Predicting national rice production 2023−2024 under rising food and energy prices and global climate change

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Abstract. The history of the food crisis since the 1990s shows that cycles and prolonged spikes in food and energy prices and climate changes have negatively impacted food production. This study aims to predict the impact of rising food and energy prices and global climate change on rice production in 2023 and 2024 at national and provincial levels. The structural vector autoregression (SVAR) analysis data from January 1993 to December 2022 from various national and international sources was used to measure the impact on a national level, and the shift-share analysis (SSA) approach was used for the rice sampling framework analysis to map the impact on provincial levels. Indonesia's rice production is predicted to decrease by 3.16% and 3.75% in 2023 and 2024 compared to 2022. Analysis by province shows a decrease in almost all major rice-producing regions in Indonesia. This study suggests that the government (1) increase rice productivity in 16 provinces and increase both rice harvest area and productivity in 9 provinces and (2) coordinate with other ministries and institutions at central and regional levels to map regencies that have the opportunity to immediately increase production, ensure and increase the availability of input, infrastructure, facilities, and anticipate pest outbreaks.

1 Introduction

Rice is Indonesia's main and strategic food. The changes in the strategic environment have pushed Indonesian rice prices to continue to increase along with the trend of rising international rice prices and declining prices of other foods. Disruptions to production and increases in global food prices are expected to continue because the EU and the USA are experiencing economic growth crises [1]. In addition, parts of Europe, Central Asia, China, the USA, and Latin America have experienced extreme hot weather since mid-2022. A slowdown in economic growth that will continue toward a global recession is expected to occur in 2023 and 2024 [2]. An increase in global food prices and energy continues to be accompanied by global and national climate change and variability, which challenges Indonesia's agricultural development, especially in rice production. This study aims to analyse the impact of rising food, energy, and global climate change prices on rice production

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in 2023 based on the history of recession since the 1990s when food, energy, and climate change prices experienced cycles and prolonged spikes. The study also seeks to predict the trends in rice production for 2023 and 2024 and formulate anticipatory policies accordingly.

Rice production areas spread across various provinces, including all provinces in Java and several outside Java, such as Aceh, West Sumatra, South Sumatra, Lampung, West Nusa Tenggara, West Kalimantan, and South Sulawesi. The analysis was also carried out at the provincial level with regard to anticipating the impacts caused by climate change, as well as increasing global food and energy prices.

2 Methodology

The study uses primary and secondary data. Primary data was obtained through field interviews with farmers, grain collectors, managers of modern rice mills, wholesalers, and retailers. Secondary data is a monthly time series for the period January 1993–February 2023, which consists of data on production, consumption, imports, exports, consumer/retail prices, prices at the wholesale level (whole trade), import prices, farmer level prices, the exchange rate against the currency foreign currency world/international prices of related commodities and oil/energy prices, and various other data and information as well as relevant government policies. The data was sourced from various institutions, including Bank Indonesia (BI), BPS-Statistics Indonesia, Ministry of Finance, Ministry of Agriculture Data and Information Center (PUSDATIN), Directorate General of Food Crops, Ministry of Agriculture, National Development Planning Agency (BAPPENAS), National Food Agency (BAPANAS), Meteorology, Climatology and Geophysics Agency (BMKG), Cipinang Central Rice Market (PIBC), State Logistics Agency (BULOG), DKI Jakarta Provincial Statistics, United States Department of Agriculture (USDA), World Bank (WB), International Monetary Fund (IMF), National Oceanic and Atmospheric Administration (NOAA) United States Department of Commerce (USDC), Bureau of Meteorology (BoM) Australia, Food and Agriculture Organization (FAO).

The study used descriptive statistics to explain the developments over the last five years up to the rainy season 2022/2023. Moreover, the study employed quantitative analysis using three approaches: (1) time series econometrics using the structural vector autoregression (SVAR) for data between January 1993 and December 2022 on a national scale to measure the impact on national production (Appendix 1), (2) shift-share analysis approach for regional growth to map the impact on provincial areas (Appendix 2), and (3) increasing production opportunity model (Appendix 3).

Three scenarios were carried out to overcome the impacts at the provincial level. Scenario 1: production increases by increasing harvested area, assuming the average productivity remains constant. Scenario 2: production increases by increasing productivity, assuming the harvested area remains constant. Scenario 3: production increases by increasing both harvested area and productivity. Based on the analysis in Appendix 3, the recommended alternative scenario is the one that results in the highest positive difference between the reduction caused by the impacts and the efforts to increase production from the three alternative scenarios.

3 Results and discussion

3.1 Situation of national rice at the beginning of 2023

As of early 2023, the national rice situation was in turmoil. From 2018 to 2022, the national rice harvest area decreased by an average of 2.06% per year, while productivity increased by

0.27% per year and production decreased by 1.78% per year. Several reasons contributing to the issue are as follows. (1) Rice production was still based on Java Island and decreased; the decline also occurred in Sumatra and Sulawesi. (2) In the main rice-producing provinces, the harvested area only increased in Lampung, DI Yogyakarta, and Bali; the increase outside these areas was only in West Sulawesi. (3) There is no significant increase in productivity in the main producing provinces. (4) Rice production in the main producing areas only increased in Lampung, Banten, and DI Yogyakarta.

In the same period, rice consumption increased. The increase in rice consumption outside Java is much higher, pushing up prices and demand for supplies from Java. As a result, the price of rice in Java and nationally also increased. Rice price increases have occurred since June 2022, driven by increased demand due to the recovery of the HORECA business, supermarkets, and other modern markets. Since October 2022, prices have increased because of rising fuel prices. Reduced subsidies have led to higher fuel prices, resulting in increased transportation and rice milling operational costs. Nevertheless, direct and online marketing, which has reduced trade margins and fees, was affected by rising fuel prices. The period from October 2022 to January 2023 was a famine period that increased competition for grain supplies from farmers, driving up producer prices. Harvesting from late December 2022 to early February 2023 under heavy rainfall and high moisture content led to decreased quality while extending processing time and increasing milling operational costs. The rising fuel prices also pushed rice selling prices to rise much higher. The delay in processing time caused a further delay in the supply of rice from the mill to the market, pushing consumer prices to remain high.

There were some concerns regarding rice surplus, supply, and distribution. The estimated surplus volume, stock at the end of 2022, would be lower than the previous year and beyond the government's reach. This was because the surplus was in the hands of households, consumers, or businesses. Therefore, imports would need to be carried out to meet the demand. Additionally, there had been a decrease in rice supply from production centres in West Java to PIBC. As a result, PIBC required additional supply and distribution from other sources. Furthermore, PIBC struggled with insufficient monthly stock, with an average below 25 tons. It relied on supplies from BULOG to cover the supply shortages. Despite the relatively small volume of imports, it has had little effect on the producer, wholesale, and retail prices. However, if there was no supply from BULOG to PIBC, the price increase and stability could get out of control.

The global economy has a significant impact on the condition of national rice. Despite the downward trend in petroleum and international fertiliser prices, rice prices continue to rise. This is mainly due to several reasons, including crop failures caused by climate issues in some countries, an increase in demand for rice due to restocking in China following the recovery of the pandemic in the Asian region, export restrictions in India, Vietnam, and other countries to prioritise domestic needs, and the prolonged conflict between Russia and Ukraine, which has pushed up the international price of rice.

3.2 Prediction of national rice production in 2023 and 2024 amid the situation of increased energy and food prices and global climate change

Based on the analysis of the impact of changes in harvested area, it was found that changes in harvested area itself account for 65–72% of the overall impact, while changes in productivity account for 9.12–16.43%. The remaining impact can be attributed to other factors, including (1) changes in world energy and domestic fuel prices, world rice prices, Indonesian import prices, and climate change, which account for 0.11–1.40%, and (2) changes in other factors such as import volume (1.42–2.75%), consumption volume (1.94–4.57%), and wholesale prices (0.71–2.68%), which have a significant impact.

Changes in productivity are influenced by various factors, including changes in productivity itself (51–53%) and changes in harvested area (31–40%). Other contributing factors include changes in world energy and domestic fuel prices, world rice prices, Indonesian import prices, and climate change (0.09–2.04%). In addition, changes in the exchange rate and import tariffs (0.70–2.85%), consumption volume (2.18–4.04%), wholesale prices (1.23–2.68%), and producer prices (1.92–2.56%) also have a significant impact on productivity. The influence contribution of each factor on productivity increases in 2024 compared to 2023. The influence contribution in the dry season or MK (April–September) is greater than in the rainy season or MH (October–March). Changes in the factors affecting harvested area and productivity must be anticipated during the rainy season and further enhanced in the dry season.

The results of measuring the elasticity coefficient of factors influencing the national harvested area are as follows. Climate change has a greater influence on harvested area elasticity (-0.0564 to -0.1881) than global energy and domestic fuel prices (-0.0381 to -0.0289). Changes in the world rice prices and Indonesian import prices range from 0.0472 to 0.5600. Other factors that affect harvested area include the exchange rate of rupiah against the US dollar and rice import tariffs, with an elasticity value of 0.0102–0.0305, import volumes (0.1414–0.3942), consumer prices (0.0082–0.0572), consumption volumes (0.1066–0.3901), wholesale prices (0.0623–0.3405), producer prices (0.0343–0.1936), fertiliser prices and labour wages (-0.1696–0.3106), and productivity (0.2766–0.6659). Changes in world rice prices and Indonesian import prices, import volumes, consumption volumes, wholesale prices, fertiliser prices and labour wages, and productivity have a large elasticity to changes in rice harvested area.

Meanwhile, the results of measuring the elasticity coefficient of factors influencing rice productivity are as follows. Changes in global energy prices and domestic fuel prices have elasticity values between -0.0103 to -0.3880, 0.0280–0.5167 for world rice prices and Indonesian imports, and -0.0328 to -0.0971 for global and national climate. Climate change has a lower impact when compared to changes in global energy and domestic fuel prices, world rice prices, and Indonesian imported prices. Other factors have respective elasticity values of 0.0265–0.4249 for the rupiah exchange rate against the US dollar and rice import tariffs, 0.0638–0.1876 for import volumes, 0.0698–0.1876 for consumer prices, 0.1515–0.2237 for consumption volumes, 0.1391–0.2263 for wholesale prices, 0.0065–0.3152 for producer prices, 0.0313–0.0920 for fertiliser prices and agricultural labour wages, and 0.2112–0.8189 for harvested areas. Increases in world energy prices and domestic fuel prices, world rice prices and Indonesian import prices, climate change and global prices, exchange rates and rice import tariffs, import volumes, consumer prices, consumption volumes, wholesale prices, producer prices, fertiliser prices and labour wages, and harvested area have a major effect on increasing productivity.

The prediction results show that world crude oil prices in 2023 compared to 2022 will decrease by an average of 15.9%, and prices in 2024 compared to 2023 will increase by an average of 2.4%. World rice prices in 2023, compared to 2022, increased by an average of 16.8%, and prices in 2024, compared to 2023, decreased by an average of 3.9%. SOI El Nino is predicted to increase by 3.79% and 4.19%, respectively, in 2023 and 2024.

The rice harvested area in 2023 compared to 2022 in MH increased by 2.49% or 115.35 thousand ha, while in MK, it decreased by 3.40% or 193.03 thousand ha. Meanwhile, in MH+MK, rice harvested area decreased by 1.44% or 148.44 thousand ha; in Jan–Dec, it decreased by 2.44% or 258.35 thousand ha. In MH of 2024, rice harvested area increased by 1.12% or 51.61 thousand ha compared to 2022 MH, while in MK decreased by 4.63% or 263.21 thousand ha, in MH+MK decreased by 1.76% or 181.35 thousand ha, and Jan–Dec decreased by 2.46% or 260.45 thousand ha.

Rice productivity in 2023 compared to 2022 in MH decreased by 0.27% or 0.01 t/ha, in MK decreased by 1.69% or 0.09 t/ha, in MH+MK decreased by 0.29% or 0.02 t/ha, and in Jan−Dec decreased by 0.73% or 0.04 t/ha. Rice productivity in 2024 compared to 2022 during MH decreased by 0.41% or 0.02 t/ha, in MK decreased by 2.11% or 0.11 t/ha; MH+MK decreased by 1.54% or 0.08 t/ha, and in Jan−Dec decreased by 1.32% or 0.07 t/ha.

Rice production in 2023 compared to 2022 MH increased by 2.22% or 553.19 thousand tons, in MK decreased by 6.77% or 1,978.79 thousand tons, in MH+MK decreased by 2.63% or 1,425.60 thousand tons, and Jan–Dec decreased by 3.16% or 1,750.96 thousand tons. Rice production in 2024 compared to 2022 MH increased by 0.70% or 175.49 thousand tons, in MK decreased by 6.6% or 1,943.17 thousand tons, MH+MK decreased by 3.26% or 1,767.68 thousand tons, and Jan–Dec decreased by 3.75% or 2,080.97 thousand tons. In 2023 and 2024, harvested area and productivity will increase in MH and decrease greatly in MK. Therefore, it is very important to secure MH and increase MK.

Some previous studies showed that climate change could result in greater dependency on food imports in developing countries and greatly influenced changes in 11% of agricultural land in those countries [3,4]. Climate change has resulted in a decline in food grain production in 65 countries and a 16% decline in gross domestic product (GDP). Hunger is predicted to hit around 600 million of the world's population, most of which is in developing countries. If mitigation and adaptation to climate change are not carried out, the global average temperature will increase to 30 °C [3]. Climate change has occurred in Indonesia, where several areas in South Sumatra and Greater Malang are at high risk of decreasing rice production [5]. Indonesia has a high risk of decreasing rice production, with an average of 1.37% per year, and has the potential to cause a decline in national food production. The impact of climate change on the level of aggregate food security and the temporary patterns experienced by rural households is greater than that of urban households.

El Nino and La Nina influence the seasonal pattern of the food security index, but in the national aggregate, it is not significant [6]. Apart from the harvested area, productivity, and production, the El Nino and La Nina phenomena have a significant impact on the temporary food security of farming households. In the national aggregate scope, El Nino has a negative effect on the aggregate harvested area of the main food commodities (rice, corn, and soybeans). In contrast, La Nina has a positive impact. The average decrease in harvested area due to El Nino is about 5.4%, while the average increase in harvested area due to La Nina is about 2.7%. The greatest impact occurs if the climate anomaly occurs in September–December and May–August. El Nino causes the average rice harvested area to fall by 3.83%, productivity by 0.15%, and production by 3.99%. La Nina increased harvested area by about 2.78%, productivity by about 0.19%, and production by about 2.95%. Variations in the impact of El Nino and La Nina on rice production between provinces are quite large. The main sources of variation are climatic conditions and the availability and quality of irrigation in the region concerned. Extreme climate causes the food security index to fall because even though La Nina has a positive impact, its magnitude is smaller than the negative impact of El Nino.

The phenomenon of climate change has an impact on floods, droughts, and pest and disease attacks. Due to extreme climatic conditions and rainfall, droughts and floods occur and are usually accompanied by pest and disease attacks. From 1994 to 2009, the average harvested area of rice affected by drought and floods was 475.84 thousand ha per year, and the total crop failure was 111.99 thousand ha per year with an estimated yield loss of 923.81 thousand tons of dry unhusked grain (GKG) per year [7]. During this period, the area affected by drought and flooding increased by 42.99% per year, puso or crop failure totalled 41.63% per year, and yield losses increased by an average of 39.32% per year. The value of yield losses caused by climate change conditions and rainfall is very high and increases yearly.

This condition is one of the reasons why the increase in rice production has been greatly disrupted, resulting in changes in supply and demand for rice commodities.

From January 1993 to December 2010, the El Nino phenomenon had a faster, greater influence, and longer-lasting impact on variations in changes in rice production than shocks caused by La Nina [8]. Compared to La Nina, El Nino has a greater impact on production, producer prices, and consumer prices but an opposite effect on consumption volume. Meanwhile, during 1993−2012, climate change conditions, which tended to be La Nina, increased production in higher-than-normal conditions for rice commodities. On the other hand, in climate conditions tended to be El Nino, the development of commodity production also tended to decrease compared to normal climate conditions and La Nina [9]. Climate change will bring about significant impacts in 2030. These impacts include (1) a decrease in rice production by 4.99%, (2) a decrease in rice consumption by 0.32%, (3) an increase in real prices for rice consumers and producers by 0.42%, (4) a reduction in household calorie consumption by 0.24% in all household groups, (5) a decrease in rice self-sufficiency ratio by 4.86%, (6) a decrease in real agricultural household income by 5.88%, and (6) a decrease in labour absorption by 1.54% [10].

A cointegration relationship exists between global oil and domestic rice prices [11]. Oil prices play quite a role in the domestic rice market price, but in general, they are still more influenced by the lagging condition of the rice price itself. A strong relationship was found between domestic market prices and energy prices [12]. The existence of a strong or weak relationship between the analysed variables can still be useful in the formulation of public policy and planning analysis [13]. Policy relaxation on monetary measures is needed to protect domestic conditions from the dynamics of global crisis shocks, one of which is caused by fluctuations in energy prices [14].

The analysis of variance decomposition, impulse response, and change effects has shown that producer prices have a higher response and degree of pass-through effect on shocks to factors that influence price volatility than consumer prices [15]. This indicates that trade liberalisation, tariff reductions, or tariff increases can create instability in producer prices but have a more or less impact on consumer prices. Import volume shocks that can arise due to government policy to maintain supply stability by importing rice will cause pressure in the form of a reduction in producer prices of more than twice the size of consumer prices (response effect of 0.07% compared to 0.03%). Furthermore, the impact of changes is almost three times higher on producer prices compared to consumer prices (pass-through degree of 0.08% compared to 0.03%). Fuel price shocks or changes in fuel prices, whether influenced by policy or not, impact consumer prices more than producer prices. Even though producer prices experience relatively small variations in changes (1.87%) compared to consumer prices (5.82%), they still have an impact on the response to changes in both producer and consumer prices. The magnitude of these changes is relatively the same (0.05% compared to 0.06%), and the effect of changes in producer prices is lower when compared to consumer prices (0.35% compared to 0.45%). Increasing fertiliser subsidies leads to higher consumer price volatility and more stable producer prices, and vice versa if subsidies are reduced. Changes in the exchange rates can affect consumer prices, with an average impact of only 0.02% and a maximum impact of 0.33%. In comparison, changes in consumer prices can reach up to 0.14% with an average of 0.13%.

Several policy interventions can influence the transmission of higher international commodity prices to domestic consumer prices. For example, tariffs on foreign trade can disrupt the relationship between global and domestic prices [16]. Higher import tariffs that can be imposed to reduce the relative price competitiveness of foreign goods and protect local producers from foreign competition can lead to lower price transmission to the extent that tariffs reduce demand for imports. Export tariffs may also be imposed to ensure that local producers sell a small or higher portion of their products on the domestic market. Their increase during periods of high global commodity prices contributes to reduced tensions on domestic prices. Exchange rate movements, usually assumed to influence trade and foreign direct investment [17], can amplify or absorb global market price shocks. For example, weakening the US dollar against the domestic currency can cause a decline in domestic oil prices. Overall, in the end, domestic supply and demand are based on indicators of production, consumption, imports, exports, output prices, and input prices. Even though the global climate change situation is reflected in oil and commodity prices, as indicators of the balance of supply and demand and global supply, the climate change situation impacts domestic production.

3.3 Rice production prediction in 2023 and 2024 amid a situation of increased energy and food prices and global climate change at the provincial level

Based on the prediction analysis, the harvested area, productivity, and rice production are expected to decrease in most of the major rice-producing regions of Indonesia, that is, 18 provinces in total, between 2023 and 2024. The decline is observed in MH, MK, MH+MK, and January–December. The same trend is also expected in 16 other provinces which are not the primary rice-producing areas.

Scenario analysis of overcoming production decline shows that scenario 2 produces the highest production, 3.92 million tons. It is higher than scenarios 1 and 3, i.e., 3.44 million tons and 3.69 million tons, respectively. Analysis based on a comparison between reduced production caused by climate change, global energy and food prices, and increased production of scenario1, 2, and 3 in the January–December period in both 2023 and 2024 shows that scenario 2 is an option for North Sumatra, West Sumatra, Riau, South Sumatra, Bengkulu, Lampung, West Java, Central Java, East Java, Bali, West Nusa Tenggara, Central Kalimantan, West Kalimantan, East Kalimantan, and Sulawesi West. Meanwhile, scenario 3 is an option for Jambi, East Nusa Tenggara, South Kalimantan, North Kalimantan, North Sulawesi, South Sulawesi, and Gorontalo. Other provinces do not have the potential to deal with the impacts of climate change, global energy, and food prices.

4 Conclusions and policy recommendations

4.1 Conclusions

Compared to 2022, harvested area and productivity increased in MH but decreased in MK, causing production to decline in MH+MK and the January to December period. In 2023, national rice production increased by 2.22% in MH (553.19 thousand tons). However, in MK, MH+MK, and January–December, production decreased by 6.77% (1,978.79 thousand tons), 2.63% (1,425.60 thousand tons), and 3.16% (1,750.96 thousand tons), respectively. In 2024, national rice production will increase by 0.70% (175.49 thousand tons) while MK will decrease by 6.64% (1,943.17 thousand tons), decrease by 3.26% (1,767.68 thousand tons) in MH+MK, and decrease by 3.75% (2,080.97 thousand tons) in January to December. Securing production at MH and increasing it in MK is very important.

Predictions at the provincial level show a decline in harvested area, productivity, and production in almost all provinces in Indonesia, both in MH, MK, MH+MK, and the January to December period in 2023 and 2024. Analysis of efforts to overcome the decline in production shows that scenario 2 produced the highest production, namely 3.92 million tons, higher than scenario 1, 3.44 million tons, and scenario 3, 3.69 million tons. Analysis based on a comparison between the decline in production caused by climate change, global energy, and food prices, and increased production shows that scenario 2 is an option for 17 provinces, scenario 3 is an option for seven provinces, and the other provinces (10 provinces) do not have the potential to handle the impacts of climate change, global energy, and food prices.

4.2 Policy recommendations

Several policy recommendations need to be considered to increase rice production, such as:

a. Echelon I units related to rice production should:
   (i) Plan and implement production based on the right scenario in each province.
   (ii) Coordinate with provincial agencies to map regencies with the opportunity to immediately increase production following the right scenario options for each.
   (iii) Coordinate with ministries and other institutions at central and regional levels to ensure and increase the availability of climate-tolerant seeds, availability of fertilisers, infrastructure, and irrigation facilities, capacity of farmers to adapt especially to climate change, and prepare for a potential outbreak of pests and diseases.

b. Coordinate with the Ministry of Forestry and Environment (KLHK) and the Ministry of BUMN to utilise land that can be used for rice cultivation, including both dryland rice and lowland and tidal rice.

c. Coordinate with the Ministry of Home Affairs to encourage local governments (provincial and district/city) to play an active role in overseeing the acceleration of planting for the final period of MK 2023 (July−September 2023) and MH 2024.

d. Coordinate with the Ministry of Trade, BULOG, the Ministry of Finance, and BAPANAS to minimise rice imports. This is because the price of Indonesian rice imports and changes in the volume of rice imports have a significant impact on changes in harvested area and rice productivity, exceeding the effects of climate change, energy prices, and domestic fuel.

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Appendix 1. SVAR model

$$HA_{it} = E_{t-n}(HA_{it}) + z_{1i}\varepsilon_{it}^{GC} + z_{2i}\varepsilon_{it}^{PO} + z_{3i}\varepsilon_{it}^{GP} + z_{4i}\varepsilon_{it}^{PW} + z_{5i}\varepsilon_{it}^{NT} + z_{6i}\varepsilon_{it}^{TM} + z_{7i}\varepsilon_{it}^{QM} + z_{8i}\varepsilon_{it}^{PC} + z_{9i}\varepsilon_{t}^{QC} + z_{10i}\varepsilon_{t}^{PG} + z_{11i}\varepsilon_{t}^{PP} + z_{12i}\varepsilon_{t}^{IC} + z_{13i}\varepsilon_{t}^{PF} + z_{14i}\varepsilon_{t}^{PU} + z_{15i}\varepsilon_{t}^{PE} + \varepsilon_{t}^{HA} \quad (1)$$

$$QP_{it} = E_{t-n}(QP_{it}) + z_{1i}\varepsilon_{it}^{GC} + z_{2i}\varepsilon_{it}^{PO} + z_{3i}\varepsilon_{it}^{GP} + z_{4i}\varepsilon_{it}^{PW} + z_{5i}\varepsilon_{it}^{NT} + z_{6i}\varepsilon_{it}^{TM}\, z_{7i}\varepsilon_{it}^{QM} + z_{8i}\varepsilon_{it}^{PC} + z_{9i}\varepsilon_{t}^{QC} + z_{10i}\varepsilon_{t}^{PG} + z_{11i}\varepsilon_{t}^{PP} + z_{12i}\varepsilon_{t}^{IC} + z_{13i}\varepsilon_{t}^{PF} + z_{14i}\varepsilon_{t}^{PU} + z_{15i}\varepsilon_{t}^{PE} + z_{16i}\varepsilon_{t}^{HA} + \varepsilon_{t}^{QP} \quad (2)$$

where:
GCit : global SOI index value of commodity i at time t
ICit : national rainfall index value for commodity i at time t
POit : real international crude oil price of commodity i at time t
GPit : real international fertiliser price of commodity i at time t
PWit: international price of commodity i at time t
NTit : rupiah exchange rate against real USD of commodity i at time t
TMit: import tariffs and real import duties for commodity i at time t
PMit : real import price of commodity i at time t
QMit: import volume of commodity i at time t
PCit : real consumer price of commodity i at time t
QCit : volume of consumption of commodity i at time t
PGit : real wholesaler price of commodity i at time t
PPit : real producer price of commodity i at time t
QPit : productivity of commodity i at time t
HAit : harvest area of commodity i at time t
PFit : real fertiliser (composite) price of commodity i at time t
PUit : real labour wages for commodity i at time t
PEit : real fuel price (premium and diesel) for commodity i at time t
E : time lag
ε : shock of variables
i : rice or dry unhusked grain
n : lag length
t : period (months) from January 1993–December 2022

Appendix 2. Growth shift-share model

$$PNij/RSij = Rayi0 \text{ with } Ra = (Yt - Y0)/Y0 \tag{3}$$
$$PPij = (Ri - Ra)\ Riyi0 \text{ with } Ri = (Yit - Yi0)/Yi0 \tag{4}$$
$$PPWij = (ri - Ri)\ Riyi0 \text{ with } ri = (yit - yi0)/yi0 \tag{5}$$
$$dQij = PNij + PPij + PPWij \tag{6}$$

where:
Yt : total harvested area (productivity/production) of rice in the national region 2023 or 2024
$Y0$: total rice harvested area (productivity/production) in the national region 2022
Yit : harvested area (productivity/production) of rice in province-i 2023 or 2024
$Yi0$: harvested area (productivity/production) of rice in province-i 2022.
yit : harvested area (productivity/production) of rice in district-i 2023 or 2024.
$yi0$: harvested area (productivity/production) of rice in district-i 2022.
PNij/Rsij : Ra = national growth or regional share = component share of harvest area growth (productivity/production) caused by external factors
PP ij : Ri = proportional growth = component of regional growth in harvested area (productivity/production) caused by a good regional rice business structure, specialising in fast growth
PPWij : ri = regional share growth = component of regional rice business growth due to competitive regional specific conditions. This growth element is a regional competitive advantage that can encourage regional export growth
dQ : SSA value = describes changes in rice farms in the analysis area

Appendix 3. Increasing production opportunity model

ILP = HA/LS (7)
GILP = ILPmax – ILPavg (8)
PPLP = GILP × (1 – CV/100) × LS (9)
GQP = QPmax – Qpavg (10)
PQP = GQP × (1 – CV/100) (11)
Scenario 1 = S1 = PPT1 = PPLP × Qpavg (12)
Scenario 2 = S2 = PPT2 = HAavg × PQP (13)
Scenario 3 = S3 = PPT3 = PILP × (QPavg + PQP) (14)

where:
ILP : harvest area index
HA : harvested area (ha)
LS : raw rice field area (ha)
GILP : gap harvest area index
PPLP : opportunity to increase harvest area (ha)
GQP : productivity gap (t/ha)
QP : productivity (t/ha)
PQP : opportunity to increase productivity (t/ha)
PPT : opportunities for increased production (t)
CV : coefficient of variation (%)
max : highest
avg : average