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Brazil's Oil Production and Trade with the United States

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ABSTRACT

Significant new discoveries of offshore oil could reshape the Brazilian economy, including its pattern of trade with the United States and the rest of the world. In this paper, we estimate a set of econometric models that relate each country's international trade in crude and refined petroleum, upstream inputs into petroleum production, transportation equipment that uses petroleum products, and other bilateral import and exports to the country's volume of domestic crude oil production. Then we use the models to project the likely impact of the anticipated boom in Brazilian crude oil production on Brazil's trade with the United States.

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Brazil's Oil Production and Trade with the United States

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I. Introduction

Significant new discoveries of offshore oil could reshape the Brazilian economy, including its pattern of trade with the United States and the rest of the world. The Tupi field was discovered in 2007 by a consortium of Brazilian and foreign companies (Petrobras, BG Group, and Petrogal). The new discoveries lie off the southern coast of Brazil, south of Rio de Janeiro and southeast of Sao Paulo. These oil and natural gas deposits lie deep below the salt layer of the ocean floor. The resulting high pressures make the resources difficult to recover, but production is still expected to be profitable. The estimated recoverable resources are vast, and their full development will require significant improvements in Brazil's energy transportation infrastructure.[2]

The economic importance of these oil discoveries has been widely recognized in projections of future global energy markets. For example, the U.S. Department of Energy's *International Energy Outlook 2011* projects that production in Brazil will increase by more than 50 percent between 2011 and 2020. Brazil is projected to move into the top tier of the world's non-OPEC oil producers.[3]

The goals of this paper are to estimate the statistical relationship between each country's volume of crude oil production and its pattern of international trade in several categories of products, and then to use the statistical models to *translate* the projected increase in Brazilian oil production into a projected change in Brazil's trade with the United States. In the rest of this Introduction, we provide an economic framework that identifies many of the ways that domestic oil production can affect international trade. These economic effects underlie the statistical relationships that we estimate.

[2] U.S. Department of Energy (2012) discusses the relevant constraints on expanding crude oil production in Brazil.

[3] However, even under these optimistic projections, Brazilian crude oil production is expected to remain less than four percent of global crude oil production.

We expect that the increase in the volume of domestic crude oil production will affect U.S. imports from Brazil in three different ways. The increase is likely to have the most direct effect on U.S. imports of crude oil and refinery products from Brazil, but it may also have less direct effects on U.S. imports of other products by lowering the fuel costs of transporting imports and exports.[4] The magnitude of these secondary effects will likely depend on the extent of regulation of energy prices in Brazil, the international arbitrage of fuel prices, possibilities for substitution among fuels, and the distribution of petroleum revenues. For example, the regulation of energy prices in Brazil limits the relative cost advantages of a more abundant domestic supply of liquid fuels. On the other hand, the boom in Brazil's energy sector could limit the expansion of other sectors of the Brazilian economy and thus limit the expansion of Brazil's exports to the United States. This economic phenomenon is often referred to as Dutch disease, based on the seminal work on booming sectors and international trade in Corden and Neary (1982) and Corden (1984). More recent theoretical and empirical analyses of Dutch disease include Acosta, Lartey, and Mandelman (2009), Beverelli, Dell`Erba, and Rocha (2011), and Rajan and Subramanian (2011).

The increase in the volume of domestic crude oil production could also have significant effects on trade in the opposite direction, from the United States to Brazil. It is likely to have the most direct effect on U.S. exports of drilling equipment from the United States, since the demand for these products in Brazil is derived from oil production.[5] It is also likely to have a positive effect on U.S. exports of transportation equipment to Brazil, since the demand for transportation equipment generally increases as liquid fuel costs decline.[6] The projected increase in crude oil production may also have less direct effects on U.S. exports of other products that are not directly tied to petroleum. For example, we expect that the

[4] The reduction in fuel costs may also reduce manufacturing costs in energy-intensive industries in Brazil.

[5] The analysis of Dutch disease in Beverelli, Dell`Erba, and Rocha (2011) specifically focuses on these types of input-output linkages between the natural resource sector and the manufacturing sector.

[6] Transportation equipment includes railway vehicles, motor vehicles, aircraft, and ships.

expansion in Brazil's oil revenues will increase incomes in Brazil, and this will in turn increase Brazil's overall expenditures on imports.[7]

While economic theory and past studies of Dutch disease help us to identify the likely economic effects, their magnitudes are fundamentally an empirical issue. Therefore, we estimate a set of statistical models that relate a country's international trade in crude oil and refinery products, upstream inputs into petroleum production, transportation equipment, and other bilateral import and exports to the country's volume of domestic oil production.[8]

The analysis in this paper is organized into two main sections. Section II presents a set of econometric models of the relationship between a country's annual crude oil production and its international trade in several categories of products. Section III combines these econometric models with projections of Brazil's future production of crude oil in order to project the impact of the anticipated boom in Brazilian oil production on the country's international trade with the United States. Section IV provides concluding remarks.

II. Econometric Models

We estimate a set of econometric models that quantify the effect of an increase in a country's oil production on its international trade. We examine the impact on five distinct categories of trade: U.S. petroleum imports, U.S. imports of all other products, U.S. exports of drilling equipment, U.S. exports of

[7] This is called the spending effect in the economics literature on Dutch disease, e.g., Corden (1984).

[8] Sardorsky (2012) also presents a set of econometric models of the relationship between the energy sector and international trade of several South American countries. However, he focuses on the effect of total energy consumption on international trade, rather than the effect of oil production.

transportation equipment, and U.S. exports of all other products.[9] We model the trade flows using the following log-linear function:

$$V_{ict} = \beta_0 \, (OIL_{ct})^{\beta_1} \, (GDP_{ct})^{\beta_2} \, (DIS_c)^{\beta_3} \; Z_t \;\; \varepsilon_{ct}$$

The dependent variable of the models, V_{ict}, is the value of U.S. exports to country c (or U.S. imports from country c) in products from category i in year t. The variable OIL_{ct} represents crude oil production in country c in year t. The econometric models include the annual gross domestic product of country c (GDP_{ct}), the international distance between the United States and country c (DIS_c), and year effects that are common across the countries (Z_t). In the models of U.S. imports, the year effects control for variation in the size of the U.S. market over time. In the model of U.S. exports, the year effects control for variation in U.S. production costs over time. The error term ε_{ct} includes any unobservable determinants of trade and any error in the measurement of trade values.

We estimate the parameters of the trade models using a data set that combines oil production data and trade data for many countries over several years. (In Section III, we will use these econometric models to quantify the impact of the projected increase in oil production in a single country, Brazil, on that country's imports and exports.) The estimation data set is a panel that covers 95 countries over the fifteen year period from 1996 to 2010. The annual data on crude oil production are from the International Energy Statistics database of the U.S. Department of Energy's Energy Information Administration (EIA).[10] The annual data on U.S. imports and exports by product and by country are from the U.S. International Trade Commission's Trade Dataweb.[11]

[9] For the sake of the analysis in this paper, petroleum products refers to HTSUS codes 2709001000 through 2710999000; drilling equipment refers to HTSUS codes 7304110020 through 7304296175, 7305111030 through 7305208000, 7306110010 through 7306298150, and 8430494000 through 8430498020; and transportation equipment refers to HTSUS codes 8601100000 through 8908000000.

[10] These data on the production of conventional liquids are publicly available at http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm.

[11] These data are publicly available at http://dataweb.usitc.gov.

We consider three different estimation techniques that rely on alternative assumptions about the error term ε_{ct}. We examine all three alternatives in order to evaluate the sensitivity of our results to these assumptions. The first and simplest estimator is log-linear Ordinary Least Squares (OLS). This model assumes that ε_{ct} has a log normal distribution. Since the models are log-linear, the estimated coefficients of the OLS models can be interpreted as elasticities. The greatest drawback of the log-linear OLS estimator is that observations with zero trade values are dropped from the estimation dataset, because the natural log of zero is undefined. In addition, Santos Silva and Tenreyro (2006) demonstrate that OLS estimates of the coefficients of log-linearized models will be biased if there is heteroskedasticity in the error term, as is often the case in cross-sectional estimation involving many countries. For these reasons, Santos Silva and Tenreyro recommend the use of Poisson models to estimate log-linearized economic models. In the Poisson model, the dependent variable is the value of the trade flow in levels rather than logs. The estimated coefficients can again be interpreted as elasticities. The Poisson model includes the same set of explanatory variables but different assumptions about the distribution of the error term. An important limitation of the Poisson model is that it imposes the unrealistic assumption that the variance of the error term is equal to its mean. The third estimator that we consider, the negative binomial model, is a generalization of the Poisson model that relaxes this restriction on the distribution of the error term. We use a likelihood ratio test to determine whether the Poisson model or the negative binomial model is more appropriate in each case. As long as the dispersion parameter of the negative binomial model is significantly different from zero, the negative binomial model is more appropriate. In all of the models that we estimate, we assume that the volume of domestic oil production is an exogenous variable, determined for the most part by natural resource discoveries.

We undertook the econometric analysis in two steps. First, we estimated unrestricted models that included all of the explanatory variables. Based on this first set of results, we re-estimated the models with exclusion restrictions on one or more of the coefficients of the models. In most cases, the preferred specification involved an exclusion restriction. Tables 1, 2, 3, 4, and 5 present the estimated coefficients of the preferred models.

Table 1 reports the estimated coefficients of the models of U.S. imports of petroleum products, based on the log-linear OLS, Poisson, and negative binomial estimators. The dependent variable is the customs value of U.S. imports from each country. The volume of domestic oil production has a significant positive effect on the value of these U.S. imports, with an elasticity that ranges from 0.7795 (for the negative binomial model) to 1.0230 (for the OLS model). An elasticity less than one indicates that the increase in the value of the imports is less than proportional to the increase in the volume of domestic oil production. This is the case for the negative binomial estimate: for every 10% increase in oil production, there is a 7.8% increase in the value of the U.S. imports from the country. In the case of the OLS estimate, the elasticity is not significantly different from one. International distance has a significant negative effect on the U.S. imports. The GDP of the country of origin is excluded from the models in Table 1, because it is not statistically significant in the unrestricted models. The likelihood ratio test rejects the Poisson model in favor of the negative binomial model, based on the test statistic reported in the last row and last column of the table. The log-linear OLS model is the least reliable of the three models, because it excludes the 192 observations with imports equal to zero.

Table 2 reports the estimated coefficients of the preferred models of U.S. imports of all other products, for each of the three estimators. The dependent variable is the customs value of U.S. imports from each country. The volume of domestic oil production has a significant positive effect on these imports, with an elasticity that ranges from 0.1957 (for the OLS model) to 0.3189 (for the negative binomial model). The GDP of the country of origin has a significant positive effect in these models of U.S. imports, reflecting the size and productive capacity of the country of origin. This is consistent with conventional gravity models of international trade. International distance again has a significant negative effect on the value of imports. The model in Table 2 does not include year effects, since the year indicator variables are not jointly significant in the unrestricted models. The negative binomial estimator is again the best of the three alternatives. Focusing on the negative binomial model, there is a significant positive effect of the volume of domestic oil production on the imports but the elasticity is much smaller than the elasticity for U.S. imports of petroleum products. We interpret the small effect on imports of these other products as the less direct effect of domestic energy production on the export competitiveness of the products, through the Dutch disease effect that we discussed in the Introduction.

Table 3 reports the estimated coefficients of the models of U.S. exports of drilling equipment. These exports are more responsive to the volume of domestic crude oil production in the destination country than the aggregate expenditures in the destination country (measured by its GDP). The elasticity estimate for the former is more than twice as large as the elasticity estimate for the latter in the negative binomial model in Table 3. The elasticity estimates with respect to the volume of domestic oil production range from 0.4263 to 0.6124, depending on the estimator. The elasticity estimates with respect to GDP range from 0.1647 to 0.2977. The year indicator variables and the GDP terms are both statistically significant in the unrestricted models. This set of econometric estimates is consistent with the predictions of economic theory that we discussed in the Introduction: since drilling equipment is a direct input into crude oil production, we expect that U.S. exports of drilling equipment will be very responsive to the level of domestic crude oil production.

Table 4 reports the estimated coefficients for the preferred models of U.S. exports of transportation equipment. The elasticity of exports with respect to the volume of domestic oil production is statistically significant for all three estimators, but it is relatively small. The elasticity estimates range from 0.1178 to 0.1646. The models in Table 4 do not include year effects, since the year indicator variables are not jointly significant in the unrestricted models. We expect that these exports will be responsive to the increased abundance and reduced cost of fuel in the oil-producing country, but the effect is less direct that the effect on drilling equipment exports. Comparing the elasticity estimates in Table 4 to their counterparts in Table 3 (the model of U.S. exports of drilling equipment), the exports of transportation equipment are more responsive to the GDP of the destination country and less responsive to the volume of domestic crude oil production.

Finally, Table 5 is the preferred model for U.S. exports of all products other than drilling equipment and transportation equipment. These exports are less responsive to the volume of domestic oil production in the destination country. We expect that an increase in oil revenues will have a positive effect on a country's import demand by increasing incomes. There is some support for this prediction in the data, but the effect is small. This is not surprising, since it is an indirect effect and since the model already captures most or all of the income effect through the GDP term.[12]

III. Projections for Oil Production and Trade

Next, we utilize the projections of Brazil's oil production from the 2011 edition of the EIA's *International Energy Outlook* (IEO). The IEO provides projections for the production of conventional liquids by country by year through 2035.[13] The projections for the early years are based on the future supply schedules for specific projects already in development. The EIA projections of production beyond the early years are modeled outcomes that correspond to a specific set of assumptions about macroeconomic conditions, world liquids production, and energy efficiency. We focus on the IEO's reference case. This case assumes that OPEC countries invest in production capacity to maintain their forty percent share of worldwide liquids production. It assumes that OECD countries will be slow to recover from the recent global financial crisis, while non-OECD countries will experience much higher growth rates. Finally, the case assumes that the transportation section continues to rely heavily on conventional liquid fuels.

[12] Since this model already controls for national income through the GDP term, the coefficient on oil production represents the incremental effect of the *composition* of income, between oil revenues and other sources.

[13] The IEO defines conventional liquids as crude oil and lease condensate, natural gas plant liquids, and refinery gain. (http://www.eia.gov/oiaf/aeo/tablebrowser/#release=IEO2011&subject=0-IEO2011&table=39-IEO2011&region=0-0&cases=Reference-0504a_1630)

The IEO compares its projections to an alternative set that are published in the International Energy Agency's *World Energy Outlook*. There are significant differences between the two sets of energy market projections when it comes to nuclear and renewable energy, but both sets of projections have similar predictions for the production of liquid fuels, the economic variable addressed in our models.

Table 6 reports the projected annual production of conventional liquids for Brazil and the entire world through 2020. Brazil's production of conventional liquids is projected to increase from 2.3 million barrels per day in 2011 to 3.5 million barrels in 2020, a 52 percent increase. The growth of production in Brazil is projected to exceed the growth of production in the rest of the world, resulting in an increase in Brazil's share from 2.78 percent in 2011 to 3.90 percent in 2020.

Figures 1, 2, 3, 4, and 5 report our estimates of the changes in international trade flows that will result from the projected increase in Brazilian crude oil production. Like the IEO energy projections, these trade effects are not complete forecasts of the value of trade flows: they do not incorporate predictions about all of the economic factors that affect the market equilibrium. They are projections that isolate the incremental effect of the projected increase in volume of domestic crude oil production. They translate the IEO projections into their impact on international trade between Brazil and the United States for the different categories of traded products. The underlying calculations combine the projections in Table 6 with the estimated coefficients on crude oil production in Tables 1, 2, 3, 4 and 5.

The five figures report the projected *cumulative growth rate* in trade at each year for the negative binomial and OLS estimators, relative to the value of trade in 2011. According to the negative binomial model in Figure 1, the projected increase in oil production in Brazil will result in a 20.3 percent increase in U.S. imports of petroleum products from Brazil (over 2011 trade) by 2015, and a 40.7 percent increase (over the same base year) by 2020. The log-linear OLS model projects a larger effect in each year, with a 40.7 percent increase over the base year by 2020. It is important to keep in mind that U.S. imports of petroleum products from Brazil accounted for less than two percent of total U.S. imports of petroleum products in 2011, so the projected percentage increase in *total* U.S. imports is much smaller. According to the negative binomial model in Figure 2, the projected increase in oil production in Brazil will have a much smaller impact, an 8.3 percent increase in U.S. imports of all other products from Brazil over the base year by 2015, and a 16.6 percent increase by 2020. The effect based on the log-linear OLS model is even smaller than the negative binomial model estimates, a 10.2 percent increase over the base year by 2020.

The models in Figure 3 indicate that the impact on the value of U.S. exports of drilling equipment to Brazil will be relatively large: a 14.3 percent increase over 2011 trade by 2015, and a 28.5 percent increase over the base year by 2020. The log-linear OLS model projects an even larger effect in each year, with a 32.0 percent increase over the base year by 2020. The projected effects on U.S. exports of transportation equipment to Brazil are more moderate. The negative binomial model in Figure 4 indicates that the change in the value of all other U.S. exports to Brazil is a 4.3 percent increase over 2011 trade by 2015, and an 8.6 percent increase over the base year by 2020. Finally, the projected effects on an aggregate of all other U.S. exports to Brazil are small. The negative binomial model in Figure 5 indicates that the change in the value of all other U.S. exports to Brazil is a 3.7 percent increase over 2011 trade by 2015, and a 7.4 percent increase over the base year by 2020.

IV. Conclusions

The EIA and other industry experts project a significant increase in Brazil's crude oil production over the next decade as the recent offshore discoveries are developed. The econometric analysis of our panel of oil-producing countries indicates that each country's domestic oil production generally has a relatively large effect on the country's pattern of trade, especially in products that use liquid fuels or products that are used in oil production. There are smaller indirect effects on trade in other categories of products. The exact magnitudes depend on the modeling assumptions that we adopt. Overall, the models suggest that the increase in oil production in Brazil will likely result in an expansion of trade between Brazil and the United States.

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Table 1: Econometric Models of U.S. Imports of Petroleum Products

Dependent variable: Customs value of U.S. imports of petroleum products

Explanatory Variables	Log-Linear OLS Model	Poisson Model	Negative Binomial Model
Production of Crude Oil	1.0230 (0.0546)*	0.7976 (0.0342)*	0.7795 (0.0332)*
GDP of the Trade Partner	Excluded	Excluded	Excluded
International Distance	-1.6361 (0.1076)*	-0.8371 (0.0337)*	-1.6176 (0.1221)*
Constant	28.7624 (1.0617)*	23.9712 (0.4348)*	30.9654 (1.1300)*
Year Effects, 1996-2009	Included χ^2 = 6.17*	Included χ^2 = 254.59*	Included χ^2 = 166.69*
Number of Observations	723	915	915
R^2 or Pseudo-R^2	0.5260	0.7537	
Estimate of α Parameter			8.2653 (0.5117)

Note: The GDP of the Trade Partner is excluded from this set of preferred models because they are not statistically significant in most of the unrestricted model. An asterisk indicates statistical significance at the 1% level.

Table 2: Econometric Models of U.S. Imports of All Other Products

Dependent variable: Customs value of U.S. imports of all other products

Explanatory Variables	Log-Linear OLS Model	Poisson Model	Negative Binomial Model
Production of Crude Oil	0.1957 (0.0312)*	0.2696 (0.0232)*	0.3189 (0.0212)*
GDP of the Trade Partner	0.9796 (0.0290)*	0.8826 (0.0375)*	0.8778 (0.0270)*
International Distance	-0.7149 (0.0657)*	-0.5780 (0.0358)*	-0.3890 (0.0545)*
Constant	2.1197 (1.0625)	3.4175 (0.1.3091)*	1.6175 (0.9786)*
Year Effects, 1996-2009	Excluded	Excluded	Excluded
Number of Observations	816	915	915
R^2 or Pseudo-R^2	0.6215	0.8393	
Estimate of α Parameter			4.4424 (0.3354)*

Note: The year effects are excluded from this set of preferred models because they are not jointly significant in the unrestricted model. An asterisk indicates statistical significance at the 1% level.

Table 3: Econometric Models of U.S. Drilling Equipment Exports

Dependent variable: FAS value of U.S. drilling equipment exports

Explanatory Variables	Log-Linear OLS Model	Poisson Model	Negative Binomial Model
Production of Crude Oil	0.6124 (0.0326)*	0.4263 (0.0279)*	0.5465 (0.0305)*
GDP of the Trade Partner	0.2977 (0.0326)*	0.1647 (0.0383)*	0.2501 (0.0301)*
International Distance	-1.0306 (0.0589)*	-0.9754 (0.0325)*	-0.8809 (0.0575)*
Constant	13.3500 (1.0960)*	18.3752 (1.0884)*	14.3421 (1.0556)*
Year Effects, 1996-2009	Included F = 6.98*	Included χ^2 = 225.35*	Included χ^2 = 111.94*
Number of Observations	751	915	915
R^2 or Pseudo-R^2	0.5367	0.7688	
Estimate of α Parameter			5.5740 (0.3596)*

Note: An asterisk indicates statistical significance at the 1% level.

Table 4: Econometric Models of U.S. Exports of Transportation Equipment

Dependent variable: FAS value of U.S. exports of transportation equipment

Explanatory Variables	Log-Linear OLS Model	Poisson Model	Negative Binomial Model
Production of Crude Oil	0.1178 (0.0333)*	0.1293 (0.0196)*	0.1646 (0.0258)*
GDP of the Trade Partner	1.0541 (0.0267)*	0.8279 (0.0220)*	0.9196 (0.0374)*
International Distance	-0.6215 (0.0753)*	-0.9521 (0.0247)*	-0.6866 (0.0592)*
Constant	-2.6621 (1.0638)	6.6056 (0.6070)*	1.2095 (1.2764)*
Year Effects, 1996-2009	Excluded	Excluded	Excluded
Number of Observations	803	915	915
R^2 or Pseudo-R^2	0.6262	0.9042	
Estimate of α Parameter			4.1365 (0.3062)*

Note: An asterisk indicates statistical significance at the 1% level.

Table 5: Econometric Models of U.S. Exports of All Other Products

Dependent variable: FAS value of U.S. exports of all other products

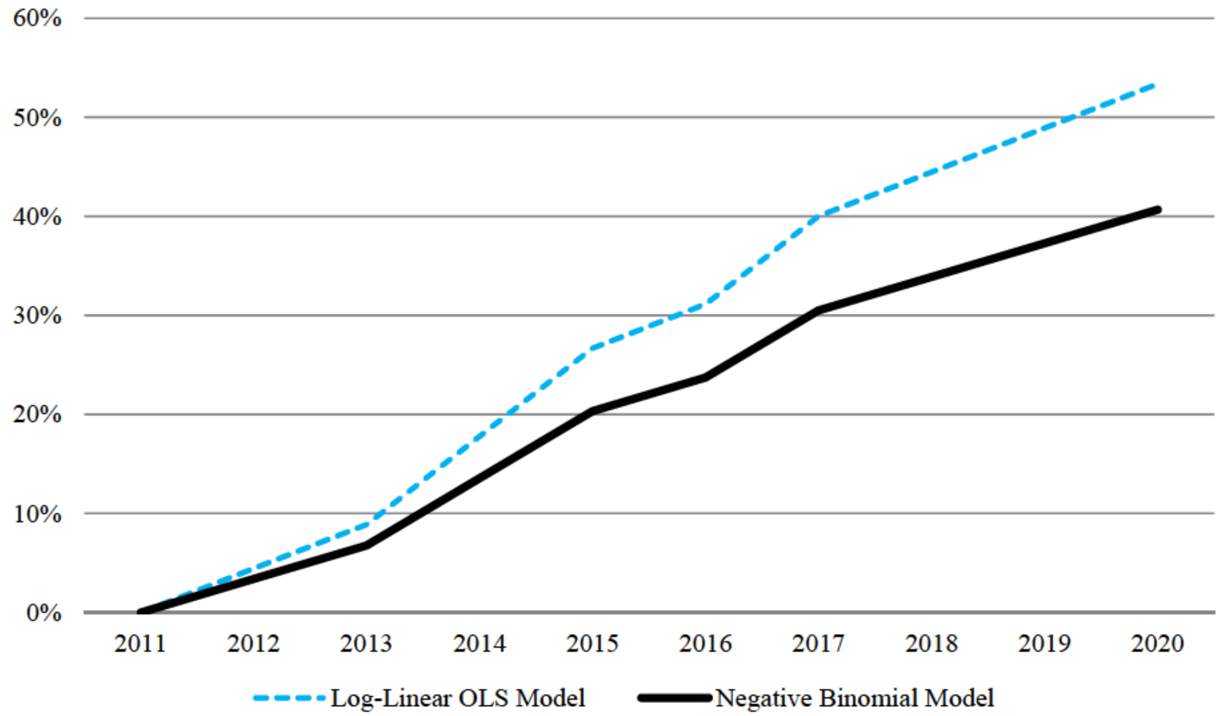
Explanatory Variables	Log-Linear OLS Model	Poisson Model	Negative Binomial Model
Production of Crude Oil	0.0416 (0.0288)	0.1401 (0.0201)*	0.1413 (0.0236)*
GDP of the Trade Partner	0.9928 (0.0197)*	0.8347 (0.0158)*	1.1645 (0.0324)*
International Distance	-0.7872 (0.0604)*	-0.8539 (0.0214)*	-0.4147 (0.0640)*
Constant	2.9879 (0.8470)*	7.5219 (0.4918)*	-5.1531 (1.1989)*
Year Effects, 1996-2009	Excluded	Excluded	Excluded
Number of Observations	821	915	915
R^2 or Pseudo-R^2	0.7024	0.8960	
Estimate of α Parameter			3.5558 (0.2955)*

Note: An asterisk indicates statistical significance at the 1% level.

Table 6: International Energy Outlook 2011 Projection of Oil Production

Year	Brazilian Production (Millions of Barrels per Day)	World Production (Millions of Barrels per Day)	Brazilian Share (Percentage)
2011	2.3	82.6	2.78
2012	2.4	84.7	2.83
2013	2.5	85.5	2.92
2014	2.7	86.4	3.13
2015	2.9	87.2	3.33
2016	3.0	88.1	3.41
2017	3.2	88.7	3.61
2018	3.3	89.2	3.70
2019	3.4	89.6	3.79
2020	3.5	89.8	3.90

Figure 1:
Projected Cumulative Growth in U.S. Imports of Petroleum Products from Brazil



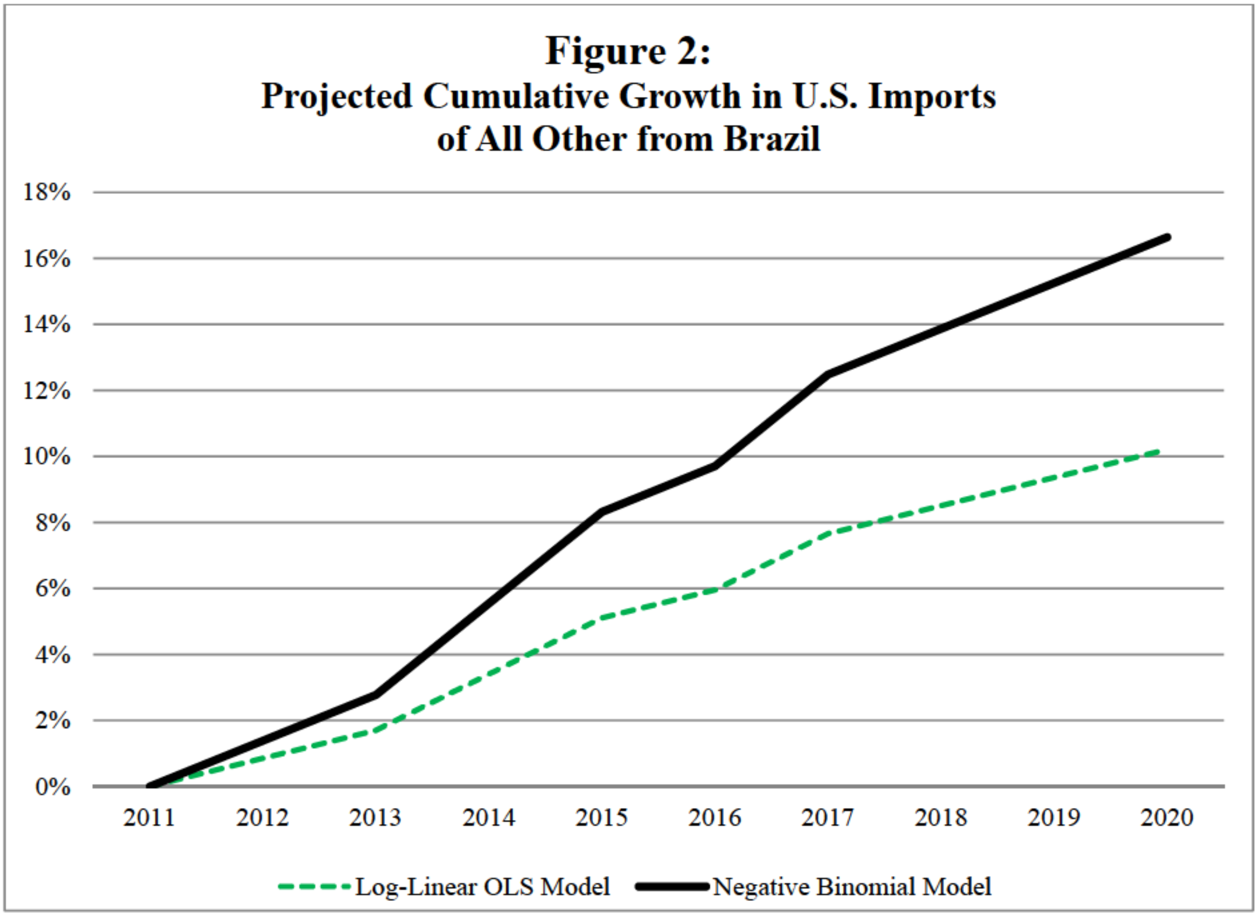
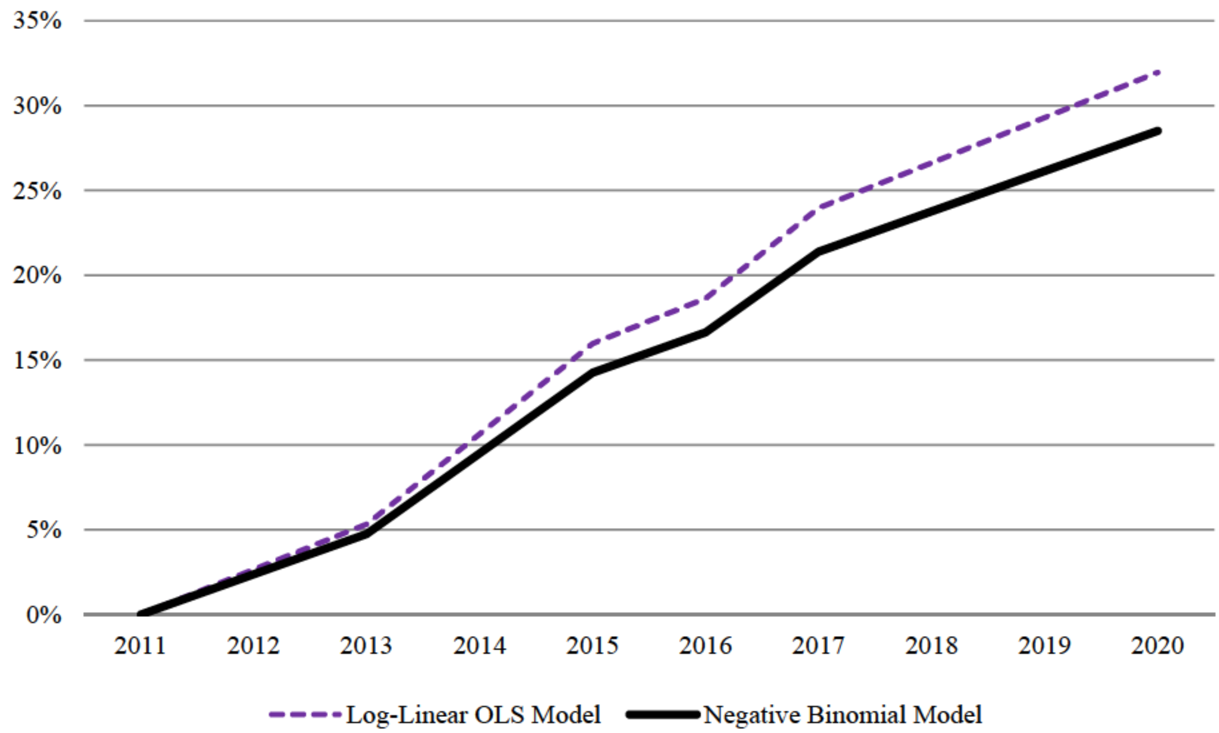


Figure 2:
Projected Cumulative Growth in U.S. Imports
of All Other from Brazil
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Log-Linear OLS Model
Negative Binomial Model

Figure 3:
Projected Cumulative Growth in U.S. Exports of Drilling Equipment toBrazil



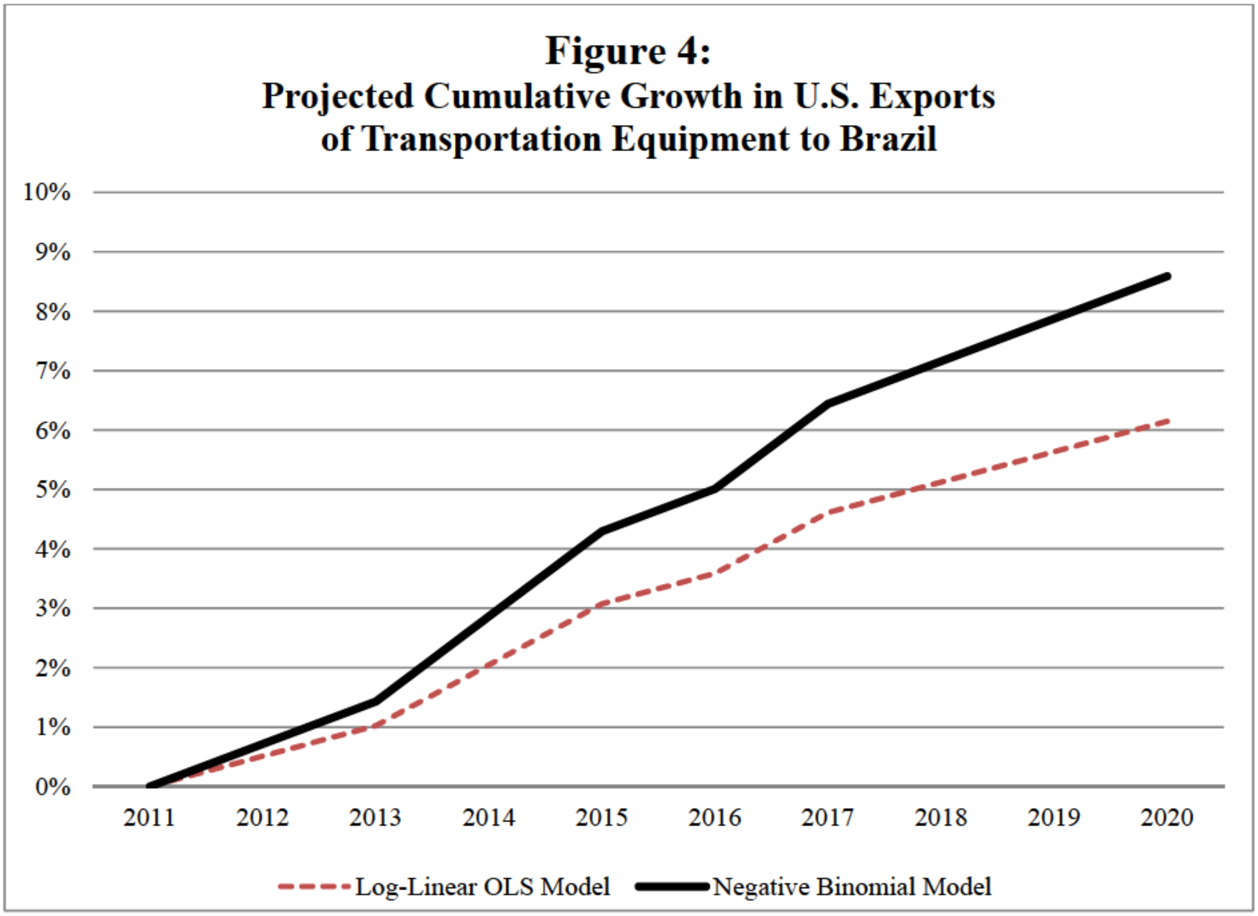


Figure 4:
Projected Cumulative Growth in U.S. Exports
of Transportation Equipment to Brazil
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Log-Linear OLS Model
Negative Binomial Model

Figure 5:
Projected Cumulative Growth in
All Other U.S. Exports to Brazil