Is the pre-salt oil competitive? Economic and environmental long run impacts from the incentives to the pre-salt – a general equilibrium approach*

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Abstract

The Brazilian oil production reached 2.7 million of barrels per day in 2011 and the projections are to more than double that until 2020. Petrobras expects more than 40% of this production to come from the pre-salt layer. The estimated reserves of oil and natural gas from the pre-salt amount 50 to 70 billion barrels of oil equivalent, and, if proved, will position the country among the top ten nations in the world in terms of oil reserves. To turn these projections in production, the investments in capital will be massive.

However, the realization of its production will depend on the oil price in the incoming years, on substantial investments and on the country efforts to reduce its CO_2 emissions. Considering such uncertainties and the importance of the oil sector to the country economy, this study aims to evaluate the competitiveness of the pre-salt oil and also to estimate the macroeconomic, sectoral and environmental impacts in the long run, until 2090, from the expected expansion in the oil extraction in the country.

To do so, we use the recursive dynamic general equilibrium model EPPA - Emissions Prediction and Policy Analysis, developed to investigate energy and climate scenarios and policies. We adapted the model, to include the pre-salt sector as a backstop technology, in order to represent the economic costs and benefits of its development as well as its capacity to compete with other energy technologies in an endogenous fashion.

The results show that the oil production from the pre-salt layer in Brazil would be competitive only after 2030 under free market assumptions. To achieve the production expected by the Brazilian government in the next years it is necessary to introduce economic incentives, considered as subsidies in the model, in order to drive investments and productive resources to the sector. This strategy, however, deviates scarce resources in the medium and long term, mostly capital, from other sectors of the economy toward the pre-salt sector, generating a lower GDP and consumer welfare when compared to a "business as usual" scenario without the presence of such subsidies. The incentive to the pre-salt oil production also produces an increase in the world cumulative greenhouse gas emissions at the end of the model horizon.

Keywords

Pre-salt. Economic impacts. Greenhouse Gases. Computable General Equilibrium.

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Introduction

Domestic oil production was 2.772 million barrels of oil equivalent (boe) per day in 2011 and the projection for 2020 is that production will more than double, with pre-salt accounting for around 40.5% of the projected production for 2020 (Petrobras, 2011). The estimated pre-salt oil and natural gas reserves are between 50 and 70 billion barrels of oil equivalent and, if proven, will increase the 2010 reserves fivefold, which will put the country among the top ten countries with the largest amount of oil reserves in the world (SEFAZ-RJ, 2010).

For these estimates to become a reality, the volume of investments in gross fixed capital formation will be high. Only Petrobras plans to invest around US$ 67 billion, from 2012 to 2016, for pre-salt exploration and development (Petrobras, 2012).

According to the Federative Republic of Brazil Ministry of Mines and Energy (2009) the Union will not invest directly in the extraction of oil from the pre-salt layer, but since it has shareholdings in Petrobras (39.8% of the share capital, taking into account the BNDESPAR and 55.7% of the common shares), it has proposed the capitalization of the company to provide it with the resources necessary for exploration of the pre-salt oil. This capitalization will be done through the onerous transfer, from the Union to Petrobras, of 5.0 billion non-transferable barrels of oil equivalent. The value determined by the government in September of 2010 was US$ 8.51 per barrel of oil. The participation of the BNDES and Caixa Econômica Federal in the capitalization, Petrobras shareholders, was also approved (Peixoto, 2010).

The shock expected from pre-salt oil production has gained attention, since in the literature considerable empirical, but not conclusive, evidence can be found of a negative correlation between an abundance of natural resources and economic growth (Rosser, 2006). One of the explanatory propositions regarding this evidence is known as Dutch disease, a name coined to characterize the economic effects in the Netherlands after the discovery of highly profitable natural gas fields in the 1960's, which led to currency appreciation and damaged to the local industry (Haddad and Giuberti, 2011).

This phenomenon is described as a chronic over appreciation of the exchange rate caused by the abundance of natural resources, leading to an exchange rate that is lower than that which would facilitate the other industries of tradable goods (Bresser-Pereira, 2008). The goal of this study was to analyze the question of possible deindustrialization using an analysis of the impacts on the sectoral output and the shift in productive factors between the sectors, due to the expansion of the country's petroleum resources.

In addition to the discussion about economic impacts, another important issue is related to the environmental concern regarding the increase of production and use of fossil fuel energy sources and the associated effect of greenhouse gas (GHG) emissions (IPCC, 2007). In the National Plan for Climate Change (Plano Nacional sobre Mudança do Clima – PNMC) a reduced Brazilian contribution to global emissions, both in relation to emissions per capita and emissions per area, is highlighted (Lei 12.187, 2009). However, Brazil's commitment to seeking a dynamic economy, whose emissions trajectory does not follow the trend of already industrialized countries with respect to GHG emissions, is emphasized in the same document.

Even when considering the fact that burning fossil fuels has not had as significant impact on the Brazilian environment as it has had on the rest of the world, this study sought to investigate whether or not there is a misalignment within the Brazilian political climate for decreasing emissions and encouraging pre-salt exploration. The situation deserves attention, since, in addition to the fact that estimated pre-salt reserves are significant, there is also the issue that the concentration of CO_2 in the gas from the pre-salt fields is higher than the concentrations in other Brazilian fields (Lima P.C.R., 2009).

Given the scenario presented, it is important to highlight that the commercial viability of Brazilian pre-salt still has not been vastly studied. Its real production will depend on the price of oil in the coming years, on increased investments and the country's efforts to decrease CO_2 emissions associated with the production and refining of oil.

Considering these uncertainties and the importance of the petroleum sector to a country's economy, this study assesses the long-term macroeconomic, sectoral and environmental impacts, up to 2090, of the expected expansion of oil production with the development of pre-salt. For this, we have used a dynamic computable general equilibrium model of the global economy, specifically constructed for the study of energy markets and which allows for the modeling of pre-salt as a new technology. This approach avoids the use of productivity and/or supply shocks in the model, making the production of pre-salt endogenous and dependent on the economic forces of supply and demand, and its cost relative to conventional technology.

Methodology

General equilibrium models represent a real, complex economy and are used to assist in the identification of general equilibrium effects caused by exogenous changes, which would not be easily identified *a priori* due to their complexity or because of unexpected and non-obvious relationships (Piermartini and Teh, 2005). Even if there is uncertainty regarding the values of the model's parameters, the use of general equilibrium models allows drawing conclusions about directions and magnitudes related to exogenous shocks, as well as comparing alternative scenarios. The analysis of the model's results therefore, allows us to identify relationships between economic agents and sectors, which might not be identified in theoretical or analytical models.

General equilibrium models represent the circular flow of goods and services in the economy, in which consumers offer labor and capital services (factor inputs) to the productive sectors, which offer goods and services to the consumers. It is also considered the existence of a reverse flow of payments corresponding to the flow of goods and services, through which consumers receive payments from the productive sectors through labor and capital services provided (income), and with the resources received, they pay for goods and services used (costs). The balance in the circular flow of goods and services in the economy is represented by the conservation of the product and the value. Product conservation occurs even when the economy is not balanced. Value conservation reflects the accounting principle of a balanced budget, where, for each economic activity, the value of costs should be balanced by the value of earnings (Wing, 2004).

The formulation of this type of model is expressed in mathematical terms as a system of simultaneous equations representing the conditions for market equilibrium. The computable general equilibrium model uses the economic theory of general equilibrium as an operational tool for analysis of empirical guidance on issues related to market economies, resource allocation, trade, technological change and shock effects, among others (Sadoulet and De Janvry, 1995).

One limitation of CGE simulations is the fact that the predictions are highly dependent on the hypotheses assumed and the calibration of the model. Therefore, this study sought to make the analysis more robust, performing a sensitivity analysis to understand the impact of the most relevant hypotheses assumed that are able to affect the results of the model.

We used the recursive-dynamic multi-regional and multi-sector computable general equilibrium model Emissions Prediction and Policy Analysis – EPPA, with a long simulation horizon, which extends through 2100. This model was developed for the study of climate and energy policies and scenarios, and its characterization is described in Paltsev et al. (2005) and Gurgel (2011). The model considers the interactions between the different economic sectors, consumers and government, as well as bilateral trade flows of goods and services between countries, representing the global economy using 16 regions and countries.

The economic data that supplies the model consist mainly of National Income and Product Accounts that represent the economic structures of the regions, derived from the Global Trade Analysis Project – GTAP (Hertel, 1997; Dimaranan and Mcdougall, 2002), a consistent database on regional macroeconomic consumption, production and bilateral trade flows. Data related with energy production and use in physical units is taken from both the GTAP 7 database and the International Energy Agency (IEA, 1997, 2004, 2005). Data correspondent to the greenhouse gases (carbon dioxide – CO_2, methane – CH_4, nitrous oxide – N_20, hydrofluorocarbons – HFCs, perfluorocarbons – PFCs and sulfur hexafluoride – SF_6) were obtained from the Environmental Protection Agency of the United States and information about other urban pollutants (sulfur dioxide – SO_2, nitrogen oxides – NOx, black carbon – BC, organic carbon – OC; ammonium – NH_3; carbon monoxide – CO and non-methane volatile organic compounds – VOC) were obtained from the database developed by Olivier and Berdowski (2001).

The EPPA was built as a non-linear, mixed complementarity problem, using the syntax of the Modeling Programing System for General Equilibrium – MPSGE algorithm, developed by Rutherford (1999), which consists of a set of algebraic equations that characterize the conditions for zero economic profit for production, balance between supply and demand for goods and factors of production, and balance between income and costs for consumers. The economic equilibrium problem, therefore, involves three inequalities that need to be satisfied: zero profit, market clearance and income balance. These conditions of inequalities are associated with a set of three, non-negative variables: prices, quantities and income levels.

The zero profit condition requires that any activity in operation must earn zero profit, i.e., the value of inputs must be equal or greater than value of outputs. The variable associated with this condition is the activity level for constant returns to scale production sectors, which means that there is economic activity and the economic profit is zero, or there is no economic activity, since the profit is negative. The condition of market clearance establishes that any good with a positive price must maintain the balance between supply and demand, and any good with an excess of supply will have a price equal to zero. The income balance condition requires that, for each agent, including the government, the value of income must be equal to the value of factor endowments and tax revenue.

In this study, the EPPA – version 5 model was used, calibrated for the base year of 2004[1]. The data from the GTAP for the global economy was organized into the countries and regions, sectors and production factors described in Table 1 below.

[1] Most recent version of the EPPA.

Table 1 – Region, Sectors and Factors in the EPPA Model

Regions	Sectors		Factors
United States (USA)	**Non-Energy**	**Energy**[2]	Capital
Canada (CAN)	Agriculture - Crops (CROP)	Coal (COAL)	Labor
Mexico (MEX)	Agriculture - Livestock (LIVE)	Conventional Crude Oil (OIL)	Crude Oil
Japan (JPN)	Agriculture – Forestry (FORS)	Refined Oil (ROIL)	Shale Oil
European Union (EUR)	Food (FOOD)	Natural Gas (GAS)	Coal
Australia and New Zealand (ANZ)	Services (SERV)	Elec.: Fossil	Natural Gas
Russia (RUS)	Chemicals, Rubber, Plastics and Paper (CRPP)	Elec.: Hydro	Hydro
Eastern Europe (ROE)	Iron and Steel Industry (IRON)	Elec.: Nuclear	Nuclear
China (CHN)	Energy Intensive (EINT)	Elec.: Wind	Wind & Solar
India (IND)	Other Industry (OTHR)	Elec.: Solar	Land – Crops
Brazil (BRA)	Transportation (TRAN)	Elec.: Biomass	Land – Livestock
East Asian (ASI)		Elec.: NGCC	Land - Forestry
Middle East (MÊS)		Elec. :NGCC– CCS	Natural Forests
Africa (AFR)		Elec.: IGCC – CCS	Natural Pastures
Latin America (LAM)		Synthetic Gas	
Rest of Asia (REA)		Biofuels - 2nd gen.	
		Shale Oil	
		Biofuels – 1st gen.	

Source: Gurgel (2011)

Production functions for each economic sector describe the combinations of primary factors and intermediate inputs to generate goods and services. In each region, there is a representative consumer that seeks to maximize welfare through consume of goods and services. The representation of the possibility of the individuals to make tradeoffs among inputs and goods, both in production and consumption, is summarized by the elasticities of substitutions in the production and utility functions. In production, this reflects the technology used, i.e., the ability to substitute different productive factors and intermediate inputs into the production process. For the representative consumer, the tradeoff between goods and services illustrates the preferences of the consumers. The government is modeled as a passive entity that collects taxes and distributes the total value of proceeds to the families.

In the model, the behavior of the productive agents is given by the behavior of the representative firm, which seeks to maximize profits subject to its technological restriction, choosing, in each region and in each sector, a level of output, a quantity of primary factors and intermediate inputs from other sectors. Whereas the representative consumer has appropriations for inputs and services that can be sold or leased to firms and choose, in each period and region, the levels of consumption and savings that maximize his or her welfare, subject to a budget constraint given by the consumer's income level.

The production technologies in the EPPA model are represented by nested CES (constant elasticity of substitution) functions with various levels of desegregation, allowing for more possibilities for substitution of inputs and making the choice of substitution elasticities more flexible.

[2] NGCC: Natural Gas Combined Cycle; CCS: Carbon Capture and Sequestration and IGCC: Integrated Gas Combined Cycle with Carbon Capture and Sequestration

In the EPPA, we use a nested structure of production that is common within the service, transportation and energy intensive sectors, as well as in other industries. Intermediate inputs are considered perfect complements, together with the capital-labor-energy bundle, which consists of an energy and value-added bundle. Certain imported goods that come from different regions are first combined as Armington goods (elasticityσ_{MM}), i.e., goods for the same industry deriving from different regions are considered imperfect substitutes, then the imported aggregate is combined with the domestic production of the good, under the elasticityσ_{DM}, in order to create a bundle of goods offered within the region.

The refined oil sector (ROIL sector) considers crude oil as a complementary intermediate input for the generation of refined oil products, and not as part of the demand for energy, as can be seen in Figure 1, below.

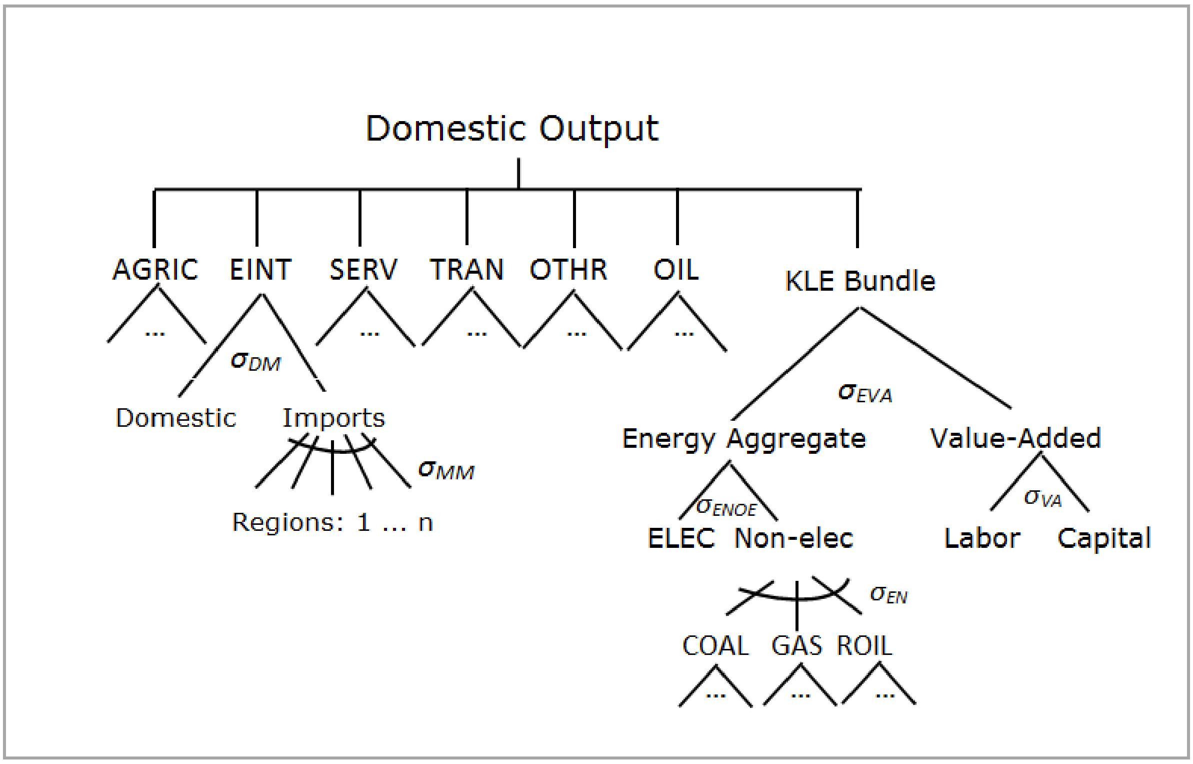


Figure 1 - Structure of Production – the ROIL sector
Source: Paltsev et al. (2005)

In the EPPA's characterization of international trade, crude oil is treated as a homogeneous product and therefore all countries and regions are given a single price. Coal, gas and refined oil are considered Armington goods, due to the differentiation of products and quality. All goods produced are sold on the global markets.

Because it uses an Armington formulation, the model has an explicit representation of bilateral trade flows in a way that all the regions are, at the same time, exporters and importers of a particular good. Bilateral flows involve export taxes, import tariffs and international transport margins, explicitly represented in the model.

Consumption, in the model, is represented by a nested CES structure to describe preferences. Elasticity among non-energy inputs for consumption varies over time and according to region, being a function of per capita income growth. Similarly, the share of consumption in each period is also updated due to per capita income growth between periods. The savings goes directing into the utility function, which generates a demand for savings and makes the consumption-investment decision endogenous.

Welfare is measured in terms of the Hicksiana equivalent variation, which measures the change in income of the consumer that is required for said consumer to reach, after a change in relative prices, the initial utility level, in each period of the model.

The model projects the GHG emissions and urban pollutants through the introduction of emissions of each GHG into the nested structure of the economic sectors responsible for them. CO_2 is generally introduced as a Leontief input associated with fuel with, a zero elasticity of substitution reflecting the reality that abatement involves using less of the fuel. In most cases, the generation of emissions of other gases is associated with specific production processes. We introduce the GHG at a higher level of the nested structure, generally with a CES structure with the substitution elasticities calibrated to the estimates of possibilities for reducing emissions, in accordance with marginal abatement curves.

In the recursive-dynamic models, such as the EPPA, the economic optimization decisions are made each period, considering only the values of prices and quantities that are valid during that period. The balance results generated in a period are then used as reference values for the optimization process of the next period.

The factors that have influenced the evolution of the model over time are related to the representation of the accumulation of capital, increase in the work force, change in the productivity of factors and inputs, change in consumption patterns from the evolution of income, and depletion of natural resources. These aspects, together with the shocks implemented in the model in the case of various scenarios, determine the dynamic process of the model.

At the end of the resolution of each scenario, the model provides estimates and projections about the growth of the GDP in the countries and regions, welfare of the representative consumer, aggregate consumption and sectoral production, consumption and production of energy at physical units, prices of goods and services, trade flows, emissions of GHG and other pollutants, as well as others.

In this study, the 5^{th} version of the model was adapted to include the production of pre-salt as a backstop technology, making the economic costs and benefits of developing pre-salt, as well as its capacity to compete with other energy technologies endogenous. This adaptation of the model was based, with the necessary adaptations for the Brazilian case, on the work of Choumert et al. (2006), which modified the original EPPA model to improve the oil and refining sector. One of the modifications was the introduction of new technologies for producing oil from non-conventional sources (oil sands in Canada and extra-heavy oil in Venezuela).

In order that the production of pre-salt was endogenous to the model, a specific production sector that produces crude oil from the fossil fuel resource extracted from the pre-salt was added, as can be seen in Figure 2. This product is considered a perfect substitute for conventional crude oil and therefore may be exported or used in the Brazilian refining sector.

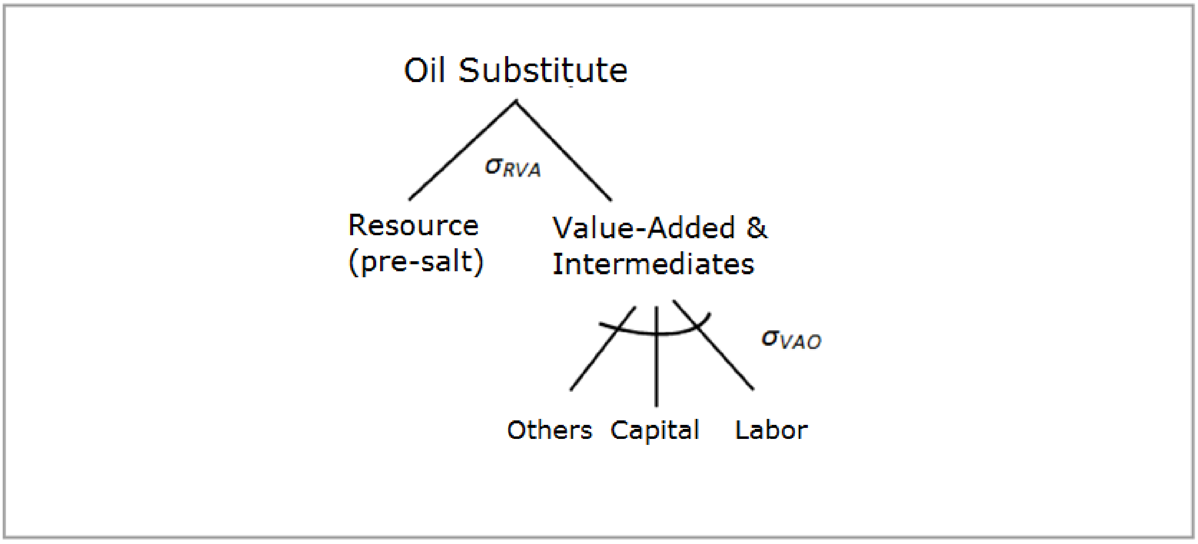


Figure 2 – Structure of Production – Pre-salt Oil Sector
Source: adapted from Paltsev et al. (2005)

The substitution elasticities used, given the shortage of detailed data about the pre-salt production costs, are the same as those for the oil sands production sector (σ_{RVA} = 0.5 and σ_{VAO} = 0.2) from the study by Choumert et al. (2006).

The model also considers the total technically recoverable pre-salt reserves[3] estimated and intends on reproducing the cost differences between its production and conventional oil production. For this, we used a cost mark-up of the new pre-salt technology in relation to the conventional resource of 1.75, calculated from the data obtained from the Federative Republic of Brazil House of Representatives (2009) and Lima K. (2010). This mark-up represents the relationship between the cost of the oil extracted from pre-salt and the cost of oil obtained from conventional reserves. In relation to the composition of inputs and productive factors in the extraction technology, Choumert et al. (2006) adjusted the percentages of capital and labor in the costs of production of oil sands based on hypotheses about the composition of the CAPEX and OPEX[4] of this resource. Due to the gap in detailed information available about the composition of the CAPEX and OPEX of the pre-salt, the same capital and labor percentages were used for the pre-salt production costs.

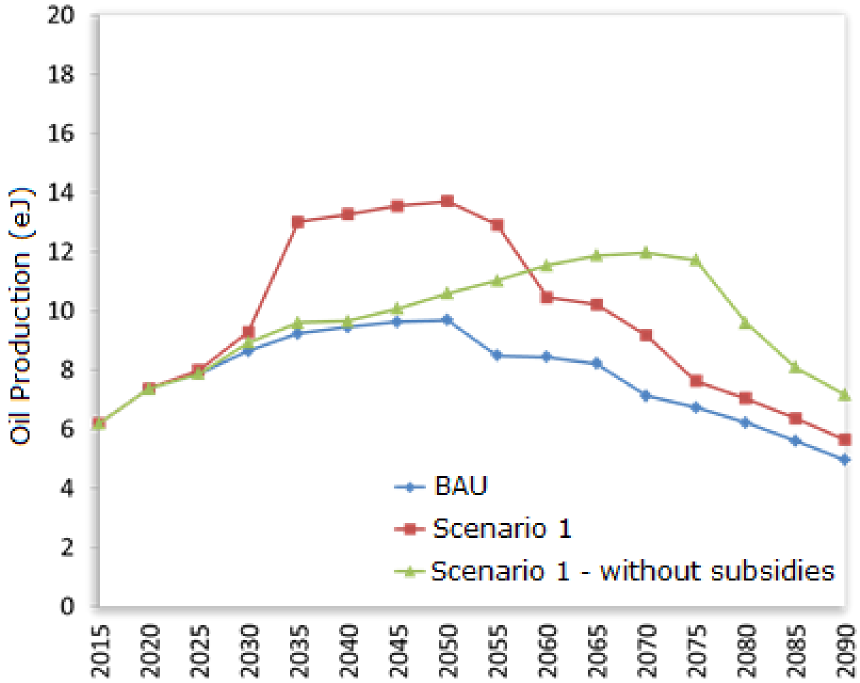
Sensitivity analyses were done to evaluate the impacts of these hypotheses on the results obtained. The initial quantity of the fossil fuel resource reserve available was calibrated and a subsidy curve[5] (Scenario 1) was introduced to allow for production of the pre-salt resource during a period prior to that which would happen endogenously if only the competitiveness of pre-salt and its opportunity costs against the conventional resource were taken into consideration.

For the analysis of the results, the simulated scenarios (Scenario 1 without subsidies and Scenario 1) are compared to the BAU (Business As Usual) scenario, which represents the trajectory of the economy as projected by the EPPA model, without considering pre-salt production, but adjusted to reproduce domestic oil production up to 2010. The differences in the results generated by the model between the simulated scenario and the BAU scenario represent the effects of pre-salt, considering the assumed hypotheses.

[3] The reserve used is 70 billion technically recoverable barrels (Lacerda, 2009).
[4] CAPEX refers to the capital costs and OPEX to the operating costs.
[5] The modeled curve uses a 50% production subsidy in 2015. There is a 10% decrease in the subsidy at each interaction of the model, from 2035 until this subsidy is zero.

Results

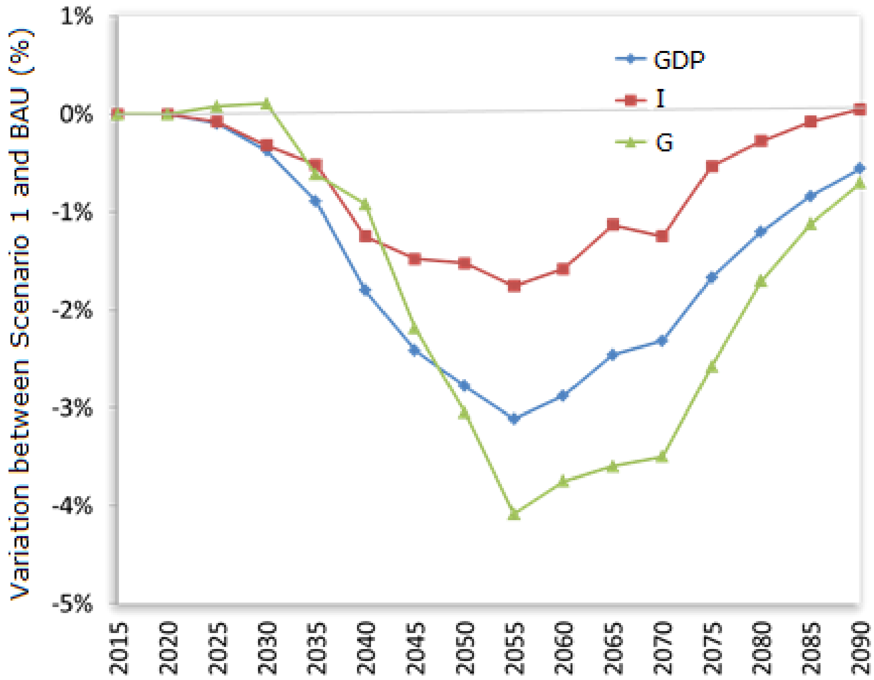
Domestic oil production in Scenario 1, in Scenario 1 without subsidies and in the reference scenario can be seen in Graph 1 below. We notice that pre-salt production in Brazil would start to become competitive in 2030, intensifying in 2050, if the market forces operate freely in the production of oil and derivatives.



Graph 1 – Domestic oil production in BAU, Scenario 1and in Scenario 1 without subsidies (eJ)

The trajectories of Graph 1 indicate that, to generate the oil production that the government expects, in the coming years, it will be necessary to introduce incentives, considered as subsidies in this model, which direct productive resources and investments toward the sector. This scenario, however, diverts scarce resources, principally capital, in the medium and long-term from other sectors, which impacts the GDP and overall welfare.

The trajectory of the variation in the GDP between Scenario 1 (with subsidies) and the BAU reference scenario, as can been seen in Graph 2 below, shows that the impact of pre-salt on the GDP is negative throughout the entire period, worsening with subsidies and becoming less negative with the progressive withdrawal of the subsidies. It is worth noting that this does not mean that the GDP, government spending and investments decrease over time, but rather that they are higher in the reference scenario.



Graph 2 – GDP, Investment (I) and Government Expenditure (G): variation between Scenario 1 and BAU (%)

In Scenario 1 without subsidies, the impact on the GDP would be positive or null until 2055, as can be seen in Table 2 below. The subsidies curve negatively impacts the GDP since these resources may be invested in other sectors or even distributed, through income transfer, to families, stimulating the production and consumption in the model.

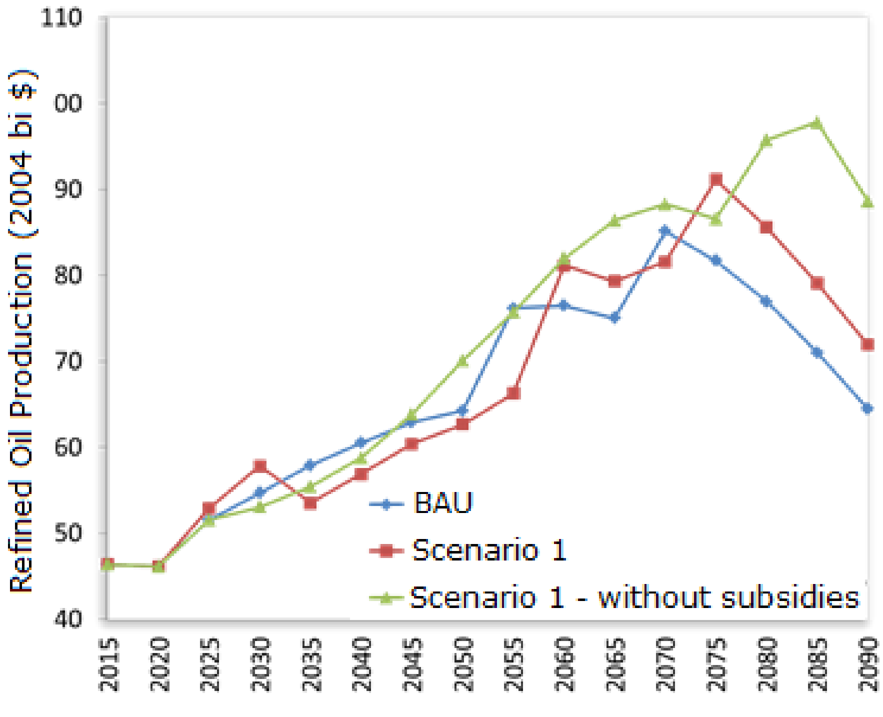
Table 2 – GDP and Welfare: variation between Scenario 1 and BAU and between Scenario 1 without subsidies and BAU (%)

	GDP Variation		**Welfare Variation**	
	Between Scenario 1 and BAU	**Between Scenario 1 without subsidies and BAU**	**Between Scenario 1 and BAU**	**Between Scenario 1 without subsidies and BAU**
2015	0.0%	0.0%	0.0%	0.0%
2020	0.0%	0.0%	0.0%	0.0%
2025	-0.1%	0.0%	-0.2%	0.0%
2030	-0.4%	0.0%	-0.8%	0.1%
2035	-0.9%	0.0%	-1.0%	0.2%
2040	-1.8%	0.0%	-2.2%	0.1%
2045	-2.4%	0.1%	-2.9%	0.0%
2050	-2.8%	0.2%	-3.2%	-0.3%
2055	-3.1%	0.0%	-3.0%	-0.2%
2060	-2.9%	-0.1%	-3.4%	-0.4%
2065	-2.5%	-0.1%	-2.9%	-0.7%
2070	-2.3%	-0.4%	-2.3%	-0.7%
2075	-1.7%	-0.5%	-2.0%	-0.6%
2080	-1.2%	-0.3%	-1.5%	-0.9%
2085	-0.8%	0.0%	-1.1%	-0.8%
2090	-0.6%	0.2%	-0.8%	-0.6%

The trajectory of the effect on the welfare of the representative consumer, as can be seen in Table 2 above, compares to the variation trajectory of Brazil's GDP between the scenarios with and without subsidies. We noticed, in Scenario 1 (with subsidies) that the welfare of the representative consumer is negatively impacted for the entire period, which is a consequence of the cost inflicted on society for the allocation of resources in a sector that, in principle, would not be competitive[6].

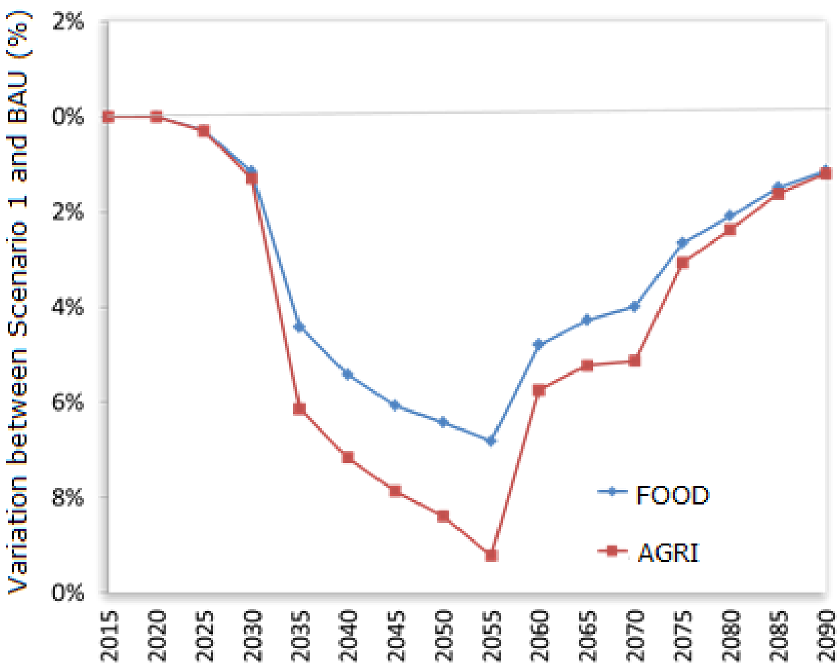
The sectoral impacts can be seen in Graphs 3 to 6. From an analysis of graph 3 (refined oil production in the base scenario, Scenario 1 and Scenario 1 without subsidies), we see that the production curve is not smooth along the horizon of the model. This result demonstrates that the sector alternates between exporting crude oil in some periods and using a higher percentage of this production in the domestic refining sector. This occurs because crude oil is considered a homogenous product in international trade and, at the same time, is the single input of the refining sector and, therefore, likely to have its production directed quickly and in large volumes for exporting or refining. Another factor that contributes to the refined oil not smooth curve is the influence of the production and consumption of ethanol in Brazil, which competes with refined oil in the transportation sector, due to the existence and growth of the flex-fuel vehicles fleet in the country.

With regards to the production trajectories of other sectors, we notice that all sectors are negatively impacted throughout the entire period (production is greater in BAU than in the subsidized Scenario 1), mainly due to the fact that pre-salt development receives resources, mainly capital, which would normally be allocated to other sectors, as shown in Tables 3 and 4. With the gradual reduction of subsidies, the allocation of resources tends to normalize within the economy, improving allocative efficiency, which also drives the gradual decrease of sectoral production losses in relation to the BAU scenario, but without ever presenting positive results.

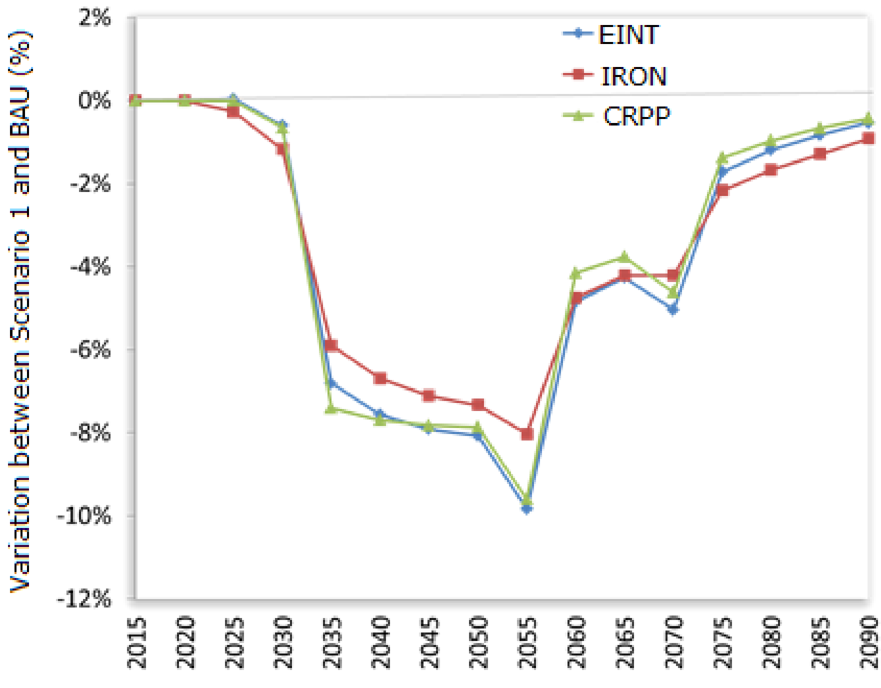


Graph 3 –Refined Oil Production: BAU, Scenario 1 and Scenario 1 without subsidies (2004 bi $)

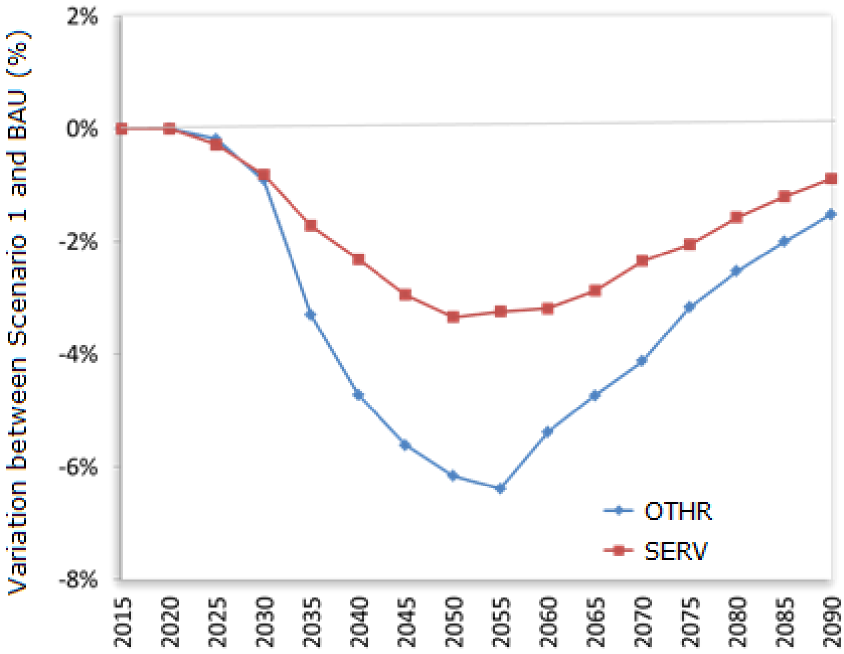
[6] The Appendix presents a brief sensitivity analysis of these results regarding variations in hypotheses related to parameters of the pre-salt oil production sector.



Graph 4 – FOOD and AGRI (Agriculture) production: variation between Scenario 1 and BAU (%)



Graph 5 – EINT, IRON and CRPP production: variation between Scenario 1 and BAU (%)



Graph 6 – OTHR and SERV production: variation between Scenario 1 and BAU (%)

Development of pre-salt oil production affects the use of primary production factors throughout the entire economy. Tables 3 and 4 present variations in the demand of capital and labor, respectively, in the economy. We notice that in the period of higher pre-salt production, a shift of these resources to the OIL sector (and in a lesser degree to OTHR) from the other sectors (mainly the EINT, CRPP and IRON).

Table 3 – Demand for capital: variation between Scenario 1 and BAU

	FOOD	AGRI	EINT	OTHR	OIL[7]	ROIL	CRPP	SERV	IRON
2015	0.0%	0.0%	0.0%	0,0%	0.0%	0.0%	0.0%	0.0%	0.0%
2020	0.0%	0.0%	0.0%	0,0%	0.0%	0.0%	0.0%	0.0%	0.0%
2025	-0.4%	-0.5%	-0.3%	-0,3%	13.6%	2.5%	-0.5%	-0.6%	-0.7%
2030	-1.7%	-1.9%	-1.7%	-1,3%	38.9%	4.9%	-2.2%	-2.2%	-2.7%
2035	-5.9%	-7.2%	-8.5%	-4,3%	129.5%	-9.6%	-10.1%	-5.8%	-9.0%
2040	-7.9%	-9.1%	-10.4%	-6,3%	126.0%	-9.1%	-11.8%	-8.2%	-11.3%
2045	-9.5%	-10.6%	-11.9%	-7,8%	122.6%	-8.0%	-13.0%	-10.3%	-12.9%
2050	-10.6%	-11.7%	-13.0%	-8,8%	118.3%	-7.0%	-13,8%	-11.5%	-13.9%
2055	-11.2%	-12.7%	-14.2%	-9,2%	141.5%	-17.1%	-14.5%	-11.5%	-13.9%
2060	-9.3%	-9.4%	-10.4%	-8,2%	64.3%	1.7%	-10.2%	-10.6%	-11.1%
2065	-8.5%	-8.7%	-9.7%	-7,3%	58.8%	1.8%	-9.3%	-9.6%	-10.1%
2070	-7.6%	-8.1%	-9.1%	-6,4%	65.7%	-7.2%	-8.4%	-8.0%	-8.5%
2075	-6.0%	-5.7%	-6.5%	-5,2%	26.0%	8.7%	-6.0%	-6.7%	-6.8%
2080	-4.9%	-4.7%	-5.6%	-4,2%	21.0%	9.0%	-4.9%	-5.3%	-5.5%
2085	-3.8%	-3.6%	-4.8%	-3,4%	18.8%	9.6%	-4.0%	-4.2%	-4.5%
2090	-3.0%	-2.9%	-4.0%	-2,6%	17.2%	10.2%	-3.1%	-3.2%	-3.5%

[7] Includes the pre-salt production.

Table 4 – Demand for labor: variation between Scenario 1 and BAU

	FOOD	AGRI	EINT	OTHR	OIL[8]	ROIL	CRPP	SERV	IRON
2015	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2020	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2025	-0.2%	-0.2%	0.0%	0.0%	19.9%	2.9%	0.0%	-0.2%	-0.3%
2030	-0.6%	-0.7%	-0.5%	0.0%	48.1%	6.8%	-0.4%	-0,4%	-0.9%
2035	-2.5%	-3.8%	-5.4%	-0.6%	144.5%	-4.6%	-5.1%	-0.6%	-4.0%
2040	-2.3%	-3.3%	-5.0%	-0.4%	140.9%	-1.5%	-4.4%	-0.6%	-3.9%
2045	-1.7%	-2.7%	-4.3%	0.3%	138.0%	1.7%	-3.8%	-0.8%	-3.7%
2050	-1.2%	-2.3%	-3.8%	0.9%	135.1%	4.2%	-3.5%	-0.9%	-3.6%
2055	-1.0%	-2.7%	-4.3%	1.2%	162.4%	-7.0%	-4.1%	-0.8%	-3.4%
2060	0.6%	0.5%	-0.6%	1.9%	77.0%	12.6%	-0.5%	-1.0%	-1.6%
2065	0.7%	0.5%	-0.6%	2.0%	70.5%	11.5%	-0.7%	-1.0%	-1.5%
2070	0.6%	-0.1%	-1.1%	1.8%	77.2%	0.2%	-1.1%	-0.7%	-1.2%
2075	1.0%	1.1%	0.4%	1.8%	34.1%	15.7%	0.1%	-0.8%	-0.8%
2080	0.8%	0.9%	0.0%	1.5%	28.0%	14.4%	-0.1%	-0.6%	-0.8%
2085	0.8%	0.8%	-0.3%	1.2%	24.8%	13.9%	-0.2%	-0.4%	-0.8%
2090	0.6%	0.6%	-0.4%	1.0%	22.2%	13.5%	-0.2%	-0.3%	-0.6%

It is interesting to note that, given the hypotheses assumed about the cost of pre-salt and the presence of subsidies, the classic symptoms of Dutch disease only present themselves during the subsidized expansion of the sector. In the period of decline of pre-salt production, the classic symptoms of Dutch disease do not appear. Furthermore, we notice that despite the limitations of the data and the dependence on hypotheses, the scenario that models pre-salt as a backstop technology allows for a representation of the development costs for pre-salt oil, which is a production source that is more onerous than conventional oil, and, therefore, if prematurely stimulated, generates an inefficient allocation of scarce resources. We notice a negative impact, not only on the GDP and welfare of the representative consumer, but also on the production of all the other sectors of the economy on different levels and trajectories.

Lastly, it is important to assess whether or not the development of pre-salt oil production will negatively affect Brazil's GHG emissions. Accordingly, the results indicate that incentives for pre-salt development will lead to an increase in GHG emissions from Brazil and globally at the end of the simulation horizon of the model. Table 5 below shows the variation in the domestic sectoral emissions at the end of the simulation horizon, where we notice a 0.2% increase in total domestic emissions. There is even an increase of global emissions of 0.1% in 2090. These values indicate a fairly modest increase in emissions, but it is important to emphasize that these impacts only consider the emissions associated with refining and not with the high volume of carbon gas associated with the gas from the producing field, not considered in the EPPA model due to a lack of data and uncertainty of information that would allow to attribute reliable emission coefficients to the extracted volume of pre-salt oil. The impact on accumulated Brazilian and worldwide emissions from 2010-2090 is -2.6% and 0.1%, respectively. The negative impact in the Brazilian case is due to the overall decline in sectoral production in Scenario 1 (with subsidies) in relation to the base scenario.

[8] Includes the pre-salt production.

Table 5 – Brazilian CO_2 equivalent emissions by source – Variation between Scenario 1 and BAU in 2090 (%)

	Variation between Scenario 1 and BAU
AGRI	-1.0 %
FOOD	1.0 %
EINT	2.6 %
OTHR	-1.1 %
ROIL	3.8 %
CRPP	0.7 %
SERV	3.3 %
TRAN	4.8 %
IRON	0.0 %
Total emissions	0.2 %

Conclusions

We have concluded, from these results, that premature stimulus of pre-salt production brings more costs than benefits to Brazil's economy, in the long-term, considering the current stage of knowledge and technological development for pre-salt exploration, the assumed hypotheses and the model used in this study. Therefore, it is recommended that pre-salt exploration is accompanied by technological development policies that are able to reduce the costs and increase the efficiency of extraction and use of this fossil resource. Additionally, despite the only slightly pronounced impact of pre-salt on greenhouse gas emissions, it becomes necessary to reconcile the Brazilian climate and energy policies, since pre-salt development is antagonistic to Brazil's policy for reducing greenhouse gases. From this study, it is also clear that there is space in the literature for simulations with alternative methods and hypotheses to better understand the phenomenon.

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Appendix – Sensitivity analysis

The representation of pre-salt production technology as a backstop technology in the computable general equilibrium model used in this study made use of economic parameters and assumptions that are not often available in the literature and, therefore, subject to questioning. In order to verify if the results obtained are sound and how some hypotheses adopted would affect the results obtained, in this section we sought to perform simple sensitivity tests. We have chosen to present some of the most relevant results of these tests, more specifically, the results regarding the GDP and welfare of the representative consumer, results of sectoral production, results regarding crude oil production (including pre-salt production) and Brazil's total greenhouse gas emissions (in CO_2 equivalent). We analyzed the results for 2030, 2050 and 2090 to represent the trajectory.

The two main hypotheses that were chosen to be tested were: elasticity σ_{RVA}, which represents the substitution elasticity between the pre-salt resources and the value-added and intermediate (capital, labor and others) bundles in the pre-salt production function, as can be seen in Figure 2 (in the simulated scenario, the value considered was the same as oil sands production of 0.5) and; the percentage of capital and labor in the pre-salt production costs (in the simulated scenario, the percentage of capital and labor in the pre-salt production costs considered was the same as oil sands production of 40% for capital and 30% for labor).

Four tests were performed: test 1, which considered a decrease in σ_{RVA} (σ_{RVA}= 0.25); test 2, which considered the same proportion of increase in σ_{RVA}(σ_{RVA}= 1.0); test 3, which considered the pre-salt production technology to be more capital intensive (proportion of capital costs at 50% and labor at 20%) and; test 4, which considered the pre-salt production technology to be less capital intensive (proportion of capital costs at 30% and labor at 40%). In the following tables, the results from the sensitivity analysis of the model, using the variation of the results obtained in the simulated test and in the original subsidized Scenario 1, can be seen.

The changes in the results are not significant (up to 1.1% for GDP; -1.32% for welfare of the representative consumer and -4.67% for total Brazilian emissions), as can be seen in Tables 6,7 and 8, below, not altering the results and conclusions, and showing the soundness of the model. For the sensitivity results regarding sectoral production, we see, again, that the model is sound from an analysis of the results from tables 9, 10 and 11 and that the sectoral result is also relatively sound. The sensitivity analysis regarding crude oil production (including pre-salt production), which may be seen in table 12, indicates that the results for this sector are more sensitive to the assumed hypotheses that were tested. This result suggests a need for further studies about the intensity of use of factors in the pre-salt exploration sector for a more suitable representation of this technology in the general equilibrium models. However, as the results from the sensitivity analysis indicate, the uncertainty about the formulation of the technology has little effect on the macroeconomics results of this study.

Table 6 – Variation in the GDP in the sensitivity tests (%)

	GDP		
	2030	**2050**	**2090**
Test 1	0.14%	1.10%	0.51%
Test 2	-0.02%	-0.10%	-0.62%
Test 3	0.06%	0.37%	-0.17%
Test 4	-0.22%	0.00%	0.09%

Table 7 - Variation in the welfare of the representative consumer in the sensitivity tests (%)

	Welfare		
	2030	**2050**	**2090**
Test 1	0.19%	0.45%	0.46%
Test 2	-0.01%	-0.66%	-1.32%
Test 3	0.68%	0.17%	-0.27%
Test 4	-0.49%	0.52%	0.20%

Table 8 - Variation in the Brazilian CO_2 equivalent emissions in the sensitivity tests (%)

	Brazilian CO_2 equivalent emissions		
	2030	**2050**	**2090**
Test 1	0.02%	3.54%	0.76%
Test 2	0.91%	0.37%	1.45%
Test 3	-4.67%	0.34%	0.08%
Test 4	-0.10%	-0.97%	-0.21%

Table 9 - Variation in the sectoral production in the sensitivity tests - 2030 (%)

	FOOD	**AGRI**	**EINT**	**OTHR**	**TRAN**	**CRPP**	**SERV**	**IRON**
Test 1	0.9%	0.21%	0.26%	0.29%	0.13%	0.18%	0.08%	0.21%
Test 2	0.50%	0.74%	1.03%	0.21%	0.98%	1.19%	0.09%	0.77%
Test 3	-1.37%	-2.46%	-4.18%	-0.82%	-4.10%	-4.58%	0.15%	-2.55%
Test 4	-0.41%	-0.33%	0.36%	-0.30%	1.01%	0.30%	-0.51%	-0.25%

Table 10 - Variation in the sectoral production in the sensitivity tests - 2050 (%)

	FOOD	**AGRI**	**EINT**	**OTHR**	**TRAN**	**CRPP**	**SERV**	**IRON**
Test 1	2.81%	4.35%	5.78%	2.15%	5.43%	6.01%	0.82%	4.01%
Test 2	-0.54%	-0.42%	0.35%	-0.60%	1.46%	0.45%	-0.48%	-0.26%
Test 3	1.54%	2.39%	2.66%	1.08%	1.94%	2.96%	0.52%	2.10%
Test 4	-0.86%	-1.59%	-1.99%	-0.16%	-1.98%	-2.55%	-0.08%	-1.41%

Table 11- Variation in the sectoral production in the sensitivity tests - 2090 (%)

	FOOD	**AGRI**	**EINT**	**OTHR**	**TRAN**	**CRPP**	**SERV**	**IRON**
Test 1	0.30%	0.32%	0.75%	0.47%	0.93%	0.55%	0.37%	0.48%
Test 2	-2.28%	-2.47%	-0.05%	-2.68%	5.03%	-0.22%	-1.62%	-1.57%
Test 3	-0.39%	-0.43%	-0.16%	-0.50%	0.55%	-0.13%	-0.29%	-0.33%
Test 4	0.36%	0.40%	0.05%	0.45%	-0.71%	0.06%	0.25%	0.26%

Table 12 - Variation in the OIL production in the sensitivity tests – includes pre-salt production (%)

	OIL Production		
	2030	**2050**	**2090**
Test 1	0.0%	0.0%	0.0%
Test 2	-6.4%	21.3%	33.6%
Test 3	18.2%	3.9%	0.0%
Test 4	1.6%	26.1%	-9.4%