8-2012

Impact of Hybrid Rice on Food Security: A Spatial Equilibrium Analysis of Global Adoption and Diffusion of Hybrid Rice Varieties

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A Spatial Equilibrium Analysis of Global Adoption and Diffusion of Hybrid Rice Varieties

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Agricultural Economics

By

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University of Bremen,
Bachelor of Arts in Political Science and Economics, 2010

August 2012
University of Arkansas

ABSTRACT

Rice is the staple crop for most consumers in Asia. More than half of the global population depends on rice. However, scarce resources for agricultural production and unfavorable conditions will make it hard to meet future demand in rice and threaten future food security. Hybrid rice technology is a method to increase the productivity of resources needed for rice production. Current developments show not only yield improvements in comparison to existing conventional and hybrid varieties, but also fuel hopes for new abiotic and biotic stress tolerance. The objective of this study is to determine what impact hybrid rice varieties can have on food security.

Using the RICEFLOW model, a spatial-equilibrium framework with detailed information about the global rice value chain, the potential for adoption and impacts on food security of new hybrid rice varieties can be estimated. Higher production quantity and significant effects on rice prices are the results. More importantly, global rice consumption demands are increasing. So far hybrid rice has already made some sizeable contributions to per-capita availability of rice in a few countries such as China. However, at forecasted demand a large-scale diffusion of hybrid rice will be needed. Accordingly, this study quantifies the impact of hybrid rice on food security and shows that the need for agricultural intensification is prevalent, of which new hybrid rice varieties present a potential to deal with food security issues. The results show that hybrid rice diffusion can increase global rice production by 12.8% up to 2025, inducing increased rice availability of up to 7.61% in the countries that are most dependent on rice as staple crop. Moreover, retail prices could be lowered by up to 134.03 % in regard to prices of 2009.

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ACKNOWLEDGEMENTS

I would like to express my appreciation for the support of my thesis to my thesis committee members Eric J. Wailes, Konrad Hagedorn, L. Lanier Nalley, and Alvaro Durand-Morat. Without their guidance, explanations, and critique I would have not been able to finish the thesis appropriately and on time. Eric Wailes was certainly irreplaceable and unique in his supervision of the thesis. Alvaro Durand-Morat's knowledge and patience were a key to the success of my thesis. Special thanks also go to Ranjitinsh Mane for teaching me valuable skills.

I would also like to thank the staff of the Department of Agricultural Economics and Agribusiness. Their work runs the department and helped my struggles to deal with the administration. Alicia Minden was irreplaceable in this regard. The importance of the staff seems to be universal. Renate Judis from the Humboldt-Universität zu Berlin and the IMRD secretariat members of the Universiteit Gent all have a large stake in the completion of my studies.

During my whole studies I was happy to receive a lot of input and support from many sides, though I received a constant backing from the Friedrich Ebert Foundation. Regarding my whole education of the past five years, the Friedrich Ebert Foundation was enabling me to follow my path.

Lastly, all the credit goes to my family. I could rely constantly on their support, also in difficult times. Without them, I clearly would not be where I am today.

DEDICATION

I dedicate this master thesis to my parents, Renate and Günter.

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ABBREVIATIONS

AGRM	Arkansas Global Rice Model
CCLS	Country-Commodity Linked Modeling System
CMS	Constant Male Sterility
CS	Condition Sensitive
CIMMYT	International Maize and Wheat Improvement Center
EGMS	Environment-Conditioned Genic Male Sterility
EPO	European Patent Office
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
GEMPACK	General Equilibrium Modelling Package
GM	Genetically Modified
HRDC	Hybrid Rice Development Consortium
IGRM	IRRI Global Rice Model
IRRI	International Rice Research Institute
NGO	Non-Governmental Organization
OECD	Organisation for Economic Co-operation and Development
PGMS	Photoperiod-Sensitive Genic Male Sterility
PIPRA	Public Intellectual Property Resource for Agriculture
PS&D	Production, Supply, and Distribution
PTGMS	Photoperiod- and Thermo-Sensitive Genic Male Sterility
R&D	Research and Development
RDD&D	Research, Development, Demonstration, and Deployment
TGMS	Thermo-Sensitive Genetic Male Sterility
USA	United States of America
UN Comtrade	United Nations Commodity Trade Statistics Database
USDA	United States Department of Agriculture
USPTO	United States Patent and Trademark Office

Rice Terminology

LGP, MGP, FRP	Long Grain, Medium Grain, and Fragrant Paddy
LGB, MGB, FRB	Long Grain, Medium Grain, and Fragrant Brown
LGW, MGW, FRW	Long Grain, Medium Grain, and Fragrant White

I. INTRODUCTION

World food prices spiked in 2007 and 2008; it was the biggest spike since the world food crisis in 1972 and 1973. Rice prices peaked in early 2008 with prices tripling in only a couple of months. In many countries this led to surges in domestic retail prices of rice, impacting food security of the population in those regions where rice is a staple crop. Especially lower income groups, whose income can barely cover food expenses, were at that time in a severe condition of food insecurity. While both the 1972/73 and 2007/08 food crises had a similar effect on food security issues, the causes differed (Dawe, 2010).

The world food crisis in the 1970s was started by a widespread drought during the summer months and reduced immensely the dry-season rice production in Southeast Asia. The drought continued in the autumn months, affecting also wheat and corn crops and increasing food prices globally. Food availability declined sharply, and national protective measures stopped global rice trade for nine months in 1973. Consequently, rice producing countries had to cope with the lack of food, and countries depending on rice imports were suddenly left with a depleted food availability (Timmer & Dawe, 2010).

The food price increase in 2007 and 2008 had different reasons. There was a slight production fall of wheat in 2007 of 3.9%, and a U.S. driven mandate for biofuel production put pressure on the availability of corn. This led to higher corn and wheat prices, but this was not solely the reason for a global food crisis (Naylor & Falcon, 2008). Speculative trading of commodities led to the price peaks. Speculative fervor in oil and metal markets spread to agricultural commodities, leading to price peaks of wheat in February 2008, of corn in June, and of oil in July (Timmer, 2008). National protective policies and declining stocks most likely caused the rice prices to spiral further upwards (Dawe, 2010; Yu, Tokgoz, Wailes, & Chavez, 2011).

What were the lessons drawn for rice availability and production from both food crises (according to Timmer & Dawe, 2010)? Before the 1970s food crisis hit, there was actually an optimistic feeling about the global food situation. The so-called *Green Revolution* introduced high-yielding seeds in the late 1960s that increased agricultural productivity tremendously. Moreover, the Green Revolution entailed a whole set of agricultural innovations in addition to high-yielding seeds, such as synthetic fertilizers and pesticides, irrigation infrastructure, and modernized management techniques (Ruttan, 1977). Norman Borlaug, the ”Father of the Green Revolution”, the International Rice Research Institute (IRRI), and the International Maize and Wheat Improvement Center (CIMMYT) were on the forefront on developing high-yielding seeds for rice and wheat. The widespread diffusion of those seeds indeed led to increased rice production mainly in South Asia and Southeast Asia, and it also led to the optimistic expectations for food security. The drought of 1972, though, changed the situation. After all, the food crisis was a shock that only enforced the trend of agricultural intensification measures that were taken during the Green Revolution. It became clear that only higher average yields could produce sufficient quantities to meet demands and on top could help setting up grain reserves that might be used in case of need. Furthermore, the temporary lock down of global rice trade led to an increased awareness among governments of rice importing countries. National research for new crops was intensified to meet the goal of self-sufficiency in crop production. Up to today, rice remains only a minor traded commodity, consequently it is produced all over the world (Timmer & Dawe, 2010, p. 5).

The last food crisis induced a global public debate about the consequences of speculations in food and about the consequences of alternative uses of agricultural products. Whereas there are different opinions about the impact of commodity speculation on food prices, the higher demand of agricultural products for different reasons is undeniable. As a matter of fact, mitigation measures such as protective trade policies and the use of national rice stocks were eventually fueling the food crisis. That led to the call for a more internationally coordinated approach in case of severe food security situations. A call that seems unreachable in the near future when taking the sensitivity of agricultural production in general and in current multilateral agricultureal trade negotiations into account. But also the importance of crop stocks was stressed again during the last food crisis, which led to realistic policy intentions to strengthen regional approaches to food security (Timmer & Dawe, 2010, p. 7).

In addition to temporary shocks on food availability, agricultural production in general and rice production in particular face certain trends to be addressed. Three often mentioned trends are demand growth, limited availability of productive land, and the climate change. The United Nations projects the world population to be 9.5 billion by 2050 (UN 2011). The population whose major staple crop is rice will increase by more than 1 billion. Moreover, agricultural products for alternative uses such as bio-energy is intensifying. Accordingly, it is estimated that production of agricultural commodities needs to double in order to meet that additional demand (Trethowan, Turner, & Chattha, 2010). Regarding rice production, though, estimates are more varying. Some projections estimate that rice production needs to increase only 5% up to 2020 (Timmer, Block, & Dawe, 2010), others speak of 8% up to 2019 (Mohanty, Wailes, & Chavez, 2010).In any case, agricultural production increase is further challenged by the limited availability of agricultural land. Regarding rice production, there has been very limited extensification of agricultural land for the last 30 years. Deteriorating land quality and the use of agricultural land for other purposes has led the United States Department of Agriculture (USDA) to estimate that there will be a decline of area available for agricultural production (USDA, 2010). Climate change is putting two main stresses on global agricultural activities: increased mean temperature and a higher probability of extreme weather events (Lobell & Burke, 2010). On a global average basis, climate change will thus potentially lead to lower yield productivity and also to a higher risk of crop failure, which increases the risk of food crises.

These current trends emphasize the need for advancements in agriculture similar to innovations such as the Green Revolution achieved on a large scale. One promising development in rice production to deal with the trend and to mitigate possible food insecure situations is the ongoing research in biotechnology. Biotechnology is mostly understood as advanced breeding methods, which can range from tissue culture to molecular markers, genetic modification (GM), or the use of bio-informatics (Stewart Jr., 2008). Regarding rice research, there are currently genetically modified rice varieties with certain advantages towards conventional rice varieties, such as the *Golden Rice*, which is used against malnutrition as it enhances Vitamin A intake. In general, however, there are global resentments either against the genetical modification of crops or against the associated business model for the commercialization of GM crops. On the other hand, some advanced breeding techniques of rice do not change the genetics of plants directly but can still enhance certain characteristics and can therefore more easily be deployed globally.

Advanced breeding techniques were first applied by Yuan Longping in China during the 1970s (Li, Xin, & Yuan, 2009). Different rice varieties with favored characteristics were cross-bred respectively hybridized systematically in order to produce hybrid varieties that entailed the advantageous characteristics of their parents. Initially, hybrid rice research aimed for increasing the yield of rice, though, contemporary research is also looking for other aspects such as resistance towards certain pests or the need for less water input. In any case, progress in hybrid rice research is expected to lead to a higher average yield of rice plants. Hybrid rice varieties have become quite successful agricultural innovations so that their deployment is relatively wide in some rice producing countries compared to other agricultural innovations (more than 60% as in China). As hybrid varieties are already diffused widely, an impact on food security for those countries consuming rice as staple crop cannot be denied. Nevertheless, diffusion rates can still improve and hybrid rice can still play a more vital role in securing food availability. In regard to future trends, it could even be said that there is an obligation to mitigate future food risks in the best possible way in which hybrid rice is able to contribute more than today. If hybrid rice can affect food security positively, *how much* can hybrid rice contribute to future food availability? Can hybrid advantages deal with increasing demand solely or will there also be a need for other agricultural innovations in order stabilize the global food situation? The objective of this thesis is to quantify what impact hybrid rice can have on future food security.

The literature deals with manifold aspects of agricultural innovations, from the development of innovations to their adoption and diffusion. Reviews of the development process of agricultural innovations mostly deal with analyzing the environment that might induce innovations such as hybrid rice varieties (e.g., Aubert, 2005; Hayami & Ruttan, 1985; Kislev & Shchori-Bachrach, 1973; Sunding & Zilberman, 2001). Regarding adoption and diffusion, there are efforts to systemize behavior of adoption of hybrid rice varieties by rice producers (e.g., Diederen, van Mejil, Wolters, & Bijak, 2003; Feder & O'Mara, 1981; Janaiah & Xie, 2010; Rogers, 2003; Shaw, 1985). Also consumer responses to hybrid rice commercialization are covered by various studies (e.g., Carletto, De Janvry, & Sadoulet, 1996; Just & Zilberman, 1983). There are numerous works dealing with current trends and their implications on rice production and rice research (e.g., Lobell & Burke, 2010; Napasintuwong, 2009; Nelson et al., 2009; Trethowan et al., 2010). Similarly, projections for agricultural production, demand for agricultural commodities, and prices can be found in various sources (Pandey et al., 2010; USDA, 2010; Wailes & Chavez, 2011). Though, there are only a few quantitative studies on what impact diffusion of hybrid rice can have on food security (Durand-Morat, Wailes, & Chavez, 2011; Janaiah & Hossain, 2003). This might be explained by the difficulty to make exact estimations. Current models that reflect global agricultural production exist and can be used for making predictions (Adenäuer, 2008; Matriz, Molina, Valera, Mohanty, & Jamora, 2010). However, those models are extremely data intensive and rely on behavioral assumptions, so that actually each result might vary from one another. It would be more accurate to say that quantitative models can hint to certain trends instead of making exact predictions. Nevertheless, a sound estimate for the impact of hybrid rice, and in fact of any agricultural advancement, can give valuable insight for policy analysts and policy makers regarding global food production and consumption, hence, for food security concerns and the need to fund such initiatives. Accordingly, this thesis aims to estimate the impact of hybrid rice on food security. Food security is here understood as the availability of staple crops at an affordable price (according to Virmani, Mao, & Hardy, 2003). RICEFLOW is a spatial partial equilibrium model and will be used in this study to reflect global rice production, consumption, and trade (see Durand-Morat & Wailes, 2010). By that, the analysis for food security impacts will focus on demanded quantities and supplied quantities as well as on the retail price. However, further implications, such as on efficiency of production input use, can also be made in order to indicate possible effects of hybrid rice adoption on other aspects of agricultural production, although this issue willis beyond the scope of this study.

This thesis will begin with a literature review to make the reader familiar with theories regarding agricultural innovations as well as with rice and hybrid rice (chapter 2). The first part of the literature review will have a theoretic focus (section 2.1). The theory of induced innovation will make the point that agricultural innovations are only developed if the environment demands them. The following section about adoption and diffusion theory will explain when and how adoption of agricultural innovations occurs. Certain considerations that can impact the diffusion process will be discussed followed by a section about intellectual property rights that illustrates the current situation of research and development. In the second part of the literature review, the evolution from conventional rice to hybrid rice will be outlined (section 2.2). The importance of rice in the global economy will be elaborated, and the aspects of research, design, development, and deployment of hybrid rice will be highlighted. The literature review will end with an outline of the deduced research questions (section 2.3); the section for the methodology follows subsequently (chapter 3). In the methodology section, methods will be discussed that could possibly be used (section 3.1). The RICEFLOW model is selected as best fitting for the purpose of this thesis (section 3.2). The data sources will be described (section 3.3) before the modeled scenarios for the calculation of the impact of hybrid rice will be presented (section 3.4). The following section will present the results of the simulations and will discuss them (chapter 4). The thesis will conclude with the implications of this thesis, with its limitations, and with possible aspects for future research (chapter 5).

II. LITERATURE REVIEW

2.1 Towards Agricultural Innovation

Innovations are generated in various stages. There are several concepts categorizing the stages such as *Figure 1*, which follows the categories listed by Sunding and Zilberman (2001, p. 211).

Figure 1. Generation of innovation.

The first stage represents the emergence of a concept or the idea. In case of making use of intellectual property, registration would present the patenting process. The third stage entails the evolution from laboratory research to scaled up development, adjusting for commercialization and the integration into the fourth stage, the production. After production follows the last step, marketing an innovation.

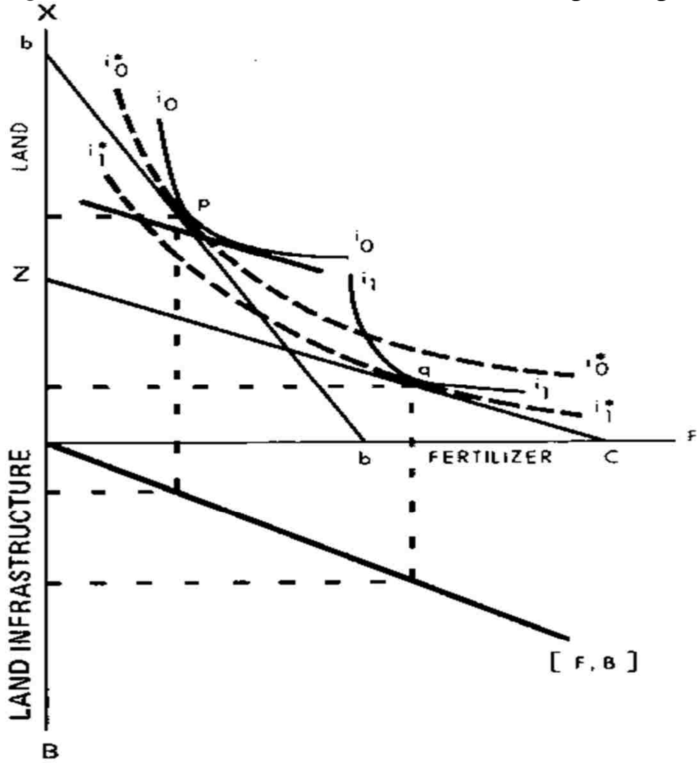
A similar but more simplified concept is known as Research and Development (R&D), which does not entail the deployment. A third complementary concept that is often used is research, design, development, and deployment (RDD&D). It emphasizes also the marketing of innovations, but puts more emphasis on the transfer from concept to production.

This chapter about theories of innovation and adoption will orient itself on the presented stages in *Figure 1*. The first stage of discovery will be discussed with the theory of induced innovation. The next three stages will be discussed in terms of how they influence adoption and diffusion of innovations, which itself occurs in the fifth stage. In that way, this chapter will answer more fundamental questions, e.g. why innovations arise and how they are deployed.

2.1.1 Induced Innovation

Sometimes innovative ideas originate from creative minds without any link to physical reality. Most often though innovations are inspired by necessities, desires or circumstances. Hayami and Ruttan (1985) argued that innovations evolve closely linked to economic conditions. They formalized the theory of induced innovations and could empirically verify it. Their argument is that development of innovations is an economic activity that is mostly affected by economic conditions. Innovations are a necessary product because of relatively scarce resources and because of beneficial opportunities. New technology is developed for facilitating the substitution of relatively abundant factors for relatively scare factors. For instance a scarcity of labor will induce labor-saving innovations. Water constraints can induce drip irrigation or other water-saving innovations. Food scarcity or high prices of commodities might lead to high-yielding crop varieties. While scarcity and opportunities are the necessary condition for the induced innovation theory, the sufficient conditions are technical feasibility and scientific knowledge. Further, if the institutional setting gives sufficient incentives for research and development, innovation activities are likely to evolve. The following figure explains the theory formally.

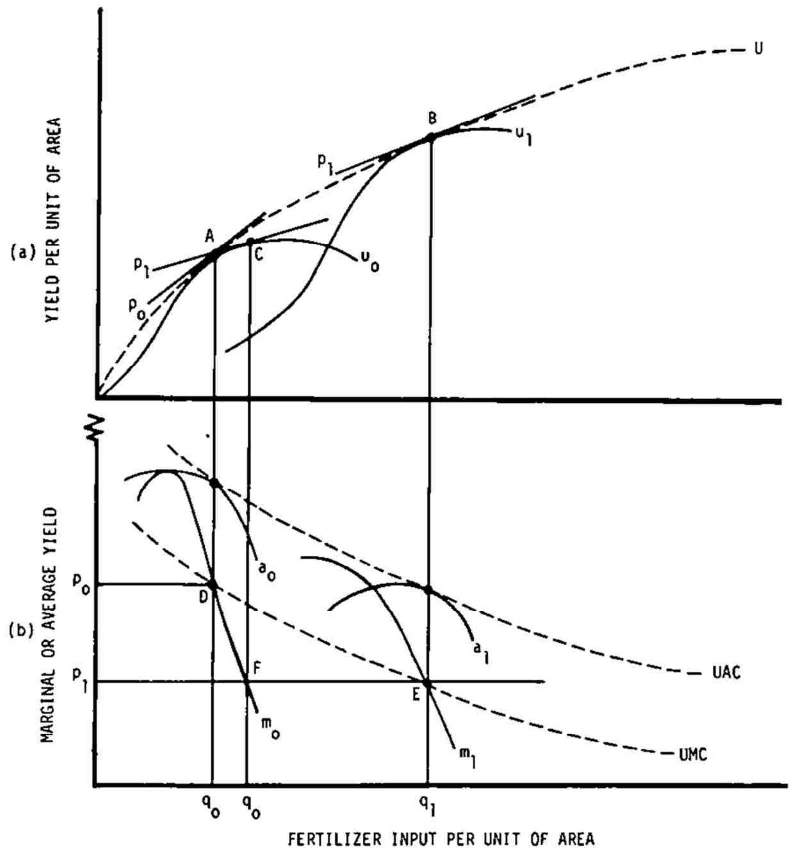
Figure 2. A model of induced technical change in agriculture.



Source: Hayami & Ruttan, 1985, p. 91

Figure 2 shows on the upper y-axis Price of Land, on the lower y-axis Land Infrastructure and on the x-axis Price of Fertilizer. Here, i_0^* represents an innovation possibility curve that embraces less elastic land-fertilizer isoquants such as i_0, which illustrates different crop varieties, cultural practices, and so on. Over time the production costs of fertilizer might shrink relatively to the price of land, this is depicted by a changing land-fertilizer price ratio from $\overline{bb}$ to $\overline{ZC}$. The induced innovation theory claims because of a changing price ratio, a new technology (e.g. a more fertilizer-responsive seed variety) will be developed to take advantage of the relative lower costs for fertilizer. This is depicted in the graph $i_1$along a new innovation possibility curve i_1^*. This new technology substitutes fertilizer for land and possibly requires better land management and better control of water. This complementary relationship between fertilizer and land infrastructure (as for example irrigation and drainage systems) is implied by a linear relationship [*F,B*].

Figure 3. Hypothetical process of the induced development of a modern high-yielding variety of rice.



Source: Hayami & Ruttan, 1985, p. 275

Figure 3 shows two graphs that depict the hypothesis of the induced innovation theory about why high-yielding hybrid rice varieties in India, Philippines, Thailand, Japan were developed from 1955 to 1975. In *Figure 3a* the metaproduction function *U* is assumed, which embraces different fertilizer response curves. Each response curve represents a rice variety, which is characterized by different degrees of fertilizer responsiveness. In this case u_0 shows a response curve for the conventional rice seed and u_1 represents a new high-yielding variety. *Figure 3b* shows the average product curve *UAC* and the marginal product curve *UMC* corresponding to u_0, u_1, and *U*. The conventional rice seed has been used traditionally and is the optimal respectively profit-maximizing variety for the fertilizer-price ratio p_0. Respectively, u_1 is the high-yielding variety that represents the optimum for a fertilizer-price ratio $p_{1,}$ whereas p_1 reflects lower fertilizer-rice price ratio than p_0. Over time the fertilizer-rice price ratio declines to p_1; but if the available rice is the conventional, then rice producers can increase their yield only from *A* to *C* (respectively from *D* to *F*). Thus the cost reduction of fertilizers results in a new equilibrium for individual producers but also in a disequilibrium in the metaproduction function. Only if a new variety $u_1$becomes available can both equilibriums be achieved. The induced innovation theory hypothesizes for the development of high-yielding hybrid rice varieties in the observed countries that the development is undertaken when the additional benefit of adjustment from *C* to *B* (respectively from *F* to *E*) is higher than the costs of development for u_1.

This is a simplified picture of the induced development of high-yielding varieties. There are various other important factors. For example the characteristics of the fertilizer response curve depends on water control and husbandry practice. If water control and husbandry practice were inadequate high-yielding varieties would not show the fertilizer-responsive character. It might also be that high-yielding varieties actually produce more yield even without fertilization when fields have good irrigation and drainage, making the proposed relationship invalid. Often weed control is also highly important. All of this raises the question if fertilizer is the sole variable or if a package of different inputs would not be a better factor in the above figure.

For current development of high-yielding varieties a wide range of economic conditions can create necessity for more yield. An increase of the global population is raising the demand for food. Since a tremendous population growth occurs in Asian countries where rice is the staple crop, demand for rice especially is growing. Accordingly rice price is likely to increase in the long-term trend if the growing demand is not met by growing supply. This higher price can be an innovation-inducing factor for new high-yielding varieties. Similarly, there is only limited agricultural space available. Therefore rising demand can only be met through intensification of agriculture, which could possibly induce new high-yielding varieties. Also the trend of global warming and extreme weather events puts additional stresses on plants, reducing average yield on many crops, among them rice. These new conditions can also be an inducing factor for the development of stress resistant varieties that have higher yields than current varieties.

The induced innovation theory explains why mechanical and biological technology is developed due to economic conditions. Inducing factors are changes in price ratios that are important for and affect the observed technologies directly. In the following we will see how innovative technologies are adopted and diffused and what might speed up or slow down these processes.

2.1.2 Adoption and Diffusion

There is generally a time lag between the development of an innovation and its commercialization. There is generally an even bigger time difference between the commercialization and its widespread use. Theories of adoption and diffusion describe when, how, and why innovations spread. Analysis of adoption behavior examines the questions of if and when individuals adopt innovations. In the sense of a new hybrid seed it analyzes if a farmer is using this seed at a certain time and how much of its farmland is planted with the new seed. Diffusion on the other hand can be understood as an aggregate adoption. The theory of diffusion tries to explain why a certain percentage of total land share is planted with a new hybrid seed or why a certain percentage of farming population is using the new hybrid seed.

Everett Rogers made the theory of diffusion popular in 1962 by studying diffusion of hybrid corn in Iowa and analyzing different diffusion rates of different counties. According to Rogers, “diffusion is the process in which innovation is communicated through certain channels over time among the members of a social system” (Rogers 2003, p. 5). In every diffusion research study, the four main elements – innovation, communication through channels, duration of time, and composition of social system – can be identified.

Innovation itself is a highly subjective perception. In general it is valid to say that if an idea seems new to an individual, it is an innovation. When speaking about technological innovation including agricultural innovation, Rogers mentions two aspects: hardware and software. In other words technological and agricultural innovations combine mostly the tool and the knowledge on how to use it. The decision to use an innovation or not is consequently a rational one – in the sense of a cost benefit analysis – but also a behavioral one – e.g. in the sense of perception of quality, environmental impact, and so on. Whether or not an innovation is eventually used is a process of evaluating information. Individual adoption is essentially “an information seeking and information-processing activity in which an individual is motivated to reduce uncertainty about the advantages and disadvantages of the innovation” (Rogers, 2003, p. 14).

Communicating the innovation is essential for a widespread diffusion. Individual information processing is necessary, but at the same time a starting point for the communication process, in which participants create and share information with each other about an innovation in order to reach a mutual understanding. Communication channels are the means through which participants communicate. For successful diffusion of an idea communication must be given (e.g. all actors speak the same language) and channels must be efficient. The speed of spreading information depends primarily on the channel, which can range from interpersonal channels to mass media.

Depending on the information processing ability of individuals and on the efficiency of communication, timing can vary. One can differentiate between time for adoption and diffusion. The individual innovation-decision process tends to follow the steps from gaining knowledge, to persuasion towards adopting an innovation, to implementation, to final confirmation about the decision made. Depending on the individual behavior and the individual exposure to information, the adoption time varies. Time for diffusion of an innovation to a certain level varies accordingly in absolute terms, but relatively it follows a similar pattern for any innovation.

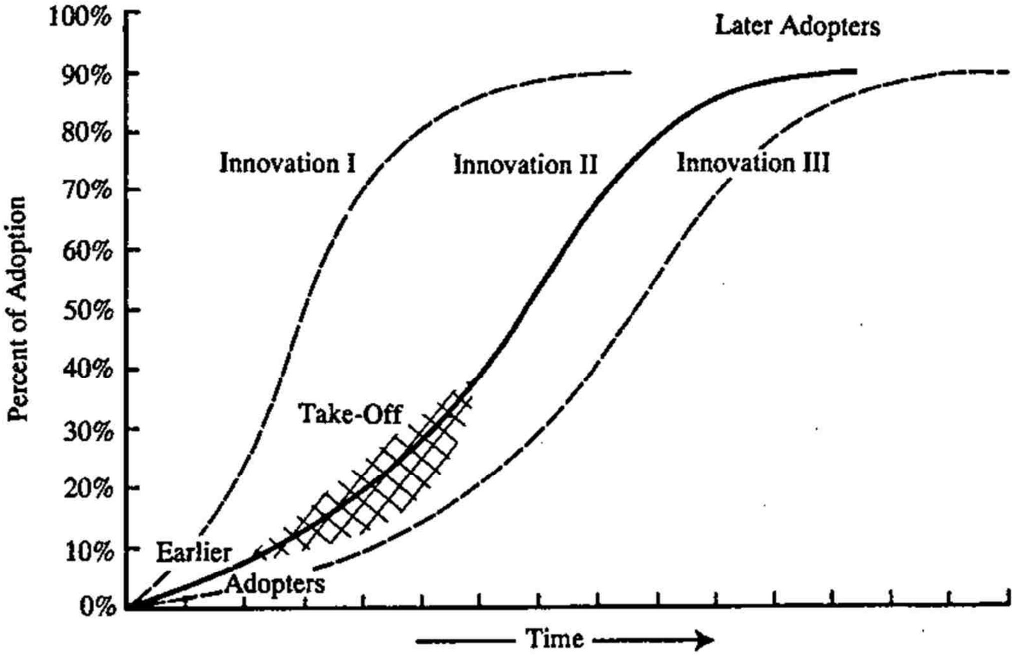
The social system is "a set of interrelated units that are engaged in joint problem solving to accomplish a common goal" (Rogers 2003, p. 23). Diffusion occurs within a social system, but its set depends on the research question of each study. The social structure of a system is decisive for innovation diffusion and depends on norms, opinion leaders, change agents, etc.

Taking the four elements into account, Rogers and other diffusion researchers found out that most diffusion occurs in a S-shaped function of time. The function can be estimated as

$$Y_t = K\left[1 + e^{-(a+bt)}\right]^{-1}$$

where Y_t is diffusion at time t (as the percentage of farmers adopting hybrid rice), K is the upper limit, a is starting point of estimation, and b is the pace of diffusion (Sunding & Zilberman, 2001, p. 228). The S-shaped function can be seen in the following figure.

Figure 4. The diffusion process.



Source: Rogers, 2003, p. 11

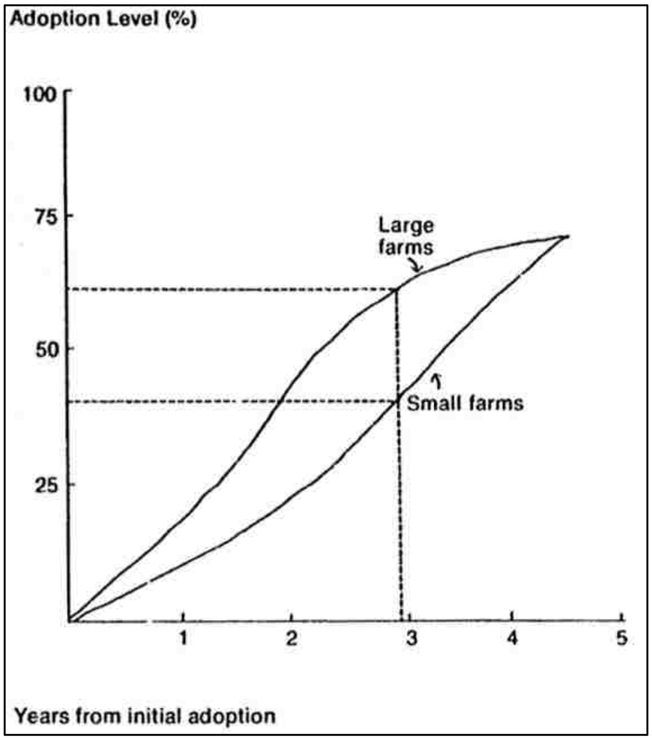
Figure 4 shows three innovation curves, which are described by the percentage of adoption on the vertical axis (i.e. rate of diffusion) and by time on the horizontal axis. One can see that the time varies for each innovation curve to mature, i.e. to reach its maximum. However, the relation between timing and adoption is similar for each curve and describes the S-shape. The initial period shows the introduction of an innovation to a social system, where only so-called “Earlier Adopters” utilize an innovation. When through communication a critical mass of adopters materializes, the take-off period begins, which has a higher marginal rate of diffusion. Eventually the rate of diffusion saturates, diffusion reaches its peak, and marginal diffusion is low. At this time only “Late Adopters” start utilizing innovations.

Griliches (1957) discovered that the three parameters of the diffusion function are significantly affected by economic variables such as rates of profitability, size of farms, and so on. Later empirical studies confirmed this basic finding (Feder, Just, & Zilberman, 1985).

Additionally, a more behavioristic research contributed to the S-shape function with different attitudes of adopters towards innovations in general. Rogers divided adopters into five ideal types: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2003, pp. 282-284). Innovators have big financial resources and human capital and are willing to invest it in uncertain investments. Innovators are often associated with cosmopolites and also have wide networks and social relationships to have early access to innovations. Early adopters are more locally integrated and are local opinion leaders; they decrease uncertainties about innovations and play an important role to trigger the critical mass of adopters. The early majority adopts ideas before the average social system's member does. They are also well integrated in communication channels, but are not, on the other hand, opinion leaders. This group amounts to roughly one third of all adopters. The late majority is more skeptical towards innovations and only adopts if the advantages are confirmed to outweigh disadvantages because of scarce resources. In addition, peer pressure is mostly necessary to convince the late majority. This group amounts to also roughly one third of all adopters. Finally, laggards are almost isolated in social networks and are the most localite adopters. Suspicion or even resistance to innovation as well as precarious economic positions can be forces why adoption occurs only late.

Paul David (1969) contributed with the threshold model towards the S-shaped adoption path. David developed an equilibrium model of innovation adoption and showed that the heterogeneity of farmers and the resulting S-shape are due to different farm sizes and farm size distribution. A minimum farm size would be required to adopt innovations. David's assumptions were verified during the green revolution for adopting high-yielding varieties (Ruttan, 1977). *Figure 5* shows different adoption curves for large and small farms. The slower diffusion rate for small farms can be seen.

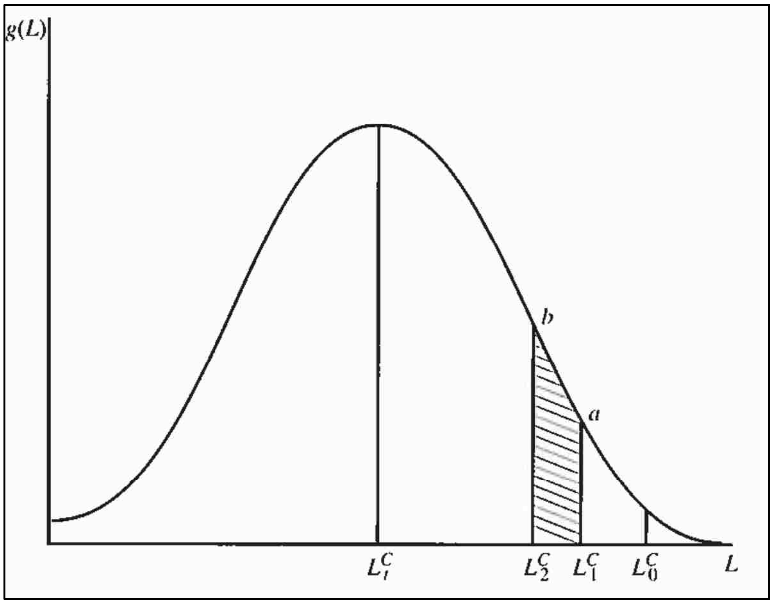
Figure 5. Stylized model of high-yielding varieties' diffusion process.



Source: Ruttan, 1977, p. 22

The threshold for minimum farm size would decrease over time, hence, more and more farmers could adopt an innovation. Later research confirmed David's finding, but different innovations' S-shape functions are due to different factors. In general, the explanations for the diffusion process have in common that a certain threshold of a certain factor or different factors need to be reached in order to diffuse an innovation widely. Exactly which factors are critical depend on the type of innovation. Caswell and Zilberman (1986) showed for example that drip irrigation systems will be adopted by farms with low water-holding capacity and would depend on well depth when irrigation relied on groundwater. In *Figure 6* the dynamics of diffusion associated with the threshold model are explained graphically.

Figure 6. Dynamics of diffusion associated with the threshold model.



Source: Sunding & Zilberman, 2001, p. 233.

For *Figure 6* it can be assumed that *L* is the farm size and *g(L)* the density of farm size distribution (*L* could also represent any other factor, which is necessary for an innovation, e.g. well depth). In this case, farm size distribution is unimodal and normal. A new innovation is introduced at time 0 that is only adopted by farms with a size larger than L_0^C. Over time the critical size declines, which results in minimal farm size of L_2^C in year 2. Hence, the marginal adoption rate is equal to the area $abL_1^C L_2^C$ between year 1 and year 2. In regard to this graph and given its unimodality, the threshold model assumes that the marginal decline for L_i^C is constant. Accordingly, the marginal diffusion increases initially and then declines, leading to a S-shaped diffusion curve as illustrated in *Figure 4*.

In summary, this past section has introduced the foundations of the diffusion of innovations theory. Building on this, the following sections will deal with various considerations that can have an impact on the pace of adoption and diffusion.

2.1.3. Geographic Considerations

Diffusion research discovered that not only microeconomic characteristics affect the rate of diffusion, but also distance and geographic considerations had to be taken into account (Diamond, 1999; Hägerstrand, 1952; Rogers, 2003). The effect is especially significant in developing countries in which infrastructures create high transaction costs including transportation costs or where means of communication are not efficient (Sunding & Zilberman, 2001, p. 235). Hägerstrand (1952) was able to model a so-called *neighborhood effect*, which suggested that there is a higher likelihood that an innovation would be adopted by someone who was closer to another adopter rather than being further away. Diamond (1999) argued that geographic barriers constrain rapid diffusion of agricultural innovations. Historical examples show that domestic animals spread from Asia to Europe rather quickly on the same geographical latitude, whereas crop and animal systems could not diffuse easily in the Americas and in Africa, where different latitudes' climates were not suitable for all crops and animals. Diamond showed that climatic conditions and latitudes need to be considered in diffusion estimation of agricultural innovations. In fact that holds also true for hybrid rice. China has been successfully cultivating hybrid rice varieties for decades now, but an adoption of those seeds by farmers in more southern regions, such as South Asia and Southeast Asia, has been difficult due to differing geographic conditions (Janaiah & Hossain, 2003). Farmers in northern Vietnam were thus far more able to adopt Chinese hybrid rice on a sustainable basis since climate zones are similar to China (Nguyen & Nguyen, 2003). On the other hand in Bangladesh, Chinese hybrid rice varieties had to be interbred with local rice varieties as restorer lines in order to be successful (Janaiah & Xie, 2010).

2.1.4 Risk Considerations

Agricultural adoption research with a focus on hybrid rice varieties during the green revolution noted that farmers in fact did not fully adopt the new seed; farmers used hybrid seeds only on a fraction of their land, whereas they continued to use conventional seeds on the remainder of their land. According to Roumasset (1976) risk was the main consideration.

The literature presents two general approaches on how to model risk in adoption of new seed varieties: one is to use a static expected utility portfolio for a discrete problem and the other is a continuous optimization that chooses the optimal land share for new technologies and uses variable inputs (Sunding & Zilberman, 2001). For the static model certain probabilities for expected outcomes are used to determine the probability for the mean profit and associated standard deviations. The probability reflects the risk, ranging from yield loss to very high yield, which can be estimated based on previous seasons. Regarding high-yielding varieties, those varieties tend to have a higher mean yield than conventional varieties, although the risk of crop failure due to pests or other external effects is higher. The static model is mostly used in literature to decide whether to adopt a new variety at all.

The continuous optimization model or the dynamic model uses a similar basis as the static model, though it makes a decision of which share of land should be planted with a new variety. Based on variable inputs, production costs, and estimated revenues, the optimal land share for the new technology is calculated and adjusted over time. Just and Zilberman (1988) argue that the continuous optimization model better suits large-scale farmers that can spread their risk among different crops, whereas the static model should rather be used for small-scale farmers that are more likely to use only one crop. However, there is no clear limit and rule when to use which model. Because of the theoretic vagueness and because of no exact specifications, this paper will not make use of risk considerations in the production function. Nevertheless, risk could still be considered in the sense of stochastic results for output variables (see section 3.2).

2.1.5 Institutional Constraints

Agricultural markets are competitive but far from being perfectly competitive. Institutional constraints and market distorting policies affect farmers' behavior and the rate of adoption and diffusion of agricultural innovations. Moreover, there also occur reverse effects where the diffusion of innovations can have an effect on the institutional setting. The literature deals mainly with the former most notably with credit and tenure issues in the context of developing countries.

Hoff and Stiglitz (1993) showed that asymmetric information and uncertainty are prevalent in rural credit markets. In rural areas where transportation costs and transaction costs to gain information about borrowers are high for commercial banks, asymmetric information between lenders and borrowers occur. Additional uncertain conditions in agriculture and financial markets in general raise the risks for lenders. Therefore it can be difficult for farmers to receive credits for new investments, e.g. for agricultural innovations. Farmers on the other hand either use their own equity if available for financing new investments or they might use their land or even their future crop as collateral. Credit constraints cannot only be a quite risky condition for farmers in the absence of safety nets or insurance, but certainly credit constraints affect adoption behavior (Hoff & Stiglitz, 1993, pp. 33-38).

Just and Zilberman (1983, 1988) implemented a credit constraint in their static model of adoption under uncertainty (see section 2.1.4). Their model presented three conditions for farmers: a binding credit constraint, a partially binding credit constraint, and no credit constraint. The three conditions correlated with farm size as an explanatory variable, showing binding constraints for small farms to no constraints for large farms. It was also recognized that the severity of the constraint could be subject to the lender's perception of the profitability of agriculture and of the profitability of the adoptable innovation. Additionally, interest rates tend to be higher for small farms so that large farms are in an even more favorable condition.

Land tenure is another institutional setting that is not per se a constraint but which also tends to impact adoption. Most literature "takes tenure as given and assesses its impact on adoption of technologies" (Sunding & Zilberman, 2001, p. 248). An important form of tenure is a land rent where the tenant pays a fixed amount of money to the landlord. Adoption behavior can be affected by different rental characteristics. If innovations make use of physical and human capital more than financial resources, the land rent will most likely have no impact on adoption behavior. In fact if an innovation is only profitable if it is utilized on a certain amount of land, a well-functioning rental market is necessary to accelerate adoption behavior (Sunding & Zilberman, 2001, p. 249). However, regarding availability of financial resources for renting additional land and regarding the usage of renting land there is again a difference between large and small-scale farmers. Large farmers own more land themselves than small-scale farmers and rent additional land in case of need. And as shown above, credit constraints might not be significant for them. Therefore risk of investment in innovations is, for large famers, not so much a matter of financial survival since they can fall back on personal property. Small farmers, though, often rent the majority of agricultural land and are constrained by credit availability. Furthermore, rental contracts range from short-term to long-term contracts. Short-term contracts tend to further deter adoption of innovation, since tenants are not secure of maintaining the same land for long. Long-term contracts, on the other hand, give incentives in maintaining the land and making use of innovations. It depends on different factors to realize a positive or negative impact of tenure on adoption behavior. Thus, whether the innovation is mobile or fixed with land is important.

A third type of major institutional constraint that is covered by the literature are complementary inputs. Some innovations might be in need of complementary inputs in order to be fully functional. The green revolution diffused high-yielding hybrid rice varieties, which required more water and fertilizer than conventional seeds. McGuirk and Mundlak (1991) recognized that adoption of high-yielding rice varieties was constrained in the Indian region of Punjab due to limits on fertilizer availability and water resources. Only private investments in new wells and private and public partnerships for fertilizer production could speed up the diffusion. High-yielding maize varieties were even more constrained since there was no disease control for the diseases from which these highy-yielding maize varieties suffered. Constraints by complementary inputs can be partially removed by a well-developed infrastructure. Recalling the neighborhood effect (according to Hägerstrand, 1952), farms further away from commercial centers tend to have lower adoption rates. One reason is that complementary inputs are not as easily available. Lower transportation costs are a mean to increase the supply of complementary inputs, hence, increase the diffusion rate.

2.1.6 Technological Treadmill

Putting all considerations that might constrain adoption of agricultural innovations aside, there are also reasons why a successful and advantageous innovation might not be beneficial after all. Cochrane (1979) argued that most of the farmers will not benefit from an agricultural innovation after a widespread diffusion. Based on Rogers' adopter categories (2003), Cochrane simplified the categories for his purposes to three: early adopters, followers, and laggards (Cochrane, 1979, p. 387). The early adopters are only a few farmers whose decision to adopt a new technology will not have a big impact on aggregate supply and retail prices. The followers correspond to Rogers' classification of early and late majority, hence, representing most of the adopters. The followers' adoption will affect significantly the production quantity marketed and will reduce retail prices as well as profits. It remains specific to the innovation if the followers gain or lose from the innovation. The laggards are the ones adopting at last or not at all. Those farmers will definitely not benefit from agricultural innovation according to Cochrane. If they do not adopt they produce the same amount as before the innovation diffused but with lower retail prices. If they adopt the price effect is likely to level out additional revenue. Eventually, the widespread diffusion of the agricultural innovation would level out revenue advantages and put all farmers in the similar situation as before the adoption of the innovation. Cochrane coined the term *technological treadmill* accordingly as the constant necessity to adopt innovation in order to keep the revenue advantage (Cochrane, 1979, pp. 387-390).

As we saw before, especially large farms adopt innovations in early stages, whereas smaller farms tend to adopt at a later stage. Therefore the structural effect of the technological treadmill might not only even out possible gains but might even worsen the situation for small farms, an effect that is especially significant in countries where there is a highly uneven distribution of farm sizes such as in most developing countries. On the other hand, the effect for consumers will definitely be positive with more quantity available at a lower price. Regarding hybrid rice for example, one can assume that a widespread diffusion of new high-yielding seeds might increase the yield but also decrease the market price, not necessarily resulting in profit gains for farmers in the long run.

Adoption research in Israel confirmed Cochrane's assumptions and complemented it. Kislev's and Shchori-Bachrach's research showed that there are groups of farmers that are advantaged in terms of human capital, such as education or social networks (Kislev & Shchori-Bachrach, 1973). Those groups are able to adopt technological innovation earlier and more efficiently than other farmers, which puts them in a constant early adopter position with accompanying benefits. In contrast, the majority of farmers with relative disadvantages in human capital will not benefit as much if at all from innovations (Kislev & Shchori-Bachrach, 1973, p. 36).

Ireland and Stoneman (1986) believe that companies, which develop new agricultural technologies, are aware of adoption behavior and dynamics, such as the technological treadmill. They argue that those companies design their products' prices accordingly, starting with low prices to increase adoption of their product and raising the prices following an increase in diffusion rates. Thinking in this regard about alternative ways of commercialization, public research and patent policies seem to be necessary to reduce farmers' input costs and to reduce negative impacts of the technological treadmill.

2.1.7 Policy and Institutional Support

Policies are market-distorting factors, which might have a positive or negative impact on adoption behavior. In general, developed countries' agricultural policies tend to stabilize output prices and make products affordable, whereas developing countries tend to tax outputs. However, input prices tend to be subsidized in any case (Sunding & Zilberman, 2001, p. 250).

This section will present briefly a non-exhaustive choice of policies with respect to effects on adoption behavior for hybrid varieties.

Price Supports

Hybrid rice varieties are produced by an expensive, research-intensive technology. High expenditures in research are usually passed on to high input seed prices for the farmers. This contradicts an aim for widespread diffusion, in which also small-scale farmers can adopt a new technology. High diffusion rates of hybrid rice therefore need either price support respectively significantly higher yields or reduction in other input costs.

Just et al. developed a model that analyzed impact of price policies on adoption under uncertainty (Just, Rausser, & Zilberman, 1986; Just & Zilberman, 1988). They included price distributions of inputs and outputs and also institutional constraints. In the case of high-yielding varieties that might have a higher risk (such as hybrid rice varieties) and using a static expected utility portfolio, price support increases the varieties' profitability, leading to higher adoption and diffusion rates. McGuirk and Mundlak (1991) found supporting facts for the model proposed by Just et al. during the green revolution in the Indian province of Punjab, where a guaranteed price enhanced the adoption rate of high-yielding rice varieties.

There is also an indirect effect of price supports in regard to availability of credits. For many small-scale farmers it is hard to receive credits because of the lack of collaterals. Some availability to credits depends on expected incomes. Price support can stabilize and increase expected income, lowering the hurdle to obtain credit and eventually increase the rate of diffusion (Sunding & Zilberman, 2001, p. 250).

Output taxation

Taxation of agricultural products is mostly prevalent in developing countries. Output taxes in general increase the consumers' price and reduce demand quantities. For agricultural output taxes specifically, it is found that relative prices of agricultural products are reduced and that price of agricultural land is depressed, which results to a reduced incentive to adopt agricultural innovations (Fulginiti & Perrin, 1990; Zhong, Turvey, Zhang, & Xu, 2011). In the case of Argentina it was found that output taxation not only decreased relative prices of agricultural outputs and slowed diffusion rates of agricultural innovations, but even reduced investments in biotechnology research (Cavallo & Mundlak, 1982).

Macroeconomic policies and international trade

General policies that affect all sectors of an economy are likely to affect adoption of innovations. These policies include fiscal and monetary policies and can have effects on the performance of the economy in general, on the inflation rate, on the interest rate, and on the exchange rate (Hughes, Penson, Richardson, & Chen, 1987). For instance if policies induce growth of GDP then farm income is likely to increase to, which possibly leads to investments in agricultural innovations. If the inflation rate, for example, is increased through monetary policies, farm income tends to increase in the short run, which might also increase adoption of innovations. In contrast, if lowered interest rates reduce capital costs and can thus increase rates of adoption for capital-intensive technologies such as hybrid rice. Finally, favorable exchange rates might increase export of hybrid rice seeds or agricultural products pushing diffusion rates globally and domestically.

International trade regimes are tightly connected to general policies and comparative advantages in various countries and therefore will affect countries' adoption and diffusion rates in different ways. Carletto et al. (1996) found that the liberalization of trade in the U.S. with Central America had a positive impact on adoption rates of new crop varieties in Central America. Moreover, changes in agricultural output led to new infrastructure such as packinghouses and transportation facilities, which again reemphasized adoption of new crops. Liberalized trade rules might therefore enhance adoption rates.

However, trade barriers can also be adoption enabling. Europe and Japan adopted high-yielding varieties and invested in other agricultural innovations such as greenhouse technologies and new irrigation systems when trade barriers prevented import of cheaper foreign agricultural products (Sunding & Zilberman, 2001). Again on the contrary, Argentina's and Chile's agricultural sector suffered in times of limited trade. New innovations were adopted and agricultural income and output enhanced only when trade got liberalized (Coeymans & Mundlak, 1993). In other words there is no blueprint on how general policies and international trade regimes might affect adoption and diffusion rates, though their effects are undeniable.

Environmental policies

Especially in developed countries environmental policies are becoming a major force for development of new technologies. Developing countries mostly focus on their agricultural policies rather than take environmental concerns into account. Nevertheless, rudimentary environmental policies that are implemented to protect humans and the ecosystems can be found in developing and developed countries. Those policies can either encourage development and deployment of new technologies but can also hamper it (compare Sunding & Zilberman, 2001, p. 252).

One example is the ban of certain pesticides. Chemicals can be highly efficient and necessary for growth of certain crops, but they can also be quite harmful. Banning chemical pesticides, on the one hand, can give the incentive to adopt new nonchemical treatments, biological control, and so on. On the other hand, it might hamper adoption of high-yielding varieties since new varieties often depend on pesticides for which there are no nonchemical alternatives.

Input subsidies

Input subsidies can have enabling and deterring effects at the same time. Subsidies had a great impact on the success of high-yielding varieties during the green revolution. They increased profitability through cost reduction and had an indirect impact through credit effects (Brooks, 2005). Similarly, subsidies for pesticides and fertilizers led to adoption of high-yielding varieties in other developing and developed countries (Sunding & Zilberman, 2001). Negative environmental side effects can occur in input subsidies, which might contradict existing environmental policies (Khanna & Zilberman, 1997). On the other hand, elimination of subsidies or even additional taxation on inputs can also lead to adoption of new technologies such as more precise application technology for reducing residues and in the long term for increasing yield.

2.1.8 Intellectual Property and Deployment

2.1.8.1 Intellectual Property in Plant Technology

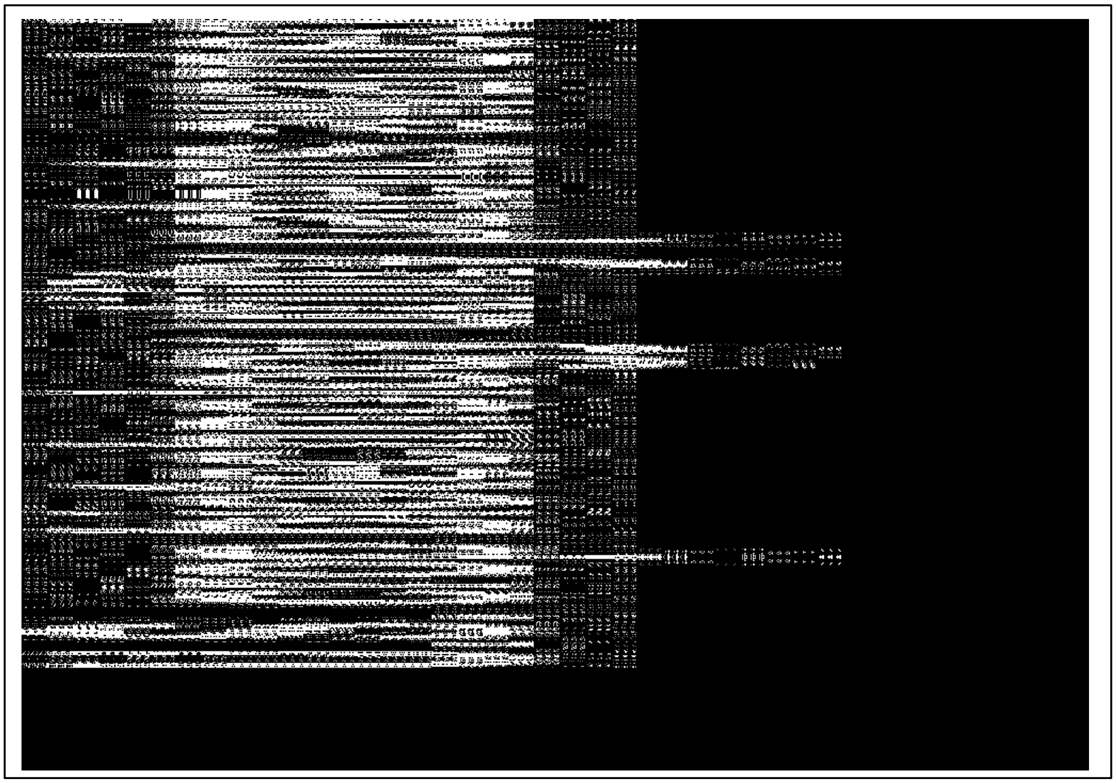
At the time when the literature about adoption and diffusion was developing, agricultural innovations were generally treated as public goods. Innovations were available to everyone and everybody could make use of these free of charge (Alston, Pardey, & Taylor, 2001). In the last several decades, however, intellectual property rights were more often utilized to create barriers to access to innovations. From public sector driven research, currently the private sector is driving progress in agricultural innovations with a different focus in mind (Kowalski, Ebora, Kryder, & Potter, 2002). Unlike the public sector, private companies try to get a net benefit from their commercialized innovations on the basis of claiming intellectual property. The intention for regulating intellectual property was to set incentives for the private sector to conduct research in expensive technologies. Accordingly, access to rights and ownership of these technologies are becoming a major issue for future research, and eventually for future diffusion of innovations related to plant technology such as hybrid seed varieties (Bennet, Chi-Ham, Graff, & Boettiger, 2008).

Intellectual property can come in different forms: copyrights, trademarks, and plant and utility patents are the most common ones. When talking about plant technology, patents[1] are the most dominant ones (Bennet et al., 2008, p. 328). However, not each innovation can necessarily be patented. In this regard, Rogers' definition of innovation is not sufficient for patents (Rogers, 2003; see section 2.1.2), because a patent can only be granted if an innovation meets a standard of novelty, non-obviousness, and utility (USPTO, 2012). Only since the 1980s – when the Patent and Trademark Law Amendments Act was implemented in the USA – have patents for

[1] Patent is the authorization by a governmental agency to an inventor to exclude anyone from the utilization of an invention.

agricultural biotechnology been widely utilized from the public and private sector (Delmer, Nottenburg, Graff, & Bennet, 2003).

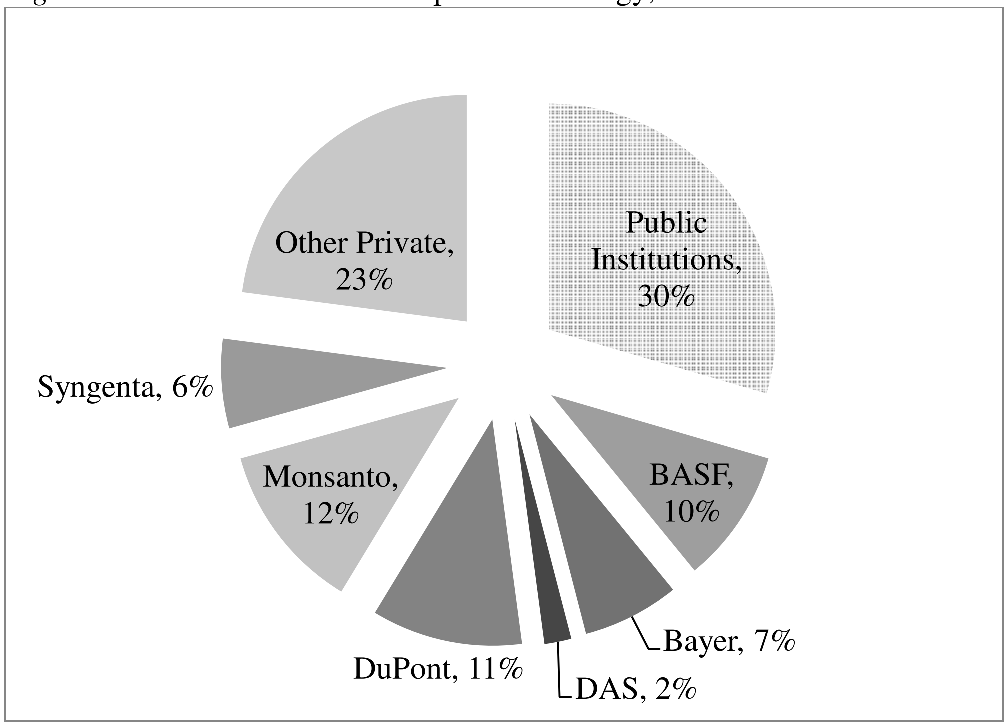
Figure 7. Patents issued by the USPTO in the area of plant biotechnologies for both public and private sector organizations between 1985 and 2000.



Source: Delmer et al., 2003, p. 1667

Figure 7 shows the total number of patents for plant biotechnology issued by the United States Patent and Trademark Office (USPTO), split between the public and private sectors between 1985 and 2000. Plant or crop technology is a subcategory in the patent classification for agricultural biotechnology and entails among other things hybrid rice seeds. Since 2000 the patents issued in this category each year in the USA vary between 400 and 700 patents. In the EU fewer patents are issued, on average 300 per year since 2000. With the issue rate in mind, a closer look at the distribution of patents between public and private sectors between 2002 and 2009 reveals that only 30% (602 in total) of all patents were issued by the EPTO and USPTO to the public sector, whereas 70% (1438) were issued to private actors (based on data from Frisio, Ferrazzi, Ventura, & Vigani, 2010). There is a clear dominance of multinational and national companies compared to government agencies, research institutes, and universities. Accordingly, the following figure is even more intriguing.

Figure 8. Patents distribution for plant technology, 2002-2009.



Data from EPO and USPTO

Figure 8 shows the split of patent authorizations to public institutions, private actors, and dominating multinational companies in hybrid rice research (see Chapter 2.2.5). 47% of all patents related to plant technology were authorized to only 6 multinational companies in the given timeframe. One can certainly say that this period showed a significant shift in utilization of innovations from a public sector deployment to a privatized commercialization. Given the patent distribution, however, one might also talk about an imperfect market for property rights on innovations, if not about an oligopolistic market. The question is how that trend of the recent period affects the diffusion of hybrid seed varieties. This question is addressed in the following section.

2.1.8.2 The Anticommons

The rise of intellectual property patents in agricultural technology gave rise to a metaphor, which distinguishes a primary factor for innovation diffusion today from innovation diffusion of pre-patent days. Garret Hardin (1968) used the term *tragedy of the commons* to emphasize the overuse of common goods. Hardin originally described a lack of incentives for people to use scarce resources sustainably. In regard to agricultural research, a free use of innovations took the incentive away from the private sector to invest in expensive research since everybody could make use of the innovations and a return for the inventors would not be secured. In theory, privatization of common resources and of innovations can help solve the tragedy of the commons (Heller, 1998). In reality, however, privatization in the sense of assigning property rights to ideas eventually led to an underuse of scarce resources. Accordingly, Heller and Eisenberg (1998) described the impact of patents as *tragedy of the anticommons*. The tragedy of the anticommons is a “result of a proliferation and fragmentation of intellectual property ownership across multiple owners” that “prevents any single institution or company from assembling all of the necessary rights to produce a product, resulting in the underuse (or nonuse) of resources” (Bennet et al., 2008, p. 331). The initial idea of promoting commercial development of new technologies through patents led to barriers for actual product development. As shown above, premarket research by the private sector is prospering since the 1980s, and through smooth transactions for licensing usage rights of patents, product development should in theory be similarly prospering. However, transaction costs, strategic behavior, and cognitive biases of participants are the main reasons why product development is hampered by patents (Coase, 1988, p. 174).

A clear example of the tragedy of the anticommons is the development of ß-carotene-enriched rice, which is the Golden Rice (Kryder, Kowalski, & Krattiger, 2000). The product development was done by public-sector researchers who wanted to make use of methods and materials, which were developed and patented by private actors. Initially there were 70 patents to be licensed from more than 32 different owners, which made the development and commercialization of this product complex and time consuming.

Whereas the anticommons of intellectual property rights can deter the development of products rather than the adoption and diffusion process of innovations, the more important question is who are the owners of patents and how the owners deploy their products.

2.1.8.3 Deploying Innovations

In the scientific and political literature about food security it can be read often that one crucial hurdle to overcome food insecurity is to improve collaboration of all stakeholders and to find more effective strategies (Boettiger & Alvarez, 2009). Symptomatically, it is argued that there is no greater incentive than food insecurity to such collaboration (Ilyas-Ahmed, Kumar, Viraktamath, Sindhu, & Yogeswara Rao, 2003). In general the stakeholders who should collaborate are mostly divided in three groups: the public, private, and civil sectors. There are different politically motivated opinions that argue for a purely privately driven research, design, development, and deployment of agricultural innovations. There are also arguments for largely limiting the scope of private actors in favor of the civil sector. This section will not take sides but point out interests and intentions, as well as comparative advantages for each of the sectors and implications for partnerships in general.

The private sector is driven by making profits. It aims for making products that the consumers want. Companies tend to utilize economies of scale, and therefore also aim for large-scale mechanized production methods for products that are exportable. Internal structures, administration, time frames, and so on are formed around the profit motive. Relationships and alliances are primarily there to make profit (James & Persley, 1990).

On the contrary the public sector's purpose is to provide public goods and to regulate private markets that generate externalities. It should develop programs and policies that optimize social welfare for the public good. Output terms are difficult to monitor; hence, administration evolved to focus on input monitoring. Moreover, procedures for checks and counterchecks tend to be time consuming and not as efficient as the private sector's workflow (Brooks, 2005).

The civil sector, which is primarily represented by NGOs and cooperatives, sees itself as the "true" representative of the society. Its interest is to improve the living situation of everyday citizens that are hampered by dysfunctional public and private sectors. In terms of hybrid seeds, the civil sector can be involved in various aspects ranging from technology generation over large-scale seed production to technology transfer. While it shares similarities with the private sector, it operates in a non-profit oriented way and mostly on local levels with local specifications (Clark, Hall, Sulaiman, & Naik, 2003).

Ilyas-Ahmed et al. carved out certain comparative advantages for each sector regarding hybrid rice RDD&D, which will be briefly listed below (Ilyas-Ahmed et al., 2003, p. 183).

According to the authors, the public sector is well equipped in technology generation because of comparative advantages including:

- accessibility to a large collection of germplasm;
- vast and well-trained human resources;
- well-developed infrastructure;
- easy accessibility to government/policymakers; and
- effective linkages with national/international public-sector organizations/institutions.

The private sector is more efficient in large-scale seed production and distribution as well as in technology generation and transfer as its comparative advantages entail:

- a result-oriented and focused approach;
- strong and efficient marketing and distribution;
- closer and effective linkages and interaction among research, production, marketing, and extension personnel; and
- fewer or no bureaucratic interferences/delays and greater flexibility.

The civil sector is generally advantaged in technology transfer and has in general the following comparative advantages:

- closer and intimate contact with farmers at grass-roots level;
- self-motivated and more dedicated personnel;
- business processes, though in a non-profit oriented way since providing social goods and serving the farming community are driving motives; and
- fewer or no bureaucratic interferences/delays depending on the size and shape of the organization.

It needs to be kept in mind that the division in three sectors only allows a broad recognition of comparative advantages. Specific public agencies, private companies, NGOs, and cooperatives are likely to differ in some points. Accordingly, chances, needs, and limitations to partnerships differ from case to case. Nevertheless it can be argued that only partnerships between all sectors can solve global issues such as food insecurity.

It is not only the international development community that increasingly sees the collaboration of all sectors as an important national and international resource (James & Persley, 1990). There are some characteristics of current RDD&D that shape the need for a partnership. Boettiger and Alvarez (2009) describe five key issues for agricultural technology deployment that can only be achieved by collaboration: market failures, missing coordination of each sectors' means and goals, unclear roles for the actors, access to financing, and missing integration of end-users in the product development process.

Those issues show that there is currently inefficiency in hybrid rice innovation and distribution. It is difficult to make assumptions on how much adoption and diffusion rates are actually negatively affected by the inefficiencies. It is also hard to assume how an optimization of comparative advantages in mutually benefiting partnerships will positively affect adoption and diffusion. Finally, it is hard to predict if partnerships will further develop and evolve in a favorable way. The Hybrid Rice Development Consortium (HRDC) of IRRI and the Public Intellectual Property Resource for Agriculture (PIPRA) are two examples in which partnerships have overcome each sectors' limitations for hybrid rice research (see section 2.2.5). In the end, however, progress towards collaboration will most likely depend more on political will rather than on rational considerations.

2.2 From Conventional Rice to Hybrid Rice

2.2.1 Rice

Rice is one of the most important staple crops in the world. Around 900 million people depend on rice either as producer (Pandey et al., 2010, p. V). Rice is cultivated in currently 114 countries, of which most are developing countries. Rice provides 27% of dietary energy and 20% of dietary protein in developing countries (Redoña, 2004). For 840 million people in chronic hunger situations, around 50% live in areas that are dependent on rice production. Eighty percent of rice is produced on primarily small-scale subsistence farms. In Asia, rice is the most important staple crop. Asian countries produce and consume around 92% of global rice. China and India combined produce more than 50% of the world's rice. Asia is also the home of the most widely produced rice species. In many Asian societies rice is featured in creation myths and has important cultural significance besides its importance for food supply and for the economy (Sharma, 2010).

Cultivated rice is a member of the grass family and belongs to two species, *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). Oryza sativa is globally cultivated whereas Oryza glaberrima is grown mostly in West Africa. Oryza sativa is thought to originate in Southeast Asia, in the region of monsoonal rainfall extending from eastern India through Myanmar, Thailand, Laos, Cambodia, Vietnam, and up to southern China. Wild rice varieties can be found there, which were probably the base of domestication (Sharma, 2010). Linguistics gives further evidence that rice was domesticated in Southeast Asia and for the importance of rice in agriculture; in several regional languages the terms for rice and food or for rice and agriculture are synonymous. Oryza sativa has two major groups of varieties: japonica and indica. Japonica rice tends to be a short-grain variety that is localized in temperate climates such as Japan, Korea, Northern China, Europe, and USA. Indica rice is the more tropically adapted variety that consists of long grains, which is mostly grown in Southern Asia. Rice is a highly productive plant. It is self-pollinating and from a single seed up to 150 seeds can be produced. The conventional produced seed is genetically identical to the parent's seed. This allows the farmer to store seeds and use it for the next season with confident expectations for the product. There are two different processes how rice can be seeded on paddies, either directly on the field or as seedlings (University of Arkansas, 2006).

Paddy rice in Asia is usually planted in flats, or sown in nurseries. When the plants are one to six weeks old they are transplanted to paddies in which they mature. Although the paddy rice process is more labor-intensive there are certain advantages involved. Plants can be transplanted when environmental conditions are favorable; stands may be more uniform than when crops would be seeded directly; it also reduces the amount of time that rice grows in the field, which makes it possible to plant rice in regions with relatively short growing seasons or to plant two or three crops in a year in areas with longer rainy seasons (University of Arkansas, 2006). Rice can be grown in various environments. It can be grown in wet environments where no other crop could be grown. For example Asia is abundant with arable land in wet environments where rice is grown under rainfed conditions. But rice can also be grown on irrigated lowlands or other areas short of rainfalls. Up to 75% of global rice supply is grown in irrigated lowland environments (IRRI, 2012). The advantage of irrigated rice production is that it can be grown continuously without need for rotation, which in some countries allows up to three harvests per year.

2.2.2 Rice in the Global Economy

When talking about rice in the international economic trade, it is differentiated between type, quality, degree of processing, and degree of milling. Regarding type, there are long-grain varieties (6.2 millimeters or longer), medium-grain varieties (between 5 and 6.2 millimeters), and short-grain varieties (less than 5 millimeters); though medium and short-grain varieties are mostly treated alike. Unlike in agronomy there is no differentiation made in global trade between African and Asian rice, neither is there a distinction made within Asian rice between japonica and indica varieties. However, there is often made the distinction between fragrant and unscented rice. Basmati and jasmine rices are usually considered as long-grain types, but marketing and pricing for these fragrant rice varieties are different from unscented rice varieties. The quality of rice is composed of various factors like percent of broken kernels, seeds, chalkiness or color. For simplification, quality is mostly differentiated by a certain share of broken kernels. Degree of processing is differentiated in three categories: paddy rice, brown rice, and milled rice. Paddy rice is newly harvested rice before husk and bran layers are removed. Brown rice still has the bran layer but the husk has been removed. Milled rice has both husk and bran layers removed. Also called white rice, it is the most commonly consumed form of processed rice (University of Arkansas, 2006).

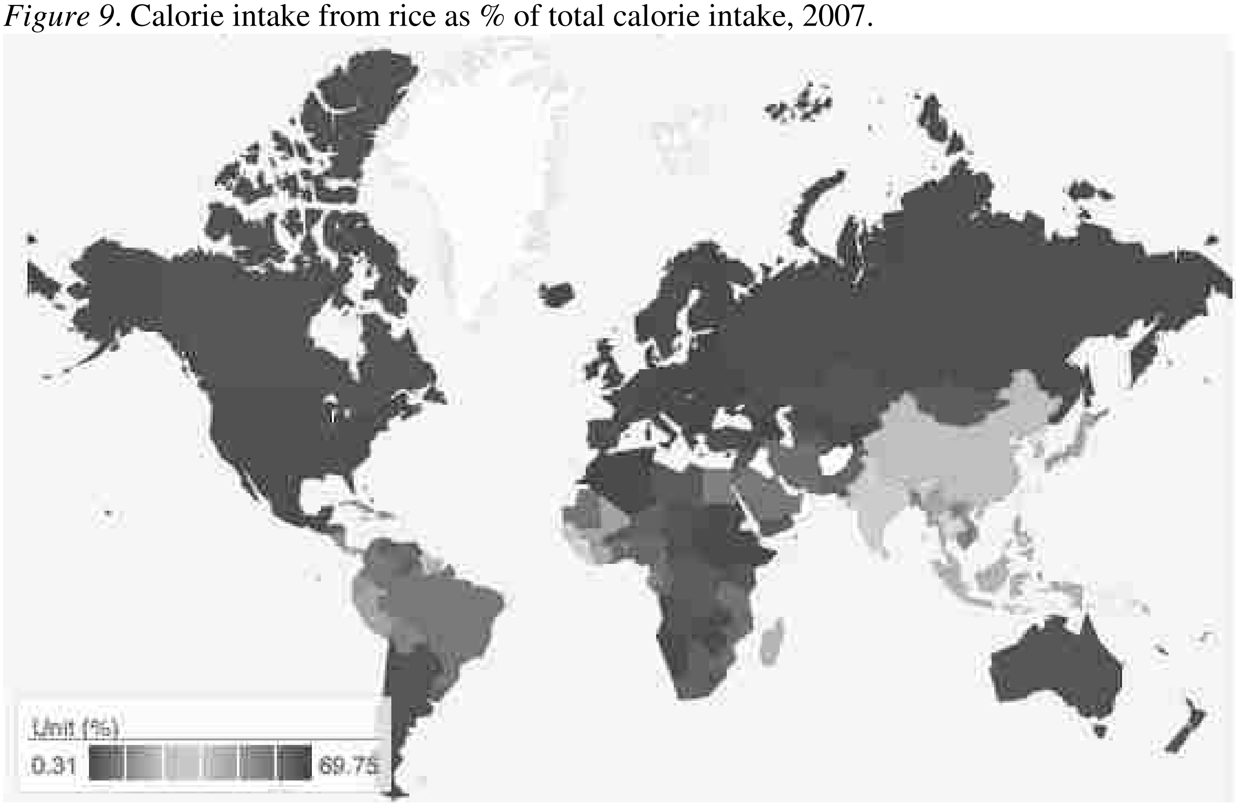
As of 2007 rice accounted for 19% of calories consumed globally and 28% in least developed countries, ranging from 2.4% in North America up to almost 50% in Southeast Asia (see *Table 1*). *Figure 9* shows the world map with colored countries according to calorie intake.

Table 1. Share of calories from rice and rice consumption by region, 2007.

Region	Total Calories Per Capita	Rice Calories Per Capita	Share of Calories from Rice	Rice Consumption (kg/capita/ year)
World	2798	533	19.0%	52.96
Least Developed Countries	2162	606	28.0%	62.61
Africa	2462	197	8.0%	19.65
Western Africa	2649	324	12.2%	32.76
Asia	2668	783	29.3%	77.89
Southeast Asia	2586	1270	49.1%	130.96
South Asia	2370	715	30.2%	72.10
North America	3727	88	2.4%	8.35
Central America	3043	106	3.5%	10.69
South America	2886	298	10.3%	29.35

Data from FAOSTAT

Figure 9. Calorie intake from rice as % of total calorie intake, 2007.



Data from FAOSTAT, mapped with WRS

Table 1 and *Figure 9* show that rice is the major staple crop foremost in South Asia and Southeast Asia, but also in some parts of South America, West Africa, and Madagascar. From a food security perspective, a sufficient supply of rice is in these regions is indispensable. Furthermore, the countries that are most dependent on rice as a staple crop are located in Southeast Asia. Measured as share of calories from rice, Bangladesh (69.8%), Laos (64.2%), Cambodia (64.1%), Vietnam (57.8%), and Myanmar (54.5%) are the countries in which rice is the most important staple crop and in which rice accounts for more than half of the daily calorie intake. Production and consumption data gives further insight in the importance of rice as a commodity. *Table 2* shows production and consumption of paddy rice equivalent of 2010.

Table 2. Leading rice-producing and -consuming countries, 2011.

Rank	Production (1000 t)		Consumption (1000 t)	
1	China	200,714	China	139,000
2	India	155,116	India	94,900
3	Indonesia	57,165	Indonesia	39,550
4	Bangladesh	51,155	Bangladesh	34,500
5	Vietnam	42,328	Vietnam	19,750
6	Thailand	31,000	Philippines	12,800
7	Myanmar	16,900	Thailand	10,400
8	Philippines	16,887	Myanmar	10,140
9	Brazil	11,300	Japan	8,050
10	Japan	10,503	Brazil	8,000
11	Pakistan	9,751	Republic of Korea	4,977
12	USA	8,391	Nigeria	5,200
13	Cambodia	6,669	USA	3,880
14	Republic of Korea	5,616	Egypt	3,870
15	Madagascar	4,500	Cambodia	3,450

Notes:
Data for production in paddy rice equivalent and data for consumption in milled rice equivalent
Data from USDA PS&D

Total production of paddy rice in 2010 was 691 million tons. *Table 2* shows again that Asian countries produce and also consume most of the global rice in absolute numbers. Despite the importance of rice in agricultural production and as staple crop, global trade is only 6.5% of consumption (compare *Table 3*). Eventually that means "that most countries are self-sufficient in rice and face increased price volatility in times of production shortfalls" (Wailes, 2005, p. 177).

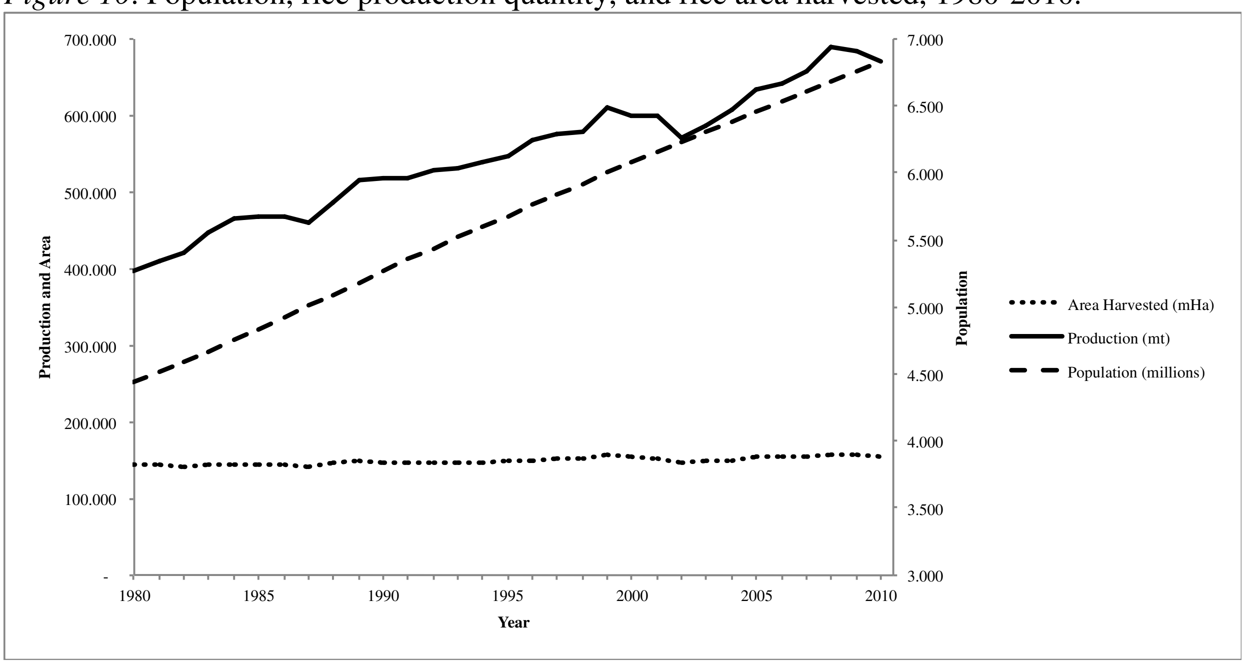
Table 3. Leading rice-exporting and -importing countries, 2011.

Rank	Exporting (1000 MT)		Importing (1000 MT)	
1	India	6,500	Nigeria	2,300
2	Thailand	6,500	Iran	1,500
3	Vietnam	6,500	Philippines	1,500
4	Pakistan	3,750	Iraq	1,200
5	USA	2,826	EU-27	1,170
6	Cambodia	1,000	Saudi Arabia	1,150
7	Uruguay	900	Malaysia	1,130
8	Burma	750	Indonesia	1,000
9	Brazil	700	Cote d'Ivoire	950
10	Argentina	630	South Africa	800
11	China	600	Senegal	750
12	Egypt	600	Mexico	725
13	Australia	450	Japan	700
14	EU-27	350	USA	603
15	Guyana	260	Brazil	600

Data from USDA PS&D

Finally, the importance of rice and a crucial trend are displayed by *Figure 10*. This figure shows production quantity of rice, area harvested of rice, and the world population between 1980 and 2010. Whereas there is a clear relation between population growth and increasing production (correlation coefficient of 0.98), the area harvested changed over three decades only marginally. Firstly, this confirms the importance of rice in regard of global food supply. Secondly, it can be stated that an increase of production quantity of rice was not achieved through an agricultural extensification. Production increase was achieved through agricultural intensification, by utilizing high-yielding rice varieties instead of extending agricultural area. Assuming that population growth will continue and that rice will remain a staple crop for a large share of the global population, the need for further intensification efforts become clear. Additionally, total area harvested is projected to decrease over the next decade, implicating a smaller production growth than demand growth (USDA, 2010). Only a strengthened increase in production yield can balance the forecast. Hybrid rice varieties were thus far a driving force in the production increase in some countries such as China and the USA. The next chapter discusses details about hybrid rice and what role hybrid rice can play in meeting growth in consumption by intensification of production.

Figure 10. Population, rice production quantity, and rice area harvested, 1980-2010.



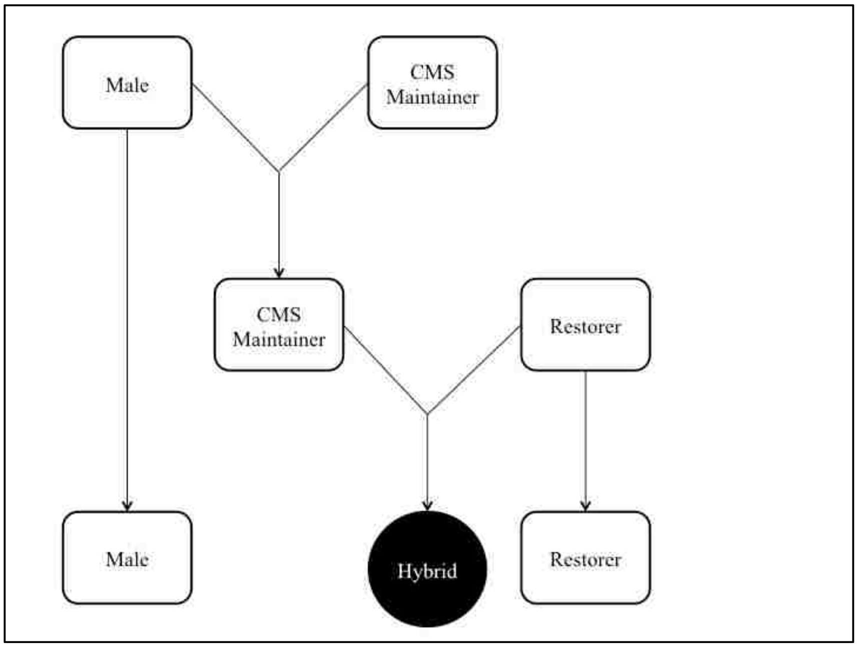
Data from FAOSTAT and World Bank

2.2.3 Hybrid Rice

Hybrid rice is the first or second generation derived from a cross between two genetically different parents. The goal is to find a hybrid rice seed that has certain advantages such as higher yields. Hybrid rice can be produced from either japonica or indica varieties. Since rice plants are naturally self-pollinating, i.e. male and female at the same time, and since the breeding of hybrid rice requires control of pollination, one parent line needs to be male sterile. This line does not have viable pollen and is therefore referred to as female and accepts pollen from other rice plants. The other parent line is the male parent line, which is a normal pollen-producing parent. There are currently two different methods commercially used to create hybrid rice: a three-line system and a two-line system.

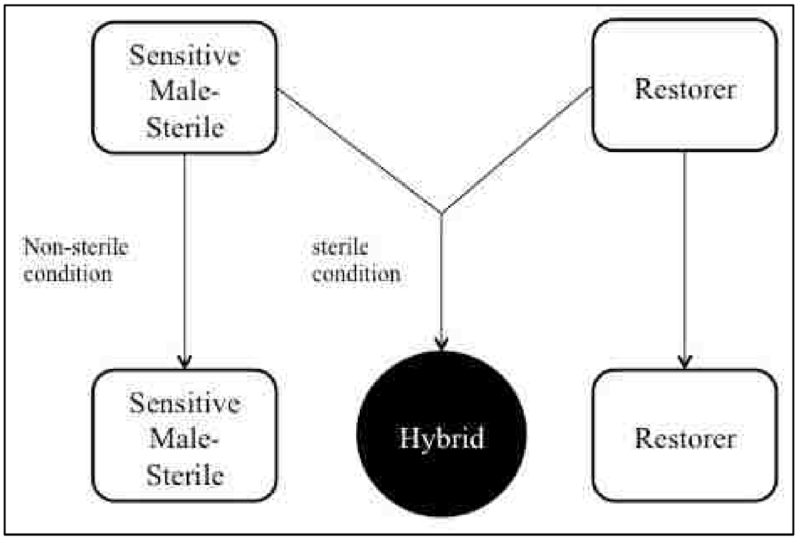
The three-line system was developed by Yuan Longping and commercialized in China in 1976; he is considered to be the "Father of Hybrid Rice." The three-line system, illustrated in *Figure 11*, utilizes a so-called maintainer line, which represents the male parent and which itself is a special varietal breed. The maintainer line is cross pollinated with a female line, which produces first generation rice seeds that are purely female seeds, also known as the cytoplasmic male-sterile (CMS) line. In a second breeding the first generation is cross-pollinated with a so-called restorer line, which restores fertility and creates second generation rice seeds. This second generation is the commercial hybrid rice to be used by farmers. The main advantage of three-line hybrids is that they have a higher output yield than conventional varieties; however, their seed costs were significantly higher because of a low seed yield of only 0.5 MT/ha (Li et al., 2009).

Figure 11. Breeding process of the three-line system.



In contrast to the CMS three-line system where a generally male sterile line is used, the two-line system, which was developed in the 1990s, makes use of a male sterile line that is sensitive to certain condition (compare *Figure 12*). As Li, Xin, and Yuan explain (2009), (Li et al., 2009) (Li et al., 2009) (Li et al., 2009) (Li et al., 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) (Li, Xin, and Yuan 2009) male sterile lines can be environmental-conditioned genic male sterile (EGMS), photoperiod-sensitive genic male sterile (PGMS), thermo-sensitive genic male sterile (TGMS), or photoperiod- and thermo-sensitive genic male sterile (PTGMS). In the sterile-condition the line can be cross-pollinated with a restorer line that produces the commercial hybrid rice seed already in the first generation.

Figure 12. Breeding process of the two-line system.



The two-line system is commonly applied today because it offers some advantages against the three-line system (according to Li et al., 2009, p. 9). It is simpler due to removal of the maintainer line, and it is commercially more sustainable and reduces hybrid rice seed costs since seed yields range between 3.0 and 3.5 MT/ha. There is no difference in agronomic performance between condition sensitive (CS) hybrid rice lines and CMS hybrid rice lines. However, CS varieties require a higher attention from seed producers and it is temporally and geographically limited.

2.2.4 Advantages and Disadvantages of Hybrid Rice

Advantages

The goal of hybrid rice breeding is to find an advantageous heterosis effect. Also called hybrid vigor, it is the phenomenon that hybrid rice seeds are superior to their parents in at least one characteristic. Heterosis has to be bred into the hybrid seed by choosing the right parents, which themselves already have desired characteristics. Typically, hybrid vigor should be high-yielding, have resistance against certain diseases, and contain a good grain quality. In the 1980s it was estimated that the potential of hybrid rice is to yield up to 21.6 t/ha (Cao & Wu, 1984). Current top yielding hybrids produce on average 12 t/ha, though there are differences in maximum yield according to hybrid variety and region (Li et al., 2009). Accordingly, estimates differ about what an advantage of using the varieties can be to individual farmers, with increases in yield ranging from 10% to 40% (Barclay, 2010). In any case, hybrid rice high-yielding potentials have a direct positive impact on the farmers' revenue for at least the early adopters.

On the cost side there are various advantages, such as a lower seed cost per unit of grain area planted. It is found that hybrid varieties have lower seeding rates than conventional varieties. For example in the USA 120 kg/ha of conventional seeds are needed on average, whereas hybrids need around 40 kg/ha of seeds (Andrews, 2006, p. 24). Other hybrid vigor characteristics have different impacts. Hybrids are a form of agricultural intensification, decreasing land area requirements. Farmers have potentially more options on how to use their land. Alternatively, farmers are not in need to cultivate as much land as with conventional rice. Hybrids do not need significantly more inputs than conventional varieties. Therefore input costs that are land area dependent (e.g. irrigation water, fertilizer) can be reduced by using hybrids. Biotic stress tolerance is a heterosis effect that hybrid breeders are seeking. Hybrids that have resistance against certain diseases do not require as many pesticides as conventional varieties.

Intensive hybrid rice research is currently conducted to adapt to climate change effects. The rise of mean global temperature and the more frequent appearance of extreme weather events pose a threat on agriculture by increasing the risk of crop failure. Current research is looking for abiotic stress-tolerant hybrid rice varieties (such as drought tolerance) to cope with climate change effects (Trethowan et al., 2010). Possible future hybrid rice varieties can therefore also reduce risk of crop failure for farmers. Despite all these advantages, there are also disadvantages associated with hybrid rice seeds.

Disadvantages

As Andrews (2006) has maintained, time required from seed development to market for a new hybrid variety takes not only up to eight years using the two- or three-line breeding techniques. It takes a similar amount of time to develop a male and female parent line that can commercialize the new hybrid variety on a large scale. The probability of finding a new hybrid variety that has desired heterosis effects is quite low; even experienced breeders can often make no exact prediction on the outcome of heterosis effects. Success is dependent on different factors such as a good team, necessary field testing capabilities, laboratories, information technology, and so on. Furthermore, different regions require testing of local rice to find out which rice plants are most suitable for parent lines. Before a new hybrid variety is actually marketed, multi-location tests need to be done to estimate the economic viability. All that adds up not only to a long-term investment for research and development, but foremost to an expensive investment (Andrews, 2006, pp. 25-27). Seed costs, therefore, tend to be expensive not only because of R&D expenditures.

In order that pollination of the female parent takes place in a controlled way, male and female parents need to be planted systematically on the field. Both parents need to bloom at the same time. Often cross-pollination is assisted mechanically. Not each female plant will be pollinated successfully and the male parents might not carry any seeds at all (Andrews, 2006). Due to these factors in combination with high R&D costs, hybrid rice seed production has significantly higher seed prices than conventional varieties. Hybrid seeds cost per unit are in general two to eight times more than conventional varietal seeds.

Another crucial disadvantage of hybrid rice is that its produced grain cannot be used as seed for the next season. Technically it is possible to grow new rice plants from hybrid rice grain; however, the heterosis effect will be lacking and yields are significantly lower making it unprofitable for farmers. Therefore farmers need to purchase each season new hybrid rice seeds.

The first hybrid rice varieties had inferior quality compared to conventional varieties (Li et al., 2009). Due to the production methods, today it is still difficult to produce hybrid rice seeds that inherit vigor advantages and have at least the same quality as conventional varieties. Poor quality is not an inherit characteristic of hybrid rice seeds, though, and more advanced breeding techniques are diminishing the quality difference (Janaiah & Xie, 2010). However, large-scale adoption of hybrid rice varieties is often slowed down by lower quality. Consumers are not willing to pay as much for the lower quality of hybrid rice as for conventional rice, often making the production of hybrid rice unprofitable for the farmers (Janaiah & Hossain, 2003).

2.2.5 Current Deployment of Hybrid Rice

Considering the advantages and disadvantages of hybrid rice and possible impact on food availability, one could assume that after more than three decades of research and development hybrid rice technology would have diffused on a large-scale. In fact the only country where hybrid rice is dominant is China. Qualitative research studies suggest that the disadvantages of hybrid rice prevail and cause farmers to hesitate to change from conventional to hybrid rice (Virmani et al., 2003). It holds especially true that a developed hybrid rice variety cannot simply be deployed anywhere. The advantages of high-yielding varieties might therefore not be as large in different countries. On the other hand the public sector seems to be aware of the advantages of hybrid rice and therefore pushes for hybrid rice research and development. Rice research and development is undertaken in many countries including Bangladesh, China, Egypt, India, Indonesia, Japan, Korea, Myanmar, the Philippines, Russia, Sri Lanka, Thailand, USA, Vietnam, and others (Virmani et al., 2003). The major hybrid rice producing countries however are much fewer.

China is the early adopter country of hybrid rice. Not only are the roots of hybrid rice here but it is also the country that achieved the highest diffusion rates of hybrid rice. According to the most recent data, hybrid rice is produced on 18.6 million hectares in 2008, which account for 63% of total rice area in China (Li et al., 2009). The large deployment is comprehensible when seeing the fact that the yield advantage of hybrid rice ranged from 17% to 53.2% between 1976 and 2008, which is on average a 30.8% higher yield than that of conventional varieties (Li et al., 2009, p. 2). Of all hybrid rice varieties grown in China 85% is indica rice and only 3% is japonica rice, the rest is a mixture of indica and japonica (Barclay, 2010). However, for all commercially deployed hybrid rice varieties it holds true that only long grain varieties are produced on a large scale, whereas short or medium grain and fragrant hybrid varieties are being developed, but only rarely deployed. Other major hybrid rice producing countries (according to area harvested) are mostly located in Asia as well, such as Bangladesh, India, Indonesia, Philippines, and Vietnam. Outside Asia only the USA has relatively high adoption numbers (see *Table 4*).

Table 4. Hybrid rice production in major hybrid rice producing countries (paddy rice equivalent).

Country	Hybrid Rice (1000 ha)	% of Total Rice Area[d]	Total Production of Hybrid Rice (1000 t)[f]	% of Total Rice Production[g]
Bangladesh[a]	735	6.5	5,365	10.9
India[b]	1,500	3.3	9,000	7.5
Indonesia[c]	62	0.4	452	0.7
Philippines[a]	346	7.8	2,387	15.1
USA[c]	175	13.9	2,082	18.9
Vietnam[a]	645	8.7	3,508	8.8
Others[c]	100	-	-	-
Subtotal[d]	3,563	2.8	22,794	3.4
China[e]	18,600	63.2	141,360	71.7

Notes:

a. Figures for year 2008. Source: Janaiah and Xie (2010)

b. Figures for 2011. Source: USDA (2012)

c. Figures for year 2009. Source: Barclay (2010)

d. Based on 2009 world area harvested without China. FAOSTAT

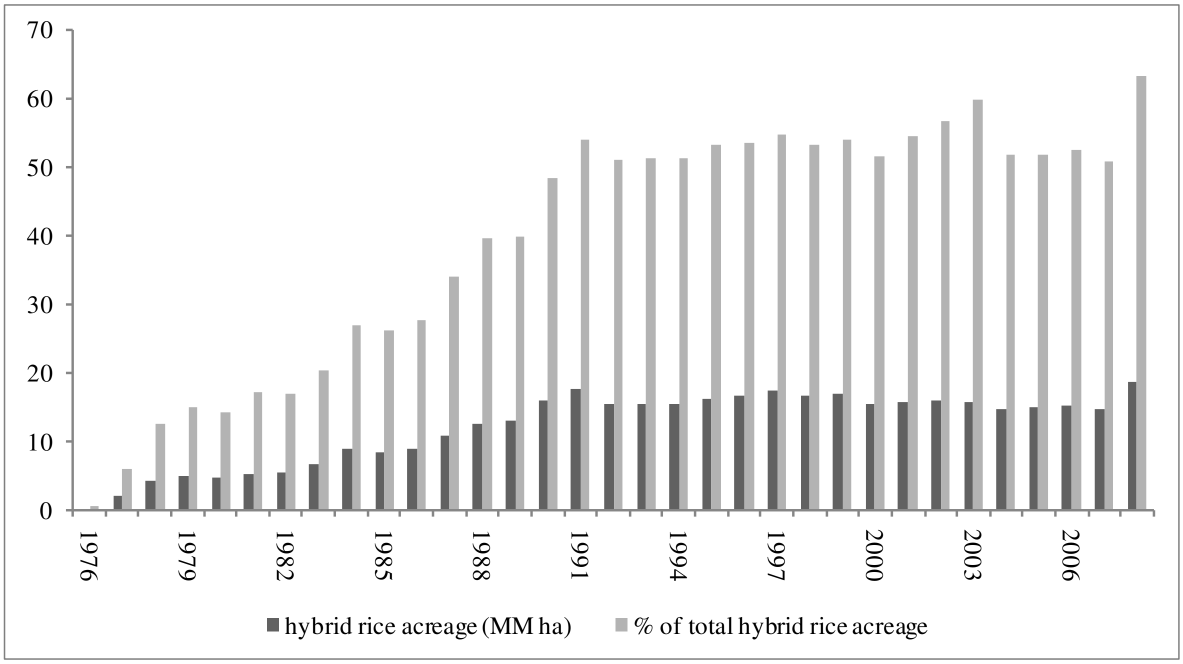
e. Figures for year 2008. Source: Li et al. (2009)

f. Figures based on calculation of production data (see *Table 26* in Appendix)

g. Based on 2010 data from FAOSTAT (see *Table 2*)

Studies for the major hybrid rice producing countries suggest that government intervention played a large role for diffusion of hybrid rice. Prominently in China, the government provided critical support through funding and policy. Lin found that in the early years of hybrid rice deployment the Chinese government's pressure was the main reason for the rapid expansion of hybrid rice, implying a forced adoption based on national food security concerns instead of an adoption because of individual economic advantages (Lin, 1991). Although in 1981 a major land reform diminished the influence that the government could have on agricultural practices, the adoption rate for hybrid rice has continued to grow (*Figure 13*).

Figure 13. Hybrid rice acreage in China, 1976-2008.



Source: Li, Xin & Yuan, 2009, p. 16

Li et al. trace the increasing diffusion back to improved hybrid vigor due to continued research and to improved distribution of hybrid rice seeds (Li et al., 2009, p. 19). Indeed, more than 1,500 hybrid rice seed companies indirectly and directly backed by the government and 23 government sponsored research institutes and universities were active by 1995.

In India, the government was originally confident of having widespread diffusion of hybrid rice by 2020 of more than 60% of total rice area (Janaiah & Xie, 2010, p. 8). However, in the first half of the 1990s hybrid rice development experienced set backs. Consumers and farmers did not accept hybrid rice due to poor grain quality, reaching an adoption rate of less than 1% by 2003 (Janaiah & Xie, 2010). The government pushed hybrid rice research and introduced new incentive policies and subsidies in 2004 (FAO, 2010). The private sector increased the investment in hybrid rice research, and improved grain quality led farmers and consumers to adopt new hybrid varieties. By 2008, 35 hybrid varieties, that were developed according to Indian needs, were released. As of today, hybrid rice is planted on 3.3% of total rice area (USDA, 2012).

Bangladesh and the Philippines had a different approach on how to adopt hybrid rice varieties. In both countries the government favored an active participation of the private and civil sectors in research. In the Philippines, IRRI started deploying hybrid rice seeds in 1994 and continued a partnership with private actors up to today (Barclay, 2010). Likewise, in Bangladesh the NGO *BRAC* has evolved into the major organization for hybrid rice research, development, and deployment. Bangladesh and Philippines also have a liberal policy on seed imports from other countries, which was especially for Bangladesh a key factor in increased diffusion rates (Janaiah & Xie, 2010; Julfiquar, Hasan, Azad, Hossain, & Virmani, 2003).

Vietnam, on the other hand, is relying almost solely on imports of hybrid rice seeds mainly from China and on a price subsidy on seed costs. However, in 2004 the price subsidy has been removed and adoption rates have remained static since then (Janaiah & Xie, 2010; Nguyen & Nguyen, 2003).

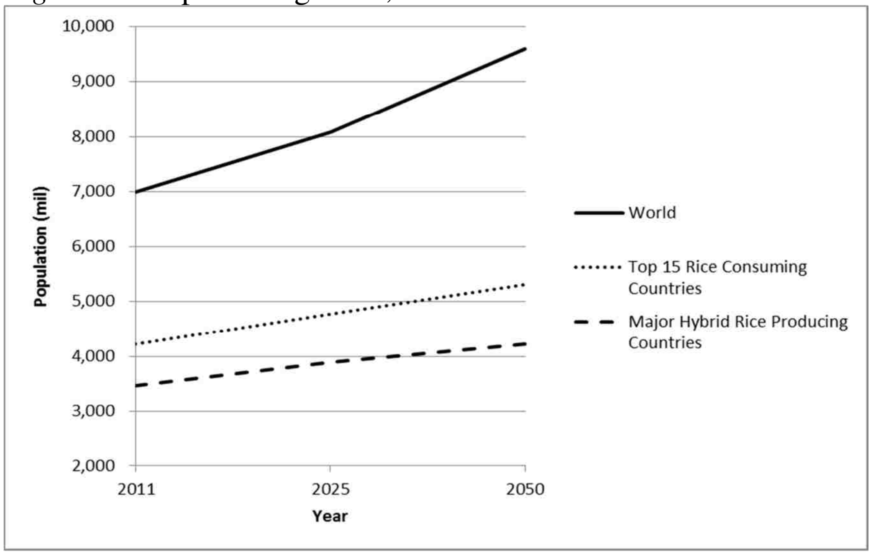
Whereas in most of the major hybrid rice producing countries research and development is either mainly financed or subsidized by the government, the USA and other countries rely more heavily on a few private companies. Multinational companies have been investing intensely in hybrid rice research since the 1980s and developed varieties that are currently mostly deployed in the USA. Whereas in the beginning hybrid rice research has been treated as essential to food supply and thus as a public good, the manifestation of intellectual property rights is changing the character of hybrid rice research (see section 2.1.8). In particular, rice producing countries that have not yet deployed large amounts of hybrid rice seeds are canvassed by multinational companies. The companies are hoping for future large selling markets, which seems realistic as large rice producing countries such as Myanmar, Thailand, and Brazil are yet to adopt suitable hybrid rice varieties. Notably even China, where hybrid rice research has been a public matter since the beginning, has created a few large seed companies that are active globally with the goal to market Chinese hybrid rice varieties. *Table 28* in the Appendix lists the major companies involved in hybrid rice research and development and where they are active. The civil sector seems to acknowledge that only in partnership with private companies hybrid rice research and development can be fruitful in the future. Most notably the hybrid rice research department of IRRI initiated the Hybrid Rice Development Consortium (HRDC) in 2008. The goal of HRDC is to support research and communicate advantages of hybrid varieties. It is collaborating with currently more than 50 public and private actors (Barclay, 2010). Other civil actors are similarly reaching for partnerships (Boettiger & Alvarez, 2009). On the one hand, public actors might benefit from those partnerships through better access to hybrid rice seeds. On the other hand, the door is wide open to mainly privately commercialize these seeds. Based on the shift of research from public to private institutions, and based on the development of public-private partnerships, it is not far fetched to say that future hybrid rice deployment will be more a private goal of making business backed by public concerns of appropriate food availability rather than vice versa.

2.2.6 Trends and Future Development of Hybrid Rice

Despite its high-yielding characteristic and its tendency for better adaptability to abiotic and biotic stress, adoption of hybrid rice has been delayed. Research and development require expensive and continuous investment through either public or private actors. At the farm level, adoption of hybrid rice might present excessive financial or management constraints due to higher seed costs and different agricultural techniques that are needed. However, continued research is promising in finding hybrid vigor that might be able to reduce adoption constraints and increase diffusion rates in the future. To do so, future hybrid vigor needs to adapt to social and environmental trends.

Perhaps the biggest challenge will be to produce a sufficient supply of rice grains in order to meet growing rice demand. Not only will the world population likely grow by 2050 to 9.5 billion people, the top 15 rice producing countries will have a population increase from 4.2 billion to 4.7 billion by 2025 and to 5.3 billion people by 2050. Today's major hybrid rice producing countries will have a population increase from 3.4 billion to 3.9 billion by 2025 and to 4.2 billion people by 2050 (*Figure 14*). Estimating naively the production increase needed to feed these additional people, today's rice production need to increase 12% by 2025 and 26% by 2050. However, keeping substitutability of crops and other factors, such as negative demand elasticites for rice in mind, current estimates speak of the necessity of production increases between 5% and 8% by 2019/2020 (Mohanty et al., 2010; Timmer et al., 2010). Currently, researches, especially in China, are working on so called "super" hybrids, which have a new one-way breeding method and which are alledged to increase productivity by up to 60% compared to three-line hybrids (Yuan, 2004). China's roadmap for large-scale diffusion of the super hybrids aims for a date of 2015 (Li et al., 2009), whereas currently only 20% of rice production consists of super hybrids (FAO, 2010).

Figure 14. Population growth, 2011-2050.



Data from PRB, 2011

A second trend that hybrid breeding technology has to deal with are abiotic stress factors. Higher mean temperature and more extreme weather events are effects of the climate change that are already prevalent. There can be positive and negative effects on crops associated to climate change. Some regions will experience a drier and hotter climate, putting pressure on crops and likely reducing crop productivity. Other regions will have more precipitation, and higher temperatures can expand agricultural production, especially in higher latitudes (Trethowan et al., 2010, p. 155). Though in total, crops will have a lower productivity especially in those tropical geographical zones where rice is primarily grown. Other abiotic stress factors are unstable irrigation water reservoir systems (Napasintuwong, 2009), soil erosion because of long-term chemical fertilizer applications (Li et al., 2009), and less arable area in general will be available (USDA, 2010). There are breeding strategies that try to obtain hybrid varieties that can cope with the changing climate (Trethowan et al., 2010); however, these hybrid varieties are yet to be commercialized.

Biotic stresses are a third trend that hybrid rice research addresses. Some hybrid varieties have seen reduced resistance to diseases and insects (Li et al., 2009), though breeders are also continuously working on developing hybrids with multiple disease and insect resistance (Zhou, Deng, & Li, 2008). In a nutshell, all these hybrid vigors in development are promising to improve food security in rice consuming countries and meet increasing demand.

Regarding these trends, few quantitative studies have been conducted to estimate the impact of hybrid rice on food security (Durand-Morat, Wailes, and Chavez 2011; Janaiah and Hossain 2003). Durand-Morat et al. (2011) found out that global total rice production would have been 2.3% lower in 2008 if hybrid rice adoption had not occurred. In China, as the major hybrid rice producer, rice prices would have been 14% higher, and in other countries rice prices would have been up to 3% higher. Moreover, they estimated that hybrid rice adoption rates had to increase up to 90% in the hybrid rice producing countries by 2020 in order to keep the same availability of rice per capita as 2008. Other authors confirm that accelerated hybrid rice adoption can potentially help keeping rice available and affordable on today's level (Janaiah & Hossain, 2003; Xie & Hardy, 2009).

2.3 Research Questions

The literature review section discussed why agricultural innovations are invented, how they are adopted and what possible constraints to adoption exist. It was further shown what role rice plays in the world and what hybrid rice can achieve. Technological innovations such as new hybrid rice varieties have the potential to increase rice productivity and possibly meet future demand. Consequently, hybrid rice has an impact on food security. The central question to answer is how large this impact can be. Therefore, this study will make projections up to 2025.

On the basis of continued population and expenditure growth, increased hybrid rice adoption will be simulated for the current major hybrid rice producing countries, whereas assumed benefits of hybrid rice can vary in each country. The countries in which rice is the most important staple crop will be analyzed in regard to food security impacts. Accordingly, this study tries to answer the following questions:

- What will be the future demand of rice?
- What will be the future supply of rice and what will be the price?
- What are the effects of continued hybrid rice adoption on production levels?
- What impact will a sustained and increasing adoption of hybrid rice have on food security?
- What are benefits for consumers of sustained and increasing adoption of hybrid rice?

It can be expected that the demand for rice as well as the retail price will increase proportionally to population growth, which will be covered partially by an increase in production quantity, primarily due to yield advantages and input efficiencies of hybrid rice varieties. The objective of this study is accordingly to give detailed answers to the research questions and to validate and quantify the expectations.

III. METHODOLOGY

3.1 Methods

The research questions touch different aspects of global rice production and consumption. The core feature is what impact a large-scale diffusion of hybrid rice can have on production, consumption, prices, and trade. It was shown above that hybrid rice characteristics can be manifold since research for new hybrid rice varieties is induced by various circumstances. Hybrid rice vigor can aim for drought tolerance, for insect resistance or simply for improved yields. In any case hybrid rice research aims for increasing average yield compared to conventional rice either under similar conditions or under certain stress situations. Consequently, a first prerequisite for the methods is that input and output characteristics of rice are represented.

More fundamentally, rice production itself is quite diverse. There is not only one rice variety, but there are short, medium, and long grain varieties as well as fragrant rice. There is neither only one processing step, but there is the processing from paddy rice to brown rice and to white rice for each rice variety as well as the processing steps vary in degrees of bran removals, e.g. lightly milled, well milled, etc. To make it more complex, each country has not only different rice consumption preferences, but has also different production and processing techniques. To have as complete a picture as possible of the rice production and a comparable benchmark to hybrid rice production, all different rice varieties and processing steps should ideally be included in the framework of analysis.

Hybrid rice is already being produced in several countries. Policies and market forces might change this situation. In fact, diffusion of hybrid rice is likely to change in the rice producing countries. Thus, this research's methods need not only to take into account the microeconomic production level of hybrid rice, but also the aggregated production levels of affected countries.

This leads us to another prerequisite, external factors influence production levels on a large scale. As hybrid rice research is driven by changing environments, agricultural production in general is affected by changing environments. An earlier section mentioned that increasing population will raise demand for food products and for staple crops such as rice in particular. On the other hand without yield improvments, decreasing land availability will limit agricultural production. Additional variables might also be taken into account; for instance, energy prices are likely to increase in the future due to manifold reasons. Since costs of fertilizer and costs of mechanization are directly correlated to energy prices, this external factor will also need to be considered. An increase in available expenditure of households might lead to a change in diet, hence, to a different demand of rice. Therefore household or per capita income might also be an exogenous variable to consider. Furthermore, there might be products that can substitute for rice, e.g. wheat. There are countless other external factors that will affect rice production and should be included in a complete framework.

Going from the country level to a global level, rice is an internationally traded commodity. Trade volumes are not as high as for other staple crops, but some countries depend to a large extent on rice imports or exports. Accordingly, trade needs to be considered in the framework as well.

Rice is a highly politicized commodity. Food security issues are a main reason for that, but also general bilateral and multilateral relationships are contributing to this fact. Regarding global rice production, this is mostly reflected in trade policies and in governmental rice stocks. When talking about rice, free trade is an illusion. Nearly every country's trade policy includes tariffs, quotas or other market distorting techniques. These are adjusted constantly and can have tremendous effects on global rice production and consumption, as the last rice price spike in 2008 showed (Dawe, 2010; Yu et al., 2011). Rice stocks are usually accumulated in anticipation of market fluctuations, but depending on a government's policy, stocks can actually also induce market fluctuations. For example, India's release of its huge stock of rice to the world market led to a drop in the rice price in 2011. This research will therefore also include policies and stocks in the methods.

Keeping those prerequisites in mind and considering the objective of this research – to reflect prices and quantities from a supply and demand framework, for production and consumption – some complexity is undeniable. There are a handful of agricultural economic models that can satisfy the requirements at least partially: the Arkansas Global Rice Model (AGRM), the IRRI Global Rice Model (IGRM), RICEFLOW, AGLINK-COSIMO, and the Country-Commodity Linked Modeling System (CCLS).

CCLS, which is maintained by the USDA, is a partial equilibrium model that solves for prices and trade under market clearing conditions for country and world commodity markets (Adenäuer, 2008). By that it equilibrates supply and demand and global imports and exports by taking into account 24 commodity markets in 39 countries. This model focuses on trade policies, but does not take into account production at all. Therefore this model is lacking some crucial aspects for analyzing impacts of hybrid rice.

AGLINK-COSIMO is a merged model by the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization (FAO). OECD's AGLINK model is another partial equilibrium model for agricultural production, which focuses mainly on OECD countries. COSIMO is also a partial equilibrium model for agricultural production, though with a focus on developing countries. By merging both models a very complete global partial equilibrium model was created that mainly analyzes domestic and trade policies' impacts (Adenäuer, 2008). This model relies on OECD-FAO Agricultural Outlook data. However, AGLINK-COSIMO does not model production characteristics, which does not satisfy this study's needs.

The IGRM is a partial equilibrium structural econometric simulation model that includes 21 countries, which are either rice producing, rice consuming, and/or rice trading (Matriz et al., 2010). It includes supply, demand, trade, stocks, policies, and market equilibrium conditions. Production takes into account rice substituting crops, and rice itself is disaggregated into japonica and indica varieties. Rice consumption interlinks food consumption with other uses such as seed requirements. By that the model is able to analyze different aspects of global rice production, though, it is mostly used for technology impact assessment on an intra-country level. This model seems to satisfy almost all of the set requirements except analyzing processing activities and inclusion of substitutes of rice.

The AGRM is a partial equilibrium model that includes 45 countries and five rest-of-the world regions. (Wailes & Chavez, 2011). The model differentiates on the production side with area harvested and yield equations between long and medium grain markets but does not investigate production further. Rather, it focuses much more on analyzing national rice policies as well as regional and global trade policies. Technically the AGRM can incorporate technology changes, though this is not its main feature. Therefore the AGRM does not meet this study's requirements.

The RICEFLOW model is a spatial partial equilibrium model that includes many rice products and markets (Durand-Morat & Wailes, 2010). It models the supply chain as well as the production chain for nine different rice commodities. It can disaggregate more than 89 countries and can generate global results on inputs, products, processing, trade and final consumption at a regional and country level. By that, it can be used for analyzing trade policies on different levels, impact of new technologies and production chain changes, as well as effects on consumption. This model seems to satisfy all needs for this study.

Due to the limitations of this study, limited resources also need to be taken into account, when choosing which model to use. CCLS and AGLINK-COSIMO are models that only researchers working at USDA and OECD-FAO have access. Similarly IGRM, AGRM, and RICEFLOW are models used for research and consulting purposes. Whereas IGRM is administered by IRRI, access to it is out of reach when not being a researcher of IRRI. AGRM and RICEFLOW, however, were developed and are managed at the University of Arkansas. Therefore, taken the model specifications into account as well as the availability of the models, this study will make use of the RICEFLOW model as it is the best fitting and most accessible model.

3.2 RICEFLOW Model

This study uses the RICEFLOW model, which was developed by Alvaro Durand-Morat and Eric Wailes (2010). It is written in GEMPACK (General Equilibrium Modelling Package), which is modeling software suitable for computing general equilibrium models. The RICEFLOW model is a multi-region, multi-product, spatial partial equilibrium framework for the global rice market, which was originally built on the basis of a spatial price equilibrium model by Takayama and Judge (1964). Takayama and Judge's model could estimate regional trade flows of rice as a result of a transaction cost optimization problem. The original

RICEFLOW model (Durand-Morat & Wailes, 2003) required a careful calibration, which proved to be difficult and often led to compromises on the values of relevant parameters, a shortcoming that could be solved by adopting another modeling approach. The updated RICEFLOW model as it is used in this study (Durand-Morat & Wailes, 2010) does not use the optimization approach but is solved by specifying behavioral equations according to neoclassical economic theory. The main differences modeled between the original and the updated RICEFLOW model, which is advantageous for the purpose of this study and can potentially reflect the global rice market more realistically, is that supply and demand functinos are assumed to be nonlinear. However, since the RICEFLOW model is written in linearized form, all non-linear equations need to be transformed to a linearized form. This leads to the consequence that the variables in the model are shown by their percentage change rather than in absolute values.

The disadvantages that accompany the updated modeling approach mainly consist of limits to create new bilateral trade flows and production. The original optimization approach could result in trade flows or expanded markets in terms of production or consumption if it optimized transaction costs. The updated version of the model allows for trade, production, and consumption to be created only on the basis of existing trade flows and outputs in the baseline. For example, if one country does not produce a kind of rice then accordingly the model will never produce this kind of rice regardless of any price incentives. Similarly, it means that only existing trade flows can vary in quantity but no new bilateral trade flow can be created, even though comparative advantages might imply it. However, the trade-off between advantages and disadvantages can be justified when keeping in mind that rice will primarily be further cultivated in countries where it is already being cultivated. The advantages in flexibility of specifications of demand and supply functions, as well as the incorporation of the Armington assumption, prevail for the purpose of this study.

Production is modeled as a composite two-stage budgeting process. The first stage determines the demand functions for intermediate composites and for value-added composites, whereas the second stage determines the demand for intermediate inputs and factors of production. The model is based on a number of independent technology variables related to productivity of factors and inputs. The demand for intermediate and value-added composites is thus a function of activity level, technological characteristics of production, producer prices for activities, and the relative prices of each composite.

Substitution effects, which can be caused by changing producer or composite prices, are modeled by the elasticity of substitution, whereas the elasticity of substitution needs to be determined beforehand and can be flexible. It can either be a Leontief function (value of zero), a Cobb-Douglas production function (value of 1) or a Constant Elasticity of Substitution function (any other value). This study specifies the production functions as Leontief functions, thus allowing no substitution effect between factors and inputs at all. The use of the Leontief function can be justified to stress the impact of scarce resources. Limitation of resources (e.g. agricultural land) stresses the need for an intensification of agriculture but also limits its use. On the other hand, new technologies are created for substituting scarce resources (e.g. fertilizer for land). However, to emphasize the potential of hybrid rice in regard to a different input use as well as to a higher yield compared to conventional rice, the assumption of no substitution can be concise. Moreover, this scenario can be understood as a “worst-case scenario” (Durand-Morat et al., 2011, p. 5).

Primary inputs of labor and capital are specified as highly elastic, whereas supply of land is highly inelastic. Intermediate inputs including fertilizers, pesticides, energy, and seeds are assumed to be perfectly elastic. Those elasticity specifications can describe the future situation for agricultural production adequately. It shows the limitation and importance of land and stresses that agricultural production does not allow substitution of land in production, thus making intensification, as through hybrid rice varieties, necessary. Additionally, it allows for other innovations by stating substitution possibilities within the other primary inputs and intermediate inputs. Finally, imported and domestically produced commodities are assumed to be unitarily elastic.

On the demand side, final consumption for each region is specified as a non-linear function dependent on price and income. Price and income elasticities of demand are taken from the Food and Agricultural Policy Research Institute (FAPRI) based on the AGRM.

Two general system constraints are imposed on the model: market clearing conditions and zero profit conditions. The market clearing conditions demand that all markets are cleared. This means in each case supply is equal to demand and a market equilibrium can be obtained. Included in the model are markets for input factors, for domestic commodities, and for composite commodities. All different stages of production are interrelated, and the market clearing conditions thus become increasingly important and complex to meet. Free variables, which are pricing variables and allow for equilibrium changes, are included for each market in the model. This means for the factor market, that supply and demand can be achieved by adjusting the factor price variable. In RICEFLOW, factors are provided exogenously in the baseline data for each country. On the other hand, commodity markets are fully adjustable markets. Commodity markets consist of domestic and composite commodity markets in which commodity supply meets local and global demand, and domestic production can either be sold locally or globally. Market clearing is used for domestic production, composite commodities, intermediate consumption, and final consumption. Similarly, imports must reflect exports so that the market clearing condition is satisfied.

The zero profit conditions demand that activities, wholesalers or producers cannot receive extra profits. This condition is not a realistic criterion to reflect the real world but much more a necessity to create clear correlation between prices and costs. The only way how normal profits may be included is through the production factor 'capital', though a disaggregation of profits and costs is not easily possible. Therefore, it means that prices only reflect costs of factors of production and input costs and that no additional value is created during the production process. Under this condition the model can display implications for consumer price changes when using a different technology much more than implying additional revenue potential for producers.

The RICEFLOW model can be run in two ways, either deterministically or stochastically. A deterministic solution is based on the determined behavior of the model as it is set through the behavioral functions. These are specified by the elasticities, which accordingly form the core of the model. This implies that only variables and functions included in the model determine the solution and that no unpredictable factors are included. Accordingly, the deterministic solution reflects the model much more than a realistic image of the world. Nevertheless, if reality is explained by a significant amount of variables, the deterministic solution can be sufficiently close to the actual outcome.

The stochastic solution also relies on the variables and behavioral functions of the model, though in addition it assumes the influence of several unknown variables that are not included in the model but are nevertheless significant for the model's solution. Rather than giving an exact outcome, the stochastic solution will present a probabilistic result based on a known historical variability. The variability is mostly based on time series data, where possible for each variable included in the model. The stochastic solution can also incorporate risk consideration of farmers on individual decision levels in regard to input factors or outputs, thus complicating the model further but also achieving more realistic projections (see section 2.1.4). To achieve a meaningful distribution of the predicted results, the model needs to be simulated a large number of times by drawing randomly distributed values for the stochastic variables.

In general, it can be said the deterministic solution predicts a more or less exact tendency of the results, whereas the stochastic solution adds the probability to which the tendency might actually hold true. Since the deterministic solution is the basis for the stochastic solution, and since the model specifications are assumed to reflect reality accurately, this thesis will focus primarily on deterministic results and their interpretation. However, one stochastic solution will also be modeled for one country – Vietnam – in order to gain additional insight on the impact of hybrid rice and to discover the possibilities of stochastic solutions for food security, which is fundamentally a concern because of uncertainty of the market.

Detailed description of included variables, equations, and model specification can be found in Durand-Morat and Wailes (2010).

3.3 Data Sources

The RICEFLOW model is a data-intensive model. To calibrate the model and the assumed scenarios, a baseline database needs to be created, which includes characteristics of hybrid rice production in the observed countries. The scenarios differ from the baseline in the incorporation of population and expenditure increases on the one hand, as well as in the assumption that hybrid rice varieties are adopted in the observed countries in higher numbers as they are today on the other hand. Thus the scenarios will allow for a comparison of the projected results with regard to food security aspects between an impact scenario and a benchmark scenario.

The baseline for this research is the 2009 calendar year. The baseline is used to project values up to the calendar years 2025. The year 2009 is used as the baseline because this year has the most recent data available that is necessary for the model. 2009 represents also the first year after the latest rice price crisis with higher than average prices. In this special situation, the baseline data for that time can be seen as a challenged case scenario for rice market impact on food security, thus, 2009 is a more appropriate baseline for calculating the impact of hybrid rice on food security. Projection data for expenditure growth and population increase allow for a mid-term outlook up to 2025. In general it holds true that longer term projections tend to become inexact, which could be reflected in the results of the modeled scenarios. Therefore, up to 2025 seems to be an appropriate timeframe. However, the results can be used as a trend to give educated guesses for the longer-term impacts of hybrid rice. Price data will be presented in USD and data about volumes in metric tons.

The database used for this study contains 60 countries/regions for which reliable data could be found for the baseline year 2009. For the impact scenario of hybrid rice adoption, data for the seven major hybrid rice producing countries are used. *Table 5* contains a list of all regions; the regions highlighted are the major hybrid rice producing countries.

Table 5. List of regions included in the RICEFLOW 2009 database.

Argentina	El Salvador	Myanmar	United Arab Emirates
Australia	Ghana	New Zealand	Uruguay
Bangladesh	Guatemala	Nicaragua	**USA**
Belize	Guyana	Nigeria	**Vietnam**
Brazil	Haiti	Pakistan	OCARI
Brunei	Honduras	Panama	OME
Cambodia	Hong Kong	Peru	EU27
Canada	**India**	**Philippines**	OAFR
Chile	**Indonesia**	Republic of Korea	OEUR
China	Iran	Saudi Arabia	ONAFR
Colombia	Iraq	Senegal	ONASIA
Costa Rica	Japan	Sierra Leone	OOCEA
Côte D'Ivoire	Laos	Singapore	OSAM
Cuba	Malaysia	South Africa	OSEASIA
Egypt	Mexico	Thailand	OWAFR

Notes:
OCARI: Other Carribean Countries include Aruba, Bahamas, Barbados, Dominican Republic, Grenada, Jamaica, Netherlands Antilles, Saint Lucia, Saint Vincent, Sao Tome, Trinidad Tobago
OME: Other Middle East Countries include Bahrain, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Syria, Yemen
EU27: Countries of EU in 2009
OAFR: Other African Countries include Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Comoros, Congo, Democratic Republic of Congo, Djibouti, Equatorial Guinea, Ethiopia, Gabon, Kenya, Madagascar, Malawi, Mauritius, Mayotte, Mozambique, Rwanda, Seychelles, Somalia, Sudan, Tanzania, Uganda, Zambia, Zimbabwe
OEUR: Other European Countries include Albania, Armenia, Belarus, Bosnia, Croatia, Georgia, Macedonia, Moldova, Norway, Russia, Serbia, Turkey, Ukraine
ONAFR: Other North African Countries include Algeria, Libya, Morocco, Tunisia
ONASIA: Other North Asian Countries include Afghanistan, Azerbaijan, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Tajikistan, Turkmenistan, Uzbekistan
OOCEA: Other Oceanic Countries include Fiji, French Polynesia, Guam, Kiribati, Micronesia, New Caledonia, Palau, Papua New Guinea, Samoa, Timor-Leste
OSAM: Other South African Countries include Bolivia, Ecudaor, Paraguay, Suriname, Venezuela
OSEASIA: Other South East Asian Countries include Bhutan, China Macao Maldives, Nepal, North Korea, Sri Lanka
OWAFR: Other West African Countries include Cape Verde, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Togo

The database is disaggregated in different activities and commodities. There are nine different product activities, which are primary production of three rice types (short and medium grain, long grain, and fragrant) and two milling stages for each rice type (paddy to brown rice and brown to fully milled white rice). Each commodity is created by an activity based on factors of production and intermediate inputs. The factors of production are land, labor, and capital. The intermediate inputs are included as exogenous commodities and consist of fertilizer, pesticides, energy, water, and seeds. The intermediate inputs are considered to have to be highly elastic, however, water is assumed to be highly inelastic.

Data for primary production come from the Food and Agriculture Organization of the United Nations' database (FAOSTAT). Primary production is disaggregated according to rice type based on information from the Ministries of Agriculture. Data for bilateral trade for each rice commodity are acquired through the United Nations Commodity Trade Statistics Database (UN Comtrade). Data for rice inventories are found at the USDA PS&D database. Finally, stock changes are deducted from the yearly inventory, in case no value is reported, no change in stocks is assumed.

The different processing activities and the composite commodities are derived the following way. Domestic production of paddy rice is combined with imports and used as input activity for the next processing step, the dehusking to brown rice. Costs are included for the de-husking milling ranging from 25 USD/t to 35 USD/t depending on milling technology by country. The milling rate from paddy to brown rice is assumed to be 0.80.

The next processing step, bran removal and full polishing from brown rice to white rice, is similarly specified. Domestic production plus imports of brown rice is used as input activity for the second milling stage. It uses milling rates, which are derived from the USDA PS&D.

The milling costs are assumed to range from 15 USD/t to 20 USD/t, again depending on the level of technology per region. The domestically produced white rice plus imported white rice minus exported white rice presents the final stock of white rice that is used for domestic consumption. Consumption data for calibration comes from FAOSTAT and USDA PS&D.

For the hybrid rice impact scenario, production cost data for hybrid rice in each of the examined countries comes from various sources and case studies, see *Table 6*.

Table 6. Data sources for the modeled scenario.

Region	Data Source	Year of Data
Bangladesh	Hossain (2008)	2007
China	Li et al. (2009)	2008
India	Janaiah and Xie (2010)	2008
Indonesia	Indonesian Center of Rice Research	2010
Philippines	Manalili, Parayno, Redondo, and Tanzo (2008)	2008
USA	University of Arkansas (2011)	2011
Vietnam	Nguyen (2008); Pingali, Morris, and Moya (1998)	2007, 1997

These sources also revealed the advantages of hybrid varieties in terms of input use on an average basis for each region. The share of hybrid rice of the total rice production was similarly gathered through different sources (see *Table 4*). From the literature it was found which kind of rice is produced by hybrid rice varieties, namely in the majority-only LGP rice, which is reflected in the usage of production factors and intermediate composites for each activity. Finally, rice production data is aggregated on a yearly basis for countries with double or trip cropping systems.

3.4 Benchmark Scenario and Impact Scenario

Starting from the baseline data two principal scenarios will be modeled and projected: a benchmark or status quo scenario as well as the hybrid rice impact scenario. With that it can be estimated what the effect of higher hybrid rice adoption will be on the global rice market as well as on food security issues.

The benchmark scenario will shock the baseline data only for the key exogenous variables of population growth and consumer expenditure in order to reflect the demand for rice up to 2025. The changes will be applied to all regions of the baseline. The prediction for population growth is taken from the United Nations, and the prediction for the expenditure increase is taken from the World Bank (see *Table 22* and *Table 23* in the Appendix). The benchmark scenario will predict an unrealistic but meaningful scenario. Stating, if all else stays constant, what will be the impact of an increased population on rice production, demand, price, and other endogenous variables. In other words, the hypothesis can be tested, in which way will the food security situation decline if additional hybrid rice varieties will not be adopted. This scenario is unrealistic since other variables are likely to change, too. However, it is still meaningful in depicting the food security situation under today's technology, thus creating a comparable benchmark for estimating the impact of hybrid rice technology. Furthermore, too many assumptions for changing variables will create higher uncertainty about the estimates of the model, limiting the significance of a deterministic approach to evaluate the impact of hybrid rice adoption.

The impact scenario differs from the benchmark scenario in that it further includes – above the assumptions of the benchmark scenario – the production cost data for hybrid rice varieties and possible output advantages in the examined countries. That can test the hypothesis, in which way hybrid rice improves the food security situation under the same general conditions as the benchmark scenario. The results can indicate the potential of hybrid rice technology in regard to national or global food security.

Two variables were changed in order to reflect the impact of hybrid rice: the composition of production factors and yield of paddy rice. First, the diffusion of hybrid rice was estimated for the projected years. This was accomplished by applying an assumed diffusion curve on the area on which hybrid rice is grown, as outlined by Rogers and explained in section 2.1.2 (Rogers, 2003). On this basis, the production cost composition could be disaggregated for the baseline data and aggregated again for each projected year. Additionally, the yield of paddy rice in hybrid rice producing countries could be estimated for each year. Although the advantages of hybrid rice heterosis can be manifold and yield advantage of hybrid rice is likely to increase further in the future, only yield advantage and production cost efficiencies of current hybrid rice varieties were incorporated in the model *Table 25* and *Table 26* in the Appendix show the production cost data and the assumed hybrid rice diffusion rates for each country. The relative differences between the production costs of hybrid rice varieties and conventional varieties are implemented proportionally according to the diffusion rate of hybrid rice per year as *Table 27* in the Appendix shows.

After gaining an initial insight of the two principal scenarios, the impact scenario will be modified. It will be simulated to measure what the impact of hybrid rice might be if only Vietnam or China will further adopt hybrid rice. Vietnam is taken because it is a hybrid rice producing country, which is highly dependent on rice as staple crop. China, on the other hand, is taken because it is the largest producer of rice and hybrid rice in the world, and China's results differ from the other countries' results in such a way that further investigation is necessary.

Subsequently, a stochastic simulation for the impact scenario of Vietnam will make the analysis more comprehensive. The benefits of stochastic results were discussed earlier. In this case, the variability of production and consumption can simulate an aggregation of different risks in addressing food security, which are drawn from timeseries data. The time series data used to develop the empirical distribution function for yields spans from 1980 to 2009 and is detrended. The variability is simulated by conducting 50 iterations per projected year (2010-2025).

IV. RESULTS AND DISCUSSION

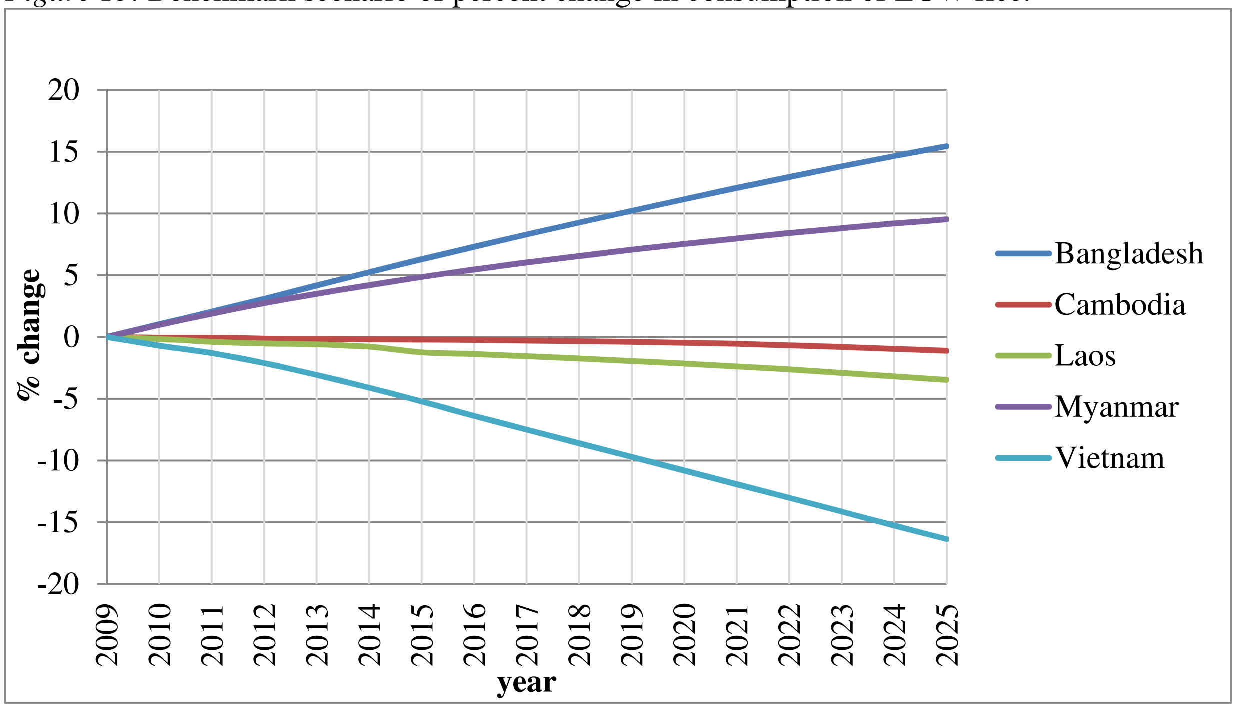
This section discusses the results for the simulated scenarios. The focus is on the retail price, the final consumption quantity, and the production of long grain white rice as this is the kind of rice that is primarily produced through hybrid rice varieties. The nominal retail price and final consumption are the primary aspects of food security that are addressed in this research, therefore the countries in which rice is the most important crop on a caloric basis are observed in detail. For the production aspects, however, the hybrid rice producing countries are studied. The benchmark scenario results are presented briefly. The subsequent discussion of the results will compare the results of the benchmark scenario with the impact scenario and draws conclusions on what impact hybrid rice can have on food security. The detailed results for each in the model included region can be found in the Appendix in *Table 13* and *Table 14* for the production quantity percent changes from 2009 baseline, in *Table 15* and *Table 16* for the final consumption quantity percent changes from 2009 baseline, and in *Table 17* and *Table 18* for the retail price percent changes from 2009 baseline. For further insight as it will be important for the analysis, demand elasticities are given in *Table 24* of the Appendix.

After a review of the deterministic results, a closer analysis will be given to China and Vietnam. These respective impact scenarios will illustrate the impact of hybrid rice on food security if only China or Vietnam further diffuse hybrid rice up to 2025. At last, results for Vietnam will be discussed using a stochastic scenario.

4.1 Benchmark Scenario

It is predicted that the global population will increase to 8 billion by 2025 and the global nominal GDP will increase by 70% (based on UN 2011). On this basis, the benchmark scenario presents estimates of the effects on production and consumption patterns. *Figure 15* takes a closer look at the domestic consumption for long grain white rice for the five countries relying heavily on rice as the staple food crop.

Figure 15. Benchmark scenario of percent change in consumption of LGW rice.



As the figure shows, Bangladesh and Myanmar are projected to increase total LGW domestic consumption, whereas Cambodia, Laos, and Vietnam will decrease. The different projections in consumption changes cannot be explained solely by the expenditure growth rates and population increase, since all five countries have similar increases in those exogenous variables. However, income and price elasticities are different and they determine the results. According to the results, Cambodia, Laos and Vietnam will not rely as much on rice as a staple crop compared to 2009. The calorie supply of rice cannot be deduced from the RICEFLOW results, but the food supply quantity in kg per capita per year can give an approximation of the consumption change.

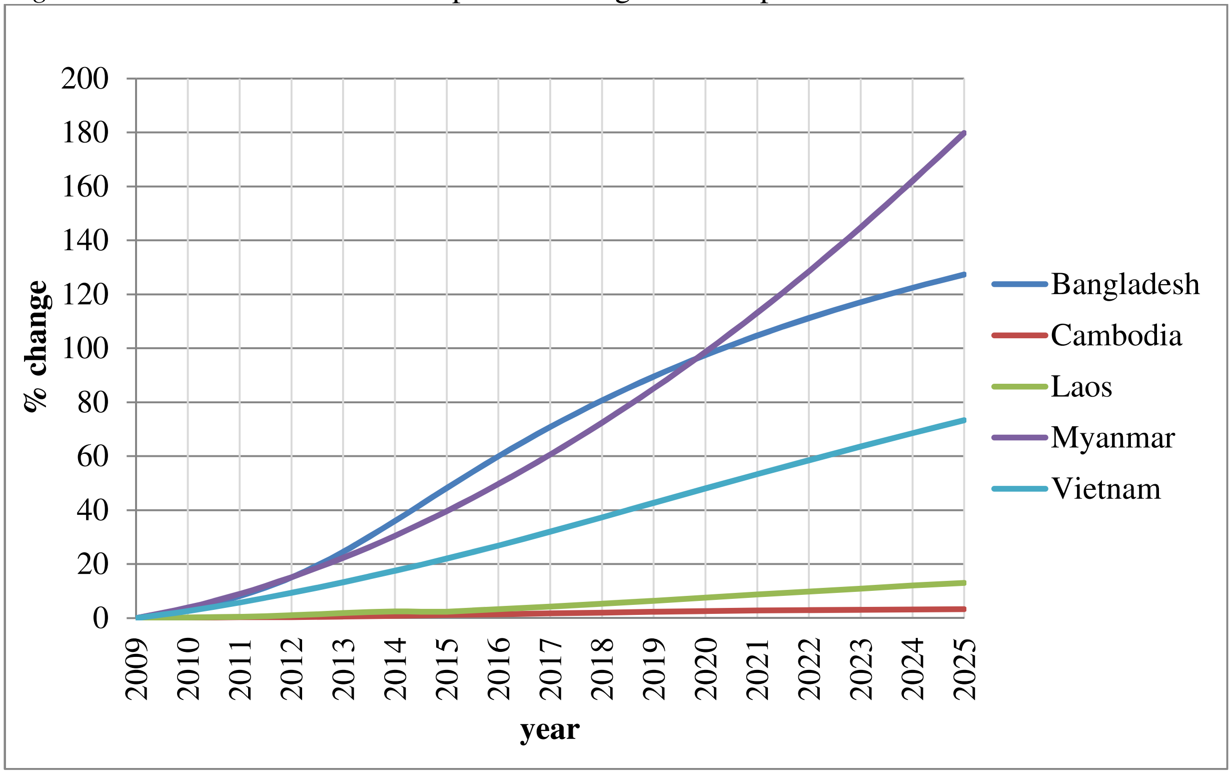
Table 7. Per capita rice consumption of LGW rice in five selected countries, benchmark scenario.

Country	Rice consumption (kg/capita/year)		
	2009	2025	change
Bangladesh	215.13	208.26	-3.19%
Cambodia	234.05	193.77	-17.21%
Laos	227.36	180.61	-20.56%
Myanmar	228.83	224.25	-2.00%
Vietnam	220.36	161.24	-26.83%

Based on data from USDA PS&D

All countries have a decrease in rice consumption per capita, indicating smaller per capita demand for rice. In economic terms, that could mean that the additional demand through population growth cannot give sufficient price incentives to produce sufficient rice globally, leading to decreased rice consumption. But it might more likely be a result of the negative income elasticities. The retail price changes and production quantities reflect that as the following figure shows.

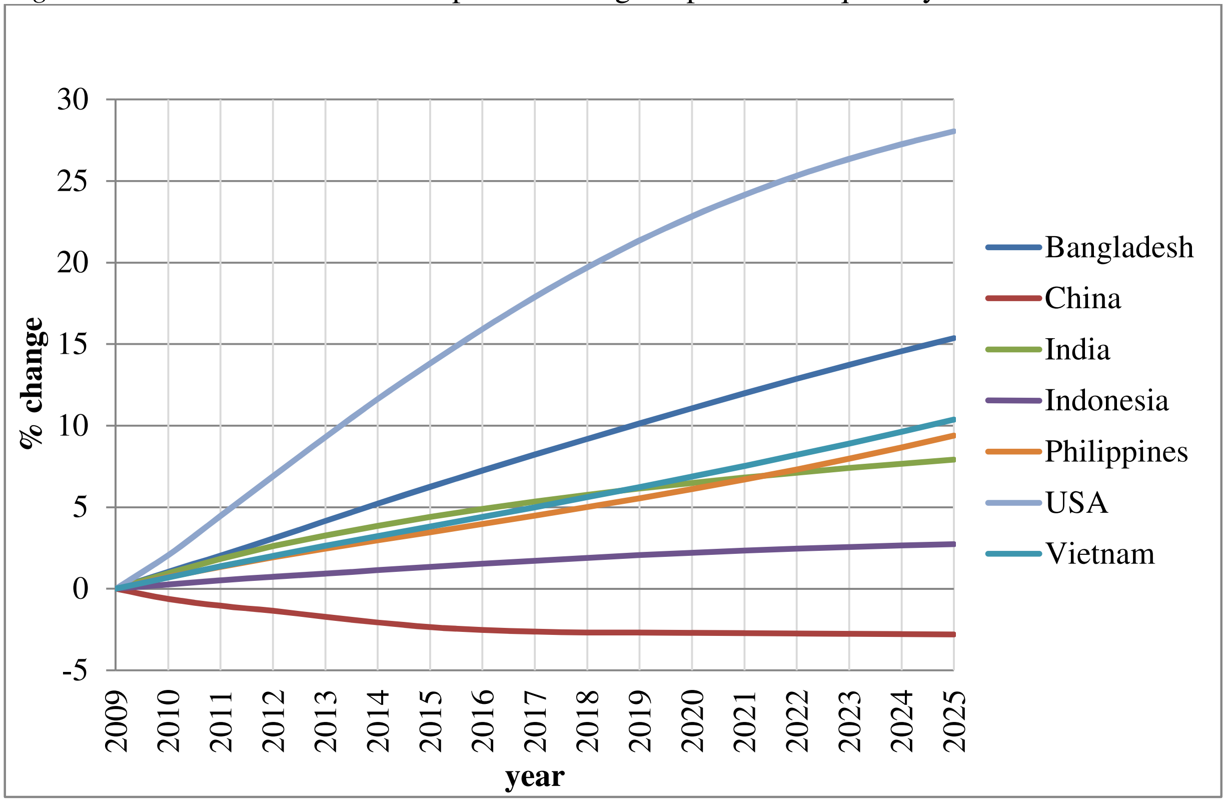
Figure 16. Benchmark scenario of percent change in retail price of LGW rice.



As expected, the nominal retail price for LGW rice is increasing in each country. Myanmar and Bangladesh have dramatic percent increases in the retail price, though Vietnam also has a large increase. This indicates again that rice production cannot meet the rice demand without higher prices. Cambodia and Laos have only very minor changes in the retail price when taking the timespan into account. Decreasing consumption of LGW combined with rising prices might indicate simply a smaller demand for rice, which can reflect changing diets[2]. In general, though, it can be said that population and expenditure increases will induce increased retail prices.

[2] Cambodia and Laos have negative rice demand elasticties with respect to income, which reduces the demand for rice in case of rising expenditure as it is simulated here (compare *Table 24*).

Figure 17. Benchmark scenario of percent change in production quantity of LGP rice.



Increased demand through prices induces an increase in production quantities. This is reflected in *Figure 17*. This graph shows the seven major hybrid rice producing countries for the benchmark scenario. Every country except China has production increases for LGP rice. In the case of China the result can be reasoned by the moderate population increase in combination with a high expenditure growth and negative income elasticity, which results in a lower demand for rice (compare *Table 24*). The high increase of production in the USA can be explained by the trade integration of U.S. rice production and the relatively small base of production in 2009. Since a large share of U.S. rice is exported, the rice producers react more intensively to increased global demand than rice producers in other countries. The following table depicts changes in global rice production.

Table 8. Global rice production of LGP rice, benchmark scenario.

Year	Global rice production (1000 t)	Change from 2009	Production of hybrid rice producing countries (1000 t)	Change from 2009	Share of production on global production
2009	613,516	-	474,738	-	77.38%
2015	629,296	2.57%	484,753	1.81%	76.80%
2020	642,512	4.73%	490,594	3.34%	76.36%
2025	655,250	6.80%	497,705	4.84%	75.96%

By 2025 total global LGP rice production will increase by 6.80% to 655 million metric tons (mmt), whereas the LGP rice production of the hybrid rice producing countries will increase by 4.84% to 497mmt. That is a negative change in the global production share of hybrid rice producing countries from 77.38% to 75.96%. Taking the changes in domestic consumption, retail price, and production for the benchmark scenario into account, it can be stated that rice availability will increase marginally, rice affordability will decrease, and global production can only meet demand with higher nominal prices.

4.2 Comparison of Impact Scenario to Benchmark Scenario

For the discussion of the comparative results, the presentation of the results is changed, examining first the differences on the production side. *Table 9* compares the production changes of the benchmark scenario and of the impact scenario. To recall, the shift in the benchmark scenario is solely induced by population growth and increased expenditure, whereas the impact scenario also accounts for higher yields due to hybrid rice adoption in the main hybrid rice producing countries and accordingly shifts in production cost efficiencies. The bold marked changes indicate the higher increase/smaller decrease in production in comparison to the 2009 baseline data. As can clearly be seen, the hybrid rice producing countries are benefitting largely by the large-scale diffusion of hybrid rice in terms of production increases. Compared to no additional hybrid rice adoption, almost 38mmt LGP rice can be produced additionally by the seven countries. On the other hand, global production of rice only increases by roughly an additional 36mmt above the benchmark scenario. Meaning, the hybrid rice diffusion does produce more rice in absolute values, though, the production is more concentrated in the hybrid rice producing countries, making them more important in global rice supply.

China is the only exception to otherwise clear results. China is producing actually less when hybrid rice adoption occurs. This might be explained by a shift in relative advantages between the rice producing countries. China had a hybrid rice adoption rate of 63.2% in 2009. Higher diffusion rates of hybrid rice up to 93.5% by 2025 make China's production more efficient, though, compared to countries such as the USA, where the hybrid rice adoption surges from 13.9% to 93%, the efficiency gains are relatively lower. This results in relatively higher production costs in China, eventually, to increasing imports of rice and decreasing production of long-grain paddy.

Table 9. Comparison of production changes for LGP rice.

Country	Rice production					Hybrid rice difference from benchmark scenario to impact scenario
		Benchmark Scenario		Impact Scenario		
	2009 (1000 t)	2025 (1000 t)	% change from 2009	2025 (1000 t)	% change from 2009	
Bangladesh	47,723	55,094	15.44%	56,443	**18.27%**	2.45%
China	170,705	166,396	**-2.53%**	164,244	-3.79%	-1.27%
India	129,198	139,365	7.87%	165,768	**28.31%**	18.95%
Indonesia	64,399	66,202	2.80%	69,634	**8.13%**	5.18%
Philippines	16,266	17,866	9.84%	20,535	**26.25%**	14.94%
USA	7,551	9,587	26.96%	10,002	**32.46%**	4.33%
Vietnam	38,895	43,196	11.06%	52,154	**34.09%**	20.74%
TOTAL	474,738	530,957	4.84%	538,779	**13.49%**	1.47%
Global	613,517	655,250	6.80%	690,749	**12.59%**	5.42%

Table 10 also draws a clear picture by illustrating the five countries, which are most heavily dependent on rice as staple food crop. In every case a higher rice consumption can be achieved with hybrid rice adoption than without; the improvements range from 0.17% for Myanmar to 7.62% for Vietnam. However, in either scenario the rice consumption is decreasing. In other words, hybrid rice diffusion can help to mitigate food insecurity, but this agricultural innovation cannot create complete food security on its own.

Table 10. Comparison of rice consumption changes for LGW rice.

Country	Rice consumption					% change between scenarios
		Benchmark Scenario		Impact Scenario		
	2009 (kg/capita)	2025 (kg/capita)	% change from 2009	2025 (kg/capita)	% change from 2009	
Bangladesh	215.13	208.26	-3.19%	210.02	**-2.37%**	0.85%
Cambodia	234.05	193.77	-17.21%	194.61	**-16.85%**	0.43%
Laos	227.36	180.61	-20.56%	184.22	**-18.97%**	1.99%
Myanmar	228.83	224.25	-2.00%	224.64	**-1.83%**	0.17%
Vietnam	220.36	161.24	-26.83%	173.53	**-21.25%**	7.62%

A look at the retail price in *Table 11* rounds up the picture. As before, we can see that hybrid rice adoption has a clear advantage for food security concerns. In every case the impact scenario shows either a smaller increase of retail prices or even a decrease. Bangladesh and Vietnam show drastic changes between the two scenarios, indicating a higher utilitzation of rice in 2025 compared to the benchmark scenario. Bangladesh seems to be a special case though. Looking at the rice consumption change, the improvement from benchmark to impact scenario is not so large that the drastic decline in retail price can be explained except that price elasticity is very low and rice consumption is saturated. Taking the rice production in consideration additionally, it seems that there is a surplus production of rice in the impact scenario, which has a tremendous effect on the domestic retail price. Since Bangladesh is increasing its production of rice by 15.5%, the tremendous effect on retail price should be explained by the trade specifications. In 2009, Bangladesh imports 0.5mmt of LGW rice and exports no rice. By 2025 the imports increased for the benchmark scenario by almost 500 per cent, to 2.48mmt; additional production and imports cannot meet demand without higher retail price. However, for the impact scenario the imports decrease by 62.76% to 0.31mmt. Keeping the limitation of the model specification in mind that no new trade flows can be created, thus that Bangladesh will never export any rice, all the effects of the surplus production – and the indicated lower need for imports – are captured domestically, hence the retail prices decrease drastically.

Very strong effects of hybrid rice on food security also occur in Vietnam, as the rice consumption increases, the production increases, and the retail price decline by 53.3% show. Cambodia has only a slight decrease of the retail price in the impact scenario, indicating a diet change – substituting LGW rice for another commodity; although there is more rice available, demand does not increase, accordingly the price is not increasing but exports expand. Myanmar seems to benefit only marginally from hybrid rice adoption. However, Myanmar is exporting rice in the 2009 baseline. In the benchmark scenario exports decrease by 72.6% and in the impact scenario the exports decrease by 88.1%. Thus, the impact scenario is increasing the volume of domestically commercialized rice and having a lowering impact on domestic retail prices in Myanmar. Finally, Laos' drop in retail prices due to hybrid rice is sharp. Nevertheless, food supply and the largely positive effects on retail price show the advantages for food security, too.

Table 11. Comparison of nominal retail price percent changes for LGW rice.

Country	Retail price changes for 2025		Hybrid rice difference from benchmark scenario to impact scenario
	Benchmark Scenario	Impact Scenario	
Bangladesh	127.34%	**-6.69%**	-134.03%
Cambodia	3.27%	**1.04%**	-2.23%
Laos	13.06%	**2.42%**	-10.64%
Myanmar	179.79%	**174.89%**	-4.90%
Vietnam	73.34%	**20.04%**	-53.3%

To sum it up, the discussion of the results of the most important countries clarifies that there are clear benefits of hybrid rice adoption in terms of food security aspects. Production quantities increase globally, retail prices decline, and rice consumption increases.

4.3 Impact Scenario for China

As the results shows, China is the only country in which production is declining in the benchmark scenario as well as in the impact scenario. However, since China is the largest producer of rice and hybrid rice as well as the largest consumer of rice, one might expect different results. To receive a better understanding of the dynamics oft he results, a more detailed look is worthwile. An impact scenario solely China is run by additionally simulating an adoption of hybrid rice only by China. The analysis of the impact on production, consumption, and on the retail price follows.

Figure 18. Production percent change of LGP rice, China.

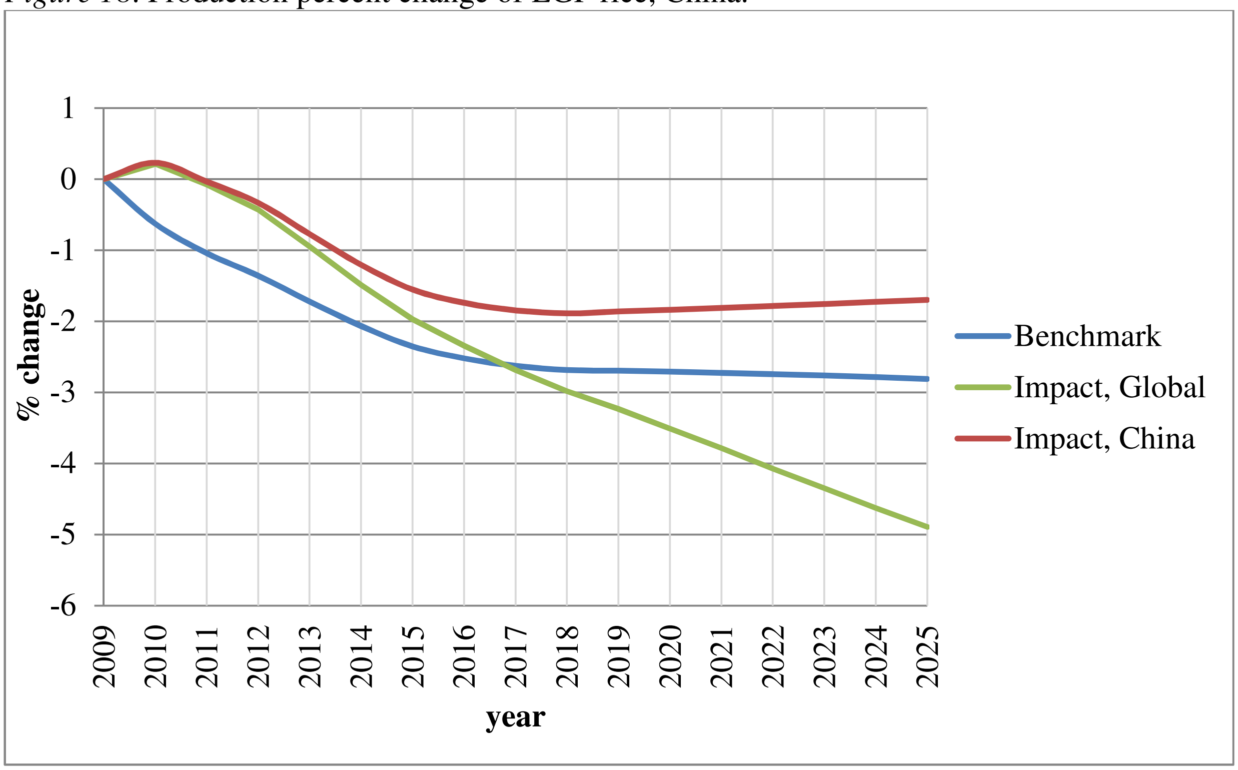
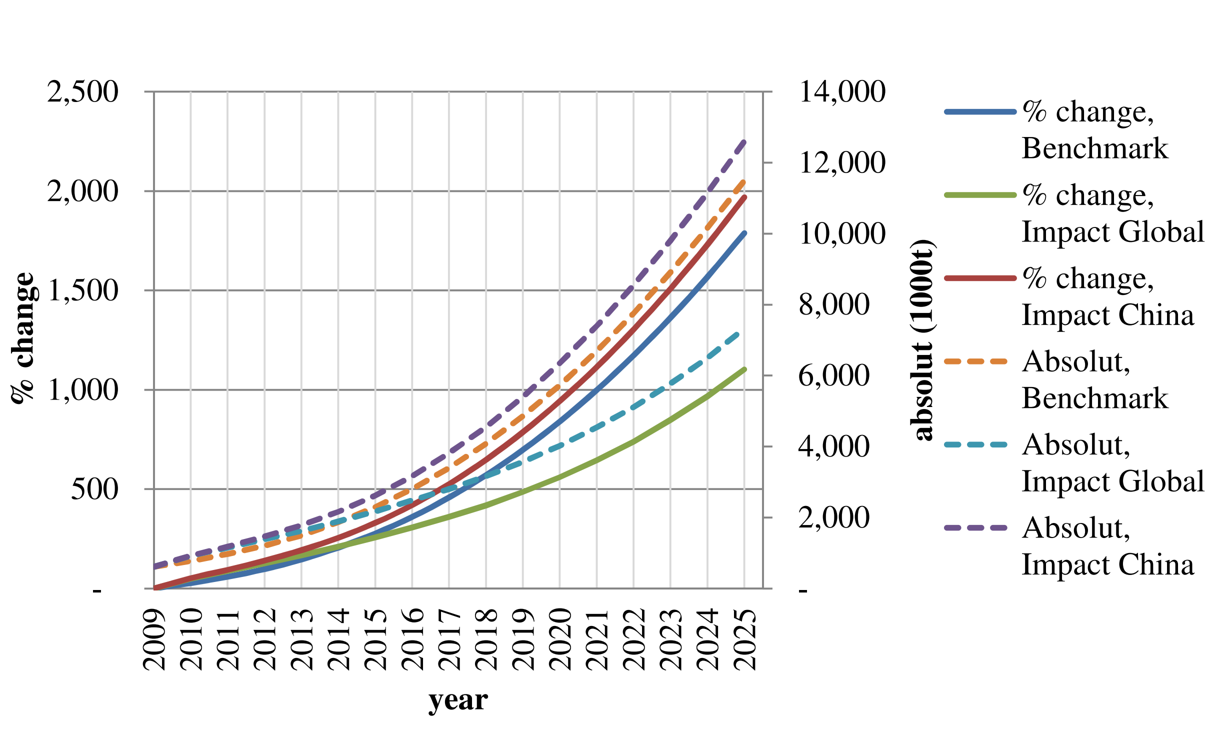


Figure 18 shows that in any scenario China's production will decrease up to 2025. There are different dynamics in the marginal decrease over time, but in 2025 it can clearly be seen that the production decrease is highest if global hybrid rice diffusion occurs, and lowest if

only China is further adopting hybrid rice varieties. This indicates a growing comparative advantage of LGP rice production for China in the China impact scenario, but a diminishing comparative production advantage in case of global diffusion. *Figure 18* restates secondly a decreasing need for rice in China; this is due to decreasing demand of rice in China as the demand elasticity with respect to income is -0.16 (see *Table 24*). Although the analysis of other projected variables in the RICEFLOW model is not the primary target of this study, an indication for the comparative prodution advantage can be given by projected changes in trade as *Figure 19* shows.

Figure 19. Changes in exports of LGW rice for China under different scenarios.



Data based on USDA PS&D

Under the global impact scenario total exports of LGW increase from 2009 levels by 1103% for 2025, in the impact scenario for China total exports increase by 1968% for 2025, and in the benchmark scenario total exports increase by 1788% for 2025. The percentage increases are quite high, though the 2009 baseline export volume of LGW rice for China was only 609,000 t, meaning the importance of China in global trade is not that significant (compare *Table* 3). Though, it also means that China is predicted to export almost 12.6 mmt by 2025, which is twice as much as the largest rice trading nations – India, Thailand, and Vietnam – export today. Taking the results for exports of those countries into consideration, China would become in any scenario one of the largest LGW rice exporter by 2025.

Additionally, the values in *Figure 19* show in comparison to each other the highest increase of exports if only China further adopts hybrid rice and the lowest increase if all seven hybrid rice producing countries further adopt hybrid rice; this indicates an increase in comparative advantages for the production for China. Moreover, China remains a net exporter of rice in any scenario.

China's rice production consist to roughly 87 percent of LGP rice and to roughly 13 percent of MGP rice, production of FGP rice is negligible. Therefore, to complete the picture of the production side, also a look on MGP rice production is necessary. The following figure shows the production changes for MGP rice in China.

Figure 20. Production percent change of MGP rice, China.

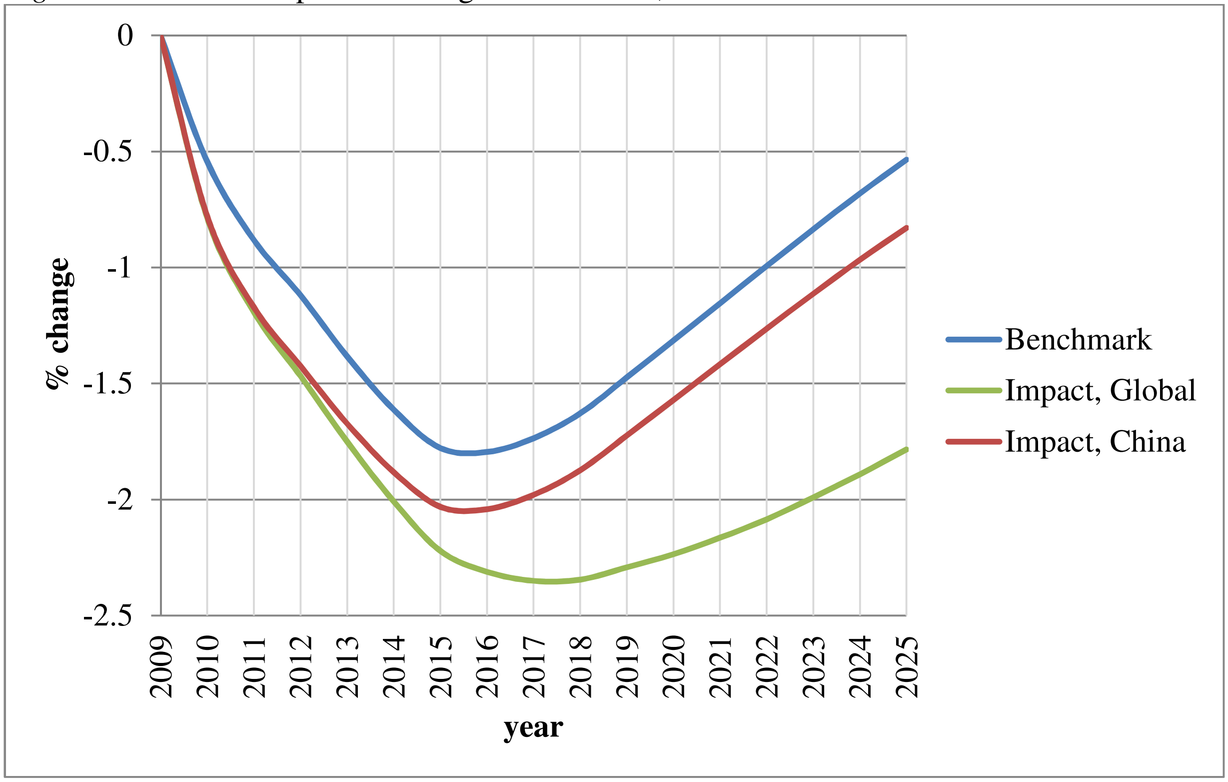


Figure 20 shows the production percent change of MGP rice in China under three different scenarios. For all three scenarios it can be seen that there is a decrease of MGP rice production in the beginning and a relative increase of MGP rice production later on. In comparison to LGP rice production it can be seen secondly that the changes are not as drastic; this is due to the fact that there is no direct effect of hybrid rice adoption on MGP rice. However, the shift from a decreasing to an increasing marginal production change occurs at the same time as the production change of LGP rice begins to stabilize (compare *Figure 18*). Therefore, starting in 2016 total rice production begins to increase again in China.

Figure 21. Consumption percent change of LGW rice, China.

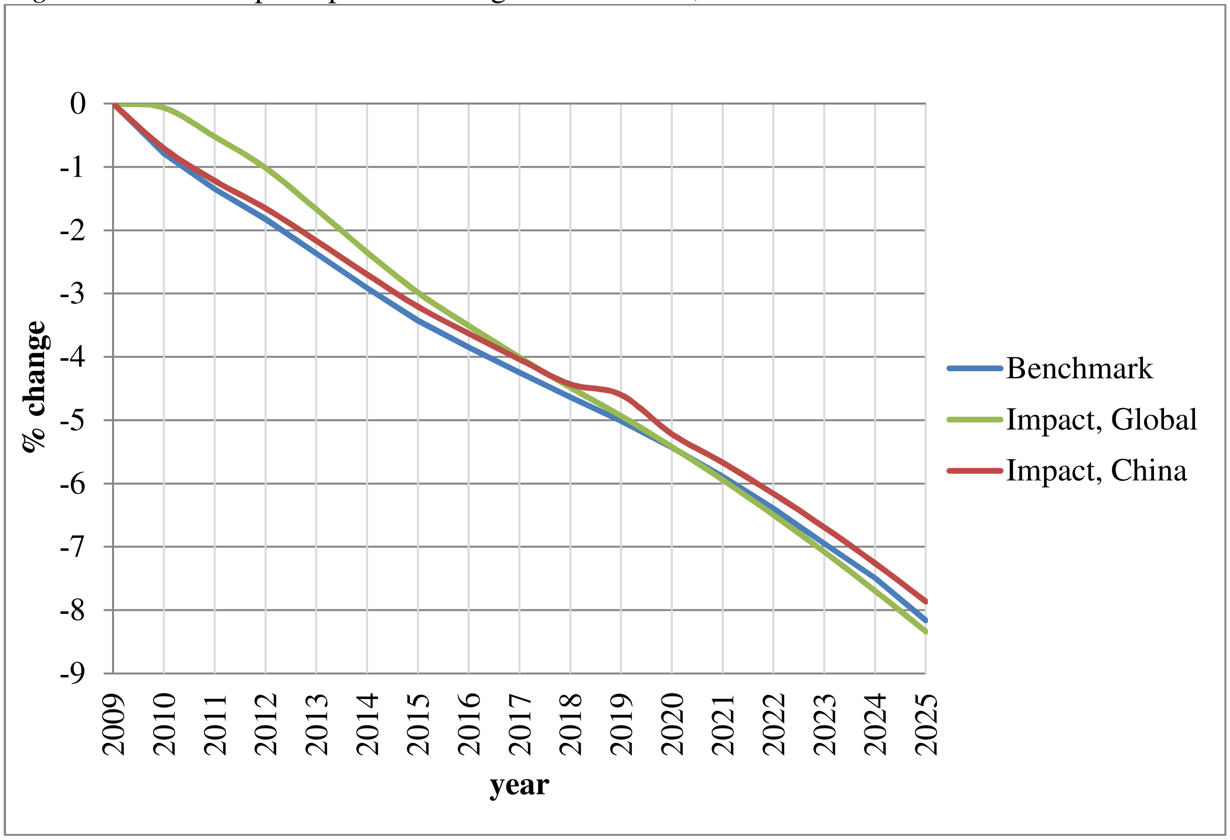
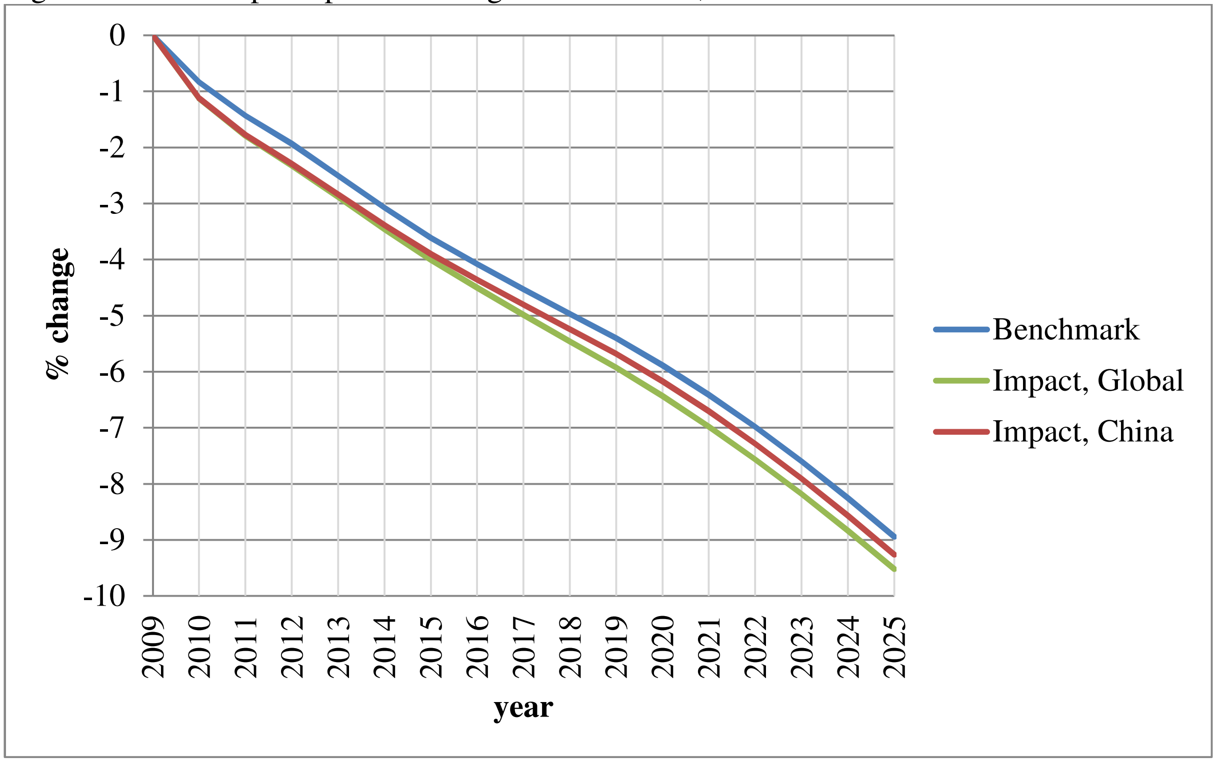


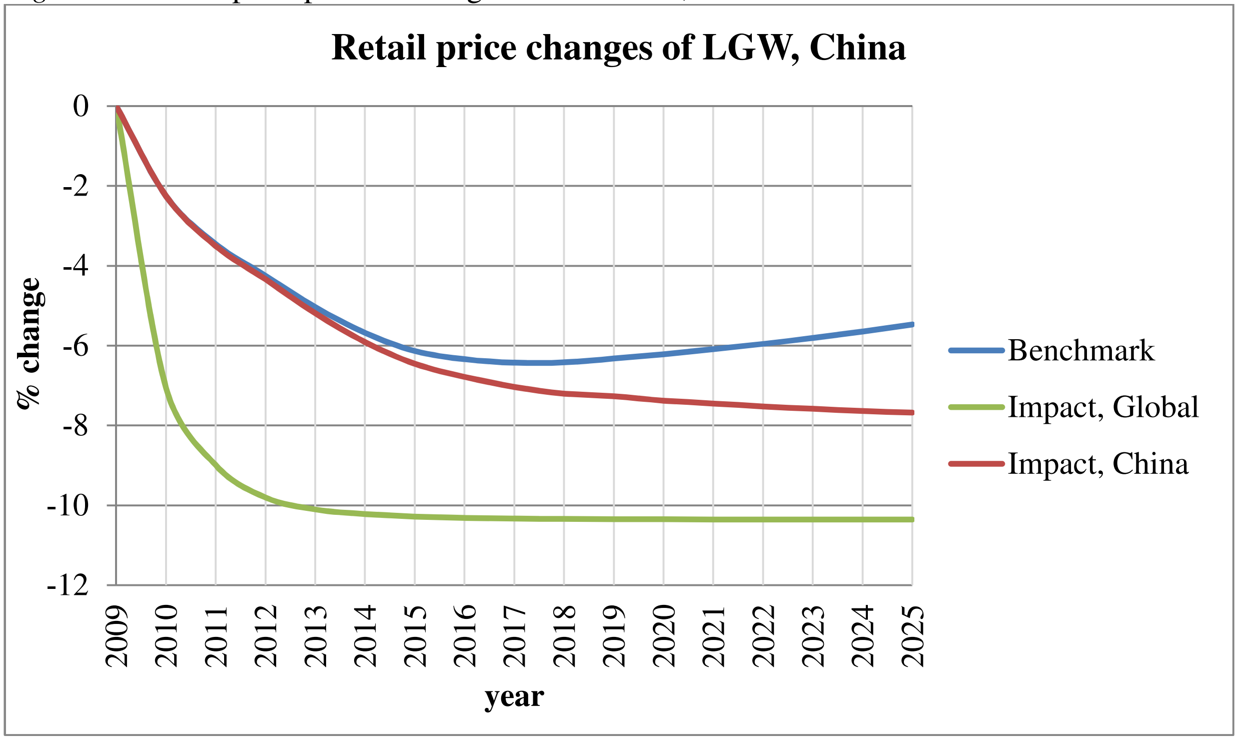
Figure 20 confirms the earlier assumption of a decreasing demand for LGW rice in China. In every scenario the consumption of rice decreases. Moreover, it decreases almost at the same rates. This is a clear indication of a changing diet and a substitution of rice as staple crop. This is also the reason why domestic production of LGP rice in China decreases over time. Moreover, the following figure shows a similar pattern of consumption change of MGW rice over time in China.

Figure 22. Consumption percent change of MGW rice, China.



A look at the retail prices (see *Figure 23*) should show an accumulation of all the findings above of the equally decreasing consumption patterns in combination with the result from above that total rice production decreases first and then starts to increase again, and in combination with an equally increasing export change.

Figure 23. Retail price percent changes of LGW rice, China.

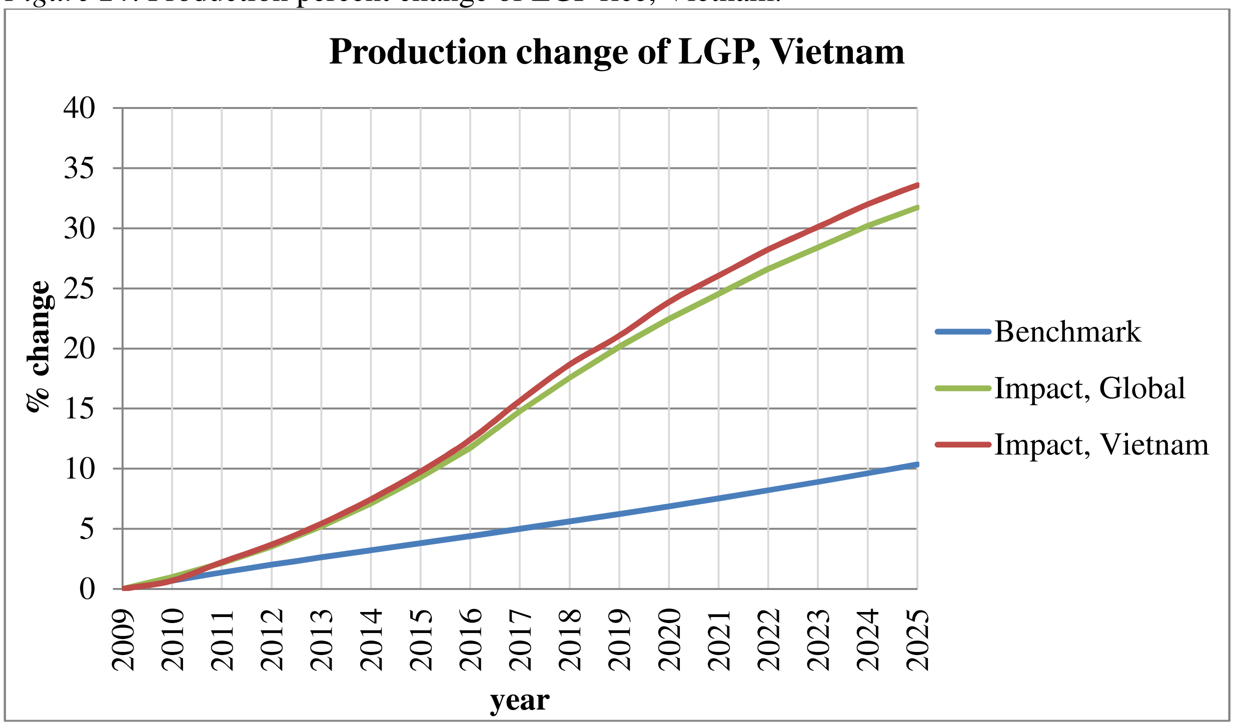


The rapid decline of rice price in the first five years for any scenario seems to follow the decreasing consumption. Recalling an increasing global demand for rice, both impact scenarios indicate stable supply/demand equilibriums in China including possible trade changes, whereas the benchmark scenario shows the limitation of rice supply globally without agricultural innovations, which induces slightly increasing prices again in China domestically. To conclude, if solely China would further adopt hybrid rice, the production would not decrease as sharply, retail prices would decrease further than under no adoption but not as much as under global adoption, but the overall difference between consumption patterns would be negligible. In any case, the average diet in China is predicted not to be as much reliant on rice anymore as today with the consequences of decreasing domestic consumption and a massive increase in exports of LGW rice.

4.4 Impact Scenario for Vietnam

Whereas the impact scenario for China gave more insight on China's special production dynamics, the impact scenario for Vietnam can also give further insight into food security issues as Vietnam produces hybrid rice and is one of the countries that is most dependent on rice as a staple crop.

Figure 24. Production percent change of LGP rice, Vietnam.



First, the production graph in *Figure 24* shows that there is only a slight difference in production between a global diffusion and solely Vietnam diffusion of hybrid rice. This can be explained by the adoption of a more efficient agricultural innovation in Vietnam leading to a comparative production advantage relative to other competitors. In combination with the following consumption graph, the production impact can be well explained.

Figure 25. Consumption percent change of LGW rice, Vietnam.

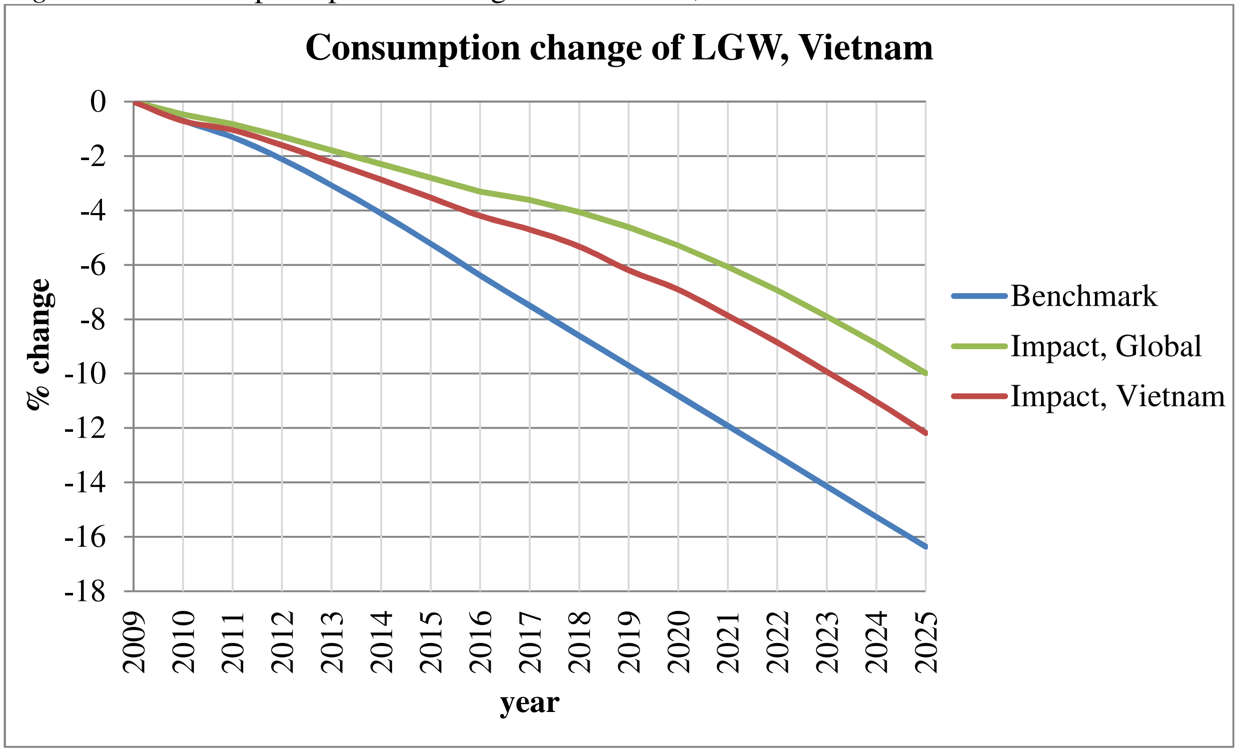


Figure 25 shows that there is a consumption decrease of LGW rice in any scenario, with the steepest decrease under the benchmark scenario and the smallest decrease under the global diffusion scenario. The difference in LGP rice production can explain the differences in consumption. In case of global diffusion, more rice is available at a lower price (see *Figure 24)*, which leads to a relatively higher consumption. But in any scenario it can also be seen that despite a decrease in consumption the production is increasing, which seems to be contradicting if Vietnam is analyzed only domestically. Furthermore, the following graph shows an increase in retail price.

Figure 26. Retail price percent changes of LGW rice, Vietnam.

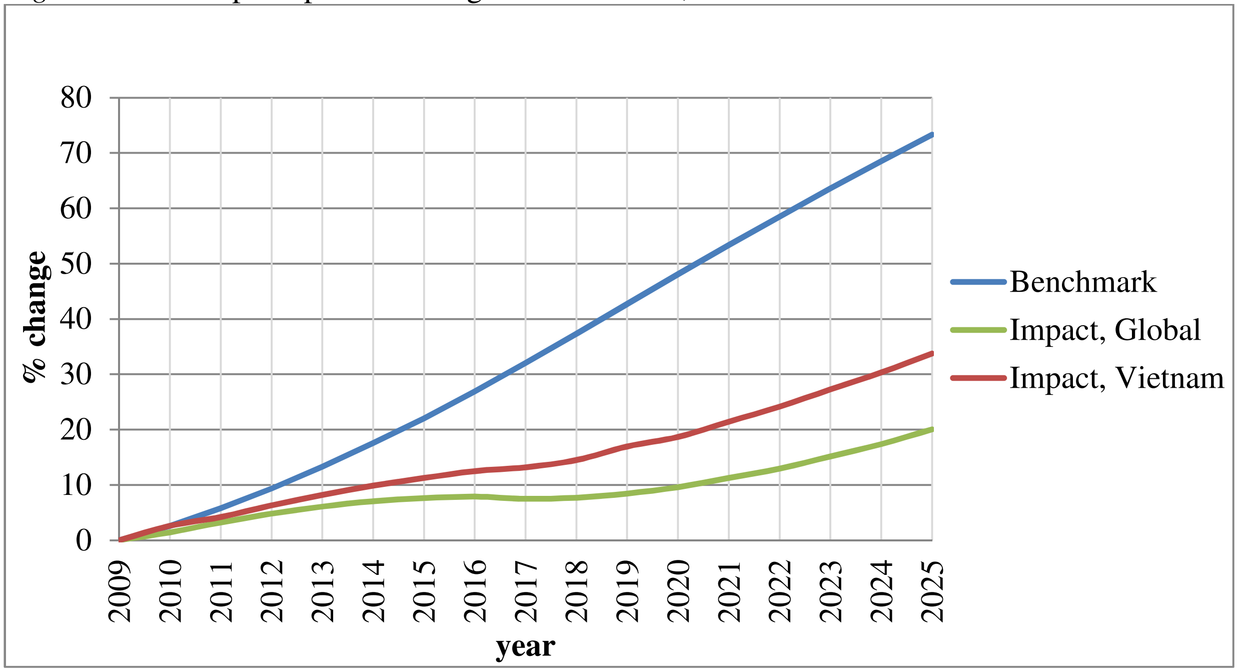
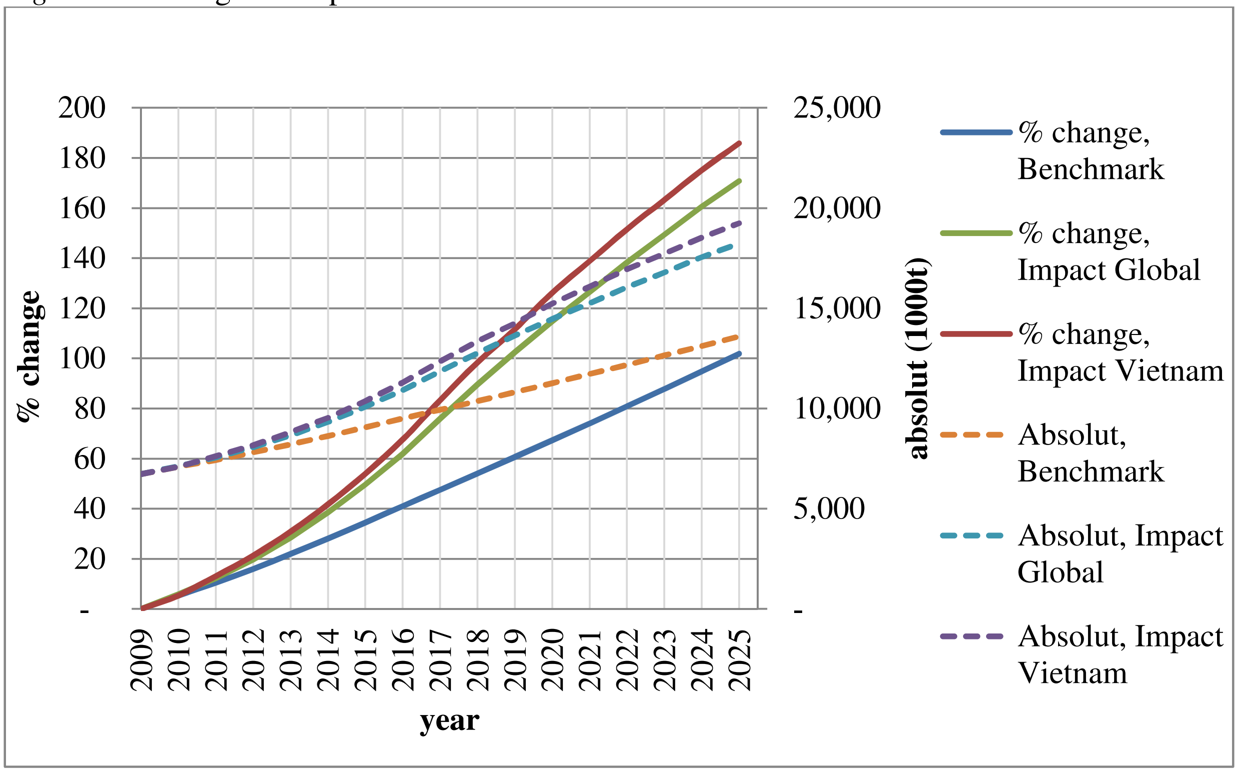


Figure 26 confirms the simple supply-demand relation by showing the expected price effects. The conclusion for food security is that the more rice Vietnam produces, the better the food availability in Vietnam. The scenarios show the according picture, if hybrid rice is not adopted at all in Vietnam, the production of rice will increase only marginally and the retail price will increase sharply. If hybrid rice is adopted globally, production increases much more and the retail price will not increase as sharply. If hybrid rice is only adopted by Vietnam, production increases even more in Vietnam, but the retail price increases more than under global adoption and less than under the benchmark scenario. Therefore regarding the above results for food supply per capita in Vietnam (*Table 10*) and regarding above mentioned possibilities in diet changes for Vietnam, the food availability will be best met in Vietnam under global adoption of hybrid rice.

A closer look on the export dynamics under the simulated scenarios can also solve the seemingly contradicting findings of increasing production, decreasing consumption, but increasing retail prices (*Figure 27*).

Figure 27. Changes in exports of LGW rice for Vietnam under different scenarios.



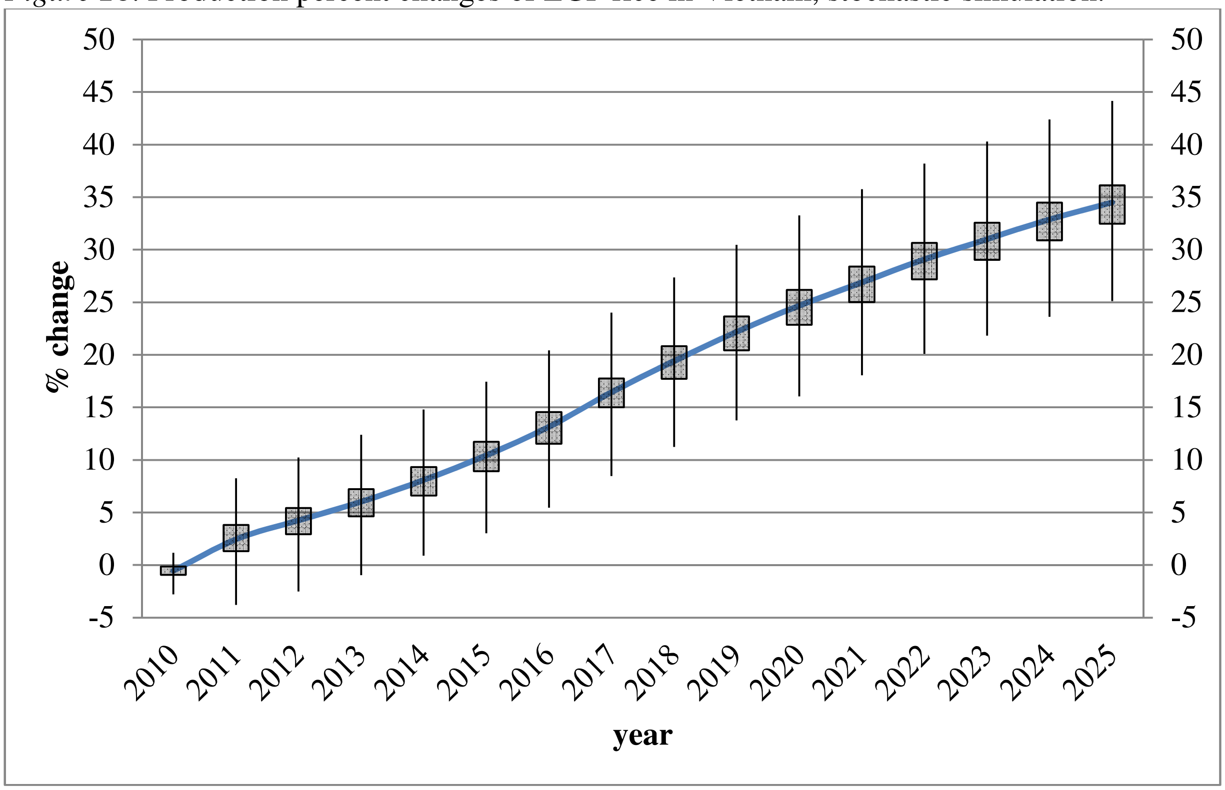
Based on data from USDA PS&D

Vietnam is already in 2009 one of the largest rice exporters with an export volume of LGW rice of 6,734,000 t. All the simulated scenarios predict that the export volume of Vietnam will further increase up to 2025 by 101.89% (13.6 mmt) under the benchmark scenario, by 170.83% (18.2 mmt) under the global impact scenario, and by 185.87% (19.3 mmt) under the Vietnam impact scenario. This makes in any case Vietnam the largest LGW rice exporter by 2025, also larger than China (compare *Figure 19*). Thus, production increases are predicted to be driven by exports respectively by global demand, which can explain domestic retail price increases in Vietnam despite of domestic consumption decreases.

4.5 Stochastic Results for Vietnam

The above deterministic results represent projections according to a certain timepath of conventional and hybrid yields. The stochastic results, on the other hand, include uncertainty projections for the rice production and availability in Vietnam under the assumption that only Vietnam further adopts hybrid rice varieties. The detailed results are listed in the Appendix in *Table 19* for production change, in *Table 20* for retail price changes, and in *Table 21* for the consumption changes.

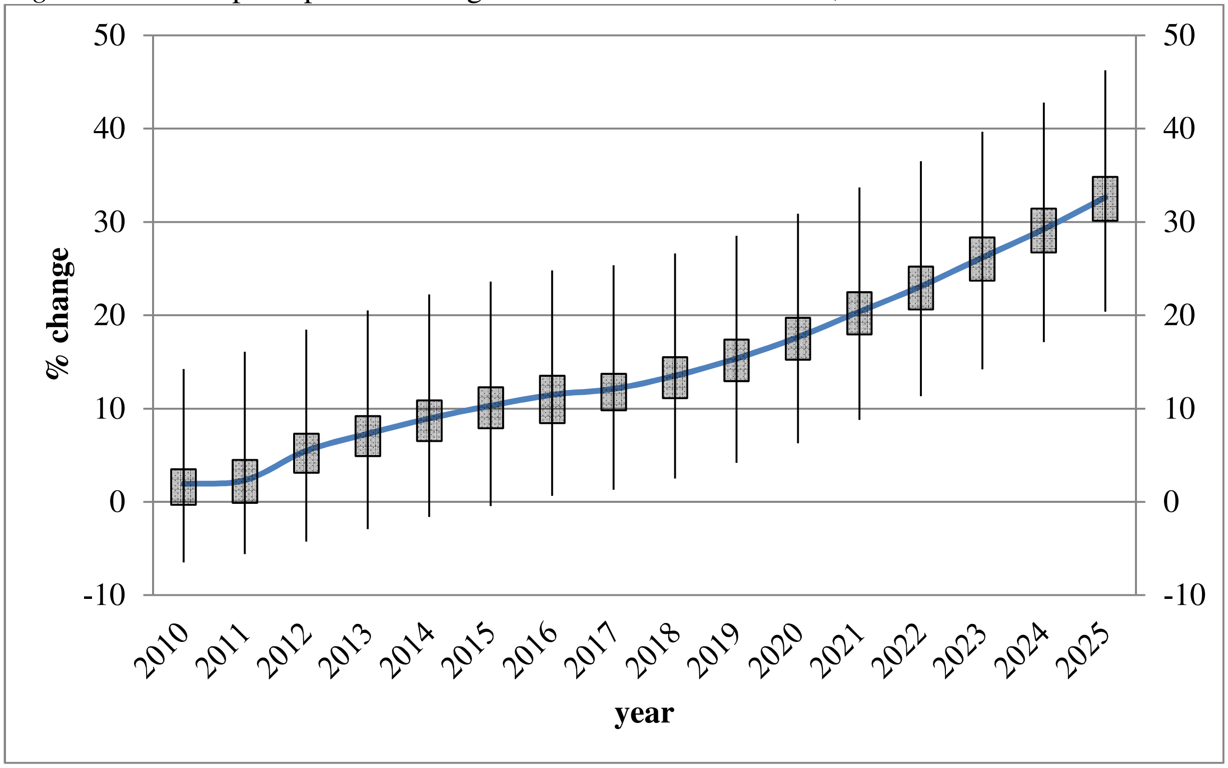
Figure 28. Production percent changes of LGP rice in Vietnam, stochastic simulation.



Notes:
The box represents the range of results between the 25th and 75th percentile, the upper line represents the results above the 75th percentile, the lower line the results below within the 25th percentile, and the blue line follows the mean of the each year’s results.

Looking at the mean production changes up to 2025, a clear upward trend can be recognized as shown in *Figure 28*; Vietnam is projected to produce almost 35% more LGP rice in 2025 than in 2009 if only Vietnam adopts hybrid rice. However, possible variability can also be seen in *Figure 26*. Whereas in 2010 the variability of rice production compared to 2009 is relatively low, ranging from a minimum of -2.8% to a maximum of 1.2% around a mean of -0.5%, however the variability in 2025 increases, from a minimum of 25.1% to a maximum of 44.1% around a mean of 34.5%. The minimum production change reflects negative shocks to rice production such as droughts or devastating monsoons. However, the minimum production change lies below the 5th percentile, representing a probability of less than 5% that such a negative shock occurs as *Table 19* shows. On the other hand, maximum production changes also occur in the stochastic projection. These are based on historical yield uncertainty. Nevertheless, it can be said that Vietnam's mean production of LGP rice will increase more with hybrid rice adoption than without hybrid rice adoption, as it was shown in the benchmark scenario and as already the deterministic scenario for Vietnam predicted. Furthermore, with hybrids a worst scenario with a production increase of 25.1% is expected, whereas under the benchmark the mean increase above 2009 is only around 10% (see *Figure 24*).

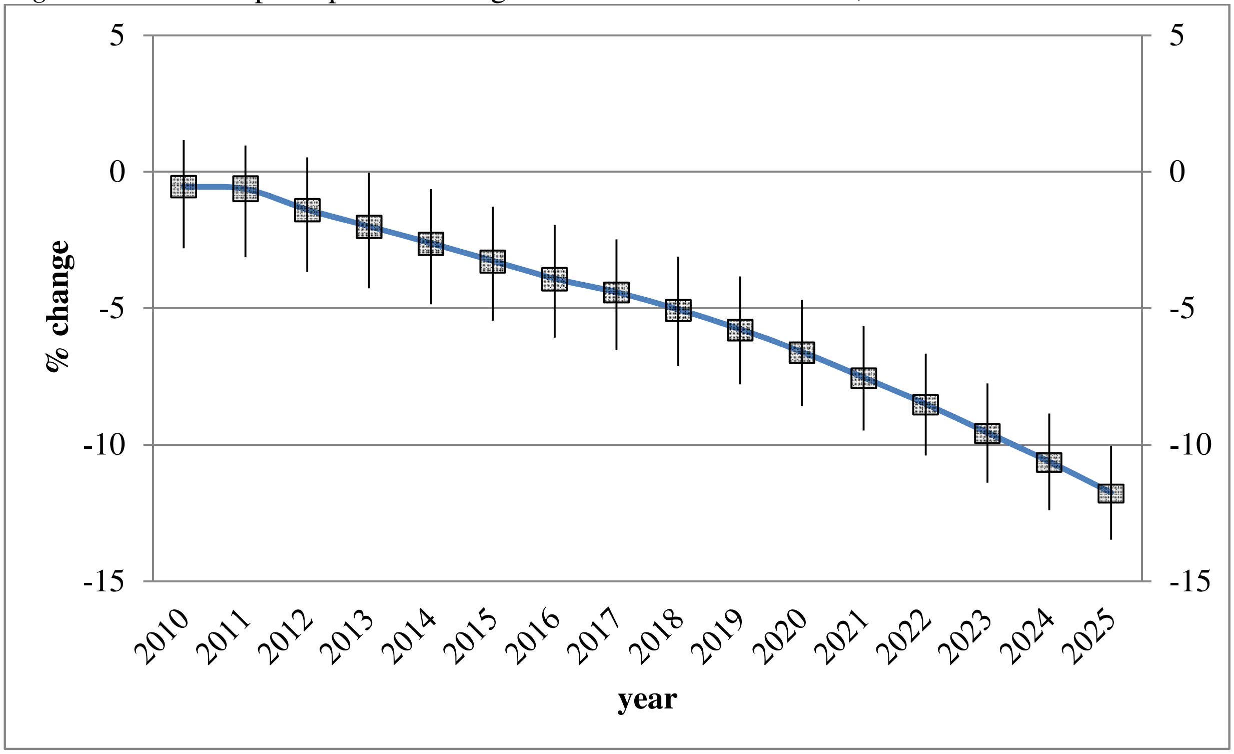
Figure 29. Retail price percent changes of LGW rice in Vietnam, stochastic simulation.



Notes:
The box represents the range of results between the 25th and 75th percentile, the upper line represents the results above the 75th percentile, the lower line the results below within the 25th percentile, and the blue line follows the mean of the each year's results.

The mean in retail price changes has a similar progression as the production change's mean. The retail price is projected to increase most likely by 33.6% in 2025 compared to 2009. The variability increases from a roughly 20% range in 2010 to a roughly 26% range in 2025. A maximum increase in retail price is projected to be 46.2% in 2025. The increase in retail price is an indication of the consumption change relative to production change, as is shown in the following figure.

Figure 30. Consumption percent changes of LGW rice in Vietnam, stochastic simulation.



Notes:
The box represents the range of results between the 25th and 75th percentile, the upper line represents the results above the 75th percentile, the lower line the results below within the 25th percentile, and the blue line follows the mean of the each year's results.

The results for the consumption change show a clear decline until 2025. The variability in the projected years is not very high, ranging between 3% and 4%. This shows the relative dependence of the Vietnamese diet on rice. Even if retail prices are high, consumption does not decrease dramatically because of inelastic demand with respect to price. On the other hand the declining trend in combination with increasing production might also indicate a diet change, becoming less reliant on rice, as the deterministic results already showed. The following table reports on the rice availabiltiy changes.

Table 12. Comparison of rice consumption changes for LGW in Vietnam, based on stochastic simulation.

Year	Scenario	Rice consumption (kg/capita/year)	Difference to baseline	Difference from scenario to benchmark
2009				
	Baseline	220.36	-	-
2015				
	Benchmark	195.85	-11.12%	-
	Mean	200.40	-9.06%	**2.32%**
	Worst case	196.35	-10.90%	**0.25%**
2020				
	Benchmark	181.68	-17.55%	-
	Mean	185.63	-15.76%	**2.17%**
	Worst case	177.26	-19.56%	**-**2.43%
2025				
	Benchmark	166.81	-24.30%	-
	Mean	170.12	-22.80%	**1.98%**
	Worst case	161.23	-26.83%	-3.35%

Table 12 compares the rice availabity in Vietnam between the baseline in 2009, the deterministic benchmark scenario, and the stochastic results. It can be seen that despite hybrid rice adoption the rice availability decreases on average up to 22.80% in 2025, but is 1.98% higher than in the benchmark scenario without hybrid rice adoption. The worst case scenario of the stochastic simulation, which is the lowest availability of rice due to negative shocks, has a lower rice consumption than the benchmark scenario (despite projections for 2015). The results above state also that rice affordability tends to be better with hybrid rice adoption than without. Therefore it can be stated that hybrid rice adoption can improve the food security situation in Vietnam and can alleviate negative shocks partially.

V. CONCLUSION

5.1 Summary

The objective of this study was to measure the impact of hybrid rice on food security aspects. A positive effect of diffusion of hybrid rice was expected, due to the advantages associated with hybrid rice. This so-called hybrid heterosis can be summarized as higher yield, different input efficiencies, and greater shock resistances than with conventional rice varieties. As Hayami and Ruttan imply (1985), environmental conditions are the inducing factors why hybrid varieties are developed. Regarding the global rice situation, growing demand, deteriorating agricultural land quality, and abiotic as well as biotic stresses are the main aspects that are likely inducing research for new hybrid vigor. On the basis of Rogers (2003), the adoption and diffusion process of hybrid rice varieties was illustrated. That created the foundation for the assumed diffusion rates of hybrid rice until 2030, which could eventually trace the impact of hybrid rice on food security up to 2025.

The spatial equilibrium model RICEFLOW was used for the quantification of the impact (Durand-Morat & Wailes, 2010). RICEFLOW includes 60 regions and simulates production processes, bilateral trade flows, and consumption patterns of different rice commodities. A benchmark scenario that included population and expenditure growth first projected the demand of rice and the according production and price changes. The impact scenario incorporated production and output characteristics of the assumed hybrid rice adoption in the seven major hybrid rice producing countries. In comparison to the benchmark scenario it could be shown that hybrid rice induces a 10.8% higher production of rice globally, and even a 12.08% higher production in the major hybrid rice producing countries. The availability of rice is improved and this enhances rice consumption per capita between 0.17% and 7.62% in the countries that are most dependent on rice as a staple crop. It can be assumed that similar positive effects are also perceptible in other countries, which depend on rice. Finally, impacts on retail prices of LGW rice are important. However, due to imprecisions that are inherent to the model, the projection results cannot be taken literally, but as merely indicating trends. The stochastic results took partially into account by introducing yield variability due to uncertainties such as climatic shocks. The stochastic results for Vietnam showed that hybrid rice adoption can improve the food security, and that even in the worst case scenario the rice availability is better with hybrid rice adoption than for the average deterministic scenario without hybrid rice adoption. In conclusion, this study quantified the impact that hybrid rice can have on food security and showed that hybrid rice adoption leads to better food availability and affordability.

This study can contribute to existing research in different ways. Regarding rice production in general, the estimation that global rice production will increase 5.6% by 2025 in the benchmark scenario is in line with other predictions on how much rice production will change under current level of agricultural technology (Mohanty et al., 2010; Timmer et al., 2010). The result, that further hybrid rice adoption will lead to an even higher production level in 2025 thus has positive effects on rice consumption and affordability, also confirms findings of different studies about the impact of hybrid rice on food security (Durand-Morat et al., 2011; Li et al., 2009). This study's results differ, however, from findings that projected that hybrid rice adoption needs to increase up to 90% by 2020 in order to keep 2008 levels of rice availability per capita (Durand-Morat et al., 2011, p. 15). Neither at this level of hybrid rice adoption rice consumption per capita can be sustained, at least in the countries that are most dependent on rice as a staple crop; projections for other countries were not specifically made in this study, however, the results indicate that this finding holds true also for other rice consuming countries. Nevertheless, increased hybrid rice adoption can definitely contribute to keep rice affordable.

This study made use of the stochastic simulation only partially for one impact scenario. Most other studies used thus far deterministic projections or projected on the basis of regressions (Mohanty et al., 2010; Timmer et al., 2010), although stochastic results can give valuable insights in the variability of the rice market. Regarding rice markets and influencing factors, stochastic simulations are already applied using different frameworks (Durand-Morat & Wailes, 2011; Wailes & Chavez, 2012), though impacts on consumption have not been fully analysed yet.The explorative approach of this thesis can therefore be a starting point to more sophisticated analysis of empirical distributions and the probability within rice markets and their effects on food security.

5.3 Limitation of Study

The limitations of this quantitative study are given foremost by the specifications of the RICEFLOW model. The model balances the global rice economy as realistically as possible and making the application of it manageable. This trade-off alone creates results, which do not necessarily replicate the global rice economy exactly. Regarding rice production in particular, one can imagine that farmers are likely to grow more than one crop and that farmers can switch between rice and other crop production somewhat easily with according effects on the farmer's income, total rice production, food security and so on. Similarly, food security is not solely determined by rice availability but also by other crops. The way the model is set up, however, it does not allow for a detailed analysis of other crops. For reasons of simplification, other crops are merged to one "other" variable.

Furthermore, the assumptions made within the specifications of the model cannot be held accountable for each possible case in rice production or rice trade. For example, the model specifies in a production function a price and a quantity variable. In order to solve this equation, one variable needs to be given, whereas the other variable can be computed. Both variables cannot be computed at the same time, making an assumption necessary about which variable's value stays the same. When talking about projections over many years, either a fixed price or a fixed quantity will not be realistic but it is necessary to solve the model.

Another limitation of this study can result through determining the elasticities that are the core of the behavioral equations of the model. There are ten elasticities for specific variables included, of which some variables contain up to nine dimensions. Some elasticities rely on assumptions, such as the factor supply and substitutability. Other elasticities are provided by FAPRI via AGRM. It is very likely to value some elasticities inappropriately, simply because knowledge about behavior of consumers and production processes cannot be complete for each region in the world, and because model specifications at FAPRI might also be deficient. Moreover, elasticities are likely to change over time when consumers develop different attitudes, different behavior due to lifestyle changes and so on. These likely changes are not addressed in the projections. Since the explanatory power of the model relies heavily on the elasticities, this limitation cannot be stressed enough.

Even if the model is specified perfectly and the behavior is reflected accurately, the results of the calculations can still differ from real world observations. This is due to the immense data requirement. Whereas macroeconomic data of production and trade can be obtained in presumably good quality from USDA and FAO, it is more difficult to collect the microeconomic data for rice production. Often data was acquired only in aggregated form, meaning it had to be disaggregated for FGP, MGP, and LGP manually, which was again based on assumptions, and those assumptions themselves were drawn from secondary sources. Moreover, hybrid rice production data was very difficult to gather. This data solely came from secondary sources that mostly created the data through experiments in controlled settings. It is likely that experimental data differs from actual field data. Sometimes, as for China, accurate data could not be found at all, so assumptions had again to be made.

A combined limitation for the model and the data sources is that the modeling is based on a yearly average. However, there are up to three rice harvesting seasons in some countries with the time of the harvesting season differing between countries. Each season tends to produce a different amount of yield, and rice production input costs differ in each season. In this regard it would be more appropriate to reflect monthly changes with the RICEFLOW model. To stretch it even further, commodity prices change daily; in this regard, a yearly projection can only give average estimates and cannot reflect dynamics in the rice market in detail.

Finally, it needs to be restated that the underlying assumption of the model projections is that only a few variables will change in the future, that is population growth, expenditure growth, and pattern of hybrid rice adoption. The assumed specific S-curve for hybrid rice adoption is clearly critical for the results. All other variables are held constant. Keeping in mind that the model also incorporates trade policies, stocks, exchange rates and other factors that are not changed, the projections will only give inexact values for the purpose of this study.

5.4 Future Research

In general, the use of the RICEFLOW model is worthwhile also for future research about the impact of agricultural innovations – such as hybrid rice – on food security. Accordingly, there are extensions and alterations that can increase the informational value of RICEFLOW, and that can eventually reverse some limitations to this study.

The incorporation of the rice harvesting seasons can give valuable insight to the dynamics of the rice market. There are differences of production quantity, hence, differences in supply, which certainly is reflected in retail prices. This analysis could give forecasts for food security concerns. Moreover, there are production advantages of hybrid rice that can have higher impacts in certain seasons, e.g. reduced water input use. A more detailed analysis might give various insights, such as when the use of hybrid rice is more beneficial. Furthermore, a sensitivity analysis of adoption and diffusion rates would be most valuable.

Regarding food security issues not only from the consumption side but also from the production side, the impact of hybrid rice adoption on different income level groups can make policy recommendations more exact. In this study it was assumed that the population of one region acts unitarily. However, usually the income elasticities and price elasticities vary between income groups. Furthermore, rice farms differ in scale and income, making adoption and impacts of hybrid rice not equal among farms. Future research could disaggregate the unitary specification and provide a more detailed insight in adoption behavior and food security impacts regarding different income levels.

The production side can further be analyzed. There are production cost efficiencies associated with hybrid rice varieties that could be implemented in the RICEFLOW model such that possible saved input factors were used for additional rice production. No analyses of impacts or inputs were developed for this study. However, it is likely that production factors released by hybrid technology are also used for the production of other commodities. The indicated changes in diets, which is the substitution of rice with other agricultural products, requires more intensive production of the newly demanded agricultural products. To analyze the spill-over effects of available production factors can be helpful for a more comprehensive look on the commodity markets, i.e. on more extensive equilibrium analyses.

A more methodological improvement of this study is a more advanced use of the stochastic simulation. As mentioned in section 3.2, stochastic solutions do not only add probabilities to the calculated outcomes of the model, but they can also incorporate risk consideration of farmers on individual decision levels. Risk in regard to input factors or adverse events can be used in simulations that predict temporary food insecure situations. In contrast, this study used the stochastic approach quite marginally by running merely 50 iterations per projection year for only one country and using time series data for variability. The underlying assumption that variability of conventional varieties is the same for hybrid rice varities does not necessarily hold true, creating the need for a different approach than to use historical variability.

Finally, this study mentioned in the literature review section the impact of intellectual property rights on the development of agricultural innovations. The distribution of the majority of patents between private actors hints to an oligopolistic market. Further investigation about the implications for future deployment and pricing of innovations in plant technology can be fruitful. Additionally, business models associated with the commercialization of crop innovations are certainly impacting diffusion rates. What the effects are on efforts to increase food security is therefore another intriguing topic for further research.

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APPENDIX

Table 13. Results, percentage change in production quantity for benchmark scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	4.36	9.97	16.41	23.85	32.51	42.41	53.93	67.11
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	1.04	2.04	3.08	4.15	5.22	6.25	7.25	8.23
Belize	1.31	2.32	3.09	3.71	4.23	4.69	5.09	5.45
Brazil	1.66	3.77	6.10	8.63	11.42	14.41	17.65	21.08
Brunei Darussalam	0.54	1.08	1.58	2.03	2.44	2.82	3.17	3.49
Cambodia	0.02	0.08	0.10	0.16	0.22	0.29	0.36	0.43
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	0.17	0.35	0.51	0.67	0.83	0.98	1.14	1.29
China	-0.63	-1.04	-1.36	-1.72	-2.07	-2.35	-2.52	-2.63
Colombia	0.59	1.14	1.70	2.25	2.78	3.28	3.73	4.14
Costa Rica	2.20	4.46	6.79	9.24	11.62	14.00	16.36	18.72
Côte d'Ivoire	0.56	1.06	1.59	2.06	2.49	2.87	3.22	3.54
Cuba	0.99	1.79	2.54	3.25	3.85	4.36	4.82	5.24
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
El Salvador	1.05	2.70	4.60	6.53	8.23	9.83	11.33	12.69
Ghana	0.56	1.19	1.72	2.19	2.62	3.01	3.38	3.72
Guatemala	2.16	4.64	7.31	9.81	12.28	14.77	17.31	19.97
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	0.32	1.11	1.75	2.29	2.74	3.13	3.49	3.82
Honduras	1.45	3.22	5.30	7.22	9.01	10.77	12.32	13.82
Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	0.94	1.84	2.61	3.27	3.86	4.39	4.89	5.34
Indonesia	0.26	0.51	0.73	0.92	1.14	1.34	1.53	1.72
Iran	0.74	1.41	2.00	2.51	2.96	3.35	3.71	4.04
Iraq	0.42	0.87	1.25	1.59	1.91	2.19	2.45	2.70
Japan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laos	0.10	0.19	0.37	0.58	0.74	0.73	0.93	1.14
Malaysia	0.63	1.22	1.76	2.24	2.68	3.08	3.44	3.79
Mexico	2.94	5.25	7.53	9.77	11.97	14.14	16.33	18.54
Myanmar	0.97	1.85	2.65	3.34	3.95	4.51	5.01	5.46
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	2.58	4.94	7.03	9.09	11.06	13.00	14.92	16.83
Nigeria	0.74	1.39	1.94	2.40	2.82	3.18	3.52	3.82
Pakistan	1.24	2.32	3.36	4.42	5.54	6.75	8.10	9.61
Panama	4.07	8.40	12.69	16.95	20.95	24.44	27.89	31.41
Peru	0.56	1.13	1.70	2.25	2.75	3.22	3.65	4.04
Philippines	0.73	1.34	1.92	2.45	2.97	3.47	3.97	4.48
Republic of Korea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	-0.33	-1.67	-3.36	-4.94	-6.55	-8.12	-9.48	-10.59
Senegal	0.61	1.19	1.71	2.18	2.59	2.97	3.31	3.63
Sierra Leone	1.47	2.66	3.65	4.52	5.27	5.94	6.55	7.11
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	-2.40	-5.60	-9.25	-13.18	-17.45	-21.77	-26.13	-30.47
Thailand	0.66	1.33	1.94	2.46	2.93	3.36	3.75	4.10
United Arab Emirates	1.72	0.13	-4.64	-11.33	-18.79	-26.46	-33.88	-40.85
United States of America	2.52	5.44	8.40	11.32	14.18	16.93	19.60	22.13
Uruguay	2.05	4.47	6.89	9.29	11.63	13.82	15.92	17.89
Viet Nam	0.70	1.37	2.02	2.63	3.23	3.81	4.39	5.00
EU27	0.35	0.74	1.13	1.45	1.68	1.84	1.93	1.97
OCARI	0.37	-0.62	-2.05	-3.48	-5.06	-6.67	-8.12	-9.38
OME	0.61	1.15	1.59	1.97	2.28	2.53	2.73	2.88
OAFR	0.86	1.52	2.09	2.60	3.05	3.44	3.80	4.14
OEUR	0.79	1.59	2.33	3.01	3.65	4.24	4.81	5.35
ONAFR	0.61	1.00	1.59	2.09	2.54	2.95	3.33	3.67
ONASIA	0.84	1.58	2.20	2.72	3.18	3.58	3.94	4.26
OOCEA	0.58	1.14	1.66	2.13	2.56	2.95	3.32	3.67
OSAM	0.77	1.52	2.26	2.97	3.68	4.36	5.03	5.68
OSEASIA	0.93	1.76	2.51	3.15	3.72	4.23	4.68	5.09
OWAFR	0.68	1.31	1.87	2.35	2.78	3.17	3.52	3.84

Table 13. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	81.88	98.30	116.24	135.67	156.54	178.78	202.30	227.00
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	9.19	10.13	11.06	11.98	12.87	13.73	14.56	15.37
Belize	5.77	6.05	6.31	6.55	6.76	6.96	7.14	7.31
Brazil	24.61	28.19	31.75	35.26	38.67	41.98	45.16	48.21
Brunei Darussalam	3.79	4.06	4.31	4.54	4.74	4.93	5.11	5.27
Cambodia	0.50	0.56	0.62	0.67	0.70	0.73	0.75	0.76
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	1.43	1.57	1.70	1.83	1.96	2.07	2.19	2.29
China	-2.69	-2.70	-2.71	-2.73	-2.74	-2.76	-2.79	-2.81
Colombia	4.53	4.89	5.23	5.57	5.89	6.19	6.49	6.76
Costa Rica	21.09	23.47	25.86	28.26	30.67	33.09	35.53	37.97
Côte d'Ivoire	3.83	4.10	4.33	4.55	4.74	4.92	5.08	5.23
Cuba	5.61	5.95	6.25	6.52	6.77	6.99	7.20	7.39
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
El Salvador	13.87	14.96	15.94	16.76	17.47	18.06	18.52	18.89
Ghana	4.03	4.32	4.58	4.82	5.04	5.24	5.43	5.60
Guatemala	22.67	25.40	28.16	30.95	33.77	36.64	39.54	42.48
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	4.12	4.38	4.62	4.84	5.03	5.21	5.37	5.51
Honduras	15.21	16.50	17.72	18.86	19.95	20.99	21.97	22.90
Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	5.76	6.14	6.49	6.82	7.12	7.40	7.66	7.91
Indonesia	1.89	2.06	2.21	2.34	2.46	2.56	2.65	2.73
Iran	4.33	4.59	4.83	5.05	5.26	5.44	5.61	5.77
Iraq	2.92	3.12	3.31	3.49	3.65	3.80	3.93	4.06
Japan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laos	1.35	1.56	1.75	1.93	2.10	2.26	2.40	2.53
Malaysia	4.10	4.39	4.65	4.88	5.10	5.30	5.48	5.65
Mexico	20.76	23.02	25.30	27.61	29.95	32.33	34.74	37.18
Myanmar	5.88	6.27	6.63	6.97	7.29	7.59	7.88	8.15
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	18.74	20.64	22.55	24.42	26.30	28.12	29.95	31.78
Nigeria	4.09	4.34	4.57	4.78	4.96	5.14	5.30	5.45
Pakistan	11.29	13.15	15.22	17.50	20.00	22.71	25.62	28.73
Panama	34.92	38.37	41.78	45.15	48.48	51.77	55.03	58.27
Peru	4.40	4.73	5.03	5.32	5.58	5.82	6.04	6.24
Philippines	5.00	5.54	6.10	6.69	7.31	7.97	8.66	9.40
Republic of Korea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	-11.47	-12.08	-12.43	-12.54	-12.44	-12.14	-11.69	-11.09
Senegal	3.91	4.17	4.40	4.60	4.79	4.96	5.11	5.26
Sierra Leone	7.64	8.13	8.60	9.04	9.46	9.86	10.25	10.63
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	-34.66	-38.65	-42.42	-45.92	-49.18	-52.18	-54.96	-57.52
Thailand	4.42	4.71	4.97	5.21	5.43	5.62	5.80	5.97
United Arab Emirates	-47.34	-53.32	-58.82	-63.80	-68.24	-72.18	-75.64	-78.66
United States of America	24.51	26.74	28.81	30.74	32.53	34.19	35.75	37.19
Uruguay	19.70	21.35	22.83	24.15	25.32	26.35	27.26	28.05
Viet Nam	5.61	6.24	6.88	7.53	8.21	8.91	9.62	10.36
EU27	1.97	1.96	1.93	1.89	1.85	1.81	1.77	1.73
OCARI	-10.45	-11.32	-11.96	-12.40	-12.66	-12.76	-12.73	-12.57
OME	2.99	3.06	3.09	3.10	3.09	3.07	3.03	2.98
OAFR	4.44	4.71	4.95	5.18	5.38	5.57	5.74	5.90
OEUR	5.86	6.35	6.80	7.23	7.64	8.04	8.41	8.77
ONAFR	3.97	4.25	4.50	4.73	4.94	5.12	5.29	5.45
ONASIA	4.54	4.79	5.01	5.19	5.36	5.51	5.64	5.76
OOCEA	3.98	4.27	4.53	4.77	4.99	5.19	5.38	5.55
OSAM	6.33	6.96	7.58	8.20	8.80	9.39	9.97	10.53
OSEASIA	5.46	5.79	6.09	6.35	6.60	6.82	7.02	7.20
OWAFR	4.13	4.40	4.64	4.85	5.05	5.23	5.40	5.55

Table 14. Results, percentage change in production quantity for impact scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	3.59	8.36	13.42	18.84	24.61	29.76	31.88	31.88
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	1.08	2.11	3.22	4.39	5.58	6.73	7.85	7.85
Belize	1.08	2.05	2.78	3.36	3.85	4.17	3.82	3.82
Brazil	1.39	3.24	5.19	7.21	9.31	11.10	11.81	11.81
Brunei Darussalam	0.38	0.82	1.21	1.52	1.80	1.97	1.90	1.90
Cambodia	0.01	0.06	0.07	0.11	0.16	0.20	0.21	0.21
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	0.16	0.32	0.47	0.61	0.75	0.87	0.96	0.96
China	0.22	-0.08	-0.43	-0.95	-1.52	-1.35	-0.35	-0.35
Colombia	0.62	1.19	1.80	2.42	3.04	3.65	4.26	4.26
Costa Rica	2.23	4.53	6.91	9.44	11.91	14.42	16.97	16.97
Côte d'Ivoire	0.42	0.84	1.29	1.68	2.02	2.23	2.23	2.23
Cuba	0.68	1.27	1.79	2.29	2.67	2.88	2.48	2.48
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
El Salvador	1.19	3.00	5.12	7.38	9.54	11.77	14.29	14.29
Ghana	0.41	0.94	1.34	1.67	1.96	2.14	2.13	2.13
Guatemala	2.22	4.77	7.53	10.15	12.78	15.48	18.36	18.36
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	0.11	0.81	1.35	1.79	2.13	2.39	2.53	2.53
Honduras	1.63	3.57	5.92	8.20	10.50	12.94	15.57	15.57
Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	1.07	2.19	3.42	4.58	5.73	7.07	8.63	8.63
Indonesia	0.45	0.93	1.39	1.93	2.49	3.04	3.69	3.69
Iran	0.69	1.34	1.91	2.40	2.82	3.17	3.40	3.40
Iraq	0.34	0.74	1.06	1.35	1.59	1.78	1.85	1.85
Japan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laos	0.08	0.12	0.24	0.38	0.44	0.25	0.21	0.21
Malaysia	0.47	0.93	1.31	1.63	1.89	2.04	1.93	1.93
Mexico	3.02	5.39	7.76	10.12	12.49	14.86	17.33	17.33
Myanmar	0.94	1.80	2.57	3.24	3.84	4.37	4.82	4.82
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	2.61	4.99	7.13	9.25	11.29	13.33	15.40	15.40
Nigeria	0.59	1.20	1.71	2.13	2.51	2.76	2.84	2.84
Pakistan	1.26	2.35	3.34	4.26	5.14	6.49	10.02	10.02
Panama	4.10	8.47	12.81	17.14	21.23	24.85	28.48	28.48
Peru	0.51	1.05	1.57	2.06	2.51	2.89	3.16	3.16
Philippines	1.16	2.23	3.50	4.99	6.72	8.71	11.06	11.06
Republic of Korea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	-0.07	-0.82	-1.21	-1.59	-2.37	-1.87	0.41	0.41
Senegal	0.49	1.00	1.46	1.85	2.20	2.45	2.48	2.48
Sierra Leone	1.47	2.66	3.65	4.52	5.27	5.94	6.55	6.55
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	-3.12	-6.17	-9.19	-12.02	-14.77	-18.94	-26.01	-26.01
Thailand	0.46	1.05	1.57	2.01	2.40	2.65	2.66	2.66
United Arab Emirates	1.96	3.51	6.44	7.43	7.04	8.56	5.06	5.06
United States of America	2.03	4.56	7.02	9.36	11.57	13.36	14.21	14.21
Uruguay	2.12	4.63	7.19	9.86	12.69	14.89	15.77	15.77
Viet Nam	0.99	2.16	3.55	5.19	7.10	9.34	12.47	12.47
EU27	0.35	0.77	1.22	1.65	2.02	2.36	2.72	2.72
OCARI	0.70	0.44	0.64	0.69	0.22	0.90	2.65	2.65
OME	0.49	0.97	1.34	1.66	1.93	2.15	2.31	2.31
OAFR	0.73	1.32	1.82	2.24	2.60	2.84	2.89	2.89
OEUR	0.59	1.27	1.88	2.41	2.89	3.19	2.98	2.98
ONAFR	0.43	0.70	1.17	1.54	1.86	2.05	1.94	1.94
ONASIA	0.66	1.33	1.90	2.39	2.82	3.06	2.98	2.98
OOCEA	0.39	0.82	1.19	1.48	1.73	1.88	1.75	1.75
OSAM	0.78	1.54	2.29	3.02	3.75	4.44	5.12	5.12
OSEASIA	0.86	1.64	2.29	2.85	3.34	3.72	3.94	3.94
OWAFR	0.53	1.10	1.59	2.01	2.38	2.63	2.68	2.68

Table 14. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	31.88	31.88	31.88	31.88	31.88	31.88	150.65	122.30
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	7.85	7.85	7.85	7.85	7.85	7.85	15.77	18.27
Belize	3.82	3.82	3.82	3.82	3.82	3.82	9.23	-10.32
Brazil	11.81	11.81	11.81	11.81	11.81	11.81	53.05	34.69
Brunei Darussalam	1.90	1.90	1.90	1.90	1.90	1.90	5.90	3.94
Cambodia	0.21	0.21	0.21	0.21	0.21	0.21	0.51	0.25
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	0.96	0.96	0.96	0.96	0.96	0.96	2.10	1.92
China	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-5.43	-3.79
Colombia	4.26	4.26	4.26	4.26	4.26	4.26	7.70	8.32
Costa Rica	16.97	16.97	16.97	16.97	16.97	16.97	35.80	39.58
Côte d'Ivoire	2.23	2.23	2.23	2.23	2.23	2.23	6.39	4.87
Cuba	2.48	2.48	2.48	2.48	2.48	2.48	8.26	4.13
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
El Salvador	14.29	14.29	14.29	14.29	14.29	14.29	26.85	31.67
Ghana	2.13	2.13	2.13	2.13	2.13	2.13	6.38	3.93
Guatemala	18.36	18.36	18.36	18.36	18.36	18.36	41.68	45.42
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	2.53	2.53	2.53	2.53	2.53	2.53	10.39	4.63
Honduras	15.57	15.57	15.57	15.57	15.57	15.57	29.58	34.85
Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	8.63	8.63	8.63	8.63	8.63	8.63	27.80	28.31
Indonesia	3.69	3.69	3.69	3.69	3.69	3.69	7.91	8.13
Iran	3.40	3.40	3.40	3.40	3.40	3.40	8.89	6.83
Iraq	1.85	1.85	1.85	1.85	1.85	1.85	3.93	3.42
Japan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laos	0.21	0.21	0.21	0.21	0.21	0.21	0.84	-3.46
Malaysia	1.93	1.93	1.93	1.93	1.93	1.93	6.04	3.70
Mexico	17.33	17.33	17.33	17.33	17.33	17.33	37.42	39.55
Myanmar	4.82	4.82	4.82	4.82	4.82	4.82	7.82	8.09
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	15.40	15.40	15.40	15.40	15.40	15.40	29.93	33.04
Nigeria	2.84	2.84	2.84	2.84	2.84	2.84	6.97	6.45
Pakistan	10.02	10.02	10.02	10.02	10.02	10.02	-47.74	-3.98
Panama	28.48	28.48	28.48	28.48	28.48	28.48	56.00	59.84
Peru	3.16	3.16	3.16	3.16	3.16	3.16	5.64	5.62
Philippines	11.06	11.06	11.06	11.06	11.06	11.06	24.45	26.24
Republic of Korea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	0.41	0.41	0.41	0.41	0.41	0.41	101.74	81.01
Senegal	2.48	2.48	2.48	2.48	2.48	2.48	6.55	4.82
Sierra Leone	6.55	6.55	6.55	6.55	6.55	6.55	10.25	10.63
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	-26.01	-26.01	-26.01	-26.01	-26.01	-26.01	84.56	-36.01
Thailand	2.66	2.66	2.66	2.66	2.66	2.66	5.38	2.06
United Arab Emirates	5.06	5.06	5.06	5.06	5.06	5.06	776.12	630.39
United States of America	14.21	14.21	14.21	14.21	14.21	14.21	43.33	31.30
Uruguay	15.77	15.77	15.77	15.77	15.77	15.77	43.36	32.46
Viet Nam	12.47	12.47	12.47	12.47	12.47	12.47	27.39	34.09
EU27	2.72	2.72	2.72	2.72	2.72	2.72	2.40	3.48
OCARI	2.65	2.65	2.65	2.65	2.65	2.65	146.14	107.44
OME	2.31	2.31	2.31	2.31	2.31	2.31	2.16	2.88
OAFR	2.89	2.89	2.89	2.89	2.89	2.89	6.74	5.04
OEUR	2.98	2.98	2.98	2.98	2.98	2.98	11.62	7.04
ONAFR	1.94	1.94	1.94	1.94	1.94	1.94	6.45	4.55
ONASIA	2.98	2.98	2.98	2.98	2.98	2.98	8.94	3.89
OOCEA	1.75	1.75	1.75	1.75	1.75	1.75	6.21	3.55
OSAM	5.12	5.12	5.12	5.12	5.12	5.12	10.14	10.50
OSEASIA	3.94	3.94	3.94	3.94	3.94	3.94	8.99	5.53
OWAFR	2.68	2.68	2.68	2.68	2.68	2.68	6.88	5.65

Table 15. Results, percentage change in final consumption for benchmark scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	1.74	3.28	4.58	5.87	7.15	8.41	9.66	10.89
Australia	2.51	4.64	6.79	9.81	12.67	15.74	19.00	22.47
Bangladesh	1.04	2.04	3.09	4.17	5.25	6.29	7.31	8.30
Belize	1.84	3.95	6.32	8.58	10.99	13.35	15.74	18.14
Brazil	0.65	1.45	2.23	2.97	3.70	4.42	5.14	5.83
Brunei Darussalam	1.82	3.56	5.24	6.92	8.59	10.28	12.00	13.72
Cambodia	-0.05	-0.06	-0.13	-0.16	-0.18	-0.21	-0.24	-0.28
Canada	2.13	3.87	5.53	7.58	9.64	11.71	13.85	16.07
Chile	1.38	2.87	4.16	5.51	6.85	8.18	9.51	10.83
China	-0.79	-1.35	-1.82	-2.36	-2.91	-3.43	-3.85	-4.25
Colombia	0.63	1.21	1.81	2.43	3.03	3.60	4.13	4.62
Costa Rica	2.22	4.53	6.96	9.55	12.07	14.59	17.10	19.62
Côte d'Ivoire	1.49	1.74	3.65	5.55	7.42	9.32	11.22	13.12
Cuba	2.01	3.47	6.08	10.61	15.29	20.11	25.06	30.15
Egypt	1.83	2.34	2.85	3.41	4.05	4.75	6.45	8.38
El Salvador	1.31	3.37	5.79	8.39	10.88	13.39	15.98	18.58
Ghana	1.33	3.95	5.71	7.45	9.18	10.89	12.65	14.45
Guatemala	2.39	5.14	8.11	10.90	13.69	16.54	19.46	22.54
Guyana	2.54	5.05	7.59	10.16	12.83	15.62	18.44	21.28
Haiti	-2.19	1.28	4.34	7.00	9.01	10.83	12.67	14.54
Honduras	1.81	4.05	6.73	9.38	12.01	14.75	17.42	20.19
Hong Kong	0.72	1.87	3.09	4.28	5.59	6.88	8.17	9.42
India	0.94	1.84	2.61	3.28	3.88	4.42	4.93	5.40
Indonesia	0.24	0.45	0.63	0.78	0.95	1.11	1.27	1.41
Iran	1.03	2.16	3.32	4.45	5.56	6.68	7.82	8.92
Iraq	3.32	7.92	12.29	16.68	21.07	25.54	30.16	34.88
Japan	-1.42	-1.25	-1.74	-2.50	-2.99	-3.49	-3.93	-4.27
Laos	-0.16	-0.39	-0.52	-0.60	-0.78	-1.23	-1.38	-1.55
Malaysia	1.93	3.72	5.55	7.41	9.30	11.20	13.11	15.02
Mexico	3.09	5.55	7.99	10.42	12.82	15.19	17.60	20.03
Myanmar	0.97	1.90	2.74	3.50	4.20	4.86	5.47	6.03
New Zealand	2.09	3.65	5.48	8.12	10.66	13.33	16.04	18.82
Nicaragua	2.68	5.12	7.29	9.41	11.44	13.45	15.43	17.41
Nigeria	3.91	7.93	11.87	15.89	20.03	24.28	28.68	33.21
Pakistan	1.87	3.59	5.41	7.34	9.32	11.35	13.44	15.54
Panama	4.07	8.40	12.69	16.95	20.95	24.44	27.89	31.41
Peru	0.59	1.21	1.87	2.53	3.20	3.84	4.45	5.03
Philippines	2.33	4.36	6.47	8.65	10.89	13.20	15.63	18.13
Republic of Korea	-2.26	-3.90	-5.74	-7.76	-9.67	-11.78	-13.82	-15.82
Saudi Arabia	2.73	5.42	8.07	10.70	13.36	16.10	19.07	22.13
Senegal	3.13	6.29	9.58	13.01	16.57	20.25	24.17	28.23
Sierra Leone	1.47	2.66	3.65	4.52	5.27	5.94	6.55	7.11
Singapore	1.68	3.63	4.90	5.66	6.26	6.95	7.77	8.64
South Africa	0.73	1.47	2.12	2.71	3.28	3.89	4.56	5.27
Thailand	-0.56	-0.59	-0.71	-1.03	-1.29	-1.57	-1.84	-2.12
United Arab Emirates	5.30	10.78	14.19	16.19	17.80	19.79	22.51	25.64
United States of America	4.05	6.75	8.58	10.20	11.74	13.19	14.66	16.13
Uruguay	1.61	2.72	3.94	5.49	7.12	8.70	10.31	11.89
Viet Nam	-0.69	-1.30	-2.11	-3.08	-4.11	-5.22	-6.39	-7.50
EU27	1.26	2.74	4.71	7.02	9.41	11.81	14.23	16.70
OCARI	3.04	6.09	9.09	12.06	15.06	18.18	21.58	25.11
OME	1.23	2.44	3.56	4.93	6.43	8.10	9.90	11.77
OAFR	3.48	6.24	9.04	11.99	14.94	17.94	20.99	24.10
OEUR	0.64	1.47	2.46	3.52	4.69	5.83	7.00	8.17
ONAFR	2.61	0.27	3.77	6.96	10.49	14.10	17.78	21.40
ONASIA	1.46	2.96	4.37	5.77	7.25	8.82	10.47	12.18
OOCEA	1.63	3.38	5.09	6.77	8.49	10.29	12.27	14.31
OSAM	0.96	1.91	2.84	3.76	4.67	5.54	6.40	7.22
OSEASIA	1.13	2.25	3.38	4.49	5.59	6.68	7.74	8.78
OWAFR	2.68	5.36	8.11	10.92	13.81	16.75	19.77	22.85

Table 15. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	12.10	13.29	14.47	15.64	16.80	17.95	19.08	20.22
Australia	25.87	29.31	32.70	36.08	39.54	43.01	46.61	49.68
Bangladesh	9.27	10.22	11.15	12.07	12.96	13.82	14.66	15.52
Belize	20.55	22.98	25.42	27.86	30.31	32.76	35.21	37.83
Brazil	6.49	7.10	7.67	8.20	8.70	9.15	9.58	9.92
Brunei Darussalam	15.43	17.14	18.85	20.57	22.30	24.03	25.78	28.16
Cambodia	-0.33	-0.39	-0.47	-0.56	-0.67	-0.80	-0.95	-1.08
Canada	18.32	20.62	22.96	25.34	27.72	30.14	32.62	34.96
Chile	12.14	13.45	14.74	16.02	17.29	18.54	19.78	20.91
China	-4.63	-5.01	-5.43	-5.89	-6.40	-6.95	-7.49	-7.87
Colombia	5.08	5.52	5.95	6.38	6.80	7.21	7.60	8.09
Costa Rica	22.15	24.70	27.26	29.84	32.43	35.04	37.66	40.41
Côte d'Ivoire	14.97	16.80	18.67	20.59	22.55	24.54	26.58	29.30
Cuba	35.37	40.74	46.27	51.93	57.74	63.58	69.58	75.97
Egypt	10.16	11.97	13.81	15.69	17.61	19.55	21.54	23.62
El Salvador	21.16	23.84	26.56	29.26	32.00	34.77	37.52	40.40
Ghana	16.27	18.11	19.95	21.79	23.63	25.47	27.31	29.42
Guatemala	25.68	28.87	32.11	35.39	38.73	42.13	45.57	49.19
Guyana	24.15	27.04	29.96	32.91	35.88	38.87	41.88	44.90
Haiti	16.43	18.34	20.27	22.24	24.23	26.25	28.29	30.36
Honduras	22.97	25.79	28.65	31.53	34.47	37.43	40.43	43.56
Hong Kong	10.69	12.00	13.33	14.62	15.88	17.10	18.32	19.22
India	5.83	6.22	6.59	6.93	7.24	7.53	7.81	8.08
Indonesia	1.55	1.69	1.81	1.92	2.01	2.09	2.16	2.31
Iran	10.03	11.12	12.22	13.32	14.42	15.53	16.65	18.27
Iraq	39.68	44.61	49.67	54.86	60.18	65.60	71.12	76.56
Japan	-4.57	-4.90	-5.25	-5.62	-6.03	-6.46	-6.91	-7.35
Laos	-1.73	-1.93	-2.15	-2.38	-2.63	-2.89	-3.18	-3.43
Malaysia	16.95	18.88	20.83	22.79	24.77	26.77	28.79	31.61
Mexico	22.49	24.98	27.51	30.07	32.66	35.30	37.97	40.70
Myanmar	6.56	7.07	7.54	7.99	8.41	8.81	9.19	9.62
New Zealand	21.62	24.54	27.43	30.27	33.12	35.98	38.95	41.61
Nicaragua	19.39	21.37	23.37	25.31	27.27	29.17	31.08	33.09
Nigeria	37.86	42.68	47.64	52.74	57.99	63.39	68.98	74.71
Pakistan	17.62	19.73	21.88	24.09	26.34	28.62	30.92	33.93
Panama	34.92	38.37	41.78	45.15	48.48	51.77	55.03	58.38
Peru	5.60	6.14	6.68	7.22	7.74	8.25	8.74	9.33
Philippines	20.70	23.35	26.07	28.86	31.73	34.66	37.69	41.05
Republic of Korea	-17.78	-19.63	-21.41	-23.12	-24.74	-26.29	-27.78	-28.67
Saudi Arabia	25.21	28.31	31.39	34.45	37.51	40.53	43.55	46.48
Senegal	32.39	36.66	41.05	45.54	50.14	54.85	59.69	64.40
Sierra Leone	7.64	8.13	8.60	9.04	9.46	9.86	10.25	10.63
Singapore	9.53	10.42	11.28	12.11	12.95	13.78	14.63	15.32
South Africa	6.01	6.78	7.57	8.40	9.25	10.12	11.00	12.36
Thailand	-2.39	-2.68	-3.00	-3.33	-3.69	-4.07	-4.46	-4.81
United Arab Emirates	29.01	32.42	35.73	38.94	42.16	45.37	48.63	52.13
United States of America	17.62	19.13	20.64	22.16	23.71	25.29	26.89	28.87
Uruguay	13.49	15.10	16.72	18.36	20.01	21.68	23.36	25.04
Viet Nam	-8.61	-9.70	-10.81	-11.92	-13.03	-14.14	-15.27	-15.86
EU27	19.20	21.75	24.32	26.91	29.53	32.15	34.79	37.47
OCARI	28.71	32.36	36.05	39.78	43.56	47.38	51.27	54.91
OME	13.67	15.60	17.58	19.58	21.60	23.64	25.72	27.49
OAFR	27.28	30.51	33.78	37.11	40.49	43.92	47.39	51.03
OEUR	9.36	10.54	11.70	12.87	14.05	15.22	16.41	17.38
ONAFR	25.02	28.68	32.36	36.06	39.79	43.55	47.36	51.34
ONASIA	13.91	15.66	17.40	19.14	20.87	22.59	24.33	26.02
OOCEA	16.40	18.52	20.68	22.86	25.08	27.30	29.64	31.59
OSAM	8.03	8.81	9.57	10.32	11.04	11.73	12.41	13.10
OSEASIA	9.80	10.80	11.78	12.74	13.67	14.59	15.47	16.34
OWAFR	25.99	29.18	32.42	35.70	39.02	42.39	45.81	49.28

Table 16. Results, percentage change in final consumption for impact scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	1.74	3.28	4.59	5.88	7.17	8.45	9.73	11.05
Australia	2.72	5.03	7.44	10.79	14.06	17.72	22.05	26.88
Bangladesh	1.08	2.11	3.21	4.39	5.56	6.72	7.83	9.08
Belize	1.88	4.02	6.42	8.72	11.17	13.63	16.23	19.14
Brazil	0.65	1.45	2.22	2.96	3.70	4.42	5.17	10.35
Brunei Darussalam	2.06	4.02	6.02	8.11	10.29	12.73	15.80	19.23
Cambodia	-0.04	-0.04	-0.10	-0.12	-0.13	-0.13	-0.12	1.27
Canada	2.25	4.10	5.92	8.18	10.50	12.88	15.46	11.82
Chile	1.38	2.87	4.16	5.52	6.86	8.19	9.53	9.78
China	-0.07	-0.52	-1.02	-1.67	-2.37	-2.49	-2.08	-0.38
Colombia	0.66	1.26	1.91	2.58	3.25	3.93	4.62	3.28
Costa Rica	2.26	4.61	7.08	9.74	12.35	14.98	17.67	17.09
Côte d'Ivoire	1.87	2.41	4.72	7.14	9.63	12.60	16.65	21.64
Cuba	2.05	3.56	6.25	10.89	15.71	20.73	26.01	31.59
Egypt	1.93	2.54	3.21	3.95	4.82	5.84	8.08	10.54
El Salvador	1.34	3.44	5.90	8.57	11.14	13.74	16.49	16.39
Ghana	1.43	4.15	6.07	8.01	9.97	12.03	14.37	16.89
Guatemala	2.43	5.22	8.23	11.10	13.98	16.94	20.04	19.81
Guyana	2.54	5.05	7.59	10.16	12.83	15.62	18.44	21.28
Haiti	-2.16	1.33	4.42	7.11	9.17	11.04	12.96	13.44
Honduras	1.85	4.12	6.86	9.57	12.29	15.14	17.99	17.98
Hong Kong	0.76	1.97	3.28	4.59	6.05	7.55	9.21	3.44
India	1.07	2.19	3.41	4.57	5.70	7.04	8.60	8.45
Indonesia	0.41	0.84	1.24	1.71	2.21	2.72	3.34	2.97
Iran	1.11	2.30	3.56	4.81	6.06	7.46	9.26	11.44
Iraq	3.35	7.99	12.41	16.86	21.33	25.91	30.72	42.23
Japan	-1.35	-1.14	-1.57	-2.25	-2.65	-3.03	-3.24	-11.83
Laos	-0.08	-0.28	-0.37	-0.39	-0.50	-0.84	-0.81	-0.85
Malaysia	2.17	4.24	6.48	8.89	11.46	14.29	17.78	21.61
Mexico	3.13	5.62	8.12	10.60	13.08	15.56	18.14	18.09
Myanmar	0.99	1.93	2.80	3.59	4.34	5.05	5.75	6.48
New Zealand	2.30	4.06	6.19	9.20	12.20	15.49	19.20	23.30
Nicaragua	2.72	5.19	7.40	9.59	11.70	13.81	15.97	15.18
Nigeria	4.00	8.07	12.07	16.15	20.35	24.78	29.63	54.59
Pakistan	2.00	3.81	5.77	7.85	10.01	12.39	15.37	18.83
Panama	4.10	8.47	12.81	17.14	21.23	24.85	28.48	29.07
Peru	0.61	1.24	1.93	2.64	3.37	4.10	4.87	1.55
Philippines	2.58	4.90	7.44	10.19	13.14	16.40	20.31	24.59
Republic of Korea	-1.92	-3.30	-4.79	-6.39	-7.79	-9.20	-10.07	-10.51
Saudi Arabia	2.87	5.67	8.48	11.30	14.21	17.30	20.91	15.54
Senegal	3.20	6.42	9.80	13.33	17.03	20.90	25.18	29.74
Sierra Leone	1.47	2.66	3.65	4.52	5.27	5.94	6.55	7.11
Singapore	1.75	3.79	5.21	6.15	6.99	7.97	9.30	10.73
South Africa	0.91	1.75	2.50	3.19	3.88	4.79	6.20	8.09
Thailand	-0.52	-0.52	-0.61	-0.90	-1.11	-1.32	-1.45	-4.34
United Arab Emirates	5.45	11.05	14.63	16.83	18.67	21.06	24.68	29.24
United States of America	4.10	6.87	8.79	10.53	12.22	13.91	15.85	18.00
Uruguay	1.62	2.73	3.96	5.52	7.16	8.76	10.39	12.04
Viet Nam	-0.46	-0.82	-1.28	-1.79	-2.30	-2.70	-2.70	-3.91
EU27	1.27	2.77	4.76	7.09	9.51	11.94	14.42	16.98
OCARI	3.18	6.34	9.49	12.65	15.90	19.37	23.43	13.47
OME	1.28	2.54	3.72	5.15	6.72	8.46	10.39	17.47
OAFR	3.51	6.30	9.13	12.13	15.14	18.23	21.48	18.94
OEUR	0.69	1.57	2.63	3.78	5.05	6.34	7.81	9.34
ONAFR	2.75	0.51	4.18	7.59	11.39	15.40	19.81	24.36
ONASIA	1.55	3.13	4.64	6.12	7.68	9.53	11.96	14.85
OOCEA	1.89	3.97	6.17	8.49	11.01	13.87	17.61	21.67
OSAM	0.97	1.92	2.87	3.81	4.73	5.64	6.55	7.35
OSEASIA	1.13	2.25	3.38	4.49	5.59	6.68	7.74	8.78
OWAFR	2.68	5.36	8.11	10.92	13.81	16.75	19.77	22.85

Table 16. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	12.25	14.86	14.29	15.70	16.48	18.47	19.16	20.43
Australia	31.71	32.40	33.09	37.99	31.21	-10.35	60.01	56.04
Bangladesh	9.93	10.64	11.88	12.94	13.90	14.65	15.69	17.45
Belize	21.74	29.50	26.27	27.57	28.84	31.65	35.73	37.94
Brazil	6.60	9.64	7.15	8.18	6.00	7.68	10.91	10.19
Brunei Darussalam	22.67	24.41	26.14	23.82	33.13	42.44	31.53	36.12
Cambodia	-0.08	1.20	-0.08	-0.41	-1.59	2.84	-0.72	-0.68
Canada	5.91	9.34	23.35	27.26	32.18	21.39	39.57	38.58
Chile	12.17	14.60	14.48	16.01	16.88	20.09	20.67	20.95
China	1.31	0.66	9.34	-9.80	9.34	-3.57	-7.15	-10.66
Colombia	6.05	6.12	6.19	6.85	8.78	6.33	8.31	9.24
Costa Rica	23.21	31.22	27.56	30.45	39.68	34.15	38.37	41.75
Côte d'Ivoire	26.64	13.32	9.34	21.76	10.88	9.34	31.68	39.15
Cuba	37.17	48.67	48.75	53.04	53.40	68.60	70.96	78.48
Egypt	13.00	21.27	17.51	17.38	20.73	24.07	26.17	26.97
El Salvador	22.10	29.76	26.89	29.78	34.74	34.18	38.29	41.52
Ghana	19.40	21.62	23.83	23.90	19.14	30.61	30.76	33.63
Guatemala	26.77	35.69	32.43	36.03	41.74	41.14	46.54	50.60
Guyana	24.15	27.04	29.96	32.91	35.88	38.87	41.88	44.90
Haiti	16.88	21.02	20.20	22.58	26.13	24.71	28.96	30.90
Honduras	24.01	32.35	28.97	32.11	37.89	36.55	41.29	44.82
Hong Kong	12.61	14.46	16.30	15.18	11.08	17.68	24.28	21.34
India	12.38	12.25	12.11	19.80	15.14	28.57	26.05	27.19
Indonesia	4.71	5.50	1.68	6.21	6.40	6.74	7.12	7.43
Iran	13.62	15.20	16.78	11.77	11.09	13.34	15.58	18.92
Iraq	40.71	50.25	50.01	55.23	58.65	63.32	74.58	77.57
Japan	-3.32	2.88	-4.42	-5.25	-8.50	-5.45	-5.81	-6.33
Laos	-0.89	-0.93	-0.97	-1.67	-1.27	-0.87	-0.47	1.57
Malaysia	25.43	28.75	32.06	27.95	41.50	55.06	36.33	42.22
Mexico	23.44	31.07	27.78	30.61	35.70	33.65	39.60	41.88
Myanmar	7.21	7.95	8.68	8.11	8.52	8.93	9.34	9.71
New Zealand	27.39	31.76	36.13	35.43	42.65	34.10	56.23	51.69
Nicaragua	20.37	27.39	23.65	25.88	28.27	28.39	31.71	34.31
Nigeria	40.27	54.51	49.83	51.28	50.86	57.98	73.59	74.55
Pakistan	22.29	25.75	29.21	21.07	20.56	23.89	27.22	33.38
Panama	36.02	45.79	42.02	45.81	51.86	50.91	56.00	59.84
Peru	6.49	12.00	6.20	7.51	6.79	8.66	9.17	10.29
Philippines	28.87	55.48	45.03	34.59	13.51	67.71	49.05	51.51
Republic of Korea	-10.95	-17.87	-24.78	-20.92	-23.58	-24.05	-24.52	-23.20
Saudi Arabia	28.79	30.53	32.27	35.50	27.71	33.39	50.43	49.90
Senegal	34.30	44.58	40.43	46.07	63.60	51.26	63.26	66.21
Sierra Leone	7.64	8.13	8.60	9.04	9.46	9.86	10.25	10.63
Singapore	12.15	21.91	14.90	13.66	7.26	22.86	20.55	18.56
South Africa	9.97	15.40	10.43	6.93	4.23	9.09	13.96	12.80
Thailand	-1.58	2.17	-3.35	-3.27	-4.70	-4.58	-4.14	-4.31
United Arab Emirates	33.79	33.58	33.37	38.37	50.34	60.81	54.15	54.57
United States of America	20.15	19.39	18.64	22.73	25.09	25.60	27.80	31.18
Uruguay	13.62	15.91	16.86	18.45	20.33	21.34	23.68	25.22
Viet Nam	-5.13	-6.35	-7.78	-8.78	-9.85	-10.91	-11.97	-9.82
EU27	19.54	23.90	24.33	27.04	30.00	32.60	34.96	37.73
OCARI	32.34	53.15	47.49	40.61	37.67	48.31	58.95	58.27
OME	14.35	11.89	17.75	19.84	22.57	25.92	29.26	27.92
OAFR	28.30	37.82	33.26	37.24	37.08	53.26	48.17	51.88
OEUR	10.88	30.99	12.61	13.08	11.50	16.00	20.50	18.41
ONAFR	28.90	43.73	36.93	37.34	9.34	26.65	53.30	55.30
ONASIA	17.74	22.07	26.40	16.87	13.95	25.72	26.83	24.81
OOCEA	25.72	30.21	34.71	28.43	41.44	54.46	49.02	43.52
OSAM	8.33	10.96	9.43	10.42	9.69	10.97	12.58	13.44
OSEASIA	9.80	10.80	11.78	12.74	13.67	14.59	15.47	16.34
OWAFR	25.99	29.18	32.42	35.70	39.02	42.39	45.81	49.28

Table 17. Results, percentage change in retail price for benchmark scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	0.23	0.52	0.84	1.20	1.59	2.03	2.51	3.03
Australia	2.15	4.90	8.01	11.38	15.04	18.89	23.00	27.30
Bangladesh	3.42	8.16	15.04	24.54	36.01	48.17	59.96	70.84
Belize	3.83	8.41	13.31	18.40	23.77	29.31	35.10	41.03
Brazil	0.36	0.84	1.41	2.06	2.81	3.69	4.70	5.86
Brunei Darussalam	2.40	5.44	8.88	12.58	16.61	20.84	25.37	30.15
Cambodia	0.08	0.32	0.39	0.61	0.87	1.15	1.44	1.74
Canada	1.85	4.18	6.87	9.93	13.29	16.90	20.80	24.95
Chile	0.48	1.03	1.60	2.21	2.86	3.53	4.25	5.00
China	-2.25	-3.46	-4.25	-5.04	-5.68	-6.13	-6.34	-6.43
Colombia	1.91	4.18	6.95	10.20	13.86	17.83	22.08	26.57
Costa Rica	2.65	5.90	9.63	13.88	18.48	23.39	28.67	34.27
Côte d'Ivoire	2.28	4.99	8.24	11.72	15.46	19.37	23.50	27.78
Cuba	2.06	4.51	7.39	10.66	14.19	17.90	21.87	26.10
Egypt	2.19	4.93	8.04	11.40	15.05	18.89	23.01	27.38
El Salvador	1.78	4.04	6.64	9.60	12.82	16.25	19.93	23.81
Ghana	2.28	5.36	8.66	12.23	16.11	20.21	24.60	29.25
Guatemala	2.00	4.53	7.44	10.75	14.38	18.28	22.50	27.00
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	1.35	3.45	5.80	8.39	11.15	14.01	17.04	20.17
Honduras	1.97	4.44	7.31	10.55	14.11	17.89	21.97	26.28
Hong Kong	2.23	5.07	8.29	11.75	15.51	19.47	23.70	28.16
India	3.69	8.71	14.59	21.19	28.63	36.96	46.30	56.50
Indonesia	1.43	2.89	4.35	5.69	7.29	8.91	10.59	12.27
Iran	3.77	8.44	13.82	19.65	25.89	32.50	39.59	46.85
Iraq	1.87	4.24	6.85	9.64	12.64	15.77	19.07	22.49
Japan	2.16	4.95	8.11	11.54	15.29	19.26	23.52	27.99
Laos	0.19	0.45	1.05	1.85	2.47	2.41	3.30	4.29
Malaysia	2.73	5.98	9.66	13.67	18.02	22.59	27.49	32.68
Mexico	1.99	4.47	7.33	10.58	14.17	18.00	22.17	26.59
Myanmar	3.90	8.95	15.18	22.32	30.52	39.64	49.67	60.60
New Zealand	2.19	5.03	8.25	11.77	15.62	19.70	24.07	28.67
Nicaragua	2.72	5.89	9.38	13.29	17.53	22.05	26.92	32.08
Nigeria	2.85	6.24	9.85	13.55	17.42	21.36	25.44	29.57
Pakistan	4.17	8.91	14.24	19.97	26.07	32.46	39.19	46.09
Panama	3.28	7.25	11.60	16.35	21.34	26.41	31.81	37.54
Peru	1.61	3.65	6.15	9.07	12.40	16.04	19.98	24.19
Philippines	3.60	7.56	12.03	16.87	22.10	27.60	33.51	39.77
Republic of Korea	1.98	4.52	7.41	10.61	14.12	17.85	21.87	26.11
Saudi Arabia	2.41	5.38	8.74	12.38	16.33	20.48	24.92	29.56
Senegal	2.09	4.64	7.48	10.47	13.67	16.98	20.47	24.06
Sierra Leone	7.91	18.51	31.97	48.46	67.94	90.45	116.36	145.90
Singapore	2.39	5.36	8.74	12.40	16.38	20.57	25.07	29.83
South Africa	1.90	4.39	7.15	9.99	12.99	16.06	19.24	22.45
Thailand	2.69	6.22	10.21	14.46	19.08	23.96	29.17	34.63
United Arab Emirates	3.02	6.64	10.70	15.05	19.72	24.61	29.80	35.17
United States of America	1.55	3.61	6.01	8.74	11.80	15.15	18.83	22.76
Uruguay	1.95	4.42	7.25	10.47	14.00	17.77	21.85	26.17
Viet Nam	2.60	5.76	9.36	13.29	17.57	22.06	26.88	32.03
EU27	1.12	2.56	4.24	6.08	7.96	9.83	11.70	13.53
OCARI	2.36	5.28	8.56	12.10	15.92	19.94	24.21	28.66
OME	1.70	3.75	5.97	8.29	10.70	13.12	15.56	17.96
OAFR	3.83	7.87	12.32	17.08	22.12	27.34	32.82	38.48
OEUR	1.95	4.35	7.06	9.97	13.08	16.31	19.69	23.16
ONAFR	2.20	4.78	7.86	11.16	14.72	18.43	22.38	26.49
ONASIA	3.30	7.19	11.42	15.82	20.43	25.18	30.05	34.90
OOCEA	2.13	4.76	7.76	11.03	14.61	18.38	22.43	26.75
OSAM	1.46	3.10	4.88	6.77	8.74	10.77	12.86	15.00
OSEASIA	4.17	9.48	15.80	22.97	30.90	39.48	48.71	58.42
OWAFR	2.53	5.57	8.94	12.47	16.22	20.09	24.13	28.28

Table 17. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	3.58	4.17	4.78	5.41	6.06	6.71	7.37	8.04
Australia	31.69	36.14	40.57	44.96	49.28	53.52	57.66	61.70
Bangladesh	80.66	89.54	97.52	104.70	111.19	117.07	122.43	127.34
Belize	47.02	53.07	59.09	65.05	70.96	76.80	82.57	88.27
Brazil	7.15	8.57	10.10	11.72	13.42	15.19	17.00	18.85
Brunei Darussalam	35.05	40.04	44.99	49.90	54.73	59.48	64.13	68.67
Cambodia	2.04	2.33	2.58	2.80	2.97	3.11	3.21	3.27
Canada	29.27	33.73	38.27	42.85	47.47	52.08	56.68	61.26
Chile	5.78	6.59	7.40	8.23	9.06	9.89	10.73	11.55
China	-6.42	-6.32	-6.21	-6.09	-5.96	-5.81	-5.65	-5.47
Colombia	31.25	36.13	41.18	46.37	51.65	56.99	62.36	67.74
Costa Rica	40.10	46.15	52.32	58.59	64.92	71.30	77.69	84.10
Côte d'Ivoire	32.10	36.43	40.68	44.82	48.83	52.70	56.42	59.97
Cuba	30.44	34.86	39.26	43.62	47.90	52.10	56.20	60.20
Egypt	31.86	36.41	40.94	45.42	49.83	54.15	58.37	62.49
El Salvador	27.82	31.91	36.04	40.16	44.25	48.30	52.29	56.21
Ghana	34.04	38.93	43.83	48.70	53.53	58.30	62.99	67.60
Guatemala	31.69	36.54	41.49	46.49	51.54	56.60	61.67	66.72
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	23.33	26.48	29.57	32.57	35.47	38.26	40.91	43.44
Honduras	30.74	35.32	39.95	44.60	49.25	53.87	58.46	63.00
Hong Kong	32.72	37.36	41.98	46.55	51.07	55.50	59.85	64.11
India	67.45	79.09	91.32	104.11	117.43	131.25	145.53	160.23
Indonesia	13.98	15.72	17.36	18.89	20.30	21.57	22.72	23.72
Iran	54.31	61.86	69.44	77.01	84.54	92.01	99.39	106.67
Iraq	25.95	29.42	32.84	36.20	39.47	42.65	45.73	48.71
Japan	32.60	37.31	42.04	46.76	51.47	56.13	60.73	65.28
Laos	5.34	6.45	7.58	8.72	9.85	10.97	12.04	13.06
Malaysia	38.01	43.44	48.85	54.19	59.47	64.63	69.69	74.63
Mexico	31.21	35.98	40.85	45.77	50.73	55.70	60.68	65.64
Myanmar	72.40	85.08	98.66	113.14	128.53	144.81	161.99	179.79
New Zealand	33.40	38.23	43.09	47.94	52.77	57.57	62.31	66.99
Nicaragua	37.47	43.05	48.76	54.54	60.38	66.25	72.13	78.03
Nigeria	33.69	37.78	41.78	45.67	49.45	53.12	56.67	60.11
Pakistan	53.03	59.95	66.71	73.29	79.64	85.74	91.58	97.15
Panama	43.48	49.60	55.82	62.11	68.45	74.80	81.17	87.52
Peru	28.60	33.21	37.97	42.85	47.82	52.83	57.86	62.86
Philippines	46.22	52.81	59.40	65.95	72.45	78.83	85.10	91.23
Republic of Korea	30.50	35.01	39.56	44.13	48.70	53.24	57.76	62.23
Saudi Arabia	34.32	39.17	44.03	48.86	53.67	58.42	63.11	67.72
Senegal	27.69	31.31	34.88	38.37	41.78	45.09	48.32	51.45
Sierra Leone	179.55	217.59	260.21	307.75	360.71	419.59	484.98	557.53
Singapore	34.72	39.70	44.64	49.53	54.34	59.04	63.65	68.13
South Africa	25.62	28.72	31.69	34.52	37.21	39.75	42.16	44.44
Thailand	40.21	45.87	51.52	57.12	62.66	68.11	73.47	78.73
United Arab Emirates	40.61	46.09	51.51	56.84	62.06	67.14	72.09	76.90
United States of America	26.88	31.15	35.50	39.91	44.35	48.80	53.23	57.62
Uruguay	30.65	35.27	39.95	44.65	49.36	54.06	58.72	63.34
Viet Nam	37.32	42.71	48.05	53.33	58.52	63.58	68.53	73.34
EU27	15.29	16.98	18.57	20.07	21.48	22.79	24.02	25.17
OCARI	33.19	37.79	42.36	46.88	51.34	55.71	59.99	64.18
OME	20.25	22.42	24.45	26.32	28.05	29.65	31.12	32.47
OAFR	44.20	49.95	55.61	61.16	66.58	71.84	76.95	81.89
OEUR	26.64	30.09	33.46	36.74	39.92	43.00	45.98	48.84
ONAFR	30.67	34.88	39.01	43.05	46.99	50.79	54.47	58.01
ONASIA	39.61	44.12	48.36	52.33	56.03	59.48	62.70	65.70
OOCEA	31.20	35.74	40.29	44.80	49.27	53.67	57.99	62.23
OSAM	17.17	19.36	21.55	23.74	25.91	28.06	30.18	32.26
OSEASIA	68.46	78.72	89.05	99.37	109.60	119.66	129.52	139.12
OWAFR	32.45	36.62	40.70	44.69	48.58	52.36	56.03	59.57

Table 18. Results, percentage change in retail price for impact scenario.

Region	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	0.19	0.44	0.70	0.97	1.25	1.53	1.81	2.09
Australia	1.38	3.48	5.67	7.85	9.98	12.04	14.07	15.86
Bangladesh	-0.37	0.71	1.19	0.95	-0.09	-1.67	-3.36	-5.02
Belize	3.01	6.99	11.16	15.39	19.69	23.95	28.21	32.29
Brazil	0.30	0.72	1.18	1.68	2.23	2.80	3.42	4.05
Brunei Darussalam	1.49	3.65	5.82	7.84	9.70	11.32	12.72	13.60
Cambodia	0.04	0.24	0.27	0.42	0.61	0.78	0.95	1.09
Canada	1.08	2.71	4.41	6.19	7.88	9.58	11.37	13.10
Chile	0.43	0.93	1.43	1.93	2.44	2.94	3.45	3.92
China	-7.05	-8.99	-9.80	-10.10	-10.22	-10.28	-10.32	-10.34
Colombia	1.65	3.64	5.98	8.62	11.42	14.34	17.36	20.36
Costa Rica	1.92	4.45	7.13	9.99	12.73	15.52	18.39	21.21
Côte d'Ivoire	1.49	3.53	5.84	8.11	10.31	12.34	14.21	15.69
Cuba	1.19	2.62	3.98	5.22	6.21	6.90	7.37	7.29
Egypt	1.30	3.09	4.81	6.33	7.66	8.70	9.52	9.80
El Salvador	1.06	2.67	4.36	6.13	7.80	9.50	11.28	13.02
Ghana	1.53	3.80	5.87	7.84	9.68	11.28	12.69	13.65
Guatemala	1.22	3.01	4.90	6.87	8.75	10.66	12.67	14.63
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	0.75	2.30	3.88	5.49	6.99	8.49	10.04	11.54
Honduras	1.18	2.94	4.79	6.73	8.57	10.45	12.40	14.31
Hong Kong	1.42	3.50	5.64	7.68	9.64	11.40	13.02	14.21
India	2.91	6.60	9.80	13.16	16.80	19.43	20.99	21.24
Indonesia	0.20	0.10	-0.05	-1.04	-1.82	-2.61	-3.93	-5.66
Iran	3.45	7.78	12.63	17.76	23.06	28.47	34.03	39.35
Iraq	1.33	3.18	5.07	6.92	8.72	10.43	12.08	13.49
Japan	1.39	3.54	5.82	8.12	10.40	12.64	14.88	16.96
Laos	-0.18	-0.09	0.28	0.78	1.01	0.49	0.75	0.92
Malaysia	1.81	4.00	6.08	7.94	9.58	10.86	11.88	12.27
Mexico	1.20	2.95	4.77	6.69	8.50	10.36	12.30	14.20
Myanmar	3.72	8.57	14.48	21.19	28.86	37.35	46.69	56.84
New Zealand	1.45	3.59	5.78	8.00	10.22	12.32	14.34	16.10
Nicaragua	2.04	4.53	7.04	9.65	12.15	14.69	17.32	19.90
Nigeria	2.05	4.91	7.87	10.81	13.75	16.60	19.38	21.96
Pakistan	3.35	7.35	11.65	16.10	20.61	25.04	29.43	33.47
Panama	2.62	5.90	9.24	12.64	15.81	18.80	21.85	24.85
Peru	1.45	3.30	5.48	7.93	10.60	13.38	16.25	19.08
Philippines	2.40	5.02	7.44	9.55	11.31	12.64	13.64	13.82
Republic of Korea	1.23	3.12	5.12	7.15	9.14	11.12	13.14	15.05
Saudi Arabia	1.65	3.96	6.39	8.85	11.26	13.61	15.94	18.06
Senegal	1.43	3.39	5.38	7.29	9.11	10.78	12.32	13.52
Sierra Leone	7.91	18.51	31.97	48.46	67.94	90.45	116.36	145.90
Singapore	1.42	3.31	5.09	6.64	7.97	8.96	9.68	9.80
South Africa	0.88	2.73	4.76	6.78	8.79	10.71	12.54	14.15
Thailand	1.80	4.64	7.70	10.76	13.88	16.93	19.94	22.69
United Arab Emirates	2.25	5.19	8.30	11.44	14.59	17.61	20.53	23.11
United States of America	1.24	2.96	4.85	6.87	9.00	11.17	13.41	15.55
Uruguay	1.14	2.86	4.65	6.51	8.28	10.05	11.89	13.63
Viet Nam	1.43	3.22	4.81	6.09	7.05	7.61	7.89	7.48
EU27	0.80	1.96	3.27	4.66	5.99	7.30	8.61	9.87
OCARI	1.61	3.87	6.24	8.60	10.92	13.15	15.32	17.26
OME	1.24	2.86	4.47	6.06	7.61	9.04	10.38	11.50
OAFR	3.07	6.37	9.76	13.14	16.39	19.41	22.23	24.56
OEUR	1.38	3.24	5.16	7.06	8.93	10.65	12.28	13.59
ONAFR	1.33	3.09	5.00	6.77	8.40	9.81	11.03	11.80
ONASIA	2.40	5.64	9.10	12.67	16.33	19.93	23.44	26.66
OOCEA	1.24	2.90	4.47	5.87	7.06	8.00	8.76	9.04
OSAM	1.33	2.84	4.43	6.08	7.73	9.39	11.05	12.67
OSEASIA	3.79	8.51	13.69	19.31	25.25	30.97	36.32	40.97
OWAFR	1.80	4.28	6.91	9.54	12.15	14.67	17.11	19.30

Table 18. Continued

Region	2018	2019	2020	2021	2022	2023	2024	2025
Argentina	2.38	2.70	3.04	3.40	3.78	4.20	4.63	5.09
Australia	17.85	19.97	22.18	24.57	27.03	29.74	32.49	35.41
Bangladesh	-5.80	-6.19	-6.40	-6.50	-6.60	-6.64	-6.68	-6.69
Belize	36.52	40.87	45.28	49.83	54.42	59.17	63.94	68.81
Brazil	4.74	5.49	6.31	7.21	8.17	9.23	10.35	11.56
Brunei Darussalam	14.82	16.34	18.08	20.15	22.25	24.70	27.19	29.97
Cambodia	1.22	1.33	1.39	1.41	1.38	1.31	1.19	1.04
Canada	15.02	17.03	19.12	21.37	23.78	26.48	29.25	32.24
Chile	4.42	4.94	5.46	6.01	6.56	7.15	7.75	8.37
China	-10.34	-10.35	-10.35	-10.35	-10.36	-10.36	-10.36	-10.36
Colombia	23.51	26.77	30.14	33.68	37.34	41.22	45.18	49.29
Costa Rica	24.24	27.37	30.59	33.99	37.59	41.52	45.55	49.85
Côte d'Ivoire	17.36	19.21	21.16	23.33	25.49	27.89	30.28	32.85
Cuba	7.69	8.49	9.59	11.07	12.59	14.48	16.41	18.67
Egypt	10.48	11.51	12.80	14.45	16.13	18.19	20.27	22.67
El Salvador	14.92	16.90	18.94	21.12	23.44	26.01	28.64	31.45
Ghana	14.85	16.24	17.68	19.41	21.24	23.40	25.66	28.14
Guatemala	16.80	19.06	21.41	23.92	26.61	29.60	32.68	35.99
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	13.18	14.86	16.59	18.40	20.31	22.39	24.49	26.69
Honduras	16.42	18.61	20.87	23.30	25.88	28.75	31.70	34.85
Hong Kong	15.68	17.40	19.30	21.48	23.70	26.24	28.80	31.62
India	20.26	18.16	14.09	11.44	9.88	9.27	9.44	9.57
Indonesia	-7.54	-9.35	-10.89	-11.77	-12.36	-12.70	-12.89	-13.00
Iran	44.79	50.23	55.60	61.09	66.60	72.27	77.98	83.74
Iraq	15.08	16.80	18.60	20.57	22.59	24.81	27.05	29.42
Japan	19.22	21.60	24.06	26.69	29.41	32.38	35.39	38.59
Laos	1.13	1.35	1.57	1.79	1.98	2.16	2.30	2.42
Malaysia	13.11	14.34	15.84	17.74	19.70	22.08	24.52	27.31
Mexico	16.30	18.49	20.77	23.21	25.83	28.75	31.77	35.01
Myanmar	68.00	80.18	93.42	107.75	123.09	139.48	156.85	174.89
New Zealand	17.87	19.54	20.84	22.33	23.99	25.95	28.09	30.29
Nicaragua	22.68	25.56	28.53	31.65	34.96	38.56	42.27	46.22
Nigeria	24.62	27.34	30.07	32.87	35.65	38.53	41.37	44.25
Pakistan	37.64	41.88	46.03	50.35	54.67	59.17	63.63	68.13
Panama	28.03	31.27	34.57	38.03	41.65	45.59	49.61	53.88
Peru	22.07	25.22	28.49	31.95	35.52	39.28	43.11	47.06
Philippines	14.64	16.02	17.83	20.16	22.56	25.50	28.47	31.92
Republic of Korea	17.14	19.33	21.60	24.03	26.57	29.38	32.24	35.30
Saudi Arabia	20.32	22.63	24.91	27.35	29.88	32.66	35.51	38.51
Senegal	14.93	16.52	18.23	20.14	22.06	24.21	26.36	28.68
Sierra Leone	179.55	217.60	260.21	307.75	360.71	419.59	484.98	557.53
Singapore	10.34	11.25	12.39	13.93	15.54	17.55	19.64	22.04
South Africa	15.85	17.61	19.36	21.20	23.02	24.93	26.81	28.73
Thailand	25.66	28.79	32.01	35.44	38.92	42.65	46.40	50.31
United Arab Emirates	25.78	28.49	31.05	33.79	36.57	39.58	42.64	45.80
United States of America	17.89	20.40	23.02	25.86	28.80	31.98	35.24	38.67
Uruguay	15.55	17.54	19.54	21.71	24.04	26.66	29.38	32.28
Viet Nam	7.69	8.45	9.60	11.24	12.95	15.14	17.38	20.04
EU27	11.16	12.44	13.71	14.97	16.24	17.53	18.78	20.03
OCARI	19.36	21.56	23.78	26.18	28.65	31.36	34.11	37.02
OME	12.65	13.82	14.89	16.05	17.23	18.51	19.81	21.12
OAFR	27.09	29.78	32.54	35.53	38.54	41.83	45.12	48.61
OEUR	15.07	16.69	18.37	20.24	22.12	24.21	26.31	28.54
ONAFR	12.86	14.18	15.68	17.46	19.27	21.38	23.51	25.88
ONASIA	29.77	32.73	35.36	37.98	40.53	43.11	45.65	48.09
OOCEA	9.72	10.75	12.05	13.69	15.40	17.49	19.61	22.06
OSAM	14.32	15.97	17.63	19.31	21.00	22.73	24.45	26.19
OSEASIA	44.97	48.15	49.73	51.61	53.79	56.40	59.43	62.29
OWAFR	21.62	24.04	26.50	29.09	31.69	34.45	37.19	40.03

Table 19. Descriptive statistics for results of production percentage change in Vietnam for stochastic simulation.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	-0.541	2.446	4.248	6.019	8.082	10.434	13.147	16.446	19.407	22.183	24.680	26.886	29.089	30.994	32.895	34.497
Standard Deviation	0.770	2.346	2.478	2.591	2.697	2.799	2.924	2.989	3.125	3.234	3.335	3.425	3.507	3.576	3.638	3.686
Minimum	-2.802	-3.782	-2.510	-0.955	0.893	3.023	5.454	8.463	11.237	13.767	16.042	18.056	20.080	21.840	23.608	25.111
Maximum	1.166	8.268	10.233	12.388	14.793	17.458	20.436	24.010	27.366	30.466	33.267	35.746	38.196	40.309	42.397	44.146
Percentiles																
95%	0.675	6.544	8.284	10.257	12.505	15.033	17.880	21.336	24.558	27.522	30.193	32.554	34.899	36.923	38.932	40.617
90%	0.497	4.925	7.638	9.566	11.775	14.266	17.078	20.500	23.686	26.612	29.248	31.578	33.895	35.894	37.881	39.549
85%	0.186	4.342	6.551	8.414	10.564	13.001	15.759	19.127	22.257	25.127	27.709	29.992	32.265	34.228	36.182	37.824
80%	0.123	3.993	6.337	8.188	10.327	12.755	15.502	18.861	21.980	24.839	27.412	29.686	31.951	33.907	35.856	37.493
75%	-0.149	3.814	5.428	7.234	9.331	11.719	14.551	17.744	20.821	23.638	26.172	28.410	30.643	32.572	34.497	36.115
70%	-0.428	2.769	4.525	6.291	8.352	10.703	13.896	17.194	19.689	22.467	24.964	27.171	29.375	31.279	33.181	34.782
65%	-0.463	2.494	4.412	6.173	8.229	10.577	13.340	16.617	19.548	22.321	24.814	27.017	29.217	31.119	33.018	34.617
60%	-0.522	2.435	4.224	5.978	8.026	10.367	13.025	16.325	19.314	22.080	24.566	26.762	28.957	30.854	32.749	34.344
55%	-0.622	2.165	3.909	5.650	7.687	10.015	12.661	15.980	18.924	21.677	24.152	26.337	28.522	30.411	32.299	33.889
50%	-0.713	2.097	3.621	5.351	7.378	9.696	12.331	15.907	18.570	21.311	23.775	25.952	28.128	30.010	31.891	33.477
45%	-0.737	2.090	3.548	5.276	7.299	9.615	12.247	15.487	18.480	21.219	23.680	25.854	28.028	29.908	31.788	33.372
40%	-0.742	1.984	3.531	5.259	7.282	9.596	12.228	15.478	18.460	21.198	23.658	25.832	28.006	29.885	31.765	33.349
35%	-0.752	1.702	3.501	5.227	7.249	9.563	12.193	15.438	18.423	21.159	23.619	25.792	27.964	29.843	31.722	33.305
30%	-0.785	1.364	3.397	5.119	7.137	9.447	12.074	15.402	18.295	21.027	23.483	25.653	27.823	29.699	31.575	33.157
25%	-0.940	1.326	2.918	4.623	6.625	8.918	11.527	15.000	17.710	20.424	22.863	25.017	27.174	29.039	30.905	32.479
20%	-1.039	1.105	2.615	4.310	6.301	8.584	11.182	14.528	17.341	20.043	22.472	24.617	26.765	28.623	30.483	32.052
15%	-1.071	0.644	2.517	4.209	6.197	8.477	11.071	14.370	17.222	19.921	22.346	24.489	26.634	28.490	30.348	31.916
10%	-1.310	0.279	1.794	3.462	5.427	7.683	10.252	13.421	16.347	19.020	21.421	23.543	25.669	27.509	29.352	30.909
5%	-1.409	-0.498	1.497	3.156	5.112	7.358	9.917	13.074	15.989	18.651	21.043	23.157	25.275	27.108	28.946	30.499

Table 20. Descriptive statistics for results of retail price percentage change in Vietnam for stochastic simulation.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1.914	2.335	5.482	7.306	8.945	10.316	11.477	12.115	13.521	15.370	17.670	20.388	23.104	26.195	29.246	32.646
Standard Deviation	3.974	4.246	4.353	4.484	4.568	4.607	4.659	4.569	4.620	4.662	4.717	4.778	4.827	4.879	4.918	4.958
Minimum	-6.485	-5.590	-4.256	-2.923	-1.624	-0.457	0.638	1.311	2.497	4.172	6.268	8.770	11.312	14.225	17.138	20.399
Maximum	14.232	16.087	18.478	20.509	22.244	23.615	24.808	25.361	26.625	28.515	30.891	33.710	36.500	39.676	42.785	46.249
Percentiles																
95%	6.085	7.557	10.026	11.978	13.695	15.102	16.348	17.002	18.309	20.197	22.549	25.327	28.090	31.231	34.321	37.760
90%	5.716	6.249	9.636	11.582	13.296	14.703	15.950	16.607	17.915	19.802	22.151	24.926	27.687	30.825	33.913	37.350
85%	4.427	5.675	8.269	10.189	11.891	13.295	14.544	15.193	16.522	18.404	20.743	23.506	26.258	29.385	32.465	35.894
80%	4.197	4.789	8.023	9.938	11.637	13.040	14.290	14.769	16.270	18.150	20.488	23.248	25.998	29.124	32.202	35.630
75%	3.516	4.511	7.295	9.195	10.885	12.286	13.535	13.730	15.521	17.397	19.728	22.481	25.225	28.345	31.419	34.841
70%	2.946	4.446	6.683	8.569	10.251	11.649	12.898	13.557	14.888	16.760	19.086	21.832	24.571	27.684	30.754	34.173
65%	2.896	3.956	6.629	8.514	10.195	11.593	12.841	13.481	14.832	16.704	19.029	21.774	24.513	27.626	30.695	34.113
60%	2.840	3.827	6.568	8.451	10.132	11.530	12.778	13.453	14.769	16.640	18.964	21.709	24.447	27.560	30.629	34.046
55%	2.828	3.248	6.555	8.439	10.119	11.516	12.765	13.315	14.756	16.627	18.951	21.696	24.434	27.546	30.615	34.032
50%	2.247	2.693	5.928	7.795	9.466	10.860	12.107	12.783	14.102	15.968	18.286	21.023	23.755	26.861	29.926	33.338
45%	2.147	1.480	5.819	7.684	9.353	10.746	11.993	12.543	13.988	15.854	18.171	20.907	23.638	26.743	29.806	33.217
40%	1.681	1.388	5.314	7.165	8.826	10.215	11.461	11.858	13.458	15.319	17.630	20.360	23.086	26.185	29.245	32.652
35%	1.291	1.153	4.889	6.728	8.381	9.768	10.964	11.657	13.010	14.868	17.174	19.898	22.619	25.714	28.769	32.173
30%	0.539	0.052	4.065	5.879	7.517	8.895	9.310	10.832	12.134	13.985	16.280	18.992	21.704	24.789	27.837	31.233
25%	-0.319	-0.118	3.116	4.899	6.515	7.884	8.437	9.818	11.116	12.955	15.238	17.935	20.635	23.708	26.746	30.132
20%	-1.789	-2.287	1.464	3.182	4.756	6.100	7.320	8.024	9.310	11.127	13.382	16.050	18.727	21.774	24.794	28.160
15%	-1.957	-2.985	1.273	2.983	4.551	5.891	7.109	7.813	9.097	10.912	13.164	15.828	18.501	21.545	24.562	27.927
10%	-3.539	-3.564	-0.561	1.057	2.561	3.864	5.055	5.758	7.022	8.804	11.017	13.640	16.280	19.291	22.281	25.619
5%	-4.702	-4.384	-1.961	-0.431	1.012	2.274	3.438	4.135	5.377	7.126	9.303	11.888	14.497	17.476	20.442	23.755

Table 21. Descriptive statistics for results of consumption percentage change in Vietnam for stochastic simulation.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	-0.541	-0.629	-1.384	-1.997	-2.613	-3.261	-3.912	-4.407	-5.043	-5.764	-6.598	-7.534	-8.503	-9.554	-10.621	-11.753
Standard Deviation	0.313	2.335	2.466	2.578	2.683	2.784	2.907	2.971	3.106	3.214	3.315	3.404	3.486	3.555	3.618	3.666
Minimum	-2.802	-3.127	-3.668	-4.265	-4.851	-5.457	-6.078	-6.536	-7.113	-7.793	-8.584	-9.472	-10.390	-11.387	-12.399	-13.474
Maximum	1.166	0.961	0.525	-0.034	-0.626	-1.272	-1.946	-2.469	-3.102	-3.838	-4.693	-5.656	-6.658	-7.749	-8.861	-10.042
Percentiles																
95%	0.675	0.665	-0.079	-0.675	-1.288	-1.944	-2.622	-3.142	-3.775	-4.512	-5.365	-6.323	-7.316	-8.266	-9.494	-10.659
90%	0.497	0.454	-0.283	-0.885	-1.502	-2.159	-2.837	-3.355	-3.986	-4.722	-5.573	-6.529	-7.519	-8.594	-9.687	-10.847
85%	0.186	0.368	-0.628	-1.239	-1.860	-2.517	-3.192	-3.706	-4.334	-5.067	-5.914	-6.864	-7.848	-8.917	-10.002	-11.153
80%	0.123	-0.024	-0.697	-1.309	-1.930	-2.587	-3.261	-3.774	-4.402	-5.134	-5.980	-6.929	-7.912	-8.979	-10.063	-11.212
75%	-0.149	-0.166	-0.989	-1.606	-2.228	-2.882	-3.520	-4.062	-4.687	-5.415	-6.257	-7.202	-8.179	-9.239	-10.316	-11.458
70%	-0.428	-0.248	-1.283	-1.902	-2.523	-3.174	-3.699	-4.205	-4.967	-5.691	-6.528	-7.468	-8.439	-9.493	-10.562	-11.697
65%	-0.463	-0.455	-1.320	-1.939	-2.560	-3.211	-3.851	-4.355	-5.001	-5.725	-6.562	-7.501	-8.471	-9.524	-10.593	-11.727
60%	-0.522	-0.461	-1.381	-2.000	-2.621	-3.272	-3.938	-4.432	-5.059	-5.782	-6.618	-7.556	-8.525	-9.576	-10.644	-11.776
55%	-0.622	-0.653	-1.485	-2.104	-2.724	-3.373	-4.038	-4.522	-5.156	-5.878	-6.712	-7.647	-8.614	-9.663	-10.728	-11.858
50%	-0.713	-0.743	-1.579	-2.199	-2.818	-3.466	-4.129	-4.541	-5.245	-5.964	-6.797	-7.731	-8.695	-9.743	-10.805	-11.933
45%	-0.737	-0.898	-1.603	-2.223	-2.842	-3.490	-4.152	-4.651	-5.267	-5.986	-6.818	-7.752	-8.716	-9.763	-10.825	-11.952
40%	-0.742	-0.942	-1.609	-2.228	-2.848	-3.495	-4.158	-4.653	-5.272	-5.991	-6.823	-7.756	-8.721	-9.767	-10.829	-11.956
35%	-0.752	-1.034	-1.619	-2.239	-2.858	-3.505	-4.167	-4.664	-5.281	-6.000	-6.832	-7.765	-8.729	-9.776	-10.837	-11.964
30%	-0.785	-1.059	-1.653	-2.273	-2.892	-3.539	-4.200	-4.673	-5.313	-6.032	-6.863	-7.795	-8.759	-9.804	-10.865	-11.991
25%	-0.940	-1.080	-1.812	-2.431	-3.048	-3.693	-4.352	-4.779	-5.460	-6.176	-7.004	-7.933	-8.893	-9.935	-10.992	-12.114
20%	-1.039	-1.191	-1.913	-2.532	-3.148	-3.791	-4.448	-4.903	-5.552	-6.267	-7.093	-8.020	-8.978	-10.017	-11.072	-12.191
15%	-1.071	-1.364	-1.945	-2.564	-3.180	-3.822	-4.479	-4.945	-5.582	-6.296	-7.122	-8.048	-9.005	-10.044	-11.098	-12.216
10%	-1.310	-1.612	-2.187	-2.805	-3.418	-4.056	-4.708	-5.197	-5.802	-6.512	-7.333	-8.255	-9.206	-10.239	-11.288	-12.400
5%	-1.409	-1.681	-2.287	-2.904	-3.515	-4.152	-4.802	-5.289	-5.893	-6.601	-7.420	-8.339	-9.289	-10.319	-11.365	-12.475

Table 22. Population growth in percentage change from baseline for regions.

Region	to 2010	to 2011	to 2012	to 2013	to 2014	to 2015	to 2016	to 2017	to 2018	to 2019	to 2020
Argentina	0.8791396	1.7582792	2.6430104	3.5291669	4.4109275	5.2836817	6.145742	6.9969736	7.8362033	8.6625898	9.4753442
Australia	1.5382219	3.0764438	4.5034443	5.8497373	7.1666382	8.4914593	9.8290249	11.164461	12.492638	13.803876	15.090942
Bangladesh	1.2264413	2.4528826	3.7566528	5.1080483	6.4603097	7.7785847	9.0550659	10.298802	11.511406	12.698685	13.864364
Belize	2.0636959	4.1273917	6.2117212	8.3173395	10.442281	12.584582	14.743258	16.915035	19.093035	21.267105	23.429711
Brazil	0.884166	1.768332	2.6511447	3.5254782	4.3793774	5.2039634	5.997715	6.7634254	7.5014234	8.2129162	8.8985477
Brunei Darussalam	1.7907538	3.5815076	5.3559308	7.1114717	8.8460891	10.558507	12.246939	13.910876	15.549806	17.163475	18.751627
Cambodia	1.1947899	2.3895797	3.6288106	4.9006726	6.1857116	7.4685246	8.7461986	10.020136	11.283903	12.530606	13.754506
Canada	0.9885159	1.9770319	2.9423288	3.8894923	4.8270636	5.7610575	6.6920054	7.6167188	8.5331344	9.4381112	10.329114
Chile	0.9189667	1.8379334	2.7442333	3.6361506	4.5112851	5.3675374	6.2039937	7.0200051	7.8140444	8.5844368	9.329714
China	0.4666429	0.9332857	1.3853373	1.817347	2.2221592	2.5943681	2.931793	3.2348503	3.5040003	3.7407407	3.9462464
Colombia	0.9879169	1.9758337	3.0391351	4.1512897	5.2798384	6.3999538	7.4976472	8.5720307	9.6279154	10.676655	11.72581
Costa Rica	1.3846881	2.7693762	4.1350093	5.4807794	6.8064804	8.1116614	9.3951528	10.655402	11.891213	13.10138	14.284833
Côte d'Ivoire	1.474299	2.948598	4.4111789	5.853765	7.2643769	8.6338231	9.9593374	11.24214	12.482055	13.679934	14.836342
Cuba	2.1482188	4.2964376	6.582458	8.9770553	11.437865	13.932645	16.4509	18.996661	21.569608	24.173674	26.811007
Egypt	-0.038305	-0.07661	-0.115669	-0.158662	-0.21239	-0.281435	-0.366027	-0.462757	-0.568632	-0.679613	-0.793107
El Salvador	1.7761573	3.5523146	5.3358817	7.1175317	8.8855353	10.630803	12.348978	14.039619	15.702533	17.339159	18.950481
Ghana	0.5601693	1.1203387	1.7152567	2.3419358	2.9957969	3.6728779	4.3719772	5.0920071	5.829054	6.5785391	7.3367763
Guatemala	2.4099299	4.8198597	7.2555266	9.7133366	12.189608	14.6813	17.186112	19.70276	22.230678	24.769948	27.320566
Guyana	2.6274804	5.2549609	7.9670743	10.748229	13.576429	16.434878	19.317228	22.224811	25.157729	28.118606	31.10879
Haiti	0.2054596	0.4109192	0.6211601	0.8388384	1.0659463	1.3042104	1.5541619	1.8163321	2.0919163	2.3821097	2.6862484
Honduras	1.3235717	2.6471434	3.9840685	5.330352	6.6789574	8.0244399	9.3654409	10.702863	12.035925	13.36411	14.686414
Hong Kong	2.0703133	4.1406265	6.2536721	8.3955237	10.547447	12.694791	14.831392	16.957115	19.070792	21.173255	23.264652
India	1.3974597	2.7949193	4.1908371	5.5807805	6.958757	8.3200255	9.6625847	10.986152	12.289788	13.573043	14.835384
Indonesia	1.033923	2.0678459	3.0970392	4.1159582	5.1164281	6.0923171	7.0417855	7.9659872	8.8653562	9.7412487	10.594568
Iran	1.1277978	2.2555956	3.3673029	4.4544247	5.5062184	6.5140249	7.4747192	8.3870872	9.2469799	10.05044	10.794943
Iraq	3.2379661	6.4759321	9.8598485	13.357888	16.926085	20.53213	24.160917	27.818395	31.518777	35.285906	39.135394
Japan	-0.030558	-0.061117	-0.110564	-0.181209	-0.275995	-0.397087	-0.545031	-0.719429	-0.92022	-1.147001	-1.399152
Laos	1.4253606	2.8507213	4.2557016	5.6456339	7.0289582	8.411301	9.7926788	11.168953	12.536363	13.889689	15.224189
Malaysia	1.6395482	3.2790965	4.9347741	6.6003325	8.2640336	9.917181	11.559102	13.193168	14.819059	16.436878	18.046329
Mexico	1.2229008	2.4458016	3.6536496	4.8420212	6.0065566	7.143862	8.2510119	9.3269444	10.372712	11.390695	12.382628
Myanmar	0.7853684	1.5707367	2.3852566	3.2158201	4.0449189	4.8589576	5.6519243	6.4236362	7.1734461	7.9028082	8.6122812
New Zealand	1.0730112	2.1460224	3.2277105	4.3131241	5.3935165	6.4621313	7.5177885	8.5622927	9.5952508	10.616755	11.626274
Nicaragua	1.4316389	2.8632778	4.3534993	5.8757196	7.3925075	8.8756493	10.315139	11.714674	13.076094	14.405936	15.708669
Nigeria	2.6218873	5.2437747	7.9376235	10.704747	13.546576	16.463212	19.455859	22.521682	25.65174	28.834152	32.060288
Pakistan	1.8493048	3.6986096	5.5794765	7.4790778	9.3799299	11.268815	13.139112	14.991775	16.830375	18.66171	20.489775
Panama	1.5701287	3.1402574	4.6942415	6.2328319	7.7576171	9.2697522	10.768746	12.25356	13.724222	15.180703	16.622714
Peru	1.1244137	2.2488274	3.4104787	4.5976715	5.7919939	6.9795936	8.1563458	9.3252067	10.487554	11.646777	12.804467
Philippines	1.7358346	3.4716691	5.2382652	7.0287384	8.8314174	10.637496	12.445471	14.257671	16.073387	17.892461	19.714432
Republic of Korea	0.4330494	0.8660987	1.2766867	1.6653012	2.0340557	2.3843133	2.7150028	3.0242794	3.3119785	3.578125	3.8225544
Saudi Arabia	2.3661659	4.7323319	7.0542554	9.3451387	11.62037	13.890241	16.160601	18.427553	20.678997	22.896933	25.06715
Senegal	2.7589319	5.5178638	8.3310193	11.19258	14.095431	17.033984	20.005405	23.009108	26.04462	29.112439	32.212845
Sierra Leone	2.2648898	4.5297796	6.7774845	9.0208147	11.267456	13.523492	15.801419	18.108295	20.436487	22.772173	25.105471
Singapore	2.0364489	4.0728977	5.4439374	6.3393611	7.0604383	7.8308244	8.6949535	9.5897152	10.505861	11.408788	12.27408
South Africa	0.6568752	1.3137504	1.8724761	2.3600131	2.8138892	3.2628001	3.7155619	4.1695345	4.6278238	5.0904319	5.5568046
Thailand	0.5766689	1.1533379	1.6969276	2.2078339	2.6849727	3.1279657	3.5384062	3.9188712	4.2709611	4.5963173	4.896386
United Arab Emirates	5.3170184	10.634037	13.647711	15.078733	16.055844	17.410623	19.325699	21.552324	23.984053	26.39412	28.62038
United States of America	0.8779933	1.7559867	2.6354335	3.5150239	4.3924914	5.2660204	6.1352823	7.0004069	7.8604879	8.7145069	9.5615823
Uruguay	0.3342304	0.6684608	1.0085884	1.3567277	1.7181504	2.0955669	2.488173	2.8906672	3.2965567	3.6974723	4.0869809
Viet Nam	1.0857283	2.1714565	3.2511173	4.3169675	5.3597983	6.3720991	7.350112	8.2920037	9.194786	10.05607	10.874139
EU27	0.2954583	0.5909166	0.8441611	1.0656137	1.2712864	1.4729348	1.6733797	1.8691604	2.0583209	2.2369927	2.4023562
OCARI	0.7771388	1.5542775	2.3202637	3.0739708	3.8140053	4.5389392	5.2480609	5.9406984	6.6154237	7.2708038	7.9054699
OME	2.5172052	5.0344104	7.4208918	9.7203244	12.001821	14.316101	16.673379	19.057251	21.460565	23.868876	26.271625
OAFR	2.4614233	4.9228466	7.4443078	10.02159	12.64807	15.318257	18.031019	20.785901	23.578728	26.404651	29.259928
OEUR	-0.157137	-0.314273	-0.476969	-0.646314	-0.820945	-1.000409	-1.187086	-1.384691	-1.595265	-1.820736	-2.062552
ONAFR	1.7133739	3.4267479	5.1352464	6.8396887	8.5429947	10.246373	11.948913	13.646097	15.331353	16.9964	18.635034
ONASIA	1.1930213	2.3860426	3.5748897	4.7668062	5.9761998	7.211589	8.4722108	9.7464985	11.019412	12.271308	13.487181
OOCEA	1.6159867	3.2319733	4.7853651	6.2937372	7.7868918	9.2864694	10.794872	12.303019	13.807865	15.303749	16.786354
OSAM	1.0622269	2.1244538	3.1858628	4.2412179	5.2821856	6.3024368	7.3004144	8.2773757	9.2330197	10.167639	11.081171
OSEASIA	1.1263998	2.2527996	3.3762943	4.492358	5.5943451	6.6771483	7.7391828	8.7809672	9.8019768	10.802204	11.781504
OWAFR	2.6808635	5.361727	8.1092052	10.923593	13.805325	16.754014	19.769969	22.850954	25.990907	29.181944	32.418277

Table 22. Continued

Region	to 2021	to 2022	to 2023	to 2024	to 2025	to 2026	to 2027	to 2028	to 2029	to 2030
Argentina	10.273506	11.056188	11.822902	12.573337	13.307276	14.024189	14.723884	15.406924	16.074199	16.726326
Australia	16.353696	17.594873	18.81322	20.007427	21.176473	22.319917	23.437493	24.528714	25.593155	26.630735
Bangladesh	15.006187	16.119225	17.201782	18.25214	19.268771	20.250605	21.196678	22.105793	22.976789	23.808782
Belize	25.576269	27.705469	29.81338	31.895417	33.949942	35.973353	37.963685	39.919299	41.839214	43.723103
Brazil	9.5578965	10.189534	10.791964	11.363355	11.902316	12.408222	12.881097	13.32106	13.728518	14.103837
Brunei Darussalam	20.313752	21.84985	23.359411	24.843201	26.301984	27.73525	29.14249	30.523702	31.878633	33.206771
Cambodia	14.951522	16.119321	17.256263	18.361713	19.434933	20.474619	21.479205	22.447753	23.379483	24.274101
Canada	11.205326	12.066629	12.911948	13.740219	14.550477	15.342446	16.115528	16.868149	17.598456	18.305328
Chile	10.048944	10.741296	11.405531	12.040411	12.644969	13.218509	13.760794	14.271938	14.752353	15.202392
China	4.1201408	4.2618931	4.3724947	4.4533019	4.5053736	4.5291253	4.5245633	4.4918402	4.4309886	4.3420622
Colombia	12.772789	13.810304	14.836063	15.847447	16.841693	17.817826	18.773527	19.703227	20.600167	21.459393
Costa Rica	15.440642	16.568111	17.666742	18.736202	19.776111	20.785936	21.765075	22.71304	23.629356	24.513592
Côte d'Ivoire	15.950496	17.021109	18.047878	19.030519	19.969054	20.86333	21.713631	22.520784	23.286031	24.010351
Cuba	29.477647	32.167679	34.879483	37.611973	40.363839	43.133167	45.917637	48.715139	51.523477	54.34066
Egypt	-0.90843	-1.027428	-1.153326	-1.290705	-1.443303	-1.612265	-1.798044	-2.002887	-2.229191	-2.478794
El Salvador	20.535346	22.092254	23.621747	25.124844	26.602384	28.05421	29.480238	30.881494	32.259294	33.614523
Ghana	8.0992678	8.8646008	9.635536	10.416879	11.210531	12.017076	12.830359	13.637309	14.420796	15.168121
Guatemala	29.88161	32.452289	35.033019	37.624603	40.227556	42.841384	45.465506	48.100301	50.746298	53.403564
Guyana	34.12602	37.166359	40.227689	43.307841	46.404811	49.516887	52.642594	55.780483	58.929234	62.08755
Haiti	3.0038011	3.3311818	3.6621484	3.9885994	4.3036287	4.6039158	4.8864062	5.1435295	5.36745	5.5511285
Honduras	16.001946	17.308392	18.601587	19.876429	21.128976	22.356925	23.559891	24.738168	25.892993	27.025035
Hong Kong	25.342379	27.402982	29.444987	31.467236	33.468536	35.447449	37.402565	39.332944	41.237861	43.11651
India	16.075682	17.292785	18.486224	19.655728	20.800965	21.921281	23.016007	24.084812	25.127449	26.143583
Indonesia	11.424757	12.230794	13.012645	13.770375	14.503904	15.212955	15.897016	16.555473	17.187587	17.792675
Iran	11.478995	12.103559	12.672086	13.189783	13.661422	14.088494	14.472996	14.821007	15.139818	15.435279
Iraq	43.071196	47.081361	51.146888	55.241565	59.346837	63.454527	67.570545	71.707647	75.885426	80.117816
Japan	-1.676442	-1.978028	-2.301788	-2.645013	-3.005371	-3.381511	-3.772556	-4.177205	-4.594216	-5.022374
Laos	16.537883	17.828793	19.091913	20.321551	21.51293	22.663533	23.771789	24.835392	25.852378	26.821259
Malaysia	19.646207	21.234901	22.811149	24.373622	25.920818	27.451544	28.964055	30.455619	31.923037	33.363605
Mexico	13.348018	14.285813	15.196629	16.081311	16.940338	17.773747	18.580937	19.360926	20.112386	20.834185
Myanmar	9.299638	9.9614995	10.596189	11.202134	11.777918	12.322715	12.83553	13.31475	13.758638	14.166093
New Zealand	12.623066	13.605003	14.568499	15.509157	16.423483	17.310181	18.169044	18.999006	19.799466	20.570101
Nicaragua	16.981979	18.221152	19.425855	20.596159	21.731958	22.832586	23.897203	24.92544	25.916911	26.871232
Nigeria	35.326554	38.634776	41.988502	45.393782	48.855171	52.37299	55.945895	59.574902	63.261013	67.004867
Pakistan	22.314386	24.129854	25.928156	27.698782	29.433792	31.12983	32.787439	34.407477	35.992403	37.544054
Panama	18.049794	19.460932	20.854885	22.22995	23.584653	24.918042	26.229106	27.516083	28.77698	30.010065
Peru	13.959719	15.10811	16.243527	17.35822	18.446137	19.504179	20.53188	21.529056	22.496631	23.435048
Philippines	21.537825	23.360939	25.182846	27.002728	28.819534	30.632137	32.43887	34.237456	36.02528	37.800055
Republic of Korea	4.0445829	4.2434059	4.4185691	4.5696348	4.6959651	4.7971473	4.8721184	4.9187898	4.9345895	4.91751
Saudi Arabia	27.187359	29.258369	31.272788	33.222517	35.102296	36.908437	38.643088	40.314488	41.934694	43.513118
Senegal	35.344714	38.507079	41.700882	44.927636	48.18834	51.482376	54.808866	58.168158	61.560707	64.986364
Sierra Leone	27.435162	29.766072	32.101131	34.444904	36.80025	39.167239	41.54343	43.926139	46.311637	48.696647
Singapore	13.112251	13.945266	14.770197	15.580885	16.371813	17.14256	17.892043	18.612679	19.295019	19.931281
South Africa	6.031323	6.5150131	6.9991007	7.4709647	7.921271	8.347048	8.7503616	9.133029	9.4986822	9.8499697
Thailand	5.1721001	5.4242903	5.6540915	5.8626096	6.0506552	6.2187417	6.3668998	6.4947482	6.6015682	6.6866787
United Arab Emirates	30.679488	32.670766	34.603088	36.489703	38.340482	40.157836	41.939467	43.684868	45.392232	47.060129
United States of America	10.401217	11.233006	12.056309	12.870488	13.675055	14.469654	15.254195	16.028833	16.793908	17.549705
Uruguay	4.4619254	4.8222461	5.1686282	5.503216	5.8272903	6.1402255	6.4404729	6.7273773	7.000492	7.2592213
Viet Nam	11.647316	12.375117	13.058873	13.700979	14.303658	14.867218	15.392445	15.882778	16.342511	16.775017
EU27	2.5545256	2.6949091	2.8233694	2.9398148	3.0441884	3.1366243	3.217159	3.2855737	3.3415828	3.3851405
OCARI	8.5185968	9.1094039	9.6766756	10.219083	10.735577	11.22531	11.688019	12.123877	12.533466	12.917208
OME	28.669087	31.066454	33.463311	35.85944	38.254451	40.6475	43.037642	45.424307	47.806965	50.184912
OAFR	32.142205	35.051024	37.986994	40.951755	43.946413	46.970451	50.022774	53.103303	56.212018	59.34878
OEUR	-2.321384	-2.597421	-2.890794	-3.201303	-3.528333	-3.871754	-4.230267	-4.600494	-4.978064	-5.359393
ONAFR	20.244202	21.824279	23.376851	24.905146	26.411533	27.895951	29.357251	30.79556	32.210981	33.603643
ONASIA	14.661255	15.794165	16.88548	17.937098	18.950799	19.925355	20.860211	21.759176	22.627567	23.469846
OOCEA	18.255327	19.71182	21.154579	22.582204	23.993533	25.387887	26.76476	28.12335	29.46291	30.782878
OSAM	11.97289	12.841406	13.685269	14.502807	15.292685	16.054094	16.786727	17.490393	18.165147	18.810998
OSEASIA	12.739004	13.673783	14.585677	15.474722	16.340822	17.183598	18.002466	18.796897	19.566303	20.310152
OWAFR	35.697243	39.019757	42.388084	45.806197	49.277011	52.800463	56.375321	60.002003	63.680897	67.412092

Table 22. Continued

Region	to 2021	to 2022	to 2023	to 2024	to 2025
Argentina	75.70268903	82.36705002	89.22512956	96.2769028	103.5246669
Australia	39.61629814	43.30881902	46.99487975	50.79698077	54.75489493
Bangladesh	105.184917	116.6501112	128.5574146	140.9131427	153.7232284
Belize	37.90179596	41.43761503	45.00969577	48.61705684	52.2587006
Brazil	73.8487941	81.49814104	89.48405924	97.82135785	106.5254976
Brunei	24.69006643	26.62722874	28.54496292	30.5146123	32.58951541
Cambodia	110.7568197	123.2223295	136.2468917	149.8453192	164.0323299
Canada	33.52969537	36.66764321	39.87933283	43.16649715	46.53090983
Chile	73.99536241	81.82515372	90.00728564	98.55761349	107.4927061
China	156.1459463	174.0761625	193.2614939	213.7897985	235.7550843
Colombia	69.11868513	76.55990728	84.3285432	92.4389991	100.9063151
Costa Rica	56.70846362	62.4265841	68.30001163	74.33105296	80.52199254
Cote D'Ivoire	47.87678382	52.21504041	56.61358537	61.07134997	65.58722825
Cuba	90.66880189	102.5917205	114.714398	127.4795285	140.8752413
Egypt	40.58561872	46.05555673	51.71558931	57.57144537	63.62899585
El Salvador	45.56484355	50.53725992	55.67497799	60.84118851	66.17484547
Ghana	158.200526	174.3012911	190.7218704	207.4292969	224.3901754
Guatemala	48.18841931	53.25873919	58.48140378	63.83431721	69.32339976
Guyana	60.90052602	65.59466867	70.34121505	75.13836924	79.98430662
Haiti	47.03520937	51.46409115	55.99530599	60.63029524	65.37049765
Honduras	58.67625575	64.86322136	71.22776877	77.78003182	84.52463752
Hong Kong	76.77914141	84.02708621	91.57219674	99.42665681	107.6031497
India	159.0031241	179.9823771	202.6609497	227.1764866	253.677782
Indonesia	91.43564165	100.4331168	109.8534733	119.7165865	130.0432661
Iran	52.4414867	57.47205576	62.6686336	68.03669851	73.58190956
Iraq	108.1125339	119.1777597	130.6565138	142.5552333	154.8800759
Japan	16.8117332	17.37658517	17.94416851	18.51449645	19.08758226
Laos	134.1285879	148.8291237	164.2089538	180.2846379	197.0724009
Malaysia	78.76209359	85.46094957	92.07981347	98.84121292	105.9293619
Mexico	57.17983318	62.83830717	68.70048623	74.77370373	81.06555707
Myanmar	78.31666503	86.21711417	94.34384117	102.698007	111.0440245
New Zealand	34.36710146	37.25828003	40.15158871	43.11386405	46.15981143
Nicaragua	42.43921336	46.0856105	49.67239075	53.34172348	57.09537377
Nigeria	99.30840635	109.2738267	119.737518	130.7243939	142.2606136
Pakistan	64.23887453	70.92521772	77.87512155	85.1774117	92.80000686
Panama	94.9745371	102.8374621	110.71692	118.6169794	126.5551618
Peru	89.13830921	97.79514195	106.8217391	116.2451929	126.055734
Philippines	78.99835826	87.11230919	95.44864813	104.0646679	112.9096119
Republic of Korea	58.33512704	63.11403138	67.83087638	72.47351585	77.0309456
Saudi Arabia	66.67522993	72.84221344	79.23737534	85.86915823	92.74631708
Senegal	69.45992697	76.57930788	83.84941987	91.26746771	98.75330199
Sierra Leone	88.62119198	97.69992199	106.9301589	116.3015028	125.8033787
Singapore	91.14553047	99.55593381	108.3363949	117.5031963	127.0733369
South Africa	64.46189435	72.35606528	80.62915641	89.29935592	98.385725
Thailand	76.06789833	83.46275006	91.16818557	99.19724936	107.5635338
UAE	61.32712477	66.94974849	72.71742104	78.63214079	84.6958844
Uruguay	60.14485871	65.41297756	70.85349336	76.47153113	82.27245308
USA	34.90899253	38.41662634	42.01545863	45.70786055	49.49626492
Vietnam	115.8125922	129.4087855	143.861539	159.224816	175.5559794
OCARI	55.58909809	61.82410726	68.18700677	74.73935081	81.50540895
OME	64.33095149	70.71870499	77.25942094	83.95366118	90.80191767
EU27	25.21541118	27.52892342	29.88981263	32.27260916	34.69861123
OAFR	88.19836099	96.36941193	104.8945482	113.7933087	123.0848195
OEUR	27.69059679	30.31190647	32.9828467	35.70642323	38.38323572
ONAFR	45.60265961	50.51146025	55.38136411	60.21818129	65.08810812
ONASIA	67.93492723	72.66200818	77.31609008	81.90699732	86.49750166
OOCEA	52.06068054	56.6391738	61.2838607	65.99340988	70.76614222
OSAM	64.5830634	71.2943832	78.20114395	85.31927115	92.78979304
OSEASIA	88.19836099	96.36941193	104.8945482	113.7933087	123.0848195
OWAFR	94.11873232	103.5046811	113.2709274	123.4309121	133.9953401

Based on UN, 2011, World Population Prospects

Table 23. GDP growth in percentage change from baseline for in the model included regions.

Region	to 2010	to 2011	to 2012	to 2013	to 2014	to 2015
Argentina	9.160916925	16.80218111	22.29188362	27.79501838	33.41799919	39.15497316
Australia	2.747031874	4.493731416	6.383997582	10.21823292	13.63963404	17.34347042
Bangladesh	5.834783895	12.75982951	20.55904881	28.42681211	36.70405604	45.28011473
Belize	2	4.652	7.896212	10.91730594	14.24482511	17.50096486
Brazil	7.489642894	11.57424932	16.42772917	22.24911563	28.23932229	34.13833112
Brunei	3.2	5.1608	6.9485336	8.870395885	10.85026186	12.87785025
Cambodia	6.69999858	13.43795929	21.2616556	29.36712361	37.89764574	46.86791819
Canada	3.071007811	5.235498975	7.234973455	10.13031774	12.993706	15.81854865
Chile	5.198136259	11.72042071	16.41267838	22.00048694	27.73450982	33.61029728
China	10.300012	20.33731309	30.5659847	42.13330892	54.69929295	67.84280008
Colombia	4.307161592	9.313905348	14.45641209	19.72140704	25.10887036	30.61366066
Costa Rica	3.5	7.308748957	11.48468176	16.15809543	20.78178983	25.52961051
Cote D'Ivoire	3.01	-3.68565	2.093211	8.116710449	14.06312952	19.99441226
Cuba	2.06463583	2.995930724	6.312234899	13.80534635	21.73097868	30.1056429
Egypt	5.18	6.12662	7.08175958	8.152577176	9.450408102	10.87326341
El Salvador	0.956552718	3.610029797	7.068056547	11.01019937	14.77060692	18.64471442
Ghana	6.620084167	24.21239805	35.63993868	47.37008057	59.34997127	71.52649663
Guatemala	2.588657511	6.026404944	9.96660799	13.57168209	17.18602991	20.94181038
Guyana	4.355789506	9.419116655	15.89253695	23.10086732	29.65227578	33.93234754
Haiti	-5.051730289	2.069389939	8.499761506	14.19599898	18.47834895	22.32588708
Honduras	2.599971293	6.216168841	10.89376039	15.57872147	20.32802435	25.41253975
Hong Kong	6.970071293	12.62450474	18.39199271	24.54957091	30.40340074	36.53236057
India	9.719104343	17.96446373	27.47169758	38.38668174	50.01116301	62.31207837
Indonesia	6.104860829	12.78946706	20.00799295	28.04852848	35.60339166	43.33278499
Iran	2.5	5.798136009	10.03006145	14.65132403	19.35202831	24.18578546
Iraq	2.764389541	14.85206861	24.3582351	33.27181646	41.48970074	49.91238487
Japan	5.1211781	4.490451031	6.266788698	8.987150953	10.60794672	12.25204405
Laos	8.417118038	17.73450947	26.6633301	35.51763692	45.68145969	59.22983545
Malaysia	7.155594744	12.1919077	17.80150308	24.28602132	31.34726644	38.13025005
Mexico	5.500262173	9.72027266	13.99936329	18.3313391	22.70959865	27.1271442
Myanmar	5.3	11.1968	17.2014272	23.06149856	29.21457349	35.57839123
New Zealand	2.500533448	3.726618779	5.547208771	9.115175295	12.41057077	15.82676768
Nicaragua	4.480370254	8.51605236	11.92572012	15.26109745	18.44270738	21.66440356
Nigeria	7.85	16.31932388	24.15850511	32.04444787	40.03957636	48.091852
Pakistan	4.357649436	6.862233023	10.60241118	15.46891727	20.95369084	26.84413558
Panama	7.462617376	15.79952295	24.32605913	33.08293378	41.45858992	48.70684046
Peru	8.794749982	16.75550805	23.96778371	31.02026576	37.49992925	44.07312882
Philippines	7.632263915	12.69098032	18.21283835	24.12348027	30.21354789	36.54624804
Republic of Korea	6.161843254	10.06313853	14.36812564	19.18946167	23.51802907	28.73821903
Saudi Arabia	3.761993182	9.634327815	14.94628307	20.68098141	26.55210316	32.38199933
Senegal	4.167529162	8.750900445	13.65556606	19.02010877	24.744976	30.64541337
Sierra Leone	4.9485	10.195925	16.26772047	23.17402306	30.55214704	38.17639243
Singapore	14.47127163	20.53824902	26.56516147	34.08170013	40.8742056	47.53568781
South Africa	2.841136858	6.297719389	9.929984576	14.30256961	18.9906406	24.10723815
Thailand	7.803404956	12.35723531	17.48805849	24.06728381	30.23246297	36.55537368
UAE	3.213266949	8.477862776	13.90125748	19.44237802	24.81728503	29.80997643
Uruguay	8.467675272	14.57938795	19.06308524	23.2842374	27.50089715	31.65180899
USA	3.029969063	4.575418599	6.457776133	9.332136089	12.50276804	15.54034277
Vietnam	6.783424448	13.12264368	20.4586866	28.8262097	37.81495723	47.69684405
OCARI	1.94362895	4.442419509	8.083122436	12.56644542	17.32953868	22.22505446
OME	4.065269368	8.505463551	13.5979136	18.90094246	24.2524728	29.57510259
EU27	1.825428164	3.509285016	4.924436963	6.898530796	9.105857234	11.52245917
OAFR	13.66863019	19.56699719	25.40954141	32.62621502	39.21115531	45.75539082
OEUR	1.369333254	3.225848695	5.453218806	7.893127311	10.56394586	13.10345413
ONAFR	3.369388056	-8.983518604	-2.836203029	2.321014882	8.465138192	14.70435159
ONASIA	6.739006124	12.82981954	18.32346385	23.76207968	29.60425158	35.83085147
OOCEA	3.384888309	7.433197688	10.80865502	13.30887193	16.97833772	25.87913209
OSAM	3.773288565	8.946105466	13.69215998	18.5812642	23.45140902	28.45499024
OSEASIA	13.66863019	19.56699719	25.40954141	32.62621502	39.21115531	45.75539082
OWAFR	6.857046058	13.96368299	21.39177258	29.03510961	36.76087955	44.56064766

Table 23. Continued

Region	to 2016	to 2017	to 2018	to 2019	to 2020
Argentina	44.99948203	50.94446079	56.85277526	62.94733269	69.23030211
Australia	21.03305604	24.99164794	28.73532574	32.47505227	36.07319276
Bangladesh	54.24471725	63.6063949	73.3734172	83.55377246	94.15514897
Belize	20.79967504	24.14012311	27.52145159	30.94277924	34.40320236
Brazil	40.17455602	46.34223648	52.78129489	59.50367186	66.52183343
Brunei	14.95432031	17.0136056	19.03183909	20.97089877	22.81330985
Cambodia	56.29273267	66.18695683	76.5655141	87.44336304	98.83547638
Canada	18.59819382	21.44455047	24.35921968	27.34384095	30.40009314
Chile	39.62276065	45.90578488	52.4715452	59.33276474	66.50273915
China	81.10238129	94.86616227	109.0913921	123.7277896	139.3887348
Colombia	36.36066173	42.36053084	48.6243942	55.16386754	61.99107771
Costa Rica	30.36537457	35.3422278	40.46257667	45.72881509	51.14332277
Cote D'Ivoire	25.39416081	30.66071556	35.23384061	39.38521525	43.59984557
Cuba	38.94612428	48.26877019	58.09010542	68.42603712	79.29133465
Egypt	15.30819394	20.49706267	25.26115988	30.19380557	35.30018584
El Salvador	22.78923038	27.06718931	31.36041714	35.96439169	40.74816983
Ghana	84.3713361	97.90193259	112.1350375	127.0866522	142.4518633
Guatemala	24.90079606	29.27071297	33.80040201	38.460362	43.2552975
Guyana	38.27633883	42.6827386	47.14998616	51.6764741	56.26055132
Haiti	26.24971138	30.2498179	34.32616435	38.47867028	42.70721735
Honduras	30.42598777	35.76323598	41.23426521	46.87071512	52.69735828
Hong Kong	42.94938152	49.66800245	56.40306256	63.12839425	69.81665842
India	75.45935672	89.67156461	105.0349613	121.6427932	139.5958595
Indonesia	51.07275538	58.92853865	66.78992694	74.63425465	82.84206461
Iran	29.15321688	33.67001126	38.29364105	42.8573312	47.57162313
Iraq	58.71104651	67.84913304	77.32974172	87.19560131	97.45413334
Japan	13.60181587	14.47065866	15.09235207	15.69017091	16.24959948
Laos	70.21669409	81.77842473	93.93285584	106.6976936	120.0904861
Malaysia	44.85120457	51.66992293	58.52513159	65.37292282	72.11706063
Mexico	31.70372139	36.44505536	41.35707735	46.44593214	51.71798569
Myanmar	42.15546846	48.94816584	55.95868347	63.18905672	70.64115235
New Zealand	18.93121952	22.00325855	25.04655146	28.29335477	31.42633246
Nicaragua	24.93809108	28.28981971	31.72900941	35.25846386	38.87104023
Nigeria	56.01476608	63.97151915	72.17009511	80.77859986	89.81752986
Pakistan	33.18634236	39.49152698	45.43119138	51.48170537	57.69082267
Panama	56.01869269	63.68521048	71.48266124	79.29524216	87.12601238
Peru	50.85395913	57.89680645	65.22777929	72.86801607	80.83730396
Philippines	42.98625509	49.61393727	56.53684701	63.79169279	71.2797281
Republic of Korea	33.76080502	38.76153235	43.79223346	48.66242214	53.50782642
Saudi Arabia	38.12774658	43.84242299	49.4633781	54.99352309	60.72828345
Senegal	36.65510238	42.84694507	49.22225423	55.78219804	62.52779798
Sierra Leone	46.08008208	54.10163155	62.39441976	70.95869301	79.70414654
Singapore	54.12094175	60.90226319	67.98196277	75.37316913	83.08958857
South Africa	29.94027834	36.30735198	42.8832896	49.7416875	56.9292885
Thailand	42.9210358	49.26331308	55.62416109	62.16037586	68.97111165
UAE	34.87905601	40.02099126	45.23217372	50.50892977	55.84753114
Uruguay	36.01487793	40.53578556	45.2190304	50.06955513	55.04424863
USA	18.65993203	21.74509026	24.91046261	28.15813463	31.49024614
Vietnam	58.28178238	68.77021602	79.67058742	90.98983443	103.022194
OCARI	27.27040927	32.54968455	38.00956501	43.67613896	49.54567471
OME	35.02252374	40.59832367	46.30171521	52.13388848	58.09552729
EU27	13.85668173	16.12558801	18.36173079	20.61167183	22.90244402
OAFR	52.17439146	58.78546769	65.68156579	72.87289324	80.37140309
OEUR	15.49318389	17.86740441	20.28580297	22.71752907	25.15654496
ONAFR	20.37013158	25.51459322	30.60580933	35.65668163	40.66861128
ONASIA	41.79305013	47.61807239	53.02550198	58.147409	63.10459408
OOCEA	30.1525452	34.41311117	38.72734574	43.1068143	47.5494927
OSAM	33.70978263	39.3338418	45.30046444	51.59890055	58.02898409
OSEASIA	52.17439146	58.78546769	65.68156579	72.87289324	80.37140309
OWAFR	52.29109088	60.10716406	68.10787833	76.42774643	85.09452844

Table 23. Continued

Region	to 2021	to 2022	to 2023	to 2024	to 2025
Argentina	75.70268903	82.36705002	89.22512956	96.2769028	103.5246669
Australia	39.61629814	43.30881902	46.99487975	50.79698077	54.75489493
Bangladesh	105.184917	116.6501112	128.5574146	140.9131427	153.7232284
Belize	37.90179596	41.43761503	45.00969577	48.61705684	52.2587006
Brazil	73.8487941	81.49814104	89.48405924	97.82135785	106.5254976
Brunei	24.69006643	26.62722874	28.54496292	30.5146123	32.58951541
Cambodia	110.7568197	123.2223295	136.2468917	149.8453192	164.0323299
Canada	33.52969537	36.66764321	39.87933283	43.16649715	46.53090983
Chile	73.99536241	81.82515372	90.00728564	98.55761349	107.4927061
China	156.1459463	174.0761625	193.2614939	213.7897985	235.7550843
Colombia	69.11868513	76.55990728	84.3285432	92.4389991	100.9063151
Costa Rica	56.70846362	62.4265841	68.30001163	74.33105296	80.52199254
Cote D'Ivoire	47.87678382	52.21504041	56.61358537	61.07134997	65.58722825
Cuba	90.66880189	102.5917205	114.714398	127.4795285	140.8752413
Egypt	40.58561872	46.05555673	51.71558931	57.57144537	63.62899585
El Salvador	45.56484355	50.53725992	55.67497799	60.84118851	66.17484547
Ghana	158.200526	174.3012911	190.7218704	207.4292969	224.3901754
Guatemala	48.18841931	53.25873919	58.48140378	63.83431721	69.32339976
Guyana	60.90052602	65.59466867	70.34121505	75.13836924	79.98430662
Haiti	47.03520937	51.46409115	55.99530599	60.63029524	65.37049765
Honduras	58.67625575	64.86322136	71.22776877	77.78003182	84.52463752
Hong Kong	76.77914141	84.02708621	91.57219674	99.42665681	107.6031497
India	159.0031241	179.9823771	202.6609497	227.1764866	253.677782
Indonesia	91.43564165	100.4331168	109.8534733	119.7165865	130.0432661
Iran	52.4414867	57.47205576	62.6686336	68.03669851	73.58190956
Iraq	108.1125339	119.1777597	130.6565138	142.5552333	154.8800759
Japan	16.8117332	17.37658517	17.94416851	18.51449645	19.08758226
Laos	134.1285879	148.8291237	164.2089538	180.2846379	197.0724009
Malaysia	78.76209359	85.46094957	92.07981347	98.84121292	105.9293619
Mexico	57.17983318	62.83830717	68.70048623	74.77370373	81.06555707
Myanmar	78.31666503	86.21711417	94.34384117	102.698007	111.0440245
New Zealand	34.36710146	37.25828003	40.15158871	43.11386405	46.15981143
Nicaragua	42.43921336	46.0856105	49.67239075	53.34172348	57.09537377
Nigeria	99.30840635	109.2738267	119.737518	130.7243939	142.2606136
Pakistan	64.23887453	70.92521772	77.87512155	85.1774117	92.80000686
Panama	94.9745371	102.8374621	110.71692	118.6169794	126.5551618
Peru	89.13830921	97.79514195	106.8217391	116.2451929	126.055734
Philippines	78.99835826	87.11230919	95.44864813	104.0646679	112.9096119
Republic of Korea	58.33512704	63.11403138	67.83087638	72.47351585	77.0309456
Saudi Arabia	66.67522993	72.84221344	79.23737534	85.86915823	92.74631708
Senegal	69.45992697	76.57930788	83.84941987	91.26746771	98.75330199
Sierra Leone	88.62119198	97.69992199	106.9301589	116.3015028	125.8033787
Singapore	91.14553047	99.55593381	108.3363949	117.5031963	127.0733369
South Africa	64.46189435	72.35606528	80.62915641	89.29935592	98.385725
Thailand	76.06789833	83.46275006	91.16818557	99.19724936	107.5635338
UAE	61.32712477	66.94974849	72.71742104	78.63214079	84.6958844
Uruguay	60.14485871	65.41297756	70.85349336	76.47153113	82.27245308
USA	34.90899253	38.41662634	42.01545863	45.70786055	49.49626492
Vietnam	115.8125922	129.4087855	143.861539	159.224816	175.5559794
OCARI	55.58909809	61.82410726	68.18700677	74.73935081	81.50540895
OME	64.33095149	70.71870499	77.25942094	83.95366118	90.80191767
EU27	25.21541118	27.52892342	29.88981263	32.27260916	34.69861123
OAFR	88.19836099	96.36941193	104.8945482	113.7933087	123.0848195
OEUR	27.69059679	30.31190647	32.9828467	35.70642323	38.38323572
ONAFR	45.60265961	50.51146025	55.38136411	60.21818129	65.08810812
ONASIA	67.93492723	72.66200818	77.31609008	81.90699732	86.49750166
OOCEA	52.06068054	56.6391738	61.2838607	65.99340988	70.76614222
OSAM	64.5830634	71.2943832	78.20114395	85.31927115	92.78979304
OSEASIA	88.19836099	96.36941193	104.8945482	113.7933087	123.0848195
OWAFR	94.11873232	103.5046811	113.2709274	123.4309121	133.9953401

Based on World Bank World Development Indicators and International Financial Statistics of the IMF, 2012

Table 24. Demand elasticities for in the model included regions.

Country	Demand elasticity with respect to price	Demand elasticity with respect to income
Argentina	-0.07	0.11
Australia	-0.41	0.43
Bangladesh	-0.01	-0.04
Belize	-0.05	0.46
Brazil	-0.1	-0.05
Brunei	-0.3	0.09
Cambodia	-0.2	-0.23
Canada	-0.21	0.47
Chile	-0.07	0.11
China	-0.16	-0.19
Colombia	-0.1	-0.05
CostaRica	-0.05	0.46
CoteIvoire	-0.55	0.14
Cuba	-0.05	0.46
Egypt	-0.15	0.3
ElSalvador	-0.05	0.46
Ghana	-0.15	0.14
Guatemala	-0.05	0.46
Guyana	-0.1	-0.05
Haiti	-0.05	0.46
Honduras	-0.05	0.46
HongKong	-0.11	-0.26
India	-0.2	-0.04
Indonesia	-0.14	-0.12
Iran	-0.35	0.2
Iraq	-0.1	0.14
Japan	-0.11	-0.26
Laos	-0.2	-0.23
Malaysia	-0.3	0.09
Mexico	-0.05	0.46
Myanmar	-0.1	0.13
NewZealand	-0.41	0.43
Nicaragua	-0.05	0.46
Nigeria	-0.15	0.25
Pakistan	-0.18	0.1
Panama	-0.05	0.46
Peru	-0.1	-0.05
Philippines	-0.25	0.15
RepKorea	-0.54	-0.27
SaudiArabia	-0.25	0.1
Senegal	-0.15	0.14
SierraLeone	-0.15	0.14
Singapore	-0.11	-0.03
SouthAfrica	-0.2	0.47
Thailand	-0.05	-0.16
UAE	-0.25	0.1
Uruguay	-0.17	0.5
USA	-0.01	0.34
Vietnam	-0.2	-0.23
OCARI	-0.05	0.46
OME	-0.25	0.1
EU27	-0.2	0.38
OAFR	-0.05	0.1
OEUR	-0.15	0.4
ONAFR	-0.2	0.3
ONASIA	-0.18	0.1
OOCEA	-0.41	0.43
OSAM	-0.07	0.11
OSEASIA	-0.3	0.09
OWAFR	-0.15	0.25

Table 25. Production cost characteristics of hybrid rice in major hybrid rice producing

Bangladesh

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	7.32			6.04		
Production Factors	relative (%)	absolut (Tk/ha)	absolut (Tk/t of yield)	relative (%)	absolut (Tk/ha)	absolut (Tk/t of yield)
Land	40	20,000.00	2,732.24	37	18,000.00	2,980.13
Capital	30	15,000.00	2,049.18	33	16,000.00	2,649.01
Labour	0	118.00	16.12	0	110.00	18.21
Intermediate Inputs						
Fertilizer	1	403.00	55.05	1	342.00	56.62
Pesticides	2	1,043.00	142.49	2	785.00	129.97
Energy	5	2,536.00	346.45	4	1,890.00	312.91
Water	18	9,109.00	1,244.40	21	10,316.00	1,707.95
Seed	4	1,882.00	257.10	3	1,229.00	203.48
TOTAL	100	50,091.00	6,843.03	100	48,672.00	8,058.28

Source of Data: Mahabub, 2008

Table 25. Continued

China

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	7.60			4.40		
Production Factors	relative (%)	absolut (Dong/ha)	absolut (Dong/t of yield)	relative (%)	absolut (Dong/ha)	absolut (Dong/t of yield)
Land	7	500.00	65.79	9	500.00	113.64
Capital	18	1,300.00	171.05	20	1,300.00	295.45
Labour	8	600.00	78.95	9	600.00	136.36
Intermediate Inputs						
Fertilizer	26	1,879.00	247.24	24	1,569.50	356.70
Pesticides	3	240.50	31.64	4	239.00	54.32
Energy	29	2,076.50	273.22	32	2,076.50	471.93
Water						
Seed	9	621.00	81.71	2	132.50	30.11
TOTAL	100	7,217.00	949.61	100	6,417.50	1,458.52

Source: Li, et al. (2009); Pingali, et al. (1998)

Exact production cost data for China could not be found, based on the fact that Vietnam's hybrid rice seeds are in the majority imported from China, the production cost characteristics of Vietnam are therefore taken.

Table 25. Continued

India

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	5.58			4.47		
Production Factors	relative (%)	absolut (USD/ha)	absolut (USD/t of yield)	relative (%)	absolut (USD/ha)	absolut (USD/t of yield)
Land	5	23.57	4.23	5	23.57	5.28
Capital	15	88.47	15.86	14	74.22	16.62
Labour	26	149.02	26.72	30	152.41	34.13
Intermediate Inputs						
Fertilizer	29	193.15	34.63	28	171.63	38.43
Pesticides	8	28.53	5.12	10	26.08	5.84
Energy						
Water	9	28.18	5.05	10	32.05	7.18
Seed	8	55.80	10.00	3	18.45	4.13
TOTAL	100	566.73	101.60	100	498.41	111.60

Source of Data: Janaiah and Xie, 2010

Note: Janaiah and Xie collected the data in three regions of India, the weighted average according to production area of each region is taken here.

Table 25. Continued

Indonesia

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	7.30			6.09		
Production Factors	relative (%)	absolut (Rp/ha)	absolut (Rp/t of yield)	relative (%)	absolut (Rp/ha)	absolut (Rp/t of yield)
Land	26	3,000,000	113,500	31	3,400,000	110,500
Capital	13	1,500,000	56,750	11	1,200,000	39,000
Labour	35	3,925,000	148,496	36	3,925,000	127,563
Intermediate Inputs						
Fertilizer	8	925,000	34,996	8	925,000	30,063
Pesticides	3	350,000	13,242	3	350,000	11,375
Energy	4	450,000	17,025	5	550,000	17,875
Water						
Seed	11	1,200,000	45,400	6	700,000	22,750
TOTAL	100	11,350,000	429,408	100	11,050,000	359,125

Source of Data: provided by Indonesian Center of Rice Research

Table 25. Continued

Philippines

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	6.89			5.78		
Production Factors	relative (%)	absolut (Peso/ha)	absolut (Peso/t of yield)	relative (%)	absolut (Peso/ha)	absolut (Peso/t of yield)
Land	5	2,794.81	405.63	3	1,626.69	281.43
Capital	23	13,244.88	1,922.33	29	16,633.64	2,877.79
Labour	44	25,542.00	3,707.11	38	21,410.68	3,704.27
Intermediate Inputs						
Fertilizer	19	10,830.14	1,571.86	19	11,026.17	1,907.64
Pesticides	2	1,361.43	197.60	3	1,607.39	278.10
Energy	1	726.28	105.41	2	991.93	171.61
Water	3	1,530.23	222.09	3	1,497.38	259.06
Seed	4	2,236.26	324.57	3	1,980.65	342.67
TOTAL	100	58,266.04	8,456.61	100	56,774.53	9,822.58

Source of Data: Manalili et al., 2008

Table 25. Continued

USA

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	9.58			8.58		
Production Factors	relative (%)	absolut (USD/ha)	absolut (USD/t of yield)	relative (%)	absolut (USD/ha)	absolut (USD/t of yield)
Land	2	247.00	25.78	2	247.00	28.79
Capital	26	629.63	65.72	26	599.39	69.86
Labour	1	25.81	2.69	1	25.81	3.01
Intermediate Inputs						
Fertilizer	20	356.96	37.26	25	421.90	49.17
Pesticides	11	175.54	18.32	17	278.62	32.47
Energy	4	167.66	17.50	4	190.14	22.16
Water	21	317.32	33.12	21	317.32	36.98
Seed	15	296.40	30.94	3	64.02	7.46
TOTAL	100	2216.33	231.35	100	2144.21	249.91

Source of Data: University of Arkansas, 2011

Table 25. Continued

Vietnam

	hybrid varieties			*conventional varieties*		
Avg. yield (t/ha)	6.7			4.35		
Production Factors	relative (%)	absolut (Dong/ha)	absolut (Dong/t of yield)	relative (%)	absolut (Dong/ha)	absolut (Dong/t of yield)
Land	7	500.00	74.63	9	500.00	114.94
Capital	18	1,300.00	194.03	20	1,300.00	298.85
Labour	8	600.00	89.55	9	600.00	137.93
Intermediate Inputs						
Fertilizer	26	1,879.00	280.45	24	1,569.50	360.80
Pesticides	3	240.50	35.90	4	239.00	54.94
Energy	29	2,076.50	309.93	32	2,076.50	477.36
Water						
Seed	9	621.00	92.69	2	132.50	30.46
TOTAL	100	7,217.00	1,077.16	100	6,417.50	1,475.29

Source of Data: Pingali et al., 1998

Table 26. Assumed diffusion of hybrid rice in major hybrid rice producing countries.

Bangladesh

avg. yield advantage of hybrid rice: 1.28 (t/ha)[a]
total area of rice production (1000 ha): 11,800[b]
total rice production (t): 49,355,000b

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	735.00	6.50	-	-
2010	1,180.00	10.00	569,600.00	1.15
2011	1,416.00	12.00	871,680.00	1.77
2012	1,770.00	15.00	1,324,800.00	2.68
2013	2,242.00	19.00	1,928,960.00	3.91
2014	2,832.00	24.00	2,684,160.00	5.44
2015	3,540.00	30.00	3,590,400.00	7.27
2016	4,366.00	37.00	4,647,680.00	9.42
2017	5,428.00	46.00	6,007,040.00	12.17
2018	6,372.00	54.00	7,215,360.00	14.62
2019	7,198.00	61.00	8,272,640.00	16.76
2020	7,906.00	67.00	9,178,880.00	18.60
2021	8,496.00	72.00	9,934,080.00	20.13
2022	9,086.00	77.00	10,689,280.00	21.66
2023	9,558.00	81.00	11,293,440.00	22.88
2024	10,030.00	85.00	11,897,600.00	24.11
2025	10,384.00	88.00	12,350,720.00	25.02
2026	10,502.00	89.00	12,501,760.00	25.33
2027	10,620.00	90.00	12,652,800.00	25.64
2028	10,738.00	91.00	12,803,840.00	25.94
2029	10,856.00	92.00	12,954,880.00	26.25
2030	10,856.00	92.00	12,954,880.00	26.25

a. Data from Hossain, 2008
b. Data from FAOSTAT

Table 26. Continued

China

avg. yield advantage of hybrid rice: 3.2 (t/ha)[a]
total area of rice production (1000 ha): 30,117[b]
total rice production (t): 197,221,000[b]

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	18,600.00	63.20		
2010	20,479.47	68.00	6,014,291.71	3.05
2011	21,684.14	72.00	9,869,250.05	5.00
2012	22,888.82	76.00	13,724,208.38	6.96
2013	23,792.32	79.00	16,615,427.14	8.42
2014	24,394.66	81.00	18,542,906.30	9.40
2015	24,997.00	83.00	20,470,385.47	10.38
2016	25,599.33	85.00	22,397,864.64	11.36
2017	26,201.67	87.00	24,325,343.81	12.33
2018	26,502.84	88.00	25,289,083.39	12.82
2019	26,804.01	89.00	26,252,822.98	13.31
2020	27,105.18	90.00	27,216,562.56	13.80
2021	27,406.34	91.00	28,180,302.14	14.29
2022	27,707.51	92.00	29,144,041.73	14.78
2023	27,858.10	92.50	29,625,911.52	15.02
2024	28,008.68	93.00	30,107,781.31	15.27
2025	28,159.27	93.50	30,589,651.10	15.51
2026	28,309.85	94.00	31,071,520.90	15.75
2027	28,460.43	94.50	31,553,390.69	16.00
2028	28,611.02	95.00	32,035,260.48	16.24
2029	28,611.02	95.00	32,035,260.48	16.24
2030	28,611.02	95.00	32,035,260.48	16.24

a. Data from Li et al., 2009
b. Data from FAOSTAT

Table 26. Continued

India

avg. yield advantage of hybrid rice: 0.87 (t/ha)[a]

total area of rice production (1000 ha): 36,950[b]

total rice production (t): 120,620,000b

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	1,500.00	3.30	-	-
2010	1,813.00	4.00	347,430.00	0.29
2011	2,217.00	6.00	795,870.00	0.66
2012	2,956.00	8.00	1,616,160.00	1.34
2013	3,695.00	10.00	2,436,450.00	2.02
2014	4,434.00	12.00	3,256,740.00	2.70
2015	5,542.50	15.00	4,487,175.00	3.72
2016	7,020.50	19.00	6,127,755.00	5.08
2017	8,868.00	24.00	8,178,480.00	6.78
2018	11,085.00	30.00	10,639,350.00	8.82
2019	13,671.50	37.00	13,510,365.00	11.20
2020	16,997.00	46.00	17,201,670.00	14.26
2021	19,953.00	54.00	20,482,830.00	16.98
2022	22,539.50	61.00	23,353,845.00	19.36
2023	24,756.50	67.00	25,814,715.00	21.40
2024	26,604.00	72.00	27,865,440.00	23.10
2025	28,451.50	77.00	29,916,165.00	24.80
2026	29,929.50	81.00	31,556,745.00	26.16
2027	31,407.50	85.00	33,197,325.00	27.52
2028	32,516.00	88.00	34,427,760.00	28.54
2029	33,255.00	90.00	35,248,050.00	29.22
2030	33,994.00	92.00	36,068,340.00	29.90

a. Data from Janaiah, 2010

b. Data from FAOSTAT

Table 26. Continued

Indonesia

avg. yield advantage of hybrid rice: 1.21 (t/ha)[a]
total area of rice production (1000 ha): 13,244[b]
total rice production (t): 66,411,000b

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	62.00	0.40	-	-
2010	264.88	2.00	245,489.64	0.37
2011	529.77	4.00	565,999.28	0.85
2012	794.65	6.00	886,508.92	1.33
2013	1,191.98	9.00	1,367,273.38	2.06
2014	1,589.30	12.00	1,848,037.84	2.78
2015	1,986.63	15.00	2,328,802.30	3.51
2016	2,516.40	19.00	2,969,821.58	4.47
2017	3,178.61	24.00	3,771,095.68	5.68
2018	3,973.26	30.00	4,732,624.60	7.13
2019	4,900.35	37.00	5,854,408.34	8.82
2020	5,959.89	45.00	7,136,446.90	10.75
2021	6,886.98	52.00	8,258,230.64	12.44
2022	7,814.08	59.00	9,380,014.38	14.12
2023	8,608.73	65.00	10,341,543.30	15.57
2024	9,270.94	70.00	11,142,817.40	16.78
2025	9,800.71	74.00	11,783,836.68	17.74
2026	10,330.48	78.00	12,424,855.96	18.71
2027	10,727.80	81.00	12,905,620.42	19.43
2028	11,125.13	84.00	13,386,384.88	20.16
2029	11,390.01	86.00	13,706,894.52	20.64
2030	11,654.90	88.00	14,027,404.16	21.12

a. Data provided by Indonesian Center of Rice Research
b. Data from FAOSTAT

Table 26. Continued

Philippines

avg. yield advantage of hybrid rice: 1.103 (t/ha)[a]

total area of rice production (1000 ha): 4,354[b]

total rice production (t): 15,771,000[b]

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	346.00	7.80	-	-
2010	435.42	10.00	98,630.26	0.63
2011	522.50	12.00	194,683.91	1.23
2012	653.13	15.00	338,764.39	2.15
2013	827.30	19.00	530,871.69	3.37
2014	1,045.01	24.00	771,005.82	4.89
2015	1,306.26	30.00	1,059,166.78	6.72
2016	1,611.05	37.00	1,395,354.56	8.85
2017	2,002.93	46.00	1,827,596.00	11.59
2018	2,351.27	54.00	2,211,810.60	14.02
2019	2,656.06	61.00	2,547,998.39	16.16
2020	2,917.31	67.00	2,836,159.34	17.98
2021	3,135.02	72.00	3,076,293.47	19.51
2022	3,352.73	77.00	3,316,427.60	21.03
2023	3,526.90	81.00	3,508,534.91	22.25
2024	3,701.07	85.00	3,700,642.21	23.46
2025	3,831.70	88.00	3,844,722.69	24.38
2026	3,875.24	89.00	3,892,749.51	24.68
2027	3,918.78	90.00	3,940,776.34	24.99
2028	3,962.32	91.00	3,988,803.17	25.29
2029	4,005.86	92.00	4,036,829.99	25.60
2030	4,005.86	92.00	4,036,829.99	25.60

a. Data from Manalili, et al. (2008)

b. Data from FAOSTAT

Table 26. Continued

USA

avg. yield advantage of hybrid rice: 1 (t/ha)[a]

total area of rice production (1000 ha): 1,463[b]

total rice production (t): 11,027,000b

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	175.00	13.90	-	-
2010	277.97	19.00	102,970.00	0.93
2011	351.12	24.00	176,120.00	1.60
2012	438.90	30.00	263,900.00	2.39
2013	541.31	37.00	366,310.00	3.32
2014	672.98	46.00	497,980.00	4.52
2015	790.02	54.00	615,020.00	5.58
2016	892.43	61.00	717,430.00	6.51
2017	980.21	67.00	805,210.00	7.30
2018	1,053.36	72.00	878,360.00	7.97
2019	1,126.51	77.00	951,510.00	8.63
2020	1,185.03	81.00	1,010,030.00	9.16
2021	1,243.55	85.00	1,068,550.00	9.69
2022	1,287.44	88.00	1,112,440.00	10.09
2023	1,316.70	90.00	1,141,700.00	10.35
2024	1,345.96	92.00	1,170,960.00	10.62
2025	1,360.59	93.00	1,185,590.00	10.75
2026	1,375.22	94.00	1,200,220.00	10.88
2027	1,389.85	95.00	1,214,850.00	11.02
2028	1,389.85	95.00	1,214,850.00	11.02
2029	1,389.85	95.00	1,214,850.00	11.02
2030	1,389.85	95.00	1,214,850.00	11.02

a. Data from University of Arkansas, 2011

b. Data from FAOSTAT

Table 26. Continued

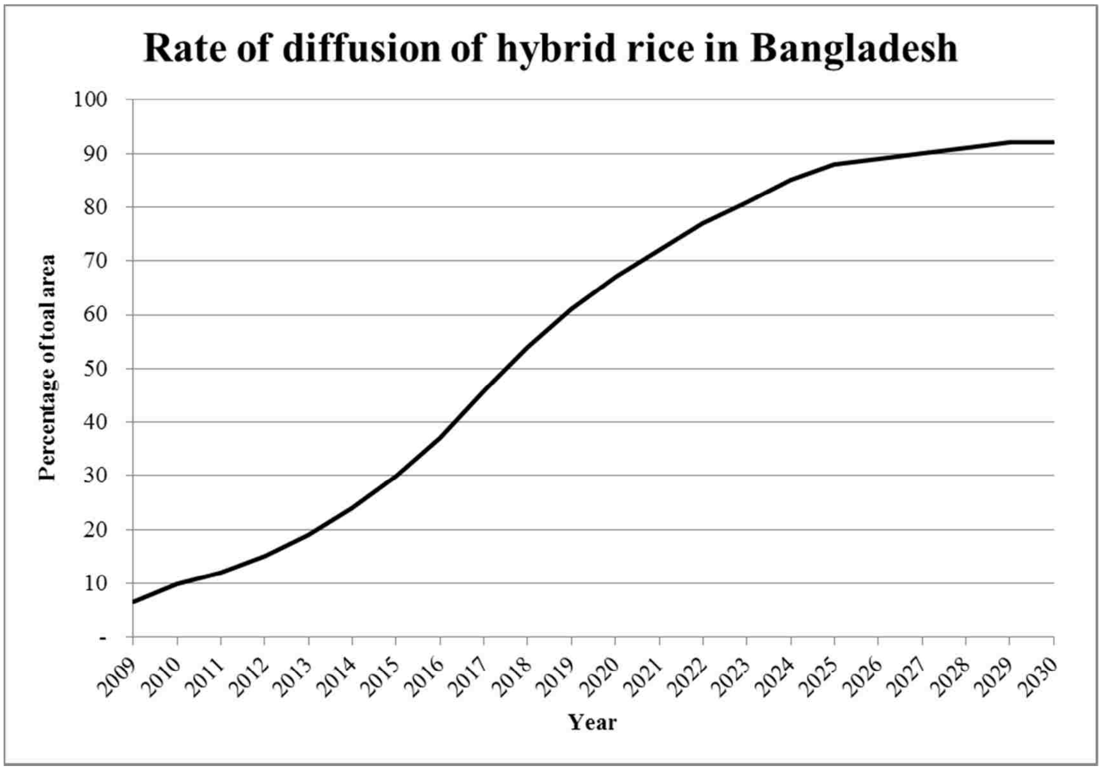
Vietnam

avg. yield advantage of hybrid rice: 1.75 (t/ha)[a]
total area of rice production (1000 ha): 7,513[b]
total rice production (t): 39,989,000b

year	area (1000 ha)	% of total area	increase to base year (t)	% increase of total production to base year
2009	645.00	8.70	-	-
2010	751.37	10.00	186,147.50	0.47
2011	901.64	12.00	449,127.00	1.12
2012	1,127.06	15.00	843,596.25	2.11
2013	1,427.60	19.00	1,369,555.25	3.42
2014	1,803.29	24.00	2,027,004.00	5.07
2015	2,254.11	30.00	2,815,942.50	7.04
2016	2,780.07	37.00	3,736,370.75	9.34
2017	3,456.30	46.00	4,919,778.50	12.30
2018	4,057.40	54.00	5,971,696.50	14.93
2019	4,583.36	61.00	6,892,124.75	17.24
2020	5,034.18	67.00	7,681,063.25	19.21
2021	5,409.86	72.00	8,338,512.00	20.85
2022	5,785.55	77.00	8,995,960.75	22.50
2023	6,086.10	81.00	9,521,919.75	23.81
2024	6,386.65	85.00	10,047,878.75	25.13
2025	6,612.06	88.00	10,442,348.00	26.11
2026	6,687.19	89.00	10,573,837.75	26.44
2027	6,762.33	90.00	10,705,327.50	26.77
2028	6,837.47	91.00	10,836,817.25	27.10
2029	6,912.60	92.00	10,968,307.00	27.43
2030	6,912.60	92.00	10,968,307.00	27.43

a. Data from Nguyen, 2008
b. Data from FAOSTAT

Table 26. Continued



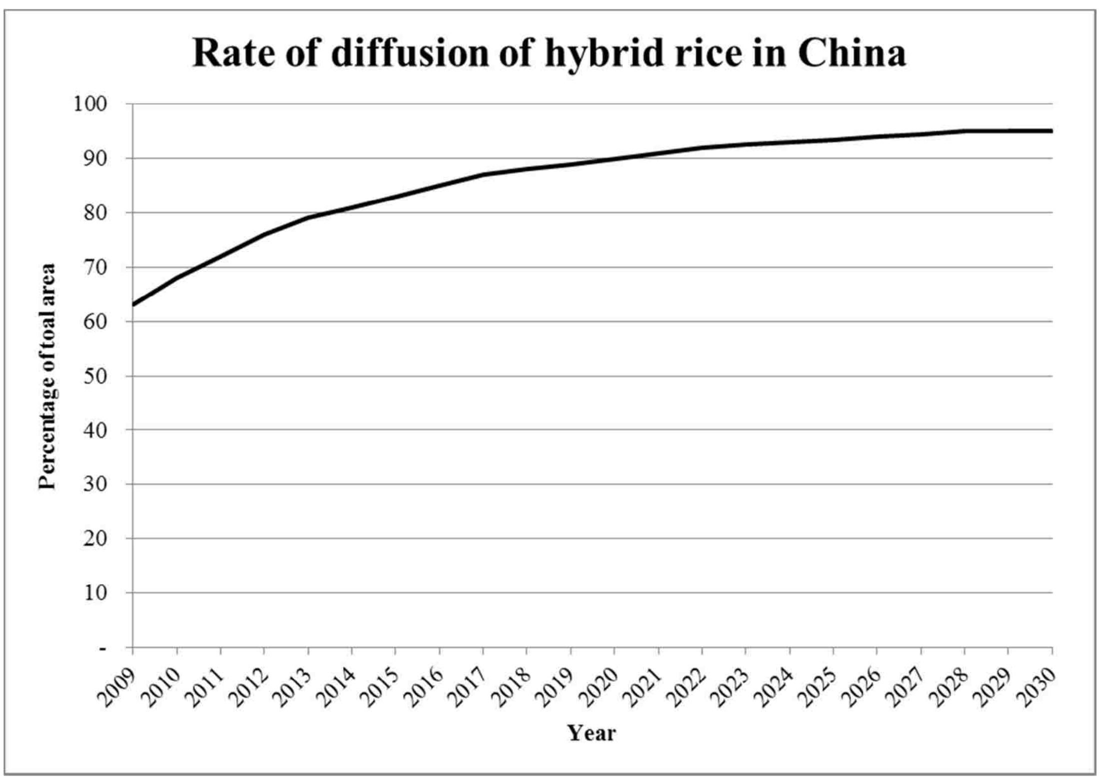
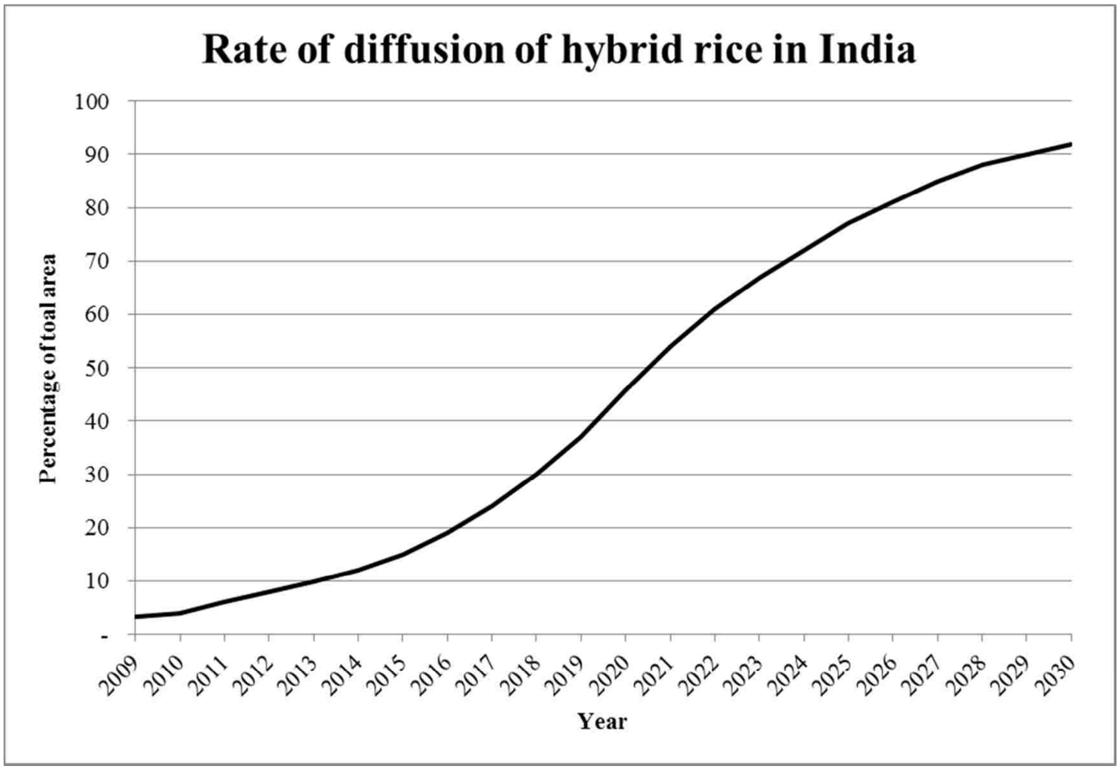


Table 26. Continued



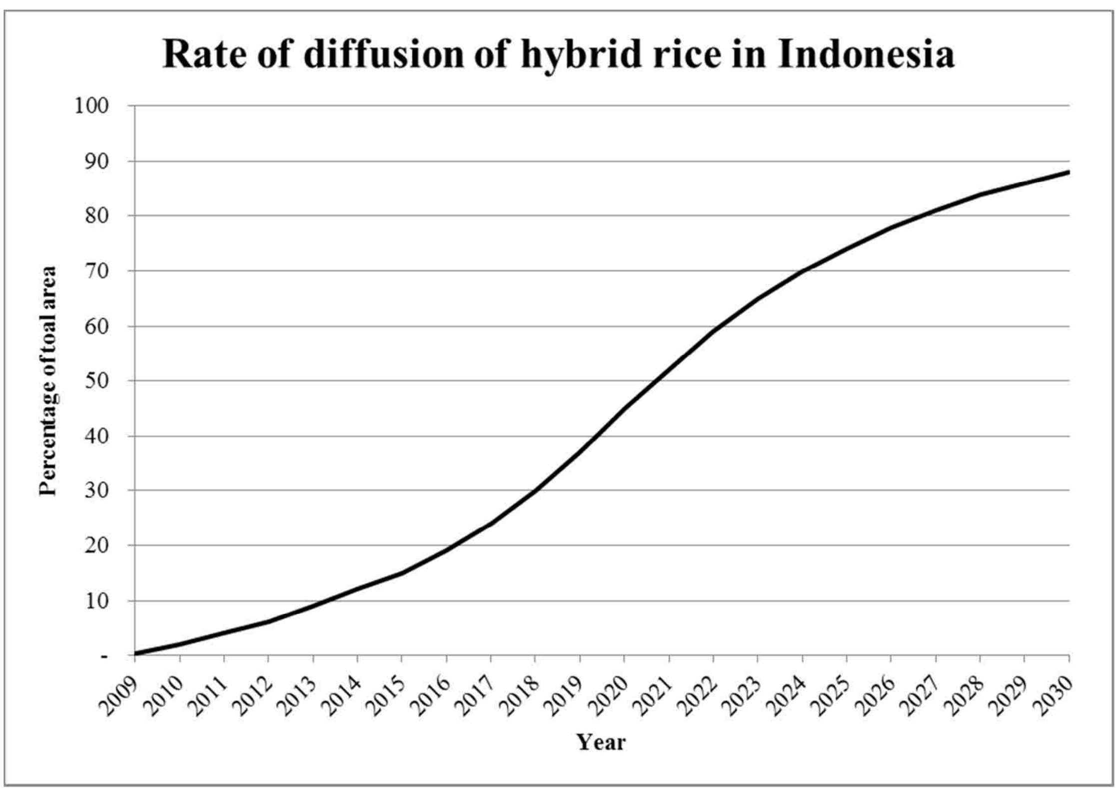
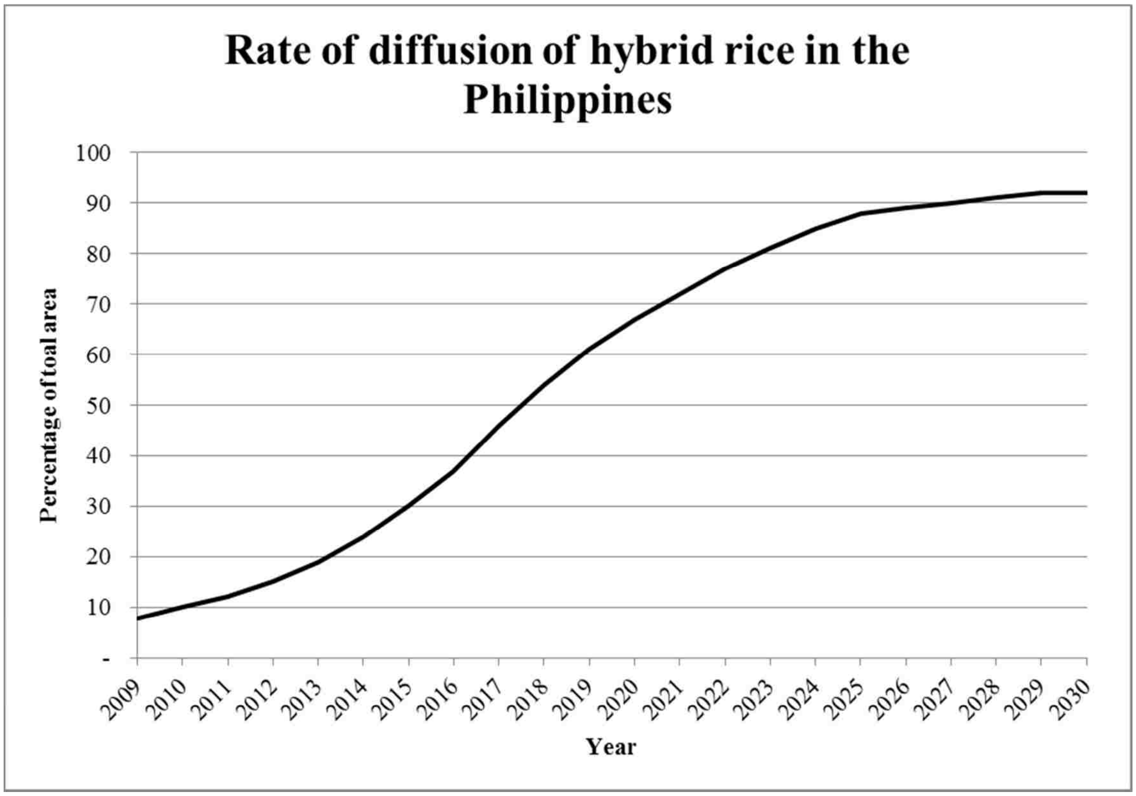


Table 26. Continued



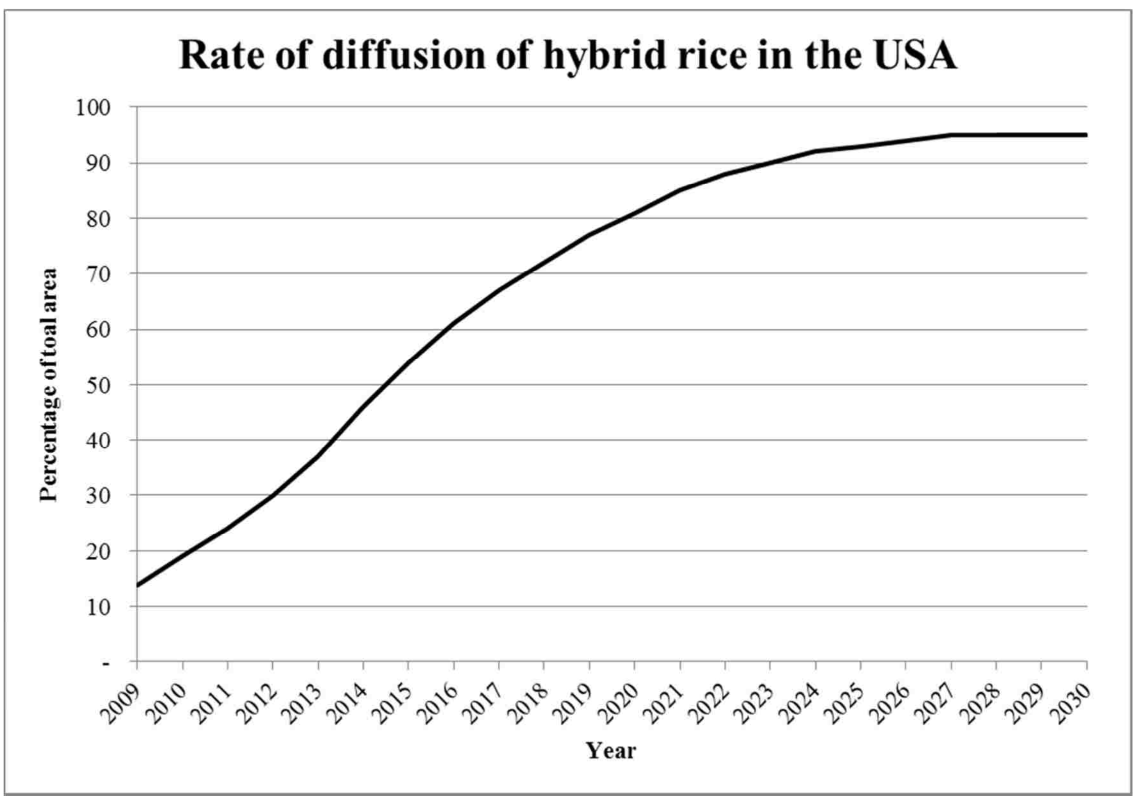


Table 26. Continued

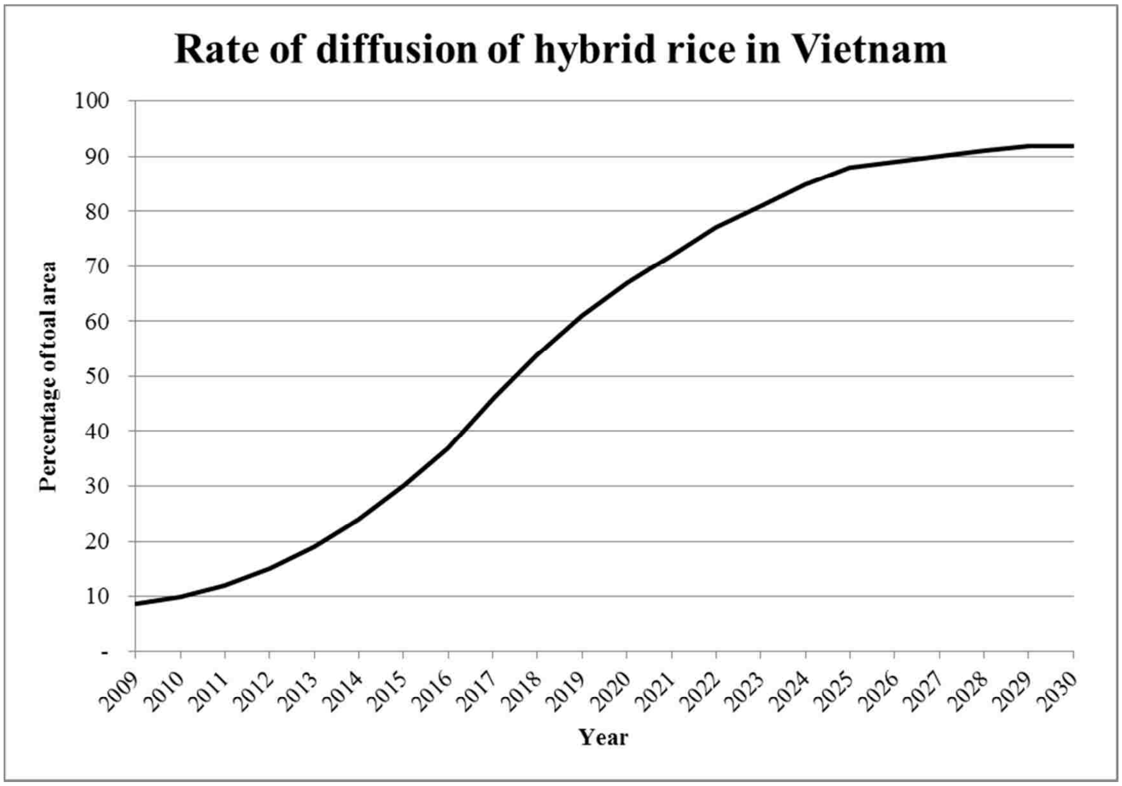


Table 27. Efficiency differences in LGP rice production between hybrid and conventional varieties and the impact on total production costs at growing diffusion of hybrid rice (in %).

Bangladesh

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	0	0	1	-3	1

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	6.50	-	-	-	-	-
2010	10.00	0	0	0.035	-0.105	0.035
2011	12.00	0	0	0.055	-0.165	0.055
2012	15.00	0	0	0.085	-0.255	0.085
2013	19.00	0	0	0.125	-0.375	0.125
2014	24.00	0	0	0.175	-0.525	0.175
2015	30.00	0	0	0.235	-0.705	0.235
2016	37.00	0	0	0.305	-0.915	0.305
2017	46.00	0	0	0.395	-1.185	0.395
2018	54.00	0	0	0.475	-1.425	0.475
2019	61.00	0	0	0.545	-1.635	0.545
2020	67.00	0	0	0.605	-1.815	0.605
2021	72.00	0	0	0.655	-1.965	0.655
2022	77.00	0	0	0.705	-2.115	0.705
2023	81.00	0	0	0.745	-2.235	0.745
2024	85.00	0	0	0.785	-2.355	0.785
2025	88.00	0	0	0.815	-2.445	0.815
2026	89.00	0	0	0.825	-2.475	0.825
2027	90.00	0	0	0.835	-2.505	0.835
2028	91.00	0	0	0.845	-2.535	0.845
2029	92.00	0	0	0.855	-2.565	0.855
2030	92.00	0	0	0.855	-2.565	0.855

Table 27. Continued

China

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	2	-1	-3	0	7

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	63.20	-	-	-	-	-
2010	68.00	0.096	-0.048	-0.144	0	0.336
2011	72.00	0.176	-0.088	-0.264	0	0.616
2012	76.00	0.256	-0.128	-0.384	0	0.896
2013	79.00	0.316	-0.158	-0.474	0	1.106
2014	81.00	0.356	-0.178	-0.534	0	1.246
2015	83.00	0.396	-0.198	-0.594	0	1.386
2016	85.00	0.436	-0.218	-0.654	0	1.526
2017	87.00	0.476	-0.238	-0.714	0	1.666
2018	88.00	0.496	-0.248	-0.744	0	1.736
2019	89.00	0.516	-0.258	-0.774	0	1.806
2020	90.00	0.536	-0.268	-0.804	0	1.876
2021	91.00	0.556	-0.278	-0.834	0	1.946
2022	92.00	0.576	-0.288	-0.864	0	2.016
2023	92.50	0.586	-0.293	-0.879	0	2.051
2024	93.00	0.596	-0.298	-0.894	0	2.086
2025	93.50	0.606	-0.303	-0.909	0	2.121
2026	94.00	0.616	-0.308	-0.924	0	2.156
2027	94.50	0.626	-0.313	-0.939	0	2.191
2028	95.00	0.636	-0.318	-0.954	0	2.226
2029	95.00	0.636	-0.318	-0.954	0	2.226
2030	95.00	0.636	-0.318	-0.954	0	2.226

Table 27. Continued

India

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	1	-2	0	-1	5

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	3.30	-	-	-	-	-
2010	4.00	0.007	-0.014	0	-0.007	0.035
2011	6.00	0.027	-0.054	0	-0.027	0.135
2012	8.00	0.047	-0.094	0	-0.047	0.235
2013	10.00	0.067	-0.134	0	-0.067	0.335
2014	12.00	0.087	-0.174	0	-0.087	0.435
2015	15.00	0.117	-0.234	0	-0.117	0.585
2016	19.00	0.157	-0.314	0	-0.157	0.785
2017	24.00	0.207	-0.414	0	-0.207	1.035
2018	30.00	0.267	-0.534	0	-0.267	1.335
2019	37.00	0.337	-0.674	0	-0.337	1.685
2020	46.00	0.427	-0.854	0	-0.427	2.135
2021	54.00	0.507	-1.014	0	-0.507	2.535
2022	61.00	0.577	-1.154	0	-0.577	2.885
2023	67.00	0.637	-1.274	0	-0.637	3.185
2024	72.00	0.687	-1.374	0	-0.687	3.435
2025	77.00	0.737	-1.474	0	-0.737	3.685
2026	81.00	0.777	-1.554	0	-0.777	3.885
2027	85.00	0.817	-1.634	0	-0.817	4.085
2028	88.00	0.847	-1.694	0	-0.847	4.235
2029	90.00	0.867	-1.734	0	-0.867	4.335
2030	92.00	0.887	-1.774	0	-0.887	4.435

Table 27. Continued

Indonesia

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	0	0	-1	0	5

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	0.40	-	-	-	-	-
2010	2.00	0	0	-0.016	0	0.080
2011	4.00	0	0	-0.036	0	0.180
2012	6.00	0	0	-0.056	0	0.280
2013	9.00	0	0	-0.086	0	0.430
2014	12.00	0	0	-0.116	0	0.580
2015	15.00	0	0	-0.146	0	0.730
2016	19.00	0	0	-0.186	0	0.930
2017	24.00	0	0	-0.236	0	1.180
2018	30.00	0	0	-0.296	0	1.480
2019	37.00	0	0	-0.366	0	1.830
2020	45.00	0	0	-0.446	0	2.230
2021	52.00	0	0	-0.516	0	2.580
2022	59.00	0	0	-0.586	0	2.930
2023	65.00	0	0	-0.646	0	3.230
2024	70.00	0	0	-0.696	0	3.480
2025	74.00	0	0	-0.736	0	3.680
2026	78.00	0	0	-0.776	0	3.880
2027	81.00	0	0	-0.806	0	4.030
2028	84.00	0	0	-0.836	0	4.180
2029	86.00	0	0	-0.856	0	4.280
2030	88.00	0	0	-0.876	0	4.380

Table 27. Continued

Philippines

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	0	-1	-1	0	1

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	7.80	-	-	-	-	-
2010	10.00	0	-0.022	-0.022	0	0.022
2011	12.00	0	-0.042	-0.042	0	0.042
2012	15.00	0	-0.072	-0.072	0	0.072
2013	19.00	0	-0.112	-0.112	0	0.112
2014	24.00	0	-0.162	-0.162	0	0.162
2015	30.00	0	-0.222	-0.222	0	0.222
2016	37.00	0	-0.292	-0.292	0	0.292
2017	46.00	0	-0.382	-0.382	0	0.382
2018	54.00	0	-0.462	-0.462	0	0.462
2019	61.00	0	-0.532	-0.532	0	0.532
2020	67.00	0	-0.592	-0.592	0	0.592
2021	72.00	0	-0.642	-0.642	0	0.642
2022	77.00	0	-0.692	-0.692	0	0.692
2023	81.00	0	-0.732	-0.732	0	0.732
2024	85.00	0	-0.772	-0.772	0	0.772
2025	88.00	0	-0.802	-0.802	0	0.802
2026	89.00	0	-0.812	-0.812	0	0.812
2027	90.00	0	-0.822	-0.822	0	0.822
2028	91.00	0	-0.832	-0.832	0	0.832
2029	92.00	0	-0.842	-0.842	0	0.842
2030	92.00	0	-0.842	-0.842	0	0.842

Table 27. Continued

USA

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	-5	-6	0	0	12

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	13.90	-	-	-	-	-
2010	19.00	-0.255	-0.306	0	0	0.612
2011	24.00	-0.505	-0.606	0	0	1.212
2012	30.00	-0.805	-0.966	0	0	1.932
2013	37.00	-1.155	-1.386	0	0	2.772
2014	46.00	-1.605	-1.926	0	0	3.852
2015	54.00	-2.005	-2.406	0	0	4.812
2016	61.00	-2.355	-2.826	0	0	5.652
2017	67.00	-2.655	-3.186	0	0	6.372
2018	72.00	-2.905	-3.486	0	0	6.972
2019	77.00	-3.155	-3.786	0	0	7.572
2020	81.00	-3.355	-4.026	0	0	8.052
2021	85.00	-3.555	-4.266	0	0	8.532
2022	88.00	-3.705	-4.446	0	0	8.892
2023	90.00	-3.805	-4.566	0	0	9.132
2024	92.00	-3.905	-4.686	0	0	9.372
2025	93.00	-3.955	-4.746	0	0	9.492
2026	94.00	-4.005	-4.806	0	0	9.612
2027	95.00	-4.055	-4.866	0	0	9.732
2028	95.00	-4.055	-4.866	0	0	9.732
2029	95.00	-4.055	-4.866	0	0	9.732
2030	95.00	-4.055	-4.866	0	0	9.732

Table 27. Continued

Vietnam

initial difference between hybrid rice and conventional rice:	fertilizer	pesticides	energy	water	seed
	2	-1	-3	0	7

year	rate of diffusion	fertilizer	pesticides	energy	water	seed
2009	8.70	-	-	-	-	-
2010	10.00	0.200	-0.100	-0.300	0	0.700
2011	12.00	0.240	-0.120	-0.360	0	0.840
2012	15.00	0.300	-0.150	-0.450	0	1.050
2013	19.00	0.380	-0.190	-0.570	0	1.330
2014	24.00	0.480	-0.240	-0.720	0	1.680
2015	30.00	0.600	-0.300	-0.900	0	2.100
2016	37.00	0.740	-0.370	-1.110	0	2.590
2017	46.00	0.920	-0.460	-1.380	0	3.220
2018	54.00	1.080	-0.540	-1.620	0	3.780
2019	61.00	1.220	-0.610	-1.830	0	4.270
2020	67.00	1.340	-0.670	-2.010	0	4.690
2021	72.00	1.440	-0.720	-2.160	0	5.040
2022	77.00	1.540	-0.770	-2.310	0	5.390
2023	81.00	1.620	-0.810	-2.430	0	5.670
2024	85.00	1.700	-0.850	-2.550	0	5.950
2025	88.00	1.760	-0.880	-2.640	0	6.160
2026	89.00	1.780	-0.890	-2.670	0	6.230
2027	90.00	1.800	-0.900	-2.700	0	6.300
2028	91.00	1.820	-0.910	-2.730	0	6.370
2029	92.00	1.840	-0.920	-2.760	0	6.440
2030	92.00	1.840	-0.920	-2.760	0	6.440

Table 28. Company involvement in hybrid rice RDD&D.

Company	Country of Origin	Active in	Working with	Backed by
Bayer	Germany	Brazil, China, India, Philippines, Indonesia, Myanmar, USA, Vietnam	Granja 4 Irmaos (Brazil), Myanmar Ministry of Agriculture, Lu Dan (China), Nong Ke (China), Hybridy Rice International (India), ProAgro (India)	
Charoen Pophand	Thailand	China, Indonesia, Thailand	Chia Tai (China), PT Bisi (Indonesia)	
HyRice Seed Technology	Philippines	Philippines	IRRI	Cornworld and East-West Seed Group
DuPont	USA	India, Indonesia	SPIC-PHI (India), IRCR (Indonesia)	
Origin Agritech	British Virigin Islands	China	Denong Zhengcheng (China), Origina Agritech (China)	
Monsanto	USA	India, Indonesia, Kenya, Philippines	Mahyco (India), Devgen (Netherlands/India)	
RB Biotech	Malaysia	Malaysia	Sunland (Singapore)	
Rice Tec	USA	Brazil, USA, Uruguay	BASF (Germany)	
Shriram Bioseed Genetics (DSCL)	India	India, Philippines, Vietnam	Bioseed Research Philippines	
Sichuan Guohao Seed Company	China	China, Indonesia	Artha Graha (Indonesia)	
Sichuan Nongda	China	Ethiopia, Guinea, Myanmar, Vietnam	Myanmar Gov, Koba Farm (Guinea)	Sichuan Agricultural University's Rice Research Institute
Sime Darby	Malaysia	Malaysia	CAAS (China)	
SL Agritech	Philippines	Bangladesh, Philippines	Yuan Longping Hightech	
Syngenta	Switzerland	China, India, Indonesia, Japan, Philippines	Sanbei (China), Orynova (Japan)	
United Phosphorus Limited	India	India		Advanta (India), Uniphos Enterprises Limited (India)
Vilmorin/Yuan Longping High-Tech Agriculture	China/France	Bangladesh, Indonesia, Malaysia, Pakistan, Philippines	Marco Polo Seeds (Indonesia, Thailand), Pt Bangun Pusaka (Indonesia), SL Agritech (Philippines), Guard Rice (Pakistan), Aftab Bahumukhi Farm/Islam Group (Bangladesh)	