

# Productivity Change of Surgeons During the Coronavirus Disease 2019 Pandemic in Japan

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## Abstract

The purpose of this study is to compute surgical total factor productivity before and during the pandemic with Malmquist index, and to evaluate the effect of coronavirus disease 2019 (COVID-19) on its productivity change. The COVID-19 pandemic has significantly shifted healthcare resources allocation; more healthcare resources have focused on measures against the COVID-19 pandemic. The authors collected data from all the surgical procedures performed in Teikyo University Hospital from April 1 through September 30 in 2019 and in 2020. Non-radial and non-oriented Malmquist model under the constant return-to-scale assumptions was employed. The decision-making unit was defined as a surgeon with the highest academic rank in surgery. Inputs were defined as (1) the number of medical doctors who assisted surgery and (2) the duration of surgical operation from skin incision to closure. The output was defined as the surgical fee for each surgery. The study period was divided into four 3-month periods. We added all the inputs and outputs of the surgical procedures for each decision-making unit during these study periods, and computed his/her Malmquist index, efficiency change, and technical change. Four thousand six hundred and two surgical procedures performed by 75 surgeons were analyzed. The productivity progressed significantly during 2019 ( $P=.008$ ) while the productivity changes in 2020 were not significantly different from 0. On year-on-year comparisons, the productivity change was not significantly different from 0. The COVID-19 pandemic had a negative impact on the productivity progress of surgery that was unrelated to its countermeasures.

## Keywords

COVID-19, productivity, Malmquist index

### What do we already know about this topic?

The coronavirus disease 2019 (COVID-19) pandemic has significantly shifted healthcare resources allocation.

### How does your research contribute to the field?

The COVID-19 pandemic had a negative impact on the productivity progress of surgery that was unrelated its to COVID-19 countermeasures.

### What are your research's implications toward theory, practice, or policy?

There might be some other routine health services whose productivity was also negatively affected by the COVID-19 pandemic due to the healthcare resources allocation shifts.

## Introduction

The Japanese government declared a state of emergency in several prefectures on April 7, 2020, to control the coronavirus disease 2019 (COVID-19) pandemic. The emergency state was expanded nationwide on April 16, 2020.<sup>1</sup> In response to this declaration of emergency, healthcare resources were allocated to COVID-19 countermeasures, which reduced the resources available for other healthcare

areas and the quality of services in such areas. For example, the number of elective surgical procedures and the availability of blood products for surgery were significantly reduced because of voluntary self-quarantine. In addition, a large number of health professionals were engaged in COVID-19 countermeasures, which resulted in staff shortages for routine health services. These COVID-19 countermeasures, combined with extreme restrictions on routine health services, might have led to a collapse of the entire healthcare



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system.<sup>2</sup> Although the state of emergency officially ended in Japan on May 25, 2020, the pandemic continued in 2021.<sup>3</sup> It is unclear whether the COVID-19 pandemic affected routine health services. In the present study, we investigated changes in the productivity of routine health services during COVID-19.

Since 2000, objective measures of efficiency and productivity have led to rapid advances in the fields of economics, business administration, and engineering.<sup>4,5</sup> Data envelopment analysis (DEA) is a standard method for efficiency measurement, while the Malmquist index (MI) is an advanced form of DEA. The MI assesses productivity changes over multiple time periods, which may be categorized into efficiency changes (ECs) and technical changes (TCs), to determine the causes of productivity changes.<sup>6</sup>

In the present study, we investigated surgeries that were not directly related to COVID-19 countermeasures. This study was performed to determine the surgical total factor productivity before and during the pandemic using MI; it was also performed to evaluate the effects of COVID-19 on productivity changes. We hypothesized that the COVID-19 pandemic significantly reduced the surgical total factor productivity.

## Methods

The Institutional Review Board of Teikyo University (Itabashi-ku, Tokyo, Japan) approved a series of our studies on surgical efficiency and productivity. The need for consent was waived by the Institutional Review Board because of the retrospective observational study design. There was no waiver number for not obtaining written informed consent.

## Data

Teikyo University Hospital is located in metropolitan Tokyo, Japan, and serves approximately 1 000 000 individuals. It has 1152 beds and an annual surgical volume of approximately 9000 cases in 13 surgical specialties. This hospital is located in a prefecture where the state of emergency was initially declared by the Japanese government, and the hospital was acutely impacted by the pandemic. We collected data for all surgeries performed in our hospital between April 1, 2020, and September 30, 2020. We also collected data for surgeries

performed between April 1, 2019, and September 30, 2019, for use as pre-pandemic control data. Data were extracted from the Teikyo University Hospital electronic medical record system by a single researcher (YN), then cross-checked by another researcher (YW). The extracted data included date of surgery, age and sex, start and end times of surgery, name of senior surgeon, number of assistants, and total surgical fees.

The following exclusion criteria were used in this study. First, surgical procedures performed under local anesthesia by surgeons were excluded because the resource utilization for these procedures is substantially different and does not permit a clinically meaningful comparison with major surgical procedures. Oral, ophthalmic, and dermatological surgical procedures were excluded because most of these surgeries are minor procedures that can be performed under local anesthesia without anesthesiologists' involvement. In addition, procedures performed under general anesthesia in these specialties do not represent the activity of surgeons. Second, procedures in which the patients died within 1 month after surgery were excluded to maintain a constant quality outcome. Patient death within 1 month after surgery does not accurately represent surgical outcome quality, but it was the only available outcome measure that was common among the various surgeries analyzed in this study.<sup>7</sup> Third, surgical procedures that were not reimbursed under the surgical payment system in 2019 and 2020 were excluded. Finally, the surgical cases with incomplete records were excluded.

## Malmquist Index (MI)

MI represents the dynamic productivity change of a decision-making unit (DMU) between 2 time periods; it is an example of comparative statics analysis.<sup>4,5</sup> MI is based on data envelopment analysis (DEA), which evaluates the relative efficiency of DMUs against a static efficient frontier during a single period. MI can be used to compare DEA results between 2 time periods, and divide the productivity change into 2 components: efficiency change (EC) and technical change (TC).<sup>6</sup> MI is defined as the product of EC and TC, where EC represents the degree of change in DMU's efficiency, while TC represents the change in efficient frontiers between the 2 time periods. The productivity change of a DMU between Periods 1 and 2 is mathematically represented as follows.<sup>5,6</sup>

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**Table 1.** Percent Changes of Productivity, Efficiency and Technique.

	19Q1=>19Q2 (before Pandemic)	20Q1=>20Q2 (during Pandemic)	20Q1=>20Q2 (Pure effects)
Productivity change (%)	+9.8 ± 4.0*	-4.5 ± 4.4	-14.3 ± 6.3**
Efficiency change (%)	-9.8 ± 4.2**	-22.9 ± 4.5**	-13.1 ± 6.5**
Technical change (%)	+19.6 ± 0.4*	+18.4 ± 0.9*	-1.2 ± 0.9

Note. Percent changes of productivity, efficiency and technique. The values are expressed as mean ± SE.

\*Indicates that the value is significantly greater than 0 ( $P < .05$ ).

\*\*Indicates that the value is significantly smaller than 0 ( $P < .05$ ).

EC =

$$\frac{\text{Efficiency of the DMU in Period2 relative to the Period2 frontier}}{\text{Efficiency of the DMU in Period1 relative to the Period1 frontier}}$$

TC =

$$\left( \frac{\text{Efficiency of the DMU in Period1 relative to the Period1 frontier}}{\text{Efficiency of the DMU in Period1 relative to the Period2 frontier}} \times \frac{\text{Efficiency of the DMU in Period2 relative to the Period1 frontier}}{\text{Efficiency of the DMU in Period2 relative to the Period2 frontier}} \right)^{\frac{1}{2}}$$

$$MI = EC \times TC$$

### Analysis Framework

We used a non-radial and non-oriented Malmquist model under constant return-to-scale assumptions,<sup>8,9</sup> which focused on surgeon activity and clinical decisions. A DMU was defined as the highest academically ranked surgeon who scrubbed in the surgery and controlled all the inputs and outputs (a senior surgeon). The inputs were the number of medical doctors who assisted the surgery (assistants), as well as the duration of the surgery from skin incision to closure (surgical duration). The output was the surgical fee. Each surgical procedure was assigned a code corresponding to the surgical fee. The fee was identical regardless of who performs surgery as long as they have medical licensure, how many assistants they use, or how long it takes to complete surgery.<sup>8,10,11</sup>

### Comparison

The study period was divided into four 3-month periods: April-June 2019 (19Q1), July-September 2019 (19Q2), April-June 2020 (20Q1), and July-September 2020 (20Q2). The sums of all inputs and outputs were used to compute MI, EC, and TC for each DMU during the study periods; these calculations were performed using DEA-Solver-Professional Software (Saitech, Inc., Tokyo, Japan).<sup>5,8</sup> All surgeons were assigned MI, EC, and TC values<sup>12</sup>; their natural logarithms were calculated to allow interpretation as percent changes.<sup>8,13</sup> Natural logarithm of MI values greater than, equal to, and less than 0 indicated increased, unchanged, and decreased productivity from Period 1 to 2, respectively. Similarly,

natural logarithms of EC and TC > 0 indicated efficiency and technical improvements, respectively. The natural logarithm of MI equals the sum of natural logarithms of TC and EC.<sup>8,13</sup>

We calculated the chronological changes in productivity, efficiency, and technique between 19Q1 and 19Q2 (19Q1=>19Q2), and between 20Q1 and 20Q2 (20Q1=>20Q2). Because the COVID-19 pandemic in Japan began in April-September 2020, the changes in productivity, efficiency, and technique in 19Q1=>19Q2 can serve as controls to identify the COVID-19 effects. We calculated the natural logarithms of MI, EC, and TC for the surgeons during these 2 intervals. Changes in 19Q1=>19Q2 were subtracted to exclude any natural changes, leaving only the pure effects of the COVID-19 pandemic.<sup>14</sup>

Then, we compared 19Q1 with 20Q1, and 19Q2 with 20Q2 to exclude any seasonal changes.

### Senior Surgeons

We analyzed the data for senior surgeons who performed surgery in all four 3-month periods. All surgeons were employed by Teikyo University and received salaries according to their rank and experience. The surgeons belong to one of the following 10 surgical specialties; cardiovascular surgery, emergency surgery, general surgery, neurosurgery, obstetrics & gynecology, orthopedics, otolaryngology, plastic surgery, thoracic surgery, and urology. The natural logarithms of MI, EC, and TC were obtained for each surgeon according to the respective surgical specialties; their means and standard errors were calculated.<sup>7</sup>

### Statistical Analysis

Excel statistics software (Social Survey Research Information Co., Ltd., Tokyo, Japan) was used for statistical analysis. The natural logarithms of MIs, ECs, and TCs for surgeons and surgical specialties were compared using *t*-tests. *P*-values < .05 were considered statistically significant.<sup>15</sup>

### Results

In total, 152 surgeons performed 3148 surgeries in April-September 2019, while 135 surgeons performed 2379 surgeries in April-September 2020. Seventy-five surgeons

**Table 2.** Percent Changes of Productivity, Efficiency and Technique From April-June 2019 to April-June 2020 (19Q1=>20Q1) of All Surgeons and of Each Surgical Specialty.

Specialty	Productivity (%)	Efficiency (%)	Technique (%)
All surgeons	+5.2 ± 4.4	-14.6 ± 4.5 **	+19.9 ± 0.5*
Cardiovascular surgery	+35.0 ± 20.8	+17.0 ± 21.6	+18.0 ± 2.3*
Emergency surgery	-4.1 ± 10.3	-25.2 ± 11.1 **	+21.1 ± 1.1*
General surgery	+1.5 ± 6.6	-19.4 ± 6.4 **	+20.8 ± 1.1*
Neurosurgery	+7.3 ± 22.1	-19.2 ± 24.9	+26.5 ± 2.9*
Obstetrics & Gynecology	+10.3 ± 10.8	-8.0 ± 11.2	+18.3 ± 1.3*
Orthopedics	+17.1 ± 10.3	-1.2 ± 10.0	+18.3 ± 0.9 *
Otolaryngology	-15.9 ± 26.8	-35.2 ± 26.3	+19.3 ± 2.8 *
Plastic surgery	-28.2 ± 25.3	-46.8 ± 24.8	+18.6 ± 1.6 *
Thoracic surgery	+17.6 ± 8.9	-2.1 ± 9.2	+19.8 ± 0.3 *
Urology	-2.9 ± 13.5	-23.3 ± 12.6	+20.3 ± 2.0 *

Note. The values are expressed as mean ± SE.

\*The value is significantly greater than 0 ( $P < .05$ ).

\*\*The value is significantly smaller than 0 ( $P < .05$ ).

**Table 3.** Percent Changes of Productivity, Efficiency and Technique From July-September 2019 to July-September 2020 (19Q2=>20Q2) of All Surgeons and of Each Surgical Specialty.

Specialty	Productivity (%)	Efficiency (%)	Technique (%)
All surgeons	-9.1 ± 5.5	-27.7 ± 5.7 **	+18.6 ± 0.5 *
Cardiovascular surgery	-16.4 ± 28.3	-37.8 ± 29.4	+21.4 ± 2.2 *
Emergency surgery	-13.5 ± 9.7	-32.3 ± 9.7 **	+18.8 ± 0.5 *
General surgery	-2.5 ± 8.2	-20.2 ± 8.2 **	+17.7 ± 0.6 *
Neurosurgery	-7.8 ± 19.6	-24.4 ± 19.8	+16.6 ± 0.4 *
Obstetrics & Gynecology	-6.3 ± 12.2	-27.5 ± 14.0**	+21.2 ± 2.6 *
Orthopedics	-2.3 ± 15.8	-20.2 ± 17.0	+17.9 ± 1.4 *
Otolaryngology	-5.0 ± 12.0	-22.4 ± 12.1	+17.4 ± 1.0 *
Plastic surgery	-26.9 ± 42.0	-45.5 ± 42.9	+18.6 ± 0.8 *
Thoracic surgery	+22.3 ± 7.2*	+2.8 ± 6.4	+19.5 ± 0.9 *
Urology	-43.3 ± 19.6**	-60.5 ± 20.3**	+17.2 ± 0.9 *

Note. The values are expressed as mean ± SE.

\*The value is significantly greater than 0 ( $P < .05$ ).

\*\*The value is significantly smaller than 0 ( $P < .05$ ).

performed surgery in all four 3-month periods. We analyzed 4602 surgical procedures performed by them.

The natural logarithms of MIs (percent change in productivity), ECs (percent change in efficiency) and TCs (percent change in technique) are presented in Table 1. Productivity significantly increased by 9.8% during 2019 ( $P = .008$ ), while the productivity change in 20Q1=>20Q2 was not statistically significant ( $P = .1545$ ). Efficiency significantly decreased by 9.8% in 19Q1=>19Q2 ( $P = .0105$ ), while technique significantly improved by 19.6% in 19Q1=>19Q2 ( $P < .0001$ ). Efficiency significantly decreased by 22.9% in 20Q1=>20Q2 ( $P < .0001$ ) while the technique significantly improved by 18.4% in 20Q1=>20Q2 ( $P < .0001$ ).

The pure effects of COVID-19 are presented in Table 1. The productivity significantly decreased by 14.3% ( $P = .0126$ ).

The efficiency also significantly decreased by 13.1% in 20Q1=>20Q2 ( $P = .0241$ ) while the technical change was not statistically significant ( $P = .0911$ ).

Changes in 19Q1=>20Q1 are presented in Table 2. There was no significant change in surgeon productivity ( $P = .2386$ ). However, efficiency significantly decreased and technique significantly improved by 14.6% ( $P < .0001$ ) and 19.9% ( $P < .0001$ ), respectively. Although all the surgical specialties made significant technical progress, none exhibited any significant productivity progress ( $P > .05$ ).

Changes in 19Q2=>20Q2 are presented in Table 3. There was no significant change in surgeon productivity ( $P = .0986$ ). However, efficiency significantly decreased and technique significantly improved by 27.7% ( $P < .0001$ ) and 18.6% ( $P < .0001$ ), respectively. Although all surgical specialties

made significant technical progress, only thoracic surgery exhibited significant productivity progress.

## Discussion

In the present study we demonstrated the negative effects of COVID-19 on surgeon productivity. These effects were investigated by dividing productivity change into efficiency and technical changes. Technical changes were consistently positive between 2019 and 2020, while efficiency changes were mostly negative. Our findings suggest that the COVID-19 pandemic significantly reduced the productivity progress of surgery, which was not directly related to the COVID-19 countermeasure, by reducing surgical efficiency. Other routine health services may also have been negatively affected because many healthcare resources were allocated to COVID-19 countermeasures.

We were unable to determine the reason for these changes because various public and hospital policies were modified during the pandemic. The state of emergency began in April 2020 and ended in May 2020. The government began promoting domestic travel in July 2020, which may have increased the number of COVID-19 patients. In response to government policies, Teikyo University Hospital reduced the number of elective surgeries by 20% on April 6, 2020, and by 50% on April 13, 2020. The restriction was eased to 70% on May 11, 2020; it was removed on May 25, 2020. In addition, some surgeons continued to work in emergency rooms because there was a shortage of emergency physicians. These policy changes reflected resources allocation toward COVID-19 countermeasures; thus, it is reasonable to assume that the productivity change was caused by the pandemic.

The patterns of productivity, efficiency, and technical changes before the pandemic in 2019 were consistent with our previous findings in a 2015 study, where we demonstrated positive productivity and technical changes between the April-June period and the July-September period.<sup>6</sup> The steady improvements in productivity and technique over time disappeared in 2020, while efficiency continued to worsen. These changes can also be attributed to the COVID-19 pandemic.

Annual comparisons in 19Q1=>20Q1 and 19Q2=>20Q2 showed the similar patterns. Despite technical improvements in all surgical specialties, only thoracic surgery exhibited a significant increase in productivity in 19Q2=>20Q2. Most surgical specialties had reduced or unchanged efficiency in the annual comparisons. Therefore, the pandemic negatively impacted surgeon efficiency. The reduced efficiency may have led to reduced productivity because efficiency changes are major determinants of productivity changes among surgeons.<sup>16</sup>

Thoracic surgeon productivity significantly increased during the July-September period between 2019 and 2020, while it decreased for surgeons in all other specialties during the same period. The reason for increased productivity

among thoracic surgeons could not be determined in the present study. However, it may have been related to the increased number of robotic thoracic surgeries performed during this period, which we speculate that resulted in their technical and productivity progress.

There were some limitations in this study. First, the nationwide fee schedule was revised on April 1, 2020,<sup>10,11</sup> and its effects on productivity could not be excluded from our analysis. However, in a previous study, we demonstrated that the effects of the fee revision on productivity was insignificant.<sup>14</sup> Therefore, we presume that the effects of the revision did not substantially influence our results. Second, this study was conducted in a single teaching hospital in Tokyo, Japan, and the results may not be generalizable to all surgeons. However, ancillary services (eg, operating room nursing and support personnel) are held constant in a single hospital. By comparing surgeons in the same institution, they all face the same systemic advantages and disadvantages of ancillary services.<sup>17</sup> Third, we did not perform a power analysis to determine sample size. Instead of a small sample of procedures, we analyzed all 4602 surgical procedures performed in Teikyo University Hospital during the study periods. We assumed that this sample was sufficiently large to prevent any type II errors.<sup>15</sup> Fourth, we excluded surgical procedures under local anesthesia, which may have resulted in selection bias. As a consequence, the number of surgical procedures performed during the pandemic may be even lower than expected compared to 2019, with an overall underestimation of the results. However, we excluded them because their resource utilization is substantially different from resource utilization during other major surgeries, and their inclusion would have prevented clinically meaningful comparisons of the surgical total factor productivity.

## Conclusions

We demonstrated that the COVID-19 pandemic had a negative impact on the productivity progress of surgery that was not related to the COVID-19 countermeasures. The productivity of other routine health services may also have been negatively affected by the COVID-19 pandemic because of changes in healthcare resource allocation.

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## Authors' Note

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## Supplemental Material

Supplemental material for this article is available online.

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