Ex-ante Assessment of Drought Tolerant Bean Technology

A case study in the series:

ECONOMIC FORESIGHT FOR UNDERSTANDING THE ROLE OF INVESTMENTS IN AGRICULTURE FOR THE GLOBAL FOOD SYSTEM

<table>
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<tr>
<th>Contributor</th>
<th>Role</th>
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<tr>
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<td>Research regarding the mechanisms of tolerance to drought, identification of the varieties, drafting of the text.</td>
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Executive summary
In this paper we apply an integrated biophysical and economic foresight modeling approach to investigate the impacts of climate change on the global agricultural economy, and the role that new crop technology could play in mitigating these impacts. In particular, we examine how the adoption of a drought tolerant common bean variety could serve as an adaptive measure in parts of the world where rising temperatures and decreasing rainfall are expected to place severe water stress on existing pulse farming systems over the period 2020 to 2050. Our study integrates the three mature, independently developed areas of crop, climate, and partial equilibrium economic modeling in order to accurately simulate climatic stress at the biophysical level, and then to register how this stress, as well as the measures taken to mitigate it, manifest at the socioeconomic level in terms of changes in supply and demand, international trade, land use, and food security. While the suite of models employed examines the global picture, our focus is on the Latin America and the Caribbean region (LAC) and Africa. The output suggests that, on average, adoption of drought tolerant common bean could mitigate climate change induced yield losses by 6% over the baseline variety. However, outcomes are nuanced in that yield impacts bear an ambiguous relation to impacts on cultivated area, production, net trade, and food security variables. Care must be taken when designing a climate change mitigating technology intervention at the country level so as to accommodate this nuance.
Introduction

Across the globe, it has become imperative to search for pathways towards reducing poverty and improving food security. Research supporting advancements in the agricultural sector figures prominently in any such strategy. There is, however, a lot of uncertainty about the capacity of agriculture to ensure food security, as reflected in ongoing debates about poverty, food security, and natural resource geopolitics (Bruckmann, 2012; Delfín, 2014). These arguments are exacerbated by current and emerging understanding of water scarcity and the potential impacts of climate change (WFP, 2014). Other factors compound the challenges we face, including the issue that climate change may affect populations that are already vulnerable and poor, as is the case in many tropical regions (Barbier, 2012; Rosegrant & Cline, 2003).

In this paper, we apply an integrated suite of ex-ante impact assessment tools to examine the potential role that an improved common bean variety could play in addressing these complex challenges. Existing bean varieties already play a central role in providing proteins, vitamins, minerals and iron for millions of people worldwide (Broughton et al., 2003; Mederos, 2006; Singh & Singh, 1992). In many cases, bean cultivation is also an important source of household income, especially in vulnerable rural communities. In many parts of the world, the importance of beans extends beyond its basic role as a food source, becoming part of the local tradition and culture (Leterme & Munoz, 2002).

Common bean cultivation is particularly prevalent in Latin America, the Caribbean, and Africa. In these regions, beans constitute the most important protein source for over 500 million people (Cortés, Monserrate, Ramírez-Villegas, Madrinán, & Blair, 2013). Beans are typically produced with few inputs on small farms (between 1 and 10 hectares) situated in a diverse range of environmental conditions. Cultivation often occurs on marginal lands, including hillside areas with low fertility, and in conditions of socio-economic vulnerability (Broughton et al., 2003; Pastor & Schwartz, 1994) (CIAT, 1994; Rosas et al., 2000).

Common bean research prioritization

As one of the early steps in this study, the International Centre for Tropical Agriculture (CIAT) undertook a prioritization of different research options related to the common bean. The study covered a range of possible trait improvements, particularly drought tolerance, water efficiency, improved yield, and consumer appeal. The study also examined a number of non-research institutional measures that could be taken, such as certified seed production, the identification of marketing channels, and the development of national and regional policies for marketing (Rodríguez De Luque & Creamer, 2014).

At the end of this exercise, the development of drought tolerant varieties of common bean emerged as the top research priority (Rodríguez De Luque & Creamer, 2014). In the present study we assess the role such a technology could play in the global food system, and especially its economic impact in the LAC and African regions. The results of this evaluation offer new insights into the potential benefits and beneficiaries of investment in this technology.
Issues motivating potential investment in drought tolerant bean

Around 60% of the world’s bean-producing regions suffer from drought conditions which can result in production losses of between 10% and 100% (Graham & Ranalli, 1997; Polanía, Rao, Beebe, & García, 2009). Given climate change, these conditions are expected to worsen in the coming decades, making the development of new drought resistant varieties an important priority.

Drought is defined as a dry period of long duration which can lead to a hydrologic imbalance (Cázares, Silva, & Medrano, 2010). Periods of water stress, due to intermittent droughts, can affect the yield and quality of the common bean (Urrea, Yonts, Lyon, & Koehler, 2009). According to Schwartz et al. (1980), low humidity can cause damage to plants due to insufficient water in the roots, accumulation of toxic ions, such as magnesium and boron, closure of the stomata, absorption of CO2, and temporary or permanent wilting. In particular, a dry period can cause poor grain filling, a reduction in the number of seeds per pod and a reduction in pod length (López Salinas, Tosquy Valle, Ugalde Acosta, & Acosta Gallegos, 2008). Beans are especially vulnerable to drought when it occurs during the flowering period (Graham & Ranalli, 1997). At such times, drought can result in yield reductions of 22% to 71% (Ramirez-Vallejo & Kelly, 1998).

Spatial extent of drought-prone areas

In Latin America, the Caribbean and Africa, it is estimated that nearly 4 million hectares of beans are affected by lack of water (Cortés et al., 2013). The main bean-producing areas where drought is a major problem are concentrated in northeast Brazil, the Pacific coast of Central America, Eastern and Southern Africa, and the Mexican plateau (I. Rao et al., 2013). With regard to the production of beans in the Mexican plateau, it is estimated that nearly 85% of the production in the spring-summer season occurs under highly variable conditions (Cázares et al., 2010). Figure 1 shows the geographic areas with the highest probability of drought in Latin America, the Caribbean and Africa, highlighting the above-mentioned areas.
Ultimately, yield losses caused by drought result in reduced farm incomes, which in turn depresses the dynamics of the bean market, discouraging both current and prospective producers. These are the dynamic feedback mechanisms we propose to explore in this report. See Annex 1 for additional information on future climate model scenarios for temperature and precipitation.

**Biophysical drought tolerance mechanisms**

In agronomic terms, a plant is considered resistant to drought if its yield under drought conditions is similar to its yield under non-drought conditions (White & Izquierdo, 1989). As discussed in (Rao, 2001), drought resistance covers a variety of mechanisms that the plant depends upon for its survival and reproduction during periods of water shortage. Primarily, this involves the maintenance of positive turgor pressure even under conditions of low water potential within the tissue. White & Izquierdo (1991) suggest the following possible mechanisms:

1. **Drought evasion**: Bean plants can evade or reduce drought-induced stress with an earlier maturity (precocity) or by delaying their stage of maturity (recovery).

2. **Drought tolerance via high water potential in the plant**: Bean plants can maintain a high level of water potential within their tissue by maintaining water intake and by reducing water outflow during drought conditions. The maintenance of water intake is achieved using two strategies: greater growth in the roots and an increase in hydraulic conductance. In beans, tolerance to drought has been associated with greater growth of the roots, because there is a further exploration, by the roots, in search of available soil moisture.

Reduction in water loss is achieved through three strategies: reduction in the area of evaporation; an increase of the resistance to water losses; and a decrease in the temperature gradient in the leaves. According to Taiz & Zeiger (2010), plants ease
the effects of abiotic stress in the leaves through changes in the leaf area. Finally, the increase in the resistance is mainly related to the closure of stomata, in order to avoid water losses.

3. **Drought tolerance via low water potential**: Bean plants can also accommodate drought conditions by adapting to low water potential through osmotic adjustment, an increase in cellular elasticity which results in greater tolerance to desiccation via membrane stability and functional proteins. Drought tolerance in certain varieties can also occur due to adaptation to the conditions associated with the drought.

Overall, the roots play a very important role in adaptation to drought due to their role in the absorption of water and minerals. In the common bean, the last sub-division of the roots is composed of absorbent hairs that are critical for the absorption of water and nutrients. The root system tends to be fasciculated, fibrous, and can vary significantly between varieties and even between different specimens of the same variety. In general, the root system is superficial and the largest volume of the whole root system is located in the first 20 cm of the soil depth (Debouck & Hidalgo, 1985). The productivity of the bean plant depends on the efficiency of the root system to take in the nutrients and water (Maiti, 1997).

**Materials and Methods**

In order to assess the potential role that technology could play in mitigating climate change impacts, we employ an ensemble of linked models which capture changes in crop physiology, climate, and the economic system. The components of this ensemble are described in the following sections.

The overall design of the assessment draws upon a three step approach. In the first step, prior to any modeling, the desired characteristics of the new technology are defined. In the second step, a crop simulation model is used to estimate the potential impact on yield of the new technology under climate change scenarios relative to a no-technology baseline scenario. In the third step, a partial equilibrium model is used to model economic impacts.

![Figure 2: Evaluation process](image)
Modeling of the baseline and drought tolerant varieties

Having identified drought tolerance as a key research priority, the goal then is to develop “virtual” representations of drought tolerant beans. This facilitates evaluation of the performance of the simulated drought tolerant crop to the “current” technology option. In order to develop the comparators, a series of regionally appropriate baseline varieties were identified with existing calibrations in the DSSAT crop model. The baseline bean varieties simulated using DSSAT for each region are presented in Table 1.

Table 1: Baseline varieties simulated in each region

<table>
<thead>
<tr>
<th>Region</th>
<th>Variety in DSSAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central America</td>
<td>IB0006, ICTA-Ostua</td>
</tr>
<tr>
<td>México</td>
<td>Jamapa</td>
</tr>
<tr>
<td>Brazil</td>
<td>Carioca, Perola</td>
</tr>
<tr>
<td>Colombia</td>
<td>Calima</td>
</tr>
<tr>
<td>South America outside of Brazil and Colombia</td>
<td>Average of Carioca, Porrillo Sintetico, Jamapa and Calima</td>
</tr>
<tr>
<td>United States</td>
<td>C-20 and Seafarer</td>
</tr>
<tr>
<td>Eastern Africa</td>
<td>Calima</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>Carioca and Brasil 2 Pico</td>
</tr>
<tr>
<td>West Africa</td>
<td>Average of Carioca, Brasil 2 Pico and Calima</td>
</tr>
<tr>
<td>Asia</td>
<td>IB0028 Jatu Rong</td>
</tr>
</tbody>
</table>

Following Rosegrant et al. (2014), improved resistance to dry periods was simulated as an enhanced capacity to access water in the soil. This was implemented in DSSAT through the modification of two parameters. The Soil Drained Upper Limit (SDUL) indicates the moisture content retained by the soil after it has been saturated and the excess has been drained by the macro-pores. The Lower Limit (SLLL) is the moisture content of the soil at which the plants will wither and does not recover their turgidity. The improved cultivar’s water extraction capacity was increased by 10% through a reduction of the SLLL parameter and an increase in the SDUL parameter in the soil profile, thus simulating enhanced access to the available water.

Modelling of yields under historical and future climates

Future climates were simulated using the average of an ensemble of five climate models (GFDL, Hgem, IPSL, Miro, and NORE). Each of these models was run under Representative Carbon Pathway (RCP) 8.5. Given the high carbon concentrations and associated climate forcing, RCP 8.5 is a pessimistic scenario in which it is assumed that governments take no measures to mitigate global warming and carbon emissions increase threefold by 2100 (IPCC, 2015; Vuuren et al., 2014).

For each map pixel, baseline yields were estimated by simulating the specified cultivars under the historical climate over a thirty year period (1981-2010) and then calculating the average yield for the time period. Future yields were estimated by repeating this process over a future period (2041-2070). In computing the relative change in yield based on the averages of the past and future periods, variation associated with extreme
climate events is reduced and the trend associated with climate change is more readily discernable. Once present and future yields were calculated in this way for each pixel, they were aggregated to food production units (FPU), the lowest level geographical unit of analysis in the IMPACT model (Robinson et al., 2015).

Economic Modelling
The economic impacts of the exogenous shocks introduced by the new technology and climate change were explored using the IMPACT model developed at IFPRI (Sherman Robinson et al., 2015; Rosegrant et al., 2014). IMPACT accounts for the international trade of more than sixty crops and related goods, and uses a partial equilibrium model to represent commercial interactions across the global market. The IMPACT model also takes into account a set of factors and assumptions that influence the general trajectory of the global economic system such as population growth and income distribution in the food policy units. IMPACT implements these assumptions in the form of “shared socioeconomic pathway” (SSP) parameterizations which characterize and quantify the user-defined socioeconomic narrative (O’Neill et al., 2014). For this study, we used the SSP2 parameterization, a conservative scenario that is typically considered "business-as-usual" (Vuuren et al., 2014).

Changes in crop performance, production and area are influenced by global markets within the IMPACT model. The relationship between the production of beans and the abilities of countries to participate in the international market depends on the global prices of the commodities. The demand, exports and imports are then derived from the interactions across this world market, taking into account the specific characteristics of each country.

Finally, IMPACT determines new technology adoption rates within each FPU assuming that the producers are rational in their choice of this agricultural innovation. The assumption within the model is that producers use the potential improvement in yield as the basis for adopting the technology or not (i.e., farmers will not adopt a technology that results in lower yields). In turn, we assume the technology would have the potential to spread starting in the year 2020 and reach a 30% adoption rate ceiling, across the area sown, by the year 2040.

In a first run of the models we compare the new technology to the baseline in the absence of climate change. This gives us a basic concept of the impact of the new technology based on purely biophysical considerations of the crop itself. Then we run the comparison given climate change in order to draw out the potential mitigation afforded by new technology. These model runs are summarized in Table 2.
<table>
<thead>
<tr>
<th>Table 2: Impact scenarios</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>No climate change</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Climate change</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

In order to determine the climate change mitigating effect of the new technology, we first calculate the percentage change in yield under climate change over the period 2020-2050 without the new technology, and then repeat this calculation in a world where the technology is made available. That is,

\[
\% \Delta y_{CCNoTech} = \frac{y_{CCNoTech2050} - y_{2020}}{y_{2020}}
\]

(1)

\[
\% \Delta y_{CCTech} = \frac{y_{CCTech2050} - y_{2020}}{y_{2020}}
\]

(2)

Finally, we define the mitigating effect of the technology on bean yield as the difference between the percentage change in yield under climate change with and without the new technology.

\[
y_{diff} = \% \Delta y_{CCTech} - \% \Delta y_{CCNoTech}
\]

(3)

We refer to this below as the yield technology differential. In the same way, we define the technology differential for area, production, and food security variables. Since net trade may be negative, the technology differential for net trade in beans is calculated in absolute terms rather than percentages.

\[
\Delta t_{CCNoTech} = t_{CCNoTech2050} - t_{2020}
\]

(4)

\[
\Delta t_{CCTech} = t_{CCTech2050} - t_{2020}
\]

(5)

\[
NT_{diff} = \Delta t_{CCTech} - \Delta t_{CCNoTech}
\]

(6)

These variables are summarized in Table 3.
Table 3: Variables analyzed in this study

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC yield technology differential</td>
<td>% change in bean yield under CC in 2050 over the baseline value in 2020 with tech. MINUS the % change in bean yield under CC in 2050 over the baseline value in 2020 without tech.</td>
</tr>
<tr>
<td>CC area technology differential</td>
<td>% change in cultivated bean area under CC in 2050 over the baseline value in 2020 with tech. MINUS the % change in cultivated bean area under CC in 2050 over the baseline value in 2020 without tech.</td>
</tr>
<tr>
<td>CC prod. technology differential</td>
<td>% change in bean production under CC in 2050 over the baseline value in 2020 with tech. MINUS the % change in bean production under CC in 2050 over the baseline value in 2020 without tech.</td>
</tr>
<tr>
<td>CC net trade technology differential</td>
<td>Change in net trade under CC in 2050 over the baseline value in 2020 with tech. MINUS the change in net trade under CC in 2050 over the baseline value in 2020 without tech.</td>
</tr>
<tr>
<td>CC total malnourished children tech. differential</td>
<td>% change in number of malnourished children under CC in 2050 over the baseline value in 2020 with tech. MINUS the % change in number of malnourished children under CC in 2050 over the baseline value in 2020 without tech.</td>
</tr>
<tr>
<td>CC food availability tech. differential</td>
<td>% change in food availability under CC in 2050 over the baseline value in 2020 without tech. MINUS the % change in food availability under CC in 2050 over the baseline value in 2020 with tech.</td>
</tr>
<tr>
<td>CC share of pop. at risk differential</td>
<td>% change in share of population at risk of hunger under CC in 2050 over the baseline value in 2020 without tech. MINUS the % change in share of population at risk of hunger under CC in 2050 over the baseline value in 2020 with tech.</td>
</tr>
</tbody>
</table>

Results

It is important to consider that all modeling is a partial representation of the reality of the system(s) of interest. In that the representation is necessarily partial, some level of uncertainty is present in each step in the modeling process. Given this uncertainty and the corresponding potential for error propagation throughout the modeling process, we evaluated the simulated crop yields against benchmark data from FAO prior to initiating the IMPACT modeling process. This evaluation offers one point of entry for understanding potential limitations of the modeling results.

Comparison to benchmark datasets

When comparing crop model results to FAO data from the same time period, we find that the two disagree by 50% - 350% in some instances. This disagreement is relatively heteroscedastic and appears to be correlated with the number of pixels modeled within each country. Several months of dialogue among the contributing modelers was unable to clarify the issue. Much of the discrepancy may be rooted in problems with the FAO bean data, which conflates several types of bean together with common bean. However, this would not explain the heteroscedasticity and the observed correlation with the number of pixels per country. That said, we were able to verify that our models were
internally consistent and generated plausible outputs. We are continuing to investigate the potential sources of error and differences between the simulated yields and the FAO database.

**Technology-based changes to yield, area, and production**

The model representations in IMPACT that drive many of the above observed changes are a function of the underlying changes in yields, area under cultivation and overall production of the commodity in question. Country level climate change impacts on bean yield, area, and production, with and without technology, can be examined relative to one another by looking at the heatmap presented in Figure 3.

![Heatmap of yield, area, and production changes](image)

**Figure 3:** Climate change impact on bean yield, area, and production for each country in LAC and Africa, with and without technology.

In the bar chart in Figure 4, we examine climate change mitigating effects of the new technology relative to the baseline varieties in each country. Generally speaking, North African countries exhibit the greatest yield differential resulting from technology, followed by SSA countries and LAC countries. Note that, for most countries, release and uptake of the
technology enhances yield gains, while for a few at the bottom of the distribution the new technology alleviates yield losses; and for two countries, Algeria and Mauritania, adoption of the technology makes the difference between yield loss and yield gain.

In the IMPACT output we observe a linear relation between each country’s projected yield technology differential and its projected area and production differentials (Figures 5 and 6). The relation is tight enough to derive two parameter formulas by which these technology differentials can be estimated from one another:

\[
Y_{\text{diff}} \approx 1.13A_{\text{diff}} + 7.75 \tag{7}
\]

\[
Y_{\text{diff}} \approx 0.4P_{\text{diff}} + 3.51 \tag{8}
\]

The fitted parameters in these formulas can be considered an extended part of IMPACT’s output. Based on their values, we can tell that all countries with a yield technology differential of less than roughly 7.8 percentage points will exhibit a negative area technology differential. Glancing at Figure 7 once more, we can see this means that all countries from about Sudan downwards are projected to have relatively less area under bean cultivation with technology under climate change than without it, even though the yield is higher. Likewise, we can see based on the parameter values in the second formula that countries with a yield technology differential of less than roughly
3.5 percentage points will exhibit a negative production technology differential. This means that countries from about Mexico downward in Figure 7 will have less production with technology than without it, despite higher yields.

Economic simulation in IMPACT

Holding climate constant, the models suggest that over the period 2020-2050 baseline variety yields can be expected to increase by an average of 33%. Over the same period, the yields of the drought tolerant bean variety can be expected to increase by an average of 36%. In the absence of climate change, then, release of the drought tolerant technology results in a 3 percentage point (pp) yield advantage over the baseline variety. This corroborates our working hypothesis regarding potential benefits of drought tolerance on a purely crop-centric biophysical basis (Figure 7).

Economic potential for drought tolerant crops under climate change

When the impact of climate change is taken into account, the average percentage change in yield over 2020-2050 is reduced to 20% and 26% for baseline and drought
tolerant varieties, respectively. Said another way, the impact of climate change is a 13 pp reduction in increases in yield for the varieties without drought tolerance.

The mean advantage of adopting the drought tolerant variety under conditions of climate change is estimated to offer an advantage of 6 percentage points. Comparing the histograms in Figures 7 and 8, the hypothesized increase in yield associated drought tolerance is evident. The area and production technology differentials are -1.5% and 6.3%, respectively. Disaggregated by region, the mean yield and production technology differentials are higher in Africa than in the LAC region; and the area technology differential is less negative in Africa than in LAC.

![Figure 8: Density plot of the difference in the percentage change in yield over 2020-2050 under climate change with and without technology.](image)

Net trade differentials are concentrated around zero, but with extremely high variance since a few countries experience drastic shifts in bean trade volumes when the technology is made available. The technology differential for food security variables is generally beneficial, and considerably more so in Africa than in LAC. Summary statistics are presented in tables 4-6.
Table 4: Summary statistics for key variables, LAC and Africa (N=48)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC yield technology differential</td>
<td>6.02965</td>
<td>4.773374</td>
<td>0.064367</td>
<td>17.56134</td>
</tr>
<tr>
<td>CC area technology differential</td>
<td>-1.47096</td>
<td>4.184391</td>
<td>-8.27747</td>
<td>11.11328</td>
</tr>
<tr>
<td>CC prod. technology differential</td>
<td>6.254371</td>
<td>11.6332</td>
<td>-8.27747</td>
<td>34.67948</td>
</tr>
<tr>
<td>CC net trade technology differential</td>
<td>-2.21848</td>
<td>21.06244</td>
<td>-50.6819</td>
<td>82.9376</td>
</tr>
<tr>
<td>CC total malnourished children tech. differential</td>
<td>-0.06257</td>
<td>0.068038</td>
<td>-0.29815</td>
<td>0.017129</td>
</tr>
<tr>
<td>CC food availability tech. differential</td>
<td>1.873604</td>
<td>0.521103</td>
<td>0.807082</td>
<td>2.890936</td>
</tr>
<tr>
<td>CC share of pop. at risk differential</td>
<td>-0.10464</td>
<td>0.135633</td>
<td>-0.65825</td>
<td>0.006249</td>
</tr>
</tbody>
</table>

Table 5: Summary statistics for key variables, Africa (N=30)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC yield technology differential</td>
<td>7.178374</td>
<td>5.073994</td>
<td>0.455534</td>
<td>17.56134</td>
</tr>
<tr>
<td>CC area technology differential</td>
<td>-0.63475</td>
<td>4.64474</td>
<td>-8.27747</td>
<td>11.11328</td>
</tr>
<tr>
<td>CC prod. technology differential</td>
<td>8.769527</td>
<td>12.63298</td>
<td>-10.0469</td>
<td>34.67948</td>
</tr>
<tr>
<td>CC net trade technology differential</td>
<td>-0.70237</td>
<td>22.7785</td>
<td>-40.816</td>
<td>82.89376</td>
</tr>
<tr>
<td>CC total malnourished children tech. differential</td>
<td>-0.06205</td>
<td>0.079172</td>
<td>-0.29815</td>
<td>0.017129</td>
</tr>
<tr>
<td>CC food availability tech. differential</td>
<td>2.102793</td>
<td>0.535707</td>
<td>0.807082</td>
<td>2.890936</td>
</tr>
<tr>
<td>CC share of pop. at risk differential</td>
<td>-0.12872</td>
<td>0.156012</td>
<td>-0.65825</td>
<td>0.002174</td>
</tr>
</tbody>
</table>

Table 6: Summary statistics for key variables, LAC (N=18)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC yield technology differential</td>
<td>4.107951</td>
<td>3.582829</td>
<td>0.064367</td>
<td>15.89412</td>
</tr>
<tr>
<td>CC area technology differential</td>
<td>-2.86464</td>
<td>2.883573</td>
<td>-5.97308</td>
<td>6.831429</td>
</tr>
<tr>
<td>CC prod. technology differential</td>
<td>2.062444</td>
<td>8.493305</td>
<td>-6.71274</td>
<td>30.43611</td>
</tr>
<tr>
<td>CC net trade technology differential</td>
<td>-4.74533</td>
<td>18.18145</td>
<td>-50.6819</td>
<td>32.97926</td>
</tr>
<tr>
<td>CC total malnourished children tech. differential</td>
<td>-0.06343</td>
<td>0.045871</td>
<td>-0.18703</td>
<td>0.002457</td>
</tr>
<tr>
<td>CC food availability tech. differential</td>
<td>1.873604</td>
<td>0.521103</td>
<td>0.807082</td>
<td>2.890936</td>
</tr>
<tr>
<td>CC share of pop. at risk differential</td>
<td>-0.10464</td>
<td>0.135633</td>
<td>-0.65825</td>
<td>0.006249</td>
</tr>
</tbody>
</table>

Effect of crop technology on net trade
Net trade volumes in beans are largely unaffected by the release and uptake of the new technology (Figure 9). However, for most countries this is because net trade remains zero throughout both climate change scenarios (with and without technology).
For a handful of countries, the net trade technology differential is substantial, on the order of \( \pm 10^3 \) metric tons (See Table 7). The impact is particularly remarkable for El Salvador and Burundi because of their small size though the veracity of this finding should be further investigated.

**Table 7: Countries with a substantial net trade technology differential**

<table>
<thead>
<tr>
<th>Countries with a net trade technology differential &gt; 20,000 MT</th>
<th>El Salvador, Ethiopia, Kenya, South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countries with a net trade technology differential &lt; -20,000 MT</td>
<td>Argentina, Brazil, Mexico, Burundi, Cameroon, Tanzania, Uganda</td>
</tr>
</tbody>
</table>

**Cluster analysis**

In pursuit of further insights into the IMPACT model output, we conducted a principle component analysis (PCA) of the six agricultural performance and food security variables described in Table 3. The analysis identified four distinct clusters which are presented in a principal component plot and hierarchical dendrogram in Figures 10 and 11.
Figure 10: PCA clusters plotted along the first two principal components.
The bar chart in Figure 12 indicates that four principal components are required to describe most of the variation in the data described by these six variables. This offers a window into the complex and dimensionally rich dynamics associated with the economic impact of crop technology as modeled in IMPACT.
Upon inspection of the clusters, we find that the countries within these clusters share a number of characteristics in common. Geographically, clusters 1 and 3 consist predominantly of Sub-Saharan African countries, while cluster 2 consists predominantly of LAC countries, and cluster 4 consists mostly of North African countries. While all LAC and African countries exhibit a positive yield technology differential, the corresponding technology differential in terms of area is negative in clusters 1 and 2, and positive in clusters 3 and 4. Most remarkably, the technology differential in terms of food security variables is high in clusters where it is low in terms of agricultural performance variables, and vice versa. These cluster characteristics are summarized in Table 8.

Table 8: Summary of PCA cluster characteristics

<table>
<thead>
<tr>
<th>Cluster 1 (N=12)</th>
<th>Cluster 2 (N=20)</th>
<th>Cluster 3 (N=28)</th>
<th>Cluster 3 (N=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC yield tech. differential: Positive but low</td>
<td>CC yield tech. differential: Positive but low</td>
<td>CC yield tech. differential: Positive and high</td>
<td>CC yield tech. differential: Positive and very high</td>
</tr>
<tr>
<td>CC prod. tech. differential: Negative</td>
<td>CC prod. tech. differential: Positive but low</td>
<td>CC prod. tech. differential: Positive and high</td>
<td>CC prod. tech. differential: Positive and very high</td>
</tr>
<tr>
<td>CC area tech. differential: Negative</td>
<td>CC area tech. differential: Negative</td>
<td>CC area tech. differential: Positive and high</td>
<td>CC area tech. differential: Positive and very high</td>
</tr>
<tr>
<td>CC food security tech. differential: High</td>
<td>CC food security tech. differential: Moderate</td>
<td>CC food security tech. differential: Low</td>
<td>CC food security tech. differential: Low</td>
</tr>
</tbody>
</table>
Discussion
Within the geographical focus of this study, release of the drought resistant bean technology unambiguously mitigates potential climate change yield losses that would otherwise occur using the baseline varieties. The specific implications of a positive yield technology differential in terms of area and production are, however, not so straightforward. In North African countries, the area and production technology differentials are both positive and high. In some Sub-Saharan African countries, the area and production differentials are both moderately positive, while in others they are both negative. In most of the LAC countries, area technology differentials are negative but production technology differentials are positive. Implications for the food security technology differentials are even more ambiguous. Many of the countries in which the food security technology differentials are highest are also those where the yield, area, and production technology differentials are lowest.

It is common for climate change adaptation planners to pursue technology interventions with the vague aim of generating a positive yield technology differential. Results such as those above strongly suggest that we take greater care in defining what it is exactly we hope to achieve through the proposed intervention. Are we interested in impacts on food security indicators? More efficient land use? Position in the international market? A positive yield technology differential does not guarantee a positive impact in any of these areas, and may even go hand in hand with a negative impact.

Much of the value of integrated modeling foresight exercises such as the one pursued in this report thus lies not in the answers it provides, but in the questions it helps us to ask, thereby refining and bringing greater maturity to our vision.

Conclusion
In this report we have applied an integrated modeling technique to assess, ex-ante, the potential of a notional drought resistant bean cultivar in offsetting the effects of climate change. With a specific geographic focus on Africa and the LAC region, this research illustrates that benefits associated with interventions such as crop technology are not a one-size-fits-all solution. Overall, we find a mean positive yield technology differential of 6%, a negative area differential of -1.5%, and a positive production technology differential of 6.3%. Release of the new technology is projected to result in drastic shifts in bean trade volumes for a handful of countries, most notably El Salvador and Burundi, but otherwise has little influence on net trade. Technology differentials for food security variables are beneficial and considerably more pronounced in Africa than in LAC. Positive yield technology differentials do not necessarily go hand in hand with positive area, production, and food security technology differentials; and in some cases appear to be inversely related.

Though the results of this exercise must be interpreted with a degree of humility since we were unable to validate the crop model output for baseline varieties against FAO data, there is still important information to arise from this study. These results show that policymakers and planners working to address climate change at the country level must think carefully about what they want to achieve beyond yield impacts when conceptualizing the impact of technology interventions as a tool for addressing climate change.
References


Annex 1: Future climate scenarios

One of the challenges in looking at agricultural technology from the ex-ante perspective is that different climate scenarios may or may not be in agreement with one another. This lack of agreement may manifest generally, or may be higher in distinct geographic locations. For purposes of illustrating the modeled climate futures and how these we generated the following graphs.

Figure A1.1: Future rainfall totals from scenario GCMs.

![Rainfall, annual total (mm) average (2041-2070)](image)

Figure A1.2: Future high temperatures from scenario GCMs.

![High temperature, annual average (C) average (2041-2070)](image)

From these graphs, it is possible to discern that the GCMs used in the analysis presented here generally tend to be more in agreement with respect to future temperature than for future precipitation. For temperature, the MIROC model shows some divergence with comparatively higher temperatures evident in Bangladesh, Cambodia, Costa Rica, Myanmar and Pakistan.

Though the above heat maps do not offer any information on the co-variability of temperature and precipitation throughout the year, countries showing lower levels of rainfall and higher temperatures would be more likely to see future drought conditions such as those highlighted in Figure 1 in the main text. The results of the economic analysis reflect the role that these combinations have in influencing future yield and thus the viability and utility of drought tolerance. Furthermore, in that future temperatures may exceed the suitable range for beans in countries even with adequate precipitation, the need for multi-strategy solutions is further illustrated.