Genetically Modified Rice Adoption: Implications for Welfare and Poverty Alleviation

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Abstract

The first generation of genetically modified (GM) crop varieties sought to increase farmer profitability through cost reductions or higher yields. The next generation of GM food research is focusing also on breeding for attributes of interest to consumers, beginning with 'golden rice', which has been genetically engineered to contain a higher level of vitamin A and thereby boost the health of poor people in developing countries. This paper analyses empirically the potential economic effects of adopting both types of innovation in Asia, including its impact on rice producers and other poor households. It does so using the global economy-wide computable general equilibrium model known as GTAP. The results suggest the very considerable farm productivity gains (even if extended beyond GM rice to include those from adopting other GM grains and oilseeds) could be exceeded by the welfare gains resulting from the potential health-enhancing

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attributes of golden rice, which would boost the productivity of unskilled workers among Asia's poor.

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• **Key words:** GMOs, Golden rice, Consumer preferences, Nutritional attributes

I. Introduction

In the late 1990s many producers of maize, soybean and canola in the US, Canada, and Argentina embraced genetically modified (GM) varieties of these commodities. Typically this technology has conferred direct benefits to farmers through reduced input costs or improved management flexibility, and indirect benefits to consumers via lower food prices. However, as public and private research expands, the next generation of GM crops promises to include GM varieties of various crops that also provide direct benefits to consumers through enhanced consumption characteristics such as improved nutritional content.

Golden rice, a GM variety of rice that has been genetically modified to produce beta-carotene, is the most important imminent product to result from this research. It has the potential to improve health in regions where rice is or could be a dietary staple for poor people. If that development leads to a widespread acceptance of genetic modification of food crops in Asian and other developing countries, direct farm productivity gains of GM agricultural technology could be reaped there as well.

This paper uses a global computable general equilibrium trade model to estimate the potential economic impacts of adoption of golden rice and other GM rice varieties in Asia. More specifically, it estimates the potential welfare gains from the consumer-focused health attribute of golden rice and compares them with the welfare benefits of producer-focused attributes of other (non-golden) GM rice varieties. It thereby extends earlier empirical economic studies of adoption of GM varieties, which focus on the welfare effects only of direct farm productivity gains and associated policy responses. It also estimates the welfare impact if GM adoption were to spread beyond rice to other grains and oilseeds, both in the absence and in the presence of richer countries choosing to ban food imports from GM-adopting countries.[1] The consumer-focused health attribute of golden rice is reflected in improved productivity of unskilled farm and non-farm workers whose

health would improve with greater vitamin A intake.

The next section provides more details of the potential of golden and other GM rice varieties. In section 3 we describe the GTAP model of the global economy and methodology used to explore their potential impacts on rice markets, on national economic welfare, and on the real household incomes of farm families and of other unskilled workers in the affected developing countries. Results are presented in Section 4 for a range of scenarios that vary the set of adopting countries and the policy responses to GM rice. The paper concludes in Section 5 by stressing the potential distributional and poverty alleviating impacts of the adoption of GM rice (and other crop) varieties in Asia.

II. Prospective Impacts of GM Rice on Asian Farm and Labour Productivity

The first generation of genetic engineering in agriculture has produced modified crops with improved agronomic traits, such as tolerance of specific chemical herbicides and resistance to pests and diseases (James 2003). The development of transgenic plants with enhanced agronomic traits is intended to increase farmer profitability, typically by increasing factor and input productivity. A second generation of GM research is now under way that is seeking also to improve various consumption attributes of products, such as enhanced nutritional content, improved durability, and better processing characteristics. Farmers would adopt this type of GM crop variety, even if it had no productivity benefits for them net the higher cost of seed and the cost of segregation and identity preservation, if they could sell these products at a higher market price. Higher prices could result from consumer perceptions that it is a better product relative not only to the other GM varieties with improved farm productivity attributes but also to non-GM varieties.

Golden rice is the most important imminent GM crop. Some GM rice varieties have the potential to boost farm productivity, with yields per hectare expected to be as much as 10 per cent higher for 40 per cent of global production within a decade, according to Brookes and Barfoot (2003, p. 48). Golden rice, however, is a GM variety that may not enhance farm productivity but could improve health

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[1] The motivation for such a ban could be genuine concern for food safety or the environment or simply because it provides a way to re-instrument economic protection for farmers in the wake of pressure to lower import tariffs. In the case of rice especially, other WTO members are putting great pressure on Japan and Korea to lower their very high tariff rates.

significantly in regions where rice is or could be a dietary staple for poor people, through providing pro-vitamin A (Dawe, Robertson and Unnevehr 2002). Due to genetic modification golden rice contains a higher level of beta-carotene, which is needed for the production of provitamin A, in the endosperm of the grain than non-golden rice.[2] It has the potential to have long-term benefits for the poor in developing countries where chronic Vitamin A Deficiency (VAD) leads to blindness, weakened immune systems, and increased morbidity and mortality for children and pregnant and lactating women. It is estimated that up to 0.5 million children suffering from VAD go blind every year, and nearly 0.6 million women die annually from childbirth-related causes, many of them from complications which could be reduced through better provision of Vitamin A (Sommer and West 1996). Focusing on the potential direct health cost estimates using a disability-adjusted life year (DALY) approach, a recent study found that introducing golden rice in the Philippines could decrease the number of DALYs lost per year due to VAD by between 6 and 47 per cent, or between 23,000 and 137,000 (Zimmermann and Qaim 2004).[3] That is equivalent to an increase in the labour productivity of unskilled workers of between 0.09 and 0.53 per cent – and could also result in non-pecuniary benefit to those people who would be feeling healthier and live longer.

The biotechnology firm Syngenta owns the rights to golden rice for commercialisation. For whatever reason (perhaps as a public relations exercise to get more-positive media coverage of GM food technology), Syngenta is helping to transfer the technology to developing countries by complying with existing biosafety and environmental risk assessment laws/regulations and making the technology freely available to farmers earning less than US$10,000 a year from rice. Farmers will also be able to save seed from their initial crop for future plantings, rather than buy it every year (Brookes and Barfield 2003, p. 10; Zimmermann and Qaim 2004, p. 15). For that reason we take the technology as given and do not include a rice biotechnology producing sector in our model.

As with the first-generation GM technology that focused on reducing producers' unit costs, the benefits from adoption of golden rice and other types of GM rice over time will be shared between producers and consumers, and hence between

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[2] See Ye et al. (2000), Beyer et al. (2002), and especially Paine et al. (2005) Beta-carotene does not occur naturally in the endosperm of rice, hence the need for genetic modification (Bouis 2000).

[3] For more on the concept of estimating impacts in terms of disability-adjusted life years (DALYs), see Murray and Lopez (1996).

adopting and non-adopting countries. If countries remain or become more open to international trade in these products the potential benefits will increase. In 2001 only six per cent of global rice production was traded internationally, but this represents an increase from 3.3 per cent a decade earlier (FAOSTAT). Production is increasing as trade barriers are lowered following WTO and regional trade negotiation rounds. GM rice adoption could contribute to that trend – or could weaken it if some countries adopt the new GM technology and, in response, others ban rice imports from adopting countries (as analysed below).

III. Model Methodology

We use a well-received empirical model of the global economy (the GTAP model) to examine the effects of some countries adopting the new GM technology without and then with specific government and consumer responses in some other countries. Being a multi-region general equilibrium model, the GTAP (Global Trade Analysis Project) model describes both the vertical and horizontal linkages between all product markets both within the model's individual countries and regions as well as between countries and regions via their bilateral trade flows. The Version 5.4 database used for these applications draws on the global economic structures and trade flows of 1997, the time of the rapid adoption of GM crop varieties. To make the results easier to absorb, the GTAP model has been aggregated to depict the global economy as having 17 regions and 14 sectors (with the focus on the primary agricultural sectors affected by the GM debate and their related processing industries).[4] We have undertaken further sectoral disaggregation of the database by separating golden rice and other GM crop varieties from non-GM varieties of rice, oilseeds, and coarse grains. There are five types of productive factors in the version used here: skilled labour, unskilled labour, agricultural land, other natural resources, and other (non-human) capital. All factors except natural

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[4]The GTAP (Global Trade Analysis Project) model is a multi-regional, static, applied general equilibrium model based on neo-classical microeconomic theory assuming perfect competition, constant returns to scale and full employment of all productive factors which are immobile internationally. International goods and services trade is described by an Armington specification, which means that products are differentiated by country of origin. See Hertel (1997) for comprehensive model documentation and Dimaranan and McDougall (2002) for details of the GTAP 5.4 database used here. The model is solved with GEMPACK software (Harrison and Pearson 1996). Welfare decomposition follows Harrison, Horridge and Pearson (1999). Previous uses of the GTAP model in assessing the economic implications of GM crop adoption include Nielsen and Anderson (2001), van Meijl and van Tongeren (2004), Jackson and Anderson (2003) and Huang et al. (2004).

resources (which are specific to primary production) are assumed to be perfectly mobile throughout the national economy but immobile internationally.

We have modified the GTAP model so it can capture the effects of productivity increases of GM crops, consumer aversion to consuming GM products other than golden rice (for which a stronger preference rather than aversion is assumed in developing countries), and substitutability between GM and non-GM products as intermediate inputs into final consumable foods.

The simulations use a standard, long-run, neoclassical GTAP closure. This closure is characterized by perfect competition in all markets, flexible exchange rates and fixed endowments of labour, capital, land and natural resources. One outcome of this specification is that wages are flexible and labour (and other factor) markets operate at full employment. In addition, investment funds are re-allocated among regions following a shock, thus equalizing expected rates of return.

A. Production

Traditionally, to distinguish GM from non-GM productivity, the GM-adopting sectors are each sub-divided into GM and non-GM product, and an output-augmenting, productivity shock is implemented on the GM varieties of these commodities to capture their higher productivity. This assumes that GM technology reduces the level of primary factors and some intermediate inputs needed per unit of output. When a region does not adopt GM technologies, no regional factor productivity shock is included and there is no distinction between GM and non-GM production in these regions. In the constant-elasticity-of-substitution production nest, producers choose first between imported and domestic inputs according to the model's Armington (1969) elasticities, and then choose whether or not to use GM or non-GM intermediate inputs in their production of final goods.

Golden rice, however, requires a treatment different from other GM rice because we assume there is no net difference between producing golden rice and non-GM rice in terms of farm productivity, with any input saving being assumed to be absorbed in the cost of segregation and identity preservation (even though that may be understating the prospective producer benefits). In that case the motivation for farmers to adopt golden rice has to come from the higher price it can attract in competition with other GM and traditional varieties, net of the extra cost of segregation and identity preservation of this superior variety.

Data on global adoption of GM technologies reveal a wide divergence in adoption across countries. In the base case simulation, we assume that 75 per cent of oilseed production in the US, Canada and Argentina is GM and that 45 per cent of US and Canadian and 30 per cent of Argentinean rice and coarse grain production is GM. Since these countries are already GM adopters in coarse grain and oilseeds, we assume they would also be the earliest adopters of GM rice once it is ready for commercial release. Those countries' farmers have shown no interest in golden rice, so it is assumed their adoption is restricted to other GM rice varieties. In the alternative scenarios involving GM rice adoption in Asia's developing countries, we compare two cases: one in which 45 per cent of the rice crop is grown with GM golden rice seed, and the other in which 45 per cent of the rice crop uses GM rice seed that enhances farm productivity. The former set of adopting farmers is assumed to be able to segregate their golden rice from other rice in order to market this product based on its enhanced nutritional composition.[5] We also consider the case where Asia's developing countries adopt GM varieties of coarse grains and oilseeds that account for 45 per cent of their production of those crops.

B. Productivity shocks

GM rice has not yet been commercialised, but several varieties have been approved for field trials and environmental release. Based on field interviews with farmers and scientists, Huang *et al.* (2004, 2005) hypothesize the impacts of GM rice adoption on rice yield and input uses. While these authors focus on potential farm productivity enhancements of this GM technology, for golden rice it is necessary to capture the impact on human health and its effects throughout the economy. As mentioned above, Zimmermann and Qaim (2004) estimate that, under conservative adoption and consumption assumptions, golden rice could lead to between a six and 47 per cent decrease in DALYs lost in the Philippines which is equivalent to an increase in unskilled labour productivity of up to 0.53 per cent. Based on those findings, we decided to represent these health impacts with an assumed 0.5 per cent improvement in unskilled labour productivity in all sectors of the golden rice-adopting developing economies (and no direct

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[5]The cost of segregation would be smaller, the more rice is consumed by the producing household or sold to local consumers, as is common in developing Asian countries. This situation is thus qualitatively different from that analyzed by Lapan and Moschini (2004) where the costs of segregation and identity preservation are assumed to be significant.

Table 1. Assumed impact of GM rice adoption on factor productivity, by sector (per cent change)

	Adoption of non-golden GM rice (impact in GM rice sub-sector)	Adoption of golden rice (impact in all sectors)
Land	6	0
Skilled labour	8	0
Unskilled labour	8	0.5 (2.0)[a]
Capital	0	0
Natural Resources	0	0
Chemical inputs	5	0

[a]The 2 per cent shock is aimed at examining how the effect would change if adopting golden rice stimulates the adoption of other nutritionally enhanced GM crop varieties that together boost unskilled labour productivity domestically by four times as much as in the case of just golden rice adoption.
Source: Authors' assumptions, based on the literature review by Huang, Hu, van Meijl and van Tongeren (2004) for column 1, and Zimmermann and Qaim (2004) for column 2.

impact on the productivity of skilled labourers, who are assumed to be rich enough to already enjoy a nutritious diet). Table 1 summarizes the productivity shocks assumed when the two different types of GM rice are adopted, to capture both agricultural productivity and direct health impacts on factor and product markets. To continue to err on the conservative side, we assume golden rice production is no more productive in the farmers' use of factors and inputs than traditional rice net of segregation and identity preservation costs.[6]

While these simulations assume biased technical change in GM non-golden rice, technical change in both coarse grains and oilseeds is assumed to be Hicks-neutral. Van Meijl and van Tongeren (2004) also assume a Hicks-neutral, output-augmenting productivity shock of 5 per cent for coarse grains, but for soybeans they assume a chemical- and labour-productivity shock. Since alternative simulations assessing the importance of these assumptions concerning biased technical change do not generate substantially different welfare results, we retained the simpler Hicks-neutral assumption.[7]

The simulations reported here are conservative estimates of the impacts of the

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[6]Zimmermann and Qaim (2004) report that breeders do not expect the presence of beta-carotine in golden rice to have any adverse agronomic impact on its production relative to current non-GM rice varieties. The reviews by Bouis (2002) and Welch (2002) are more positive, suggesting nutritionally enhanced cultivars are more resistant to disease, their roots extend more deeply into the soil so they require less irrigation and are more drought resistant, they release chemical compounds that unbind trace elements in the soil and thus require less chemical inputs, and their seeds have higher survival rates.

adoption of golden or other GM rice in that they assume only 45 per cent adoption in each case. This captures the medium-term impact rather than the potential impacts of full adoption in the long term. One could also interpret these results as additive in either of two ways: both golden and non-golden GM rice could be adopted simultaneously so as to account for a total of 90 per cent of rice production, in which case their welfare effects could be summed; or, if golden rice had the same farm cost-saving effects as non-golden GM rice, the full productivity effects of golden rice would be given by the sum of those generated by these two simulations.

It needs to be kept in mind that the 0.5 per cent unskilled labour productivity shock accounts for only the direct labour productivity impacts (based on estimates by Zimmerman and Qaim 2004) of golden rice, ignoring the non-pecuniary benefits in terms of poor people feeling healthier, living longer and spending less on medical care. Also, if farmers gain from golden rice adoption, presumably they would be more favourably disposed to consider the adoption also of nutritionally enhanced varieties of wheat and other crops (development of which is already well under way). To capture a sense of how significant that might be, we parenthetically show results for one other simulation in which the productivity growth for unskilled labour is four times that examined for golden rice alone.

C. Consumption

In order to capture consumer aversion to GM products in some OECD countries, elasticities of substitution between GM and non-GM products in those regions are set at low levels.[8] Once golden rice is introduced, consumers in developing Asia are assumed to prefer it over other rice. For simplicity and to continue to be conservative, we ignore the possibility that consumers of inferior grains might shift to golden rice and instead just represent the consumer response as involving demand for non-golden rice shrinking by 45 per cent, so that golden rice accounts for 45 per cent of total rice demand in adopting countries. And since developing Asian countries are only very slightly different from 100 per cent rice self-sufficient, we assume the productivity-enhancing effect of the consumer health benefit of golden rice is confined just to the adopting countries.

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[7]The results from sensitivity analysis are available from the authors.

[8]Elasticities of substitution are included in the computation of the distribution of GM and non-GM consumption of coarse grains, oilseeds, and rice within each region. Systematic sensitivity analysis indicates that varying the elasticities of substitution for these commodities has minimal impact on the model solution. Again, details are available from the authors.

D. Factor ownership

GTAP provides a comprehensive decomposition of changes in national economic welfare as measured by the equivalent variation in income. National measures of welfare changes hide the distributional implications within countries of GM adoption and trade policy responses, however, and thus fail to provide insights into the political economy of GM policy choices. While the total economic benefits from trade typically decrease when inefficient policies such as import bans are implemented, some groups within national economies will benefit. Hence further analysis of the intra-national distribution of effects of adoption by some countries and of policy reactions by other countries is desirable.

We examine the effects on intra-regional distribution of income by dividing the economy into three groups of households: farmers, unskilled labourers, and owners of human and other capital. Income of each group comes from a combination of factors. Farm households earn income from farm and non-farm activities. The existing GTAP database provides information about the availability and use of land, unskilled labour, skilled labour, other natural resources and other capital in the agricultural sector, and likewise in other sectors. Non-farm activities of farm households are assumed to earn income from factors in the same proportion as activities conducted by the typical urban capital-owning household. Hence factor shares for farm households are a weighted sum of factor shares used in agricultural production and the factor income shares of capital owners. The shares of farm household income from non-farm activities are assumed to be 90 per cent in Japan and Korea, 50 per cent in China and the EU, 35 per cent in US and Canada, 25 per cent in Australia, New Zealand, and Eastern Europe, and 20 per cent in all Latin American countries, India, South and South-east Asia, South African Customs Union and the Rest of the World. The remaining Sub-Saharan African countries are assumed to gain 10 per cent of their farm household income from non-farm activities. Unskilled labourers are assumed to receive all their income from unskilled labour. In the absence of sufficient national household surveys we simply assume the expenditure shares are the same for all households within each country, so real household incomes are calculated by deflating by the national consumer price index. The use of the CPI to capture changes in consumer expenditure underestimates the impact of GM crop adoption on poor Asian farmers and unskilled labourers who spend a relatively large proportion of their income on food.

VI. Scenarios and Results

Two sets of simulations are compared to the base case to explore the national, regional and global impacts of GM rice adoption in Asia. The first set assumes that the US, Canada and Argentina adopt GM coarse grains and oilseeds (but not rice). This is modelled as a Hicks-neutral productivity shock on the GM varieties to capture their higher productivity. The these simulations in this first set are:

Sim 1: US, Canada and Argentina adopt GM coarse grains and oilseeds (farm productivity shock);

Sim 2: As for Sim 1 + China, South and Southeast Asian countries adopt golden rice (rice demand/supply and unskilled labour productivity shocks);

Sim 3: As for Sim 2 + EU-15, Japan and Korea impose a ban on imports of rice (and coarse grains and oilseeds) from countries adopting GM varieties of those crops (trade policy response shock).

The second set of simulations assumes that the US, Canada and Argentina join developing Asia in adopting GM non-golden rice, modelled as a factor productivity shock on the GM varieties to capture their higher farm productivity. Thus:

Sim 4: As for Sim 1 + China, South and Southeast Asia as well as the US, Canada and Argentina adopt non-golden GM rice (farm productivity shock);

Sim 5: As for Sim 4 + China, South and Southeast Asia also adopt GM coarse grains and oilseeds (extra farm productivity shock);

Sim 6: As for Sim 5 + EU-15, Japan and Korea impose a ban on imports of rice, coarse grains and oilseeds from countries adopting GM varieties of those crops (trade policy response shock).

The estimated national economic welfare effects of these shocks are summarized in Table 2. Assuming no adverse reaction by consumers or trade policy responses by governments, the first column shows that the adoption of GM varieties of coarse grains and oilseeds by the US, Canada and Argentina would have benefited the world by almost US$2.3 billion per year, of which $1.3 billion is reaped in the adopting countries. Asia and the EU enjoy most of the rest, through an improvement in their terms of trade, as net importers of those two sets of farm products. The only losers in that scenario are countries that export those or related competing products. Australia and New Zealand lose because their exports of grass-fed livestock products are less competitive with now-cheaper grain-fed livestock products in GM-adopting countries.

Table 2. Economic welfare effects of GM rice, coarse grain and oilseed adoption by developing Asia and the US, Canada and Argentina (equivalent variation in income, US$ million)

	Sim 1 (base)	Sim 2	Sim 3	Sim 4	Sim 5	Sim 6
China	107	1783	1919	871	964	1001
India	0	575	575	458	709	696
Other South + SE Asia	36	949	952	671	760	781
Japan and Korea	322	567	-1789	429	486	-6306
USA + Canada	1011	1218	686	1035	1021	539
Argentina	312	314	218	318	314	241
Other Latin America	89	126	862	93	89	910
Australia + New Zealand	-14	-9	84	-18	-21	132
EU15	267	603	-2895	314	338	-3801
Sub-Saharan Africa	1	15	107	6	7	168
Rest of World	159	275	318	203	220	186
WORLD total	2290	6416	1036	4379	4887	-5452

Source: Authors' model results.

Column 2 of Table 2 shows the projected gains from golden rice adoption by developing Asia. They are almost three times the gains in Simulation 1 from GM maize and oilseed adoption in the Americas, amounting to an extra $4.1 billion per year globally (over and above the $2.3 billion benefit from prior GM maize and oilseeds adoption in the Americas). Asian countries adopting golden rice capture all but one-fifth of those additional gains. The sources of their gains are revealed in Table 3. Most of the gains come directly from the enhanced productivity of unskilled labour, but some is due to improved efficiency of national resource use given the presence of price-distorting policies in the adopting countries. Not surprisingly, adopting countries experience a slight worsening in their terms of trade.

The numbers in parentheses in Table 3 show how much larger these effects would be if the adoption of golden rice stimulated the adoption of other nutritionally enhanced GM foods that quadrupled the boost to unskilled labour productivity. That greater shock boosts welfare in the adopting countries by more than four times, because the adverse terms of trade effect is only slightly greater in this case. Global benefits would be $17.4 billion per year instead of $6.4 billion if that labour shock in developing Asia was 2 per cent instead of just 0.5 per cent.

Table 3 also reveals the impact of this technology on real net incomes of two groups of poor households, namely farmers and those earning from just their

Table 3. Decomposition of national economic welfare effects for Simulation 2 (NA and ARG adopt GM maize and oilseeds, developing Asia adopts golden rice) and percentage change in real household incomes of farmers and unskilled labourers

	(equivalent variation, US$ million)				Real net household income of:	
	TOTAL welfare gain, *due to:*	Enhanced allocative efficiency	Change in terms of trade	Enhanced pro-ductivity of Asian unskilled labour or Amer-ican farms	Farmers (% change)	Unskilled labourers (% change)
China[a]	1783 (7209)	400 (1288)	-208 (-379)	1573 (6268)	0.00 (0.89)	0.01 (0.65)
India[a]	575 (2528)	143 (408)	-134 (-143)	569 (2267)	-0.01 (0.42)	0.00 (0.28)
Other Sth + SE Asia[a]	949 (4140)	163 (466)	-241 (-425)	1032 (4110)	-0.03 (0.37)	0.01 (0.49)
Japan and Korea	567	160	436	0	0.01	0.01
USA + Canada	1218	139	-268	1305	-0.17	0.02
Argentina	314	21	-50	338	0.05	0.12
EU15	603	327	311	0	-0.02	0.00
Sub-Saharan Africa	15	11	4	0	-0.03	-0.02

[a]Numbers in parentheses refer to the variation in which the 0.5 per cent unskilled labour productivity shock is replaced with a 2 per cent shock, which assumes the adoption of golden rice stimulates the adoption of other nutritionally enhanced GM crop varieties that together boost unskilled labour productivity domestically by four times as much as in the case of just golden rice adoption.
Source: Authors' model results

unskilled labour. These impacts are a consequence of changes in factor rewards weighted by their importance in generating the households' income, net of changes in consumer prices weighted by the importance of rice and other products in household expenditure. It turns out the net effects for both these groups are close to zero from the 0.5 per cent shock to unskilled labour productivity. However, if that shock were to be four times as large because of the adoption also of other nutritionally enhanced GM crops, the numbers in parentheses in the final two columns of Table 3 show that real incomes of farm households would be boosted by 0.9 per cent in China and by 0.4 per cent in Asia's other developing countries. The technology in that case would also boost households dependent solely on unskilled wage earnings: increasing these incomes by 0.7 per cent in China, 0.3 per cent in India and 0.5 per cent in other South and Southeast Asia. Other households in those countries also gain, so as a share of GDP the welfare gain is equivalent to 0.5 per cent for China and around 0.1 per cent for other developing Asia (or about

four times that in the case of a 0.5 per cent labour productivity boost). The GDP boost from this golden rice technology makes developing Asia more affluent, which expands its demand for exports from the rest of the world, so all other regions gain as well through improved terms of trade, although only slightly relative to the percentage gains to the adopting countries.

The first two of these simulations assume there is no adverse consumer or policy reaction in countries to whom the GM adopters export. If instead the EU, Japan and Korea were to place a ban on imports of these products from the GM-adopting countries (as indeed the EU has been doing since 1998 through a de facto moratorium on the authorization of new releases of GMOs), Simulation 3 in Table 2 shows the global welfare gains are diminished markedly. An examination of the distribution of those changes in welfare reveals that the benefit to the American adopters of GM maize and oilseeds is reduced by one-third, whereas the benefit to the Asian adopters of golden rice does not fall at all (in fact it rises slightly). The latter is mainly because those countries are and remain almost 100 per cent self sufficient in rice and do not export much rice to the moratorium countries because of those countries' extremely high tariffs on rice imports. Also, developing Asia gains very slightly from a reduction in the price of their imports of maize and oilseeds from America. The biggest losers economically from the moratorium are of course the countries imposing the import ban, against which needs to be weighed the value they place on the certainty of not importing GMOs following GM adoption abroad (which cannot be measured in our model). The rest of the world gains from the moratorium, including Sub-Saharan Africa and the rest of Latin America, either because they are able to import these products more cheaply from the GM-adopting countries or because they are able to export non-GM varieties of those crops to the moratorium countries and receive higher prices than previously (assuming they can verify that their produce is GM-free).

How do these results for golden rice compare with the gains that would come from adopting GM rice varieties aimed solely at enhancing farm productivity? Assuming the farm productivity gains reported in column 1 of Table 1 were achievable, the welfare effects of introducing non-golden GM rice in developing Asia (and in North America and Argentina) are shown under Sim 4 in Table 2. When compared with Sim 1 (just American adoption of GM maize and oilseeds), the addition of rice in those countries and in developing Asia almost doubles the global welfare gain (from $2.3 to $4.4 billion per year). If that prompted developing Asia to also adopt GM varieties of coarse grains and oilseeds, the

global gains would rise to \$4.9 billion (Sim 5 in Table 2). Simulations 4 and 5 assume no policy reactions abroad though. Sim 6 in Table 2 estimates the outcome if the EU, Japan and Korea were to ban imports of those products from GM-adopting countries. In that case, so large is the cost of protection to those import-banning countries that the world economy is worse off than without any GM adoption. But notice again that that moratorium would not alter very much the welfare gain to developing Asia, for similar reasons to the golden rice case. More importantly, though, the impact on welfare in developing Asia, even when GM adoption in Asia spreads to coarse grains, oilseeds and non-golden rice, is nowhere near as great as with the adoption of golden rice.

V. Conclusions

The above results suggest that Asia's developing countries could benefit from GM technologies in a number of respects. First, GM crop technologies promise to enhance welfare in the countries willing to adopt these new varieties. The first-generation, farm-productivity enhancing GM varieties alone will boost welfare in the adopting countries, and more so if adoption extends beyond rice to maize and oilseeds, even if rich countries impose a ban on imports of affected crop products from the adopting countries. And those welfare gains will alleviate poverty directly in those countries through boosting the real household incomes of both farmers and unskilled labourers.

Second, adoption of golden rice could lead to greater improvements in national welfare gains and to poverty alleviation, assuming the estimated health gains reported in Zimmerman and Qaim (2004) are reliable and translate as assumed here into a permanent boost to unskilled labour productivity. Substantial welfare gains are expected even based on conservative assumptions regarding adoption rates and health benefits and by assuming that golden rice has no positive effect on farm productivity (other than through the unskilled labour effect which impacts on all sectors in the adopting countries). Moreover, we include no valuation of the non-pecuniary welfare gain to VAD sufferers from being able to reduce that vitamin deficiency through access to golden rice. If other developing countries, particularly in sub-Saharan Africa, also adopted that rice, the global welfare gains and alleviation of poverty and ill-health would be even greater (see Anderson and Jackson 2005). As the numbers in parentheses in Table 3 reveal, the gains would be greater still if golden rice adoption encouraged the adoption of other

nutritionally enhanced GM crop varieties.

The stakes are thus very high. Developing Asian countries need to assess whether they share the food safety and environmental concerns of the Europeans regarding GMOs. If not, their citizens in general, and their poor farmers, unskilled workers and VAD sufferers in particular, have much to gain from adopting GM varieties of rice and other foods. And, unlike the case for North America and Argentina where there is a heavy dependence on exports of maize and oilseeds, the welfare gains from GM crop adoption by developing Asia would not be jeopardised by rich countries banning imports of those crop products from the adopting countries, since high rice tariffs already limit trade with those countries anyway.[9]

Acknowledgment

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[9]That is not to say the high tariffs on rice imports by Japan and Korea are unimportant. If those two countries halved their rice tariffs instead of banning imports from GM countries, welfare in those countries would be $8 billion per year more instead of $2.3 billion less than in Simulation 2 (assuming consumers in those countries are indifferent between golden and traditional rice). Southeast Asian and other rice exporters would be better off as well with that greater access to Northeast Asian markets, so global welfare in that case would be $6.2 billion more instead of $5.4 billion less than in Simulation 2, a difference of $11.6 billion per year. That is, liberal trade and technology policies can be mutually reinforcing in terms of enhancing welfare. For a more-general analysis of the impact of protection policies on the benefits of adopting GM varieties, see Anderson and Nielsen (2004).

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