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Performance, intensity and efficiency of agricultural research investment in Malaysia

(Prestasi, intensiti dan keberkesanan pelaburan penyelidikan sektor pertanian di Malaysia)

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Keywords: agricultural investment, research, intensity, efficiency, Malaysia

Abstract

Despite having been identified as one of the growth drivers to food security, agricultural research investment in Malaysia demonstrates a stagnating and deterioration trends to underinvestment over the years. Previous studies identified the positive associations between agricultural research and economic development and growth. Currently, none of the comprehensive studies had looked at research investment and its impacts on agricultural growth in Malaysia. Thus, this study measures performance and the effectiveness of investment in the agricultural sector and uses both historical and primary data from multiple series of surveys on Agricultural Science and Technology Indicators (ASTI). The most recent ASTI data was obtained through primary surveys conducted in 2018/2019, covering the database for the period 2013 to 2017 from 33 agricultural research agencies from public and private sectors, including public universities in the country. Interviews using structured questionnaires were used as survey instruments to obtain data on investment from 2013 to 2017. The historical ASTI data was available from previous survey rounds. All data were aggregated and merged with existing ASTI datasets to show long-term trends at the national, regional and global levels. Several analyses and parameters including ASTI Intensity Index (AII), total factor productivity (TFP), output growth decomposition, and returns on investment are applied to identify the performance, intensity and efficiency of agricultural research in Malaysia. The AII reached a maximum level in 2002 with a value of 0.81, indicating the investment effort was 80% of that of the United States in 2011. However, stagnated investment caused Malaysia's AII dropping to 0.35 in 2016, resulting in the investment gap or the year to increase by almost 40%. The results of TFP for the total agriculture confirmed that there was no significant growth in agricultural productivity in Malaysia, while the output growth was largely due to increased use of inputs. The result of output growth decomposition revealed that the total output was largely contributed by increasing the harvested area and crop yield. The analysis on returns of R&D investment indicated that oil palm dominated knowledge stocks since the year 2000 and is projected to be the highest by 2050, followed by fruits and fisheries industry. The investment projections shows that MPOB will continue to grow until 2050 while MARDI stagnates, with its knowledge stock remaining low as in 2017. Malaysia has now

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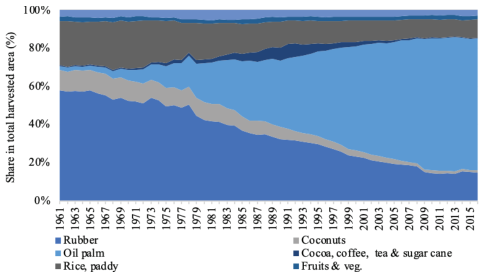
been confronted with several consequence from poor performance in research, which resulted in zero growth, mainly due to diminishing research investment during the past years, albeit spending below its potential investment, hence the R&D system became less efficient with unpredicted returns. The findings of this study are crucial and useful for future research directions and policy formulation to reinforce the agricultural sector in this region.

Introduction

The development approach that prioritised the production of high-value crops for higher economic returns as practised by the then British colonials during pre-independence era had highly shaped and influenced the status quo and trends of agricultural development in Malaysia. During British rule, agricultural growth and development were largely focused on plantation crops, which will be referred to here as commodity crops-(i.e, rubber, palm oil and cocoa) and the detriment of primary food crops (i.e. rice, fruits and vegetables). Consequently, the commodity crops have shown the largest share of land use, output, export earnings and labour usage, and the most developed links with downstream activities for decades. The share of commodity crops in the total crop harvested area in 1961 (i.e. four years after independence) was 72% with 62% of the total area being allocated for rubber. In 2016, the area of commodity crops tremendously increased to 85%, yet the composition of this area changed substantially during this period – rubber decreased to only 14% of the total area, palm oil grew from 2% in 1961 to 70% in 2016 while cocoa industry collapsed during the 1980s and the early 1990s and has not recovered since then (*Figure 1*). The distinction between commodity and food crops is further reflected in the government legislation. The Ministry of Primary Industry (MPI) focused policies and regulations on commodity crops (palm oil, rubber and cocoa), while the Ministry of Agriculture and Food Industries (MAFI) has political responsibility for the rest of the crops and livestock. With positive relationships between the export earnings and the national income, the commodity crops continued dominating the government's bold agendas across primary national development plans and policies including investment allocation and human resource capacity in the R&D sector through affiliated research institutes – Malaysia Palm Oil Board (MPOB), Malaysian Rubber Board (MRB), and Malaysian Cocoa Board (MCB). Malaysian Agricultural Research and Development Institute (MARDI), widely referred to as the leading agricultural R&D organisation in the country, is accountable for the remaining agricultural research. Other research contributions include the private sector becoming prominent, focusing on high-value plantation crops especially Sime Darby, FELDA and universities also have significant research contributions.

R&D from public and private sectors remain as key driver of agricultural growth worldwide, besides being the main source of technical change and improvement in productivity. Hence, the reduction of public investment in research and extension or low efficiency in the process of production and transfer of knowledge to agricultural producers could have strong negative effects on future agricultural growth in Southeast Asia. Past studies revealed the positive associations between agricultural research and economic development and growth (Fan 2000, Beintema et al. 2006 and Kristkova et al. 2017). The Organisation for Economic Co-operation Development (OECD) reviewed the role of agricultural research and development in fostering innovation and productivity in agriculture and found that the return of investments in agricultural R&D is generally high.



Source: Food and Agriculture Organisation (2020)

Figure 1. The composition of agricultural land in Malaysia (1961 – 2016)

However, the findings differ across commodities and other production factors (OECD 2010). In Latin America and the Caribbean (LAC), agricultural R&D was identified as the main driver of agricultural productivity over the past three decades (Nin Pratt et al. 2015). In the same region, higher levels of R&D and improved human resource capacity were not only needed to achieve productivity growth, but also to address food security and poverty alleviation (Stads et al. 2016). Similarly, Bishwajit (2014) argues that South Asian countries need to increase investment in agricultural R&D and implement institutional reforms to confront emerging challenges while pursuing food security both at national and regional levels, and Southeast Asia has no exception to these trends. Maredia and Raitzer (2012) assembled evidence on the impacts of agricultural R&D in Southeast Asia based on a comprehensive review of 42 studies. Their findings showed evidence of large benefits accruing to crop improvement research on rice. However, research on rice commands only a declining fraction of total agricultural research investments in the sub-region, and according to Maredia and Raitzer (2012), evidence of impacts in other areas and for different crops were relatively low or utterly lacking. Underlying the Global Food Projection 2020, Rosegrant et al. 2001 suggested that policymakers in the developing world must evaluate investment options wisely to ensure appropriate allocation decisions across sectors.

In Malaysia, recent studies have focused on the analysis of R&D on specific crops, such as rubber (Abdulla and Arshad 2017), rice (Harun 2017), and palm oil (Kushairi et al. 2019), among others, but no comprehensive study has looked at agricultural R&D investment and its impacts on agricultural growth. Being a highly dependent country on food imports, extremely specialised in the production of palm oil, facing climate change, resource degradation, and questions on the sustainability of its production scheme, this kind of analysis is the most needed in Malaysia. Using recently updated data from the Agricultural Science and Technology Indicators (ASTI 2020), this study measures the impacts of agricultural research investment on agricultural growth and productivity by focusing on the public sector. The main objective is to identify the performance, intensity and efficiency of agricultural research in Malaysia. As part of the overarching goal, this study looks at the efficiency in the use of input in research, the productivity of the research system, and factors driving productivity including the quantity and quality of human resources, the cost structure, resource allocation and research outputs. Using the information on the allocation of researchers across crops and other research activities and production, this study gauges the intensity and returns of research investment and finally, projections of future R&D investment under different assumptions will be used to discuss likely challenges faced by the Malaysian agricultural sector.

Conceptual framework, methods and materials

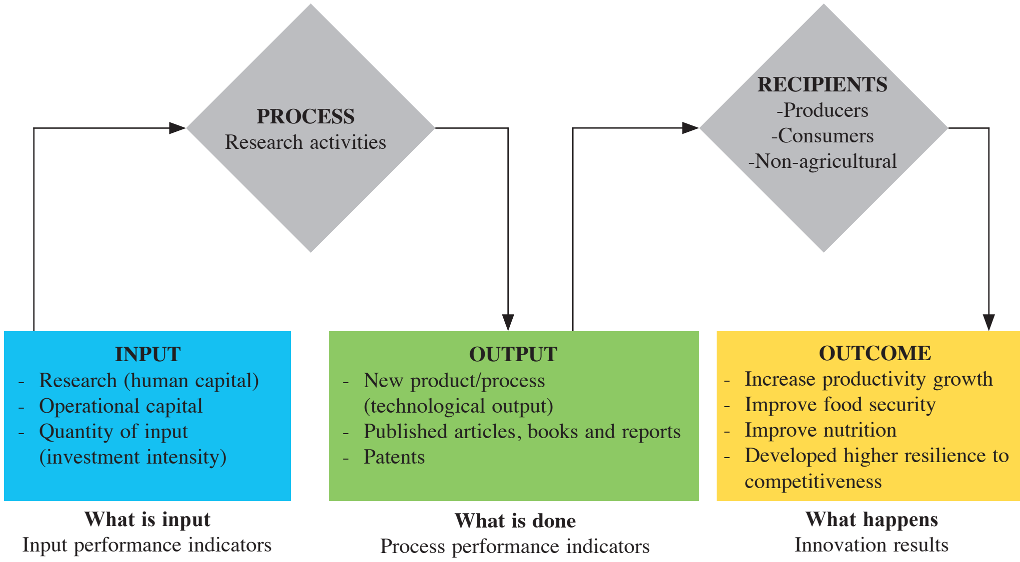
The assessment of R&D systems at the national level integrates the most critical segments of research activity and their surrounding environment showing the connections among them. This framework will be a reference for the analysis of R&D performance in the next section. Coccia (2001 and 2005) adapts and develops a model of R&D activity with components shown in *Figure 2*. *Input* are the resources of the system, which generate the research process. They include human capital (researchers), information, ideas, equipment, and other investments (libraries, labs, buildings, etc.), organisation, and source of financing.

The *production process* of a research body transforms the input into output through research projects, training courses, technological services, etc. The *output* of the research system includes new products and processes (technological output) associated with the publication of books and reports, project results, software innovations, and patents, among others. R*ecipients* are the agents that incorporate research output into the production process of goods and services. They can benefit from increased income or profit, cost minimisation, access to new markets, increased market shares, increased consumption, etc. The *Outcome* is the change that results from adopting the research outputs that are relevant to the users. The research process occurs under an internal organisation and institutional governance that directly influences employees' motivation and access to resources. The external environment and structural characteristics of the economy are also essential constraints in different ways, some of the critical variables that affect the efficiency of the research system. Thus, the assessment of both internal and external environments often becomes a significant aspect of research productivity.

There are specific questions to be answered in analysing the performance of research systems related to the different components of the research process shown above. The goal of the analysis of the *Input* component is to answer the question: "*Does the country/institution have the right portfolio of resources for technological innovation?"* and requires the use of different indicators to measure input quantities, quality, and resource mix, referring to total R&D spending and intensity, quality of human capital, costs, and cost composition (salaries and capital costs). The research process component focuses on the efficiency of the production process of new technologies, relating the quality and quantity of research outputs to the quantity and quality of inputs used in the R&D activity. Indicators to evaluate the research process link outputs and inputs in different partial or total productivity measures, including total output/total input, number of varieties released per researcher in a particular period, number of articles published per researcher, etc. When looking at the outcomes of the research process, the questions to be answered are; "*Does the country or organisation realise the target of technological innovation?*", "*Are those concerned, aware of the impact resulting the R&D process on the direct or indirect recipient of research outputs, including the economic and social impact of the research activities?*". Key components of the research system analysis look at the links between the research system and the economy/society to determine the degree to which the country's R&D policy and investment goals have been achieved. There are several difficulties associated with the measurement of impact at this phase of the analysis, including severely biased, attribution problems that result in mismatching research benefits with costs, causing implausible measures (Alston et al. 1998; Alston and Pardey, 2001; Pardey et al. 2006, Alston et al. 2011). Nevertheless, obtaining measures of the impact of the research process is a vital component of the evaluation of the R&D policy and investment. Measures of financial and economic returns to R&D investment are frequently used at this level.

Total factor productivity

This study uses the Lowe index defined in O'Donnell (2011) to calculate output, input, and total factor productivity (TFP) indices. This index uses linear weighting functions and prices as measures of value. Unlike widely used indices that also use prices



Source: Adapted from Laliene and Sakalas (2014)
Figure 2. Conceptual structure of R&D productivity assessment in research systems

like the Törnqvist and Fisher indices, the Lowe index can be used for multi-lateral and multi-temporal comparisons. The index aggregates *m* outputs *y* and *n* inputs *x* of a production unit *i* in period *t*:

$$Q_{i,t}(y) = \Sigma_m y_{i,m,t} \times p_{m,to} \quad [1]$$

$$X_{i,t}(x) = \Sigma_n x_{i,n,t} \times w_{n,to} \quad [2]$$

Where Q and X are the output and input indices and p_m and w_n are the output and input prices, respectively, and t_o is the reference period of the prices used as a weight in the index. The TFP index is then defined as:

$$TFP_{i,t} = \frac{Q_{i,t}}{X_{i,t}} \times \frac{X_{i,to}}{Q_{i,to}} \quad [3]$$

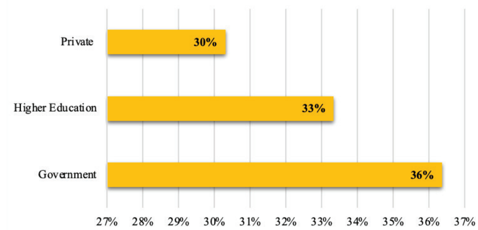
Defined in this way, the index measures the TFP of unit *i* in period *t* relative to its TFP in the period *to*. Given its axiomatic properties as a 'well behaved' index number, the Lowe index can also be defined to compare TFP across time and production units:

$$TFP_{it,jto} = \frac{Q_{i,t}}{X_{i,t}} \times \frac{X_{j,to}}{Q_{i,to}} \quad [4]$$

In this case, the index measures the TFP of unit *i* in period *t* relative to the TFP of unit *j* in the period t_o.

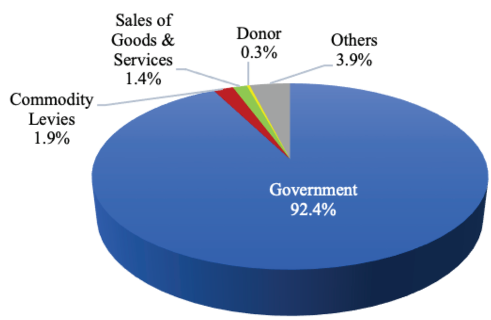
Data calibration

This study utilised the historical and most recent updated data from multiple series of surveys on Agricultural Science and Technology Indicators (ASTI). ASTI follows the definition of agriculture provided by the Food and Agriculture Organizsation of the United Nations (FAO), which comprises crops, livestock, forestry, fisheries, natural resources, on-farm postharvest activities, as well as the socioeconomic aspects of primary agricultural production. It provides a comprehensive and trusted source of information on agricultural R&D systems across the developing world (*Appendix 1*). The most recent ASTI data was obtained through primary surveys conducted between 2018 – 2019, covering database for the period 2013 to 2017 from 33 agricultural research agencies of public and private sectors, including public universities in the country that participated voluntarily. Interviews using structured questionnaires were used as survey instruments to obtain data on investment for the 2013 to 2017 period. The participating agency can be grouped into three groups; the most significant participant in the government agency (36%), followed by the higher education (33%), and the private sector (30%) (*Figure 3*). The historical ASTI data was available from previous survey rounds. Although data on the private sector was also collected, this paper emphasised public R&D investment which comprised of government agencies and higher education (i.e. universities). All data were aggregated and merged with existing ASTI datasets to show long-term trends at the national, regional, and global levels. The data on investment mainly consists of human capacity, research output, and institutional developments that can be used to illustrate trends and gaps in a country's agricultural system.



Source: Primary survey (2018/19)

Figure 3. Composition of the respondent by research sector (n = 33)



Source: ASTI database (2020)

Figure 4. Sources of agricultural research funding in Malaysia, 2013 – 2017

Performance and capacity of agricultural research

Research funding and expenditure

The source of research funds for Malaysia's public research were mainly government funds. On average, the research fund accounted for 92.4% of the total funding in 2013 to 2017, much higher than the previous contribution indicated government contributions accounted for two-thirds of total agricultural research funding in 2002 – 2003 (Bientema and Stads 2008). Lederman and Maloney (2003) identified the association between country development and research investment and found positive impacts on GDP per capita for high-income countries due to higher government capacity to mobilize public expenditure. Others funding includes commodity levies, and sales of goods and services by the system contributed to 3.3% (*Figure 4*).

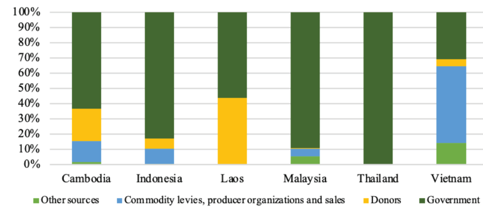
A comparison of R&D funding sources across the region shows that the three countries with large research systems rely primarily on government funding. Commodity levies, producer organisation and sales are larger sources of financing in Indonesia (10%), Cambodia (14%), Vietnam (50%) compared toMalaysia (5%). Donor sourcing seems more significant in lower-income countries (Laos and Cambodia) (*Figure 5*).

Malaysia has been the largest spending on agricultural R&D investment compared to other developing countries with a similar size of the research system in Asia, yet the trend is stagnating for almost 20 years. The investment during this period fluctuated up to 600 million constant PPP dollars showing negative growth rates in recent years as investment declined from 653 million dollars in 2013 to 627 million dollars in 2017, albeit increases in the number of researchers. Malaysia's total average public research spending between 2013 and 2017 reached 642 million constant dollars, equivalent to the current RM1,024 million (*Figure 6*). As of 2017, Malaysian public research investment has increased 21% since the year 2000.

Despite MARDI's central role in agricultural R&D, the commodity-based research agencies: MPOB, MRB and MCB spent nearly twice as much on agricultural research, representing almost half the national total. Research on commodity crops received the highest share of both investment and human resources, and even the investment increased tremendously from 123.9 to 364.5 (millions of 2011 PPP dollars) in 2000 and 2017, respectively. On the other hand, MARDI received much lower in recent years and even more flattened investment patterns. As per the 2013 – 2017 average, the commodity boards accounted for 57.6% of total investment while MARDI received 25.3%, with the remaining investment going to higher education (6%) and others (11%) (*Figure 7*).

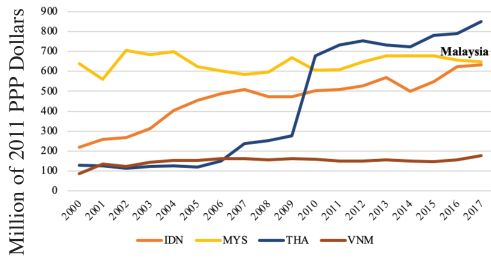
Operating costs and salaries accounted for over 90% of the total expenses in Malaysia, while capital costs were relatively small. Despite increases in the number of full-time equivalents (FTE) researchers, the cost per researcher decreased due to declining research investment in the past two decades. Notice that the number of FTE researchers increased significantly between 2003 and 2010, as shown in *Figure 8*. The main consequence of this increase is a substantial reduction in the cost of capital per researcher and a relative increase in operating expenses concerning both salaries and capital. Increased operating costs per researcher and a decrease in capital costs likely boosted the researcher's productivity.

Salaries showed the highest contribution to total R&D costs in Malaysia (*Figure 9*), accounting for 67% of total expenses in 2017, much higher than in Thailand (52%) and substantially higher than Indonesia's values (39%). Thus, despite a lower share of the operational cost than other countries, Malaysia showed a higher operating cost per FTE than Thailand and



Source: Calculated by authors using data from ASTI (2020)

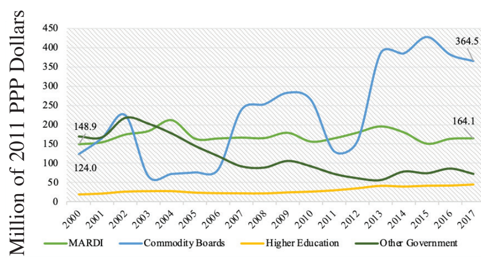
Figure 5. Comparison of agricultural research funding in Southeast Asia (%), 2013 – 17



Source: ASTI database (2020)

Note: IDN, MYS, THA, and VNM are the country codes for Indonesia, Malaysia, Thailand, and Vietnam, respectively

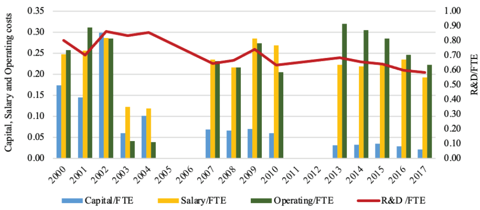
Figure 6. Public agricultural R&D investment in selected developing countries, 2000 – 17



Source: ASTI database (2020)

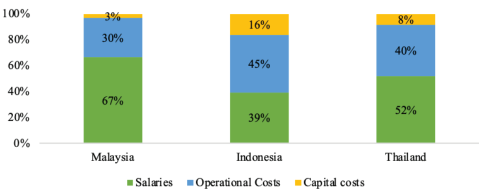
Figure 7. Public investment in agricultural research (mill. 2011 PPP dollars) in Malaysia, 2000 – 17

Indonesia. Although the lowest capital spending seems to result from changes in the early 2000s when the number of researchers increased, capital costs saw a significant reduction from 25% in 2000 (*Figure 9*) to 3% observed in 2017.



Source: Calculated by authors

Figure 8. Capital, salary, and operating costs per researcher (mill. 2011 PPP/FTE) in Malaysia, 2000 – 2017



Source: Calculated by authors

Figure 9. Composition of R&D costs between developing countries (%), 2017

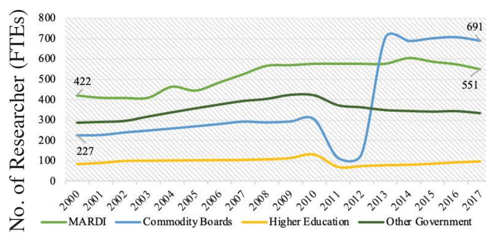
Human resource capacity

Malaysian public agricultural research capacity significantly increased from 1,150 (2012) to 1,709 (2017) full-time equivalent (FTE) researchers, with the majority of researchers being in the commodity boards, reaching 709 FTEs in 2016 and 699 FTEs on average in 2013 – 2017. The commodity boards represent 40.9% of the total FTE researchers in the public sector, followed by MARDI (33.9%), other government agencies (20%), and higher education (5.1%) (*Figure 10*).

As with other indicators, commodity boards have the most significant and growing share of PhDs in total FTEs. In 2017, less than one-fourth of Malaysian agricultural researchers hold a PhD degree, while most researchers held an MSc (42.5%) and a BSc (35.8%) degree. The share of PhDs has deteriorated due to retirement and more restricted funding for sponsorship educational programs. The number of researchers with an MSc degree, on the other hand, even increased since 2010 when the government revised a recruitment policy for new researchers prioritising MSc holders' candidates as a minimum qualification. In addition, the government also granted researchers already in the system to upgrade to an MSc degree through sponsorship programs. These efforts to ensure a higher quality of research outputs led to increased efficiency in public research (*Figure 11*).

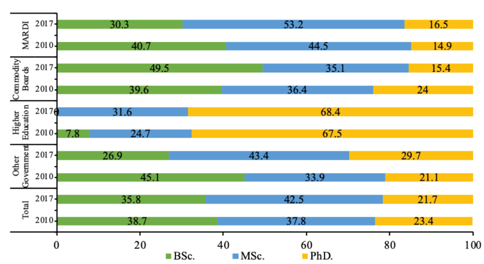
Compared to the other two significant R&D investing countries in the region, Malaysia showed the largest ratio of PhD/MSc and the largest share of researchers with a PhD degree. These values are much higher than those of Indonesia and Thailand (*Table 1*). These numbers show that Malaysia has the highest quality of human resources in the region, which should explain in part also Malaysia's high productivity per researcher and its relatively high cost per researcher.

Figure 12 shows that over half of Malaysian researchers are 40 years old and below across institutes and degree levels. More than 70% of PhD researchers range from 41 to 60 years old, while about 30% are 50 years old and above. The current



Source: ASTI database (2020)

Figure 10. Public agricultural researcher, Full-Time Equivalent (FTE), 2000 – 2017



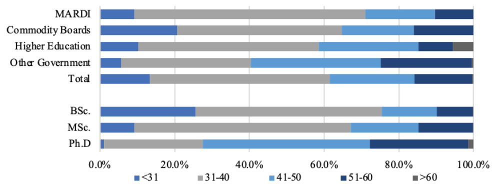
Source: ASTI database (2020)

Figure 11. Share of qualification by institutional category in Malaysia (%), 2010 & 2017

Table 1. Researchers' skill, Southeast Asia Countries, 2017

Country	PhD/MSc (%)	PhD, FTE (%)
Malaysia	74.0	28.4
Indonesia	63.0	24.2
Thailand	54.0	17.9
Average	64.0	23.5

Source: Calculated by authors



Source: ASTI database (2020)

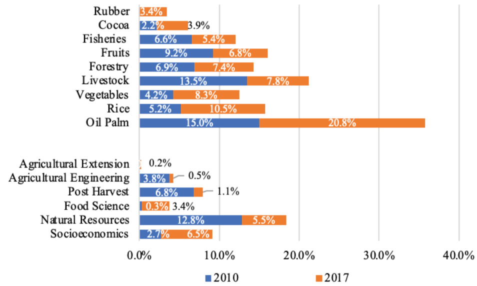
Figure 12. Age composition of researchers in Malaysia by institutional category (%), 2017

situation might be a concern since the retirement age at many government agencies in Malaysia start between 56 to 60 years old.

Women's participation in agricultural research indicates a rapid increase over the years. In 2017, this share had risen to more than half of the total number of the researcher. The rapid rise is mainly due to the rising student ratio of women to men in most universities. Currently, two-thirds of Malaysian university students (across all sciences) are female. This gender gap is less evident in agricultural sciences than in the social sciences. Yet, women still tend to be higher than men in agricultural and veterinary faculties by a ratio of 1.3 to 1.0 (Yong 2017).

Research focus and output

Positioned as the top agricultural commodity in Malaysia, oil palm has been the primary research focus in Malaysia's agricultural research. MPOB remains as the leading agency in oil crop research. *Figure 13* compares research focus in 2010 and 2017 in specific commodities and cross-cutting research areas as a percentage of researchers in total FTEs. Palm oil remained



Source: ASTI database (2020)

Figure 13. Breakdown of research areas, 2010 and 2017

the main focus area in 2010 as well as 2017, increasing the number of researchers from 15% to 20%. On the other hand, rice, vegetables, forestry, cocoa, and rubber received more attention in 2017 relatively compared to 2010 with a growing number of researchers. The rest, livestock, fruits, and fisheries showed a lower make-up of total researchers in recent years. Compared to other research areas, socioeconomics and food sciences increased in the total number of researchers, while natural resources, post-harvest and agricultural engineering showed smaller contributions in FTE for the year 2017 than in 2010.

Results and discussions

Institutional profile

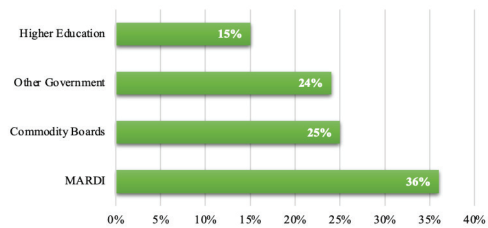
The public sector has the most extensive agricultural research activity in Malaysia, while the Malaysian Agricultural Research and Development Institute (MARDI) is the leading organisation in the country, accounting for 36% of total human resource capacity in 2017. MARDI is administered by the Ministry of Agriculture and Food Industries (MAFI), focusing on research on food crops, mainly including rice, horticulture, and livestock, while the commodity-based research organisations (i.e., commodity boards) consisting of Malaysia Palm Oil Board, Malaysia Cocoa Board, Malaysia Rubber Board, accounted for 25% of total researchers, managed by the Ministry of Plantation Industries and Commodities (MPIC). The remaining is Forest Research Institute Malaysia (FRIM), the Fisheries Research Institute and the Veterinary Research Institute (URI) classified as 'Other Government' institutes. Two of Malaysia's states, Sabah and Sarawak, exercise a greater degree of autonomy and, as such, operate their crop, forestry, and fisheries research agencies. The higher education sector plays a relatively limited role in Malaysia's agricultural R&D, accounting for 15% of the country's research capacity in 2017 (*Figure 14*). Universiti Putra Malaysia (UPM) is the largest of these agencies, by far. It comprises four related faculties focused on agriculture, veterinary medicine, forestry, food sciences and technology, the Institute of Agricultural and Food Policy Studies and the Institute of Tropical Agriculture and Food Security. Other crucial agricultural research performers in the higher education sector include the Universiti Kebangsaan Malaysia (Faculty of Science and Technology) and the MARA University of Technology (Faculty of Plantation and Agrotechnology). The private research sector also plays a vital role in the Malaysian agricultural R&D, and the most significant contributors are Sime Darby Plantation and FELDA, both of which emphasise oil palm research.

The intensity of research investment

During the past two decades, agricultural research investment in Malaysia has been stagnated with a slight increase from 638.8 million (constant PPP dollars) in 2000 to 648.1 mill. by 2017 (*Figure 15*). The investment in Indonesia showed a decreasing trend and only Thailand increased during the same period of high agricultural commodity prices. The three countries remain the major investors and the countries with the most developed agricultural research systems in the region.

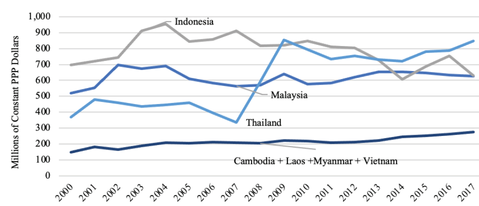
Comparisons of absolute levels of R&D investment can only provide partial information on a country's efforts on R&D investment given that this level depends on several country-specific factors like the size of the economy, the size of the agricultural sector, and income. A better measure of this effort is 'investment intensity'. There are different possible measures of investment intensity, the most used being the Intensity Ratio (IR) comparing R&D investment to the size of the agricultural sector (IR = R&D/AgGDP). This study uses the ASTI Intensity Index (AII) which combines the IR with two additional intensity ratios calculated as R&D divided by GDP (the size of the country's economy) and R&D divided by GDP per capita (the country's average income). By combining different intensity ratios, the AII avoids the most misleading comparisons that result from the use of the IR (see appendix and Nin-Pratt 2016).

Therefore, the AII is applied to measure research investment intensity in Malaysia. The AII is calculated as an index relative to the AII of the US. For example, a country with an AII of 0.5 in 2000 means that this country's investment intensity in that year was half of the intensity of the US in 2011. An additional advantage of



Source: Primary survey (2018/19)

Figure 14. Human resource capacity (FTEs) in Malaysia by research institutions (2017)



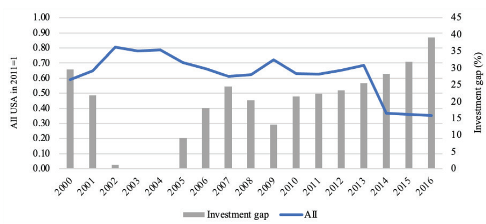
Source: Authors based on ASTI (2020)

Figure 15. Agricultural research investment (mill. Constant 2011, PPP), Southeast Asia (SEA) Countries, 2000 – 2017

the AII, resulting from the method used for its calculation, is that it also provides a measure of potential R&D investment. When comparing countries with similar sizes of the economy, the agricultural sector, and similar income, the AII can be used to determine which of these countries are investing the most in R&D. Assuming that similar countries (in terms of income, size of the economy, and size of agriculture) can potentially invest similar levels of R&D, we can then say that the level of investment of the country investing the most among this group of countries is the investment target for countries in this group investing less. We define the investment gap of a country as the difference between the potential or target investment of this country and its actual investment measured in percentage. R & D investment intensity reached a maximum in 2002 with an AII value of 0.81, meaning that the investment effort was 80% of that of the United States in 2011. That same year, the investment gap was only 1% and the next year it reached 0%, meaning that Malaysia was investing at its potential (i.e. no gap). However, because of stagnated investment after that year, Malaysia's AII dropped to 0.35 in 2016, and the investment gap in that year increased to almost 40%. This implies that Malaysia has significantly reduced its investment efforts to less than half of what they were in 2002 and that it should increase investment by 40% to close the investment gap (*Figure 16*).

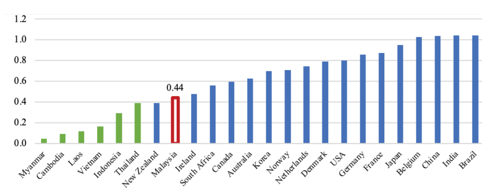
Further, we compare Malaysia's investment efforts with a diverse group of countries including countries with the highest levels of investment intensity for the period 2013 – 2016 and other Southeast Asian countries. It is noticed that intensity levels are comparable in the sense that investment efforts are measured relative to each country's investment possibilities in terms of income, size of the agricultural sector, and size of the economy. The AII for Malaysia on average for the period was 0.44, showing that Malaysia was still making similar investment efforts to high-income economies like New Zealand and Ireland. Malaysia is the country with the highest AII value in the region, with a similar AII to Thailand (0.39) and higher than Indonesia's (0.29). Investment intensity in other Southeast Asian countries are very low, with values that go from 0.16 in Vietnam to 0.05 in Myanmar (*Figure 17*).

How volatile is an investment in R&D? *Figure 18* shows the annual growth rates of R&D investment from 2014 to 2017 for Malaysia, Indonesia, and Thailand, and volatility is calculated as the standard deviation of those growth rates. The smaller the volatility the most stable and reliable investment is. Even though R&D investment in Malaysia appears to be less volatile in the region, this is not a strength for the country given that the low volatility is the result of almost zero growth in the last five years.



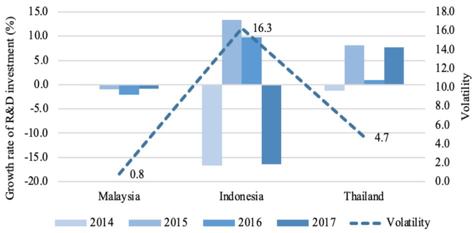
Source: Calculated by authors
Note: ASTI Intensity Index (*AII*) measures the investment intensity of Malaysia relative to that of the United States in 2011=1.The investment gap is calculated as the ratio of Malaysia's actual R & D investment and potential investment (see appendix and Nin-Pratt, 2016)

Figure 16. ASTI Intensity Index (AII) and investment gap for Malaysia, 2000 – 2016



Source: Calculated by authors

Figure 17. ASTI Intensity Index for selected countries in average values, 2013 – 2016



Source: Calculated by authors using data from ASTI (2020)

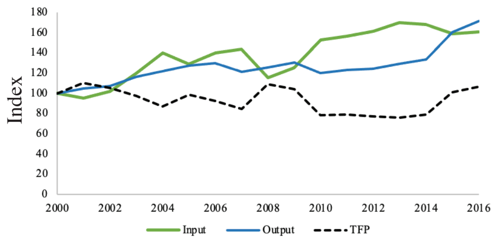
Figure 18. The growth rate of R&D investment, 2014 – 2017 and volatility of investment between SEA countries

Total factor productivity

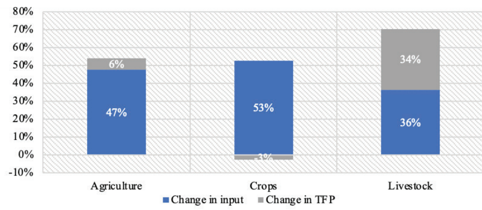
One of the crucial indicators to measure the efficiency of input use in agricultural production systems is agricultural productivity. As a productivity measure, total factor productivity (TFP) accounts for the contribution of all major inputs used in the production process, and by comparing total inputs used with output resulting from production, it provides a measure of how productively inputs are used and how efficient the production process will be (FAO 2018). According to IFPRI (2018), TFP is an indicator of how efficiently agricultural land, labour, capital, and inputs are used to produce agricultural outputs and is measured as the ratio of output to total inputs. The agricultural system in a region is considered more efficient if more output is produced from a given level of input, or conversely, the fewer input are used to produce a certain quantity of output. Detailed secondary data to calculate TFP was not readily available and building a new dataset for TFP analysis was beyond the scope of this work. Instead, the available data from USDA-ERS (2019) and FAO (2020) at the national level was used to get a rough picture of the performance of agriculture in Malaysia in recent years and the contribution of different activities to growth. TFP was calculated for the agricultural sector and the crop and livestock subsectors. Prices for output and input were all in 2007's RM values. Input included cropland, animal stock, machinery, fertiliser, feed, and labor. To calculate the TFP of the crop and livestock subsectors, cropland, machinery, and materials including fertiliser pesticides and seeds were used as inputs in crop production, while animal stock and feed were the input of the livestock sector. Labor, only available for agriculture in the USDA-ERS dataset, was allocated to crops and livestock production using detailed data on labor in agriculture from the Department of Statistics of Malaysia (DOSM 2020).

The TFP for Malaysian agriculture was calculated by dividing output according to the weighted sum of labour, agricultural land, livestock capital, machinery, crop inputs (fertiliser, pesticide and seed), and livestock inputs (feed and pharmaceutical) between 2000 and 2016 period, using the year 2000 as a baseline index (2000 = 100). *Figure 19* displays trends of output, input, and TFP indices for agriculture, crops and livestock, and land and labor productivity for Malaysia between 2000 and 2016. Agricultural output in Malaysia increased 71% between 2000 and 2016, equivalent to an annual average growth rate of 3.4%. Most of this growth is explained by growth in input which increased 61% during the same period. Certainly, there is no indication of significant TFP growth in total agriculture in Malaysia during the past decade (2000 to 2010). TFP in 2016 was only 7% bigger than in 2000, thus it is not possible to determine if this is an indication of an improved and sustainable trend in agricultural TFP.

Figure 20 confirms that increases in yields are largely stemming from increasing inputs, hence TFP shows no growth in total agriculture. For total agriculture, of 53% growth between 2000 and 2016, 47% corresponds to input growth and only 6% to the TFP growth. The performance of crop production is even worsening than that of agriculture as it shows negative TFP growth and total growth of 50% for the



Source: Calculated by authors
Note: The total outputs and inputs are calculated using the year 2000 as the baseline index
Figure 19. Trends of total agricultural output, input and total factor productivity (TFP) for Malaysia, 2000 – 2016

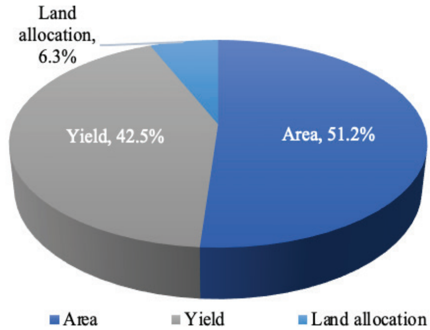


Source: Calculated by authors
Figure 20. Change in output and the contribution of input and TFP for Malaysia, 2000 and 2016

period. In contrast, livestock showed better performance with 34% TFP growth while the remaining 36% resembles input growth, implying a more efficient and productive sector than crop and total agriculture.

Output Growth Decomposition

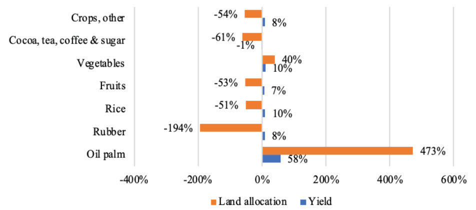
We decompose total output growth in crop production into the contribution of changes in total harvested area, the contribution of yields, and the contribution of changes in land use within the total harvested area. We also show the contribution of different crops to yield growth and changes in land allocation. The analysis of output growth decomposition shows that more than half of the increase in crop output between 2000 and 2016 is explained by increased harvested area (51%), while 43% of output growth was the result of growth in yields. Changes in land allocation resulted in 6% of total output growth (*Figure 4.8*).



Source: Calculated by authors
Figure 21. Contribution to total output growth in crops (Malaysia), 2000 – 2016

Figure 22 shows the contribution of individual crops to the 42% increase in yields and the 6% output increase from changes in land allocation in *Figure 21*. The result showed that Oil palm dominates changes in crop production in Malaysia, in both land allocation (473%) and yield (58%). In the case of land allocation, a 473% contribution to output growth means that there was an extremely large increase in the share of oil palm in the total harvested area resulting in an output increase of 473%. However, this expansion of oil palm displaced other crops, reducing output. The highest reduction in output (194%) resulted from the reduced share of rubber in the total area but we also observe significant reductions in the areas planted with rice, fruits, cocoa, coffee, tea, and sugar that harmed total crop output. The only activity that increased its share in the total harvested area was vegetable production, contributing to 40% and 10% on land allocation and yield, respectively.

In summary, what we observe in the crop subsector is a continuous expansion of the area of oil palm displacing other crops. Notice that despite reductions in the area share, most crops contributed to increased yields. For example, the average share in the harvested area of fruits and vegetables between 2000 and 2016 was 2% but together they explain 17% of the total contribution of yield to output growth. The equivalent



Source: Calculated by authors

Figure 22. Contribution of different crops to changes in yield and land allocation (Malaysia), 2000 – 2016

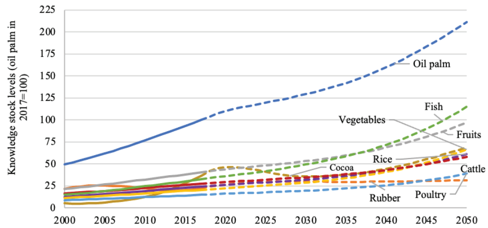
figures for oil palm are 62% of the area and 58% contribution to output growth through yield increase.

Returns on research investment

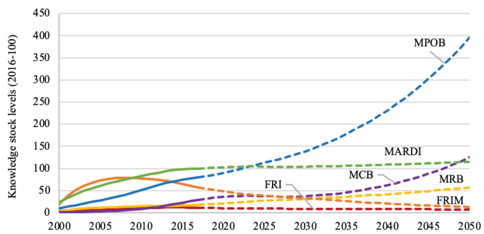
What is the benefit of investing an extra dollar in R&D in different agricultural activities? To answer this question, we need to know how much Malaysia has invested in different activities in the past and what is the productivity response to this extra dollar invested. Total R&D investment can be used to measure the total knowledge (knowledge stock) the country has accumulated in a particular activity. For example, we can build this knowledge stock as the sum of all R&D investments in the past in that activity; however, the knowledge generated by this investment does not last indefinitely. Some of this knowledge becomes obsolete or decays as it is replaced by new knowledge or it becomes of no value as demands for new technologies change with time. We can think of R&D as an investment that builds knowledge capital, and knowledge decay is equivalent to capital depreciation. The fact that R&D investment results in accumulated knowledge are a consequence of its lagged effect. A dollar invested in a year *t* does not influence productivity that same year. It takes time for this investment to generate return (increase productivity, reduce losses or decrease yield variability) and when it does, it keeps generating benefits for several years. This is what is known as the lagged effect of R&D investment.

To look at returns to R&D investment in Malaysia, we used past R&D investment from ASTI (2020) to calculate knowledge stocks for each major agricultural activity assuming a depreciation rate of 0.15, the most frequent value used in the literature which refers to a range of accepted values between 0.10 and 0.25 (Esposti and Pierani 2003). Malaysia's knowledge in the production of different activities is not only the result of investment and knowledge generated within the country but could also result from knowledge generated in other countries. This knowledge can 'spill in' Malaysia and be used by producers. For example, new rice varieties produced in Thailand could be imported by seed companies and sold to Malaysian farmers. We assume that knowledge stocks from other countries can benefit Malaysia depending on the 'proximity' between Malaysia and those countries: the more similar the climate and output composition of other countries to that of Malaysia and the closer those countries are (geographically), the more Malaysia can benefit from the knowledge generated in those countries. We calculated knowledge stocks of other countries using ASTI (2020) global dataset as we did for Malaysia and weighted those stocks by our measure of proximity to Malaysia to obtain the knowledge spillovers from the rest of the world available for agricultural production in Malaysia. Finally, following Fuglie (2018), we assume that a 1% change in the knowledge stock in Malaysia results in a TFP change of 0.21% (i.e. R&D elasticity).

Figures 23 and *24* show the evolution of knowledge stocks by activity and major research institutes and projections of the future evolution of these stocks if Malaysia continues to invest in each activity (institute) at historical rates (growth rates between 2000 and 2017). In 2000, the oil palm knowledge stock was between two and six times larger than those other activities. If the country continues with the same pattern of investment as in the recent past, the highest



Source: Elaborated by authors using data from ASTI (2020)
Note: R&D investment is projected to grow at the same rates observed between 2000 and 2017
Figure 23. Evolution of knowledge stocks for different activities based on historical R & D investment and projections (Malaysia), 2000 – 2050



Source: Elaborated by authors using data from ASTI (2020)
Figure 24. Evolution of knowledge stocks for main research institutes based on historical R&D investment and projections (Malaysia), 2000 – 2050

knowledge stocks by 2050 will be of oil palm, fruits and fish. Rice, vegetables, cocoa and cattle will reach similar levels of knowledge stock but below those of fish and fruits, while rubber and poultry will show the lowest stocks. While no growth is projected for knowledge stocks of rubber production after 2020 – 2025, poultry stocks will grow at similar rates as knowledge stocks of vegetables, rice and cattle.

Figure 24 displays the knowledge stocks are total stocks of some of the main research institutes in Malaysia (based on their share in total R&D investment). If the country continues with the same investment priorities as in the past, Malaysian Palm Oil Board's (MPOB) knowledge stock would grow exponentially until 2050 while the knowledge stock of the Malaysian Agricultural and Research Development Institute (MARDI) would stagnate and remain at the 2017 level. The country's knowledge on forestry and fisheries would remain at low levels relative to other activities and could even decline as shown by the evolution of stocks of the Forestry Research Institute Malaysia (FRIM) and the Fisheries Research Institute (FRI). Notice that stocks of the Malaysian Rubber Board (MRB) and the Malaysian Cocoa Board (MCB) are projected to grow even though rubber production has been reducing area and output for several years.

Table 2 shows the value of the output of different activities and compares it with the knowledge stocks (including spillovers) in each of those activities, also showing their respective shares, and the output (in dollars) obtained by investing one extra dollar in each activity. The knowledge stock of oil palm amounts to $7.7 billion or 36% of total knowledge stock in the country, a value close to the share of oil palm in total output (39%). The second activity of importance of the size knowledge stock is fruits. In this case, Malaysia has invested much more in fruits (14% of total knowledge stock) than in other activities, given that fruit represents only 1.7% of the total value of output. A similar situation is observed in cocoa, roots and tubers, vegetables, and cattle. On the other hand, knowledge stocks of rubber, poultry and coco palm, represent a smaller share in total knowledge than the importance that these activities have on total output. Rice and fisheries show higher shares in knowledge stock than in output, but the differences are significantly smaller than the differences observed in cocoa, fruits and cattle.

The last column in *Table 2* shows the productivity response of an extra dollar invested in each activity. This response depends on the R&D elasticity mentioned above (which we assumed to be the same for all activities) and it is positively correlated with the output-knowledge stock ratio of each activity. As expected, the highest

Table 2. Output, knowledge stocks and response to R&D investment for main agricultural sub-sectors (Malaysia), 2016

	Value of output		Value of knowledge stock		
	Mill. 2011 $	Share (%)	Mill. 2011 $	Share (%)	Output (2011 $) per one extra dollar of R&D invested
Oil palm	12,988	39.1	7,668	35.7	0.36
Rubber	2,570	7.7	711	3.1	0.76
Cocoa	20	0.0	1,079	4.6	0.00
Rice	2,094	6.3	1,871	8.7	0.23
Roots and tubers	40	0.1	873	4.1	0.01
Coco palm	186	0.6	54	0.3	0.72
Fruits	519	1.6	3,112	14.5	0.03
Vegetables	1,051	3.2	1,594	7.4	0.14
Cattle and dairy	149	0.4	2,120	9.9	0.01
Poultry	9,660	29.0	1,163	5.4	1.74
Livestock, other	1,187	3.6	508	2.4	0.49
Fisheries	2,807	8.4	2,496	11.6	0.24

Source: Elaborated by authors based on ASTI (2020)
Note: (a) The response in productivity per unit of output is calculated by multiplying the output/knowledge stock ratio of each activity by the R&D elasticity. An elasticity of 0.21 was used for all activities

response is obtained from those activities in which Malaysia has invested less relative to its importance in agriculture. This is the case of poultry ($1.74/dollar) followed by rubber ($0.76/dollar), coco palm ($0.72/dollar), pigs ($0.49/dollar) and oil palm ($0.36/dollar). The response of fisheries, rice and vegetables is lower but still significant, while cocoa, roots and tubers, cattle and fruits show very low response.

The effect of one dollar invested in R&D influences productivity over a relatively long period and its contribution to productivity will not be the same every year. Take for example the response of poultry productivity to an extra dollar invested in R&D ($1.74) as shown in *Figure 15*. In the year of investment (year 0), there will be no effect on productivity. In year 1, there could be a small impact, but it will be less than $1.74. The effect on productivity will continue to increase until it contributes its full $1.74 increase in productivity. After that year, the contribution will decrease as the knowledge generated by that dollar invested in year 0 starts to depreciate and continues to decrease thereafter until it gets close to $0.0 between 36 to 38 years after investment. Is this distribution of the benefits of investment across time what is used to measure the rate of return of an extra dollar in R&D.

The same calculation to compare returns to R&D investment across major research institutes in Malaysia using values of the output activities researched in each institute and the total knowledge stock of the institute to calculate the knowledge stock ratio. As results are sensitive to the choice of R&D elasticity, which is assumed equal to 0.21, the calculation of benefit-cost ratio (BCR) and internal rate of return (IRR) for R&D elasticities of 0.10 and 0.42, respectively. Columns 2 to 4 of *Table 3* show BCR using R&D elasticities of 0.10, 0.21 and 0.42, respectively. The highest returns to R&D investment in Malaysia as of 2016 were obtained from investment in the production of poultry, coco palm, pigs, oil palm, rubber and fisheries, in that

Table 3. Benefit-Cost Ratio and Internal Rate of Return of an extra R&D dollar invested in different activities (Malaysia), 2016

	Benefit-cost ratio			Internal rate of return (%)		
	R&D elasticity			R&D elasticity		
	0.10	0.21	0.42	0.10	0.21	0.42
Poultry	4.4	9.3	18.6	22.9	36.2	53.2
Coco palm	1.8	3.9	7.7	11.3	20.8	32.4
Pigs	1.2	2.6	5.2	7.1	15.5	25.6
Oil palm	0.9	1.9	3.8	4.0	11.6	20.6
Rubber	0.8	1.7	3.4	3.1	10.4	19.0
Fisheries	0.6	1.3	2.5	0.6	7.2	15.0
Rice	0.6	1.3	2.5	0.5	7.2	15.0
Vegetables	0.4	0.7	1.5	–3.3	2.3	8.9
Fruits	0.1	0.2	0.4	–10.5	–7.1	–2.9
Roots and tubers	0.1	0.2	0.3	–11.4	–8.1	–4.3
Cattle	0.0	0.1	0.2	–13.7	–11.0	–7.9
Cocoa	0.00	0.01	0.02	0.0	0.0	–16.0

Source: Elaborated by authors based on ASTI (2020) and FAO (2020)
Note: An interest rate of 5% was assumed to calculate the BC. Returns to forestry not calculated

order. Notice that investments in poultry, coco palm and pigs are less sensitive to changes in the assumed R&D elasticities or the response of the investment in terms of productivity. In the case of these three activities, BC ratios are bigger than 1 even with the lowest elasticities used (0.10). Investments in oil palm, rubber, fisheries and rice result in BC ratios higher than 1 with elasticities of 0.21 and 0.42. Finally, investments in vegetables, fruits, roots and tubers, cattle and cocoa are not justified if benefits are measured as increases in productivity given that the BC ratio is less than 1 no matter which elasticity is used in the calculation of returns. IRRs lead to the same conclusions (IRR greater than 5%) with rates of 36% for poultry, 21% for coco palm, 16% for pigs, 12% for oil palm, 10% for rubber and 7% for fisheries and rice (R & D elasticity of 0.21).

Table 4 presents the equivalent calculations for Malaysia's main research institutes. The highest returns to R&D investment result from research in livestock by MARDI (i.e. poultry, sheep and goats and cattle), followed by MPOB and MRB. Notice that when total returns to investments in MARDI are considered (crops and livestock), they are still higher than returns for FRI and MCB. IRR for MARDI livestock, MPOB and MRB are 16%, 12% and 10%, respectively, assuming an R&D elasticity of 0.21.

Several caveats should be considered when analysing these results. First, benefits are measured in terms of productivity growth only. Other criteria's could also be considered to measure benefits, depending on the country's priorities, for example, growth in agricultural exports, employment generated in rural areas or contribution of R&D investment to poverty alleviation among several others. Different priorities could lead to very different results in measured returns. Second, the productivity response is defined using the same arbitrarily chosen elasticity values for all activities (within normal observed ranges). However, we expect responses to be different between activities. For example, average yields of oil palm have been rising steadily but yield

Table 4. Benefit-cost ratio and internal rate of return of an extra R&D dollar invested at different research institutes (Malaysia), 2016

	Benefit-cost ratio			Internal rate of return		
	R&D elasticities			R&D elasticities		
	0.10	0.21	0.42	0.10	0.21	0.42
MARDI (livestock)	1.3	2.6	5.3	7.2	15.7	25.8
MPOB	0.9	1.9	3.8	4.0	11.6	20.6
MRB	0.8	1.7	3.4	3.1	10.4	19.0
MARDI	0.7	1.4	2.8	1.5	8.5	16.6
FRI	0.6	1.3	2.5	0.6	7.2	15.0
MARDI (crops)	0.3	0.6	1.3	–4.1	1.2	7.5
MCB	0.0	0.0	0.0	0.0	0.0	–16.0

Source: Elaborated by authors based on ASTI (2020) and FAO (2020)
Note: An interest rate of 5% was assumed to calculate the BC. FRI = Fisheries Research Institute; MRB = Malaysian Rubber Board; MCB = Malaysian Cocoa Board; MPOB = Malaysia Palm Oil Board; MARDI = Malaysian Agricultural Research and Development Institute. Returns to investment in the Forestry Research Institute Malaysia were not calculated

increases are slow compared with other crops (Woittiez et al. 2017). Returns to R&D investment in oil palm will depend on the pace at which new technologies are adopted and increase productivity. Another important consideration is that the public R&D system in Malaysia increased its productivity significantly in recent years. The effect of this transformation on productivity growth is still to be seen but, in the future, it results in a higher response to R&D.

Conclusions and policy implications

Results of the analysis showed that Malaysia has been underinvesting in agricultural R&D, which could result in slow productivity growth in the coming years. The smaller volatility in Malaysian R&D investment discovered through this study is explained in part by almost zero growth in the last five years. The results of TFP for the total agricultural confirmed that there was no significant growth in agricultural productivity in Malaysia, while the output growth was largely due to increased use of inputs. TFP, labour and land productivity showed similar trends, indicating low or no productivity growth. Productivity measures of crop and livestock subsectors indicated a poor performance of crops and sustained growth of livestock productivity. The result of output growth decomposition revealed that the total output was largely contributed by increasing the harvested area and crop yield. Land allocation showed very small contributions to both total agricultural output and individual crops. Oil palm, the most important agricultural commodity in this country, continued its contribution consistently in both land allocation and crop yield and thus dominating the growth of agricultural production and reducing other crops' harvested area including rubber, rice, fruits, cocoa, coffee, tea and sugar affected negatively. On contrary, vegetables contributed positively, hence showed better performance. However, most crops increased in yield despite having diminished in harvested areas.

The analysis of returns on R&D investment indicated that oil palm has dominated knowledge stocks since the year 2000 and is projected to be the highest by 2050, followed by fruits and fisheries. While the lowest stocks are projected to be rubber and poultry assuming that investment trends will continue as in the past.

Across major research institutes in Malaysia, investment projections show that the MPOB will continue to grow until 2050 while MARDI stagnates, with its knowledge stock remaining at 2017 levels. The FRIM and FRI are projected to decline while the MRB and MCB are projected to grow if the same investment priorities remain as in the past. The highest response is obtained from those sub-sectors with a significant share in total agricultural output and in which Malaysia has invested less relative to its importance in agriculture, including poultry, rubber, coco palm and pigs. The response to R&D investment in fisheries, rice and vegetables was found to be lower but still significant, while cocoa, roots and tubers, cattle and fruits show very low responses.

From the several analyses above, this study provides economic and policy insights to respond to overarching questions; what is the status quo of agricultural R&D in Malaysia, how has the country performed during the past decades, how efficient is the public R&D system is, and what is the return on investment across agricultural sub-sectors in the country. Malaysia has now been confronted with several consequences from poor performance in R&D research, which resulted in no growth, mainly due to diminishing research investment during the past years, albeit spending below its potential investment. As a result, the R&D system becomes less efficient and unpredicted returns. The findings of this study are crucial and useful for future R&D directions and policy formulation to reinforce the agricultural R&D sector in this region.

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Abstrak

Indikator pelaburan penyelidikan sektor pertanian yang merupakan antara pemacu sekuriti makanan menunjukkan tren yang statik dan merosot di Malaysia menjadikan prestasi pelaburan penyelidikan sektor pertanian negara berada di bawah tahap sasaran sebenar. Situasi ini dijangka memberi impak kepada pertumbuhan sektor pertanian yang seterusnya akan menjejas strategi yang digariskan dalam agenda sekuriti makanan negara. Secara global, kajian saintifik telah membuktikan hubungan yang positif dan signifikan di antara penyelidikan pertanian dan pertumbuhan ekonomi sesebuah negara. Di Malaysia, sehingga kini tiada kajian yang komprehensif menilai impak pelaburan penyelidikan ke atas pertumbuhan sektor pertanian. Justeru, kajian ini mengenalpasti prestasi, intensiti dan keberkesanan pelaburan penyelidikan sektor pertanian di Malaysia. Kedua-dua kumpulan data primer dan sekunder digunakan dalam kajian ini. Data primer dikumpul melalui kajian *Agricultural Science and Technology Indicators (ASTI)* 2018/19 menggunakan kaedah temubual bersemuka dan soal-selidik berstruktur melibatkan 33 agensi penyelidikan di sektor pertanian yang terdiri daripada sektor awam, sektor swasta dan universiti. Pengkalan data kajian ASTI yang telah dikumpul melalui beberapa siri survei ke atas agensi penyelidikan di sektor pertanian bagi tempoh 2013 – 2017. Kesemua data dianalisis dan fokus parameter adalah *ASTI Intensity Index (AII), total factor productivity (TFP), output growth decomposition,* dan *returns on investment (ROI)* bagi menilai prestasi, intensiti dan keberkesanan pelaburan penyelidikan bagi sektor pertanian di Malaysia. Nilai indeks (*AII)* 0.81 menerangkan tahap intensiti pelaburan penyelidikan sektor pertanian yang maksimum telah mencapai 80% pada tahun 2002, namun trend pelaburan yang statik adalah antara penyebab indeks *AII* merosot kepada 0.35 pada tahun 2016 menyebabkan jurang di antara jumlah sasaran pelaburan dan jumlah sebenar telah meningkat sehingga 40%. Nilai *TFP* mengesahkan tiada pertumbuhan yang signifikan ke atas produktiviti pertanian di Malaysia dan ini menjelaskan pertumbuhan output adalah disebabkan pertambahan nilai input dalam ekosistem penyelidikan pertanian. Dapatan *Output Growth Decomposition* menunjukkan jumlah output pertanian disumbangkan dari peningkatan jumlah keluasan yang seterusnya memberi sumbangan kepada peningkatan hasil tanaman. Analisis pulangan pelaburan (*ROI*) penyelidikan sektor pertanian menunjukkan komoditi kelapa sawit mendominasi *knowledge stocks* pada tahun 2000 dan diunjur kekal dominan sehingga 2050, diikuti oleh sub sektor buah dan perikanan. Dari aspek agensi penyelidikan utama di Malaysia, unjuran *knowledge stock* menunjukkan prestasi pelaburan MPOB terus meningkat, manakala MARDI kekal statik dengan nilai yang rendah. Kajian ini merumuskan bahawa pertumbuhan sektor pertanian Malaysia dipengaruhi oleh prestasi pelaburan penyelidikan yang merosot sejak bertahun yang lalu, malah jumlah perbelanjaan penyelidikan pertanian tidak mencapai sasaran, sekaligus memberi implikasi kepada kualiti penyelidikan dan pembangunan di sektor pertanian. Dapatan kajian ini menyediakan garis panduan kepada halatuju agenda penyelidikan dan pembangunan bagi memperkukuhkan sektor pertanian negara di masa hadapan.

Appendix 1 – ASTI

The Agricultural Science and Technology Indicators (ASTI) Indo-Pacific project, facilitated by the Asia-Pacific Association of Agricultural Research Institutions (APAARI) and the International Food Policy Research Institute (IFPRI), empowers partners in the region to collect time-series data on the funding, human resource capacity, and outputs of agricultural research in countries in the Indo-Pacific. The project supports the production of analysis, capacity-building tools, and outreach products to help facilitate policies for effective and efficient agricultural research. ASTI is widely recognised as the authoritative source of information on the status and direction of agricultural research systems in developing countries. In 2017, the International Food Policy Research Institute (IFPRI) entered into a strategic partnership with the Asia-Pacific Association of Agricultural Research Institutions (APAARI) to conduct data collection, analysis and dissemination of Agricultural Science and Technology Indicators (ASTI) in the Indo-Pacific region. ASTI Indo-Pacific works with national and regional partners to conduct institutional survey rounds that collect data on agricultural research investment. Data collection is updated every five years in Cambodia, Fiji, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand and Vietnam. In addition to data collection, ASTI Indo-Pacific aims to build capacity within national agricultural research institutes for policy-relevant analysis of agricultural research systems and dissemination and advocacy activities to ensure uptake of crucial messages at national and regional levels.