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Compliance Costs for Regulatory Approval of C_4 Rice

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So far, most new biotech crops have been developed by transforming one or two genes with preferred traits. Compliance costs for regulatory approval of this type of crop vary among countries and according to whether the new biotech crop is a food or non-food crop. However, whether a new biotech crop with multiple transformed genes would cost significantly more and take much more time to be approved is unknown. This paper estimates the compliance costs for the regulatory approval of C_4 rice, a new GM rice plant required several gene transformations, assuming it would be realized simultaneously in the 13 Asian countries in 2035. We found it to be $18.8 million (undiscounted), around 16.3% of the total research and development (R&D) costs. We also estimated the present value of R&D costs for C_4 rice in 2017 prices to be approximately $106 million. These estimated R&D costs could be useful to quantity the net welfare benefits from the introduction of C_4 rice. In addition, donors could use this result as a guideline to fund additional investment required to develop C_4 rice.

Key words: Asia, biofortified, biosafety, C_4 rice, compliance cost, regulatory approval, R&D.

Introduction

So far, we know that no biofortified (genetically modified/engineered, GM) rice has been grown commercially. Several confined field trials of first- and second-generation GM rice[1] have been conducted in many countries by the International Rice Research Institute (IRRI) and its associated partner institutes. Some of this GM rice is waiting for its regulation and commercialization (Demont, Chen, Ye, & Stein, 2013, cited in Demont & Stein, 2013). Nonetheless, regulators have approved GM rice for commercialization (Pritchard, Ortiz, & Shekar, 2016; Sui et al., 2017). It is likely that GM rice will be commercialized soon, but it might take a while because domestic regulatory approval is a lengthy process and/or regulators might simply delay the decision of approval while acquiring new information. For example, Golden rice (Vitamin-A-enriched GM rice) was expected to be commercially available first in 2002, but Bangladeshi and Indian regulators have yet to approve it (Wesseler & Zilberman, 2014). In China, two insect-resistant GM rice lines were granted biosafety certificates after 10 years of comprehensive biosafety assessment (Lu, 2016), but are yet to be cultivated commercially.

Even though the estimated annual benefits from the first- and second-generation GM rice developed thus far could be $64 billion USD[2] globally (Demont & Stein, 2013), regulators may be cautious of its approval and may not want to be a first-mover. This may be because of precautionary risks of GM rice for human and environmental health and anti-GM worries. And, thus, there is a cost of delaying the regulatory approval and subsequent commercialization. Because of delaying commercialization of a GM crop, the forgone welfare benefits could be hundreds of millions of dollars (Smyth & Phillips, 2002, and Pray, Bengali, & Ramaswami, 2005, cited in Smyth, Kerr, & Phillips, 2017). In the case of Golden rice, Wesseler and Zilberman (2014) estimated that a forgone benefit of 10-year delay in the introduction could be between $0.71 and $2.83 billion (compounded net present value). It could be $199 million

1. *GM rice can be categorized as (i) first-generation GM rice, which is focused mainly on farmers' benefits, e.g., herbicide-tolerant, insect-resistant, drought-tolerant, drought- and salinity-tolerant (DST), and submergence-tolerant (Sub1). The main focus was to increase yields, improve resistance to biotic and abiotic stresses, and lower the cost of rice production; (ii) second-generation GM rice is focused on consumer benefits, i.e., nutritionally enriched rice (Golden rice, folate-rice, multi-biofortified rice; Anderson, Jackson, & Nielsen, 2004; Demont & Stein, 2013); and (iii) third-generation GM rice, which is focused on farmers' benefits under extreme climatic stress conditions, i.e., C_4 rice, which is expected to yield more under high temperature with less nitrogen and less water than the current rice.*

2. *All figures in this paper are in US dollars unless otherwise noted.*

annually for India only. In this article, we argue that the regulatory approval of C_4 rice, a multi-gene engineered rice, could be delayed similar to Golden rice. However, if the introduction of Golden rice will have not found any potential heath and ecological risks, commercialization of C_4 rice could be faster.

Most new biotech crops, including first- and second-generation GM rice, have been developed by transforming one or two genes with preferred traits. Compliance costs for regulatory approval of this type of crop vary among countries and according to whether the new biotech crop is a food or non-food crop (Smyth et al., 2017). However, whether a new biotech crop with multiple transformed genes would cost significantly more and take much more time to be approved is unknown. In this article, we quantified the domestic regulatory approval costs of C_4 rice, a third-generation GM rice under development, assumed to be commercialized in 2035 and adopted by the major rice-producing and -consuming countries in Asia. The regulatory approval of this new GM rice could be challenging because it would be engineered with several required traits. Because of the nature of C_4 rice, the costs of compliance for regulatory approval could be enormous and take much more time. However, the hope is that, if other GM rice already developed and waiting for regulation and commercialization (e.g., Golden rice) becomes approved before the introduction of C_4 rice, then approval of this new rice could be easier and less costly. Considering the worst-case scenario, we estimated that the domestic regulatory cost of C_4 rice to be adopted by 13 Asian countries[3] could be up to $18.8 million, if the country's public organization files for approval.

History and Development of C_4 Rice

The idea behind developing a C_4 rice plant is to save the world, providing enough food for the more than 9 billion people projected for 2050, for their food and nutritional security that the current rice, a C_3 plant, is unlikely to secure under the pressure of high population growth and extreme climate change scenarios. John Sheehy, a plant physiologist at IRRI, was the first one who conceived the C_4 Rice Project.[4] The goal of this project was to improve photosynthetic efficiency in rice by introducing a two-celled C_4 cycle and thus increase rice yield. In other words, the goal was to create a new rice plant (C_4 rice) close to a plant that uses C_4 photosynthesis.[5] For example, maize, sugarcane, and sorghum plants use C_4 photosynthesis, whereas rice plants use C_3 photosynthesis. In 1999, John Sheehy invited world-renowned rice scientists to attend a workshop to discuss the feasibility of this project. Unfortunately, the workshop concluded that it was unfeasible at that moment because of the unavailability of methods and technology required to deliver the scientific objectives (Sheehy, Mitchell, & Hardy, 2000). However, in 2006, he organized another workshop to discuss the evaluation of the new pathways to C_4 rice and he gained momentum for his idea (Sheehy et al., 2007). In 2008, to invent C_4 rice, an international C_4 rice consortium was formed at IRRI with funds from the Bill & Melinda Gates Foundation (BMGF). At that time, several other world-renowned organizations, including the University of Cambridge, University of Oxford, University of Minnesota, Australian National University, and University of Toronto, partnered with IRRI to realize the project.

To develop C_4 rice, a total of 13 genes would be engineered into C_3 rice (Quick, 2012). The development phases of the C_4 rice plant were divided into four: (i) gene discovery and molecular toolbox, and characterize regulatory controls; (ii) transform rice to express Kranz anatomy and the C_4 metabolic enzymes; (iii) optimize C_4 function in transgenic rice; and (iv) breed C_4 from transgenics into local varieties (IRRI, 2012, and Table 1). Initially, the project life-span was considered to be 15 years, which started in October 2008. This project already successfully finished the first two phases, although the second phase had a one-year lag in the initial time-span. Currently, the project has entered into its third phase of plant development (Roeber & Bernds, 2015), and the final development stage is expected to be finished by 2023 (Column 2 in Table 1).

C_4 Rice for Future Global Food Security

Rice is the staple food for more than one-half of the world's population (Islam, Rahman, Islam, & Naidu, 2016; Muthayya, Sugimoto, Montgomery, & Maberly, 2014), and is considered a basic source of calorie and protein intake. Currently, approximately 470 million metric tons of milled rice are produced annually in the

3. *Bangladesh, Cambodia, China, India, Nepal, Pakistan, Sri Lanka, Indonesia, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam.*
4. *A detailed description about this project can be found at https://c4rice.com/the-project-2/.*
5. *This idea of C_4 photosynthesis is not new; it was discovered more than one-half century ago (a detailed review can be found in Furbank, 2016).*

Table 1. The roadmap to C_4 rice.

Phases	Commercial pathway of C_4 rice	Initial time-frame (IRRI, 2012)	Tentative time-frame (Sage, undated)	Our estimates
Phase I	Gene discovery and molecular toolbox, and characterize regulatory controls	2009-2011	2009-2011	2009-2011
Phase II	Transform rice to express Kranz anatomy and the C_4 metabolic enzymes	2012-2014	2012-2015	2012-2015
Phase III	Optimize C_4 function in transgenic rice	2015-2019	2016-2020	2016-2022
Phase IV	Breed C_4 from transgenic into local varieties	2020-2023	2021-2025	2023-2028
Product prototype development (Phases I-IV) (years)		15	17	20
Post-development (years)			5	7
Commercialization			2030	2035

world, of which 90% are produced and consumed in Asia (US Department of Agriculture [USDA], Foreign Agricultural Service [FAS], 2016). Rice provides up to one-half of the total caloric and protein intake to millions of hungry and poor people living in Asia. Rice is also becoming an important staple food in Africa. Additionally, billions of people are engaged in the global rice value chain for their employment as well as their livelihood. Therefore, rice is crucial for global food and nutritional security, and for alleviating rural poverty.

In the future, global rice security could be hampered because of the following challenges that the world rice sector is likely to encounter. First, population growth could outpace rice production growth due to exhausting the existing rice technologies, and indeed this has already occurred (Nadarajah, 2016; Ray, Mueller, West, & Foley, 2013). Therefore, the additional rice needed to meet the demand from the growing population might not be achieved. Second, a significant amount of land currently under rice cultivation could be lost because of rapid growth in urbanization, so the area under rice cultivation is likely to shrink. Third, the global rice sector could encounter frequent biotic stresses (e.g., pests and diseases) and abiotic stresses (e.g., droughts and floods) because of the erratic climatic behavior; therefore, substantial yield could be lost. Fourth, in some areas, irrigation water could be unavailable for rice cultivation because of overexploitation (e.g., this has already happened in Punjab, India). Finally, the demand for rice by Africans is expected to increase in the future; therefore, demand-led pressure on the global rice supply is likely to rise.

To help solve these problems, rice scientists invented C_4 rice that could yield 50% more than current rice with 40% less nitrogen and 50% less water (Sheehy et al., 2007). The yield benefits could be realized only in the irrigated rice areas, and the magnitudes of the benefits could vary in the adopting countries. Using an ORYZA model, a crop growth simulation model for rice, Murty et al. (2016) estimated that the yield benefits could be between 1% and 120% higher than those of current rice, depending on the quality of the soil in the adopting countries. If these yield advantages of C_4 rice could be realized in 13 Asian countries, then global rice production would increase by 3% to 5% in 2050 compared with the baseline values of 2050, estimated by Bairagi, Mohanty, Murty, and Wiebe (2017) using a partial equilibrium economic model (IMPACT).[6] Because of the increased rice supply, the global rice price could decline by 9% to 14% in 2050; therefore, rice consumption could increase by 3% to 5%. Finally, they found that the number of people at risk of hunger and the number of malnourished children globally would decline by 1% to 2% and 0.5% to 0.8% in 2050, respectively. Thus, we conclude that C_4 rice could ensure future world food and nutritional security through a sustained rice supply under the challenging circumstances mentioned before.

Price of Innovation and Regulatory Approval Cost of C_4 Rice

Because of the restricted policies related to intellectual property rights (IPR) of IRRI, finding the detailed processes and costs associated with the pre- and post-development of a new GM rice (e.g., discovery and proof of concept, introgression, breeding, and confined field tri-

6. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed by the International Food Policy Research Institute (IFPRI).*

Table 2. Investment in C_4 Rice Project globally.

Funder	Grantee	Grant commission date	Grant amounts distributed	Duration of grant activities	Annually distributed ($ million)
BMGF	IRRI	October 2008	$11,017,675	2009-2011	$3.67
BMGF	Shanghai Institute of Biological Sciences	October 2010	$481,388	2010-2012	$0.16
BMGF *	IRRI	May 2012	$8,375,747	2013-2015	$2.79
The UK Govt. and IRRI †	IRRI	-	$5,624,253	2013-2015	$1.87
BMGF	University of Oxford	August 2015	$150,000	-	
BMGF	University of Oxford	October 2015	$6,999,794	2016-2019	$1.75
Total			$32,648,857	2009-2019	$3.00

Notes: Data were gathered from the different press releases of Bill & Melinda Gates Foundation (BMGF) and International Rice Research Institute (IRRI) websites.
**, † According to IRRI (2012), BMGF, the UK government, and IRRI jointly put $14.0 million into the second phase of the C_4 Rice Project. To estimate the contribution by the UK government and IRRI, we deducted the BMGF contribution.*
- denotes unknown.

als, and compliance cost for regulatory approval) is challenging and almost impossible. Thus, the following estimation of the price of innovation for C_4 rice and costs associated with its domestic regulatory approval is based on personal communications of scientists and regulatory affairs officials of the Golden rice project at IRRI, Philippines, and the available information published in journal articles, books, and scientific reports.

The Roadmap to C_4 Rice

As before, the development phases of C_4 rice were divided into four, presented in Table 1.[7] At the beginning of the C_4 rice project, it is assumed that the prototype of C_4 rice will be created within 15 years of starting this project. However, based on the estimates by Rowan F. Sage, professor of the University of Toronto, Phase IV could be finished by 2025 and C_4 rice could be commercialized by 2035. We support Sage's roadmap because Phases III and IV usually take much more time, which was the case for Golden rice. However, we have a much more conservative estimate of about 20 years (2028) required to obtain the product prototype. In addition, a total of seven years is likely to be required for C_4 rice to be commercialized. For the whole period, 2009 to 2034, we estimated a total of $83.2 million (excluding indirect costs) to be required for investment in research and development (R&D), including regulatory approval cost, for C_4 rice. This estimated R&D cost is lower than the industry estimates by McDougall (2011), who estimated a total of $136 million to be required by any major biofortification company for development to commercialization of any new GM product.

Costs Associated with Development Phases I-III

IRRI started the C_4 Rice Project with a grant of $11.0 million by BMGF for the first phase (Table 2). In October 2010, BMGF also granted $481 thousand to the Shanghai Institute of Biological Sciences for this stage. For the second phase, a total of $14.0 million was spent, jointly funded by BMGF, the UK government, and IRRI. Note that these first two phases were greatly dependent on extensive genetic screening of rice plants, led first by John Sheehy and then by Paul Quick from IRRI. The third phase (2016 to 2019), emphasizing an integrated "systems" approach and "synthetic" approach to plant biology, is coordinated by Jane Langdale, professor of the Department of Plant Sciences at the University of Oxford.[8] This third phase of the project is also being funded by BMGF, but at a level less than the first two phases ($7.0 million).

Costs Associated with the Final Development Phase (Phase IV)

Recall that, at the beginning of the C_4 Rice Project, the cost of R&D was estimated at approximately $5.0 million per year (IRRI, 2012). However, the amount spent

7. Note that the technical aspects of the development phases of C_4 rice can be found in Sheehy et al. (2000, 2007), Kajala et al. (2011), von Caemmerer, Quick, and Furbank (2012), Karki, Rizal, and Quick (2013), and Rizal et al. (2012).

8. Retrieved from https://c4rice.com/the-project-2/our-history/.

Table 3. Estimated R&D costs required to develop C_4 rice.

Research, development, breeding, trials, and regulatory phases	Estimated R&D for C_4 rice		
	Required time (year)	Per-year required R&D ($ million)	Total required R&D ($ million)
Phase I ^	3.0	$3.8	$11.4
Phase II ^	4.0	$3.5	$14.0
Phase III	7.0	$3.0	$21.0
Phase IV	6.0	$3.0	$18.0
Subtotal (Phases I-IV)	20.0	$3.2	$64.4
Subtotal (Phases I-IV), including universities and private companies spending unseen**			(64.4 × 1.5) = $96.6
Regulatory process*	7.0		$18.8
Total	27.0		$115.4

Notes:
^ *from Table 2*
* *estimated for 13 Asian countries, so the simulated mean (1.44 in Figure 2) was multiplied by the total number of C_4 rice-adopting countries*
** *arbitrarily assumed the spending by the universities and private companies for developing C_4 rice to be 1.5 times*

during the previous phases was between $1.75 and $3.7 million annually (Table 2). In terms of average, approximately $3.0 million per year has been awarded thus far. We assume that a similar amount will be required annually for Phase IV of the C_4 Rice Project, amounting to $18.0 million for 2023 to 2028 (Table 3).

Finally, after finishing Phase IV, the end product would be a prototype of C_4 rice. Based on the above estimates, a total of $64.4 million is expected to be spent for obtaining the prototype of C_4 rice (discovery to product development, Phases I to IV). Note that the estimated costs are included only as direct R&D grants, which may not reflect the actual amount of R&D to be spent for this project. For example, a scientist who is engaged in this project is also engaged in other activities that are not linked to this project. So, the actual amount of R&D investment in this project could be less than the estimated amount. However, we argue that it also could be more than the estimated R&D because many personnel are engaged in different universities and private companies besides IRRI and its partner organizations in the C_4 Rice Project may be working on similar things. Additionally, similar biofortification processes may be conducted for different crops by several scientists globally. This must be taken into consideration in the cost analysis. As this is unknown, we arbitrarily assumed that the total cost of R&D, including the contribution of universities and private companies, could be at least 1.5 times the estimated R&D, amounting to around $96.6 million (= 64.4×1.5).

Compliance Cost for Approval of C_4 Rice

In the literature, studies related to quantifying the compliance costs for approval of a GM crop are very limited and none of the studies reported actual regulatory approval cost estimates. The reason could be that this is a very sensitive issue that biotech companies do not want to share or because of IPR-related restrictions. A recent study by Smyth et al. (2017), most probably the only rigorous study in this field, quantified the regulatory approval costs using a meta-analysis method. This study found that the average cost of regulatory compliance for a single new trait in a single market is around $7.8 million. We argue that their estimates could be somewhat overestimated, based on the following rationale.

Figure 1 illustrates the regulatory approval costs for GM crops, adopted from Smyth et al. (2017).[9] Note that there is a debate about whether a particular activity is a component of compliance cost or a product development cost (Falck-Zepeda et al., 2007). This figure clearly depicts that compliance costs of approval for a GM crop diverge whether it is a food or non-food crop. Among the food crops, compliance costs for GM maize differ significantly from those for rice and other edible crops. Note that, if the compliance costs of GM maize

9. *This study cited Pray et al. (2005, 2006), Falck-Zepeda et al. (2007), Falck-Zepeda and Cohen (2006), Kalaitzandonakes et al. (2007), and Bayer, Norton, and Falck-Zepeda (2010). In addition, we included Ramaswami and Pray (2006), Stein et al. (2008), and Chow et al. (2010) in the analysis.*

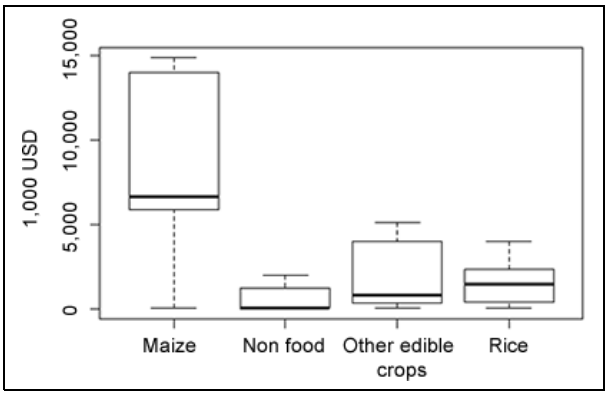

Figure 1. Regulatory approval costs for GM crops.

Source: Authors' data computed from data reported in Tables 3.4 and 3.5 in Smyth et al. (2017), where Pray et al. (2005, 2006), Falck-Zepeda et al. (2007), Falck-Zepeda and Cohen (2006), Kalaitzandonakes et al. (2007), and Bayer et al. (2010) were cited. In addition, we included Ramaswami and Pray (2006), Stein, Sachdev, and Qaim (2008), Chow, Klein, and Laxminarayan (2010), and Falck-Zepeda, Gruère, and Sithole-Niang (2013).

Notes: Other edible crops include banana, beans, eggplant, mustard, papaya, potatoes, soybeans, sugarcane, tomato, and vegetable; non-food crops include cotton and jute.

estimated by Kalaitzandonakes, Alston, and Bradford (2007) were excluded, then the average approval cost of GM maize would have been similar to the approval cost of GM rice. If Smyth et al. (2017) could have estimated the regulatory approval cost without this study, then their number would have been significantly lower. Note also that Kalaitzandonakes et al. (2007) estimated a compliance cost incurred by the biotech developers seeking regulatory approval of two GM maize lines in 10 key producing and importing countries in the world at about \$6-15 million. This estimate could be correct based on the fact that they considered that the biotech company will be seeking approval of its GM maize in 10 countries. However, their number is almost one-half the estimates by McDougall (2011), who estimated the regulatory approval cost of a new GM crop to be around \$35 million. Note that his estimation was based on whether the new GM crop "had received cultivation approval in two countries and import approvals from at least five countries" and whether a private company had filed for approval.

From the above discussion, two important points can be noted: (i) regulatory approval costs could vary significantly based on the number of countries in which the biotech developers are seeking approval for cultivation and importation of a GM crop, and (ii) the costs could also vary based on whether private or public companies are seeking approval. These are the two key facts that were ignored by Smyth et al. (2017); thus, their numbers could be overestimated. For example, if a private biotech company is seeking approval of its newly developed GM crop in 10 countries (some cultivating and importing countries), then approval costs could surpass \$50 million (10 multiplied by the average cost estimates, for example). Therefore, rather than adopting the average number estimated by Smyth et al. (2017), we followed a straight-forward strategy to estimate the compliance costs for approval of C_4 rice to be adopted in 13 Asian countries.

Table 4 presents the country-specific compliance costs for regulatory approval of GM rice developed thus far. We find that the costs vary between \$73 thousand in Indonesia and \$4.0 million in India. Table 4 also reveals that, for Golden rice, the costs are much higher than the mean regulatory cost. In the Philippines, they are around \$137 thousand, but \$2.2 to 4.0 million for India. Note that the major shares of this cost accrue from the toxicity tests (animal, food, and environmental safety studied) and regulated confined trials and unregulated trials. In the case of C_4 rice, we argue that the cost for approval in a single market could be similar to that of Golden rice in India. Although this depends on whether any further toxicity tests done in the United States or EU are to be required by the country-specific government. Because the biosafety procedures in Bangladesh, India, and the Philippines are similar, further toxicity tests are unlikely to be required. In that case, on the whole, the compliance costs for approval of C_4 rice in 13 Asian countries could be lower.

Based on the personal communications of IRRI scientists, the compliance costs for approval of Golden rice for the three countries could be \$6.0-8.0 million. We argue that the compliance costs for C_4 rice could partially depend on the effect of Golden rice on humans and the environment. For example, by the time of C_4 commercialization, the impact of Golden rice on human life and environmental health could be realized. If no negative impact on humans and the environment is found, then biosafety regulation could be faster, easier, and more cost-effective for C_4 rice. Furthermore, the current technology, for example, CRISPR/Cas9 used for target gene editing, is much more advanced than the technology available when the C_4 Rice Project started. With the new advanced technology, the targeted rice gene could be edited to have C_4 function and thus the new C_4 rice plant would not be considered transgenic in some countries.

Table 4. Country-specific cost of compliance for regulatory approval of GM rice.

GM rice	Countries	Regulatory cost ($ '000) Min	Max	No. of countries seeking approval	Source
Golden rice	India	2,213	2,515	1	Stein, Sachdev, & Qaim (2006)
Golden rice	India	4,000			Ramaswami and Pray (2006)
Rice	India	1,500	2,000	1	Pray et al. (2005)
Golden rice	Philippines	134		1	Falck-Zepeda et al. (2007)
Xa21 BBR rice	Philippines	128		1	Falck-Zepeda et al. (2007)
Bt rice	Philippines	691		1	Bayer et al. (2010)
Bt rice	Indonesia	73		1	Falck-Zepeda et al. (2007)
Bt rice	Costa Rica	2,800		1	Falck-Zepeda and Cohen (2006)
Virus-resistant rice	Costa Rica	680		1	Sittenfeld (2002) cited in Falck-Zepeda and Cohen (2006)
Average		1,358	1,447		

Notes: Bt denotes insect resistance; BBR stands for bacterial blight resistant. Golden rice is a beta-carotene (SGR1)-enriched GM rice.

According to these facts, we estimated a regulatory cost of approximately $18.8 million employing a Bayesian simulation method. We used only the reported country-specific compliance costs for regulatory approval of GM rice in Table 4 along with other food crops in Figure 1. We assumed a normally distributed likelihood function along with a prior mean and standard deviation adopted from Smyth et al. (2017). Figure 2 illustrates the simulated results, which reveal that the posterior mean compliance cost is $1.44 million. We multiply this mean compliance cost by the number of C_4 adopting countries, and find that the regulatory compliance costs for approval of C_4 rice could be $18.8 million, which are around 16.3% of the total R&D costs required for C_4 rice.

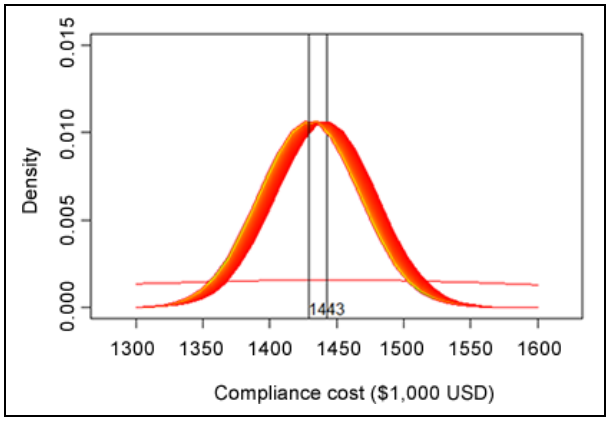

Figure 2. Simulated compliance cost for C_4 rice in a single market.

Source: Authors' computation based on only compliance cost of food crops reported in Tables 3.4 and 3.5 in Smyth et al. (2017), where Pray et al. (2005, 2006), Falck-Zepeda et al. (2006), Falck-Zepeda and Cohen (2006), and Bayer et al. (2010) were cited. In addition, we included Ramaswami and Pray (2006), Stein et al. (2008), Chow et al. (2010), and Falck-Zepeda et al. (2013).

Present Value of Innovation and Compliance Costs

In this article, we also estimated the present value of innovation and compliance costs in 2017 prices. To convert these costs to the current price, we compounded them from 2009 to 2016 and discounted them from 2018 to 2035, with a 10% discount rate. This discount rate considered here is slightly high because potential risks are involved in the C_4 innovation process. Note that, in the global perspective, developing countries tend to use higher discount rates (above 10%) than developed countries (Bairagi, 2015).[10] We found that the present value of innovation and compliance costs for approval of C_4 rice in the 13 countries was approximately $106 million.

In sum, our estimated R&D costs could be useful to quantify the net welfare benefits from the introduction of C_4 rice. In addition, donors could use this result as a guideline to fund the additional investment required for developing C_4 rice. However, this should be used with caution because the estimates are backed by neither any actual estimates nor any rigorous econometric methods.

10. *Discount rates used by the different developed and developing countries can be found in Harrison (2010).*

Conclusions

This article estimates R&D costs, including a regulatory cost, for approval of C_4 rice to be adopted in 13 Asian countries. Most new biotech crops have been developed thus far by transforming one or two genes with preferred traits, whereas, to develop a C_4 rice plant, several genes would need to be transformed. It is unknown in the literature whether a new biotech crop with multiple transformed genes would cost significantly more and take much more time to be approved. In this article, we estimate the price of innovation for C_4 rice and the costs associated with its domestic regulatory approval based on the personal communications of scientists and regulatory affairs officials of the Golden rice project at IRRI, Philippines, and the available information published in journal articles, books, and scientific reports. We assume that the prototype of C_4 rice could be created by 2028 and C_4 rice would be commercialized in 2035. We also assume that the regulatory process would begin simultaneously after obtaining the prototype. We find that the estimated compliance costs for the regulatory approval of C_4 rice in a single market would be approximately $1.44 million. For the 13 adopting countries, the regulatory cost was estimated to be around $18.8 million (undiscounted), which is 16.3% of the total R&D costs required for C_4 rice. It is expected that the regulatory process would finish within seven years. Finally, we estimated a present value of innovation and compliance costs for approval of C_4 rice in the 13 countries at approximately $106 million.

In this article, we argue that the compliance costs for C_4 rice could depend somewhat on the effect of Golden rice on humans and the environment. It is expected that the impact of Golden rice on human life and environmental health could be realized by the time of C_4 commercialization. If no negative impact on humans and the environment is found, then biosafety regulation could be faster, easier, and more cost-effective for C_4 rice. Furthermore, the current technology, for example, CRISPR/Cas9 used for target gene editing, is much more advanced than the technology available when the C_4 Rice Project started. With the new advanced technology, the targeted rice gene could be edited to have C_4 function and thus the new C_4 rice plant would not be considered transgenic in some countries. Therefore, the regulatory process could be easier and faster, resulting in lower regulatory costs and less time required to be commercialized.

We believe that our estimated R&D costs could be useful to quantify the net welfare benefits from the introduction of C_4 rice. In addition, donors could use this result as a guideline to fund the additional investment required for developing C_4 rice.

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