The Effects of Hosting the Olympic and Paralympic Games on COVID-19 in Tokyo: Real-time Analyses and Ex-post Evaluation

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Abstract

We present a series of quantitative analyses conducted from mid-May 2021 to mid-June 2021, which examined the effects of hosting the Tokyo 2020 Olympic and Paralympic Games on the spread of COVID-19 in Tokyo. Our real-time analyses pointed out that (i) the direct effects on the spread of COVID-19 of welcoming foreign visitors related to the Games to Japan or allowing spectators in the competition venues would be limited or manageable, but (ii) the festive mood generated by the Games could greatly contribute to the spread of COVID-19 if it led to a decline in people's willingness to take preventive actions against infection. Ex-post, the key takeaways of our real-time analyses are qualitatively in line with available empirical evidence. We also discuss the lessons of our experiences for a future pandemic.

Keywords: Agent-Based Model, COVID-19, SIR Model, Tokyo 2020 Olympic and Paralympic Games

JEL Codes: C53, E65, Z28

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1 Introduction

In this paper, we present a series of model-based quantitative analyses conducted from mid-May to mid-June 2021, which examined how the Olympic and Paralympic Games would impact the course of COVID-19 in Tokyo. The Tokyo 2020 Olympic and Paralympic Games were originally scheduled to take place in the summer of 2020. The COVID-19 pandemic made it inevitable for the event to be postponed to the summer of 2021. However, with COVID-19 far from being under control in many parts of the world and with substantial uncertainty regarding the COVID-19 situation in Tokyo around the time of the event, the public debate on whether it would be safe to host the Games intensified around April 2021.

Commentators, policymakers, and public-health experts voiced their views in various venues. However, there had been no quantitative evaluation of the effects of hosting the Olympic and Paralympic Games on infection until we released our analysis in Section 2 to the public on May 21. On June 17, we released a set of reports that investigated questions not fully explored in our May 2021 report. As discussed in section 5, our reports were widely read by policymakers and the public.

Table 1: Timeline

Date	Events/Release of Our Reports	Note
January 8, 2021	Start of the second SOE in Tokyo	
March 22, 2021	End of the second SOE in Tokyo	
April 25, 2021	Start of the third SOE in Tokyo	
May 21, 2021	*The Effects of Hosting the Olympic and Paralympic Games on COVID-19: A Quantitative Analysis*	Fujii and Nakata (2021b)
June 17, 2021	*The Effects of the Olympic and Paralympic Games on COVID-19: Summary*	Fujii and Nakata (2021d)
June 17, 2021	*The Effects of the Olympic and Paralympic Games on COVID-19: Direct Effects*	Chiba et al. (2021)
June 17, 2021	*The Effects of the Olympic and Paralympic Games on COVID-19: Indirect Effects*	Fujii and Nakata (2021c)
June 20, 2021	End of the third SOE in Tokyo	
July 12, 2021	Start of the forth SOE in Tokyo	
July 21, 2021	Start of the Olympic Games	
August 8, 2021	End of the Olympic Games	
August 20, 2021	*The Effects of the Olympic Games on CVID-19: Ex-Post Assessment*	Fujii and Nakata (2021e)
September 30, 2021	End of the forth SOE in Tokyo	

Notes. These original reports—written in Japanese—are at `https://covid19outputjapan.github.io/JP/resources.html`.

The purpose of collecting our original reports in a research paper is twofold. The first purpose is to share our analyses with a wider audience of researchers and policymakers. Our reports were originally written in Japanese, and thus were not accessible to many non-Japanese researchers who might be interested in our analyses. Additionally, our reports—intended to be accessible to non-specialists—were abstracted from many technical details, although we made replication codes available to the public at the time.[1] This paper fills in those gaps.

The second purpose is to describe in some detail the context in which we conducted our analyses and how the public and policymakers perceived them in the periods leading up to the Games. Throughout the COVID-19 crisis, model-based analyses—in particular, simulation-based scenario analyses on infection and hospitalization—played a key role in informing policy in many countries. Proper investigations of model-based analyses during the COVID-19 crisis are likely to help future generations of researchers provide policymakers with better analyses and communicate better with the public. We believe that our unique experience of using model-based analyses to contribute to a heated national debate in real-time can provide researchers around the world with food for thought on the role of model-based analyses in informing policymakers and the public.

Our May-21 analysis investigated how the arrival of the Games-related foreign visitors would affect infection in Tokyo.[2] At the time of analysis, the estimated number of visitors was approximately 70,000 for the Olympic Games and 35,000 for the Paralympic Games. On the one hand, the size of this inflow was relatively large compared to the number of visitors from April 2020 to April 2021—shown in see Figure 1—when the average was approximately 20,000 people in a month. On the other hand, the size of this inflow represented only 0.75 percent of the population in Tokyo, which appeared too small to have a substatial impact on the COVID-19 situation in a city of about 14M people, especially given that all visitors were required to test for infection before and after arrival and that they were required to follow rules on where they could visit during their stay. Thus, the quantitative effects of welcoming foreign visitors on the spread of COVID-19 in Tokyo were a priori unclear and warranted an investigation. Yet, until our report on May 21, Japanese policymakers and the public were not only uninformed about how the Games might affect the course of COVID-19, but also uninformed about the expected level of infection when the Games would take place.[3]

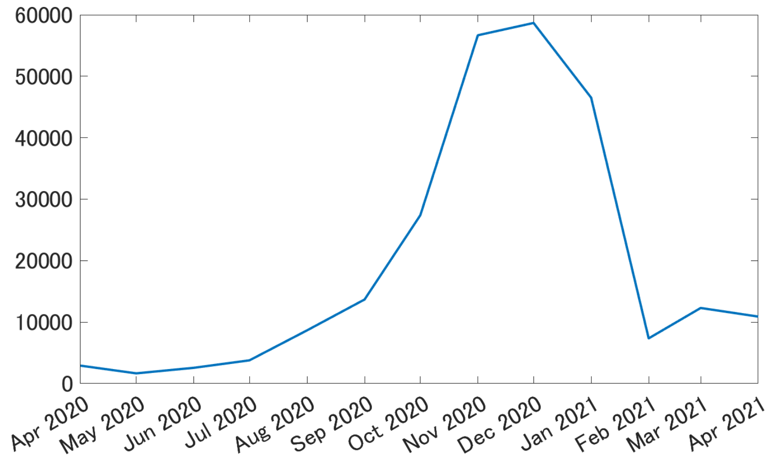
We analyzed this issue by examining the effects of a temporary increase in susceptible and infectious populations in a single-group SIR (Susceptible-Infected-Recovered) model. An implicit assumption in the use of a single-group SIR model was that foreign visitors would behave and interact in the same manner as Tokyo residents. In reality, Games-related visitors would be isolated and tested frequently. Thus, the effect of exogenous shocks to susceptible and infectious populations calculated in this model represented an upper bound

[1] Replication codes were provided to the public on May 21st. `https://covid19outputjapan.github.io/JP/files/Olympics_replication.zip`.

[2] Fujii and Nakata (2021b).

[3] There were only few medium-term and long-term projections of COVID-19 available in April and May that extended to late July and early September when the Games would take place.

Figure 1: Number of Foreign Visitors, Monthly



Source: Japan National Tourism Organization and authors' calculations. Data accessed at `https://www.jnto.go.jp/jpn/statistics/visitor_trends/index.html`. See Fujii and Nakata (2021b).

for the effect of foreign visitors on infection in Tokyo. Under our baseline calibration, the upper bound was 15 new cases per day, a very small number in a city with a population of about 14 million that generated a few thousand new cases per day when the Games began.

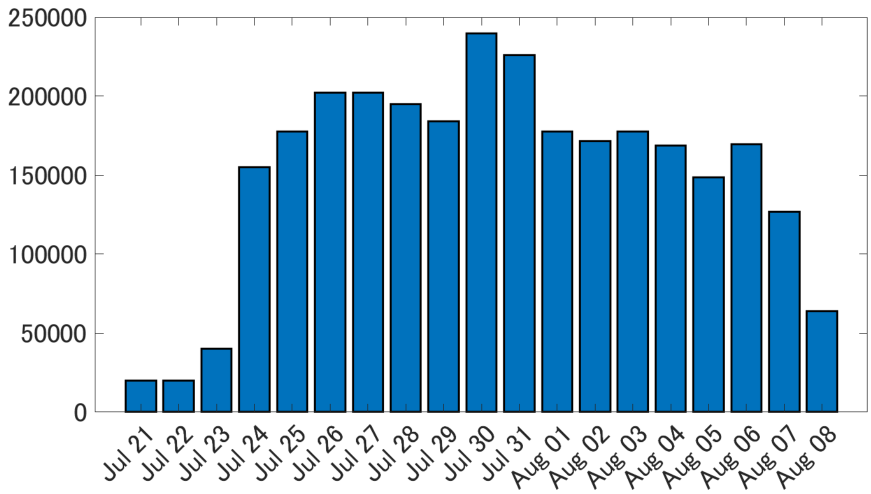
Our June-17 analysis investigated how allowing spectators at competition venues would affect infection in Tokyo.[4] By early June 2021, the public debate shifted from whether it would be safe to host the Games at all to how to host the Games safely. In particular, the public debate began to focus on the question of whether it would be safe to allow spectators at competition venues. As discussed in the Online Appendix A, the expected daily number of spectators during the Olympic period was likely to be above 1 percent of the Tokyo population, substantially higher than the average number of spectators at other large-scale events (including music concerts and cultural events) in Tokyo since the pandemic began, making it useful to conduct a quantitative analysis.

Using an agent-based model and a multi-group SIR model, we found that the effect of allowing spectators at venues would depend significantly on the proportion of people who would stop by bars and restaurants before or after watching the Games. When that proportion is about 20 percent, the effects on infection one week after the close of the Olympic Games would be less than 50 new cases in both agent-based and multi-group SIR models. This number is, again, a relatively small figure considering the size of Tokyo.

In both May-21 and June-17 reports, we investigated how the Games would influence

[4]Fujii and Nakata (2021d), Chiba et al. (2021), and Fujii and Nakata (2021c).

Figure 2: The expected number of spectators



Source: Authors' calculations. See Online Appendix A for details.

the course of COVID-19 by affecting behaviors of Tokyo residents, for instance, by promoting festive moods and discouraging people and businesses from adhering to various government requests to control infection. We called this effect of the Games the "indirect effect" because it was not directly related to foreign visitors and spectators who are more actively involved in the Games. We found that the indirect effect could become very large. One of the June-17 reports summarized key findings from our reports in Table 2.

Table 2: Effects of the Games on COVID-19 in Tokyo—Summary

	Foreign Visitors	Tokyo Residents	
		Spectator Effects	Indirect Effects
Number of people	about 100 thousands	about 180,000 thousands	about 14M
New daily cases	below 15	10-80	can be very large
ICU beds	below 3	2-10	can be very large
Qualitative assessment	Limited	Manageable, but be careful with "announcement effects"	Need to be very careful

Notes. From Fujii and Nakata (2021d).

The Olympic Games took place between July 21 and August 8. On August 20, we released a report providing an ex-post evaluation of our analysis, drawing upon circumstantial evidence on how the Olympic Games influenced the course of COVID-19 in Tokyo.[5] Key takeaways from the report were that (i) our May-21 result seemed to be in line with the number of reported Games-related infection, (ii) our June-17 result on the effect of allowing

[5]See Fujii and Nakata (2021e).

spectators in venues could not be known because no spectators were allowed, and (iii) our warning in both reports regarding the indirect effects seemed to have been the right message at the time. In Section 4, we provide an update of our assessment.[6]

In conducting these quantitative analyses, we aimed to strike the right balance between timeliness and quality. Unlike standard academic research, our goal was to contribute to the policy debate in real time. In all reports, we could certainly have spent more time making the analysis more rigorous. However, to contribute to the policy debate in real-time, it was imperative that the analysis was delivered to the public and policymakers in a timely manner. Given the time constraint we faced, our goal was to maximize insights and policy implications subject to a certain quality standard. In particular, we employed modelling approaches that were as simple as possible and thus as error-free as possible, yet that were likely to generate results as insightful and policy-relevant as possible.

The paper is organized as follows. Section 2 presents our analyses in the May-21 report. Section 3 presents our analyses in the June-17 report. Section 4 discusses our ex-post evaluation of how the Games might have influenced infection in Tokyo. Section 5 discusses the impact of our real-time analysis on the government's policy decisions and the public's behaviors. Section 6 concludes.

2 May 21 report

In this section, we present our analysis conducted in mid-May, about two months before the start of the Games. We examined how the increased inflow of foreign visitors associated with the Olympics and Paralympic Games would affect the spread of COVID-19 in Japan. We also examined how much infections would increase if the festive mood associated with hosting the Games caused people to become more active–which we called "indirect effects."

2.1 Model

To quantify the effects of increased inflows of foreign visitors on infection, we used a SIR model of Fujii and Nakata (2021a). The model is formulated in discrete time with each period interpreted as one week. Let subscript t denote time period, S_t, I_t, R_t be the number of susceptible, infectious, and recovered individuals, respectively, D_t be the number of

[6] A report provided by the Tokyo Organizing Committee of the Olympic and Paralympic Games (TOCOG) at the same meeting contrasts the baseline results in our May-21 report with actual outcomes, showing that Olympics-related infection was more contained in reality than what our report suggested. https://www.2020games.metro.tokyo.lg.jp/docs/%E7%AC%AC2%E5%9B%9E%E6%9D%B1%E4%BA%AC2020%E5%A4%A7%E4%BC%9A%E9%96%8B%E5%82%AC%E9%83%BD%E5%B8%82%E6%9C%AC%E9%83%A8%E4%BC%9A%E8%AD%B0.pdf

cumulative deaths, and H_t be the number of ICU patients. In addition, N_t is the number of newly infected individuals and V_t is the number of vaccine shots administered at period t. The path of vaccine shots V_t is given outside the model and all the other variables evolve according to the model

$$\begin{aligned}
N_t &= \beta_t \frac{(1-h\alpha_t)^2}{POP_0} I_t S_t \qquad (1) \\
S_{t+1} &= S_t - N_t - V_t \\
I_{t+1} &= I_t + N_t - \gamma I_t - \delta_t I_t \\
R_{t+1} &= V_t + \gamma I_t \\
H_{t+1} &= H_t + \delta_t^{ICU} N_t - \gamma^{ICU} H_t - \delta_t I_t \\
D_{t+1} &= D_t + \delta_t I_t
\end{aligned}$$

where POP_0 is the population at the initial period and $\{\beta_t, h, \alpha_t, \gamma, \gamma^{ICU}, \delta_t, \delta_t^{ICU}\}$ denotes the model parameters. Table 3 collects descriptions of these parameters and the values used in our analysis.

The equation (1) describes newly infected cases, and this part of the model is non-standard relative to the literature. Namely, the multiplicative factor $(1-h\alpha_t)^2$ is specific to our setting. This formulation follows the work of Fujii and Nakata (2021a), which, used it to capture relationships between the spread of COVID-19 and economic activities. Here α_t represents the degree of reduction in economic activities, and a large α means that people slow down economic activities to reduce infections, e.g., stay home to avoid social interactions. In terms of the model, when α is close to zero, the reduction in economic activities is small, and (1) indicates that there will be more newly infected cases. On the other hand, when α is larger (i.e., $1-h\alpha_t$ is closer to zero), there is more reduction in economic activities, and infections tend to be lower. The parameter h represents the elasticity of economic loss on people's mobility. This parameter plays a less prominent role in the current analysis, and we refer interested readers to Fujii and Nakata (2021a) for details. The rest of the models are relatively standard, possibly except for the ICU equation. Although standard approaches model the number of new ICU-admitted patients as a function of I_t, this feature does not seem to substantially affect the results.[7]

We chose Tokyo as the unit of analysis. We applied the above SIR model using the infection data in Tokyo. We assumed all the visitors would stay in Tokyo, even though some events would take place in other regions of Japan. We made this choice because the majority of the venues were located in the Tokyo metropolitan area and because we did not

[7]We modified this feature of our model for later analyses starting from the beginning of July 2021.

have accurate information on the fraction of visitors who would move across different regions. Focusing on Tokyo would lead to an overestimate of effects because the size of visitors used in our analysis would be larger than the actual one. Thus, our estimate should be interpreted as an upper bound on the effects in Tokyo.

The most important modelling decision was that we used a single-group SIR model.[8] This modelling choice meant that visitors would interact with local residents at the same level as residents would with other residents. This assumption was consistent with an overestimate of contact rates between Tokyo residents and foreign visitors because the majority of visitors stayed in designated facilities and because the Japanese government required visitors to follow rules on where they could visit. Therefore, analogous to focusing on Tokyo as the unit of analysis, the use of a single-group model meant that our estimate should be interpreted as an upper bound on the effects of foreign visitors on infection.

2.2 Effects of foreign visitors

To study the effects of the Games-related foreign visitors, we simulated the paths of new COVID cases and ICU using the above SIR model under two scenarios. The first scenario was "no Games" where the simulation was run in a normal way. In the second scenario, the Olympic and Paralympic Games took place, where (S_t, I_t) were increased at the start of the events and decreased at the end. We interpreted the differences in new cases and ICU cases between these scenarios as the effects of increased inflows of foreign visitors due to the Olympics and Paralympics. Economic activities were set at the same level in the two scenarios. In other words, Japanese residents were exercising the same degree of preventive measures with respect to infections. In this sense, we isolated the effects of inflows of the Games-related visitors from the effects of residents being less cautious due to the Games.

The first period of the simulations ($t = 1$) was the second week of May, 2021, and the last period was the last week of December, 2021. For the scenario with the Games, (S_t, I_t) were increased at two periods: the first was the third week of July and the other was the third week of August. The first increase corresponded to the Olympic Games and the second to the Paralympic Games. As a baseline, we assumed that 100 visitors were infected at arrival, but that screening did not detect them. According to the relative size, about 70 visitors to the Olympic Games were infected, and about 30 to the Paralympic Games. The rest of

[8]Clearly, a more natural approach was to use a two-group SIR model, where Tokyo residents and foreign visitors were partitioned into their own groups. However, this approach would require specifying a contact rate matrix, which controls the frequency of interactions between Japanese residents and visitors in the model. We opted out of this scenario because it was challenging to specify the contact rate matrix with the available information at the time of analysis and because we wanted to work with a framework that is a minimal departure from Fujii and Nakata (2021a) in order to minimize the possibility of mistakes.

70,000/35,000 visitors were in S_t. Also, we assumed that these visitors departed at the end of the third week of August and the third week of September, respectively. In addition, we assumed that 50 percent of the visitors were fully vaccinated and the rest had no vaccination at baseline. The efficacy of the vaccine, in terms of protection from infection, was assumed to be 76.75 percent, which was the average efficacy rate of AstraZeneca and Pfizer vaccines (Scientific Advisory Group for Emergencies, 2021). To check the robustness of our results, we also conducted a sensitivity analysis by varying the number of infected visitors and the ratio of fully vaccinated visitors.

For model parameters, we either estimated them from data or calibrated them based on the information available at the time of analysis. We chose the recovery rates, γ, γ^{ICU}, so that the means of recovery period were 12 days for "I to R" and 28 days for "ICU to R." With γ and the data on newly infected cases, vaccine rollouts, and deaths, we constructed the paths (S_t, I_t, R_t, D_t) up to the initial time period. Then, we solved the equation for I_{t+1} to obtain δ_t. Additionally, from the past path of ICU patients, we backed out δ_t^{ICU}. For the transmission rate β_t, we estimated h and α_t using data on GDP and people's mobility, which in turn enabled us to estimate β_t using the equation (1). In this way, we obtained the past path of time-varying parameters.

Table 3: Model Parameters

Parameters	Description	Values used in analysis
β_t	the transmission rate	min: 0.98 max: 1.05
h	the elasticity of economic loss on mobility	2.22
α_t	the reduction in economic activities	min: 0.01 max: 0.13
γ	the recovery rate of infected individuals	7/12
γ^{ICU}	the recovery rate of ICU patients	7/28
δ_t	the death rate of infected individuals	min: 0.004 max: 0.015
δ_t^{ICU}	the transition rate from newly infected cases to ICU	min: 0.009 max: 0.033

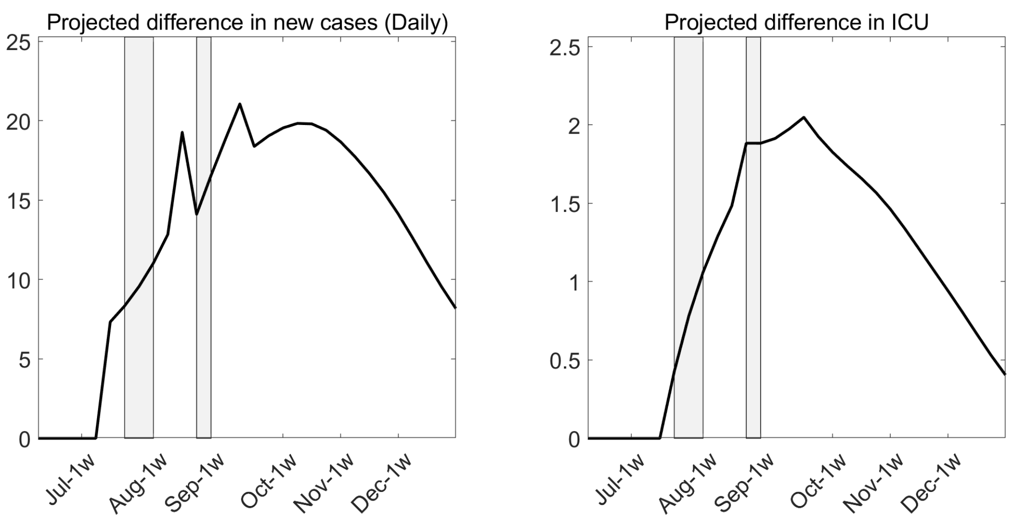
Notes. The table collects descriptions of the model parameters and values used in the analysis. For time-varying parameters, we show the minimum and maximum values used. For further details, see Fujii and Nakata (2021a).

For the simulations, we needed to set the paths $\{V_t, \alpha_t, \beta_t, \delta_t, \delta_t^{ICU}\}_{t\geq 1}$. For the vaccine path, we assumed that 66,000 shots per day were administered in Tokyo, which would translate to 600,000 shots per day nationally. To construct V_t, we assumed that the efficacy of the first and second shots was 62.5% and 89.5% (Scientific Advisory Group for Emergencies, 2021), respectively, for reducing infection and that there was a two-week lag between the time of vaccine administration and the development of immunity. We set the level of economic activities depending on whether the government issued a state of emergency (SOE). Since April 25, Tokyo had been under the third SOE, and various measures were taken to reduce people's mobility. In the model, α_t during the third SOE was set to the average of α_t in

May 2020 and January 2021—these periods correspond to the first and second SOE. The third SOE would be lifted when the newly infected cases in one week fall below 450. In the simulations, the lifting of SOE occurred at the third week of June. After the third SOE was lifted, α_t would go back to the pre-pandemic level (February 2020) over the span of 10 weeks. For $\{\beta_t, \delta_t, \delta_t^{ICU}\}$, we used some weighted averages of their recent past values, and they were further adjusted for effects of COVID variants and vaccine rollout.

Figure 3 displays the differences in new cases (daily) and ICU with the no-Games case as baseline. The number of daily new cases is about 15 people higher with the Games than without the Games on average throughout the simulation horizon. For ICU, the difference between the two scenarios was at most two people. In the second week of May, daily cases in Tokyo were around 800, and the number of ICU patients was around 70. We characterized these increases in new cases and ICU cases caused by the increased inflow of visitors as "limited."

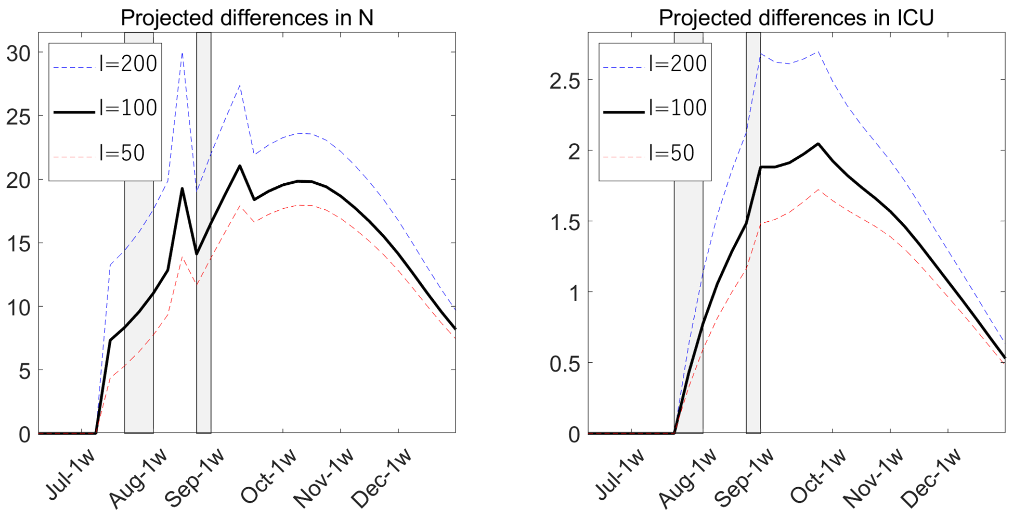
Figure 3: Effects of increased inflow of foreign visitors due to the Olympics and Paralympics



Source: Authors' calculation.

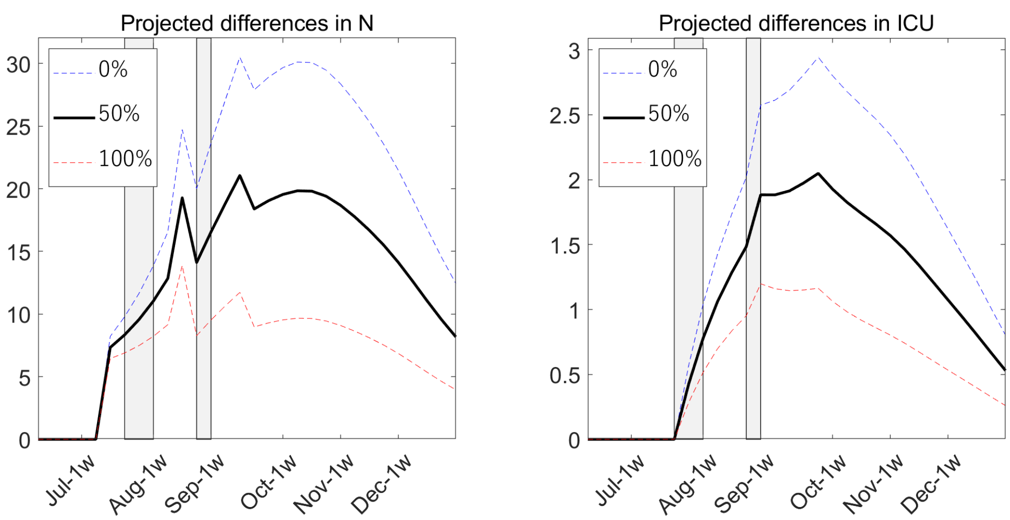
As robustness checks of the main results, we conducted two sets of sensitivity analyses where we varied (i) the number of infected visitors and (ii) the ratio of fully vaccinated visitors. Figure 4 shows the results of the first sensitivity analysis by changing the number of infected visitors over $\{50, 100, 200\}$. As seen from the figure, the results remained qualitatively unchanged when we changed the condition. Also, Figure 5 shows the results for the second sensitivity analysis where we varied the ratio of fully vaccinated visitors over {0%, 50%, 100%}. Analogous to the previous case, the results changed only moderately as the vaccination rate varied.

Figure 4: Sensitivity Analysis: Infected Visitors



Source: Authors' calculation.

Figure 5: Sensitivity Analysis: Vaccination Rate



Source: Authors' calculation.

We reported two additional sets of analysis in our May-21 report—not shown here for the sake of brevity. First, we looked at projections of new cases and ICU when the SOE was lifted earlier and how the change affected the results of the above analyses. The second analysis considered a scenario where new variants with higher infection rates were brought into the country due to the increased inflows. For the latter analysis, there remained much uncertainty regarding newly emerging variants at the time of analysis, and our results were presented with this caveat. Yet, we highlighted the possibility that new variants could drastically change the projections due to their higher infection/mortality rates, and in hindsight, this point was qualitatively borne out by data.

2.3 Indirect effects

To examine the indirect effects of the Games, we conducted simulations where we increased the level of economic activities during the Games to capture the possibility that the festive mood associated with hosting the Games caused people to become more active.

In terms of the simulation details, we lowered α_t—a variable capturing the decline in economic activity—by 1 or 3 percentage points when the Games would take place.[9] Admittedly, changing α_t in this way may not fully capture what would occur in reality, but this exercise provided a simple way to quantify the importance of the indirect effect.[10]

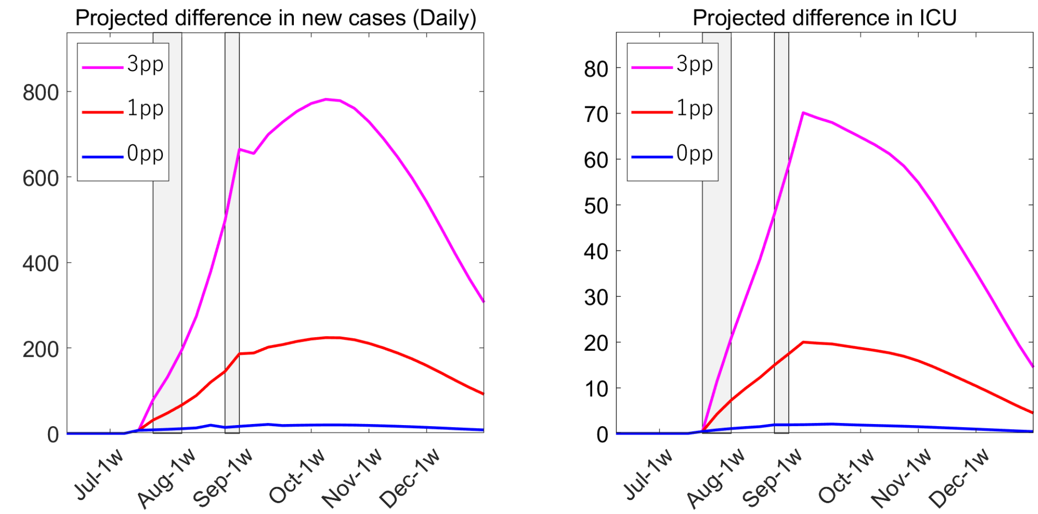
Figure 6 displays the effects of higher α (1 or 3 percentage points) on new cases and ICU relative to the no-Games case. The blue lines at the bottom are the same lines as those in Figure 3. According to the figure, the effects of mobility change among residents would be much larger than those of increased inflows of visitors. Taking averages over the periods of July-September and October-December, the differences in new cases were about 130 and 160 for the 1 percentage point case and 450 and 570 for the 3 percentage point case. When there was no mobility change, the difference in new cases was about 15. For ICU, the average differences over the same periods were about 12 and 11 for the 1 percentage point case and 41 and 39 for the 3 percentage points case, whereas it was at most 2 in the case of no mobility change. Thus, our analysis suggested that changes in mobility would have a greater impact on the spread of COVID-19 than the inflow of the Games-related foreign visitors.

The key reason why the indirect effects are much larger than the effect of foreign visitors is the size of the population directly affected. The indirect effects are about how the Games would affect the behaviors of the entire population in Tokyo—about 14M—which is much larger than the number of Games-related foreign visitors. Thus, even a small change in the behaviors of Tokyo residents could lead to a large increase in the number of new COVID-19 cases.

[9] Note that the difference in α_t between November 2020 and January 2021 was about 3 percentage points: in November 2020, economic activities were at the highest level within the year since the pandemic started, and the economy slowed down in January 2021 due to the second SOE issued by the government.

[10] This approach of quantifying the indirect effect of the Games is consistent with that taken in Furuse et al. (2021).

Figure 6: Indirect effects of the Games: May-21 Report



Source: Authors' calculation.

3 June 17 reports

The effects of the Games on infection would not be limited to those associated with the Games-related foreign visitors; some Tokyo residents would also go to watch the Games or volunteer at the competition venues. While the infection risk at the competition venues was thought to be very small, spectators and volunteers might engage in high-risk behaviors—such as going to restaurants and bars with friends—after watching the games or volunteering. If spectators and volunteers were more likely to contract COVID-19, so were their families and friends. We call these effects on infection associated with spectators and volunteers the "spectator effects."

In this section, we present our analyses of the spectator effect from the June-17 report. At the time of the analysis, we did not have enough time to collect information on the expected number of spectators for the Paralympic Games. Thus, our analysis solely focused on spectator effects for the Olympic Games.

We used two distinct models to quantify the spectator effects. The first model was an agent-based model, which one of us—Asako Chiba—used throughout the COVID-19 crisis to advise the Japanese government. Chiba's model is similar to that of Kerr et al. (2021). The second model was a multi-group macro-SIR model that is a variant of Fujii and Nakata (2021a). As a general principle, it is better to address the same issue using different models to see the robustness of key results from each model. For this report, the Fujii-Nakata team collaborated with Asako Chiba, hoping to provide the public with more robust analyses than each of us could individually.

3.1 Model

3.1.1 An agent-based model

The first model we used to investigate the spectator effects is an agent-based model. The structure of the model is largely identical to the one employed in Chiba (2021a) and Chiba (2021b), which is based on the work by Kerr et al. (2021).

The agent-based model describes the process where the virus spreads through people's contacts in various places—layers—when people's detailed attributes are given. To analyze the direct impact of the spectators' mobility, we modify the model used in Chiba (2021a) and Chiba (2021b) in the following five ways. First, the model introduced restaurants and bars—widely believed to be the riskiest places where the infections occur during the Olympic Games—as a layer. Second, in correspondence to the first modification, we added people's eating habits to their attributions. Third, the expected number of contacts in each place, which had been set to a fixed value in Chiba (2021a) and Chiba (2021b), was modified to be adjusted dynamically depending on the size of the population there. Fourth, as the analysis focuses on the short-run effects in Tokyo, we use only the census data of residents in Tokyo to obtain the joint probability distribution of attributions. Finally, we abstracted from people's flow between other prefectures and Tokyo.

To reproduce the population in Tokyo, we created agents using the joint probability distribution of age, sex, schooling/ working status, industry, and family members obtained from the latest census data, as of 2015. The number of agents was 72,771, which means that the population was scaled down to 1/192. Using a survey conducted in March 2011 by Nomura Research Institute [2020], we set the frequency of eating out to three times per week for 25% of all residents in Tokyo, twice per month for 44%, and never for 33%. Agents interact with each other at six layers, namely: home, workplaces, nursing homes, high and low-risk restaurants and bars, and other general activities. In each layer, each person contacts a certain number of people. These contact groups at home, workplace, and nursing home were determined at the beginning of the first period,[11] and kept fixed in the subsequent periods. Contacts in high and low-risk restaurants and bars are updated every period depending on the number of spectators for the Games and their eating habits. At the beginning of every period, people were randomly selected with probabilities reflecting their frequencies of eating out. Of all visitors to bars and restaurants, 10% and 90% were assumed to be in high and low-risk bars and restaurants, respectively (Foodist 2021). Similarly, contacts in the layer of

[11] One period in the simulations corresponds to one day.

the other general activities were shuffled every period.

Virus transmission from an infected person to a non-infected person occurs with a certain probability when the people come into contact with each other. The probability depends on the relative risk of infection defined for each layer, the transmissibility of the infected person determined by their viral loads, and the susceptibility of the non-infected person.

During the period of the Olympic Games, a certain number of residents in Tokyo were expected to watch the games in competition venues and live broadcasting events.[12] The greatest concern was that a certain fraction of the spectators would stop by bars and restaurants before or after the games. People's gathering in stadiums and live broadcasting places itself was not regarded as risky. In fact, the TOCOG had been planning to set strict rules on spectators' behaviour in stadiums in the case they were allowed. Therefore, our analysis focused on the increase in the number of contacts in high and low-risk bars and restaurants, abstracting from the possibility of infection taking place in stadiums and live broadcasting places, which was widely believed to be minor.

3.1.2 A multi-group SIR model

The second model used to investigate the spectator effects was a multi-group extension of Fujii and Nakata (2021a). We allow for four groups indexed by $j \in J = \{1, 2, 3, 4\}$. $j = 1,\ 2,\ 3$ are for groups of people who go to a competition venue during the first, second, and third week of the Olympic Games, respectively. $j = 4$ indicates a group of people who do not go to the competition venues.[13]

One key difference between a single-group SIRD model and a multi-group SIRD model lies in the determination of the number of newly infected people. In a single-group SIRD model, the number of newly infected people is proportional to the matching between the susceptible and infectious populations. In a multi-group SIRD model, the number of new cases for group i is determined by the matching between the susceptible population i and all the infectious population $j \in J$. The relative contribution of each matching is determined

[12] For simplicity, we assumed that all of the spectators were residents in Tokyo.

[13] One important remark is that we assume that the four groups are different from each other only concerning the decision and timing of being at the venues during the Olympic period, either as spectators. In other words, we do not consider the different characteristics and behaviors among the four groups except whether they visit the competition venues on a specific date. In reality, a spectator who decided to watch the Olympic Games might be less concerned about the spread of disease than the rest of the population. In this case, representative spectators might have higher contact rates than non-spectators do, from which we abstract. In addition, agents in a model economy do not form an expectation of the future state of the spread of COVID-19 and economic activity. Hence, a representative individual in a spectator group acts exactly the same as a non-spectator group, except when the spectator group is present at the competition venues. Therefore, the model can be reduced to a single-group SIRD (Susceptible-Infected-Recovered-Dead) model up to the first week of the Olympic Games.

by contact rates $\rho_{ij,t}$ where $i, j \in J$. Here, ρ_{ij} denotes a contact rate between the infectious group i and the susceptible group j. See Online Appendix B for the detailed explanation of a multi-group SIRD model used in this paper.

In the space below, we discuss the details of the contact rates ρ_{ij}. Let P_t be a contact matrix whose elements are contact rates $\rho_{ij,t}$. Diagonal elements—$\rho_{ii,t}$—represent the relative risk of infection of a matching within one particular group $i \in J$ at time t. For instance, $\rho_{11,t}$ represents how likely the matching between the susceptible population among the first-week spectators and the infected population among the first-week spectators produces new cases within the first-week spectators at time t. As discussed above, agents in group $i \in \{1, 2, 3\}$ are different from the rest of the population only in the ith week of the Olympics. Therefore, $\rho_{ii,t} = 1$ when $t \neq T_i$ where T_i denotes the ith week of the Olympic Games. The contact rate ρ_{ii,T_i} captures the relative likelihood of infection resulting from the interaction among the spectators at ith week of the Olympic Games.

Off-diagonal elements—$\rho_{ij}(i \neq j)$—represent the relative strength of the matching between the susceptible population among group i and the infectious population among group j. For instance, ρ_{12,T_2} indicates how likely the matching between the susceptible population in the first-week spectators and the infectious population in the second-week spectators resulted in new cases among the first-week spectators at the second week of the Olympics. In other words, the effects of increased mobility of the second-week spectators on the new cases among the first-week spectators in the second week of the Olympics are captured by ρ_{12,T_2}. We assume that the interaction between the susceptible group i and the infectious group j resulted in a greater number of new cases among group i only when the infectious group j is the spectators at time t. Hence, we impose the following restriction: $\rho_{ij,t} = 1$ if $t \neq T_j$.

Next, we briefly discuss how the values of contact rates are determined. As discussed above, the contact rate $\rho_{ij,t}$ captures the relative increase of infection risks among group i caused by the interaction with group j at time t. In the context of this study, the increase in infection risks is due to the behavioral changes of spectators during the weeks of the Olympic Games. Hence, the values of contact rates ρ_{ij,T_j} can be calculated if we can quantify the relative increase of infection for group i caused by the spectators at jth week of the Olympics. To quantify this relative increase in infection risks, we follow the method used by Chiba (2021). In the model, the relative increase of infection is based on the parameters controlling the relative infection risks at several locations estimated by Chiba (2021a), the size of spectator groups, and their behaviors after watching the Olympic Games.

The behaviors of the spectators are measured by the likelihood of visiting restaurants after watching the games, denoted by $(1 - p)$, and by the ratio of high-risk restaurants, denoted by q. For instance, if more spectators visit high-risk restaurants after watching the games, they are exposed to higher infection risks. In addition, non-spectators who are at the restaurants also face higher infection risks as the number of people at the restaurants is higher than usual, as some spectators are there additionally.

For the share of visitors who go straight home, we choose the following three values: $p \in \{0.2, 0.5, 0.8\}$. The ratio of high-risk restaurants in Tokyo, q, is set to 0.4 in all simulation cases. The exact parameter values for each scenario are reported in Table 4. Based on the parameter values, we can calculate the relative infection κ and thereby the contact rates $\rho_{i,j}$. The resulting diagonal and off-diagonal elements of each scenario are presented in Table 5. As expected from the construction, the relative risk is higher if the number of spectators is larger, and more people dine at restaurants after visiting the venues. We also observe that the decrease in the diagonal elements of a contact rate matrix is more significant if we reduce the probability of dining out at restaurants after the Games.

Table 4: Key Parameters

Variable	Symbol	Values
Size of first-week visitor	n_1	$\{542860, 336430\}$
Size of second-week visitor	n_2	$\{1608824, 895412\}$
Size of third-week visitor	n_3	$\{1208606, 695303\}$
Probability of going straight home	p	$\{0.2, 0.5, 0.8\}$
Probability of high-risk restaurants	q	0.4

Table 5: Elements of the Contact-Rate Matrix

Diagonal Elements

	$p = 0.2$	$p = 0.5$	$p = 0.8$
100% Spectators	6.51	4.27	2.56
50% Spectators	5.70	3.95	2.51

Off-diagonal Elements

	$p = 0.2$	$p = 0.5$	$p = 0.8$
100% Spectators	1.10	1.06	1.02
50% Spectators	1.06	1.04	1.01

For the size of spectator groups, we consider two cases. In the first case, we assume that all individuals who purchase the tickets watch the Games at the competition venues. In the second case, we assume that 50 percent of individuals who have tickets watch the Games on site.[14] Based on these assumptions and the estimated number of spectators each day reported in Figure 2, we compute the size of each group $j \in \{1, 2, 3, 4\}$, denoted as n_j.

[14]We assumed that it was not possible to reduce the number of volunteers for managing the Olympic Games. Hence, the number of volunteers is 26,000 for each case.

The initial period of the simulation is the third week of June, denoted as T. The projected path of fatality rates, the severity rate, and the raw transmission rate in the baseline without spectators are determined in a way that is similar to how they are set in Fujii and Nakata (2021a) and is described in Online Appendix B.3.

As a baseline, we simulated the model assuming that no spectators were allowed. Then, we considered six scenarios in which spectators are allowed. The six scenarios are differentiated based on two dimensions: the size of spectator groups and the share of those who go straight home.

3.2 Effects of Spectators

3.2.1 An agent-based model

Table 6 illustrates the scenarios tested in the simulations. Scenario 1 is the case without any spectators, whereas Scenarios 2, 3, and 4 are cases with spectators. Scenario 2 is the baseline case when spectators are allowed. In this base case, the number of spectators is 243,000 per day.[15] 20% and 40% of them visit high- and low-risk bars and restaurants, respectively; 40% go straight back home. In Scenario 3, the proportion of people who go straight back home is doubled to 80%. In Scenario 4, the total number of attendance is doubled to 486 thousand, with the proportion of visiting bars and restaurants is the same as in Scenario 2.

Table 6: Key parameter values in the agent-based model

Scenario	Number of spectators	High-risk layer	Low-risk layer	No-risk layer
Scenario 1: w/o spectators	-	-	-	-
Scenario 2: with spectators (baseline)	423,000	20%	40%	40%
Scenario 3: with spectators (proportion of going straight home is doubled)	243,000	7%	13%	80%
Scenario 4: with spectators (total attendance is doubled)	486,000	20%	40%	40%

We also consider other interventions that have been implemented in reality: PCR tests were conducted on 30% of the symptomatic cases every day, and those who tested positive were quarantined. We set the test sensitivity to 70%. As for the vaccines, all healthcare workers and 50% of the elderly aged 65 and above were assumed to have finished the second dose as of the opening ceremony. We set their susceptibility to 5% of that before vaccination (Polack et al. (2020)). As working-from-home was still partly in place, workers who were in

[15]For simplicity, we call the sum of actual spectators and volunteer staff as the number of spectators. 150,000 people visit stadiums— which was estimated using the number of tickets sold and refunds—67,000 people visit live broadcasting places, and 26,000 people attend as volunteer staff. See Online Appendix A for the derivation of these figures.

teleworkable jobs were assumed to work from home with probability 50% (Chiba (2021a) for the definition of teleworkable jobs). As the mobility decreased due to the requirement that bars and restaurants should close at 20:00, the probability that people attend in the layer of high and low-risk restaurants and the other general activities are assumed to decrease by 50% of the normal times.[16]

Once people in the model have contracted the virus, they probabilistically get worse or recover. As they develop symptoms, they become noninfectious, presymptomatic, moderate, severe, critical, and die in the worst case. The probabilities with which infected people get worse or recover depend on their age group. The duration of transition from one status to the next is assumed to follow a log-normal distribution with the moments defined for each status.

Figure 7 shows the projection of daily confirmed cases during the Olympic Games and the subsequent 10 days. The assumptions common to all scenarios are that the daily confirmed cases are 400 and that the number of recovered is 200,000 as of July 23rd, the opening day of the Games. The results shown are the average value from 1,500 simulations.

Scenario 2—the baseline case with spectators—adds 41 cases per day and 54 cases per day on the closing day and 10 days thereafter to those in Scenario 1–the case without any spectators. The additional cases are smaller when we double the proportion of going straight back home: the differences between Scenarios 1 and 3 are 26 on the closing day and 36 in 10 days. In Scenario 4 where we double the total number of attendance, the additional cases are 232 on the closing day, which expands to 313 in 10 days.

To summarize, under the reasonable assumption regarding the total number of attendance and the rate of visiting bars and restaurants, the direct effect of allowing spectators on the cases is manageable. The reason is that the total number of attendees is relatively small compared to the size of the population in Tokyo: 243,000 spectators in Scenario 2 account for only 1.7% of the total population in Tokyo. Thus, even if 20% of those who come to stadiums and live-broadcasting places drop in at high-risk bars and restaurants, virus expansion is not markedly affected.

Nevertheless, it is worth noting that allowing spectators increases the risk of infection at the individual level. Table 7 demonstrates a rough calculation of the amount of risk in each layer and in total.[17] As noted earlier in this section, people in the model are likely to get infected if they come into contact with many others at a place where the relative likelihood of transmission is high. Thus, one can roughly evaluate the risk at the individual level in

[16]Contacts among teachers and students at schools are ignored because they were closed for summer vacation during the period of the Olympic Games.

[17]We abstracted from nursing homes. Only a small proportion of the total population in Tokyo live in the nursing homes.

each layer by multiplying these two factors, and the total risk by summing up the risk in each layer. As shown in Table 7, the total risk that a person is exposed to amounts to 129.0 if she visits high-risk bars and restaurants, which is much higher than 4.7, the amount of risk without any involvement in the high-risk activities. Such a simple calculation reveals that the total amount of risk faced by individuals who visit high-risk bars and restaurants when spectators are allowed is substantially higher than that of average individuals when spectators are not allowed. However, such changes do not significantly affect the situations at the macro-level, as the number of visitors to high-risk bars and restaurants during the Olympic Games is limited in size.

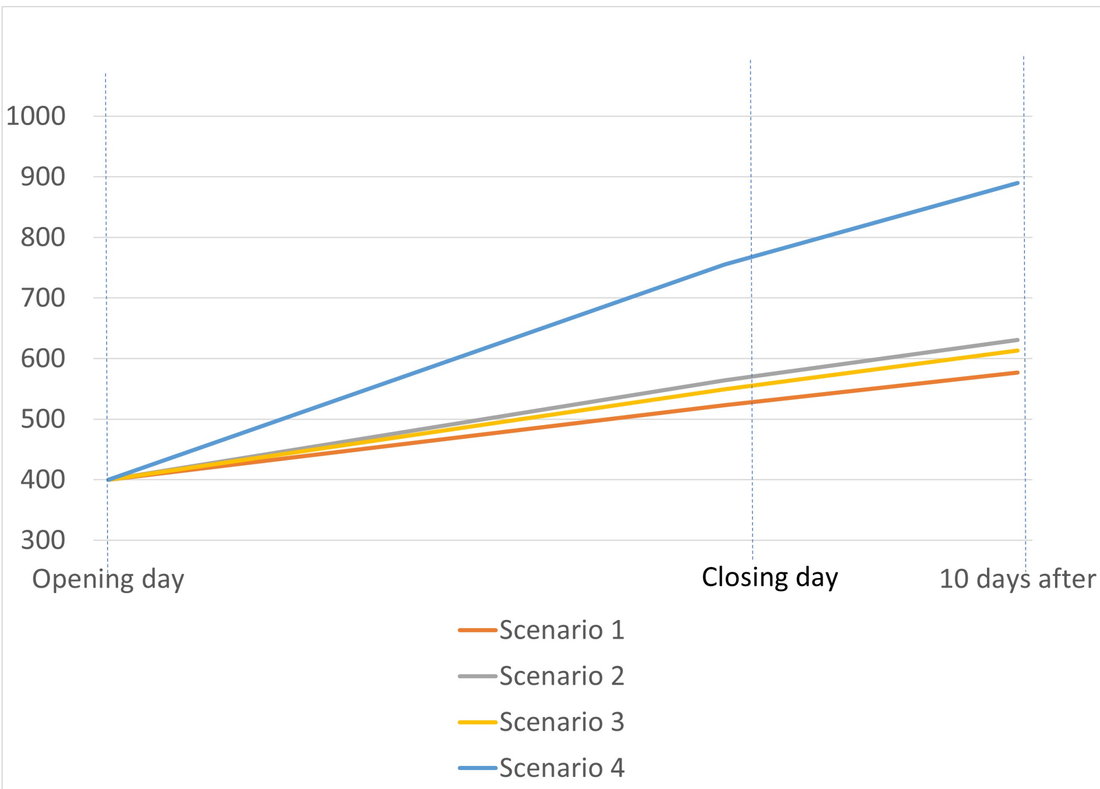


Figure 7: COVID-19 cases in Tokyo during the Olympic Games and the subsequent 10 days.

3.2.2 A multi-group SIR model

Table 8 shows the spectator effects of the Games on the number of new cases per day. We report the largest deviation values from the baseline "no-Games" case. In all the scenarios we considered, the largest deviation occurred in the first week of August, which is the last week of the Olympic Games.

As expected from the characteristics of the contact rate matrix, the number of newly infected people will increase as the number of spectators and the probability of dining at

Table 7: Risks in each layer and in total

	Home	Workplace	High-risk bars and restaurants	Low-risk bars and restaurants	Other general activities	Total risk
(a) Relative likelihood of transmission	0.8	0.04	25	2	0.3	
	(Representative person in Scenario 1)					
(b1) Expected number of contacts	2.25	10	0.026	0.234	4.5	
(c1) Relative risk (a) * (b1)	1.8	0.4	0.65	0.468	1.35	**4.7**
	(Visitor in high-risk bars and restaurants in Scenario 2)					
(b2) Expected number of contacts	2.25	10	5	0.234	4.5	
(c2) Relative risk (a) * (b2)	1.8	0.4	125	0.468	1.35	**129.0**

Table 8: Direct Effects on Daily Number of Newly Infected (First Week of August)

	$p = 0.2$	$p = 0.5$	$p = 0.8$
100% Spectators	+ 81	+ 49	+ 22
50% Spectators	+ 24	+ 15	+ 7

restaurants increase. In the worst-case scenario in which 80 percent of total ticket holders do not go straight home after visiting the venues, the average number of newly infected individuals on a day would increase by 81. However, if we could restrict the number of spectators by half and successfully reduce dining-out rates, this increase would be limited to 7 new cases per day.

In addition, the decrease in spectators by half would reduce the number of new cases by more than a factor of two. In the model, the number of new cases for the spectator groups is determined by a quadratic matching of the susceptible and infected populations. As we assume the constant fraction of each group j is distributed across susceptible and infected populations, doubling the number of spectators roughly doubles the number of susceptible and infected individuals in each group. Therefore, the newly infected cases will be roughly quadrupled through quadratic matching, as both $I_{j,t}$ and $S_{j,t}$ are roughly doubled, even if the reduction in contact rates is not as significant as in a case of a low dining-out probability. Still, encouraging the spectators to go straight home could mitigate the direct effects, even if we allowed all ticket holders to watch the Games at the competition venues.

3.3 Indirect effects

We modeled the indirect effects as the increase in the transmission rate $\tilde{\beta}_t$ from one week prior to the start of the Olympic Games to one week after their conclusion. It has two interpretations. The first interpretation is the increase in the raw transmission rate β_t, as individuals reduce the degree of preventive measures at the individual level, such as reduced mask usage. The second interpretation is the increase in mobility. People might socialize with their friends more frequently under the festive atmosphere of the Games. We meant to capture capture both types of behavioral changes by the increase of $\tilde{\beta}_t$.

We specified the increase in the transmission rates in the following manner. First, we assumed that the transmission rate would increase to the level of a period between the end of March to the middle of April. The transmission rates were relatively high during this period, reflecting the end and beginning of Japan's academic and business year. According to our estimate, the average transmission rate from the end of March to the middle of April was 23 percent higher than the recent four-month average. Second, we allocated these increases to the five weeks, from the third week of July to the second week of August, in the following manner: 30 percent weight for the third week of July, 80 percent weight for the Olympic period, and 30 percent weight for the second week of August. Thus, the transmission rate would increase by 7 percent in the week before and after the Olympic period and by 19 percent during the Olympic period. These weights were equivalent to assigning 100 percent weight for the Olympic period only. As a sensitivity analysis, we also considered the case in which the transmission rate would increase only by half of the baseline magnitude.

Figure 8: Indirect effects of the Games: June-17 Report

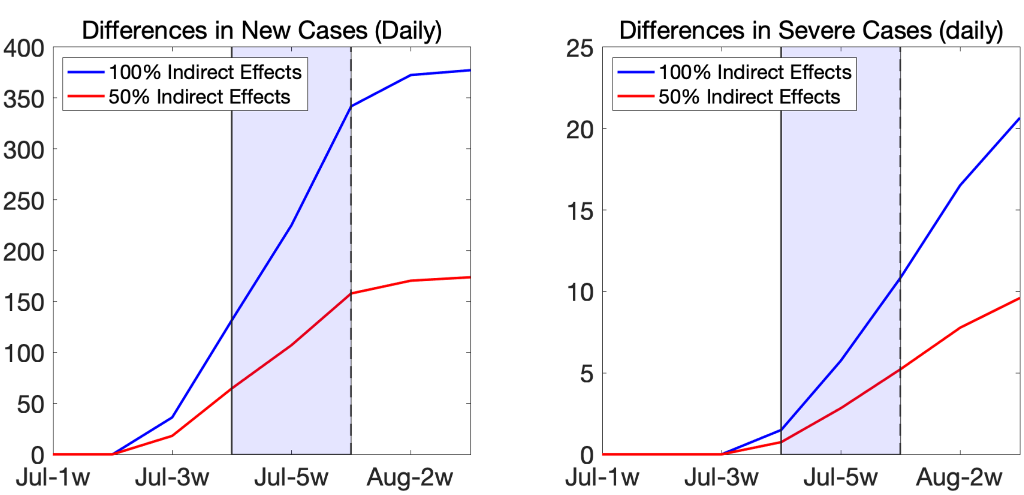


Figure 8 shows the differences in new cases and severe cases between the baseline scenario and each of the two scenarios with the indirect effects. According to the figure, the indirect effects would be much larger than the spectator effects. In the second week of August, new cases increased by almost 350 per day. This increase would be more than three times as many as the largest deviation in the direct effects. In addition, the increase of new cases and severe cases in the second week of August in the full effect case would be slightly more than twice as much as the increase in the half effect case. This larger response reflected cumulative effects over time. If the number of newly infected individuals increases, the size of the infected population would also increase. This increase would further increase the number of newly infected people and severe cases in the next week.

3.4 Key takeaways

In our June-17 report, beyond our quantitative analysis, we emphasized the following two messages. First, the spectator effect and the indirect effect could not be separated. If the government allowed a large number of spectators in competition venues, some may perceive it as a signal that COVID-19 was under control and become less cautious. That is, allowing a large number of spectators in competition venues could amplify the indirect effect. We used the term the "announcement effect" to emphasize the inseparable nature of the spectator effect and the indirect effect associated with the Games.

Second, we emphasized the uncertainty in the COVID-19 outlook throughout the Games and recommended that the TOCOG and the government remain flexible in the number of spectators allowed. The TOCOG and the government were planning to announce the number of spectators in the second half of June, a month before the Games. In one month, the COVID-19 situation in Tokyo could change dramatically. Thus, there was a benefit in leaving flexibility, as opposed to making a firm non-state-contingent commitment regarding the number of spectators at this stage. In particular, we emphasized—regardless of the number of spectators they would announce in June—the need for them to clearly communicate to the public that, if infection rapidly increased prior to, or during, the Games, they would be ready to ban all spectators in competition venues.

4 Ex-post Evaluation

This section is an updated version of the report we released on August 20, 2021. We updated our evaluation, taking into account the empirical estimates of the causal effects of hosting the Olympic Games, adding a new discussion on successes and failures of our original analyses, and providing lessons for real-time analyses in a future pandemic.

4.1 Effects of foreign visitors

Table 9: Our Assumptions/Predictions versus Actual Values/Estimates of the Actual Values

Key Assumptions	Our Assumption	Actual Values
The number of Foreign Visitors (May 21)	105,000	58,000
The average number of new daily infections during the Olympic period in Tokyo (May 21)	500	
The average number of new daily infections during the Olympic period in Tokyo (May 21)	600	2,816
Effects on New Daily Infections	**Predicted Effects**	**Estimates of Actual Effects**
Effects of Foreign Visitors (May 21)	15	12
Effects of Spectators (June 17)	[10, 80]	N/A
Indirect Effects (May 21)	[40,140]	0-1,100
Indirect Effects (June 17)	[100,250]	

Notes. These original reports—written in Japanese—are at `https://covid19outputjapan.github.io/JP/resources.html`.

What were the effects of foreign visitors during the Olympic period? According to data published on the TOCOG website regarding the number of positive COVID-19 cases among Games-related visitors, staff, volunteers, and contractors, there were 863 positive cases between July 1 and September 8, resulting in an average of approximately 12 new cases per day.

The effect of foreign visitors could be smaller or larger than the observed positive cases for two reasons. First, the observed positive cases do not include secondary (or higher-degree) transmissions. This consideration suggests that the effect of foreign visitors is larger than the observed cases. Second, given the rapidly rising number of cases in Tokyo during the period, some of the Games-related infections likely occurred outside the Olympic venues. Indeed, among the 863 positive cases reported by the TOCOG, 609 cases were residents of Japan. Some of these cases may not be traced back to infected foreign visitors. This consideration suggests that the effect of foreign visitors is smaller than the observed number. With these two factors working in opposite directions, it is difficult to provide a definitive answer as to whether the effects of foreign visitors are larger or smaller than the number reported by the TOCOG.

With this caveat in our mind, we judge that the predicted effect in our May 12—15 per day—is sensible to the extent that the number of observed positive cases—12 per day—is a good approximation of the effect of foreign visitors,

We assumed that the number of Games-related foreign visitors would be 105,000, but the actual number was around 58,000. We had assumed that the average number of new daily infections would be around 500 during the Olympic Games, but the actual number was approximately 2,800—almost six times as many. If we were to rerun our simulation using these two actual numbers, we would like to obtain an estimate greater than 15. A simple multiplicative extrapolation is not accurate because the model is nonlinear, but such a simple back-of-the-envelope calculation suggests an adjusted estimate of 47. Because we computed the upper bound estimate by assuming that Olympic athletes would behave as casually as normal citizens, the adjusted number of 47 is still sensible.

The key qualitative takeaway of the analysis was that the direct effects of foreign visitors would likely be limited. Regardless of whether evaluating our predicted effects unconditionally or conditionally—conditionally on the actual path of infection and the actual number of foreign visitors—the qualitative takeaway turned out to be sensible.

4.2 Effects of spectators

On July 8—about three weeks after our analysis and two weeks before the Games began—the government decided not to allow spectators at the competition venues in Tokyo in response to the rapid increase in new cases. Thus, it is infeasible to compare our analysis against data.[18]

4.3 Indirect effects

The effects of foreign visitors is quantitatively small and spectators were not allowed in event venues. Thus, we could interpret the overall effects of hosting the Olympic Games as largely capturing the indirect effects.

Three papers employ synthetic control methods to causally estimate the overall effects of hosting the Olympic Games on infection in Tokyo or Japan. Yoneoka et al. (2022) estimate that the effects on daily infection from July 23 to August 8 are around 54,000 per 1 million population.[19] This estimate means about 320 new daily infections in Tokyo. Esaka and Fujii (2022) provides eight different estimates, all of which are higher than 1,000 and average around 1,100.[20] Yamamoto et al. (2022) provide two estimates based on two alternative specifications: one is around 1100 and the other is around 0.[21]

[18] There were volunteers at the venues, who could have contributed to the spread of the virus. However, given their relatively small size, we conjecture that the effect of volunteers on COVID-19 in Tokyo was minimal.

[19] They report that the observed cumulative number of cases was 61 percent higher than the counterfactual trajectory, comprising 143,072 to 89,210 confirmed cases (p=0.023) respectively.

[20] Their tables report estimated effects on average new daily infections from July 23 to August 22, but their figures show the daily path of estimated effects. We used these figures to compute the estimated effects from July 23 to August 8.

[21] They reported the path of the effect on new daily infections through September 30, 2021, in their figures 3 and 7. We obtain the estimates for the Olympic period from these two figures.

Thus, we have a wide range of empirical estimates, suggesting a high degree of uncertainty. Note that these estimates discussed in the previous paragraph are point estimates. Some estimates are provided with a confidence interval, which tends to be wide. The wide range of point estimates—as well as the large confidence intervals for these estimates—is understandable because computing the counterfactual path of infection in the case of no Olympic Games presents several identification challenges, as discussed in Online Appendix E.

Unconditionally, our numbers in both May-21 and June-17 reports fall in the lower range of available empirical estimates. If we were to rerun our simulation using the actual number of the new daily infections during the Olympic Games, our numbers would have been much higher. A simple multiplicative extrapolation suggests [225, 788] in the May-21 report and [469, 1173] in the June-17 report. These adjusted numbers are more in line with the range of available empirical estimates.

The key qualitative takeaway from both reports was that the indirect effects could be very large. This takeaway is consistent with the fact that some of the empirical estimates discussed above do point to a very large effect of hosting the Olympic Games.

4.4 Evaluation

We characterize our analysis of the effects of foreign visitors as a success. Our key takeaway was qualitatively sensible. Our estimate was also quantitatively sensible—both unconditionally and conditionally—in light of the available empirical evidence.

We characterize our analysis of the indirect effects as a mixed success. Although the qualitative takeaway and the adjusted estimate—conditional on the actual path of new daily—are sensible, the unconditional estimates all fell in the lower end of the range of available empirical estimates.

Looking at Table 9, the most salient gap between our analysis and the actual data or empirical estimates is the assumed path of new daily infections during the Olympic Games. It would have been better for us to adopt a higher infection path as the baseline and/or at least consider a few additional alternative scenarios featuring a much higher infection path. Based on the available information at the time of our analysis, could we have done that? We argue that, though our baseline assumption is not as groundless as one would think ex-post, we could have done better.

In mid-May and in the first half of June when we were preparing the reports, new daily infections were either rapidly declining to a low level or stable at a low level. Although the risk of the delta variant was well recognized, the timing and consequences of the spread of the delta variant were highly uncertain. Also, based on how the government issued the state-of-emergency order and how people responded to it in previous waves, it was reasonable to expect that the government would consider issuing the state-of-emergency order if the number of new daily infections exceeded 1,000, and that the public would respond by refraining from going out.

However, we argue that it would have been possible for us to adopt a higher infection path as the baseline and/or at least consider a few additional alternative scenarios featuring a significantly higher infection path, especially for our June-17 report. There are three factors: (i) the availability of more pessimistic forecasts, (ii) a heightened sense of urgency among some infectious disease experts, and (iii) a high degree of uncertainty in infection dynamics during a pandemic.

Although no other projection was available for the Olympic period in mid-May when we were preparing the May-21 report, there were a few other infection projections available in the first half of June when we were preparing the June-17 report.[22] And, at least one of them projected an infection path that turned out to be even higher than the actual path, suggesting a considerable uncertainty in the infection outlook. It would have been prudent for us to consider such an alternative scenario in our report.[23]

We occasionally communicated with infectious disease experts involved in policy advice. As discussed earlier, we sent the drafts of both reports to them prior to the releases and asked for their feedback. However, our communication with them was still limited. Frequent communication with them would have made us more aware of the risk of the delta variant earlier and might have prompted us to adjust our baseline and consider a few additional risk scenarios.

Our failure to consider a higher baseline infection path in the June-17 report also reflects a failure to fully appreciate the high degree of uncertainty regarding infection dynamics during a pandemic. For example, the public responded to the fifth infection wave of July and August 2021 differently compared to previous waves, making the fifth wave substantially larger than the previous ones. In a pandemic, many factors affecting infection dynamics—variants, vaccines, and the public's willingness to accept various NPIs—are time-varying. As a result, the next infection wave could be quite different from previous waves. In such a situation, it would be prudent to consider a wide range of alternative scenarios.

In summary, our experience suggests that if future researchers were to conduct a real-time analysis during a pandemic, they would be better off if they (i) pay close attention to a

[22]On June 9, Nishiura (2021) and the National Institute of Infectious Diseases, independently, presented the first projections of the proportion of the Delta variant at the Advisory Board on COVID-19 (MHLW).

[23]In the June-17 report, we did consider an alternative scenario where the number of daily new infections during the Olympic Games was around 1000. Even that scenario seems too optimistic in retrospect.

wide range of contemporary analyses by other researchers, (ii) communicate more frequently with infectious disease experts, and (iii) consider a wide range of alternative scenarios to take into account a high degree of uncertainty in infection dynamics during a pandemic.

5 The Impacts of Our Real-Time Analyses

In this section, we present the public impact of our real-time analysis (media coverage and actual policy changes) and how it could have affected the discrepancies between our models and the actual infection path during the Games.

5.1 Media citation and policy presentation

We began our analysis of the effect of the Games on the spread of COVID-19 on May 12, 2021. We completed the analysis on May 18 and circulated the first draft of our report to members of the Office for COVID-19 and Other Emerging Infectious Disease Control (Cabinet Secretariat), the Subcommittee on Novel Coronavirus Disease Control, and the Advisory Committee on the Basic Action Policy on May 19. After incorporating the comments we received from them—which were largely positive—we posted the report to our website on May 21.

At 6 pm on May 23, we held an online press conference to present our analysis to the public. About 60 people—mainly from the media— attended the press conference. We also presented our report at an informal online study group of public-health experts at around 9pm on the same day. A few Media outlets reported our analysis on the following day. Over the next few weeks, both domestic and foreign media reported our analysis. See Table 10 for media citations.

On May 25, we informally presented our analysis to several members of the Tokyo Organizing Committee of the Olympic and Paralympic Games (TOCOG). On May 28, we were invited to present our work at the Second Round-Table Meeting with Experts organized by TOCOG. See Table Table 11 for the list of policy presentations.

On June 2, we initiated our analysis of the impact of spectators on the spread of COVID-19. On June 16, we completed the analysis and circulated a set of reports to some members of the aforementioned Offices and Committees, as well as the TOCOG. After incorporating the comments we received, we released the reports to the public on June 17. On the same day, we held an online press conference, attended by approximately 50 people. Over the next several days, Japanese media outlets reported our analyses. We were again invited to present our analyses at the Fourth Round-table Meeting with Experts by the TOCOG on

Table 10: Selected Media Coverage

Date	Media	Title
		May-21 Report
May 23	Sankei Shinbun (2021)	The Effects of Olympics-related Foreign Visitors "Limited": An Estimate from the University of Tokyo
May 24	NHK (2021)	How Would the Olympic Games Affect Infection? An Estimate from the University of Tokyo
May 24	Nikkei (2021a)	The Effects of Olympics-related Foreign Visitors "Limited": Limiting People's Movement Needed
May 25	Asahi Shinbun (2021a)	Limiting People's Movement Key to Holding "Safe" Olympics: Study
May 26	Wall Street Journal (2021)	Japan Looks to Extend Covid-19 State of Emergency
May 28	Kyodo Tsushin (2021)	More Movement During Tokyo Games May Increase Infections: Expert
May 30	Jiji Tsushin (2021a)	The Olympic Games: Limiting People's Movement Key, Effects of Foreign Visitors Limited. An Estimate from the University of Tokyo
June 8	Financial Times (2021)	Tokyo warned locals pose greater Covid risk to Olympics than visitors
June 12	BBC News (2021)	Tokyo Olympics: Why people are afraid to show support for the Games
		June-17 Reports
June 17	Jiji Tsushin (2021b)	Olympics spectators: Going to restaurants and bars spreads infection. Going home straight key.
June 18	Asahi Shinbun (2021b)	Olympics-related Events Could Increase Infection by Hundreds
June 18	Nikkei Shinbun (2021)	People's Movement Likely to Increase After the SOE: Possibility of another SOE during the Olympic Games
June 21	Mainichi Shinbun (2021)	Festive Mood from the Olympics Could Increase Infection by Hundreds in Tokyo
June 21	Nikkei (2021b)	Spectators could reach 200 thousands per day. Going home straight key.

Table 11: Policy Presentations

Date	Presentation	Report
May 28	The Second Round-table Meeting with Experts by TOCOG	*The Effects of Hosting the Olympic and Paralympic Games on COVID-19: A Quantitative Analysis*
June 18	The Fourth Round-table Meeting with Experts by the TOCOG	*The Effects of the Olympic and Paralympic Games on COVID-19: Summary*
August 20	The Fifth Round-table Meeting with Experts by the TOCOG	*The Effects of the Olympic Games on CVID-19: Ex-Post Assessment*

June 18.

As soon as the Olympic Games concluded, we began our analysis of the ex-post evaluation. On August 20, we released our report on ex-post evaluation. We presented our report at the Fifth Round-table Meeting with Experts by the TOCOG on the same day. Overall, our real-time analyses were widely read by policymakers and the public in Japan.

5.2 The Impact on the government policy

How much of the impact did our analyses have on the Japanese government's decisions regarding the Olympic Games? We argue that our analyses likely played only a minor role in the key policy decisions, but might have played some role in helping the government and the scientific advisers communicate their decisions to the public more effectively than otherwise.

A large number of factors—including non-epidemiological ones—likely influenced the decision to host the Olympic and Paralympic Games in the summer of 2021. For example, the number of infections was often substantially higher in many American and European cities hosting large-scale sports events than in Tokyo. Postponing the Games for another year when the infection situation was favorable in the eyes of international participants would have been costly from the perspective of international politics. Many accounts of the Olympic Games suggest that the government's decision to host the Olympic Games was unwavering from the beginning, despite the strong opposition from many Japanese citizens at some point. Thus, it is highly unlikely that our May-21 report played any role in the government's decision to continue as planned.

However, our May-21 analysis—being the only quantitative risk assessment of the Olympic Games for about one month—was likely to be helpful for the government in communicating the risks involved in hosting the Olympic Games to the public. In particular, our analysis clarified the potential effects associated with foreign visitors versus those associated with increased mobility of Japanese citizens. Our analysis may have helped the government deliver the message of "It is possible to host the Olympic Games without materially worsening the infection outcome if Japanese citizens do not relax their social distancing behaviors," with some analyses to support the claim.

Our May-21 analysis was also likely to be helpful for experts in communicating the risks involved in hosting the Olympic Games to the public. On June 18, a group of public-health experts—"A Voluntary Independent Group of Experts for COVID-19 Response in Japan"—released a report called "Recommendations about COVID-19 risks related to holding the 2020 Tokyo Olympic and Paralympic Games" and handed the report to relevant parties including the Tokyo Organizing Committee of the Olympic and Paralympic Games and the Prime Minister.[24] The report emphasized indirect effects of the Games, echoing key takeaways from our May-21 and June-17 and using our simulation results in the May-21 report as well as Furuse et al. (2021) to support their key messages.[25]

Another key impact of our May-21 report was that it broke the taboo of analyzing the effects of the Olympic and Paralympic Games. Because the public debate over whether to host the Games became heated and emotional in the spring of 2021, many researchers were hesitant to conduct any analysis on this issue.[26] After our report, several researchers embarked on similar analyses. See Appendix E for more details.

Our June-17 reports were likely to be helpful for the government in communicating their initial decision in late June to allow some spectators at the event venues and the subsequent decision to reverse the course when the infection started to increase rapidly in mid-July. Our finding that the effects of allowing spectators at event venues would be manageable was supportive of the initial decision. Our finding that the indirect effect could be very large—especially if the infection situation is much worse than our baseline assumption—was supportive of the subsequent reversal when the number of infections started rising rapidly in early July.[27]

5.3 The Impact on the public

How much did our reports impact people's behaviors during the Olympic and Paralympic Games? Our reports informed the public about the risks involved in hosting the Olympic and Paralympic Games directly via media and indirectly via the government's communication. However, it is nearly impossible to gauge the extent to which our risk assessments affected their behaviors. Because the public was inundated with various pieces of information about infection by media and the government throughout the COVID-19 crisis, we conjecture that the marginal effects of our analysis on people's behaviors were likely to be quite limited.

When conducting an ex-post evaluation of a prediction, it is essential to consider the potential impact of the prediction on actual policy or behavior, particularly when the prediction has been widely disseminated to policymakers and the public. For example, if the public responded to our analysis on the indirect effect by behaving more cautiously to avoid infections, that would work to reduce the actual magnitude of the indirect effects. As discussed thus far in this section, we conjecture that the impact of our analyses on actual policy

[24] https://corona.go.jp/minister/pdf/kishakaiken_shiryo_20210618.pdf

[25] They used the term "contradictory messages" to refer to what we call "indirect effects."

[26] See Fujii and Nakata (2022).

[27] Our June 17 report emphasized the importance of being flexible about the decisions on allowed spectators and of managing the indirect effects of allowing spectators.

decisions and public behavior was likely quite limited, though our analyses were likely helpful for the government's risk communication. Thus, we judge that both the gap between the predicted and actual effects of foreign visitors and the gap between the predicted and actual indirect effects are unlikely to be significantly affected by this concern.

6 Conclusion

In this paper, we presented a series of quantitative analyses conducted from mid-May to mid-June of 2021, which examined the effects of hosting the Tokyo 2020 Olympic and Paralympic Games on the spread of COVID-19 in Japan. Our real-time analyses pointed out that (i) the effects on the spread of the disease of welcoming additional foreign visitors to Japan or allowing spectators in competition venues would be either limited or manageable, (ii) while the festive mood generated by the event could greatly contribute to the spread of the disease if it led to a decline in people's willingness to take preventive actions. Ex-post, we argue that our analysis of foreign visitors was a success, whereas our analysis of the indirect effect was a mixed success.

We also provided readers with the context in which our analyses were conducted and how the public and policymakers perceived them. We hope that our unique experience of using model-based analyses to contribute to a heated national debate in real-time can offer valuable insights for other researchers interested in informing policymakers and the public.

References

Asahi Shinbun (2021a). Limiting people's movement key to holding 'safe' olympics: Study. https://www.asahi.com/ajw/articles/14357743.

Asahi Shinbun (2021b). Olympics-related events could increase infection by hundreds. https://www.asahi.com/articles/ASP6K72H4P6KULBJ010.html.

BBC News (2021). Tokyo olympics: Why people are afraid to show support for the games. https://www.bbc.com/news/world-asia-57395010.

Chiba, A. (2021a). The effectiveness of mobility control, shortening of restaurants' opening hours, and working from home on control of covid-19 spread in japan. *Health & Place*, 70:102622.

Chiba, A. (2021b). The effects of the increase in human mobility associated with the games on covid-19. Technical report, Mimeo, 2021a.

Chiba, A., Fujii, D., and Nakata, T. (2021). The effects of the olympic and paralympic games on covid-19: Direct effects.

Esaka, T. and Fujii, T. (2022). Quantifying the impact of the tokyo olympics on covid-19 cases using synthetic control methods. *Journal of the Japanese and International Economies*, 66:101228.

Financial Times (2021). Tokyo warned locals pose greater covid risk to olympics than visitors. https://www.ft.com/content/9efb00cc-1445-4e4b-8e35-2b342091800e.

Fujii, D. and Nakata, T. (2021a). Covid-19 and output in japan. RIETI Discussion Paper Series 21-E-004, The Research Institute of Economy, Trade and Industry.

Fujii, D. and Nakata, T. (2021b). The effects of hosting the olympic and paralympic games on covid-19: A quantitative analysis.

Fujii, D. and Nakata, T. (2021c). The effects of the olympic and paralympic games on covid-19: Indirect effects.

Fujii, D. and Nakata, T. (2021d). The effects of the olympic and paralympic games on covid-19: Summary.

Fujii, D. and Nakata, T. (2021e). The effects of the olympic games on covid-19: Ex-post assessment.

Fujii, D. and Nakata, T. (2022). Covid-19 crisis: A tale of two economists.

Furuse, Y., Ko, Y., Oshitani, H., and Suzuki, M. (2021). Covid-19 projections in tokyo from june to september. *Advisory Board on COVID-19 for the Ministry of Health, Labor, and Welfare*.

Jiji Tsushin (2021a). The olympic games: Limiting people's movement key, effects of foreign visitors limited—an estimate from the university of tokyo. https://www.jiji.com/jc/article?k=2021053000182.

Jiji Tsushin (2021b). Olympics spectators: Going to restaurants and bars spread infection. going home straight key. https://www.jiji.com/jc/article?k=2021061701225.

Kerr, C. C., Stuart, R. M., Mistry, D., Abeysuriya, R. G., Rosenfeld, K., Hart, G. R., Núñez, R. C., Cohen, J. A., Selvaraj, P., Hagedorn, B., et al. (2021). Covasim: an agent-based model of covid-19 dynamics and interventions. *PLOS Computational Biology*, 17(7):e1009149.

Kyodo Tsushin (2021). More movement during tokyo games may increase infections: Expert. https://english.kyodonews.net/news/2021/05/c1e952dec5e0-more-movement-during-olympics-paralympics-may-increase-infections-panel.html.

Mainichi Shinbun (2021). Festive mood from the olympics could increase infection by hundreds in tokyo. https://mainichi.jp/articles/20210621/k00/00m/050/314000c.

NHK (2021). How would the olympic games affect infection? an estimate from the university of tokyo. https://www.nhk.or.jp/politics/articles/lastweek/61196.html.

Nikkei (2021a). The effects of olympics-related foreign visitors "limited": Limiting people's movement needed. https://www.nikkei.com/article/DGXZQOUA240FS0U1A520C2000000/.

Nikkei (2021b). Spectators could reach 200 thousands per day. going home straight key. https://www.nikkei.com/article/DGXZQOUE0724O0X00C21A6000000/.

Nikkei Shinbun (2021). People's movement likely to increase after the soe: Possibility of another soe during the olympic games. https://www.nikkei.com/article/DGXZQOUA185PD0Y1A610C2000000/.

Nishiura, H. (2021). A scenario analysis submitted to the advisory board for the ministry of health, labour and welfare on june 9, 2021.

Polack, F. P., Thomas, S. J., Kitchin, N., Absalon, J., Gurtman, A., Lockhart, S., Perez, J. L., Pérez Marc, G., Moreira, E. D., Zerbini, C., et al. (2020). Safety and efficacy of the bnt162b2 mrna covid-19 vaccine. *New England journal of medicine*, 383(27):2603–2615.

Sankei Shinbun (2021). The effects of olympics-related foreign visitors “limited’: An estimate from the university of tokyo. https://www.sankei.com/life/news/210523/lif2105230044-n1.html.

Scientific Advisory Group for Emergencies (2021). Spi-m-o: Summary of further modelling of easing restrictions - roadmap step 2, 31 march 2021. Technical report, UK government.

Wall Street Journal (2021). Japan looks to extend covid-19 state of emergency. https://www.wsj.com/articles/japan-looks-to-extend-covid-19-state-of-emergency-11622029625.

Yamamoto, N., Mitsuhashi, T., Tsuchihashi, Y., and Yorifuji, T. (2022). Causal effect of the tokyo 2020 olympic and paralympic games on the number of covid-19 cases under covid-19 pandemic: An ecological study using the synthetic control method. *Journal of Personalized Medicine*, 12(2):209.

Yoneoka, D., Eguchi, A., Fukumoto, K., Kawashima, T., Tanoue, Y., Tabuchi, T., Miyata, H., Ghaznavi, C., Shibuya, K., and Nomura, S. (2022). Effect of the tokyo 2020 summer olympic games on covid-19 incidence in japan: a synthetic control approach. *BMJ Open*, 12:e061444.