# Understanding China’s Soybean Boom from Historical Validation

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**Abstract**

China's soybean demand boom in the past two decades has been very dramatic. It involves socioeconomic and environmental interactions of multi-coupled systems. Economic growth and restructuring of feed industry intensified China's soybean meal demands. Brazil, as well as Argentina and the US stepped in to satisfy this increased demand. In the case of Brazil, rapid technical change, coupled with expansion in cultivated area, played a key role in meeting the increased soybean demand in China. The goal of this research to is to identify the key economic drivers of this historical growth in soybean trade, output and land use in Brazil, China and the US over the period of 2004-2011 and quantify their contributions using the GTAP-BIO model. This period provides a very interesting laboratory in which to test the validity of this model, as well as to decompose the diverse drivers of growth in soybean trade. With a validated historical model in place, we plan to project future soybean production and trade changes and investigate the role of China's agricultural policy and genetically-modified (GM) technology have played through counterfactual simulations.

***Keywords:*** Genetically-modified technology; international soybean trade; historical validation; computable general equilibrium; Global Trade Analysis Project.

## 1. Introduction

Soybeans are one of the most traded agricultural commodities worldwide. Global soybean production has doubled by about 200 million metric tons (FAO 2015a), and the global soybean exports has increased by 10 fold featured by China's soybean boom in the past two decades (UN Comtrade 2016). The globalization of soybean trade has important implications for agriculture, land use, and the environment. After further processing and separating, soybean crushing industries produce soybean meal and soybean oil as co-products. Soybean meal is an excellent protein source for both livestock feed and human food. Soybean oil is usually used as edible oil and a feedstock for biodiesel production. Currently, the US, Brazil, and Argentina are the largest soybean producers. Among these three countries, Brazil is the largest soybean exporter (Brown-Lima, Cooney and Cleary 2009). China has a long-standing tradition of soy-based diets. The high income growth in China has motivated its livestock and soy-based products consumption, and that made China the largest soybean consumer in the world, which could affect the global soybean market. However, even though over 90% of China's imported soybeans are Genetically Modified (GM) (Lucht 2015), China prohibits GM soybean cultivation due to food safety and environmental contamination concerns (Wong and Chan 2016). Imported GM soybeans are major sources for livestock feed and edible oil, and domestic non-GM soybeans are consumed for food purposes. Many countries have similar GM soybean policies. Currently, only 9 countries produce GM soybeans, which are the major soybean exporters as well. [1]

From 2004 to 2011, global soybean production has increased by 56 million metric tons (MMT), composed of respective 25 and 17 MMT production expansion in Brazil and Argentina, in particular. Over this period, Brazil and the US, the two largest global soybean exporters,

[1] The 9 countries are the US, Argentina, Brazil, Canada, Mexico, Paraguay, South Africa, Uruguay, and Bolivia.

drastically expanded their soybean exports to China by 290% and 120%, respectively, accompanied by export contraction from these two countries to the EU by 40% and 36%, respectively. Brazil's GM soybean production has increased from 20% to 80%. This evolution of soybean production and trade was mainly driven by China's soybean boom, of which soybean imports grew at 15% per year. In 2014, China's soybean imports were about 6 times higher than its soybean production, and China absorbed 72% and 60% of Brazil's and US's soybean exports, respectively.

Many socio-economic situations changed over this period that drove these trends. For example, on the demand side, China doubled its GDP in 2004-2011, which generated high demands for livestock products, a major consumer for soybean meals. The goal of producing more meat and milk raised protein content requirements in feed formulations and intensifies China's soybean meal demands (Gale 2015). Meanwhile, China's GM soybean cultivation prohibition and corn stockpiling policies motivated local farmers to switch from soybean to corn production, leading to a 15% cumulative soybean production decline in 2004-2011. The Chinese government subsidized soybean land inputs to bolster declining soybean production. At the same time, on the supply side, rapid technical change and harvested area expansion in Brazil enabled expansion of soybean supplies for the Chinese market. The aggressive soybean expansion strategy in Brazil enabled it to surpass the US and become the largest soybean exporter in the world. In addition, biofuel mandates from the US, Brazil, and the EU generated competition for land use. Historical economic and policy interactions among the three focal regions play an important role in triggering China's soybean boom. The goal of this research is to assess the impacts of GM technologies in soybean production, evaluate the relative importance of these diverse drivers of soybean trade, production, and harvested area growth and quantify their contributions from historical validation process in 2004-2011.

## 2. Literature review

Early literature on soybean market mainly examined soybean production changes in the US, Brazil, and Argentina. In the late 1990s and early 2000s, Brazil and Argentina gradually became leading global soybean producers after the US due to the high investment in soybean production. Soybean production situations in the US, Brazil, and Argentina are frequently compared. The soybean production growth in the US is much slower than in the Brazil. Political reforms, more engagement in international business, improvements in transportation system, farm management improvements, government supports, availability of arable land, and favorable climate conditions have helped Brazil to rapidly expand soybean production during the past decades (Schnepf, Dohlman and Bolling 2001; Sutton, Klein and Taylor 2005). US production costs are lower before taking rents into account, and after rents' costs favored Argentina and Brazil (Sutton et al. 2005; Leibold and Osaki 2009). The US is also more efficient in international transportation than Brazil and Argentina (Sutton et al. 2005). In addition, there aren't much farmland for the US to expand, and corn-based ethanol subsidies motivated the US farmers to switch to corn production (Hauser 2002). Soybean production and trade display a strong seasonal pattern: South America dominates from June to October, and the US dominants from November to May (Song et al. 2009; Glauber and Miranda 2016). More soybean production in Southern hemisphere emphasizes the current seasonal pattern in soybean trade, stock and prices (Glauber and Miranda 2016), confirming a competitive relationship between the US and South American soybean exporters. Indeed, Plato and Chambers (2004) found that a one percent increase in soybean production in South America would decrease the US season-average prices by one-quarter percent based on 1987-1999 monthly prices.

China's role in global soybean market has attracted increasing attention over the past two decades. Investigations on price linkages of traded soybean future contracts in China, the US, Brazil, and Argentina from 2002 to 2011 by Christofoletti, Silva and Mattos (2012) confirmed the dominant role that US has played in international markets. They also found that price linkages between China and the other three markets have become stronger, indicating China's growing participation in international markets. By developing a US-China two-country partial equilibrium model, Song et al. (2009) predicted that China will continue to be the largest soybean importer in the world. They showed that China had stronger market power than the major exporters, and the major exporters can expand their markets in other countries to strengthen their market power. They mentioned a strong demand in research on understanding all aspects of international soybean market, especially on China's role on soybean demand side. So far, none of the past literature has comprehensively studied the mechanisms driving developments in international soybean market. This research aims to fill this gap and offer a more complete view of the individual driver of international soybean trade.

## 3. Materials and methods

### 3.1. Model

In this study, we modify and use the GTAP-BIO model (Taheripour and Tyner 2013), a multi-regional and multi sectoral Computable General Equilibrium (CGE) model. In this model, all producer and consumer behaviors are defined and linked through consistent economic theories and assumptions for demands, supply, trade, as well as macroeconomic equilibrium. It allows for multiregional and inter-industrial analyses. Countries (regions) are linked through international trade and investment flows. The trade linkages track all exports and imports by commodity, source, and destination. Armington assumption structure is applied by differentiating products by country of origin (Armington 1969). GTAP is widely used to investigate the economic and environmental impacts of changes in one economy on itself and others. A Partial Equilibrium (PE) model, in contrast, neglects inter-industry details. Therefore, a PE model is appropriate for regional/sectoral policy analyses, but not the best fit for a comprehensive global analysis as this study aims to do.

Besides essential assumptions and fundamental structures inherited from the standard GTAP model, GTAP-BIO has the following attributes that are appropriate for this study.

- It disaggregates soybeans from oilseed sector, and rapeseeds, palm fruit, and other oilseeds are also included.
- Soybean crushing industries are introduced and produce soybean meal and oil as by-products (Taheripour et al. 2008).
- It uses a nesting structure to simulate demand for animal feeds, including energy and protein feed items, such as soybean meal and corn grain. The nesting structure allows substitution among alternative feed items in response to changes in their prices.
- It includes 18 Agro-Ecological Zones (AEZs) (Lee et al. 2005). All land cover data (including forest, pasture, and cropland), harvested area, and crop production can be traced at AEZ level.
- Introduced biofuel products and by-products allow us to examine the impacts of historical biofuel policies on crop production.

### 3.2. Feature of implementation

To tackle GM and non-GM soybean issue over the period of 2004-2011, we split soybean commodity into two parts: GM soybean and non-GM soybeans, which are subsequently combined into a single composite, soybean commodity. Both GM and non-GM soybeans are categorized based on imported and domestic sources. A new soybean nest enters production, consumption, and trade modules.

Land is supplied as forest land and cropland-pasture mix at the bottom layer in our model (Fig. 1). Cropland-pasture mix further serve as land supply basis for different crops and livestock pastures. Soybean composite compete land with other crops. GM and non-GM soybeans are essentially the same commodity where land is highly mobile between two types of soybean production, especially for GM soybean producing countries.

The original GTAP-BIO model assumes perfect labor and capital mobility between agricultural and non-agricultural sectors. However, the wages for farm and non-farm workers with comparable skills are unlikely to be equated in the near term, as would be the case if perfect mobility of labor and capital mobility is assumed (Keeney and Hertel 2005). In countries like China, the rural-urban wage gap is very large (Zhao 1999). We adopt Keeney and Hertel (2005)'s imperfect mobility of labor and capital specification in GTAP-AGR model. Constant elasticity of transformation (CET) functions are introduced to "transform" labor and capital between agricultural and non-agricultural sectors (Keeney and Hertel 2005). Capital and labor are assumed perfectly mobile amongst agricultural sectors and amongst non-agricultural sectors, respectively. Fig. 2 presents the theoretical structure of this implementation.

On production side, soybeans and soybean meal serve as protein sources for animal feed. GM and non-GM soybeans are highly substitutable as soybean-based feed protein sources (Fig. 3). Coarse grains and their by-products are feed energy sources. The energy-protein composite is substitutable with other feed items through nesting structure in Fig. 3. It allows for protein intensification application in China's feed industry development.

Private consumers also consume soybean composite directly (Fig. 4). The substitutability between GM and non-GM soybean on consumers' side depend on consumers' preferences for GM soybeans.

### 3.3. Historical validation and decomposition

Data on historical macroeconomic changes, productivity improvements in crop production, China's national agricultural policies, improvements in China's feed industry, and changes in biofuel production at the global scale are extracted from the existing reliable resources to represent important historical changes in the global economy, including evolutions in the soybean market. The collected data items are introduced into the GTAP-BIO model to simulate the historical changes in the global economy between 2004 and 2011. The SUBTOTAL function, a command in GTAP, enables us to partition all the shocks into several groups, and the sum of the contributions of these groups exactly equal to the overall simulation results (Harrison, Horridge and Pearson 2000). This decomposition process allows us to identify the contributions of major socio-economic drivers to the changes in global soybean market and bilateral soybean trade over the period 2004-2011.

### 3.4. Data and experimental design

#### 3.4.1. Base data

The base data in this analysis is the 2004 GTAP-BIO data based on GTAP v7. The cost and sale structures of the original database were not fully appropriate for soybean production, crushing and livestock analyses, especially in China. Original database mainly undermines China's soybean inputs in crushing industries and total outputs in dairy farm sectors. We updated and modified the GTAP input-output (I-O) table for China based on its official I-O table for 2002. The cost structures in livestock, processed livestock, oilseed crushing industries, processed food and feed, energy intensive industries, and other industry and service sectors are updated through sale structure modifications in crop, livestock, oilseed crushing, and other industry and service sectors. After updates and adjustments, for example, soybeans sold to soybean crushing industries increased from 11.6% to 58.3%, and soybean used in soybean crushing industries increased from 13% to 40.4% of total sales.

With updated China's I-O table based on intended data sources, we further split soybean sectors into GM and non-GM soybean commodities. We assume that non-GM soybeans consume more fertilizers and are mainly consumed by food industries; GM soybeans cost more in seed purchase and are major inputs for soybean crushing industry. The scale of GM and non-GM soybean production is derived from harvested area shares (GMO Compass 2008).

The original GTAP-BIO database contains 19 regions, which we aggregate into six regions: US, EU, Brazil, China, South other American countries (S_o_Amer),[2] and the Rest of the World (RoW). Parameters are also adjusted accordingly based on standard GTAP practices for aggregation.

Tariffs for oilseeds, vegetable oil, and oilseed meals are adjusted to reflect the tariffs in TASTE (Horridge and Laborde 2008) by modifying the GTAP-BIO model and applying Malcolm (1998)'s approach to database adjustments.

Income elasticities for the agricultural sectors are adjusted by modifying the expansion and substitution parameters[3] in the constant different of elasticities (CDE) minimum expenditure function to match Muhammad et al.(2011)'s estimates on food income elasticities based on 2005 data. We keep substitution elasticities as in the source database. The adjustment procedure follows

[2] S_o_Amer excludes Brazil.

[3] The expansion and substitution parameter in CDE minimum expenditure function correspond to INCPAR and SUBPAR in GTAP respectively. Please see Chapter 14 Behavior Parameters of GTAP database documentation by (Hertel et al. 2008) for more details.

the Engel aggregation, Cournot aggregation and symmetry conditions of standard GTAP calculation and calibration procedures (Hertel et al. 2008).

Based on past literature and the nature of soybean trade, we propose macroeconomic growth, agricultural productivity, China's livestock demands, domestic agricultural support, border policies, and biofuel policies as potential drivers for China's soybean boom and Brazil's soybean supply expansion in 2004-2011.

3.4.2. Macroeconomic drivers

In 2004-2011, China has had a high income growth, accompanied by significant inflows of capital and investments Table 1. China's economic growth generates high livestock and crop demands. Brazil and S_o_Amer countries maintain a moderate GDP growth but high investment growth. High investment growth in South America stimulates their agricultural productivity.

Real GDP growth is assumed driven by other macroeconomic drivers (population, skilled and unskilled labor, capital accumulation, investments, and agricultural productivity). Productivity changes differ between agriculture, where estimates of TFP are available, and the non-farm sectors, where labor productivity is inferred as a residual – i.e., it changes in such a way as to hit the observed GDP target.

3.4.3. Agricultural productivity

The soybean production surge in Brazil and S_o_Amer countries is motivated by agricultural productivity through GM soybean adoption along with soybean harvested area expansion (OECD 2015). China has limited soybean productivity growth due to its soybean cultivation prohibition (Zhao and Zhou 2016). However, GM soybean imports are officially approved through legislation (Zhang 2014).[4] GM soybeans are composed of over 90% of imported

[4] This GM soybean cultivation prohibition and import permission policies are not unique to China. Most of the countries share similar policies. Please see more information on GMO FAQ (2016).

soybeans  in China (Lucht 2015), which constitutes two-thirds of China's domestic soybean consumption (Zhang 2014). China has been gradually losing comparative advantage in soybean production. Additionally, Agricultural productivity in other crops potentially affects soybean production through input competitions.

Fuglie and Rada (2013) provide agricultural TFP estimates for the aggregate agricultural sector across a range of countries. Non-soybean crops are assumed to grow at national average level. Productivity is adjusted to target soybean output growth (Table 2). Meanwhile, land-based endowment productivity is used to target soybean harvested area growth. Agricultural productivity grows in RoW is assumed to grow at the same average rate. Fig. 5 presents base year's (2004) and target year's (2011) GM and non-GM soybeans' production shares.

3.4.4. China's livestock industry demand

Development in China's livestock industry increases the soybean demand from two channels: the increase in protein intensity requirements in feed formulation and the escalation of feed provision driven by livestock demands. In 2004-2011, China's oilseed meal intensity in formulated feeds has risen by 19% and soybean meal intensity has grown by 43.4% (USDA 2016a). China's processed feed inputs to non-ruminant sector also increased by 107% (Gale 2015). Productivity growth and consolidation in processed feed industry increases soybean meal and other oilseed meal inputs and decreases other energy inputs (grains) in feed formulations. Capital and labor productivity growth in feed industry lowers the costs and boosts outputs.

3.4.5. Domestic agricultural support

As the world's largest agricultural producer, which employs 31% of that the workforce and generates 10% of its GDP, China has provided increasing support to its agricultural production (OECD 2016). China expenditures on major agricultural subsidy programs over the period of

2004-2012 mainly concentrated on input subsidies followed by financial awards (transfer payments), improved seed, agricultural machinery, direct payments to producers, and agricultural insurance. With off-farm work opportunities rising, China faced the challenge of maintaining its agricultural outputs (Gale 2013).

China began direct subsidies to soybeans from 2003 and initiated price support for soybeans from 2007 to incentivize domestic soybean production (Gale 2013). Historical observations show that China emphasized its agricultural support for grains and oilseeds for their land uses. China also provided insurance benefits, land transfer awards, livestock facility construction grants, "Green channel" toll reduction for livestock products, which increased China's demands for soybeans indirectly (Gale 2013). Chinese government significantly subsidized oilseed production for their land uses, and financial benefits also notably biased towards oilseed production.

However, China's domestic agricultural supports for other grains put soybean production at disadvantage. For example, China increased price supports for wheat, rice, and corn by 45%, 88%, and 54%, respectively, which were much higher than soybeans' 41% of price support growth in 2008-2011 (Lee et al. 2016). In particular, the nation-wide corn stockpiling policies starting from 2007 made China collect corn at minimum selling prices and sell to the state storage facilities (Wu and Zhang 2016). High corn prices incentivized Chinese farmers to turn soybean cropland, grassland, deserts, and marshes into corn cropland. Soybean production got heavily impacted consequently.

In Brazil, the support to agricultural producers is quite low compared to the total production, which implies that small tax/subsidy distortions were provided to producers. Most of the agricultural incentives were provided through price support policies, concessional investment credit allocations, and promoted diversity of private financing instruments, and agricultural insurance (OECD 2015).

Here, we draw on independent efforts by the OECD to quantify the effects of complex agricultural policies using Producer Support Estimates (PSEs). It is measured at farm gate level indicating annual monetary transfers to agricultural producers, irrespective of their nature, objectives for impacts on farm production or income (OECD 2003). The PSE contains four categories of support: Single Commodity Transfers (SCT), Group Commodity Transfers (GCT), All Commodity Transfers (ACT), and Other Transfers to Producers (OTP). Seven broad categories are used to measure budgetary transfers, which correspond to six GTAP categories: output, intermediate, land-based, labor-based, capital-based, and all factors payments (Boulanger, Philippidis and Jensen 2016).[5] All agricultural growth is percentage changes in tax or subsidy distortions, which is the percentage change in (1+% ad valorem rate).

3.4.6. Border policies

Border policy is a potential driver of change for soybean output and trade. Here, we focus on the import tariff distortions (1+% ad valorem tariff rates) for all regions. Since 60% of agricultural products imported are destined for the processing industry, the border policies of processing industries can also impact soybean outputs and trades (OECD 2016). We include border tariffs for all tradeable commodities for all regions based on TASTE database by Horridge and Laborde (2008).

China maintained a low soybean import tariff rate and high soybean meal and oil import tariff rates to encourage soybean imports and protect domestic crushing industries (Brown-Lima et al. 2009). However, China did favor soybean meal imports from non-Brazilian South America,

[5] Please see Boulanger, Philippidis and Jensen (2016) for a detailed matching description from OECD categories to GTAP categories.

because its domestic soybean oil and meal production were not able to meet their growing demands (Westcott 2010). Even though China has increased its soybean oil and meal tariffs in general, its tariff rate is relatively low compared to other regions. South Korea significantly raised their out-of-quota soybean import restrictions for many countries including China to protect their local agricultural industry (Choi, Francom and Ting 2012), and they declined their feed imports for livestock production and increased importing meat and other livestock products (Lee et al. 2016). Most of the soybeans produced in S_o_Amer are from Argentina. Tariffs on imported soybean oil from Argentina have declined a lot for most of the countries in RoW. Among RoW countries, India is the largest Argentina's soybean oil consumer with 31% of tariff power decline. South Korea, Bangladesh, and Iran are also large soybean oil importers for Argentina with tariff declines.

### 3.4.7. Biofuel policies

Biofuel production increased dramatically in the US, the EU, and Brazil over this period. These biofuels mainly include corn-based and sugarcane-based ethanol, soybean-based and rapeseed-based biodiesel (Table 3). Biofuel production has increased the demand for crop feedstocks, thereby boosting the demand for farmland.

## 4. Results and Discussion

Our historical validation practice can replicate more than 95% of historical China's trade changes (Fig. 6). Beyond replication of historical percentage changes in soybean output and trade volumes, the results partition them into contributions of each driver from each region described above. We group GDP growth, population growth, labor and capital accumulation, and investment changes as macroeconomic drivers. Agricultural productivity is divided into productivity from other crops, from GM soybeans, and from non-GM soybeans. Policy driver stands for biofuel policies, domestic agricultural support, China's corn stockpiling policies, as well as border policies.

Livestock feed development in China is listed as an individual driver due to its significant contribution to global soybean evolution. These drivers from each different region insert different scales of impacts on other regions' soybean output and trade changes.

Fig. 7 presents regional contributions to each region's total soybean output. Regions on the horizontal axis denote those produce soybeans. For example, at the far left, the grey bar on the left denote Brazil's total output. Colored stacked bars on the right decomposes Brazil's soybean output changes into aggregate contributions from China, Brazil, US, and other regions[6]. It shows us that economic drivers from each region itself and China positively impact each region's soybean outputs, confirming China's demand forces in global soybean production changes. For each major soybean exporter, drivers from its major competitors significant dampen their output growth, indicating a competitive relationship. It also tells us that China is the major destination for US' and Brazil's soybeans, and other South American countries mainly export their soybeans to other countries.

Here, we mainly focus on soybean output changes in Brazil (Fig. 8), China (Fig. 9), and Brazil-China bilateral soybean trade (Fig. 10). In these figures, horizontal axes represent different groups of drivers. Colored stacked bars denote drivers from different regions. Grey bars aggregate these contributions and represent total contributions from different drivers at global scale. The far left "total" column summarizes total soybean output/trade changes and aggregate contributions from different regions.

Decompositions of Brazil's soybean output changes (Fig. 8) and Brazil-China bilateral soybean trade (Fig. 10) follow consistent patterns. China's economic and restructuring of the feed industry drove up soybean demands, and thus motivated Brazil's soybean supply. China's

[6] Other regions include S_o_Amer and RoW.

domestic policies also bolstered its soybean output (Fig. 9), but did little to slow imports (Fig. 10). Meanwhile, rapid agricultural productivity boosted Brazil's soybean supply, and Brazil has been gradually taking over the US and becoming the largest soybean supplier. Being the largest soybean consumer in the world, China inserted greater impacts on Brazil than Brazil's impacts on China. As a spillover system, the US imposed greater impacts on Brazil than on China, confirming a competitive relationship.

## 5. Conclusions

This study identifies major historical drivers of soybean production and trade relationships among China, Brazil, and the US through validation practice over the period of 2004-2011. It enables us to better understand interactions among multiple supply and demand systems. We find that China's economic growth and restructuring of the feed industry were the major soybean demand drivers. Brazil's soybean productivity growth through GM technology adoption facilitated global soybean supply improvement to meet growing demand from China. In this supply-demand relationship, China's demand power is much more influential to Brazil than Brazil's supply impacts on China. Meanwhile, we also confirm the competitive relationship of soybean supply between US and Brazil despite of different seasonality pattern of soybean production.

With historical decomposition mechanism in place, we also want to know the counterfactual consequences if China embraced GM soybean technology in history and if China didn't implement domestic agricultural policies to bolter soybean outputs.

Our results suggest that China has inserted competitive market power in soybean import markets in history (Song et al. 2009). This pattern will continue in next 10 years according to agricultural trade projections from (USDA 2016b). It means China's soybean demand behavior will continue resulting in corresponding supply responses in Brazil and the US. First, China's food and feed consumption will keep growing accompanied with income and population growth. Second, China's national agricultural sustainability plan in the next 15 years aims to achieve higher agricultural investments, endowment efficiency improvements, management system developments, and continuing Grain for Green program.[7] Third, China's future GMO policy is still unclear: China's consumers are against GM soybeans for safety concerns, while the Chinese government is willing to adopt biotechnology to improve productivity (Minter 2016). All these factors are key components from China's demand side that may induce Brazil's and the US' responses.

Future supply side changes may affect Brazil and the US soybean production and exports through competitive relationships. For example, infrastructural inconvenience impedes Brazil in soybean price competitiveness. High soybean transportation costs from Mato Grosso[8] to the ports in the south heavily influences soybean prices at costs of farmers' profitability. Brazil government and private companies have been investing in transportation infrastructure improvement (CommodityBasis 2017). Lower soybean prices in future will benefit Brazil's soybean exports to China. Brazil's soybean export expansion may lead to the US soybean export contraction. Our future analyses will address all these historical and future questions to better understand global soybean supply, trade, consumption nexus.

[7] Grain for Green program aims to convert croplands and steep slopes to forests. It is one of the largest ecological program in China (Liu et al. 2014).
[8] Mato Grosso produces the largest percentage of soybeans in Brazil. It accounts for about one-third soybean production in Brazil (Brown-Lima, Cooney and Cleary 2009).

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## Tables

### Table 1. Historical macroeconomic indicator growth for all six regions in percentage change in 2004-2011

| | US | EU | Brazil | China | S_o_Amer | RoW |
|---|---|---|---|---|---|---|
| Population | 6.46 | 2.32 | 7.74 | 3.71 | 9.24 | 11.69 |
| Skilled labor | -9.35 | 14.87 | 21.25 | 6.23 | 20.22 | 12.48 |
| Unskilled labor | 14.83 | 0.07 | 10.33 | 6.05 | 14.68 | 12.21 |
| Capital accumulation | 11.85 | 16.47 | 23.76 | 121.47 | 35.68 | 32.89 |
| Investments | -7.45 | 3.35 | 68.67 | 130.66 | 107.44 | 25.37 |
| Agricultural Productivity | 14.75 | 13.13 | 27.24 | 25.08 | 8.12 | 15.73 |
| Implied rate of growth in labor productivity | 5.50 | -33.87 | -1.21 | 9.31 | 5.79 | -6.62 |
| GDP | 8.66 | 8.75 | 32.95 | 101.95 | 44.23 | 22.88 |

Data for population, investments, GDP, World Development Indicators (WDI), (World Bank 2015); skilled labor and unskilled labor quantity, Global Bilateral Migration Data Base (GMig2 database), (Walmsley et al. 2013); capital stock, Penn World Table (PWT), (Feenstra, Inklaar and Marcel 2013).

### Table 2. Percentage growth in agricultural technology and targeted soybean outputs and harvested areas (2004-2011)

| Region | Aggregate TFP changes in non-soybean outputs | TFP changes in GM soybean outputs | TFP changes in non-GM soybean outputs | Soybean output growth | Soybean harvested area growth |
|---|---|---|---|---|---|
| US | 14.75 | 10.75 | -2.15 | 11.98 | 4.55 |
| EU | 13.13 | -1.78 | -5.27 | -2.08 | -6.47 |
| Brazil | 27.24 | 157.37 | 28.79 | 43.87 | 21.04 |
| China | 25.08 | 14.79 | 8.83 | -15.05 | -19.03 |
| S_o_Amer | 8.12 | 31.97 | 19.01 | 32.54 | 38.33 |

TFP changes in soybean outputs are inferred by the model composed of observed Hicks-neutral technical change and inferred weighted input-biased technical change. Brazil, S_o_Amer, and the US have the highest soybean TFP growth, consistent with their output growth.

Data for TFP, (Fuglie and Rada 2013); Soybean output growth and harvested area growth, (FAO 2015b).

### Table 3. Biofuel production growth in 2004-2011 in percentage change

| Biofule | US | EU | Brazil |
|---|---|---|---|
| Ethanol-Corn | 308.46 | 490.81 | |
| Ethanol-Sugarcane | | 1153.02 | 50.65 |
| Biodiesel-Soybeans | 1935.55 | 127.61 | |
| Biodiesel-Rapeseeds | | 236.78 | |

**Figures**

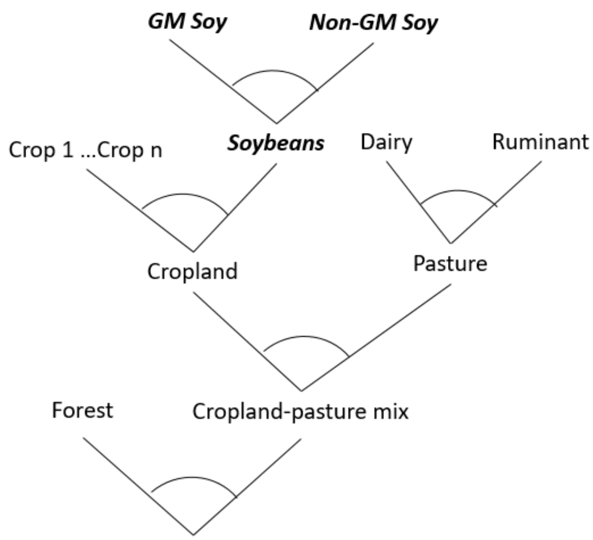


**Fig. 1. Land supply nests.**

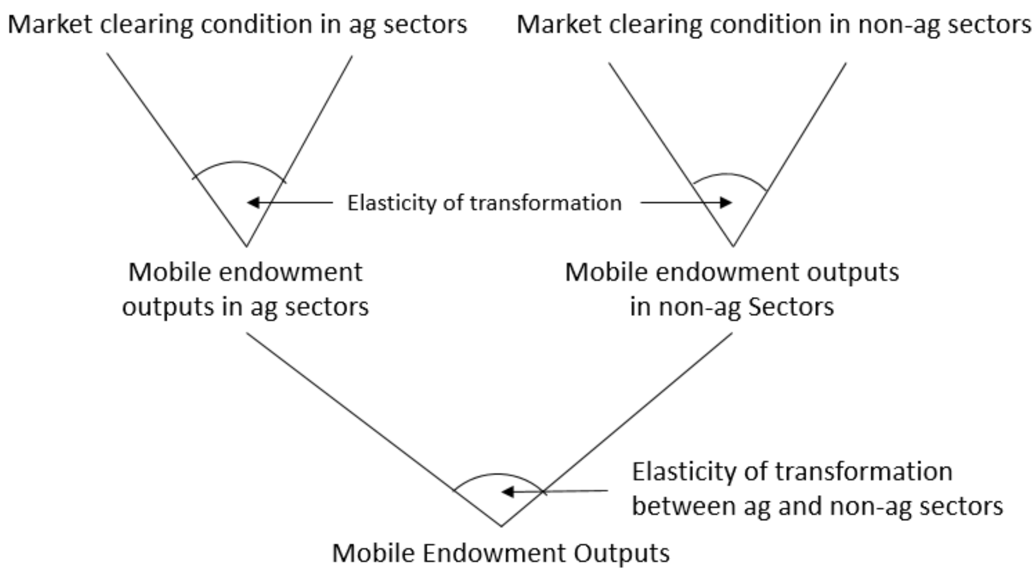


**Fig. 2. Mobile endowment nests**

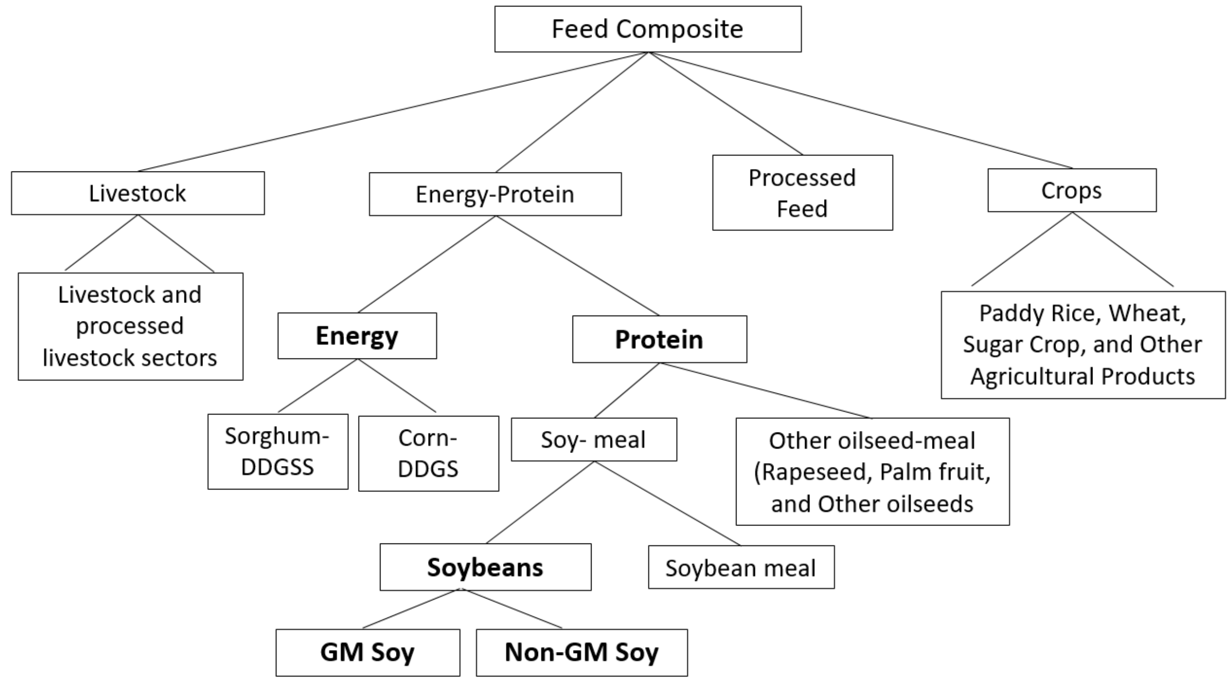


**Fig. 3. Feed composite nested structure with soybean sub-nest.**

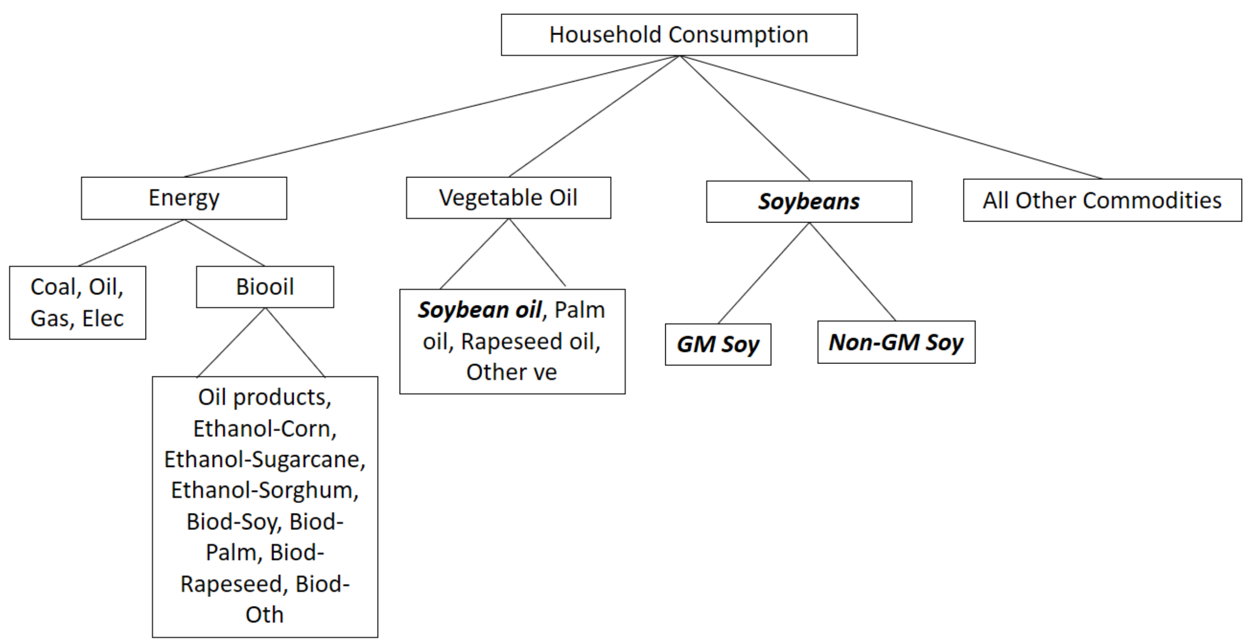


**Fig. 4. Household consumption structure with soybean sub-nest.**

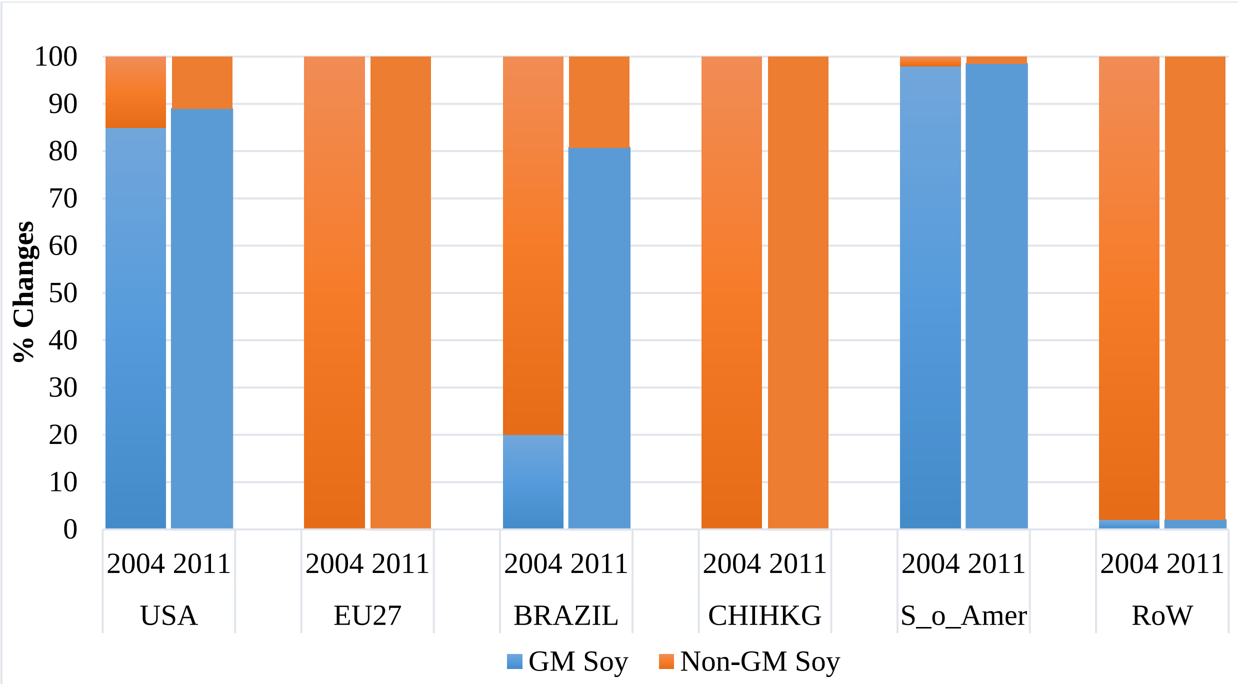


**Fig. 5. Soybean production share changes in 2004 and 2011.**

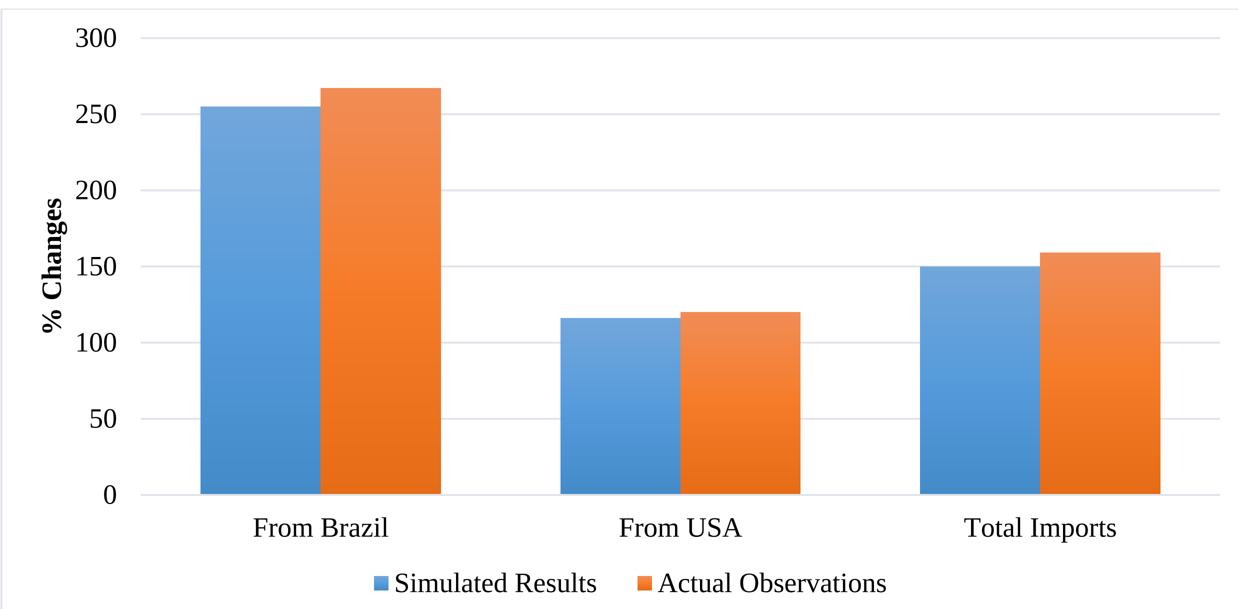


**Fig. 6. Comparison of simulated results and actual observation of China's trade changes (2004-2011).**

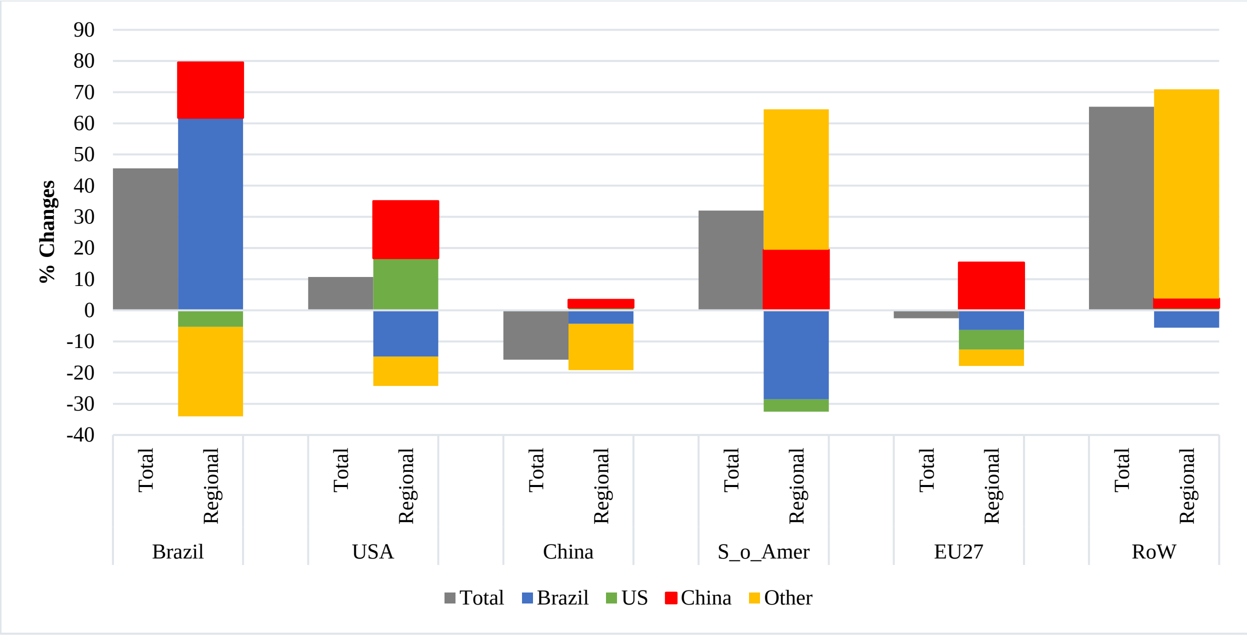


**Fig. 7. Soybean output regional decomposition.**

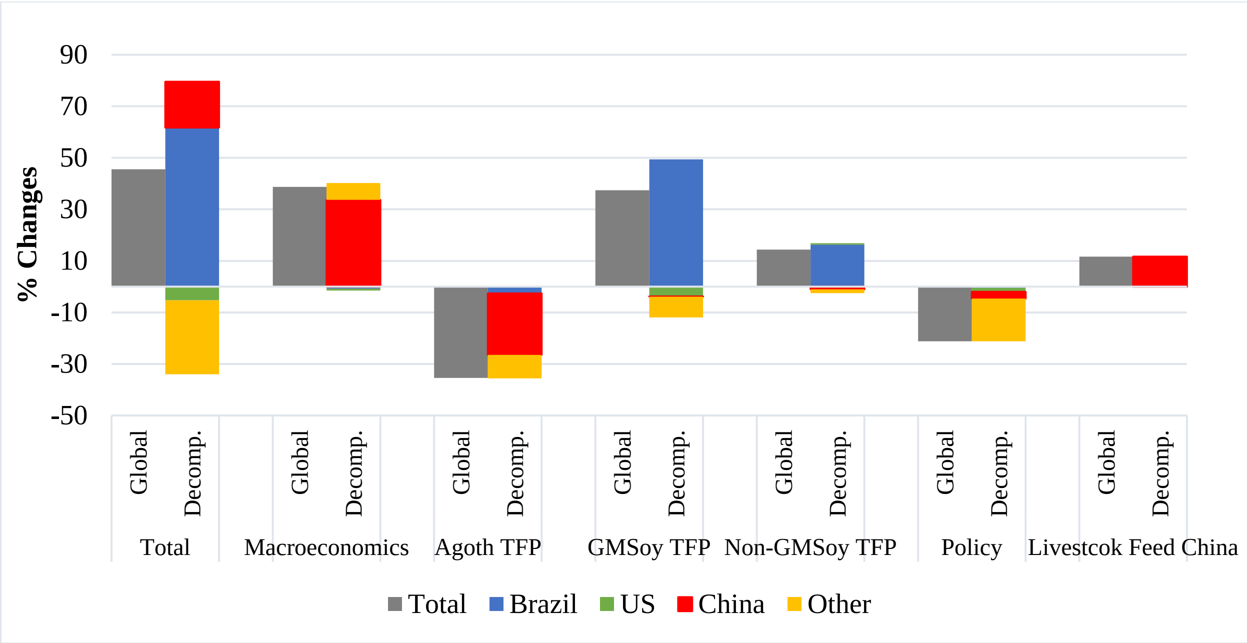


**Fig. 8. Brazil soybean output decomposition by grouped regional economic driver.**

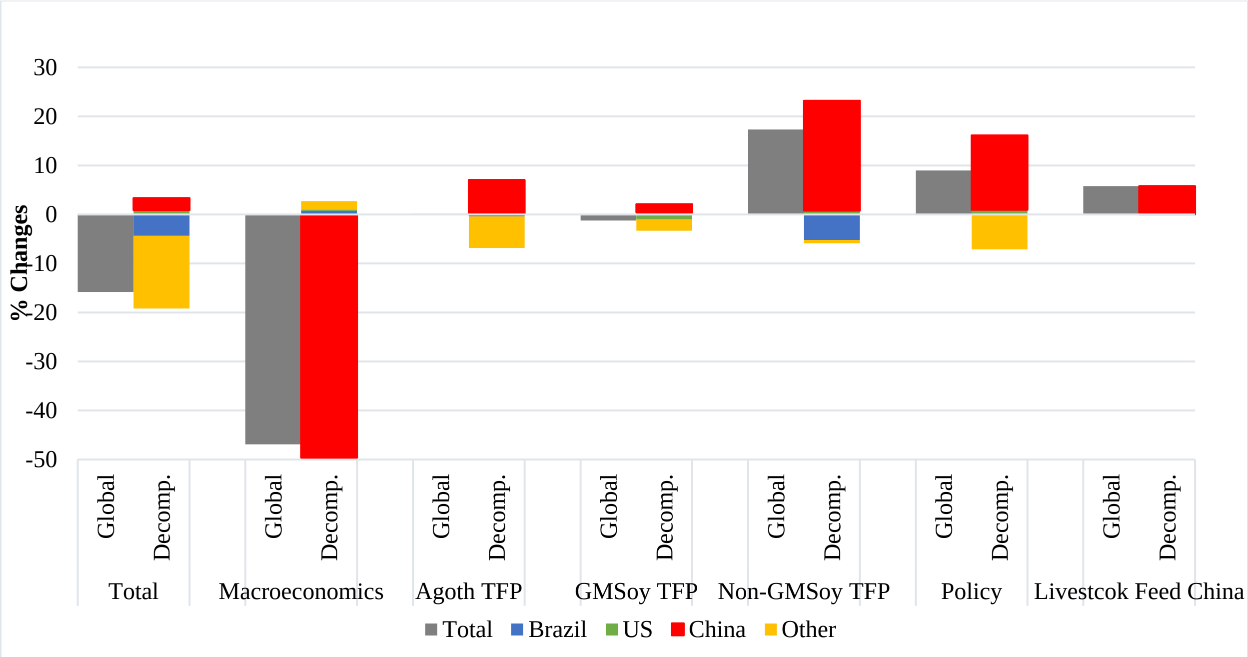


**Fig. 9. China soybean output decomposition by grouped regional economic driver.**

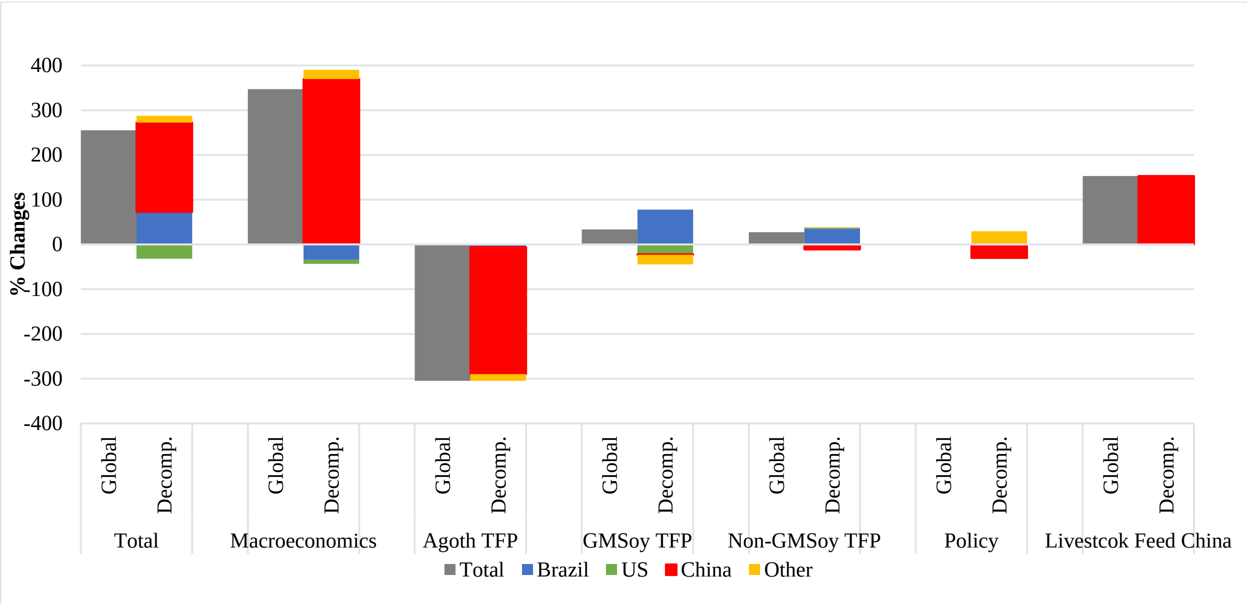


**Fig. 10. Brazil-China soybean trade decomposition by grouped regional economic driver.**