.045***	0.017*	0.016
	(0.021)	(0.012)	(0.008)	(0.009)
Temperature (°C, t-7)		0.004	0.075	0.215***
		(0.013)	(0.041)	(0.029)
Temperature (°C, t-14)			-0.019	0.087***
			(0.017)	(0.025)

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Temperature (℃, t-21)				-0.227*** (0.027)
Local cases (per 1000, w-1)		5.574*** (0.200)	2.614* (1.192)	11.66*** (1.370)
Local cases (per 1000, w-2)			4.533*** (1.139)	-1.663* (0.826)
Local cases (per 1000, w-3)				1.859*** (0.434)
Imported cases (per 1000, w-1)		27.33*** (1.826)	56.48*** (6.050)	48.83*** (3.319)
Imported cases (per 1000, w-2)			-39.02*** (7.436)	33.39*** (8.136)
Imported cases (per 1000, w-3)				-114.6*** (15.47)
Constant	-5.835*** (0.799)	-6.475*** (0.550)	-6.607*** (0.550)	-7.753*** (0.514)
N	801	794	787	780
AIC	23749.1	9162.8	6563.1	5193.3
BIC	23777.2	9223.6	6656.5	5319.1

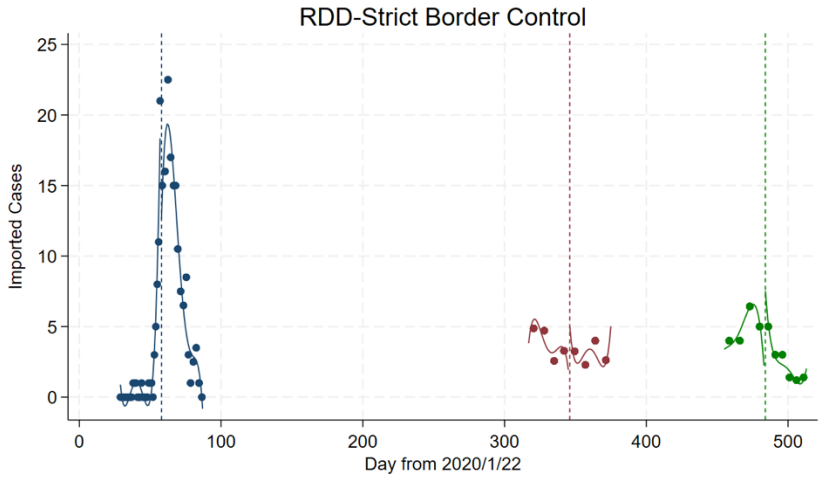
NOTE: The values in brackets are standard errors; w-1, w-2, and w-3 represent controls for the mean values of the previous 1, 2, and 3 weeks, respectively; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

APPENDIX FIGURE 2: Breakpoints Detected by Structural Break Analysis (Daily Data)

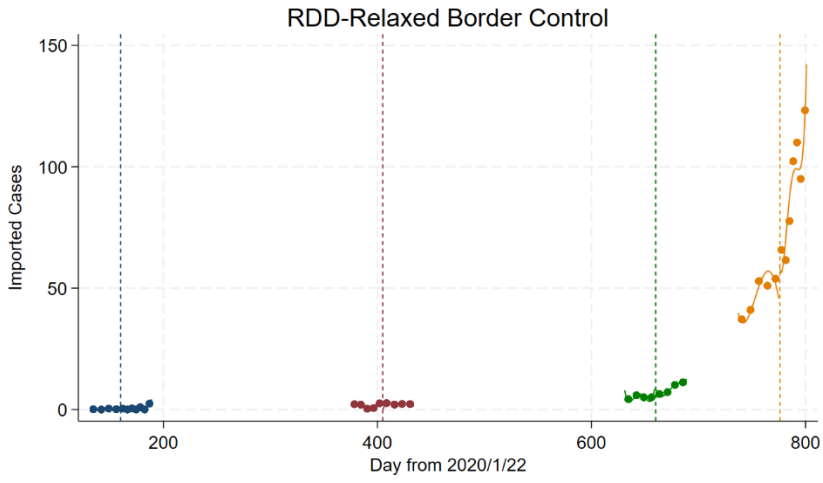


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APPENDIX FIGURE 3-1: RDD for Strict Border Control (Imported Cases)

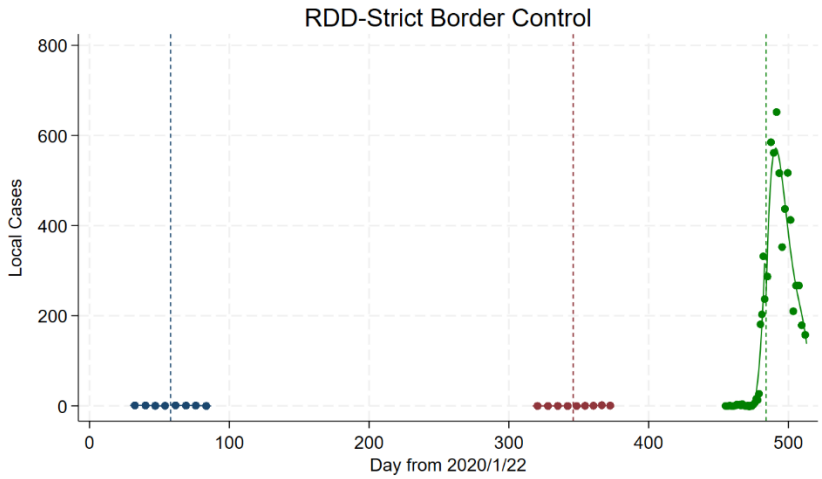


APPENDIX FIGURE 3-2: RDD for Relaxed Border Control (Imported Cases)

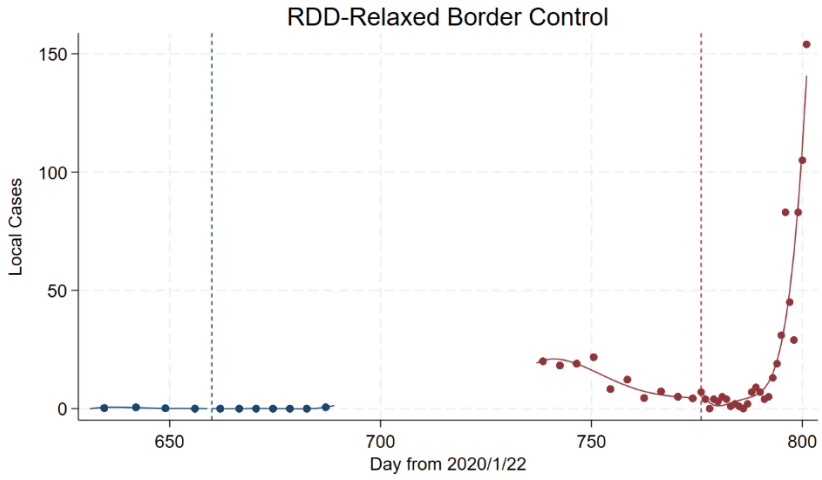


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APPENDIX FIGURE 4-1: RDD for Strict Border Control (Local Cases)



APPENDIX FIGURE 4-2: RDD for Relaxed Border Control (Local Cases)



NOTE: The figures for the first two cutoffs are omitted due to no local cases around the cutoffs

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