Potential Impacts of a Green Revolution in Africa – The Case of Ghana

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Abstract

Agricultural growth in Africa has accelerated, yet most of this growth has been driven by land expansion. Land expansion potential is reaching its limits, urging governments to shift towards a green revolution type of productivity-led growth. Given the huge public investments required, this paper aims to assess the potential impacts of a green revolution. Results from a CGE model for Ghana show that green revolution type growth is strongly pro-poor and provides substantial transfers to the rest of the economy, thus providing a powerful argument to raise public expenditure on agriculture to make a green revolution happen in Africa.

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Agriculture, Green Revolution, growth, poverty, Africa, Ghana, CGE

1. Introduction

Agricultural growth in Africa has accelerated in recent years, yet most of this growth has been driven by land expansion. Since further expansion of cultivated agricultural land is reaching its limits in the process of rapid urbanization and population growth in many countries, the need for a shift towards productivity-led agricultural growth becomes urgent in Africa. The Green Revolution experience in Asia has demonstrated that rapidly increasing agricultural productivity is possible in a relatively short time period. The Asian experience has also shown that such growth has to be supported by a combination of adequate public investments, promoting pro-rural policies and a bundle of measures that enable farmers to access modern inputs, agricultural extension services, financial services, and markets (Hayami and Ruttan 1985, Hazell and Ramasamy, 1991, Bautista, 1997, Evenson and Gollin, 2003).

Potentials for a green revolution exist in Africa: yields are far below their potentials and the use of modern inputs such as fertilizer and high-yielding varieties of seeds is extremely low (Evenson 2003, Evenson and Rosegrant, 2003, Johnson et al. 2003). In most African countries, irrigation is only 2 – 5 percent of total crop area and less than 20 percent of the irrigation potential has been realized in the region (FAO 1997).

In recent years, green revolution type of agricultural development is therefore being increasingly seen as one of the most important opportunities to accelerate growth and poverty reduction in Africa. Continent-wide initiatives such as the Comprehensive African Agriculture Development Program (CAADP) have set concrete growth and public spending targets for agriculture.[1] Many national policymakers have committed to increase investment in agriculture and emphasized the role of agriculture in their national development strategies (e.g. NDPC 2005; NNPC, 2007). The need for a green revolution type of agricultural growth has been further boosted by the recent world food price crises that added to the voices advocating measures to facilitate supply-side responses in Africa (von Braun 2008, FAO 2008, World Bank 2008).

Economists have long argued that agriculture plays an important role for development. Jorgenson (1961) and Kuznets (1966) were among the first to stress the importance of productivity-led agricultural growth for economy-wide growth and development. Many authors further document that the agricultural sector has the highest growth multiplier effects and is the most effective in reducing poverty at early development stages (Johnston and Mellor 1961, Mosley 2002, Delgado 1998, Diao et al. 2007a, World Bank 2007). Cross-country evidence also supports the importance of agriculture for development. Tiffin and Irz (2006) prove that in most cases causality runs from agricultural growth to growth of overall economy, supporting the argument that agriculture has acted as the engine of growth. Moreover, it has been shown that a lack of agricultural productivity growth can severely constrain economy-wide growth (Irz and Roe 2005).

Despite the absence of explicit arguments against the promotion of agriculture, doubts do exist among economic scholars and policy makers, particularly for Africa. Green-revolution type of development in Africa will require strong policy support and

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[1] CAADP targets include achieving 6 percent of annual agricultural growth rate and devoting at least 10 percent of the government expenditure to agriculture.

massive investments (Coady and Fan 2008).[2] Given the large amount of investments required to foster productivity-led agricultural growth, it is important to provide solid evidence on the potential benefits of a green revolution in Africa. This paper therefore aims to contribute to the existing literature and the policy debate on an African green revolution by focusing on three main questions: what are the economy-wide impacts of green-revolution type agricultural growth? How does agricultural growth contribute to poverty reduction? To what extent will large investments in the agricultural sector benefit the rest of the economy?

We chose Ghana as an agriculture-based African country that is committed to an agriculture-led strategy (NDPC, 2005), as a case to address these questions. Moreover, Ghana has experienced two decades of persistent growth with a record of positive per capita GDP growth over the last 20 years. Ghana is also bound to become the first Sub-Saharan African country to achieve the first Millennium Development Goal (MDG1) of halving poverty and hunger ahead of the target year of 2015. Agriculture remains the biggest contributor to GDP and employment, and recent agricultural growth rates have been above average economy-wide growth. The continuation of this successful development is not only necessary but also possible given that current yields are well below the achievable yields for most staple crops in the country (MoFA, 2007a). Ghana is therefore a prime candidate to become a frontrunner in an African Green Revolution and possibly set an example for other African countries to follow.

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[2] In this paper, we focus on the impacts of agricultural growth acceleration rather than the institutional challenges associated with it. For an overview on institutional issues see for example Hazell and Ramasamy (1991) and Mosley (2003).

To analyze the role of a green revolution type of agricultural growth for Ghana's future development, we develop a dynamic general equilibrium model to link agriculture to other sectors and to link income growth to poverty reduction. In this model, we go beyond the conventional approach of CGE modeling and disaggregate the economy into different agroecological zones and different income groups. We further link this economy-wide model to a micro-simulation module, which includes the full sample of national household survey data. This level of disaggregation is important to capture Ghana's significant heterogeneity in agricultural production and consumption patterns across regions and household groups and the large disparities in development between the northern part of the country and rest of the country.

Based on this model, we simulate a green revolution type of growth scenario to evaluate the potential synergies among different agricultural sub-sectors and between agriculture and the rest of economy. We quantitatively assess the contribution of agricultural growth to the rest of economy by measuring visible and invisible monetary transfers from agriculture to the nonagricultural economy following a methodology developed by Winters et al. (1998).

The remainder of the paper is structured as follows. Section 2 summarizes Ghana's recent growth characteristics including major opportunities and challenges facing green revolution type growth acceleration. Section 3 presents the methodology and the data. Section 4 discusses the model results and Section 5 concludes.

2. Potentials for a green revolution in Ghana

Agriculture in Ghana accounts for 40 percent of GDP, three quarters of export earnings, and employs 60 percent of the labor force. With an average annual rate of 5.5 percent, Ghana's agricultural growth has been more rapid than growth in the non-agricultural sectors in recent years (World Bank, 2007). However, significant differences exist in the growth performance and contribution to overall agricultural growth across different agricultural sub-sectors (table 1). The main driving factor behind the rapid agricultural growth is the crop subsector (excluding cocoa), the largest subsector in agriculture, accounting for more than two-thirds of the agricultural economy. Staple crops such as maize, sorghum, rice, cassava, yam, plantain, pulses, and oilseeds dominate this subsector. Some high value crops such as vegetables and fruits are also included, but they play a relatively modest role in overall agricultural growth given their small size.

Cocoa is Ghana's most important traditional export crop and has received special attention from the government in terms of financial and policy supports. As a result, together with favorable world prices in recent years, the cocoa sector has grown most rapidly except for the period of 1996-2000 (table 1). Thus, cocoa's contribution to agricultural growth is almost three times of its size in the economy (table 1).

Table 1. Agricultural GDP growth and contribution to agricultural GDP growth

	1991-95	1996-2000	2001-05	2006
Growth (annual %)	2.0	3.9	5.5	5.6
Crops other than cocoa	1.5	3.4	4.5	5.8
Cocoa production and marketing	7.0	6.0	14.8	8.3
Forestry and logging	1.9	10.8	5.1	2.5
Fishing	1.8	0.6	3.0	3.6
Share of AgGDP (%)				
Crops other than cocoa	69	68	68	66
Cocoa production and marketing	8	9	10	13
Forestry and logging	7	9	10	10
Fishing	15	14	12	11
Contribution to agricultural GDP growth (%)				
Crops other than cocoa	51	60	55	69
Cocoa production and marketing	28	14	28	19
Forestry and logging	7	24	9	4
Fishing	14	2	7	7

Source: Ghana Statistical Service data, Bogetic et al. 2007.

As in most African countries, agricultural growth in Ghana has been mainly driven by land expansion rather than productivity growth. Table 2 shows that cultivated land has expanded by 60 percent over the last 12 years from 4.5 million hectares in 1994 to 7.2 million hectares in 2006. Land expansion has slowed down in recent years, but continued to expand at an annual rate of 2.8 percent. The cocoa sector has been the main driver of land expansion. Cocoa area has increased by 1.7 times over the last 12 years, while the total increase of cultivated land for the other crops amounted to 40 percent in the same period.

Measured by the crop GDP in constant terms, land productivity did not increase in the last 12 years. Compared with the initial level in 1994, total land productivity actually fell between 1997 and 2002, and recovered only in the recent years, primarily driven by the growth in cocoa (table 2).

Table 2. Agricultural GDP, land expansion and land productivity in Ghana (1994-2006)

	1994	2000	2006	Overall growth rate (1994-2006)	Annual growth rate 1994-1999	Annual growth rate 2000-2006
Land productivity (cedi per hectare)*						
Crop and cocoa	155	112	159	0.91	-4.77	5.97
Cocoa	162	87	188	1.56	-10.49	13.67
Crops other than cocoa	154	121	149	0.69	-4.97	3.62
Land allocation (in 1,000 hectares)						
Cultivated land	4,500	6,100	7,195	4.10	5.39	2.79
Cocoa land	687	1,500	1,835	7.01	13.62	3.42
Crops other than cocoa	3,813	4,600	5,360	3.31	3.59	2.58

Source: Own calculations based on FAO 2008, IMF various issues, Ghana Statistical Services
Note: * Land productivity is calculated as GDP at constant 2000 prices divided by hectares of cultivated land. The value is reported in new Ghana cedi.

While structural change in crop production helps to improve land productivity, the dominant factor to measure land productivity is yield growth. In contrast to rapid land expansion, national yield levels of major food crops in Ghana have only improved modestly over the last 12 years (table 3). When looking at the agro-ecological zone level, in several cases yields even fell in recent years from their levels in the mid 1990s. For example, maize yield only increased in the Coast zone and was stagnant and even fell in the other three zones of the country.

Table 3. Yields of major crops by agro-ecological zone (1994-2005)

	Maize		Rice		Cassava	
	1994-1997	2002-2005	1994-1997	2002-2005	1994-1997	2002-2005
Coast	1.32	1.69	3.64	2.16	10.46	13.02
Forest	1.45	1.48	1.79	1.99	7.37	8.25
Northern Savannah	1.21	1.16	1.94	2.22	7.07	9.26
Southern Savannah	1.53	1.44	2.09	2.24	9.01	7.54
National	1.51	1.56	1.94	2.18	11.87	12.53

Source: MOFA 2007 and FAO 2008. Note: national data is from FAO.

These yields are much lower than the achievable yields for many crops in most zones of Ghana. According to Ministry of Food and Agriculture, yields for most crops are 20-60 percent below their achievable level under existing technologies combined with the use of modern inputs such as fertilizers and improved seeds (table 4).

On the demand side, market opportunities do exist to support agricultural growth in Ghana. Like many other African countries, Ghanaian households spent 40 to 50 percent of incomes on food.[3] Food demand from the domestic market is expected to further grow with income and population growth and the process of urbanization (Diao et al. 2007b). There are also considerable potentials for import substitution through increased competitiveness. Ghana imports 60 percent of rice and 90 percent of poultry meat consumed domestically. Demand for these two commodities is highly income elastic, indicating a rise in imports in the future without improvements in domestic competitiveness. Moreover, as Thailand, Malaysia, Brazil, and many other developing countries have demonstrated, rapid diversification of agricultural exports is possible and can help to accelerate growth in agriculture and economic transformation in general (Breisinger et al. 2008).

[3] We use the recent national household survey, GLSS5 2005/06 for the analysis. See appendix A1 for expenditure patterns.

Table 4.Yield gaps in Ghana

Crop	Average yields (1990-2006) Mt/ha	Achievable yields (Mt/ha)	Yield gap (Mt/ha)	Yield gap (%)
Maize	1.5	2.5	1.0	40.0
Rice	2.1	3.5	1.4	40.0
Millet	0.8	1.5	0.7	46.7
Sorghum	1.0	1.5	0.5	33.3
Cassava	11.9	28.0	16.1	57.5
Cocoyam	6.7	8.0	1.3	16.3
Yam	12.4	20.0	7.6	38.0
Plantain	8.1	10.0	1.9	19.0
Sweet Potato	8.5	18.0	9.5	52.8
Cowpea	1.0	1.3	0.3	23.1
Groundnut	0.8	1.0	0.2	20.0
Soybean	0.8	1.0	0.2	20.0
Cocoa	0.4	1.0	0.6	60.0

Source: Ministry of Food and Agriculture (MOFA) 2007

Note: According to MOFA's definition, achievable yields are derived from on farm observations, where recommended technologies have been used together with more effective extension services.

The above discussion indicates that potentials for a green revolution exist in Ghana on both supply and demand sides. In the following sections, we present the model developed for this study to capture these supply and demand side linkages. We then apply this model to assess the potential impacts of the green revolution on growth and poverty reduction in Ghana.

3. Developing an economy-wide model to assess potential impacts of a green revolution in Ghana

The ability to capture the links between agriculture and other sectors of the economy in combination with assessing poverty impacts makes computable general equilibrium (CGE) models a strong tool to analyze the potential impacts of agricultural policies and strategies.[4] We therefore develop a dynamic CGE (DCGE) model that captures the most important characteristics of the Ghanaian agricultural sector and its linkages to the rest of the economy for this study.[5] While this model does not attempt to make precise predictions about the future development of the Ghanaian economy, it does measure the role of agricultural growth for economy-wide growth and poverty reduction.

Different from traditional CGE models that focus on national economies with multiple production sectors, our DCGE model considers sub-national heterogeneity in agricultural production. Thus, the supply side of the model defines agricultural production at the agro-ecological zonal level. The demand side of the model considers both the zonal level consumption structure and different consumption patterns by income levels. While the linkages between demand and supply through changes in income (an endogenous variable) and productivity (often an exogenous variable) are one of the most important general equilibrium interactions in our model, production linkages also occur across sectors through the input demand for both primary factors and intermediates as well as the competition in factor markets. Modern agricultural inputs such as improved seeds and fertilizer are the main drivers of a green revolution and are explicitly included in the model as intermediate inputs. While the model captures the increased demand for fertilizer and improved seeds in the agricultural growth process, the availability of these inputs at a price affordable to Ghanaian farmers will be key for a successful green

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[4] CGE models are economy-wide, multi-sectoral models that solve simultaneously and endogenously for both quantities and prices of a series of economic variables.

[5] A CGE model is constructed consistently with the neoclassical general equilibrium theory. The theoretical background and the analytical framework of CGE models have been well documented in Dervis, de Melo and Robinson (1984), while the detailed mathematical presentation of a CGE model is described in Loefgren et al. 2002. A dynamic CGE model from which our Ghana model is developed can be found in Thurlow 2004.

revolution. We do not, however, explicitly model the market supply chain of modern inputs and hence implicitly assume that demand for these inputs can be satisfied by market supply. However, for other commodities, either agricultural or nonagricultural, the trade structure is modeled in a similar ways as in other CGE models That is, the linkages between the domestic and international markets for a particular good (e.g. rice) are captured by assuming price-sensitive substitution (imperfect substitution) between foreign goods (rice) and domestic production (rice).

Investments affect production overtime and productivity growth is also a gradual process. Capturing these dynamic processes is a key component of our DCGE model. Given the complexity of the model setup for Ghana in terms of the large number of production sectors in both agriculture and non-agriculture in combination with highly disaggregated agricultural production and household groups across sub-national regions, it is unrealistic to fully develop an inter-temporal general equilibrium model for this study.[6] Thus, we follow the recursive dynamics approach in the model. With such model setup, the dynamics occur only between two periods at a time and consumption smoothing along the growth path as well as intertemporal investment and saving decisions are not taken into account. Instead, private investment and hence capital accumulation are determined by a Solow type of saving decision in which savings are proportional to the income. The mathematical presentation and corresponding model parameters and variables are listed in the Appendix. The robustness of the model has been tested in a series of sensitivity tests (Breisinger et al. 2009).

[6] An intertemporal general equilibrium model in literature is often with relatively aggregated economic structure. See Diao et al. (2005) for the growth linkage analysis in the case of Thailand as an example.

A highly disaggregated social accounting matrix (SAM) for Ghana has been constructed based on the most recent data for this study.[7] This SAM represents the Ghanaian economy in 2005 and has 28 agricultural subsectors that are further disaggregated into the four agro-ecological zones as discussed above. The input side of the agricultural structure is also highly disaggregated. Not only the key intermediates such as fertilizer and seeds are included, the factor markets are also disaggregated into agricultural family labor that is employed only in agriculture at the zonal level, unskilled labor that can move between agriculture and non-agriculture, skilled labor employed mainly in the nonagricultural sectors. Agricultural land can be allocated among different crops within each zone, but cannot move across zones. The SAM captures remarkable differences in production structures between the Northern Savannah and the other zones of Ghana exist. While the Northern Savannah zone produces more than 34 percent of the country's cereals and about 40 percent of livestock, the Northern Savannah has the lowest contribution to agricultural exports (only 10 percent). Cocoa is the most important export crop in Ghana, but it can only be grown in forest and in parts of the coast zones. The limited export opportunities for the Savannah zones' agriculture will become a challenge for these zones to benefit from any export-oriented growth strategy that will be discussed later.

To capture the linkages of agriculture with the rest of the economy, the SAM and the model include 32 nonagricultural sectors, of which many are agricultural processing sectors, which is consistent with Ghana's current manufacturing structure. Service sectors are also highly disaggregated in order to capture the sector's market linkages with

[7] The SAM aggregated to the national level is available on IFPRI's website (http://www.ifpri.org/data/ghana03.asp).

agriculture and non-agriculture through transportation, trade, and financial services, which are all explicitly defined in the model.

The SAM first aggregates consumers by rural and urban location, and then by the four zones. Households in the country's capital city, Accra, are separated as a standalone group because of their very different income level and consumption patterns from the rest urban households in the coast zone (where Accra is located). We then further classify households according to 10 decile groups that are defined by per capita income levels nation wide. In total, there are 90 representative household groups in the model. Incomes distributed to households are endogenous variables. While rural households earn their income from factors (land, capital, family labor) employed in agricultural production, they also participate in the non-farm activities through markets for unskilled and skilled labor that are economy-wide factors. Urban households earn capital income and wages for skilled labor employed in the non-agricultural activities and wage income for the unskilled labor employed in both agricultural and nonagricultural activities. To capture growth impact on poverty, the DCGE model is further linked with a micro-simulation model, which includes all sample households in the survey dataset.[8] The full set of sectors and institutions included in the model is documented in appendix A2. The model equations are described in appendix A3.

[8] We use the Ghana Living Standard Survey 5 (GLSS5) to construct the SAM and hence all sample households in GLSS5 and used on the micro-simulation model have their 'representative' households in the DCGE model. Both model codes and parameters are available from the authors upon request.

4. Analyzing potential impacts of a green revolution in Ghana

We use the DCGE model described in the previous section to simulate the potential impacts of a green revolution in Ghana. Two scenarios are considered: in the first scenario we simulate a "business as usual" situation of economic development, which is called the "baseline". In this scenario we assume that the Ghanaian economy will continue to grow along the recent trends over the next 10 years until 2015. In the second scenario, we model an accelerated growth path that is associated with the green revolution. In this scenario, exogenous increases in total factor productivity (TFP) at the sub-sector level (crops and livestock production) are the driving forces for agricultural growth to attain achievable yields nation-wide by 2015. Land expansion remains at baseline levels. In most cases we report the model results at the national level as averages, yet the model simultaneously solves for zonal level results in the simulation. We take the different growth potentials among the four zones into consideration in designing the TFP growth rate, while unevenly distributed growth opportunities among farmers within each zone are not taken into account. For example, for farmers in areas with high agricultural potential, better market access conditions and relatively high market participation rates (such as in some areas of East Ghana's forest zone), maize yields are likely to be doubled once modern inputs are used. However, in some areas of northern Ghana with its long-term trend of land degradation, achieving a 30 percent increase in maize yields may be a challenge.

By contrasting model results of the Green Revolution scenario with those derived from the baseline, the transformative power of agriculture in Africa can be assessed and analyzed. The use of the DCGE model allows for a detailed analysis of constraints, tradeoffs and linkage effects in the process, yet its results should be interpreted as a best case scenario under which necessary investments in agricultural productivity are realized.

In the baseline scenario, land expansion is the main factor for agricultural growth, a situation consistent with the growth pattern of the last 10 years. Together with modest increases in productivity, agriculture grows at 4.2 percent annually between 2006 and 2015. Industry and services also grow according to their recent trends, at 5.6 percent and 5.2 percent per year, respectively.

In the second scenario (green revolution scenario) we target the crop yields to reach their achievable level over the next 10 years. To target these yields, we choose a level of annual change in TFP coefficients for each individual crop across the four zones to endogenously obtain the crop yield levels consistent with achievable yields by the end of the simulation period.[9] These yield levels correspondent to those presented in table 4. This requires approximately 4.6 – 8.1 percent of annual TFP growth for most crops. This growth combined with productivity growth in the non-crop sectors (mainly livestock), and the endogenous accumulation of capital and reallocation of unskilled labor in the economy, Ghana's agricultural sector will grow at an average annual rate of 6 percent over the next 10 years, a growth rate consistent with the CAADP target set by the New Partnership for Africa's Development (NEPAD). Given that the agricultural sector is the largest sector in the Ghanaian economy, together with its strong multiplier effects, a

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[9] In the CGE model producers in crop sectors (similar as in the other production sectors) choose inputs (such as land, labor, capital, and a set of intermediate inputs) simultaneously to maximize their profits using a given technology. As both outputs and inputs (including land) are endogenous variables in the model, it is impossible to directly target crop yield levels exogenously. Following neoclassical theory, total factor productivity (TFP) is an exogenous variable in the CGE model's production functions, Thus, we have to impose the exogenous "shock" on this parameter in the simulation in order to target specific yield levels.

green revolution type of agricultural growth results in substantial growth of the national economy, 5.8 percent annually compared to 4.9 percent in the baseline scenario (table 5).

Table 5. GDP and sectoral growth in baseline and green revolution scenarios

	Data	Simulation results	
	2001 – 2006 average (%)	Baseline	Green revolution
		2006 – 2015 annual average (%)	
Annual GDP growth		4.9	5.8
AgGDP	4.2*	4.2	6.0
Industry	5.6	5.6	6.0
Services	5.2	5.2	5.5
Contribution to GDP growth			
AgGDP		31.8	39.4
Industry		31.7	28.4
Services		36.5	32.3
Share of GDP	2005	2015	
AgGDP	38.7	37.6	38.1
Industry	27.9	27.9	27.5
Services	33.4	34.5	34.4

Source: Ghana CGE model simulation results
* AgGDP annual growth rate is the average of 1990 – 2006

In the baseline scenario more than 65 percent of growth in national GDP and 62 percent of growth in AgGDP comes from factor accumulation of which land expansion explains almost 40 percent of AgGDP growth (table 6). The green revolution type of growth is led by productivity improvements, which becomes the dominant factor to explain growth (table 6).[10]

[10] Increased labor supply land expansion at the national or zonal level and productivity growth at the sub-sector level are exogenous variables in the model, while capital accumulation is endogenously driven by the savings. The private savings rate is constant, yet total savings are determined by the income level of each household and the allocation of public spending on investment. Public investment is a residual variable between government income, an endogenous variable, and non-investment spending that exogenously changes overtime, and foreign inflows, which is an exogenous variable.

Table 6. Sources of growth in the baseline and green revolution scenarios

	Decomposition of GDP growth		Decomposition of AgGDP growth	
	Baseline	Green revolution	Baseline	Green revolution
Labor	26.9	22.4	15.0	10.8
Land	12.7	8.7	39.5	27.5
Capital	26.2	22.2	7.9	5.3
Productivity	34.2	46.7	37.5	56.4

Source: Ghana CGE model simulation results
Note: GDP and AgGDP annual growth rates sum to 100

Moreover, the green revolution and its spillover effects are strongly pro-poor. The model results show that the national poverty rate will fall to 12.5 percent by 2015 under the green revolution scenario, down from 16.9 percent in the baseline's 2015 and from 28.5 percent of its 2005/2006 level. Poverty decreases for both rural and urban households, underlining the benefits of a green revolution for both consumers and producers. However, poverty remains high in the Northern Ghana, indicating that more targeted measures will be needed to reduce poverty in the North.

Table 7. Poverty impacts in the baseline and green revolution scenarios

	Initial poverty rate	Final poverty rate under…	
		Baseline scenario	Green revolution
	2005/6	2015	2015
Poverty incidence (%)			
National	28.5	16.9	13.5
Urban	10.8	7.6	5.7
Accra	10.6	7.7	5.3
Coast	5.5	2.8	2.0
Forest	6.9	4.2	2.9
South Savannah	21.6	15.2	12.6
North Savannah	31.9	25.7	22.3
Rural	39.2	23.7	19.2
Coast	24.0	8.8	5.1
Forest	27.7	12.3	7.9
South Savannah	36.7	12.5	9.7
North Savannah	68.3	55.5	49.6

Source: Ghana CGE model simulation results

The Green revolution has been a key ingredient for initiating and supporting broader economic transformation in many countries. However, unleashing a green revolution has often required massive public investments and therefore raised the question about the cost of such growth acceleration. Thus, it is necessary to understand the benefit of green revolution measured in monetary terms. Here we apply a method developed by Winters et al. (1998) to quantitatively measure such monetary benefits that account for both visible and invisible transfers of agriculture to the non-agricultural economy. This definition is based on the insights of development economists in 1950s and 1960s who characterized the dynamics of the economic development process as a dual system (Lewis, 1954; Fei and Ranis, 1961; Jorgenson 1961). Visible transfers are those that can be observed from a country's statistics such as agricultural trade surplus that is often a main provider of the foreign exchange needed to finance imported capital and intermediate goods used by nonagricultural sectors. However, the majority of monetary transfers from agriculture to non-agriculture are often invisible and not recorded in a country's statistics. An important invisible transfer stems from decreases in domestic agricultural prices, which often result from improved agricultural productivity. The invisible nature of these transfers has frequently led to the underestimation of the role of agriculture in economic development. As a consequence, the policy and investment priorities of governments have typically concentrated on promoting agricultural exports to generate visible surpluses.

Based on the model results of the green revolution scenario and to assess surplus transfers under this scenario, we first disaggregate increased market demand for agricultural goods as consumer goods, intermediate and investment goods. In financial terms (measured in million new cedi)[11], the total financial transfer out of agriculture amounts to about 792 million cedi over the next 10 years between 2006 and 2015, equivalent to 12.9 percent of increased GDP over the same period. In 2015 alone, the transfer is equivalent to 1.09 percent of total GDP in this specific year (table 7). However, the visible transfer in this period is actually negative. This transfer includes the net value between increased demand for agricultural goods by the non-agricultural sector and for non-agricultural goods by the agricultural sector (which is negative) in the domestic market and the agricultural trade surplus (which is positive, see table 7). With 3,134 million cedi of accumulated agricultural trade surplus over the period of 10 years, the visible transfer through foreign markets is huge. However, the transfer in the domestic market as the net value of increased demand for the agricultural goods and for

[11] One New Ghana cedi is about 1 $US.

the non-agricultural goods is negative and substantial (-472 million cedi over the 10 years), which leads to an overall negative total visible transfer out of agriculture.

Table 8. Visible and invisible transfers of a financial surplus from agriculture under the green revolution scenario

	million cedi, Accumulated between 06-15	As % of accumulated increases in GDP between 06-15	million cedi, in 2015	As % of GDP in 2015
Financial transfer out of agriculture	792	12.9	157	1.09
Net visible transfer from agriculture	*-1,581*	*-25.7*	*-330*	-2.29
Through domestic markets	-4,714	-76.8	-966	-6.71
Through foreign trade	3,134	51.0	636	4.42
Net invisible transfer from agriculture	*2,372*	*38.6*	*487*	*3.38*
Through lowered agricultural prices	515	8.4	101	0.70
Through increased nonagricultural prices	1,239	20.2	260	1.81
Through increased factor prices	912	14.8	189	1.32
Through change in the exchange rate	-294	-4.8	-64	-0.44
Corresponding monetary value of net physical flows out of agriculture	792	12.9	157	1.09
Product contribution	*829*	*13.5*	*166*	*1.15*
Net transfer through domestic markets	-2,011	-32.7	-406	-2.82
Net transfer through foreign markets	2,840	46.2	572	3.98
Factor contribution	*-38*	*-0.6*	*-9*	*-0.06*
From staples	149	2.4	28	0.19
From import substitutables	-18	-0.3	-4	-0.03
From export agriculture	-169	-2.7	-33	-0.23

Source: Ghana CGE model simulation results

The invisible transfer out of agriculture can be decomposed into four parts: through lowered agricultural prices, through increased nonagricultural prices, through increased returns to factors employed in the agricultural sectors and changes in the foreign exchange rate. In total, the net invisible transfer from agriculture is 2,372 million cedi over the 10 year period and 487 million in 2015 alone. Lowering agricultural prices results in 515 million transfer out off the agricultural sector, while increased agricultural exports that cause a real exchange rate appreciation becomes a negative factor in the invisible transfer (-294 million cedi during 2006-2015). Because returns to the factors moving into agriculture increase, it constitutes a positive invisible transfer as agriculture has to pay a higher price for the increased employment of factor inputs (912 million cedi during 2006-2015).

We further evaluate the monetary value of the net physical flows in the forms of products and factors. For the products, we decompose the contribution into domestic and foreign markets, while for the factor contribution we disaggregate it into staples, import substitutable and export agriculture. The contribution of production is positive, mainly due to the increased agricultural trade surplus (visible transfer), while the factor contribution is negative, since more factors are employed in agriculture under the green revolution scenario.

By distinguishing between export and staple agriculture we can further evaluate the different roles of these two agricultural sub-sectors in economic development. Productivity growth in staple agriculture implies that a country can produce more food and agricultural materials using less labor input. This further lowers the cost of labor and allows labor to migrate from rural to urban sectors and engage in non-agricultural growth given that the education system provide the skills for such migration. As shown in table 8, the factor contribution of staples is positive with 149 million in total between 2006 and 2015 in the scenario. This result is consistent with what has been observed in many Asian countries during their development process, i.e., the supply of low-cost labor is critical to support the development of labor-intensive manufacturing and services.

On the other hand, the factor contribution through export agriculture is negative at -169 million cedis for the same period. Surplus transfers of export agriculture are often highly visible and help to provide foreign exchange earnings to the nonagricultural sector for importing capital goods and intermediates, and hence, the export agriculture has played an important role in the development. However, without productivity growth in staple agriculture, growth in export agriculture can raise the demand for food, which can result in either higher food prices in domestic markets or the need for more food imports. Also, increased demand for labor and capital to support growth in export agriculture can inflate factor prices. Under these conditions, it often becomes difficult to develop labor-intensive manufacturing and services, and such a situation could significantly slow the structural transformation.

5. Conclusion

Impressive growth and record poverty reduction over the past 20 years have made Ghana an African success story. Agricultural growth has played an important role in this impressive development and the agricultural sector will continue to play such role in Ghana's future development. However, agricultural growth in Ghana has been mainly driven by area expansion as opposed to the green revolution type growth in many Asian countries, in which growth is productivity-led.

Potentials for a green revolution exist in Ghana, exemplified by significant gaps between current and achievable yields for many crops. To understand the importance and impacts of a change from the land expansion-led current growth pattern to a productivity-led green revolution type growth, we developed a dynamic CGE model for Ghana. The model disaggregates agricultural production to the agro-ecological zonal level and a macro-to-micro-simulation model includes all sample households of the most recent national household survey to assess the potential growth and poverty impacts of green revolution type agricultural growth over the next 10 years.

By closing the existing yield gaps, together with comparable productivity growth in the livestock sector, Ghana will be able to reach 6 percent average annual agricultural growth over the next 10 years, a growth rate consistent with the CAADP goal set by African policymakers. The green revolution benefits the whole economy through strong linkages between the agricultural sectors and the rest of the economy. In this process, incomes of both rural and urban households increase and the resulting additional demand for agricultural products can be met by domestic supply without significantly lowering their prices. Green revolution type of growth is also pro-poor. At the national level, the scenario shows that the national poverty rate will fall to 12.5 percent by 2015 lifting an additional 850,000 people out of poverty compared to the baseline. However, poverty levels in the North Ghana remain high, indicating the need for additional and target measures beyond the green revolution.

Achieving a green revolution requires a significant increase in public investments in agriculture, rural infrastructure and marketing. By taking into account both visible and invisible transfers from agriculture to the non-agricultural economy we show that a green revolution type of agricultural development will provide huge benefits to the economy. Measured in monetary terms, total financial transfers from agriculture to the rest of the economy is equivalent to 13 percent of increased GDP in the next 10 years. Invisible transfers such as achieved through lowering food price are the dominant source for this substantial contribution. This finding, together with the assessment of economy-wide impacts of a green revolution type of agricultural growth, provides further evidence on the important role agriculture can play in economic development and the urgent need to support agricultural growth through raising investment.

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Tables in Appendix

Table A1. Household budget shares and income elasticity

	Current budget		Marginal budget		Income elasticity	
	Urban	Rural	Urban	Rural	Urban	Rural
Foods	43.5	52.0	34.6	49.0	0.8	0.9
Maize	0.8	1.8	0.4	1.2	0.4	0.7
Rice and wheat	3.7	4.3	2.6	4.4	0.7	1.0
Roots	3.0	2.6	2.2	3.3	0.7	1.3
Other food	7.2	8.6	5.2	7.3	0.7	0.8
Plantain	1.2	1.1	0.9	1.3	0.8	1.3
Chicken	1.6	1.1	2.0	1.5	1.2	1.3
Other livestock	10.8	15.6	8.5	14.4	0.8	0.9
Fish	1.9	2.1	1.8	2.3	1.0	1.1
Other foods	13.3	14.7	10.9	13.2	0.8	0.9
Non-foods	46.1	37.0	56.6	40.0	1.2	1.1
Clothing	10.4	11.0	8.9	11.0	0.9	1.0
Other manufactures	7.0	9.6	6.9	9.7	1.0	1.0
Fuels	3.8	5.1	8.0	3.5	2.1	0.7
Durable equipment	9.4	4.8	20.9	7.6	2.2	1.6
Water and	0.5	0.1	0.7	0.2	1.4	2.1
Services	25.4	17.4	20.0	19.0	0.8	1.1

Source: Estimates using the 2005/06 Ghana Living Standards Survey (GLSS5).[12]

[12] We thank Bingxin Yu who provided the elasticity estimation for this study.

Table A2 Sectors/commodities in the Ghana CGE model

Agriculture	Industry	Services
Cereal crops	***Mining***	***Private***
Maize	***Food processing***	Trade services
Rice	Formal food processing	Export services
Sorghum and millet	Informal food processing	Transport services
Other cereals	Cocoa processing	Communication
Root crops	Dairy products	Banking and business
Cassava	Meat and fish processing	Real estate
Yams	***Other manufacturing***	***Public and community***
Cocoyam	Textiles	Community, other services
Other staple crops	Clothing	Public administration
Cowpea	Leather and footwear	Education
Soybeans	Wood products	Health
Groundnuts	Paper, publishing and printing	
Fruit (domestic)	Crude and other oils	
Vegetables (domestic)	Petroleum	
Plantains	Diesel	
Other crops	Other fuels	
Export crops	Fertilizer	
Palm oil	Chemicals	
Other nuts	Metal products	
Fruit (export)	Machinery and equipment	
Vegetables (export)	***Other industry***	
Cocoa beans	Construction	
Industrial crops	Water	
Livestock	Electricity	
Chicken broiler		
Eggs and layers		
Beef		
Sheep and goat meat		
Other meats		
Forestry		
Fishery		

Table A3. CGE model sets, parameters, and variables

Symbol	Explanation	Symbol	Explanation
Sets			
$a \in A$	Activities	$c \in CMN(\subset C)$	Commodities not in *CM*
$a \in ALEO(\subset A)$	Activities with a Leontief function at the top of the technology nest	$c \in CT(\subset C)$	Transaction service commodities
$c \in C$	Commodities	$c \in CX(\subset C)$	Commodities with domestic production
$c \in CD(\subset C)$	Commodities with domestic sales of domestic output	$f \in F$	Factors
$c \in CDN(\subset C)$	Commodities not in *CD*	$i \in INS$	Institutions (domestic and rest of world)
$c \in CE(\subset C)$	Exported commodities	$i \in INSD(\subset INS)$	Domestic institutions
$c \in CEN(\subset C)$	Commodities not in *CE*	$i \in INSDNG(\subset INSD)$	Domestic non-government institutions
$c \in CM(\subset C)$	Aggregate imported commodities	$h \in H(\subset INSDNG)$	Households
Parameters			
$cwts_c$	Weight of commodity c in the CPI	$qdst_c$	Quantity of stock change
$dwts_c$	Weight of commodity c in the producer price index	$\overline{qg}_c$	Base-year quantity of government demand
ica_{ca}	Quantity of c as intermediate input per unit of activity a	$\overline{qinv}_c$	Base-year quantity of private investment demand
$icd_{cc'}$	Quantity of commodity c as trade input per unit of c' produced and sold domestically	$shif_{if}$	Share for domestic institution i in income of factor f
$ice_{cc'}$	Quantity of commodity c as trade input per exported unit of c'	$shii_{ii'}$	Share of net income of i' to i (i' ∈ INSDNG'; i ∈ INSDNG)
$icm_{cc'}$	Quantity of commodity c as trade input per imported unit of c'	ta_a	Tax rate for activity a
$inta_a$	Quantity of aggregate intermediate input per activity unit	$\overline{tins}_i$	Exogenous direct tax rate for domestic institution i
iva_a	Quantity of aggregate intermediate input per activity unit	$tins01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
$\overline{mps}_i$	Base savings rate for domestic institution i	tm_c	Import tariff rate
$mps01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates	tq_c	Rate of sales tax
pwe_c	Export price (foreign currency)	$trnsfr_{i\,f}$	Transfer from factor f to institution i
pwm_c	Import price (foreign currency)		

Table A3 continued. CGE model sets, parameters, and variables

Symbol	Explanation	Symbol	Explanation
Greek Symbols			
α_a^a	Efficiency parameter in the CES activity function	δ_{cr}^t	CET function share parameter
α_a^{va}	Efficiency parameter in the CES value-added function	δ_{fa}^{va}	CES value-added function share parameter for factor *f* in activity *a*
α_c^{ac}	Shift parameter for domestic commodity aggregation function	γ_{ch}^m	Subsistence consumption of marketed commodity c for household h
α_c^q	Armington function shift parameter	θ_{ac}	Yield of output c per unit of activity a
α_c^t	CET function shift parameter	ρ_a^a	CES production function exponent
β^a	Capital sectoral mobility factor	ρ_a^{va}	CES value-added function exponent
β_{ch}^m	Marginal share of consumption spending on marketed commodity c for household h	ρ_c^{ac}	Domestic commodity aggregation function exponent
δ_a^a	CES activity function share parameter	ρ_c^q	Armington function exponent
δ_{ac}^{ac}	Share parameter for domestic commodity aggregation function	ρ_c^t	CET function exponent
δ_{cr}^q	Armington function share parameter	η_{fat}^a	Sector share of new capital
υ_f	Capital depreciation rate		
Exogenous Variables			
$\overline{CPI}$	Consumer price index	$\overline{MPSADJ}$	Savings rate scaling factor (= 0 for base)
$\overline{DTINS}$	Change in domestic institution tax share (= 0 for base; exogenous variable)	$\overline{QFS}_f$	Quantity supplied of factor
$\overline{FSAV}$	Foreign savings (FCU)	$\overline{TINSADJ}$	Direct tax scaling factor (= 0 for base; exogenous variable)
$\overline{GADJ}$	Government consumption adjustment factor	$\overline{WFDIST}_{fa}$	Wage distortion factor for factor f in activity a
$\overline{IADJ}$	Investment adjustment factor		
Endogenous Variables			
AWF_{ft}^a	Average capital rental rate in time period t	QG_c	Government consumption demand for commodity
$DMPS$	Change in domestic institution savings rates (= 0 for base; exogenous variable)	QH_{ch}	Quantity consumed of commodity c by household h
DPI	Producer price index for domestically marketed output	QHA_{ach}	Quantity of household home consumption of commodity c from activity a for household h
EG	Government expenditures	$QINTA_a$	Quantity of aggregate intermediate input
EH_h	Consumption spending for household	$QINT_{ca}$	Quantity of commodity c as intermediate input to activity a
EXR	Exchange rate (LCU per unit of FCU)	$QINV_c$	Quantity of investment demand for commodity
$GSAV$	Government savings	QM_{cr}	Quantity of imports of commodity c
QF_{fa}	Quantity demanded of factor f from activity a		

Table A3 continued. CGE model sets, parameters, and variables

Symbol	Explanation	Symbol	Explanation
Endogenous Variables Continued			
MPS_i	Marginal propensity to save for domestic non-government institution (exogenous variable)	QQ_c	Quantity of goods supplied to domestic market (composite supply)
PA_a	Activity price (unit gross revenue)	QT_c	Quantity of commodity demanded as trade input
PDD_c	Demand price for commodity produced and sold domestically	QVA_a	Quantity of (aggregate) value-added
PDS_c	Supply price for commodity produced and sold domestically	QX_c	Aggregated quantity of domestic output of commodity
PE_{cr}	Export price (domestic currency)	$QXAC_{ac}$	Quantity of output of commodity c from activity a
$PINTA_a$	Aggregate intermediate input price for activity a	RWF_f	Real average factor price
PK_{ft}	Unit price of capital in time period t	$TABS$	Total nominal absorption
PM_{cr}	Import price (domestic currency)	$TINS_i$	Direct tax rate for institution i (i ∈ INSDNG)
PQ_c	Composite commodity price	$TRII_{ii'}$	Transfers from institution i' to i (both in the set INSDNG)
PVA_a	Value-added price (factor income per unit of activity)	WF_f	Average price of factor
PX_c	Aggregate producer price for commodity	YF_f	Income of factor f
$PXAC_{ac}$	Producer price of commodity c for activity a	YG	Government revenue
QA_a	Quantity (level) of activity	YI_i	Income of domestic non-government institution
QD_c	Quantity sold domestically of domestic output	YIF_{if}	Income to domestic institution i from factor f
QE_{cr}	Quantity of exports	ΔK^{a}_{fat}	Quantity of new capital by activity a for time period t

Note: Most parameters are calculated from the social accounting matrix for Ghana. The SAM aggregated to the national level is available on IFPRI's website (http://www.ifpri.org/data/ghana03.asp).

Table A3. CGE model equations

Production and Price Equations

$$QINT_{c\,a} = ica_{c\,a} \cdot QINTA_a \qquad (1)$$

$$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca} \qquad (2)$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot \alpha_{f\,a}^{vaf} \cdot QF_{f\,a}^{\;-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad (3)$$

$$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_{f\,a}^{va} \cdot \alpha_{f\,a}^{vaf} \cdot QF_{f\,a}^{\;-\rho_a^{va}} \right)^{-1} \cdot \delta_{f\,a}^{va} \cdot \alpha_{f\,a}^{vaf} \cdot QF_{f\,a}^{\;-\rho_a^{va}-1} \qquad (4)$$

$$QF_{f\,a} = \alpha_{f\,a}^{van} \cdot \left(\sum_{f' \in F} \delta_{f\,f'a}^{van} \cdot QF_{f'a}^{\;-\rho_{f\,a}^{van}} \right)^{-\frac{1}{\rho_{f\,a}^{van}}} \qquad (5)$$

$$W_{f'} \cdot WFDIST_{f'a} = W_f \cdot WFDIST_{f\,a} \cdot QF_{f\,a} \cdot \left(\sum_{f'' \in F} \delta_{f\,f''a}^{van} \cdot QF_{f''a}^{\;-\rho_{f\,a}^{van}} \right)^{-1} \cdot \delta_{f\,f'a}^{van} \cdot QF_{f'a}^{\;-\rho_{f\,a}^{van}-1} \qquad (6)$$

$$QVA_a = iva_a \cdot QA_a \qquad (7)$$

$$QINTA_a = inta_a \cdot QA_a \qquad (8)$$

$$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a \qquad (9)$$

$$QXAC_{a\,c} = \theta_{a\,c} \cdot QA_a \qquad (10)$$

$$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \theta_{ac} \qquad (11)$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{\;-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}-1}} \qquad (12)$$

$$PXAC_{a\,c} = PX_c \cdot QX_c \left(\sum_{a \in A'} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}-1} \qquad (13)$$

$$PE_{cr} = pwe_{cr} \cdot EXR - \sum_{c' \in CT} PQ_c \cdot ice_{c'c} \qquad (14)$$

$$QX_c = \alpha_c^t \cdot \left(\sum_r \delta_{cr}^t \cdot QE_{cr}^{\rho_c^t} + (1 - \sum_r \delta_{cr}^t) \cdot QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} \qquad (15)$$

$$\frac{QE_{cr}}{QD_c} = \left(\frac{PE_{cr}}{PDS_c} \cdot \frac{1 - \sum_r \delta_{cr}^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \qquad (16)$$

Table A3. continued. CGE model equations

$QX_c = QD_c + \sum_r QE_{cr}$	(17)
$PX_c \cdot QX_c = PDS_c \cdot QD_c + \sum_r PE_{cr} \cdot QE_{cr}$	(18)
$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c}$	(19)
$PM_{cr} = pwm_{cr} \cdot \; 1 + tm_{cr} \; \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c}$	(20)
$QQ_c = \alpha_c^q \cdot \left(\sum_r \delta_{cr}^q \cdot QM_{cr}^{-\rho_c^q} + (1 - \sum_r \delta_{cr}^q) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}}$	(21)
$\frac{QM_{cr}}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1 - \sum_r \delta_{cr}^q} \right)^{\frac{1}{1+\rho_c^q}}$	(22)
$QQ_c = QD_c + \sum_r QM_{cr}$	(23)
$PQ_c \cdot \; 1 - tq_c \; \cdot QQ_c = PDD_c \cdot QD_c + \sum_r PM_{cr} \cdot QM_{cr}$	(24)
$QT_c = \sum_{c' \in C'} \; icm_{c\,c'} \cdot QM_{c'} + ice_{c\,c'} \cdot QE_{c'} + icd_{c\,c'} \cdot QD_{c'}$	(25)
$\overline{CPI} = \sum_{c \in C} PQ_c \cdot cwts_c$	(26)
$DPI = \sum_{c \in C} PDS_c \cdot dwts_c$	(27)

Institutional Incomes and Domestic Demand Equations

$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{f\,a} \cdot QF_{f\,a}$	(28)
$YIF_{i\,f} = shif_{i\,f} \cdot \left[YF_f - trnsfr_{row\,f} \cdot EXR \right]$	(29)
$YI_i = \sum_{f \in F} YIF_{i\,f} + \sum_{i' \in INSDNG'} TRII_{i\,i'} + trnsfr_{i\,gov} \cdot \overline{CPI} + trnsfr_{i\,row} \cdot EXR$	(30)
$TRII_{i\,i'} = shii_{i\,i'} \cdot (1 - MPS_{i'}) \cdot (1 - \overline{tins}_{i'}) \cdot YI_{i'}$	(31)
$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{i\,h} \right) \cdot \; 1 - MPS_h \; \cdot (1 - \overline{tins}_h) \cdot YI_h$	(32)
$PQ_c \cdot QH_{c\,h} = PQ_c \cdot \gamma_{ch}^m + \beta_{ch}^m \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma_{c'h}^m \right)$	(33)
$QINV_c = IADJ \cdot \overline{qinv}_c$	(34)
$QG_c = \overline{GADJ} \cdot \overline{qg}_c$	(35)

Table A3. continued. CGE Model Equations

$$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} trnsfr_{i\,gov} \cdot \overline{CPI} \tag{36}$$

System Constraints and Macroeconomic Closures

$$YG = \sum_{i \in INSDNG} \overline{tins}_i \cdot YI_i + \sum_{c \in CMNR} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f \in F} YF_{gov\,f} + trnsfr_{gov\,row} \cdot EXR \tag{37}$$

$$QQ_c = \sum_{a \in A} QINT_{c\,a} + \sum_{h \in H} QH_{c\,h} + QG_c + QINV_c + qdst_c + QT_c \tag{38}$$

$$\sum_{a \in A} QF_{f\,a} = QFS_f \tag{39}$$

$$YG = EG + GSAV \tag{40}$$

$$\sum_{r\ c \in CMNR} pwm_{cr} \cdot QM_{cr} + \sum_{f \in F} trnsfr_{row\,f} = \sum_{r\ c \in CENR} pwe_{cr} \cdot QE_{cr} + \sum_{i \in INSD} trnsfr_{i\,row} + FSAV \tag{41}$$

$$\sum_{i \in INSDNG} MPS_i \cdot \ 1 - \overline{tins}_i \ \cdot YI_i + GSAV + EXR \cdot FSAV = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \tag{42}$$

$$MPS_i = \overline{mps}_i \cdot \ 1 + MPSADJ \tag{43}$$

Capital Accumulation and Allocation Equations

$$AWF^a_{f\,t} = \sum_a \left[\left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}} \right) \cdot WF_{f\,t} \cdot WFDIST_{f\,a\,t} \right] \tag{44}$$

$$\eta^a_{f\,a\,t} = \left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}} \right) \cdot \left(\beta^a \cdot \left(\frac{WF_{f,t} \cdot WFDIST_{f\,a\,t}}{AWF^a_{f\,t}} - 1 \right) + 1 \right) \tag{45}$$

$$\Delta K^a_{f\,a\,t} = \eta^a_{f\,a\,t} \cdot \left(\frac{\sum_c PQ_{c\,t} \cdot QINV_{c\,t}}{PK_{f\,t}} \right) \tag{46}$$

$$PK_{f\,t} = \sum_c PQ_{c\,t} \cdot \frac{QINV_{c\,t}}{\sum_{c'} QINV_{c'\,t}} \tag{47}$$

$$QF_{f\,a\,t+1} = QF_{f\,a\,t} \cdot \left(1 + \frac{\Delta K^a_{f\,a\,t}}{QF_{f\,a\,t}} - \upsilon_f \right) \tag{48}$$

$$QFS_{f\,t+1} = QFS_{f\,t} \cdot \left(1 + \frac{\sum_a \Delta K_{f\,a\,t}}{QFS_{f\,t}} - \upsilon_f \right) \tag{49}$$