Paper to be presented in the XXIII Input Output conference (IIOA)

Mexico DF, 22-25 June 2015

THE COST OF FAILING TO PREVENT GAS SUPPLY INTERRUPTION: A CGE ASSESSMENT FOR PERU

CARLOS A. ROMERO
Instituto de Economía, Universidad Argentina de la Empresa, Buenos Aires, Argentina

OMAR O. CHISARI
Instituto de Economía, Universidad Argentina de la Empresa and Conicet, Buenos Aires, Argentina

LEONARDO J. MASTRONARDI
Instituto de Economía, Universidad Argentina de la Empresa, Buenos Aires, Argentina

ARTURO L. VÁSQUEZ CORDANO
OSINERGMIN, GĔRENS Graduate School, Lima, Perú

Abstract[1]

Since 2000, there has been a noticeable progress in social and economic indicators of Peru. Even though the country risk has diminished dramatically, several threats remain. One of the key ones is the possibility of involuntary (transitory or permanent) interruptions of the natural gas pipeline transportation system. Shortages of natural gas due to pipelines failures can wreak havoc on the Peruvian economy because it is a basic input for domestic manufacturing and household energy consumption, and because it generates important sources of revenues for the government.

Given the significant endowments of natural gas reserves in Peru (Camisea gas field) and the relevance that this fuel has taken in the Peruvian energy matrix and the national economy, it is important to analyze the impact that a transportation constraint on gas flows could have for the domestic consumers, as well as for LNG exports. Earthquakes, unexpected social unrest or intentional actions could interrupt the service of some of the fundamental pipelines of the grid, generating adverse impacts on the stability of the Peruvian economy.

One pipeline with three branches connects the upstream to the distribution centers. To have a quantitative appraisal of the cost of disruption we built a CGE model for Peru, containing 26 sectors, two households (Rich and poor), a government and the rest of the world.

To take into account the economy wide impact of the interruption of gas supply, it is necessary to construct a model that gives the economic value of the infrastructure considering modifications of relative prices, markets reactions and income effects. This assessment can be also used to evaluate projects of protection and adaptation of the infrastructure. We simulate different scenarios considering the three most important branches of the Camisea pipeline. The results show that those shocks would represent an important decline of GDP in the short run when substitution is limited (about 75% in annual terms or 0.2% by day) and an abrupt reduction of welfare for households. The estimated daily cost is in the range of 335 million of US dollars for the worst case scenario.

---

[1] We thank CONCYTEC (National Council of Science, Technology and Innovation of Peru) for allowing access to its bibliography database. The expressed opinions and conclusions correspond to the authors and do not necessarily express the official position of the institutions to which they are affiliated.

1 INTRODUCTION

Since 2000, there has been a significant progress in social and economic indicators of Peru. This improvement was fostered by favorable terms of trade and sound economic policies, including a market-friendly orientation and exports promotion. Even though the country risk has diminished dramatically, several threats remain. One of the key ones is the possibility of involuntary (transitory or permanent) interruptions of the gas pipeline transportation system. Shortages of natural gas due to pipelines failures can wreak havoc on the Peruvian economy because it is a basic input for domestic manufacturing and household energy consumption, and because it generates important sources of revenues for the government.

Given the significant discoveries of natural gas deposits in Peru and the relevance that they have taken in the energy matrix and the national economy (Dammert and Molinelli, 2006; Dammert, García and Vásquez, 2006), it is important to analyze the impacts that a transportation constraint on gas flows could have for the domestic consumers, as well as for liquefied natural gas (LNG) exports (an important source of revenues and foreign currencies for the Peruvian government). Since 2004, primary liquid and dry gas has been supplied by the Camisea gas field to domestic users and to the export market. Camisea represented a 97% of total gas production and 93% of the total gas reserves in 2013 (Tamayo, Salvador, Vásquez y García, 2014)

Earthquakes, unexpected social unrest or intentional actions[2,3] could interrupt the service of some of the fundamental pipelines of the grid. Some statistics illustrate that possibility: between 2004 and 2014 the regions in which those pipelines operate experienced 40 seismic movements, of which 14 had a register higher than 6.5 points in the Richter scale and resulted in more than 700 casualties.

Vásquez (2012) and Vásquez et al. (2013) analyzed the criteria for assessing and regulating safety measures in the oil and gas industry to prevent disasters and minimize accidental pollution. They described the institutional regulatory mechanisms which govern the monitoring of safety standards in Peru. Beyond these mentions of the risks related to potential disasters, we have not found cost estimates associated with them in Peru.

Even if disasters are low probability events and if precautionary measures are taken in countries where these events are frequent, the costs may be substantially high. In a global study, Barro (2009) estimated that the impact on GDP is about 15 times greater than the effect of economic fluctuations[4].

The estimation of the economic impact of disasters (natural or man-made) has not been anexplored area of study yet (Cavallo *et al*., 2010) and most models address the problem with a macroeconomic perspective. Less effort has been applied to the estimate of sectoral impacts and on

---

[2] Valuation report on taxonomy of risks affecting Transportadora de Gas del Perú S.A. (December 27, 2013).

[3] "Plan de Contingencias del Proyecto de Exportación de GNL Pampa Melchorita" (Inspectra S.A. July 2003).

[4] The study contains 60 catastrophes in 35 countries during 100 years.

relative prices. In fact, in addition to the macroeconomic perspective[5], there is another scope of research that focuses on the regional and sectoral impacts. The input-output analysis (IO), models based on social accounting matrices (SAM) and the computable general equilibrium (CGE) approach give instruments for complementary assessments and are the methods used in studies as those of Okuyama (2007) and Okuyama and Santos (2014). Some of those studies have a global perspective. Horridge, Madden and Wittwer (2005) analyzed with a CGE model the economic impact of the floods in Australia. Xie *et al*. (2013) evaluated the costs of rebuilding after an earthquake with a dynamic CGE model of the Sichuan province in China. Through a SAM-based model, Okuyama and Sahin (2009) estimated the overall impact of 184 disasters between 1960 and 2007.

Thus, to take into account the economy wide impact of the interruption of gas supply in Peru, it is appropriate to construct a model that estimates the economic value of the infrastructure considering modifications of relative prices, markets reactions and income effects. This assessment can be also used to evaluate projects of protection and adaptation of the infrastructure.

The effects of disasters on capital infrastructure often have significant indirect effects and temporal persistence of the initial impact. Therefore, an important subset of this literature, specifically measures the effect of disruptions to infrastructure services. For example, Zhang and Peeta (2011) used a CGE model to analyze the interdependence of transport infrastructure, energy and communications. Furthermore, by IO analysis, Rose and Wei (2013) estimated the economic losses of a port shutdown. Furthermore, empirical literature have addressed the effect of interruptions in energy infrastructure services (e.g., Rose and Guha, 2004; Rose, Oladosu and Liao, 2007, Greenberg et al., 2007).

Three pipeline branches connect the gas upstream sector to the distribution centers in Peru. To have a quantitative appraisal of the cost of disruption, we built a CGE model which contains 26 sectors, two households (rich and poor), a government and the rest of the world. The energy supply is represented in the model by twelve sectors: extractive activities (oil, natural gas liquids –NGL-, and dry natural gas), refining oil, NGL processing (fractionation), biofuels (diesel and ethanol), electricity generation, as well as transmission and distribution of electricity and gas. The model was

---

[5] Research on the impact of natural or man-made disasters is in its infancy with very few articles examining any aspect of the disaster phenomena. Some of the few studies available that are worth noting are Albala-Bertrand (1993), Horwich (2000), Selcuk and Yeldan (2001), Benson and Clay (2004), Halliday (2006), Coffman and Noy (2009), as well as Noy and Bang Vu (2010). Two recent studies on the subject are Lazzaroni and van Bergeijk (2014), Klomp and Valckx (2014) as well as Felbermayr and Gröschl (2014). The first provides a meta-analysis of 64 primary studies published between 2000 and 2013 on the macroeconomic impact of natural disasters. It found that disasters on average have a negative impact in terms of direct costs and an insignificant impact in terms of indirect costs. The second performs a meta-regression analysis of previous studies (using more than 750 estimates) to examine the relationship between economic growth per capita and natural disasters, finding that there is a negative genuine effect of natural disasters on economic growth over the period 1970 and 2011. Another finding of this study is that climatic disasters in developing countries have the most significant adverse impacts on economic growth. The third elaborated a comprehensive database from 1979 and 2010 of disaster events and their intensities from primary geophysical and meteorological information to perform meta-regression analysis in order to assess the relationship between GDP per capita and the occurrence of disasters. It showed pervasive evidence that natural disasters do indeed lower GDP per capita temporarily.

developed under request and collaboration with OSINERGMIN (the Peruvian energy and mining regulator)[6].

The paper is organized as follows. In Section 2, we present the methods used to compute the SAM for Peru, the inclusion of the natural gas industry in the model and the construction of the CGE model. In Section 3 we summarize the basic results from disaster analysis simulations and a sensitivity analysis for the worst-case scenario. Finally, in Section 4 we conclude with the main lessons based on the results of the model.

2 CGE MODEL FOR PERU FOCUSED ON ENERGY SECTORS

The basic data for the CGE model are obtained from the social accounting matrix (SAM). Most of the information contained in the SAM comes from the national accounts, government budgets, international trade database, household surveys, and the latest available input-output matrix. However, this information is usually found at low sectoral disaggregation levels. Therefore, we have conducted an exhaustive compilation of sectoral information in order to obtain the necessary data to disaggregate energy sectors in the SAM. In this section we summarize the most critical aspects of the collection and processing of data.

2.1 SAM: Data and methodology

Data for the CGE model are obtained from a SAM that was built to represent the year 2010. The model includes 26 production sectors: 7 primary sectors (agriculture and mining), 2 industries, 12 energy-related sectors (primary, secondary and transmission and distribution sectors) and 5 service industries. The energy sectors include the following activities: oil extraction, extraction of natural gas liquids (NGL), extraction of natural gas (dry gas), refining oil, NGL processing (fractionation), biodiesel, bioethanol; generation, transmission and distribution of electricity, as well as transportation and distribution of gas.

The aggregate supply, demand and added value (AV) of each sector were obtained from the Instituto Nacional de Estadística e Informática of Peru (INEI). Production Values (PV) of each sector were calculated keeping constant the ratio (AV/PV) of the Input Output Tables (IOT) from 2007. The production factors are labor and capital and their values were obtained by the sectoral distribution arising from the IOT. The sectoral distribution of final demand (consumption, investment and exports) was estimated using data from INEI and IOT 2007.

Table 1 shows sectoral ratios in terms of Gross Domestic product at basic prices (GDP bp) and factor intensities from labor and capital (L and K). The first column presents the sectors from the SAM.

---

[6] The development was funded by OSINERGMIN through the research projects: “Elaboración de un modelo de equilibrio general computable,” Contrato AMC Nº 014-2011, and “Adecuación de la matriz de insumo-producto del MEGC,” Contrato ADS Nº 034-2013.

We could also observe that the participation of gas transportation and distribution is small. However, for the purposes to simulate a disaster scenario in the gas infrastructure system is crucial to take into account this disaggregation for the gas transportation sector, since it has an essential role of domestic and international sales of gas[7].

Table 1: Peru, 2010. Structure of added value and factors intensities (%).

Nº	Sectors	Millions of Nuevos soles			Factor intensity	
		L	K	GDP bp	L	K
1	Agriculture and livestock	4 524	20 571	25 095	18.0%	82.0%
2	Forestry	309	882	1 191	25.9%	74.1%
3	Fishing	833	2 089	2 923	28.5%	71.5%
4	Extraction of oil	384	4 491	4 874	7.9%	92.1%
5	Natural gas liquids (NGL)	248	2 905	3 154	7.9%	92.1%
6	Dry Natural gas	82	963	1 045	7.9%	92.1%
7	Copper	2 438	13 240	15 678	15.6%	84.4%
8	Gold	2 848	9 444	12 291	23.2%	76.8%
9	Rest of metal mining	4 632	13 947	18 579	24.9%	75.1%
10	Non-metallic mining	198	919	1 117	17.7%	82.3%
11	Oil refining	416	1 667	2 084	20.0%	80.0%
12	NGL processing	150	599	749	20.0%	80.0%
13	Biodiesel	2	44	46	4.2%	95.8%
14	Bioethanol	6	125	132	4.9%	95.1%
15	Intensive industry energy use	5 158	16 661	21 820	23.6%	76.4%
16	Rest of industry	14 029	28 287	42 316	33.2%	66.8%
17	Electricity generation	291	2 049	2 340	12.4%	87.6%
18	Electricity transmission	96	503	599	16.1%	83.9%
19	Electricity distribution	350	1 369	1 719	20.3%	79.7%
20	Gas transportation	5	309	314	1.7%	98.3%
21	Gas distribution	33	63	96	34.0%	66.0%
22	Construction	13 290	19 275	32 564	40.8%	59.2%
23	Trade, Restaurants and Hotels	18 020	44 239	62 259	28.9%	71.1%
24	Transport (paved roads, railroads)	5 168	16 505	21 673	23.8%	76.2%
25	Communication	3 171	6 965	10 136	31.3%	68.7%
26	Other services	59 778	61 042	120 821	49.5%	50.5%
	Total	**136 460**	**269 155**	**405 615**	**33.6%**	**66.4%**

Source: INEI, Own elaboration

2.2 The inclusion of Natural Gas Industry in the SAM

The SAM constructed separates dry natural gas (Sector 6) from natural gas liquids (NGL - Sector 5) to model the various uses that these energy products have. Also, we disaggregated oil refining (Sector 11) and NGL processing (fractionation -Sector 12). This is done with the aim of capturing the separate effects from the different sectors supplying primary energies on the processing of final energy products. The NGL fractionation products are natural gas and liquefied petroleum gas (LPG) destined to transportation and residential consumption. The products from oil

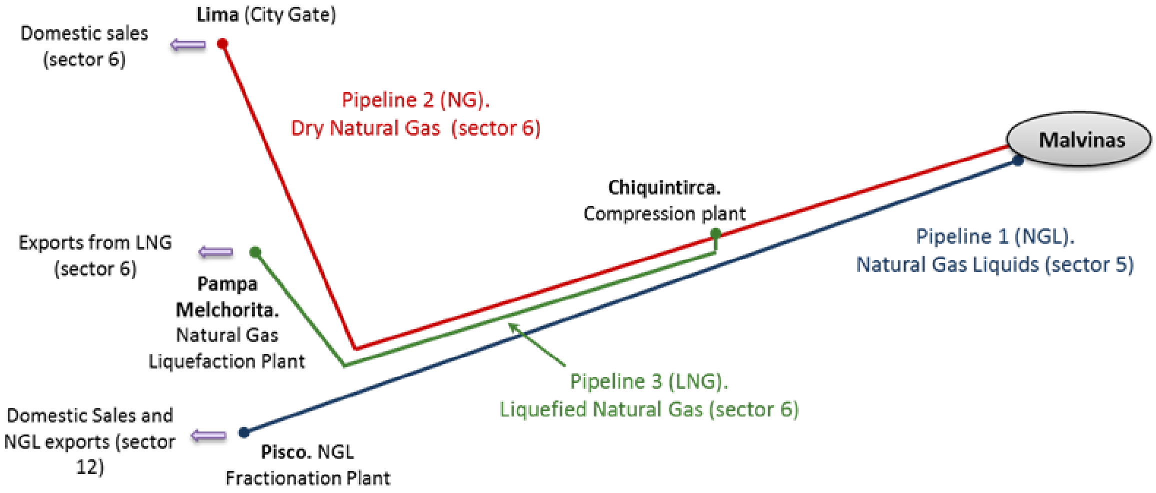
---

[7] For a detailed description of the procedures and data sources used to build the SAM, see Vásquez et al. (2015).

refining are gasoline, diesel and fuel oil which are demanded by the transportation sector, households, the manufacturing industry and the power generation sector.

Figure 1 shows the principal pipeline branches that transport natural gas from Camisea (Malvinas) to the transformation plants and final destinations.

Figure 1: Scheme of main natural gas pipeline branches in Peru



Source: Tamayo et al. (2014), own elaboration

Production of natural gas at Camisea is in charge of Pluspetrol Consortium. The totality of the extracted gas is treated in the liquids separation plant at Malvinas in the region of Cusco where natural gas liquids are separated from dry gas. The pipeline transportation system composed of pipeline branches 1 and 2 is in charge of Transportadora de Gas del Peru (TGP).

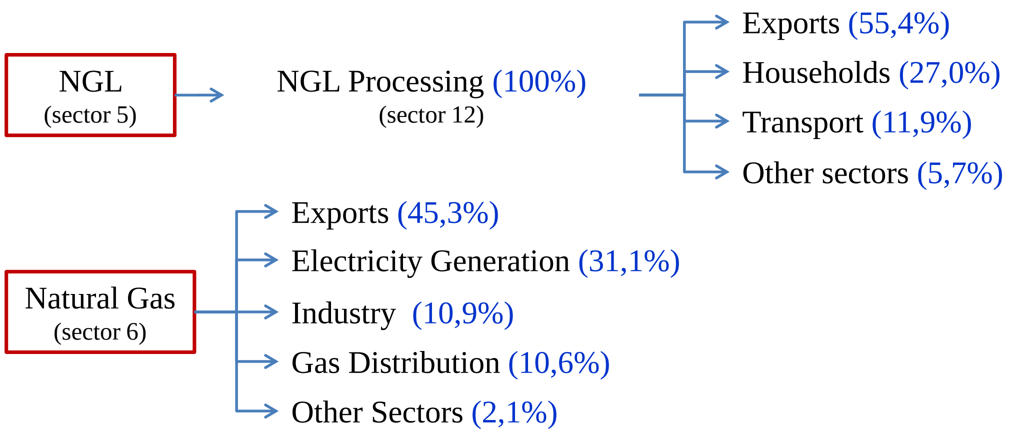
Natural gas liquids (NGL) are transported to Pisco (Pipeline 1). In Pisco, the NGL fractionation plant produces gas derivatives that are then sold to both domestic and export markets. This activity is considered a refining process. Therefore, Sector 5 only sells NGL to sector 12 (NGL processing) and after the fractionation this sector sells to the intermediate and final demand the final products of NGL processing.

The dry gas is transported to Lima (Pipeline 2), where natural gas is sold to the domestic market. The gas for export (liquefied natural gas – LNG) uses Pipeline 3, after passing through the compression facility at Chiquintirca. Then, the gas is transported to the LNG plant at Pampa Melchorita. Pipeline 3 and liquefaction are led by Peru LNG.

The pipeline transportation network is an essential input for the gas industry. The mechanism of transmission of potential failures or disasters on the networks goes through the sales structures of the sectors of extraction and fractionation of natural gas (see Figure 2). The magnification of the impact will depend on the elasticity of substitution of the gas production functions from the purchasing sectors.

In 2010, the total value of production (VP) of Dry Natural Gas (sector 6) was estimated in s/. 1.676 billion. Of this amount, 45,3% corresponds to LNG exports (see figure 2) and the rest to domestic sales. The VP of Gas Natural Liquids (sector 5 –GNL) was s/5.059 billion The value of production of NGL processing (sector 12) was obtained from production data and import prices from the Peruvian Ministry of Energy and Mines (MINEM), ascending to s/. 7.136 billion.[8]

Figure 2: Sales structure for extractive and fractionating gas sectors



Source: Own Elaboration

Figure 2 shows that the natural gas liquids (NGL) are only sold to NGL processing (sector 12) as intermediate inputs. The final products from fractionating sector are natural gasoline and LPG. Demand for this liquids come from the export market (55%), household consumption (27%) and the domestic transportation sector (12%).

The distribution of natural gas is more complex. It is distributed between the purchasing from the gas distribution company (Calidda) and large industrial users.

Regarding the dry natural gas demand (Sector 6), Figure 2 shows that the most relevant consumer was the export market (45%). Gas exports correspond to LNG. The domestic consumers are led by electric generation (31%), followed by industry and purchases from the distribution company. Both cases are near 11% from total sales of Sector 6.

---

[8] In 2010, Camisea sales accounted for 91.6% of total gas sales. For a detailed description of the inclusion of energy sectors see Romero et al. (2013).

2.3 CGE characteristics in the Peruvian model[9]

The agents of the model are two representative households (rich and poor) and 26 production sectors, a consolidated public sector and the rest of the world. Each production sector produces one good, using intermediate inputs and factors of production. The model is flexible to address different elasticities of substitution and parameters of production (e.g. coefficients of production and efficiency levels), as well as different degrees of factor mobility. Regarding factor endowments, capital is fully employed, while the labor admits unemployment. The basic simulations assume that a labor is perfectly mobile between production sectors, but only a certain proportion of capital is mobile. We assume that 9% of the total capital is mobile across sector. This parameter was calibrated to replicate the ex-post growth observed for Peru (in a recursive dynamic model). Our CGE model has all basic properties from the Walrasian perspective, and it is numerically solved using GAMS/MPSGE[10]. Subsequent modifications in relative prices and the response of activity levels due to said elasticities of substitution and mobility of resources can explain why certain industries and technologies expand or contract.

Except for wages (since there is a disequilibrium in the labor market for the benchmark year 2010), prices are computed to simultaneously clear all markets. For an extended algebraic presentation of the model see OSINERGMIN (2015) and Chisari *et al*. (2010).

On the supply side, the production function in each sector is a Leontief function between value added and intermediate inputs. The intermediate inputs function is also a Leontief function of all goods, which are strict complements in production. Instead, value added is a Cobb-Douglas function of factors of production (labor, capital specific to the sector and mobile capital –non specific- between sectors from Peru).

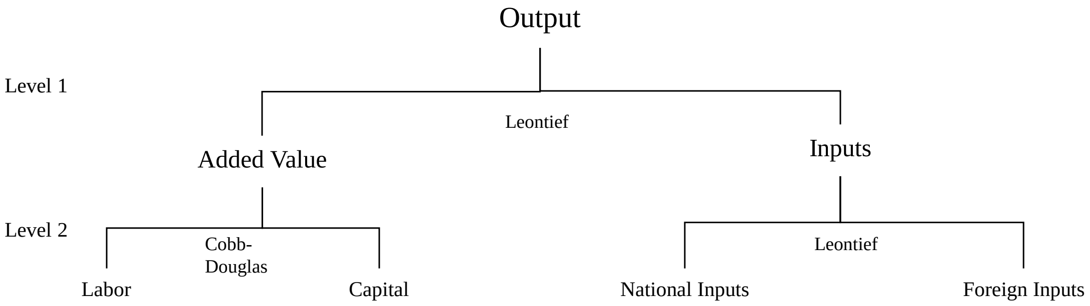
Thus, output *x* is produced with intermediate consumption and added value. Intermediate consumption is represented as a nested Leontief production function. At the intermediate level, goods and services are complementary and the elasticity of substitution between them is zero. The basic simulations assume that value added is represented as a Cobb-Douglas function. The coefficients associated for each factor are their share of participation in the output. Figure 3 shows the structure of production.

---

[9] Another CGE model of the Peruvian economy has been elaborated by Vásquez and Balistreri (2010) using the GTAP Database ver. 6 reported by Rutherford (2005). The objective of this effort was to calculate the marginal cost of public funds of mineral and energy taxes in Peru. Our CGE model differs from Vásquez and Balistreri's because our model offers a precise description of the natural resource, mining and energy sectors of the Peruvian economy, which allow us perform specific policy analysis on the extractive industries and the energy transportation system, which is of interest for this paper.

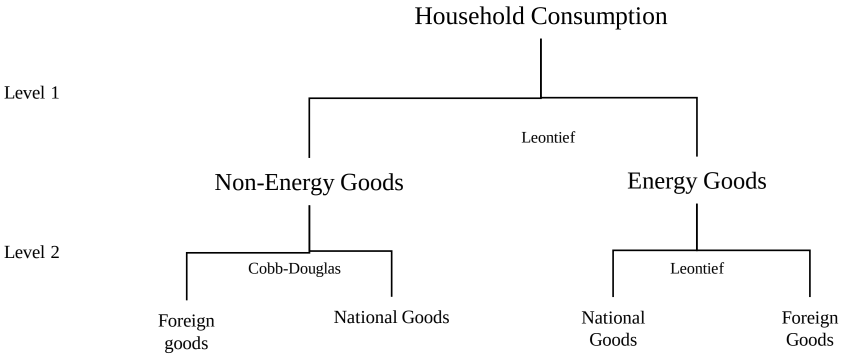
[10] The solution of the model is obtained using the representation of General Equilibrium and using the Mixed Complementarity Approach –see Ferris and Pang (1997) for a survey of the mathematical method and Böhringer and Rutherford (2008) for a recent description on the usefulness to model energy sectors in CGE. The model is developed in the environment of GAMS/MPSGE (see Rutherford, 1999). At present, it can be used in interface with GAMS (see Brook *et al*,1992).

Figure 3: Structure of production



The demand side is modeled with two representative households, a national consolidated government and an external sector. Households have Cobb-Douglas utility functions for the basic simulations, and they buy or sell common goods and investment goods. The choice of the optimal proportion of the consumption good is obtained from a nested production function into the utility function, through a process of cost minimization. Households decisions on the composition of their basket of consumption are represented in a similar way to the production structure (see Figure 4). On the second level, we adopted a nested utility function with an elasticity of substitution equal to 0 (Leontief function) between energy goods and non-energy goods. In a second level, we adopted a Cobb Douglas function (with a elasticity of substitution equal to 1) for all energy goods (national and foreign).

Figure 4: Structure of utility function



The government is represented as an agent that participates in the market economy for investing, consuming and making transfers to households. It exhibits a Cobb-Douglas utility function; its main source of income is tax collections (though it also makes financial transactions through the bonds account).

The external sector buys domestic exports and sells imports to the country, and collects dividends from investments. It also makes transactions of bonds. This implies, following the closure rule, that there is not trade balance and there are financial compensatory movements of capitals. Though it could be interesting to analyze the results under trade balance, the National Accounts of Peru showed that the country was still taking debt at the benchmark year; so the model was calibrated considering that scenario. This implies that when trade balance is positive, the surplus is used to repay debt; instead, when the trade balance is negative, the country delays the repayment of debt.

The modeling of unemployment is quite important for the case of Peru. The assumption of full-employment could modify the evaluation of benefits of trade liberalization (see Diao et al. 2005). For instance, in full-employment models, an increase demand for labor (due to increased domestic activity and exports) leads to higher real wages, for the origin of comparative advantage is progressively eroded. However, in models with unemployment, real wages are constant and exports increase is higher.

To represent unemployment in a Walrasian general equilibrium model is necessary to specify a rule of determination of wages. For this paper, we take the assumption of downward inflexibility of real wages. The wage is adjusted by CPI index to close the labor market.

3 RESULTS FROM SIMULATIONS

Given the significant discoveries of natural gas deposits in Peru in the area of Camisea and the relevance that they have taken in the Peruvian energy matrix and the national economy, it is relevant to analyze the impact that a transportation constraint on gas flows could have for the domestic users as well as for gas exports. Earthquakes, unexpected social unrest or intentional actions could interrupt the service of some of the fundamental pipelines of the grid. In general, disasters can generate significant costs to the economy if they exhibit the duration of the interruption of gas flows is long. Beyond the virulence of the disaster itself, the final impact on the economy depends on the production chains and the level of household consumption.

The paper simulates disaster scenarios related with blocks 56 and 88 in the Camisea region. They represent the 91.6% of total gas production of Peru in 2010. As we mentioned before, these blocks supply three principal gas pipeline branches:

- Pipeline 1 (NGL): Malvinas – Pisco.
- Pipeline 2 (Natural Gas): Malvinas – City Gate (Lima)
- Pipeline 3 (LNG): Chiquintirca – Pampa Melchorita.

Simulations consider interruptions in the mentioned pipelines taking into account the backward and forward linkages in the Peruvian economy. The effects are related to the results from the CGE model that was described in the previous section. A loss of efficiency is represented as an increase in the necessary quantity of inputs per unit of output. Five scenarios are simulated:

- Pipeline 1 Interruption (P1I): Service interruption in Pipeline 1 (which supplies the natural gas fractionation plant in Pisco). Constraint on domestic sales (intermediate and final demand) on the NGL sector (Sector 5).

- Pipeline 2 Interruption (P2I): Service outage in Pipeline 2 (which supplies the City Gate in Lima) between Malvinas and Lima. Constraint on domestic sales (intermediate and final demand) on the extraction of dry natural gas sector (Sector 6).
- Pipeline 1 Exports Interruption (P1XI): Interruption of Natural Gas Fractionation exports (Sector 12).
- Pipeline 2 Exports Interruption (P2XI): Service outage in Pipeline 3 (arm of pipeline 2 between Chiquintirca and Pampa Melchorita which supplies LNG exports). Equivalent to a constraint of zero exports from the Dry Natural Gas sector (Sector 6).

Table 2 shows the *annual* results for the simulations of the model in percent deviations from the initial benchmark (based on the 2010 SAM described above). We present the main indicators of economic activity of the Peruvian economy: the variation of GDP (at market prices), the variation in the welfare of households and government (measured by the equivalent variation) and the variation in the activity level of energy sectors.

Table 2: Results from simulations based on CGE model
(% annual deviation from the initial benchmark, year 2010)

Indicators	**P1I**	**P2I**	**P1XI**	**P2XI**
GDP	-65.76	-75.81	-0.89	-0.23
Welfare of agents				
Poor household	-75.13	-75.56	-0.42	-0.41
Rich household	-72.86	-77.72	-0.31	-0.36
Government welfare	-29.53	-53.03	-0.42	0.36
Activity level of energy sectors				
4- Oil Extraction	-83.42	-87.37	0.40	0.00
5- Natural Gas Liquids	-91.67	-92.09	-60.30	0.00
6- Dry Natural Gas	-87.98	-91.67	0.00	-45.31
11- Oil refining	-79.45	-83.90	0.73	-0.04
12- NGL processing	-90.75	-91.12	-55.58	-0.04
17- Electricity generation	-79.79	-84.90	0.12	-0.16
18- Electricity transmission	-81.25	-87.17	0.21	-0.10
19- Electricity distribution	-77.86	-81.23	-0.05	-0.29
20- Gas transport	-78.50	-84.74	0.21	-0.12
21- Gas distribution	-75.74	-80.67	-0.05	-0.22

Source: Own elaboration.

Note that the simulation assumes that the gas interruption covers a whole year, and that the economy fails to find substitutes for the resource. Taking a hypothesis of short-term interruptions (with the elasticities used in the CGE model), we present in Table 3 a possible hypothetical scenario that models the cost of the disaster depending on its duration (within a day, a week, a month or a quarter). A linear cost hypothesis assumed, which implies the proportional distribution of annual effect throughout the period.

We have not found in the literature information regarding the shape of the temporary cost curve due to disaster for Peru. So, the results can be seen as a lower bound of social cost, to get an idea of the willingness to pay for prevention that should be taken into account. It should be expected that initial costs should be higher and then decline with time since the economy could adapt post disaster via substitution for example

Table 3: Social value of simulated disasters in millions of US dollars

Interruption duration	**P1I**	**P2I**	**P1XI**	**P2XI**
1 day	-290	-335	-3.9	-1.0
1 week	-2031	-2342	-27.5	-7.1
1 month	-8706	-10035	-117.7	-30.4
3 months	-26117	-30106	-353.1	-91.3

Source: Own elaboration.

First, we simulate a disruption of Pipeline 1 between Malvinas and Pisco (P1I) in the upstream (which supplies the NGL fractionation plant in Pisco) generates an important decline on the NGL sector and their forward linkage sector (NGL fractionation). This sector will suspend exports and will only supply the domestic market. The spillover effect on the economy will be smaller than the fall of Pipeline 2 (economy falls 65%) and the transmission mechanism will have a strong direct impact on the transport sector due of its numerous forward linkages to the rest of Peruvian sectors. The estimated daily social cost for this kind of interruption is close to US$ 290 million by day.

Disruption of Pipeline 2 (P2I) that supplies Lima City Gate causes a sharp drop in dry gas sector (gas extraction) in terms of value added. The shock stops exports of LNG; thus those gas exports will be diverted to the domestic market. The effect on the economy (GDP falls 75%) is observed with a sharp contraction of related sectors, mainly downstream sectors such as electricity and gas intensive industries. The social cost of this event is around U$ 335 million per day.

Finally, we simulate an outage on exports pipelines. Disruption of NGL exports (simulation (P1XI) causes a fall about 0.9% in the economy and the outage in the exports of LNG (simulation P2XI) generates a relatively small effect on the Peruvian economy (GDP falls 0.23). The social cost to suspend these exports is relatively low, between U$ 1 and 4 million per day.

In terms of income distribution, except for the interruption of Pipeline 2 (P2I), poorer households are more affected than wealthy households. The determinants of these results are the high observed unemployment and impossibility of substitution of energy goods. The government in all simulations increases its fiscal deficit as a part of endogenous countercyclical policies that are determined within the model.

We have also computed a total interruption scenario (TI) which combines simulations P1I and P2I. The results are shown in Table 4 below; the figures are quite the same because simulation P2I dominates the rest and its results are similar to those of TI scenario. The results are also presented in the next subsection with a sensitivity analysis of the results.

These scenarios only consider productive effects of the disaster, but do not contain probable environmental effects. Vásquez et al. (2013) lists various scenarios of environmental disaster to cause disruption of pipelines such as gas leakages.

3.1 Sensitivity analysis: Possibility of technology substitution

The main result of the previous section is that the outage in the three pipelines (TI) generates the most important effect on the economy. As mentioned above, those results were obtained assuming that during the period of one year there is no possibility of replacing such technologies to produce and transport energy. Given that it is likely that upon the occurrence of disasters (as the simulated before) the production system of the country in an emergency could change to adapt to the new environment, we propose some alternatives considered "plausible" or "probable" to occur in order to see how sensitive are the proposed scenarios before this hypothesis.

In order to perform a sensitivity analysis, we combine three substitution possibilities in the Peruvian productive structure (changing level 2 in Figure 3), and it will be considered in the TI simulation in order to compare the results:

- Total Interruption (TI): Outage in pipelines 1, 2 and 3. This scenario is the result of combining simulations P1I and P2I.
- Substitution with NGL imports (NGLimp): This scenario allows high substitution in intermediate and final consumption between national NGL fractionation (Sector 12) and imports of NGL fractionation from the rest of the world.
- Substitution in the electricity generation sector (EGen): This scenario consists of modifying the Leontief technology in electricity generation to allow the substitution of the scarce input (dry natural gas extraction from Sector 6) with oil refining (Sector 11).
- Possibility of combined cycle in transport vehicles (CCT): This scenario allows the transport activity to substitute between the purchases of oil refined (Sector 11), NGL fractionation (Sector 12) and gas transportation (Sector 20).
- Combinated effects (CE): We combine the three scenarios in a combined one (NGLimp+EGen+CCT).

The Armington elasticity of substitution in the NGLimp case used in the nesting of the sectors is 20. This was established as a consequence that there are no imports of this product in the benchmark. In the cases CCT and Egen, the nesting was built with an elasticity of substitution equal to 1.

Table 4 shows the results of possible scenarios that may follow before shocks like those simulated before, but including now the corresponding sensitivity analysis. As it can be expected, the impacts are weakened by the presence of alternatives of substitution. When the alternatives of substitution in generation of electricity are combined (EGen), the impact is lowered (to -65%, of

GDP) while when transport has the possibility of substituting gas (CCT), the gain (loss reduction) is equivalent to 7 points of GDP.

It can also be observed that if substitution were possible in all cases simultaneously (CE), then total savings would be approximately of 66% exceeding the addition of individual savings (when substitution is limited to only one of the products). It is an important result because we observe that the willingness to pay for an alternative technology that combines the substitution scenarios (CE) is bigger than the direct addition of scenarios.

Table 4: Sensivity analysis on the Total Interruption Scenario
(% deviation from the initial benchmark, year 2010)

Indicators	**TI (Base)**	**NGLimp**	**EGen**	**CCT**	**CE**
GDP	-75.81	-75.43	-65.78	-68.72	-27.92
Welfare of agents					
Poor Household	-75.56	-75.44	-75.14	-72.38	-27.91
Rich Household	-77.72	-77.62	-72.86	-74.40	-32.23
Government welfare	-53.03	-53.09	-29.61	-48.96	-17.05
Activity level of energy sectors					
4- Oil Extraction	-87.37	-87.38	-82.87	-7.02	9.16
5- Natural Gas Liquids	-92.09	-97.63	-91.67	-91.67	-91.67
6- Dry Natural Gas	-91.67	-91.67	-91.67	-91.67	-91.67
11- Oil refining	-83.90	-83.90	-78.82	-72.52	5.83
12- NGL processing	-91.12	-97.58	-90.75	-90.56	-90.91
17- Electricity generation	-84.90	-84.88	-79.80	-81.93	-33.70
18- Electricity transmission	-87.17	-87.17	-81.27	-84.46	-35.68
19- Electricity distribution	-81.23	-81.18	-77.87	-77.79	-30.33
20- Gas transport	-84.74	-84.73	-78.53	-84.10	-44.64
21- Gas distribution	-80.67	-80.70	-75.76	-91.98	-75.01

Source: Own elaboration

Additionally, Table 5 shows the social value of the calamity in the scenarios presented above when there is a full interruption of the system (TI). The results should be compared with that simulation to understand the gains obtained when technology substitution is possible. Having the potential capacity of importing fuels for domestic use and possessing alternative technologies for energy consumption (e.g. different modes of transportation) might very well reduce the social costs of a gas interruption. The results should be compared with this simulation to understand how important it can be the substitutability between technologies. The differences could be read too as the willingness to pay (or buy) these technologies. As we can see, the import of new products and the domestic production of these as well as the chance to possess alternative energy generation technologies (for transport for example) can potentially reduce the social costs of gas interruptions.

Table 5: Sensitivity Analysis on the Social Value of Simulated Disaster in millions of US dollars

Interruption duration	TI (base)	NGLimp	EGen	CCT	CE
1 day	-335	-333	-290	-303	-123
1 week	-2342	-2330	-2032	-2123	-862
1 month	-10035	-9985	-8708	-9097	-3696
3 months	-30106	-29956	-26123	-27291	-11087

Source: Own elaboration

On average, it is observed that the scenario which allows NGL imports save about of 1% of the total social costs in the TI scenario. Moreover, the alternative of thermal power plants generating electricity by using oil instead of natural gas can reduce by 13.5% the social costs. A portion of the public and private transportation in Lima has dual technology. If this ratio was risen (increasing the substitution between natural gas and oil), the social costs would be reduced by 10%. Finally, the combination of the three effects together slashes costs by 63%.

4 CONCLUSIONS

Disasters can affect a country's energy infrastructure and generate long interruptions of vital public services. This is especially true for Peru in the case of disruptions in power lines and natural gas pipelines.

However, to date there was not available a quantitative assessment encompassing direct and indirect effects of the social cost for that economy of those interruptions.

Even though interruptions were included in several private projects evaluation, it would be expected that those evaluation focus on sectoral analysis assuming constancy of fundamental macroeconomics indicators and relative prices. However, given the key role of natural gas sector for the Peruvian economy and the absence of substitutes in the short run, it could be expected that the social costs of gas supply interruptions as a consequence of failures in the infrastructure (pipelines, NGL fractionation plants, gas separation plants, etc.) should be higher. This context makes necessary to conduct a social evaluation considering the social costs of failures in the energy infrastructure, considering the change in relative prices and the linkages among sectors in an economy.

The aim of this paper was then to estimate the impact on the Peruvian economy of failures in the gas transportation infrastructure. To achieve this objective, we built a computable general equilibrium model of the Peruvian economy in 2010, with a detailed representation of energy sectors.

The simulations confirm that restrictions on gas pipelines as a consequence of disruptions or disasters have strong effects on the economy, particularly when they affect pipelines that supply gas to domestic users (industries and households). The social costs of interruptions are lower when the affected pipelines supply the gas export industry and other industries that have less intensive backward and forward linkages with the rest of the economy.

Our simulations also provide measures of opportunity cost estimates that may be useful for the evaluation of projects related to energy technology substitution that could help to increase the resilience of the economy. How much should Peru pay for a back-up technology?

We find that the duration of interruptions is relevant for the valuation of disruption impacts. An extreme case considered would be a three-month interruption in the upstream supply of gas in Malvinas, equivalent to a failure near the Malvinas-Pisco and Malvinas-Lima pipelines. It could generate a cost of about 19 points of GDP (about 30 billion US dollars). That means that a failure for seven days would amount to 1.5% of GDP.

These results assume that there are not possibilities for substitution. One obvious alternative would be the possibility of substituting the interrupted service with imports or other products. In the case that no additional investments were required for this substitution, those costs could be reduced to 7% of GDP in three months.

5 REFERENCES

Albala-Bertrand, J. M., 1993. *Political economy of large natural disasters*. Oxford: Clarendon Press.

Benson, C., and E. Clay, 2004. *Understanding the economic and financial impacts of natural disasters*, Disaster Risk Management Series N^o 4.

Barro, R., 2009. “Rare Disasters, Asset Prices, and Welfare Costs,” *American Economic Review,* 99(1): 243-264.

Cavallo, E., S. Galiani, I. Noy and J. Pantano, 2010. “Catastrophic Natural Disasters and Economic Growth,” IDB Working Papers Series IDB-WP-183.

Coffman, M., and I. Noy, 2009. *Hurricane Iniki: Measuring the long-term economic impact of a natural disaster using synthetic control*. University of Hawaii Economics Working Paper 09-05.

Chisari, O., C. Romero and others, 2010. “Un modelo de equilibrio general computable para la Argentina 2006”. Serie de Textos de Discusión N° 63, Instituto de Economía, FACE- UADE.

Dammert, A. and F. Molinelli, 2006. “¿Qué significa el Proyecto Camisea?” Documento de Trabajo N^o 23, Oficina de Estudios Económicos, OSINERGMIN.

Dammert, A., R. García and A. Vásquez, 2006. “Los efectos económicos del proyecto Camisea en el Perú, 2005-2014,” Documento de Trabajo N^o 14, Oficina de Estudios Económicos, OSINERGMIN.

Felbermayr, G. and J. Gröschl, 2014. “Naturally negative: The growth effects of natural disasters,” *Journal of Development Economics*, 11(4): 92-106.

Greenberg, M., N. Mantell, M. Lahr, F. Felder and R. Zimmerman, 2007. “Short and intermediate economic impacts of a terrorist-initiated loss of electric power: Case study of New Jersey,” *Energy Policy*, 35(1): 722-733.

Halliday, T. 2006. “Migration, risk and liquidity constraints in El Salvador,” *Economic Development and Cultural Change*, 54(4): 893–925.

Horwich, G., 2000. Economic lessons of the Kobe earthquake. *Economic Development and Cultural Change*, 48(3): 521–542.

Horridge, M., J. Madden and G. Wittwer, 2005. “The impact of the 2002–2003 drought on Australia,” *Journal of Policy Modeling,* 3(3): 285–308.

Klomp, J. and Kay Valckx, 2014. “Natural disasters and economic growth: A meta-analysis,” *Global Environmental Change*, 26(2): 183-195.

Lazzaroni, S. and P. van Bergeijk, 2014. “Natural disasters’ impact, factors of resilience and development: A meta-analysis of the macroeconomic literature,” *Ecological Economics,* 107 333-345.

Noy I. and T. Bang Vu, 2010. “The economics of natural disasters in a developing country: The case of Vietnam,” *Journal of Asian Economics*, 21(4): 345-354.

Okuyama, Y., 2007. “Economic Modeling for Disaster Impact Analysis: Past, Present, and Future,” *Economic Systems Research,* 19(2): 115-124.

Okuyama, Y. and S. Sahin, 2009. “Impact Estimation of Disasters: A Global Aggregate for 1960 to 2007,” The World Bank, Policy Research Working Paper 4963

Okuyama, Y. and J. Santos, 2014. “Disaster Impact and Input-Output Analysis,” *Economic Systems Research*, 26(1), 1-12.

Robinson S., A. Cattaneo, A. and M El-Said, 2001. “Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods,” *Economic System Research*, 13 (1): 47-64.

Romero, C., O. Chisari, E. Greco, L. Mastronardi and J. Vila Martínez, 2013. “Actualización del modelo de equilibrio general computado para Perú con énfasis en el sector energético,” Informe Final, Contrato OSINERGMIN AMC N° 0034-2013.

Rose, A. and G. Guha, 2004. “Computable general equilibrium modeling of electric utility lifeline losses from earthquakes,” en: Y. Okuyama y S. Chang (Eds), *Modeling Spatial and Economic Impacts of Disasters* (New York: Springer)

Rose A., G. Oladosu and S. Liao, 2007. “Business Interruption Impacts of a Terrorist Attack on the Electric Power System of Los Angeles: Customer Resilience to a Total Blackout,” *Risk Analysis*, 27(3): 513-531

Rose, A. and D. Wei, 2013. “Estimating the Economic Consequences of a Port Shutdown: The Special Role of Resilience,” *Economic Systems Research*, 25(2): 212–232.

Rutherford, T.,2005. *GTAP6inGAMS: the dataset and static model*. Working paper prepared for the workshop: Applied general equilibrium modeling for trade policy analysis in Russia and the CIS. Available at http://www.mpsge.org/gtap6/gtap6gams.pdf.

Selcuk, F., and E. Yeldan, 2001. “On the macroeconomic impact of the August 1999 earthquake in Turkey: A first assessment,” *Applied Economics Letters*, 8(7): 483–488.

Tamayo, J., J. Salvador, A. Vásquez and R. García (ed.), 2014. *La Industria del Gas Natural en el Perú*: A diez años del Proyecto Camisea. Lima: OSINERGMIN.

Vásquez, A., O. Chisari, L. Mastronardi and C. Romero 2015. “Restricciones al transporte de gas y evaluación de costos sociales: Un análisis de equilibrio general computado”. Documento de Trabajo N^{o} 33, Oficina de Estudios Económicos, OSINERGMIN, Mimeo.

Vásquez, A., J. Salvador, R. García and V. Fernández, 2013. "Assessing risks and regulating safety standars in the oil and gas industry: the Peruvian experience," Documento de Trabajo N^{o} 31, Oficina de Estudios Económicos, OSINERGMIN.

Vásquez, A., 2012. *The Regulation of Oil Spills and Mineral Pollution*: *Policy lessons for the U.S.A. and Peru from the Deep Water Horizon blowout and other accidents*. Berlin: Lambert Academic Publishing.

Vásquez, A. and E. Balistreri, 2010. "The marginal cost of public funds of mineral and energy taxes in Peru." *Resources Policy*, 35(4): 257-264.

Xie, W., N. Li, J-D. Wu and X-L. Hao, 2013. "Modeling economic costs of disasters and recovery involving positive effects of reconstruction: analysis using a dynamic CGE model," *Natural Hazards and Earth System Sciences,* 1: 6357-6398.

Zhang, P. and S. Peeta, 2011. "A generalized modeling framework to analyze interdependencies among infrastructure systems," *Transportation Research Part B: Methodological*, 45(3): 553-579.