Three Essays on Economic Development in the Natural Resources Sector

by

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Abstract

This thesis examines two ongoing development projects that received financial support from international development organizations, and an alternative mining tax proposed by the academia.

Chapter 2 explores the impact of commoditization of coffee on its export price in Ethiopia. The first part of the chapter traces how the Ethiopian’s current coffee trade system and commoditization come to be. Using regression analysis, the second part tests and confirms the hypothesis that commoditization has led to a reduction in coffee export price.

Chapter 3 conducts a cost-benefit analysis on a controversial, liquefied natural gas export project in Peru that sought to export one-third of the country’s proven natural gas reserves. While the country can receive royalty and corporate income tax in the short and medium term, these benefits are dwarfed by the future costs of paying for alternative energy after gas depletion. The conclusion is robust for a variety of future energy-price and energy-demand scenarios.

Chapter 4 quantifies through simulation the economic distortions of two common mining taxes, the royalty and ad-valorem tax, vis-à-vis the resource rent tax. The latter is put forward as a better mining tax instrument on account of its non-distortionary nature. The rent tax, however, necessitates additional administrative burdens and induces tax-avoidance behavior, both leading to a net loss of tax revenue. By quantifying the distortions of royalty and the ad-valorem tax, one can establish the maximum loss that can be incurred by the rent tax. Simulation results indicate
that the distortion of the ad-valorem tax is quite modest. If implemented, the rent tax is likely to result in a greater loss.

While the subject matters may appear diverse, they are united by one theme. These initiatives were endorsed and supported by authorities and development agencies in the aim of furthering economic development and efficiency, but they are unlikely to fulfill the goal. Lessons for international development can be learnt from successful stories as well as from unsuccessful ones.
Co-Authorship

Chapter 4 in this thesis is co-authored with Prof. Glenn Jenkins, my thesis supervisor.
Acknowledgements

I have always aspired for a career in international development, what motivated me to enroll in graduate studies a decade ago. At the time, I was but a student with very limited experience. A decade since then, I am a graduating doctoral candidate and a practitioner in international development. What little achievement this may be, it would not have been possible without the support of many in every step of the way. In my academic life, several individuals deserve special mention.

I am blessed by having two supervisors that have helped me in ways far beyond thesis supervision. Prof. Robin Boadway indulged me to write on real development problems, while Prof. Glenn Jenkins took me to actual project evaluation assignments and introduced me to the vast field of international development. The combined result is a thesis that covers highly practical matters of economic interest.

I am extremely grateful to Prof. Ruqu Wang, Prof. Beverly Lapham and Prof. Allen Head, for their gracious intervention which facilitated my transfer to Queen’s Economics Department’s doctoral program.

Last but not least, I would like to thank my family and close friends for their unyielding support, encouragement and patience.
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Chapter 1

Introduction

This thesis contains three studies covering two development initiatives and a tax reform proposal pertaining to different natural resources subsectors. The first two studies are the reflections and extensions of issues that I encountered, but owing to time constraints did not explore fully during actual development project evaluation assignments.

These projects and proposal are endorsed or funded by authorities and international organizations in the interest of economic development and efficiency. While the subject matters of these studies may appear dispersed and unrelated, they are united by one theme – in their individual ways the initiatives and the proposal have major design flaws. Consequently, their ability to promote economic development and efficiency is hindered.

The first paper concerns coffee trade in Ethiopia, which is governed by a complicated but inefficient network linking smallholder coffee growers with exporters and all intermediate agents in between. In December 2008, the Government of Ethiopia installed a new coffee trading platform with the financial support of international donors such as the United State Agency for International Development (USAID). Named Ethiopian Commodity Exchange (ECX), this new platform was designed to overcome market failures and inefficiencies. In its attempt to preempt collusions between local traders and exporters at the expense of smallholder farmers, the ECX inadvertently created a logistics system that eroded the traceability of coffee beans. Traceability being an essential
characteristic of gourmet coffee that fetches a premium, its erosion is expected to reduce coffee export prices.

This hypothesis is confirmed by regression analysis using an extensive dataset that includes all (legal) monthly coffee export transactions between 2007 and 2012. There are additional factors that influence coffee export prices, such as export time, export destination, coffee variety and coffee quality. Even when these factors are accounted for, there is a price gap between traceable and non-traceable export coffee of 12%.

The second paper deals with a liquefied natural gas (LNG) export project in Peru. The Camisea gas field was first discovered in the early 1980s, but its development was delayed owing to a disagreement between the Peruvian government and private oil and gas companies over the intended market of the Camisean gas. In the early 2000s, the Peruvian government finally agreed to export a significant share of the Camisean gas – representing one-third of the country’s proven natural gas reserves – despite strong domestic oppositions. The concern was that the LNG export project would accelerate gas depletion, forcing an energy-deficit Peru to revert to reimporting gas substitutes at much higher costs. Similar to the ECX, this Peru LNG export project received substantial financing support from development finance institutions including the World Bank and the Intern-American Development Bank.

A cost-benefit study was performed to compare the project’s short and medium term benefits to Peru, in terms of royalty and corporate income tax collection, against the long
term consequences of accelerated gas depletion. In the base case analysis, efforts were made to use only government data that was already available to Peru’s decision makers in the mid-2000s, when the project was approved. In the extensions, the analysis considers a range of scenarios that vary by energy price forecasts and alternative energy substitutes. In all cases, the cost of alternative energy far exceeds the project’s benefits from royalty collection. The LNG project should not have been approved.

The third paper deals with a more theoretical issue on mining taxation. It is often argued that royalty and ad-valorem tax are distortionary whereas the resource rent tax is neutral on operations decisions. This paper quantifies through simulations the magnitude of efficiency loss induced by the former. All taxes under comparison have a simplistic, single-rated structure, and the tax rates are calibrated to yield equivalent expected government revenue. The focuses are on the distortions on the cut-off grade and premature termination decisions that translate to monetary losses. Simulations are run for different scenarios that represent mining projects of varying profitability. While the royalty’s efficiency loss can be substantial for highly profitable projects, the revenue-equivalent ad-valorem tax’s loss is limited even under extreme circumstances. The paper then discusses a limitation of the simulation methodology that points to a refinement of the conventional efficiency argument for the rent tax.

Currently, royalty and ad-valorem tax are the dominant forms of mining tax, and since 1970s there have been calls for their replacement by the resource rent tax on account of its non-distortionary property. However, the rent tax’s relative advantage is shown to be
quantitatively immaterial, and thus the potential reward from a mining tax reform would be marginal. In the development context especially, limitations on administrative capacity and ineffective financial auditing system would further weigh against rent tax reform in practice.

Over half a century of international aid and economic reforms have undoubtedly produced many successful stories. This thesis however focuses on two development projects and an alternative mining tax regime that, while promising, are unlikely to further the cause of economic development or efficiency in the host countries that implement them. The underlying economics of these initiatives is of interest in itself, but more importantly, it is hoped that the lessons drawn from these studies can inform decision makers and perhaps prevent mistakes in countries currently evaluating similar initiatives.
Chapter 2
Eroded Coffee Traceability and Its Impact on Export Coffee Prices for Ethiopia

2.1 Introduction

Coffee is the single most important foreign exchange earner for Ethiopia. It accounted for 32 percent (823 million USD) of the total value of exports in 2011 and constitutes a significant income source for 15 million people in the workforce (Ministry of Trade 2012). Historically, coffee was marketed through an auction system that was fraught with problems. In late 2008, the Ethiopian Commodity Exchange (ECX) replaced the old auction regime as the principal coffee trading platform. Critics argued that the way ECX handles its coffee trade operations led to commoditization, whereby coffees with considerable differentiability in cup taste, and spatial or grower origin became homogenized. The operations have eroded coffee traceability and concealed from overseas coffee importers credible information regarding the coffee’s origin. The potential monetary loss can be substantial, as Ethiopia has more recognized coffee varieties than anywhere in the world, and many varieties enjoy high international repute. Regression analysis using the Ethiopian Ministry of Trade’s dataset on export coffee indicates that eroded traceability reduces coffee export prices by about 12 percent.

The Ethiopian government and international development agencies have invested substantial resources in promoting the coffee sector. Past interventions included sponsoring agricultural research and marketing development. Several studies have been conducted on the coffee sector that can inform interventions design. For example,
Gebreselassie and Ludi (2008) explain why some households decide not to participate (i.e., selling outputs) in the coffee market. Boansi and Crentsil (2013) investigate what drives coffee output and producer prices, while Worako et al. (2008) focus on how price fluctuations abroad are transmitted to various levels of the domestic coffee value chain. The research that is most relevant to the present study is by Arslan and Reicher (2010), which finds that the trademarking of three Ethiopian coffee varieties in 2004 increased their export prices by 10 percent. The absolute value of their estimate is strikingly similar to this paper’s findings, although the signs of the estimates are different, since eroded traceability has the opposite effect of trademarking on export prices, by diminishing coffee differentiability from the perspective of overseas coffee buyers.

2.2 Institutional Background

2.2.1 A Brief History of the Ethiopian Commodity Exchange

ECX was officially launched in April 2008 as a trading platform for cereals. It was envisioned as a revolutionizing institution providing many of the services that are ordinarily performed by the private sector in mature cereals supply chains. Its operations include an auction floor in Addis Ababa to facilitate cereal trade; a clearing system to settle sales contracts; regional assaying centres to determine the quality of cereals; regional warehouses to preserve cereal quality; and free, real-time, multimedia dissemination of price information to local markets. The integrated operations are meant to assure buyers of the quality of their purchase; protect cereal sellers against late payments and defaults; and empower farmers by enhancing price transparency. ECX was
designed to improve cereals market efficiency by reducing transaction costs for all participants (Gabre-Madhin and Goggin 2005).

Policy makers planned to incorporate coffee into the ECX trading platform since its inception, although preparation was expected to take time. The founding of ECX coincided with the 2007–2008 world food-price crisis, when grain prices spiked. In anticipation of price rises, cereals sellers ceased bringing shipments to ECX, greatly reducing its throughput and revenues and undermining its financial independence. In December 2008, the ECX authority swiftly introduced coffee (Gabre-Madhin 2012) to ensure ECX’s financial survival.

Whereas the trading of cereals through ECX was voluntary, the trading of coffee through ECX was compulsory under a government proclamation (Proclamation No. 602/2008). In addition to creating a thicker coffee market, the proclamation in effect guarantees a constant income stream for ECX. The mandatory incorporation of coffee to ECX brought the demise of Ethiopia’s old coffee trade regime, which had operated for three decades.

2.2.2 The Old Coffee Trade Regime

The old regime was installed by the communist Derg in 1977 to tighten control over the coffee sector. When the current government came to power in 1991, it initiated limited liberalization that permitted greater private participation in the coffee sector, although the reform was partial, for fear that unrestrained liberalization would breed vertical
integration. The coffee supply chain remained heavily regulated and compartmentalized, both geographically and functionally. In particular, coffee growers were required to sell all outputs in auction houses; it was not until 2001 that they could engage in direct export if they could find international buyers, bypassing the auction system. However, direct export has historically accounted for no more than 15% of annual exports. For local traders who purchase coffee from farmers, the auction system remains the only legitimate marketing channel.

Figure 2-1 presents a schematic of the coffee supply chain. Two features of the old regime deserve attention. First, the coffee trade was centred on auction houses. Considerable efforts were invested in keeping consignments separate in storage. Prior to an auction, samples of the consignments, along with sellers’ information, were put on display, and sellers were present throughout the auction process. Second, before coffee shipments could be transported abroad, exporters had to acquire clearance from the Cupping and Liquoring Unit (CLU), a government agency tasked with assuring export coffee quality. CLU graded each shipment by cup tasting and physically counting the defects in a sample. Coffee of quality below a certain threshold was rejected. As will

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2 Each agent in the supply chain fulfils a designated purpose. Sebsabies, or petty coffee collectors, were only licensed to buy from farmers; arrabies, or wholesalers, could only buy from sebsabies and sell coffee in auction houses; exporters and domestic suppliers in turn could only buy from auction houses; domestic roasters could only buy from domestic suppliers. All licensees were restricted to operate within specific geographic areas (Petit 2007). However, loopholes in the system allowed some exporters to achieve vertical integration to a degree, as some exporters were able to run coffee-collecting businesses (as arrabies) and held dual-seller licences by proxy. Having two licences allowed them to buy back their own coffee in auctions (LMC International 2000, p. 22; Mezlekia 2009).
3 Smallholder farmers account for 95 per cent of total production, the balance being from private or state-owned plantations (Chemonics International 2010, p. 3).
become apparent, CLU’s assessment of export coffee quality is important in the regression analysis that follows.

**Figure 2-1: Coffee Flow in Ethiopia before ECX**

Note: Direct export by coffee producers (farmer cooperatives and plantations) was not permitted until 2001, and even today accounts for a minor share of total coffee exports.

Despite having operated for decades, the old coffee regime was fraught with problems. First, contract enforcement was weak. Buyers could renege on bids with impunity. When bids were honoured, payments were often delayed and occasionally defaulted. Second, the distance between auction houses and local markets, coupled with weak telecommunications infrastructure, prevented coffee farmers from acquiring information on real-time prices. There was anecdotal evidence that sellers and buyers at auction houses colluded by underbidding and arranging surreptitious payments. Through collusions, the sellers could persuade coffee farmers into accepting lower procurement prices, and the buyers could reduce tax charges which were based on the underbid auction prices. The regime created an environment that was unsatisfactory to producers, suppliers and the government.
2.2.3 ECX’s New Coffee Trade Regime

From December 2008 ECX replaced the old auction system. Figure 2-1 is still an accurate depiction of the coffee flow, except that ECX replaces the auction houses. Local traders bring coffee to ECX’s regional offices, where ECX staff sample the coffee and assign it a geographic label and a grade. Coffee shipments are then taken to nearby ECX warehouses where coffee of the same zonal label and grade are stored in the same compartment without identity tags or other means of distinction. Sellers then sell the coffee on ECX’s trading floor. Unlike the auction system, coffee samples are not put on display, nor is the identity of sellers revealed. Buyers acquire no more information than that provided in coffee contracts, namely, the coffee variety (indicated by the zonal label), its grade and volume. ECX also broadcasts coffee prices in real time. Contract settlement takes place within a few days. ECX adopts a first-in-first-out delivery system: coffee that is stored the earliest is delivered first to the next immediate buyer. In practice, buyers receive from ECX coffee of the agreed variety, grade and volume, but the shipments are almost certainly not those initially offered on the trading floor, which will be delivered to future buyers in unrelated transactions. Figure 2-2 presents a schematic of ECX’s coffee trade operations, which closely mimic its cereals trade operations.

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4 ECX members maintain both pay-in and pay-out accounts in designated banks. ECX transfers deposits between accounts to clear transactions; it boasts a settlement period of one day after transaction (T+1).
Jimma (personal interviews with farmers and traders in several villages close to Jimma, 1–5 June 2012), attest to ECX’s contribution in facilitating transactions clearing and enhancing price transparency. The ECX system was also designed to thwart seller–buyer collusion. The concealment of seller identity during bidding is insufficient to achieve this, as colluding parties may identify each other by specific price–volume signals. Instead, first-in-first-out delivery is the centrepiece. As buyers no longer receive the specific lots that the counterparty put on sale, the former’s incentive to collude all but vanishes. From the perspective of ECX, it is immaterial which lots the buyers receive, so long as the contract specifications (variety, grade, and volume) match. It is likely that storage without identification has been adopted from the cereals trade operations to reduce operating costs.


2.2.4 Commoditization of Ethiopian Coffee

The ECX coffee regime is marked by a trend towards commoditization, as is evident in the way coffees are stored and delivered. To store similar coffee in the same compartment without distinction is to disregard the subtle differences in cup taste within a grade category, and specific spatial and grower origin under the same zonal label. First-in-first-out delivery has a similar effect of homogenizing the coffee, as buyers will receive a coffee blend from multiple, anonymized sources. ECX’s plan for storing coffee in silos is also suggestive of this trend (personal interview with two senior ECX officials, 8 June 2012). Interestingly, the Ethiopian government also endorses commoditization, as indicated in a 2011 directive that all export coffee be shipped in bulk containers. Previously, the industry practice was to keep coffee in 60 kg jute bags, which had the advantage that different coffee lots could be transported in a single container while maintaining lot separation. Shipment in bulk containers would require large overseas wholesalers to repackage coffee beans, and force out of the market many medium-sized distributors and specialty coffee roasters who bought small volumes. Faced with strong resistance, the government revoked the directive within a month (Mezlekia 2011).

Coffee that passes through ECX thus becomes less distinct in cup taste and is non-traceable in spatial or grower origin. Compared to coffee that is directly exported by producers, ECX-sourced coffee is a less differentiated product, although it may be of the same quality at the farm level.
While commoditization is the direct consequence of measures taken to thwart collusion, it can be understood in a broader historical context. Commoditization and the subsequent weakening of linkages between coffee merchants actually eased the government’s apprehension about the predominance of private interests in the coffee sector – historically the most important in the Ethiopian economy. In addition, because there was little preparation time in introducing coffee to ECX, the coffee regime was modelled on ECX’s cereals trade operations.

Ever since details of the ECX regime were announced in 2008, industry practitioners and observers at home and abroad have continually voiced concerns that commoditization eliminates traceability. The general opinion is that the mixing of coffee beans is equivalent to the blending of French wines in a “big, nasty cuvée” (quoted in Bjerga and Patton (2011a)). The Specialty Coffee Association of America (SCAA) was particularly concerned that ECX ruled out the purchasing of coffee from a single source. To accommodate overseas specialty coffee buyers, ECX established a second platform, direct specialty trade (DST), that traded fully traceable coffee. Prior to a monthly DST auction, ECX posted information on individual lots on its website, including the grower, geographic origin and cup profile. Coffee samples were also sent to registered potential bidders upon request. DST was initiated in February 2010 but was quickly discontinued.

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5 There has been no lack of media coverage. See Allison (2009), Frenette (2010), and Bjerga and Patton (2011b) for examples.
after two trading sessions, owing to the small number of transactions. Since then ECX has made no further attempt to trade traceable coffee.

2.2.5 The Consequence of Comoditization

Cereals are bulk commodities, and commoditization is suitable as it takes advantage of any economies of scale in their marketing. However, commoditization is inappropriate for Ethiopian coffee because of its great product differentiability. Whereas cereals have only a few key quality indicators, connoisseurs have developed a rich lexicon comparable to that used for wine to describe coffee’s complex cup taste. Storing homogenous cereals in bulk does not significantly alter the quality, but storing coffee in bulk would eliminate the distinct characteristics of individual lots. Furthermore, cereals and coffee have different consumer groups. Cereals are mostly consumed by locals for subsistence, with little attention paid to their origin. In contrast, coffee drinkers increasingly care about coffee traceability, which is a prerequisite for coffee certification and a desirable characteristic of gourmet coffee. This information is lost through commoditization, and the mandatory trading of coffee through ECX forces much of the export coffee to undergo this anonymizing process. Its imperfections notwithstanding, the old coffee regime preserved coffee traceability – the ability to guarantee the origin of coffee – more

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6 It is unclear why DST failed to generate as much interest as had been anticipated. One plausible reason may be due to DST’s exclusive criteria. On the supply side, only specialty-grade coffee could be traded through DST; on the demand side, only 30 buyers, all overseas, were registered (ECX 2010a). In addition, sellers had to demonstrate that coffee farmers would receive at least 85 percent of the free on board (FOB) price (ECX 2010b, p. 20). This left only 15 percent of the proceeds to be divided among other participants in the value chain. This last requirement greatly diminished the attractiveness of DST as a marketing channel for potential sellers.

7 The most common certifications include shade-grown, organic and Fairtrade certifications.
effectively than does the current regime. ECX has artificially created an information problem, as coffee exporters can no longer validate the coffee’s spatial or grower origin to overseas buyers. The transition from the auction system to ECX represents a transition from a game of complete information to one of incomplete information from the perspective of the overseas buyers. It is predicted that non-traceability will suppress the price of non-traceable coffee.⁸

2.3 Empirical Evidence

Recall that there are two legal channels for coffee export. Exporters that do not grow coffee must buy from ECX, while coffee producers may export coffee directly. As overseas buyers can establish direct contact with producers, direct export coffee (hereafter producer coffee) is perfectly traceable. In contrast, coffees that are purchased from ECX (hereafter trader coffee) are non-traceable by design. Whereas traceability adds value by enhancing product differentiation, commoditization diminishes it. It is hypothesized that, holding everything but the source of coffee constant, overseas buyers will pay less for trader coffee in response to commoditization.

2.3.1 Data Source

⁸ See Annex A.
During a field study, a dataset on export coffee transactions was acquired from the Ministry of Trade (MOT) of Ethiopia which contains enough information to test the hypothesis. Table 2-1 shows several random entries from this dataset.

<table>
<thead>
<tr>
<th>Obs</th>
<th>Year</th>
<th>Month</th>
<th>Exporter</th>
<th>Coffee</th>
<th>Grade</th>
<th>Destination</th>
<th>Weight (MT)</th>
<th>FOB value (000s USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2008</td>
<td>Apr</td>
<td>Company 1</td>
<td>Jimma</td>
<td>4</td>
<td>South Africa</td>
<td>144</td>
<td>320.1</td>
</tr>
<tr>
<td>2</td>
<td>2009</td>
<td>Dec</td>
<td>Company 2</td>
<td>Teppi</td>
<td>2</td>
<td>Belgium</td>
<td>72</td>
<td>210.7</td>
</tr>
<tr>
<td>3</td>
<td>2010</td>
<td>Sept</td>
<td>Cooperative 1</td>
<td>Limmu</td>
<td>5</td>
<td>France</td>
<td>36</td>
<td>91.3</td>
</tr>
<tr>
<td>4</td>
<td>2011</td>
<td>June</td>
<td>Company 3</td>
<td>Yirgacheffe</td>
<td>3</td>
<td>US</td>
<td>431</td>
<td>2,938.4</td>
</tr>
<tr>
<td>5</td>
<td>2011</td>
<td>June</td>
<td>Cooperative 2</td>
<td>Yirgacheffe</td>
<td>3</td>
<td>US</td>
<td>125</td>
<td>915.4</td>
</tr>
<tr>
<td>6</td>
<td>2012</td>
<td>Aug</td>
<td>Company 4</td>
<td>Harar</td>
<td>4</td>
<td>Japan</td>
<td>16</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Note: Exporters are anonymized in this table; coffee grade is assigned by CLU.
Source: Ministry of Trade (MOT), Ethiopia.

In total there were around 13,000 export transaction entries from 2007 to 2012. The dataset contains information on the value, volume and destination country of green (unroasted) coffee exported by individual exporters on a monthly basis. As explained, export regulations oblige coffee exporters to acquire clearance from CLU (see Figure 2-1), whether the shipments are producer coffee or trader coffees. The MOT dataset contains information about the variety and grade of shipments, as assigned by CLU. Note that CLU grading is a quality control measure that occurs before the actual shipment, but after the negotiation of contracts between exports and overseas buyers. As such, CLU grading however does not affect the coffee export prices. If two coffee shipments register the same variety-grade label, they are deemed by CLU to share a similar cup quality.
Slightly fewer than 270 companies and farmers cooperatives exported coffee between 2007 and 2012. For the purpose of regression analysis, extensive efforts were made to identify whether the exporters grew own coffee, in which case their shipments would be classified as producer coffee, and otherwise as trader coffee sourced from ECX. Several methods were used conjointly to arrive at a decision. After classification, observations were grouped together by the exporter type (producer or trader), coffee variety and grade, export destination and export date. For each group of observations, the total export value (USD) and volume (kg) were calculated. Dividing the former by the latter yielded the simple monthly average export prices for producer coffee and trader coffee of particular varieties and grades that were shipped to particular countries at a particular time. The prices of producer and trader coffee were in turn matched to compute the dependent variable used in the regression.

2.3.2 Regression Model and Results

9 The most direct method is to check company websites. Companies that own processing plants and warehouses, but not coffee farms, must be traders. Occasionally, the websites indicated whether coffee is purchased from ECX. However, this method has limited application as not all Ethiopian companies maintain websites. Second, company names that contain such key words as “trading” or “general import–export” indicate that these are trading companies, while some private coffee plantations are named “agro-business”. The state-owned plantation enterprises and farmer cooperative unions are easily identifiable by their names. A third method is to search for companies in the membership lists of various organizations, including ECX, the Ethiopia Coffee Exporters Association, and the Ethiopia Coffee Growers and Exporters Association (ECX 2013; ECEA 2013; Boot 2011, p. 39). Traders are likely to be members of the first two, whereas membership of the last is restricted to producers. Lastly, the volume, frequency and variety of export shipments provide supporting evidence, as producers are unlikely to produce huge volumes and export different coffee varieties regularly throughout the year. Of the 13,000 raw entries, around 500 (involving 24 exporters) remained unidentified. These shipments are assumed to be trader coffee, on account of the historically high share of trader coffee (no less than 85 per cent of total exports).
Of the 13,000 raw entries in the MOT dataset, about 30 percent (4,100 entries) could be matched with the four categories (export date, coffee variety, grade, and destination country). The matched entries produced 699 observations, constituting the full sample for regression analyses.\(^\text{10}\)

The following regression model is designed to test the hypothesis:

\[
y = \frac{P_P - P_T}{P_T} = \beta_0 + \beta_1 P_{NY} + \beta_2 \text{Coffee} + \beta_3 \text{Grade} + \beta_4 \text{ECX} + \varepsilon \quad (2-1)
\]

The average export price of producer coffee is denoted as \(P_P\) and that of trader coffee \(P_T\), both expressed in USD per kilogram and computed as described in the previous paragraph. The dependent variable is the percentage difference (\%) in export price between producer coffee and trader coffee of a particular variety and grade that is exported to a particular country in the same month of a given year. To give an example, Observations 4 and 5 in Table 2.1 have the identical coffee characteristics and export date and destination. The unit prices for these two export transactions (\(P_P\) and \(P_T\)) are matched to produce one observation for the regression. The way the dependent variable is defined controls for the macro environment (export date and destination) and the bean’s inherent characteristics (variety and grade) to the extent possible. The percentage difference, if it

\(^{10}\) Regressions were run using samples that cover 70% of raw entries, which produce quantitatively similar results; see Tables 2-3 and 2-4.
exists, is due entirely to the sourcing of coffee, and not to difference in export time, destination or the coffee’s inherent characteristics.\textsuperscript{11}

The first regressor ($P_{NY}$) is the monthly average coffee price at the New York Mercantile Exchange, published by the International Coffee Organization (ICO 2013). A limitation of the MOT dataset is that not all entries contain information on whether the export coffee is Fairtrade or organic certified. This prevents the use of certification as a control variable in the regression model, even though certification is a potential driver of the price spread. It is plausible that any observable change in the percentage difference is due to certification which is unobservable in this dataset – recall that producer coffee is traceable and certifiable, whereas the ECX-sourced trade coffee is not.\textsuperscript{12}

$P_{NY}$ is inserted as a proxy for certification, since certification either acts as a price floor (in the case of Fairtrade) or adds a premium (in the case of organic or shade-grown) above the prevailing market price (FLO 2013). As the world price drops, so too will the general export price of Ethiopian coffee. However, the percentage difference should increase because the producer coffee price would proportionally fall by less than that of

\textsuperscript{11} Controlling for coffee characteristics is important in view of the possibility of self-selection: coffee producers may choose to export high-quality coffee at a higher price and sell the remainder through ECX at a lower price. Low-quality, ECX-sourced coffee will be branded as trader coffee and exported for a lesser value simply because of its low quality, regardless of commoditization. Controlling for coffee characteristics ensures that the two coffees that are being compared are similar in quality.

\textsuperscript{12} Organic coffee consistently accounts for around 5 per cent of Ethiopia’s total annual exports, and this trend persists in the coffee trade at ECX (self-derivation based on ICO data). In other words, the growing gap, if it exists, cannot be explained by a larger volume of producer coffee receiving certification. The only way that certification may influence the price gap is through fluctuations of the general coffee price at the global level, which is captured by the variable $P_{NY}$. 

19
trader coffee, as some portion of producer coffee is certified.\textsuperscript{13} Expressed in dollars per kilogram, $P_{NY}$ is in principle in an inverse relationship with the dependent variable; the first coefficient estimate, $\beta_1$, is expected to be negative.\textsuperscript{14}

The second and third sets of regressors (Coffee and Grade) are dummy variables for coffee type and grade. Since traceability is more important for high-end products, the impact of its erosion should be more salient for the famous coffee varieties, namely Yirgacheffe, Sidamo and Harar. Similarly, holding everything else equal, higher grades should be more affected by eroded traceability.

The final regressor, ECX, indicates whether the export date was before or after the coffee trade platform transited to ECX in December 2008. The commoditization of trader coffee is expected to widen the price spread, as the price of trader coffee $P_T$ decreases. The high level of publicity drawn by industry practitioners meant that the impact of commoditization on export price was immediate, with no time-lag effect. If eroded traceability indeed suppresses the export price of trader coffee, the price spread will

\textsuperscript{13} Fairtrade-certified producer coffee always stays above a minimum price threshold, whereas trader coffee may drop below it. When the drop in global coffee price is significant, the percentage difference will increase. In the case of organic or shade-grown certification, the inverse relationship between percentage difference and global market price can be demonstrated by a simple mathematical manipulation. As before, let $P_P$ and $P_T$ denote the export price of producer coffee and ""der coffee, and let $\theta$ denote the certification premium. The original percentage differential is $y_1 = \frac{(P_P + \theta) - P_T}{P_T}$. When the
global coffee market faces a downturn, the coffee export price reduces by a general factor of $\alpha$, and the new percentage difference becomes $y_2 = \frac{((1-\alpha)P_P + \theta) - (1-\alpha)P_T}{(1-\alpha)P_T}$. Note that $y_1 < y_2$, for any $\alpha > 0$.

\textsuperscript{14} Caution must be taken against a literal interpretation of the coefficient estimate. It cannot be assumed that certification would increase the spread by a percentage equivalent to the coefficient estimate ($\hat{\beta}_1$), which is affected by 1) certification itself; and 2) the unknown portion of producer coffee in each observation that are certified. For all intents and purposes, the regressor is added to net out the otherwise unobservable impact of certification in creating the price wedge.
grow, holding everything equal. The purpose of the regression analysis is to test whether this coefficient estimate, $\hat{\beta}_4$, is positive and statistically significant. There are no unmentioned independent variables that can systematically explain the price differential.

### 2.3.3 Regression Results

Aside from the transition to the ECX system, there is no policy change in the coffee sector during this time interval, much less one that would have had an uneven impact on the two types of exporters. Figure 2-3, created to understand the distribution of the percentage difference by year, shows revealing trends.

**Figure 2-3: Scatterplot of Percentage Difference in Coffee Export Prices by Year**
Each of the 699 observations is represented by a dot in Figure 2-3. As a reminder, each observation represents the percentage difference of export coffee ($\frac{P_P - P_T}{P_T}$), of a particular variety and grade, to a particular country at a particular time. If there is no great difference in coffee export price, the dots would cluster around the red vertical line marking zero percent. The chart shows that in 2007 and 2008 the means of the percentage differences in coffee export price are approximately zero. This contrasts with the later years when the distribution of dots has shifted to the right, beginning in 2009.

A second observation is that the sample displays heteroskedasticity. Prior to ECX, there is a greater variance in the percentage differences. There are also outliers that showed producer coffee to be sold at a price considerably higher than trader coffee, by more than 200 percent in several cases. These are either indications of erroneous coding in the dataset, or the results of unusual circumstances.15

Two sets of regressions are performed. The first employs robust regression, which involves an algorithm that weighs down outliers, leverage and influential points to offset their dominating influence on the regression line.16

\[ \text{The regression is performed using the econometrics software Stata, with the \textit{rreg} command.} \]

---

15 The disappearance of the outliers may be an indication of ECX’s success in curbing collusions. Under the old regime, exporters who colluded would have difficulty justifying why they had paid little for the coffee lots, but received high export prices. Therefore, to pre-empt government audits these exporters underreported the true value of the export. This can explain the vast price spread between producer coffee ($P_P$) and trader coffee ($P_T$). Under the ECX system, the incentive to collude vanishes, as does the incentive to underreport the export value of coffee. Therefore, no outliers were observed after 2009.

16 The regression is performed using the econometrics software Stata, with the \textit{rreg} command.
Table 2-2: Regression Analysis Results Using the First Sample

<table>
<thead>
<tr>
<th></th>
<th>Robust regressions</th>
<th>OLS regressions with robust standard errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) With Controls</td>
<td>(2) No Controls</td>
</tr>
<tr>
<td></td>
<td>(3) With Controls</td>
<td>(4) No Controls</td>
</tr>
<tr>
<td>ECX</td>
<td>12.07***</td>
<td>14.52***</td>
</tr>
<tr>
<td></td>
<td>(6.51)</td>
<td>(6.85)</td>
</tr>
<tr>
<td></td>
<td>(3.93)</td>
<td>(3.64)</td>
</tr>
<tr>
<td>P\textsubscript{NY}</td>
<td>(-2.32^{**})</td>
<td>(-2.18^{**})</td>
</tr>
<tr>
<td></td>
<td>((-3.28))</td>
<td>((-2.66))</td>
</tr>
<tr>
<td></td>
<td>(-3.169^{***})</td>
<td>(-2.699^{***})</td>
</tr>
<tr>
<td>Controls</td>
<td>Coffee, Grade</td>
<td>Coffee, Grade</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>R\textsuperscript{2}</td>
<td>0.228</td>
<td>0.064</td>
</tr>
<tr>
<td>Observations</td>
<td>699</td>
<td>699</td>
</tr>
</tbody>
</table>

Note: t statistics in parentheses; OLS, ordinary least square.
* p < 0.05, ** p < 0.01, *** p < 0.001

Column (1) in Table 2-2 reports results from a robust regression using the full sample (699 observations); 21 observations receive a final weight of zero and are in effect removed. As hypothesized, the coefficient estimate for P\textsubscript{NY} is negative. Most importantly, the coefficient estimate for ECX validates the hypothesis that eroded traceability suppresses coffee export prices. Holding everything else constant, differences in coffee prices are estimated to have increased on average by 12.0 percentage points since ECX, with a 95 percent confidence interval of ±3.6 points (8.4 to 15.7). This result is consistent with the first observation made by visual inspection of Figure 2-3. The estimates for P\textsubscript{NY} and ECX are statistically significant, although those for the control dummies are by and large insignificant. The latter is surprising given the expectation that commoditization would have a greater impact on the famous coffee varieties, or on superior-quality coffee.

Column (2) in Table 2-2 presents results from another robust regression. The two sets of dummy variables, Coffee and Grade, which are added as controls in the first regression, are removed, leaving only two regressors, ECX and P\textsubscript{NY}. The coefficient estimates are statistically significant and quantitatively similar to those in Column (1).
In the second set of regressions, observations with the absolute percentage difference exceeding a certain threshold are omitted, in order to rule out outliers. That threshold is chosen to be ±150 percent. This is equivalent to imposing the condition that no observation in the sample will register one coffee being sold at less than 40 percent of the other’s value.\(^{17}\) The lower limit seems reasonable considering that the two coffees were similar in inherent characteristics, and shipped to the same country in the same month of a year. Compared to the robust regression, the removing criterion drops fewer (9) observations from the full sample. Ordinary least square (OLS) regression was then run on the slightly reduced sample, using robust standard errors, since tests indicate the data are heteroskedastic. As shown in Columns (3) and (4) in Table 2-2, the regression results are similar to those of robust regressions.

The previous regression results are based on a 699-observation sample that matched raw entries in the MOT dataset by four categories: export date, coffee variety, coffee grade and destination country. Its advantage is that the resulting matched entries are the most comparable. The disadvantage is that only 30 percent of raw entries are utilized for regression analysis. Therefore, two alternative samples are compiled using broader categories. In the second sample, continent replaces country as the destination criterion. A third set is created by removing the destination criterion entirely. The result is two samples of 653 and 452 observations covering 66 percent (8,800) and 68 percent (9,000)

\[^{17}\left| \frac{p_{t'} - p_t}{p_t} \right| \leq 150\% = \frac{6}{4} \text{ implies } \frac{p_{t'}}{p_t} \in \left[ \frac{4}{10}, \frac{10}{4} \right].\]
of raw entries, respectively. Relaxing the matching criteria reduces the sample size because more raw entries are grouped together.

Table 2-3: Regression Analysis Results Using the Second Sample

<table>
<thead>
<tr>
<th></th>
<th>Robust regressions</th>
<th>OLS regressions with robust standard errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) With Controls</td>
<td>(2) No Controls</td>
</tr>
<tr>
<td>ECX</td>
<td>9.019***</td>
<td>10.75***</td>
</tr>
<tr>
<td></td>
<td>(4.55)</td>
<td>(4.81)</td>
</tr>
<tr>
<td>P_NY</td>
<td>−1.400</td>
<td>−0.577</td>
</tr>
<tr>
<td></td>
<td>(−1.86)</td>
<td>(−0.68)</td>
</tr>
<tr>
<td>Controls</td>
<td>Coffee, Grade</td>
<td>None</td>
</tr>
<tr>
<td>R_2</td>
<td>0.235</td>
<td>0.038</td>
</tr>
<tr>
<td>Observations</td>
<td>653</td>
<td>653</td>
</tr>
</tbody>
</table>

Note: t statistics in parentheses; OLS, ordinary least square. * p < 0.05, ** p < 0.01, *** p < 0.001

Table 2-4: Regression Analysis Results Using the Third Sample

<table>
<thead>
<tr>
<th></th>
<th>Robust regressions</th>
<th>OLS regressions with robust standard errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) With Controls</td>
<td>(2) No Controls</td>
</tr>
<tr>
<td>ECX</td>
<td>13.91***</td>
<td>10.37***</td>
</tr>
<tr>
<td></td>
<td>(5.85)</td>
<td>(3.70)</td>
</tr>
<tr>
<td>P_NY</td>
<td>−1.571</td>
<td>−0.0186</td>
</tr>
<tr>
<td></td>
<td>(−1.84)</td>
<td>(−0.02)</td>
</tr>
<tr>
<td>Controls</td>
<td>Coffee, Grade</td>
<td>None</td>
</tr>
<tr>
<td>R_2</td>
<td>0.371</td>
<td>0.035</td>
</tr>
<tr>
<td>Observations</td>
<td>452</td>
<td>452</td>
</tr>
</tbody>
</table>

Note: t statistics in parentheses; OLS, ordinary least square. * p < 0.05, ** p < 0.01, *** p < 0.001

Tables 2-3 and 2-4 present the results of the robust regressions and OLS regressions using robust errors for these two samples. The coefficient estimates for the ECX effect, \( \hat{\beta}_4 \), are quantitatively similar to those in Table 2-2, although the estimates for coffee certification, \( \hat{\beta}_1 \), lose statistical significance. For the purpose of this study, it suffices that
the sign for the ECX coefficient estimate is positive, which confirms that the general conclusion is robust and insensitive to the way the sample is compiled.

2.3.4 Monetary Loss
Commoditization suppresses the export price of trader coffee compared with that of producer coffee, leading to a widening price spread. It is possible using the regression results to provide a measure of the monetary loss. With the ECX effect, the percentage difference is

\[ y = \frac{P_p - P_T}{P_T} = \beta_0 + \beta_1 P_{NY} + \beta_2 \text{Coffee} + \beta_3 \text{Grade} + \beta_4 \text{ECX} + \varepsilon \]

Without the ECX effect, the difference would be

\[ y' = \frac{P_p - P_T'}{P_T'} = \beta_0 + \beta_1 P_{NY} + \beta_2 \text{Coffee} + \beta_3 \text{Grade} + \varepsilon. \]

The counterfactual export price of trader coffee \((P_T')\) is not observable in reality. Since changes in export price that affect the supply–demand relationship would induce a feedback effect, the true \(P_T'\) is difficult to pin down. However, a first-order approximation of the counterfactual price can be determined by subtracting \(y'\) from \(y\), omitting the feedback effect. The difference \((\Delta)\) between \(P_T'\) and \(P_T\) represents the loss resulting from commoditization, per kg of trader coffee exported:
\[ \Delta \equiv P_T' - P_T = \frac{\hat{\beta}_4 (P_T)^2}{P_T - \beta_4 P_T} \] (2-2)

The calculation requires \( P_T \). This is not an issue for transactions of trader coffee in the MOT dataset that can be paired up with corresponding entries of producer coffee. For the unmatched entries, making inferences about losses is difficult owing to missing producer prices. For this exercise, the third sample was used as it covers 68% of raw entries. Using the coefficient estimate for the ECX effect (\( \hat{\beta}_4 \)) of 14 percent, the per-unit loss (\( \Delta \)) was computed for each of the observations in the third sample. Multiplying the per-unit loss by the corresponding volume of trader coffee and summing gives a monetary loss estimate of 191 million USD for the 68 percent of raw entries that are covered. The figure is then adjusted upward to account for the remaining 32 percent not covered, to arrive at a final estimate of 280 million USD. Given Ethiopian coffee farmers capture 53 percent of the export value (Sentayhu 2011), an overall reduction of 14 percent in export value implies that coffee farmers lose 7.4 percent of the proceeds from the export coffee trade.

Admittedly, the 280 million USD is the amount of gross revenues forgone. The net amount foregone should be less considering exporters of producer coffee incur extra costs in finding overseas buyers and in adopting processing procedures that comply with their specifications. However, the net amount would not be substantially less than the gross amount since marketing is an activity at the final, exportation stage of the coffee supply chain. There is no change to upstream activities – if farmers of producer coffee have been supplying the market at the current quality-price bundle, they are willing to supply the
same bundle at a higher price level. The 280 million USD of gross revenue forgone is but the information rent that was lost as a result of eroded traceability.

2.4 Discussion and Conclusions
Although first-in-first-out delivery is necessary to break collusion, there is one mitigating measure to restore traceability, as follows. First, upon arrival, all coffee jute bags are attached with ECX scan tags that identify their spatial or grower origins. There is no change to the auction procedures or to the first-in-first-out delivery system which is successful in thwarting collusion. However, during settlement, exporters should be given the option to acquire from the scan tags information about the spatial or grower origin of coffee lots they happen to receive. To recover increased operating costs and to ensure upstream traders and coffee farmers will receive a share of the benefits of recovered traceability, a supplementary fee can be charged to those who opt to receive the information. This is a form of price discrimination. Exporters that supply to more discerning overseas buyers will find it advantageous to acquire the information.

While the proposal calls for an initial investment in installing the scan tag system, the operating costs is minimal given the low costs of scan tags. Between 2009 and 2012, the gross loss is 280 million USD. If a 20 percent (56 million USD) provision is made as the extra cost for marketing producer coffee, the net loss amounts to 224 million. A scan tag system is unlikely to cost as much, but even if it does, the investment can be recouped
within several years. This is a very attractive public investment in any sector, especially in the agriculture sector.

The success of development initiatives in the agriculture sector depends on the voluntary participation of farmers and collaboration with other actors such as traders or input suppliers. Development agencies often expend much resource in persuading farmers into adopting new technologies or practises that improve yield or quality. In comparison, the proposed scan tag system can be implemented by one agency (i.e., the ECX) and require little coordination with upstream actors. This can be the most cost-effective of all interventions for the coffee sector.

The findings in this study by no means discredit ECX’s contributions in enhancing coffee sector efficiency. Rather, it is hoped that the findings can help the ECX authority to fine-tune coffee trade operations. The widening price differential between producer coffee and trader coffee is predicted by standard economic theory, and finds support in empirical evidence. The commoditization of coffee at ECX is a captivating example of economics at work.
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3.1 Introduction

In the second half of the 2000s, Peru faced a decision whether to conserve its natural gas reserves in the Camisea gas fields for future domestic consumption, or to implement a project for the exportation of liquefied natural gas (LNG). Named Peru LNG (PLNG), the project consists of the construction of a natural gas liquefaction plant, a marine loading terminal and a gas pipeline that connects to the Camisea gas fields, which contain over 90 percent of Peru’s proven natural gas reserves. The total investment was estimated to be 3.9 billion USD, making PLNG the largest single private investment in Peru’s history.

In the late 1990s, the foreign company that had discovered the Camisea fields proposed a similar project but was rejected by President Alberto Fujimori who favored domestic consumption. In the 2000s, during Ollanta Toledo’s presidency the government approved a project of export LNG despite opposition from civil society. Echoing Fujimori, the concern was that Peru’s gas reserves might be insufficient to simultaneously satisfy the export commitment and long term domestic needs. On the other hand, proponents of the project claimed it would generate millions of dollars from tax revenues, on top of spurring economic activities from domestic procurement and local employment. The purpose of this cost-benefit analysis (CBA) is to evaluate the claims of both sides, to shed light on the policy question regarding the disposal of Camisea natural gas. The findings
unequivocally support the opposition’s argument. Peru may revert to being an energy net importer as early as the mid-2030s.

The economics of the Peru’s LNG export project touches on several strands of research in the resource economics literature. Hotelling’s seminal work (1931) predicts how a mining firm would choose an extraction path that takes into account the Hotelling rent of the underground resource. The Hotelling rent, however, includes only the firm’s opportunity cost in terms of future revenues foregone, and the societal opportunity cost is not internalized. As such, numerous Hotelling-inspired theoretical models (Herfindahl 1967; Okzan and Okzan 2013) that yield (constrained) optimality or efficiency under a variety of circumstances can only be understood in reference to the firm, but what is optimal and efficient to the firm is not necessarily optimal to society. When the distinction between private and social optimality is recognized, the optimal extraction problem is often framed in the context of environmental externalities (Chakravorty et al. 2008) or non-competitive market structure (Daubanes 2011), and rarely of competing claims for the usage of a resource. The nature of the issue involved in Peru’s LNG export comes closest to that in Im et al. (2006) or Roumasset and Wada (2012) that feature multiple sources of demand, although these models involve solving a single optimization problem, from the social planner’s perspective. The Peru’s LNG export and the many real-life situations it presents suggest an approach to the problem in the principal-agent framework that requires dual optimization of the private investor and the social planners’ problems.
Peru’s experience with LNG export foreshadowed a situation that currently confronts many countries, as cost-reducing shipping and drilling technological advancements and the explosive growth of the Asian energy markets have thrust a global dash for LNG development. Currently, two LNG projects are underway in the Russian Far East (OGJ Sept. 2013); six projects in USA and three in Canada have received government approvals (Doshi 2012; OGJ Nov. 2013), with several more approval-pending (OGJ Oct. 2012; OGJ Nov. 2012; OGJ Oct. 2013); an ambitious floating LNG terminal was announced in Australia (Oil Drum 2011). Beyond the resource rich regions, similar private initiatives have been brought forward to countries with recent gas discoveries, although not conventionally associated as being natural gas producers. These include Cyprus (OGJ Nov. 2013), Ghana (OGJ June 2011), Mozambique (OGJ Dec. 2012), and Israel (OGJ Oct. 2013), to name a few.

The LNG opportunity has sparked national debate in the countries concerned, especially in USA and Israel. Then as now, balancing export commitment with domestic needs is at the core of the debate. The governments are called upon to design suitable LNG export strategies. While the legislative panel review in USA is ongoing, the Water and Energy Ministry of Israel recommended a 40% to 60% split between export and domestic market (OGJ Oct. 2013). At the same time, in Malaysia and Indonesia the dwindling petroleum supply, compounded by increasing domestic gas demand, will necessitate a revision of
their LNG export policies.\textsuperscript{18} Hence, the findings in this study are relevant to policy makers in the process of reviewing LNG export projects proposed by private investors.

The findings do not lend itself to the energy independence argument, nor is it against the energy trade surplus argument, as are often evoked by both sides of the LNG debate. The economic viability of LNG export is rather project- and country-specific, depending on the specific terms of the projects and the amount of available resources. The paper however does set out an explicit evaluation criterion that gives adequate attention to the economic benefits and the true opportunity costs of a LNG project for the host country.

3.2 A History of the Camisea Project

3.2.1 History of Camisea I

Discovered by the Royal Dutch Shell (Shell) in 1983, the Camisea gas fields in the Peruvian Amazon were heralded as one of the most important natural gas reserves in Latin America. The Camisea fields consist of two major deposits, marked Block 88 and Block 56. Throughout the 1990s Shell negotiated with the Peruvian government for the commercial exploitation of Camisea gas. This project eventually fell through in 1998 owing to disagreements over a number of issues. Fundamentally, whereas Shell intended gas exportation, the government gave priority to domestic consumption. Their conflicting preferences were responses to the same phenomenon that Peru had traditionally relied on

\textsuperscript{18}Indonesia has reached a paradoxical juncture where LNG is simultaneously exported to Japan and imported from USA (Kennedy 2013).
hydropower and imported petroleum products to meet its energy needs, and the natural gas market remained underdeveloped. For Shell, gas exportation could mitigate demand risk. On the other hand, the goal of the government, headed at the time by President Alberto Fujimori, was to improve Peru’s hydrocarbon trade deficit by substituting imported petroleum products with Camisea gas in the energy matrix.¹⁹

Upon Shell’s withdrawal, the Peruvian government organized an international tender for the three components of the Camisea project: 1) gas extraction and processing near the Camisea fields; 2) gas transportation in a pipeline that traversed across the Andes; and 3) the distribution network around the state capital Lima. To conserve Camisea gas for domestic use, Furjimori in conjunction with the Congress passed laws that proscribed gas exportation unless the proven gas reserves could meet the total of projected domestic demand for the next twenty years.²⁰ The Ministry of Energy and Mines (MEM) was to undertake annual review of Peru’s proven gas reserves and domestic needs for the next 20 years. If in any one year the total projected demand exceeded the proven reserves, gas producers must suspend supplying gas to exporters until the next year’s evaluation. In effect, the sheer prospect of abrupt interruption in feed gas was sufficient to deter private investment in gas export projects.

¹⁹ The possibility of supplying the domestic market had been explored but the parties were irreconcilable about the price and quantity of gas to be sold domestically. See Banco Wiese Sudameris (2002), The Economist (1998) and Accion Ciudadana Camisea’s webpage for details about the Camisea project during this early phase.
²⁰ Congress Law N° 27133, Article 4, and Executive Order N° 040-99-EM, Section 2.1.
In 2000, a group of international oil and gas companies won all components under the guise of three nominally independent consortiums. Consorcio Camisea was entitled the right to extract natural gas from Block 88 of the Camisea fields for 40 years. Transportadora de Gas del Peru (TGP) was awarded the transportation concession, with a 33-year terms. Although gas export was not explicitly ruled out, the Fujimori administration inserted a clause in Block 88’s license agreement, similar to that expressed in the aforementioned executive order. The extraction right for the adjacent Block 56 was not assigned at this time. Construction began in 2001 and in late 2004 Camisea gas from Block 88 reached Lima. Collectively, this phase of the Camisea project was dubbed Camisea I.

3.2.2 History of Camisea II

In 2003, several key consortium members formed another consortium to execute Camisea II, concerning the exportation of liquefied natural gas (LNG). Named Peru LNG (PLNG), the new consortium was to build a natural gas liquefaction plant at a costal site that turned natural gas into liquid. The project also required a feedstock pipeline that tapped

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21 Section 5.11 of the Block 88 License Agreement reads: “The export of natural gas [...] can be made as long as the supply of the domestic market for the following twenty (20) years is guaranteed, according to forecasted natural gas demand [...] as published annually in the Reference Plan of Hydrocarbons of the Ministry of Energy and Mines.” (MEM 2000).

22 In 2006, the Toledo administration granted Consorcio Camisea Block 56’s extraction right without putting it out to tender, for which it was heavily criticized. The government had created a situation that precluded competition between gas companies. Given the geographical proximity of Block 88 and Block 56, and that gas reserves in Block 56 was insufficient to justify building an independent pipeline, gas output from the two blocks would share the same pipeline. However, the gas transportation concession contract allowed Consorico Camisea to have exclusive use of the pipeline for 10 years. Consorico Camisea exercised a de facto stranglehold on the marketing of gas in Block 56 since no other company could use the pipeline without its consent (Gamboa et al. 2008). Hence, no other developer would bid for Block 56’s exploitation right, even if it were put to open tender.
into the main pipeline operated by TGP, and marine loading and docking facilities for the
LNG to be loaded to tankers for export. Altogether the total investment cost for PLNG
was expected to cost 3.47 billion USD. 43.4% of the investment was funded by equity
and the balance by loans from international financial institutions. If financing costs were
included, the total investment cost amounted to 3.97 billion USD (IFC 2008a). With or
without financing costs, PLNG boasts the largest foreign direct investment in the history
of Peru.

The LNG plant’s feed gas would come from Block 56 and Block 88 of the Camisea
fields. PLNG concluded an 18-year gas supply agreement with the sister company
Consortio Camisea. Commencing June 2010, PLNG would receive a daily gas delivery
volume of 620 million cubic feet (MCF). This implied a commitment of 4.20 trillion
cubic feet (TCF) of natural gas, or one third of the country’s proven reserves, over the
contract period. Since Block 56’s gas deposit was insufficient to fulfill the contract
obligation, natural gas would be partly sourced from Block 88. Figure 3-1 illustrates the
locations of the Camisea project.

While serving as the President of Peru from 2001 to 2006, Alejandro Toledo was
instrumental in dismantling the gas export restriction. Previously, export must cease at
any point in time if MEM’s yearly evaluation found the total proven reserves insufficient
to meet the domestic demand for the next 20 years, from the time when the evaluation
took place. Toledo however annulled Fujimori’s executive order. Gas reserves were now
considered sufficient if, “on the date of signing the contract for the sale of natural gas for export”, there was enough to supply the domestic market for 20 years (Executive Order Nº 050-2005-EM). Once contracts were signed, gas export would be allowed to continue regardless of unforeseen changes in domestic demand.

Since its inception, the Camisea project has met with opposition from conservation groups that hold reservations about the project’s adverse impacts on the Amazon forests and the lives of the aboriginal peoples that dwell within. When PLNG came to light, they were joined by those, echoing Fujimori, held that Camisea gas should be restricted for domestic use.
To placate opposition, Consorcio Camisea upgraded its Camisea’s proven reserves estimate from 10.9 to 13.4 TCF in early 2008 (IFC 2008a), and further to 14.1 TCF in early 2009 (Gestión 2009a). However, the upgrade announcements were not substantiated by two independent assessments (GCA 2009a; GCA 2009b; NSAI 2010). In explaining the discrepancy (Gestión 2009b), Consorcio Camisea gave hints to how its estimate was derived. Hydrocarbon deposits are classified along two dimensions, certainty and commercial recoverability. A comparison of how Consorcio Camisea defined reserves with the industry standards (SPE 2007) suggests that 3.1 of its last estimate of 14.1 TCF should really be classified as resources, or gas deposits that did not meet the criteria of reserves, much less proven reserves. There are indications that gas deposits were misclassified.

3.2.3 IDB and IFCs’ Involvement in Camisea II

Opponents to Camisea II attempted to block PLNG from obtaining financing from international financial institutions, a strategy employed by the conservation groups during Camisea I. Despite its previous modest success, the strategy failed. In December 2007 IDB approved a direct loan of 400 million USD and a syndicated loan of 400 million, together accounting for one third of PLNG’s total borrowings. While conceding

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23 One of the consulting companies, Gaffney, Cline and Associates was hired by the Camisea operators. Its reserves estimate was 8.80 TCF.

24 In 2012, additional gas reserves in the Camisea fields were discovered and confirmed by the government. As of December 2012 Peru registered a proven reserve of 15.38 TCF; see Section 3.4.3. Prior to 2012, proven reserve estimates increased modestly from 11.82 to 12.70 TCF between 2007 and 2011.

adverse environmental impacts, IDB approved the loans on economic grounds: “PLNG will spend approximately 1 billion USD on local salaries and goods and services [...] Additionally and as a result of the project, the Peruvian government will receive an average of 200 million per year in incremental royalties and 150 million in additional income taxes over the first 20 years... The entire project is expected to yield 4.8 billion in net present value terms in cumulative economic benefits.” (IDB 2006) In addition, IDB claims the project “represents a major step in the country’s efforts to develop its energy sector and achieve oil and gas self-sufficiency [emphasis added]” (IDB 2007). One may wonder for how long can Peru remain energy self-sufficient by the end of the project’s life, with one third of its proven reserves being exported.

Following IDB, IFC approved a USD 300 million loan in February 2008. This is the largest IFC transaction in Latin America (PLNG 2009). Although the loan amount was 40 percent of IDB’s, IFC’s role was no less vital by virtues of its stature among development finance institutions. IFC also highlighted the economic benefits of tax revenues, job creation and local procurement (IFC 2008b).

Since IDB’s project appraisal report on PLNG is not publicly available, it is unclear whether or not IDB gave sufficient considerations to the popular belief that export might occur at the expense of domestic needs. IFC’s appraisal report was however acquired. Gas reserves sufficiency was mentioned as a risk factor: “[c]oncerns have been raised by

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26 Adverse environmental impacts are in fact presented as an “additionality” that justifies IDB’s involvement: “[t]he Bank's participation in this project contributes significantly to the environmental and social management plans and systems of the companies, especially in terms of investments in community development and environmental protection” (IDB 2007).
CSOs [civil society organizations] and other parties that Peru may not have sufficient reserves to supply both Peru LNG, and meet forecasts for domestic gas demand beyond 20 years.” However, the report fell short of providing a mitigation strategy, but merely suggested that “the rising domestic demand for gas from Peru’s expanding economy as well as export requirements for the Project will be met from a combination of the expansion of current resources and future gas finds in Peru” (IFC 2008a).

Figure 3-2: Highlight of Events over the Course of the Camisea Project

- **Shell**
  - **1983-87**: Royal Dutch Shell discovered Camisea gas fields (Block 88 and 56).
  - **1998**: Negotiation between Shell and the government of Peru reached deadlock; Shell pulled out.
  - **1998-2000**: Fujimori and the Congress enacted natural gas export restrictions.

- **Camisea I**
  - **2000**: Concession contracts for the Camisea project were awarded to the present group of operators.
  - **2004**: Commercial production commenced, supplying the domestic market.

- **Camisea II**
  - **2001-06**: Toledo drastically relaxed the natural gas export restrictions set by Fujimori.
  - **2003**: Peru LNG was formed by the Camisea operators for the exportation of LNG.
  - **2007-08**: IFC and IDB granted loans to PLNG.
  - **2010**: PLNG began commercial operation; the first LNG shipment arrived Mexico in June.

Both IDB and IFC highlighted the immediate benefits the project would bring to Peru’s economy as a justification for their loans to PLNG. It is, however, contrary to the fundamentals of economics that a decision be made based solely on what will be gained, without taking into account of what could be lost – that is, without taking into account of the opportunity costs. With the LNG project, the most significant opportunity cost is the
cost of acquiring an alternative energy resource to replace the exported gas. While the question on reserves adequacy was muted in IFC’s appraisal, it was clearly voiced in the public discourse. Jenkins (2007) conducted a preliminary study of the project that pointed out the dangers of the project creating an economic loss to Peru; a summary report was circulated on the internet and made available to both international financial institutions. Jenkins’ study was also cited in an open letter to IFC, signed by a dozen of international NGOs that opposed the project (Amazon Watch 2008).

3.3 CBA Analysis

3.3.1 Theoretical Underpinning

The CBA is undertaken from the perspective of Peru. Within Peru there are several major stakeholder groups, namely 1) the government; 2) domestic consumers of natural gas; 3) domestic contractors and the part of the labor force that are employed by the LNG project; and 4) the local population that live within the project’s area of influence. Since the consortium members that own and operate the Camisea project will remit profits aboard, the companies’ after-tax financial performance is not a consideration in this analysis. The relationship between the economic costs and economic benefits of the LNG project, as well as the evaluation criteria can be illuminated with several mathematical equations.

Let $R_t^D$ and $CIT_t^D$ represent the royalties and the corporate income taxes (CIT) collected by the government at time $t$, for the natural gas that is supplied to the domestic market.
denoted by the subscript $D$. Likewise, let $R_t^E$ and $CIT_t^E$ represent the royalties and the CIT associated with the LNG project, denoted by the subscript $E$. Royalties are collected from Consorcio Camisea, the licensed gas producer, whether the gas are sold domestically or aboard. CIT are paid not just by PLNG, but also by Consorcio Camisea and TGP.

Denote the benefits of domestic procurement and job creation by $A_t$, the benefits that Peruvian gas users will generate from receiving Camisea gas by $B_t$, and the adverse socio-environmental impacts by $C_t$. Let $P_t^G$ and $Q_t^G$ denote the unit price and volume of Camisea gas sold domestically, and let $P_t^I$ and $Q_t^I$ denote the unit price and barrels of oil imported to replace the exported gas. Suppose PLNG’s project life is $T$ years. Since natural gas is a non-renewable resource, its depletion is inevitable. Let $T'$ represents such a date, where $T' > T$.

During the project life, the government will receive tax revenues ($R_t^E$ and $CIT_t^E$), and the difference between $A_t$ and $C_t$ is the benefits to society. Until natural gas depletes at date $T'$, the Peruvian customers enjoy the benefits of its usage ($B_t$), at a cost ($P_t^G Q_t^G$) paid to the Camisea gas producers. Past $T'$, it is assumed that Peru will resume importing petroleum products for its energy need, as was the case before Camisea I.\textsuperscript{27} At a discount rate of $\beta$, the present value of the economic resource flow to Peru in the with-project scenario (denoted by $\Pi'$) can be summarized by the following equation:

\begin{equation}
\end{equation}

\textsuperscript{27} Alternative energy solutions, including hydropower and natural gas imports, are explored, but none appears to be attractive on economic grounds. See Section 3.4.2.
As noted, the Camisea project is foreign-owned, and all financial profits will be remitted aboard. Since companies’ after-tax profitability does not affect Peru’s net proceeds from this LNG project, it does not enter into the equation. By the same token, the companies will defray all costs associated with bringing the Camisea gas to domestic users’ doorstep. For Peru, the resource cost of Camisea gas exactly equals the final price domestic customers paid to the companies.

In the project’s absence, reserves depletion will occur at date $T''$, with $T'' > T'$. The economic resource flow to Peru in the without-project scenario (denoted by $\Pi''$) becomes

$$
\Pi'' = \sum_{t=0}^{T''} \beta^t (B_t - P^G Q^G_t) + \sum_{t=0}^{T''} \beta^t (R^D_t + CIT^D_t) - \sum_{t=T'+1}^{\infty} \beta^t P^I_t Q^I_t.
$$

(3-2)

Equation (3-2) is similar to Equation (3-1), except that Peru no longer receives royalties and CIT from operations associated with the LNG project, and that the reserves depletion date is extended to $T''$. 

48
More realistically, as PLNG crowds out supply to the domestic market, domestic gas users consume less gas but pay more on a per unit basis since the increased scarcity would exert an upward pressure on gas price. The result is a lower net benefit to the domestic gas users \((B_t - P_t^G Q_t^G)\) in the with-project scenario. While the project’s impact on the tax revenues from domestic sales \((R_t^D\) and \(CIT_t^D)\) during the project life is ambiguous, it is evident from a mathematical relation that the overall net economic benefits from domestic sales are reduced due to crowding out, although the magnitude is difficult to quantify.\(^{28}\) For simplicity the crowding-out effect is assumed away. Between times 0 to \(T\), Peruvian industries receive the same quantity of gas at the same price in both scenarios, but the total amount of gas available to domestic customers will last longer, until \(T''\) without the project. This simplification renders the project to appear more favorable economically.

In performing an economic analysis, it is imperative to capture only the incremental difference between the with-project scenario and the without-project scenario. Define the incremental difference \((\Delta)\) as the with-project resource flow \((\Pi')\) minus the without-project resource flow \((\Pi'')\):

\[^{28}\text{Suppose the benefit per unit of gas consumption is } B, \text{ or } B_t = B Q_t^G. \text{ For any positive quantity consumed it must be the case that } B \geq P_t^G. \text{ Royalty and CIT are increasing with the quantity supplied and price. Suppose } R_t^D = \tau_R P_t^G Q_t^G \text{ and } CIT_t^D = \tau_{CIT} P_t^G Q_t^G, \text{ where } \tau_R \text{ and } \tau_{CIT} \text{ represent the respective tax rates whose sum must be less than unit. In each period the net benefit of domestic sales is } \pi_t = (B_t - P_t^G Q_t^G) + (R_t^D + CIT_t^D) = B Q_t^G - P_t^G Q_t^G (1 - \tau_R - \tau_{CIT}). \text{ Given that price is decreasing with the quantity supplied } \left(\frac{\partial P_t^G}{\partial Q_t^G} < 0\right), \text{ it is obvious that the derivative with respect to the quantity supplied is positive } \left(\frac{\partial \pi_t}{\partial Q_t^G} > 0\right). \text{ In other words, the larger the quantity supplied, the greater is the net benefit of domestic sales. It can also be verified that crowding out reduces the welfare of domestic gas users, and has an ambiguous effect on tax revenues.}\]
\[
\Delta = \Pi' - \Pi''
\]
\[
= \sum_{t=0}^{T} \beta^t (R^E_t + CIT^E_t + A_t - C_t) - \sum_{t=T'+1}^{T''} \beta^t (R^D_t + CIT^D_t)
\]
\[
- \sum_{t=T'+1}^{T''} \beta^t (B_t - P_t^G Q_t^G) - \sum_{t=T'+1}^{T''} \beta^t P_t^I Q_t^I. 
\tag{3-3}
\]

The first term is the discounted sum of royalties and CIT associated with the LNG project, and this represents the incremental benefits. IDB and IFC emphasized this first term in their analysis, but attached little importance to the socio-environmental costs \((C_t)\) and the opportunity costs (the rest of the terms).

A vigorous analysis should weigh the first term against the rest of the terms in Equation (3-3). The LNG project is economically viable if and only if the sum is a positive number. However, there are challenges in performing a CBA based on Equation (3-3). First, the benefits of domestic procurement and employment \((A_t)\) cannot be determined without first computing their economic values, which is information intensive. It can be expected that the true economic surplus of such items to be a small fraction of what the private investors bore as financial costs, after netting the opportunity costs of the resources Peru used in providing the goods, services and local labor. Secondly, the impact on the Peruvian consumers \((B_t)\) is difficult to quantify. The question rests on the user’s type, and whether a substitute is available. Lastly, monetizing the socio-environmental impacts \((C_t)\) are either controversial or challenging, if not both as in the case of aboriginal interests. Given the information constraints, these variables cannot but be dropped. In all likelihood, incorporating these missing variables would only weigh
against the LNG project. Equation (3-4) defines the incremental benefits and costs that will be captured in the CBA analysis:

\[
\Delta = \sum_{t=0}^{T'} \beta^t (R^E_t + CIT^E_t) - \sum_{t=T'+1}^{T''} \beta^t (R^D_t + CIT^D_t) - \sum_{t=T'+1}^{T''} \beta^t (P^I_t Q^I_t - P^G_t Q^G_t). \tag{3-4}
\]

To recapitulate, the first term refers to the additional tax revenues generated by the LNG project. However, had Camisea gas not been exported, taxes can still be collected from their domestic sales at a later date. The second term represents the taxes foregone. Lastly, the remaining term represents the additional costs of energy incurred to Peru as a result of accelerated gas depletion. Domestic consumers must pay for the use of energy with or without the project. In one case the payment will be made to foreign oil companies, and in another to Consorcio Camisea and TGP.

### 3.3.2 Elements of the CBA Model

To determine the first term in Equation (3-4) which represents the total tax revenues paid to the government, a detailed financial model was constructed for PLNG. Its first component is an investment schedule which indicates the amount of capital expenditures incurred during the construction phase, followed by a tax depreciation schedule to determine depreciation allowances. Secondly, a loan schedule computes loan disbursements as well as interests and principal repayments over the tenor of the loans. The third component makes forecasts about PLNG’s operating revenues, fixed and variable operating costs, based on the sales agreement made with PLNG’s sole client,
Repsol CG Commercialization de Gas S.A. (Repsol CG), and on the gas purchase and
gas transport agreements with Consorcio Camisea and TGP. Taking the difference
between operating revenues and operating costs gives earnings before interest, taxes,
depreciation and amortization (EBITDA). Lastly, an income tax statement is constructed
to determine CIT liabilities by netting depreciation allowances, interest payments, loss
carry-forward and other deductible items. Along the way, royalties are calculated and the
second-order benefits of CIT contributions from Consorcio Camisea and TGP are
approximated.\(^{29}\)

\(R_t^D\) and \(CIT_t^D\) in the second term of Equation (3-4) can be calculated in essentially the
same way as for \(R_t^E\) and the portion of \(CIT_t^E\) paid by Consorcio Camisea and TGP.\(^{30}\) Once
the financial models for Consorcio Camisea and TGP were built, the computation of
\(R_t^D\) and \(CIT_t^D\) is relatively straight-forward, for a given gas price forecast and a given
counterfactual quantity of natural gas that could be supplied to the domestic market.

The last term in Equation (3-4) is a function of a number of factors, including future
energy prices (\(P_t^G\) and \(P_t^I\)), future gas demand and its oil equivalence (\(Q_t^G\) and \(Q_t^I\)), and
lastly the size of the proven gas reserves. The larger the reserves, the later the oil import
date, and thus the less is the present value of the opportunity costs. The first step in

\(^{29}\) Similar financial models were constructed for Consorcio Camisea and TGP. Although the companies
produce and transport gas for both PLNG and the domestic market, the consolidated financial statements
do not distinguish the two types of sales. There is insufficient information to isolate the cost of goods sold
and other operating costs associated with the portion of sales to PLNG. Therefore the CIT liabilities for
Consorcio Camisea and TGP must be imputed.

\(^{30}\) Sales to PLNG and sales to the domestic market are subject to different royalty tax regimes. Both
regimes are modeled to capture the royalty collected from the LNG project \(R_t^E\), and the future royalty
forgone \(R_t^D\).
deriving a numerical value for this last term is to determine the expected date of reserves depletion. This is achieved by comparing the total available gas reserves with the forecasted cumulative demand in each scenario. Once $T'$ and $T''$ are known, the second step is to convert the forecasted gas demand for each period ($Q^G_t$) into barrels of oil ($Q^I_t$) using energy equivalence. Multiplying the quantity of gas or oil-equivalence demanded by the respective price forecasts ($P^G_t$ and $P^I_t$), gives the cost of energy for each energy source. The difference of the products is the additional costs of energy incurred in order to substitute petroleum products for gas.

3.3.3 Data Source and PLNG Operations

The parameters that populate the model were taken from a collection of publicly available information. Primary sources include 1) publications by the Ministry of Energy and Mines (MEM) of Peru that contain estimates on the size of gas reserves and domestic gas demand forecasts; 2) the original concession contracts for Block 88 and Block 56; 3) company credit reports and audited financial statements (PLNG, Consorcio Camisea and TGP) published by credit rating agencies; 4) IFC’s project appraisal report on PLNG; 5) publications by the Energy Information Agency (EIA) of USA that give energy price forecasts. The primary information are crosschecked and, to the extent possible, verified.

31 To give a stylized example, given one BCF of gas contains 1,089,000 MMBtu of energy and each barrel of oil contains 5.98 MMBtu (self-derivation based on Beychok (2012)), it takes about 182,000 barrels of oil to replace one BCF of gas. In the actual conversion, care was taken to adjust how the ways gas is consumed by domestic users affect the oil equivalence.

32 The rating agencies are Apoyo and Associates, (AAI, associated with Fitch Ratings) and Equilibrium Clasificadora de Riesgo (ECR, associated with Moody’s Ratings) and Pacific Credit Rating (PCR). The credit reports for the past two years are downloadable at company websites: www.aai.com.pe; www.equilibrium.com.pe; and www.ratingspcr.com.
with secondary sources. The derivations of various financial and economic parameters are documented in Annex B. Here it suffices to highlight some key aspects of PLNG’s operations.

PLNG has a project life of twenty years, inclusive of two years of construction period starting 2008. The capital investment was 3.47 billion USD, of which 2.25 billion USD was debt-financed. Financing was sourced from IDB (800 million), IFC (300 million), several export-import banks (950 million) and local bonds.

PLNG will acquire in total 4.20 TCF of natural gas from the Camisea fields. Its liquefaction plant has an annual capacity of producing LNG equivalent to 218 trillion British thermal units (TBtu). The entire LNG output is sold to Repsol CG under an 18-year term LNG sales agreement.

Since PLNG’s gas sales price is a function of the price Repsol CG receives in overseas markets, it is necessary to mention how the latter disposes of the LNG. Repsol CG is contracted to sell two-thirds of the LNG to Mexico, and the rest to Asian and European markets on an ad hoc basis. Sales to Mexico are indexed to Henry Hub. Repsol CG will

33 To be technically precise, the LNG plant has a nominal capacity of 4.4 million metric tons per annum (MMTA), as it is an industry practice to express LNG output in weight unit. For the purpose of this paper, gas quantity is more conveniently expressed either in energy unit (Btu) or in volume unit (cubic feet), depending on the context. Energy unit is preferable for gauging the monetary value of the gas, since gas price is quoted in US dollars per million British thermal units (USD/MMBtu). Volume unit is preferable when comparing gas quantity with the country’s available reserves, which is given in cubic feet. While all three measures are convertible, this paper drops the weight unit to avoid adding to the confusion.
receive 90% of the Henry Hub price, minus 3 US cents per MMBtu.\textsuperscript{34} Sales to other markets are determined by the spot price. It is assumed in this study that Repsol CG will sell the remaining one third of the LNG in Asia where gas price has been the highest.

The feed gas cost and gas transport fee paid to Consorcio Camisea and TGP, as well as royalties are all functions of the LNG price in overseas markets (what Repsol CG receives). The determination of royalties follows an especially elaborate scheme. PeruPetro, a state-owned enterprise tasked with negotiating oil and gas projects on the government’s behalf, regularly reports the overseas price and royalty payment for each LNG shipment. Given an overseas price, the model’s royalty estimate closely matches that in PeruPetro’s reports (2010 to 2013). This gives confidence that royalty payment is modelled precisely, which is important considering this constitutes the most significant source of benefits for Peru.

\section*{3.4 CBA Results}

The CBA analysis was conducted for three scenarios that vary in energy price forecasts, the size of gas reserves, and domestic demand forecasts. It is more convenient to discuss this set of parameters separately for each scenario.

\textsuperscript{34} To give a numerical example, if the Henry Hub price is 1 USD/MMBtu, Repsol CG will receive 88 US cents for the LNG that is shipped to Mexico.
For all scenarios, an economic discount rate of 8% is applied to discount the stream of economic benefits and costs. The Ministry of Economy and Finance (MEF) of Peru issued a set of guideline, the National Public Investment System (SNIP), used to evaluate all public investment projects. It recommends a real discount rate of 10% (SNIP 2012), implying that the next best alternative use of public funds will generate an economic benefit of 10%. It is however felt that the discount rate appropriate for this study needs a downward adjustment, in view of a study by Munilla (2010) which investigated how the Camisea project’s tax revenues were distributed and managed by the various recipients. Between 2004 and 2010, 16% of the tax revenues were allocated to the national government, 64% to the sub-national governments and the balance of 20% to a national defense fund, which is treated as expenses of current consumption. If under ordinary circumstances such funds would reduce the need for government borrowing, they would generate an economic return of 10% to the economy. If instead 80% are available to reduce the government’s capital market borrowing, then the rate of return on these incomes would be reduced to 8%. The discount rate of equal value is chosen in recognition of MEF guideline for public projects evaluation and the particularity of the formula that directs the distribution of tax revenues from the LNG project.

3.4.1 Scenario 1 Overview

Scenario 1 only makes use of information that was available around late 2007. The purpose is to evaluate the project using as much information as was available to decision makers at round the time of loans approval. Although IDB and IFC did not incorporate
reserves depletions into their analysis, the issue was clearly voiced in the public discussion. Key parameters are extracted from known studies commissioned or conducted by IDB or IFC on PLNG. As such, this part of the CBA analysis does not enjoy the benefit of hindsight.

Before presentation of analysis results it is conducive to describe the economic situation in late 2007. Natural gas market outlook was then positive. IFC’s gas price forecasts ranged between 6 and 7 USD/MMBtu at Henry Hub, and between 8 and 9 USD/MMBtu in Asia (IFC 2008a). This study takes the upper limits for a more optimistic estimation of the tax revenues. As per Pluspetrol, the operator of the Camisea fields with 27% interest in Consorcio Camisea, gas supply to the domestic market are priced at 4 USD/MMBtu for sales to the petrochemical industry, and between 1.59 to 2.7 USD/MMBtu for sales to other domestic customers (GCA 2009b). Lastly, the long-term price forecast for crude oil was 50 USD/barrel (IFC 2008a), to which are added the costs of refining, marketing and distribution to derive a final consumer price of approximately 61 USD/barrel. In real terms, the future cost of Camisea gas to be paid by domestic consumers ($P^G_t$) is assumed to remain from 1.59 to 4 USD depending on the consumer types, and the future cost of refined oil ($P^O_t$) to be at 61 USD/MMBtu in accordance with the World Bank forecast.

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35 Unless stated otherwise, all prices are at the 2008 level, and all rates are in real terms.
36 Curiously, feed gas to PLNG is priced at 0.51 USD/MMBtu.
37 Self-derivation based on the before-tax, gasoline price breakdown in US (EIA 2013a).
38 Domestic gas prices are not subsidized and are thus the true costs paid by Peru to Consorcio Camisea. In addition, gas transportation fee is around 0.66 USD/MMBtu (self-derivation based on credit agencies’ reports on TGP).
MEM of Peru certified the country’s total proven reserves to be 11.8 TCF (MEM 2008).

Table 3-1 below provides a breakdown of reserves by block and reserves category. The Camisea fields hold a lion’s share of Peru’s total reserves by any standard.

Table 3-1: Peru’s 2007 Reserves Estimates by Reserve Category (TCF)

<table>
<thead>
<tr>
<th>Natural gas fields</th>
<th>Proven*</th>
<th>Probable*</th>
<th>Proven and Probable**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camisea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block 56</td>
<td>2.94</td>
<td>1.18</td>
<td>3.53</td>
</tr>
<tr>
<td>Block 88</td>
<td>8.21</td>
<td>2.70</td>
<td>9.56</td>
</tr>
<tr>
<td>Subtotal</td>
<td>11.15</td>
<td>3.88</td>
<td>13.09</td>
</tr>
<tr>
<td>Others</td>
<td>0.67</td>
<td>2.95</td>
<td>2.15</td>
</tr>
<tr>
<td>Total</td>
<td>11.82</td>
<td>6.83</td>
<td>15.24</td>
</tr>
</tbody>
</table>

* Proven reserves has at least a 90% chance of being present; probable reserves has at least a 50% chance.

** 100% of proven reserves plus 50% of probable reserves.

Source: MEM (2008)

In accordance with industry practices, MEM’s reserves estimates are classified into three categories by the probability of being present: proven, probable and possible. Proven reserves have at least a 90% chance of being present and probable reserves have at least a 50% chance. Since possible reserves have a mere 10% chance of being present, it is not included as part of the total available reserves. To avoid supply interruption and gas shortfall penalties, it has been an industry practice to contract out only from proven reserves. In this study, the proven reserves is taken to be Peru’s total available reserves in the base case, supplemented by a sub-scenario that augments the total available reserves by 50% of the probable reserves.

A year before loan approval, IDB commissioned a consulting firm, Apoyo Consultoria (Apoyo), to conduct a study on Camisea I. According to Apoyo (2007), Peru’s
cumulative domestic gas demand was expected to be 6.5 TCF over the period from 2007 to 2033.\textsuperscript{39} The composition of demand is 2\% by residential users and \textit{natural gas vehicles}, 15\% by industries, 59\% by power plants, and the remaining 23\% by the petrochemical sector. For this study, demand past 2033 is assumed to grow at a constant rate of 2\% per year.\textsuperscript{40}

\subsection*{3.4.2 CBA Results for Scenario 1}

As will become apparent, Scenario 1 describes the most favorable macro-environment of all three scenarios. Table 3-2 below summarizes the CBA’s findings.

\begin{table}[h]
\centering
\caption{CBA Results Summary - Scenario 1 (2007 estimates)}
\begin{tabular}{|l|c|c|}
\hline
 & Proven & Proven and Probable \\
\hline
Total available reserves (TCF) & 11.8 & 15.2 \\
\hline
\textbf{Financial analysis} & &  \\
Equity IRR & 12.8\% & 12.8\% \\
Project IRR & 7.6\% & 7.6\% \\
\hline
\textbf{Economic analysis} & million USD & million USD \\
ENPV @ 8\% economic discount rate & -3,199.9 & -967.2 \\
\hline
\textbf{Immediate benefits (+)} & &  \\
CIT ($CIT_t^E$) & 764.7 & 764.7 \\
PLNG & 66.6 & 66.6 \\
Upstream suppliers & 698.2 & 698.2 \\
Royalty ($R_t^E$) & 1,481.8 & 1,481.8 \\
\hline
\textbf{Opportunity costs (–)} & &  \\
CIT foregone ($CIT_t^D$) & 145.7 & 53.9 \\
Royalty foregone ($R_t^D$) & 294.1 & 171.5 \\
Difference in energy costs ($P_t^I Q_t^I - P_t^G Q_t^G$) & 5,006.6 & 2,988.4 \\
\hline
\end{tabular}
\end{table}

\textsuperscript{39} Own derivation based on Apoyo (2007).
\textsuperscript{40} For the period between 2007 and 2033, the implied long run average demand growth rate in Apoyo (2007) is 8\%, which may not sustain.
<table>
<thead>
<tr>
<th>Earliest oil import date (year)</th>
<th>With project</th>
<th>Without project</th>
</tr>
</thead>
<tbody>
<tr>
<td>2036</td>
<td>2043</td>
<td>2052</td>
</tr>
<tr>
<td>Million barrels of oil import during the interval</td>
<td>1,015.7</td>
<td>1,031.1</td>
</tr>
</tbody>
</table>

** Crude oil price at 50 USD/barrel, implying a final refined oil price of 61 USD/barrel

The model forecasts an equity internal rate of return (IRR) of 12.8%, and a project IRR of 7.6%, as compared to IFC’s project IRR projection of 6.0% (IFC 2008a). The difference is due to differences in several assumptions, mostly notably in natural gas price forecasts. The financial model can reproduce a project IRR of 6.6%, if the full set of IFC assumptions is adopted. Similarity in the project IRR projections gives confidence that the current financial model is a fair approximation to the original.

From Peru’s standpoint, the private return for the foreign investors is immaterial. The economic viability of this project rests entirely on what Peru as a whole will receive. In this scenario, the government collects 1.48 billion USD of royalty plus 765 million of CIT, both in present value at an economic discount rate of 8% (in real terms). It is noteworthy that PLNG accounts for only 8.7% (66.6 million) of the total CIT contributions. This is not surprising considering that PLNG’s depreciation allowances—the sum of construction costs, financing costs and interest during construction—reached 3.83 billion. The total tax revenues amount to 2.25 billion in present value.

With the project, gas exhaustion is expected to occur in 2036. Without the project, gas depletion is deferred to 2045. During the nine-year interval, approximately 1,016 million

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41 The equity IRR is based on net income (after tax and financing), whereas the project IRR is the after-tax internal rate of return for the whole project, before financing.
barrels of refined oil are required to replace the exported gas. At 61 USD/barrel, the total cost of replacement oil amounts to 6.06 billion in present value. If, during the same interval, the domestic consumers could buy the exported gas at the current contracted price, they only need to pay 1.05 billion USD altogether for the gas itself and the transportation fee. Either way Peru’s energy need will be satisfied, but importation of petroleum substitute imposes an additional cost of 5.00 billion on Peru. In addition, of the 1.05 billion paid to the Camisea operators, the government could collect another 440 million of royalties and CIT revenues that are now forgone. The economic benefits of royalty and CIT in the short and medium term are outweighed by the opportunities costs by 3.20 billion.

It may be argued that Peru will find alternative solutions to its energy problem without resorting to oil imports. Two possible solutions were explored, and namely re-importation of natural gas, and hydropower, but neither seems to be economically attractive.

A supplementary CBA was conducted under the assumption that, instead of importing petroleum, Peru will re-import LNG. Equation (3-4) is still a valid evaluation criterion, except that the product $P_i Q_i$ in the last term now represents the cost of importing LNG and must be re-estimated. Otherwise, the numerical estimates for other variables are the same as those in Table 3-2. Natural gas re-importation would call for the construction of a regasification terminal; the one currently built by Mexico to make use of Respol CG’s LNG is estimated to cost 900 million USD (Samsung 2012), plus operating and
maintenance costs. At the forecasted long term natural gas price of 7 USD/MMBtu at Henry Hub, the FOB (inclusive of liquefaction at the source country and shipping) price of LNG for Peru should not be less than 8 USD/MMBtu. The 4.2 TCF of LNG alone would cost 3.17 billion USD in present value. When the construction costs of the regasification plant is included, the total cost of imported gas is around 3.67 billion as compared to the cost of Camisea gas for Peruvian gas users, estimated at 1.05 billion. This implies an additional energy cost of 2.25 billion. When the LNG project’s tax revenues and the tax revenues foregone (440 million, as reported in Table 3-2) are all accounted for, the total opportunity costs amount to 2.65 billion. Given the project would generate a gross benefit of 2.25 billion of tax revenues for Peru, the net economic NPV in this case would be -438 million USD.

As for hydropower, it is a poor substitute for industries – constituting 38% of the total demand – that rely on natural gas as a heating fuel or a chemical ingredient. This aside, it can be inferred from Apoyo’s gas demand forecasts that, from 2030 onward, gas-fired power plants will produce upwards of 36,000 Gigawatt-hour (GWh) of electricity each year.42 With an average availability factor of 0.7, to produce the equivalent amount of hydroelectricity would require no less than 5.87 Gigawatt (GW) of new installed hydropower capacity. To put this figure into perspective, Peru has 23 hydropower plants

42 The figure is derived from first multiplying the public utilities’ annual demand (MMCF) by the energy content of natural gas known as higher heating value (MMBtu/MMCF), and secondly dividing the product by the heat rate for gas-fired plants. The heat rate is the amount of energy required to produce one kilowatt hour of electricity (Btu/kWh), which varies by energy source. As a side note, gas-fired plants are typically more efficient than fuel-oil-fired plants; the respective heat rates are 8,152 and 10,829 Btu/kWh (EIA 2013b). The relative inefficiency of oil-fired plants increases the LNG project’s opportunity costs as more barrels of replacement oil is required, for the same amount of electricity produced by natural gas.
as of 2012, with a total installed capacity of 3.6 GW (MEM 2012a). This implies an additional installed capacity of 160%. It is a challenge in itself to find suitable sites for the many new hydropower plants, not to mention the monetary and environmental costs involved. Given Peru has been harnessing hydropower as a major energy source for three decades, it is likely that hydro power plants were already built in places that are the least expensive to build.\textsuperscript{43} To count on hydropower replacing natural gas would imposes great risks to Peru’s future energy security.

Column 2 of Table 3-2 presents results for a sub-scenario that adds 50 percent of the probable reserves to the total available reserves, now totaling 15.2 TCF. The economic outcome improves drastically. Increasing the total available reserve defers the earliest with-project importation date to 2043, thereby reducing the present values of the opportunities costs from 5.45 to 3.21 billion. The ENPV however remains negative at -967.2 million.

\textbf{3.4.3 Scenario 2 Overview}

The commercial operation of PLNG commenced in mid-2010, in the wake of the 2009 financial crisis. Scenario 2 gauges the economic contribution of PLNG to the Peruvian economy given the evolving circumstances.

\textsuperscript{43} Using a sample of 71 hydroelectric projects financed by World Bank from 1965 to 1986, Bacon et al. (1996) estimated that on average hydropower projects experienced a cost overrun of 27%. It can be expected that the actual construction costs for the 5.87 GW installed capacity will negate the 2.25 billion tax revenues the project is supposed to bring.
Three factors have had a major impact on the project outcome. First, the Henry Hub price of gas has fallen considerably as shale gas extraction technology became economical, bringing an ample supply to the US market. Consequently, Henry Hub gas price has dropped from the 2007 level from 6.5 to 3.5 USD/MMBtu. EIA’s latest Henry Hub forecasts are bleak, with price ranging from 3.2 to 5.7 USD/MMBtu (in 2012 prices) between 2013 and 2030 (EIA 2012). Also in 2012 prices, the price forecast for crude oil will reach 82 USD/barrel by 2030, which implies a final refined oil price of 101 USD/barrel. In contrast, Asian LNG prices has risen sharply. In this analysis the gas price in Asia is taken to be 12 USD/MMBtu,

Second, Consorcio Camisea had twice upgraded the reserves estimate, from the initial 10.9 to 14.1 TCF in 2009. The upgraded figures were found to be exaggerated by two consulting companies that carried out independent assessments of Camisea’s gas reserves. There was no significant finds between 2008 and 2011, but in 2012 additional proven reserves in the Camisea fields was indeed confirmed by MEM. Consequently, Peru’s total proven reserves increased to 15.38 TCF as of December 2012. Probable reserves decreased moderately to 5.44 TCF. Since the projection period in the spreadsheet model starts from 2008, 1.2 TCF of gas is added to 2012’s proven reserves estimate to account for the volume extracted during the interval. Table 3-3 presents the quantity of gas that was actually in place in December 2007.

Third, after a decade of promotion, the Peruvian industries are taking an active interest in
Table 3-3: Peru’s Updated Reserves Estimates by Reserve Category as of 2007 (TCF)

<table>
<thead>
<tr>
<th>Natural gas fields</th>
<th>Proven*</th>
<th>Probable*</th>
<th>Proven and Probable**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camisea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block 56</td>
<td>3.56</td>
<td>0.97</td>
<td>4.05</td>
</tr>
<tr>
<td>Block 88</td>
<td>12.02</td>
<td>1.64</td>
<td>12.84</td>
</tr>
<tr>
<td>Subtotal</td>
<td>15.58</td>
<td>2.61</td>
<td>16.89</td>
</tr>
<tr>
<td>Others</td>
<td>1.00</td>
<td>2.83</td>
<td>2.42</td>
</tr>
<tr>
<td>Total</td>
<td>16.57</td>
<td>5.44</td>
<td>19.29</td>
</tr>
</tbody>
</table>

* Proven reserves has at least a 90% chance of being present; probable reserves has at least a 50% chance.
** 100% of proven reserves plus 50% of probable reserves.

reequipping their facilities to burn natural gas, only to find that the proven reserves is inadequate for their needs. News of shortage emerged as early as June 2009, before the commercial operation of PLNG (La Republica 2009), and domestic gas supply is being rationed. According to MEM’s latest estimate, the total domestic demand from 2010 to 2040 is 15.8 TCF, as compared to 6.3 TCF between 2007 and 2033 in Scenario 1.44

3.4.4 CBA Results for Scenario 2
CBA results for the second scenario are summarized in Table 3-4.

<table>
<thead>
<tr>
<th></th>
<th>Proven</th>
<th>Proven and Probable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total available reserves (TCF)</td>
<td>16.6</td>
<td>19.3</td>
</tr>
</tbody>
</table>

Financial analysis
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Equity IRR</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Project IRR</td>
<td>5.4%</td>
<td>5.4%</td>
</tr>
<tr>
<td>million USD</td>
<td>million USD</td>
<td></td>
</tr>
</tbody>
</table>

44 Own derivation based on MEM (2012b).
Economic analysis

ENPV @ 8% economic discount rate

<table>
<thead>
<tr>
<th></th>
<th>-4,989.7</th>
<th>-3,481.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Immediate benefits (+)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIT ($CIT^E_t$)</td>
<td>773.1</td>
<td>773.1</td>
</tr>
<tr>
<td>PLNG</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Upstream suppliers</td>
<td>749.1</td>
<td>749.1</td>
</tr>
<tr>
<td>Royalty ($R^E_t$)</td>
<td>1,765.4</td>
<td>1,765.4</td>
</tr>
<tr>
<td><strong>Opportunity costs (−)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIT foregone ($CIT^D_t$)</td>
<td>171.8</td>
<td>131.7</td>
</tr>
<tr>
<td>Royalty foregone ($R^D_t$)</td>
<td>346.3</td>
<td>265.5</td>
</tr>
<tr>
<td>Difference in energy costs ($P_t^I Q_t^I - P_t^G Q_t^G$)</td>
<td>7,010.0</td>
<td>5,622.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Earliest oil import date (year)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>With project</td>
<td>2036</td>
<td>2040</td>
</tr>
<tr>
<td>Without project</td>
<td>2042</td>
<td>2045</td>
</tr>
<tr>
<td>Million barrels of oil import during the interval</td>
<td>970.1</td>
<td>1,003.0</td>
</tr>
</tbody>
</table>

** Crude oil price at 82 USD/barrel, implying a final refined oil price of 100 USD/barrel

In this scenario, the equity IRR for PLNG drops to 8.3%. It comes as a surprise that royalty collection actually increases moderately by 283 million USD, from 1.48 to 1.77 billion despite the ailing Henry Hub market. Further analysis traces this counterintuitive result to the risk-sharing structure embodied in the royalty regime. In essence, royalty is a convex function of overseas gas price, that is, royalty increases more (less) at the margin at a higher (lower) overseas price. Given the respective gas prices at Henry Hub and in Asia, the weighted royalty tax is 0.7076 USD/MMBtu in this scenario, and is 0.6997 USD/MMBtu in the previous. Sales to the blooming Asian markets thus make up for the losses at Henry Hub.

Alongside 2012’s new discovery that added 3.10 TCF of gas to the proven reserves, the forecasted domestic demand has grown by 150%. Gas depletion is expected to occur in 2036, as before, and the quantity of oil replacement (970 million barrels) is similar to that in Scenario 1 (1.02 billion barrels). Both observations indicate that domestic demand
growth almost negates the economic gains, in terms of reducing reliance on oil imports, from new gas discovery. Nevertheless, additional energy cost raises from 5.00 to 7.01 billion due to rising forecasted oil price. Peru foregoes another 518 million of royalty and CIT from counterfactual sales to the domestic market. In summary, while the LNG project is expected to generate 2.54 billion of gross economic benefits, the economic costs total 7.53 billion. Peru will suffer from a net economic loss of 4.99 billion.

3.4.5 Scenario 3 Overview

The LNG project’s short history is marked with episodic outbreaks of opposition at various levels of society. In July 2009, seven Peruvian departments perused joint legal action against the federal government’s approval of the project. In place of PLNG, they argued natural gas transported through a South Andean pipeline could aid economic development in Southern Peru (La Jornada 2009). Demonstrations against the project have been frequent, but in June 2010, protestors of several thousand strong staged road blocks in the Cusco Region, where the Camisea fields is located, and were joined by several thousand more in Lima (La Jornada 2010). In response to popular protest, former President Alan Garcia issued an executive order that set a minimum royalty for future LNG contracts (Executive Order N° 039-2010-EM). He also reinstalled Fujimori’s order that Camisea developers must guarantee domestic supply for twenty years at the time of LNG export (Executive Order N° 053-2010-EM).45 Contract renegotiation was soon

45 See Section 2.2.
suspended as the current incumbent president Ollanta Humala dislodged Garcia from office.

In honoring his pledge to rectify Camisea II, Humala issued an executive order that earmarks Block 88 for domestic uses (Executive Order N° 008-2012-EM). Export gas can now only be sourced from Block 56. Renegotiation is likely to take time, as the Camisea developers offered 2.5 TCF of Block 88’s proven reserves – the volume in Block 88 initially committed to the LNG project – to the lenders group as collateral that backed PLNG’s financing (Gestión 2011). Legal issues need to be resolved with international financing institutions before the Camisea developers can continue negotiation with the government. International financial institutions’ involvement has the anticipated effect of mitigating policy risks for private investors, but creates obstacles for Peru to correct a past mistake.

Perhaps the Humala administration was unaware of the latest reserves estimates when issuing the executive order in mid-2012, but restricting gas export to what is available in Block 56 is unlikely to leave a significant impact. Since Block 56 is estimated to hold 3.56 TCF of proven reserves, PLNG may still export 85% of the 4.2 TCF intended. Humala can conserve no more than 0.64 TCF of natural gas for Peru.

3.4.6 CBA Results for Scenario 3
For completeness, a final CBA analysis was conducted to quantify how the executive order may help reduce Peru’s economic loss. The renegotiation is assumed to bring no changes to the tax regime or to other terms in the licensing agreement. Energy price forecasts, domestic demand forecasts and reserves estimates are identical to Scenario 2. The exportable volume of natural gas however is reduced from 4.2 TCF to 3.56 TCF in the base case, and to 4.05 TCF in the sub-scenario. In this scenario, the ENPV improves from -4.99 billion to -4.36 billion in the base case, indicating a reduction in economic loss by 628 million. For the sub-scenario, the reduction in loss is negligible.

<table>
<thead>
<tr>
<th>Table 3-5: CBA Results Summary - Scenario 3 (2012 estimates)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total available reserves (TCF)</strong></td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Financial analysis</strong></td>
</tr>
<tr>
<td>Equity IRR</td>
</tr>
<tr>
<td>Project IRR</td>
</tr>
<tr>
<td><strong>Economic analysis</strong></td>
</tr>
<tr>
<td>ENPV @ 8% economic discount rate</td>
</tr>
<tr>
<td><strong>Immediate benefits (+)</strong></td>
</tr>
<tr>
<td>CIT (\text{CIT}_t^E)</td>
</tr>
<tr>
<td>PLNG</td>
</tr>
<tr>
<td>Upstream suppliers</td>
</tr>
<tr>
<td>Royalty (\text{R}_t^E)</td>
</tr>
<tr>
<td><strong>Opportunity costs (−)</strong></td>
</tr>
<tr>
<td>CIT foregone (\text{CIT}_t^D)</td>
</tr>
<tr>
<td>Royalty foregone (\text{R}_t^D)</td>
</tr>
<tr>
<td>Difference in energy costs (P_t^I Q_t^I - P_t^G Q_t^G)</td>
</tr>
<tr>
<td><strong>Earliest oil import date (year)</strong></td>
</tr>
<tr>
<td>With project</td>
</tr>
<tr>
<td>Without project</td>
</tr>
<tr>
<td>Million barrels of oil import during the interval</td>
</tr>
</tbody>
</table>

**Crude oil price at 82 USD/barrel, implying a final refined oil price of 101 USD/barrel**
3.5 Sensitivity Analysis and Discussion

The analysis results in the previous section depend on the interaction of a set of variables. Since many parameter values cannot be determined with absolute certainty, sensitivity tests are conducted to test how changes in several critical variables influence the economic outcome. To save space, this section only reports the results from one such test for Scenario 2 which reflects the latest development. The sensitivity test is performed on the price of oil. The results are given in Tables 3-6. As a reminder, the long term price of crude oil and refined oil is 82 and 101 USD/barrel respectively in Scenario 2. The ENPV in the base case is -4.99 billion USD, and is -3.48 billion in the sub-scenario. The project is still economic unviable when the price of refined oil dropped to 85 USD/barrel.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>101</td>
<td>-4,989.7</td>
<td>-3,481.2</td>
</tr>
<tr>
<td>69</td>
<td>85</td>
<td>-3,690.3</td>
<td>-2,445.8</td>
</tr>
<tr>
<td>73</td>
<td>90</td>
<td>-4,098.1</td>
<td>-2,770.8</td>
</tr>
<tr>
<td>78</td>
<td>95</td>
<td>-4,505.8</td>
<td>-3,095.7</td>
</tr>
<tr>
<td>82</td>
<td>101</td>
<td>-4,989.7</td>
<td>-3,481.2</td>
</tr>
<tr>
<td>86</td>
<td>105</td>
<td>-5,321.4</td>
<td>-3,745.5</td>
</tr>
<tr>
<td>90</td>
<td>110</td>
<td>-5,729.2</td>
<td>-4,070.5</td>
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<tr>
<td>94</td>
<td>115</td>
<td>-6,137.0</td>
<td>-4,395.4</td>
</tr>
<tr>
<td>98</td>
<td>120</td>
<td>-6,544.8</td>
<td>-4,720.3</td>
</tr>
</tbody>
</table>

The crux of the problem is that Peru receives only a fraction of the LNG sales proceeds, but will pay a much higher price for petroleum substitutes than it would for Camisea gas, as is apparent from the following calculation. Table 3-7 below reports the royalty fee for different gas price levels in the overseas markets. For the same overseas gas price, royalty from sales to Mexico is less than the royalty from sales to Asia because the LNG to
Mexico is priced at 3 US cents less than 90% of the Henry Hub price; recall Repsol CG’s LNG supply agreement with Mexico.

<table>
<thead>
<tr>
<th>Gas price</th>
<th>Royalty</th>
<th></th>
<th>Gas price</th>
<th>Royalty</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HH</td>
<td>Asia</td>
<td></td>
<td>HH</td>
<td>Asia</td>
</tr>
<tr>
<td>3.00</td>
<td>0.150</td>
<td>0.150</td>
<td>9.00</td>
<td>0.906</td>
<td>1.125</td>
</tr>
<tr>
<td>4.00</td>
<td>0.151</td>
<td>0.159</td>
<td>10.00</td>
<td>1.118</td>
<td>1.357</td>
</tr>
<tr>
<td>5.00</td>
<td>0.195</td>
<td>0.239</td>
<td>11.00</td>
<td>1.326</td>
<td>1.588</td>
</tr>
<tr>
<td>6.00</td>
<td>0.279</td>
<td>0.425</td>
<td>12.00</td>
<td>1.535</td>
<td>1.820</td>
</tr>
<tr>
<td>7.00</td>
<td>0.487</td>
<td>0.656</td>
<td>13.00</td>
<td>1.744</td>
<td>2.052</td>
</tr>
<tr>
<td>8.00</td>
<td>0.695</td>
<td>0.889</td>
<td>14.00</td>
<td>1.952</td>
<td>2.284</td>
</tr>
</tbody>
</table>

** All figures are in USD/MMBtu.

Even when gas price reaches 14 USD/MMBtu, the government collects an upmost royalty of 2.28 USD/MMBtu. Based on the terms of the present gas purchase agreements, future Peruvian consumers will pay a weighted average cost of 2.32 USD/MMBtu for the Camisea gas, and another 0.66 USD/MMBtu for its transportation to Lima. In contrast, at the refined oil price of 85 USD/barrel, and given each barrel of oil contains 5.98 MMBtu, oil replacement will cost 14.21 USD/MMBtu. On a per MMBtu basis, oil replacement is 11.23 USD more expensive than Camisea gas. Peru collects no more than 2.28 USD of royalty but will pay no less than 11.23 USD extra to replace every MMBtu of Camisea gas exported.

### 3.6 Conclusions

It may appear that natural gas that is left underground has little or no immediate value. Following the same logic, it may also appear that receiving some tax revenues from a
LNG project that exports one third of Peru’s gas reserves is better than conserving the natural gas and receiving nothing. If such is the basis of comparison, it is understandable why the government gave the green light to the project, and why development banks approved loans to PLNG. However, at the risk of repetition, projects cannot be evaluated solely on the basis of its immediate gross benefits without regard to the potential opportunity costs. If only the gross benefits are considered, one might be impressed by the billions in royalty and CIT revenues generated for Peru. The billions of tax revenues are however dwarfed by the billions more incurred on importing petroleum substitutes.

When Peru exhausts its natural gas resources, the private investors of the Camisea project will look for better opportunities in other countries; none will be defray the costs they impose on Peru. By that time Peru will have followed Indonesia’s footsteps which, having exhausted much of its petroleum resources amidst growing domestic demand, lapsed from being a net oil exporter to a net importer in 2004. Since then rising oil price has forced the Indonesian government to divert an increasing share of public funds to subsidies fuel (Ministry of Finance of Indonesia 2010; The Economist, 2013). With or without subsidy, it will be the future generation of Peruvians that pay for the current generation’s mistake. According to Scenario 2’s estimate, PLNG will generate a rate of return on equity of 8.3%, which is marginally satisfactory at best to compensate for the capital investment and the risks involved. By lending to PLNG, IDB and IFC have done Peru a disservice.
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Chapter 4

A Comparison on the Economic Efficiency of Three Archetypical Mining Taxes by Simulations

4.1 Introduction

First proposed by Garnaut and Clunies Ross (1975), the resource rent tax and its variants have been lauded as an ideal tax instrument for the extractive industries. It is well documented and modelled that the unit-based royalty and the value-based ad-valorem tax, the two dominant mining taxes that put into practice, distort decisions at the margin. In contrast, the rent tax is non-distortionary, admittedly under certain simplifying assumptions such as risk-neutral preference.46

Despite its superior theoretical properties the rent tax is not without its drawbacks. There are reservations about the tax administration burdens or the fiscal risks a pure resource rent tax would impose on the host countries.47 Also, as will be discussed, companies can also reduce tax liabilities by reducing the nominal economic rent through cost-shifting, transfer pricing or changing the debt-equity ratio. These potential drawbacks are not

46 In the literature, the ad-valorem tax is commonly referred to as a valued-based royalty. In this paper, the royalty refers specifically to a mining tax that levies a fixed, per-unit charge on the quantity of mineral output, whereas the ad-valorem tax refers specifically to a mining tax that levies charges proportional to the market value of the mineral output. The namesake rent tax, in contrast, levies charges on the proportion of profit that is considered above normal, that is, on economic rent.

47 For instance, in order to preserve, neutrality the rent tax calls for a partial cash refund to offset the cumulative losses a financially unsuccessful project incurs following winding up – even when it has paid no taxes. Otto et al. (2006) provides an extensive qualitative discussion on administrative burden and fiscal risks.
readily quantifiable or observable. Consequently, they are only discussed in the text of many studies but are never formally incorporated into theoretical models. Without a unifying framework, it is impossible to compare the rent tax’s potential drawbacks against the distortions of royalty and ad-valorem tax. The rent tax’s proponents remain confident of its overall advantage, while the skeptics remain skeptical.

This paper attempts to gauge the overall advantage of the rent tax indirectly, by quantifying through simulations the efficiency loss induced by royalty and ad-valorem tax. It may be difficult to estimate the additional administration costs induced by the rent tax as it is very case-specific, but monetizing the efficiency loss of royalty and ad-valorem tax is quite feasible. If the efficiency loss is significant, then the rent tax is likely to outperform notwithstanding its drawbacks; otherwise, royalty and ad-valorem tax are likely better tax instruments notwithstanding the distortions.

This paper is organized as follows. Section 4.2 presents a stylized theoretical model that reiterates the consensus on the non-distortionary nature of the rent tax, as compared to royalty and ad-valorem tax. Section 4.3 presents a spreadsheet model that implements the theoretical model, and also describes the set of parameters relevant for the simulations. Section 4.4 reports the simulation results for multiple scenarios which are characteristic of mines of varying profitability. The core comparison metrics is the monetized efficiency loss caused by royalty and ad-valorem tax. Section 4.5 discusses several model specification and robustness issues. Lastly, Section 4.6 concludes.
The methodology requires the probability distribution of prices (and more broadly other factors that determine economic rents) be known, such that royalty and ad-valorem can be calibrated to yield equivalent expected tax revenue as the rent tax. To anticipate the main findings, the efficiency loss of royalty can be substantial, but that of ad-valorem tax is consistently insignificant. The standard efficiency argument for the rent tax, although valid, is not quantitatively material.

The findings can be interpreted into two ways. A strong claim, which stems immediately from the findings, would be that the rent tax’s potential distortions are likely to outweigh its efficiency gain. However, the methodology presumes the probability distribution of prices be known, a condition that is rarely satisfied. In reality, the ad-valorem tax may be set excessively high causing substantial distortion. A weaker claim would be that an efficiency argument can still be made for the rent tax, because of the impossibility of setting a revenue-equivalent ad-valorem tax. The rent tax owes its efficiency to incomplete information and not to its inherent, non-distortionary properties which are conventionally put forward in the theoretical literature.

4.2 Model Setup
The following model has highly stylized assumptions and abstracts from complications that may lead to inefficient equilibrium in the without-tax scenario. The rent tax’s theoretical advantage is most salient in the absence of complications which, as suggested by Boadway and Keen (2008, 2014), justify interventions that improve efficiency.
For start, suppose a mining company operates a mining field with sufficient ore deposits to sustain extraction for certain duration. Both the company and the host government are risk-neutral, and share the same discount rate. The former’s objective is to maximize profit, and the latter’s is to raise revenue using one of the three tax instruments: royalty, ad-valorem tax, rent tax. The mining field is divided into evenly sized blocks with a uniformly distributed ore grade. In every period, the company extracts ores from one such block to produce mineral. For simplicity, it is assumed that any unextracted ore within this block is irrecoverable in future.

At the beginning of a period, the mineral price fluctuates follows a (two-point) probability distribution which is a common knowledge. Contingent on the price realized, the company makes two joint decisions. The first is whether to operate for one more period, or to terminate the project permanently. The second is to determine the quantity of ore to be extracted, should the project continues. Since there is ore grade difference, the second decision is equivalent to choosing a cut-off grade. For as long as the project is ongoing, the company makes decisions on these two aspects of mining operations.

### 4.2.1 Decisions Without Mining Tax

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48 This second mine characteristics is perhaps more appropriate for underground vein mines than for open pit mines, where it may be possible to extract the periphery or salvage the tailing.

49 In practice, the company has a third option to suspend (mothball) operations until market conditions turn favorable. Here mothballing is omitted since its determining factors are similar to those that influence the closing decision.
This section characterizes the set of factors that affect the company’s decisions in the absence of mining tax. Denote the project’s net present value (NPV) at time $t$ by $\pi_t$, the price at time $t$ by $P_t$, the constant unit cost of extraction and processing by $C$, and the periodic fixed cost by $F$. Suppose the total quantity of ore deposits in each block is one (hundred) ton, and the ore grade follows a uniform distribution: $g = (1 - q)$. If the quantity of ore extracted equals $q$, then the cut-off grade, that is, the quality of the marginal ore mined, is $(1 - q)$. While a project can span multiple periods, its NPV at any period is represented by

$$
\pi_{t,N} = \max_{q \in [0,1]} \int_0^q (1 - x)\, dx P_t - qC - F + \beta E[\pi_{t+1}^N],
$$

where $\beta = \frac{1}{1 + r}$ is the discount factor, and the discount rate $r$ reflects the opportunity cost of capital. The last term, $E[\pi_{t+1}^N]$, is the expected project NPV in the next period and is a function of future prices and the company’s contingent actions. Superscripts are inserted to indicate different mining tax regimes and managerial decisions. The first superscript $N$ (for neutrality) indicates that no mining tax is levied, and the second superscript $C$ indicates that the project continues for one more period.

Since unextracted ore deposits are irrecoverable, the choice of $q_t$ has no impact on future profitability. The optimal extraction quantity satisfies the first order condition:
\[ q_t^N (P_t) = 1 - \left( \frac{C}{P_t} \right)^{50} \] (4-1a)

If the project continues for one more period, its optimized NPV would thus be

\[ \pi_{t}^{N,C} (P_t) = \left( \frac{P_t^2 - C^2}{2P_t} \right) - C + \frac{c^2}{P_t} - F + \beta E[\pi_{t+1}^N]. \]

If it is terminated, the project NPV would be

\[ \pi_{t}^{N,T} = -A, \]

where the second superscript \( T \) stands for termination, and \( A \) is the project’s constant abandonment cost.\(^{51}\)

For any period the project NPV is the maximum of the two functions:

\[ \pi_{t}^{N} = \max \{ \pi_{t}^{N,C} (P_t), \pi_{t}^{N,T} \}. \]

\(^{50}\) If ore deposits are recoverable, the first order condition will include an additional term, \( \frac{\partial}{\partial q_t} E[\pi_{t+1}^N] \), that represents the Hotelling rent. Under this specification, the royalty and ad-valorem tax not only distorts the extraction quantity per-period, but also the intertemporal extraction profile. Applied work by Deacon (1993) and Slade (1984) however show the latter distortion is less significant than the former. In any case, for the purpose of simulations, the distortion from reduced extraction would be maximized when ore deposits are irrecoverable.

\(^{51}\) More realistically, as time progresses more areas are mined and require rehabilitation, which necessitates a higher abandonment cost.
The project will continue as long as the current mineral price is such that \( \pi_t^{N,C}(P_t) \geq \pi_t^{N,T} \). The price threshold (\( \bar{p}_t^{N} \)) for closure is implicitly defined in the equation

\[
\pi_t^{N,C}(\bar{p}_t^{N}) - \pi_t^{N,T} = 0.
\]

This implies

\[
\left( \frac{\bar{p}_t^{N} - C^2}{2\bar{p}_t^{N}} \right) - C + \frac{C^2}{\bar{p}_t^{N}} - F + (1 - \beta)A = 0 \quad \text{if } t \text{ is the last period, (4-1b')}
\]

\[
\left( \frac{\bar{p}_t^{N} - C^2}{2\bar{p}_t^{N}} \right) - C + \frac{C^2}{\bar{p}_t^{N}} - F + \beta E[\pi_{t+1}^{N}] + A = 0 \quad \text{otherwise.} \quad (4-1b'')
\]

Except for the last period, the project’s expected future value \( E[\pi_{t+1}^{N}] \) is an indeterminant that depends on output price forecasts and contingent decisions. Therefore, generally the price threshold \( \bar{p}_t^{N} \) must be solved backward, by first solving \( \bar{p}_{t+1}^{N} \). The project will terminate if the current mineral price falls below this threshold \( (P_t < \bar{p}_t^{N}) \), but will otherwise continue \( (P_t \geq \bar{p}_t^{N}) \).

### 4.2.2 Decisions Under Royalty and Ad-valorem Tax

Now suppose a royalty is levied on the amount of mineral produced at a fixed unit charge of \( \tau \). An ongoing project has a NPV of
\[ \pi^{Q,C}_t(P_t; \tau) = \max_{q \in [0,1]} \int_0^q (1-x) \, dx \, (P_t - \tau) - qC - F + \beta E[\pi^{Q}_t+1]. \]

The superscript \(Q\) (for quantity) indicates the project is subject to a royalty whose tax base is mineral quantity. The optimal ore extraction quantity is given by

\[ q^Q_t = 1 - \left( \frac{c}{P_t - \tau} \right), \quad (4-2a) \]

and the termination price threshold by

\[ \left( \frac{(P^Q_t - \tau)^2 - c^2}{2(P^Q_t - \tau)} \right) - C + \frac{c^2}{(P^Q_t - \tau)} - F + \beta E[\pi^Q_t+1] + A = 0. \quad (4-2b) \]

Instead of a royalty, if an ad-valorem tax of rate \(\phi\) is levied, the project’s NPV then becomes

\[ \pi^{V,C}_t(P_t; \phi) = \max_{q \in [0,1]} \int_0^q (1-x) \, dx \, P_t(1-\phi) - qC - F + \beta E[\pi^V_t+1]. \]

The superscript \(V\) (for value) indicates the firm is subject to an ad-valorem tax that is based on mineral value. The ore extraction function is similar to the previous:

\[ q^V_t = 1 - \left( \frac{c}{P_t(1-\phi)} \right), \quad (4-3a) \]

The price threshold is embedded in the equation
\[
\left(\frac{(\bar{p}^Q_t (1-\phi))^2 - c^2}{2\bar{p}^Q_t (1-\phi)}\right) - C + \frac{c^2}{\bar{p}^Q_t (1-\phi)} - F + \beta E[\pi^V_{t+1}] + A = 0. \tag{4-3b}
\]

From Equations (4-1a), (4-2a) and (4-3a), it is obvious that royalty and ad-valorem tax reduce ore extraction quantity: \(q^N_t \geq \{q^Q_t, q^V_t\}\) for any \(\{\tau, \phi\} > 0\). Consequently, the price threshold is risen: \(\bar{p}^N_t < \{\bar{p}^Q_t, \bar{p}^V_t\}\).\(^{52}\)

### 4.2.3 Decisions Under Rent Tax

The tax base of a resource rent tax is the namesake economic rent. In this paper, attention is restricted to an archetype of the rent tax as proposed by Garnaut and Clunies Ross (1975).

The rent tax allows the company to earn a normal profit that is entirely tax exempt. Determining a firm’s after tax profit requires a characterization of the tax base, which is defined as the firm’s profit in the current period, minus the “normal return allowance” for that period. Only the portion of profit in excess of this allowance is considered economic rent and liable to the rent tax.

Denote the normal return allowance by \(D_t\), whose balance will change depending on the profit made at \(t\). In the following equations, two superscripts are inserted to distinguish

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\(^{52}\) See Proposition 1 in Annex C.
the allowance’s beginning balance (0) and closing balance (1). The evolution of the normal return allowance is described by the following formulae:

\[
D_t^1 = \max\{D_t^0 - \left(\int_0^q (1-x) dx \ P_t - qC - F\right), 0\}^53
\]

\[
D_{t+1}^0 = (1+r)D_t^1.
\]

If the project has experienced a succession of high mineral prices, then the normal return allowance \(D_t\) will approach zero: \(\lim_{P_t \to \infty} D_t^1 = 0\). Conversely, if the project has experienced a market downturn, \(D_t\) increases over time: \(\lim_{P_t \to 0} D_t^1 = D_t^0 + qC + F > D_t^0\). Since economic rent is the tax base, the company is entitled to earning a normal profit that compensate for the cost of capital. If however the cumulative realized profit has been less than normal, the company can earn a profit without taxation, up to the amount of the shortfall plus interest. This is shown in second equation where the closing balance of the allowance in the previous period is carried forward to the next period at an interest rate \((r)\) that reflects the opportunity cost of capital for the company.\(^54\) Since normal profit is tax exempt, the allowance \(D_t^0\) functions as a tax credit.

If cumulative profit is less than normal when the project terminates, the government refunds to the company an amount equivalent to the tax value of the normal return

\(^{53}\) In the first period, all pre-operations expenses \((E)\) such as mine exploration and development costs are added to the allowance at the start of operations: \(D_0^1 = \max\{D_0^0 - \left(\int_0^q (1-x) dx \ P_0 - qC - F - E\right), 0\}\).

\(^{54}\) Fane (1987) and Bond and Devereux (1995) show that the appropriate rate should be risk-free and not risk-adjusted, providing that the government can commit to allowing for full deductible (and refund) of the unused allowance. Be that as it may, this should be the rate of return on capital required by the company. Under some conditions, it is equivalent to the interest rate on riskless bonds.
allowance. Denote tax refund by \( R_t: R_t = TD_t^0 \), where \( T \in [0,1] \) is the rent tax rate. The refund is necessary to ensure that all revenue and cost items in the company’s NPV functions \( \{\pi^{R,C}_t, \pi^{R,T}_t\} \) are reduced by exactly the same percentage \( T \) in present value terms. In effect, the NPV of the project for the mining company is reduced by \( T \) percent, which is transferred to the government.

An operating projects has the profit function

\[
\pi^{R,C}_t(P_t; T) = \max_{q \in [0,1]} \int_0^q (1 - x) dx P_t - qC - F - T \max\{\int_0^q (1 - x) dx P_t - qC - F - D_t^0, 0\} + \beta E[\pi^{R,R}_{t+1}].
\]

The superscript \( R \) (for rent) indicates the firm is subject to the rent tax. If it earns economic profit, that is, when \( \int_0^q (1 - x) dx P_t - qC - F \geq D_t^0 \), the company is liable to taxation. Thus, the optimal ore extraction quantity \( (q^R_t) \) satisfies the first order condition:

\[
\begin{cases}
(1 - q^R_t)P_t = C + T(1 - q^R_t)P_t - C & \text{if } \int_0^{q^R_t} (1 - x) dx P_t - qC - F > D_t^0 \\
(1 - q^R_t)P_t = C & \text{if } \int_0^{q^R_t} (1 - x) dx P_t - qC - F \leq D_t^0
\end{cases}
\]

In the first case, the project earns economic rent and is thus liability to the rent tax – note that the first order condition consists of a tax component \( T((1 - q^R_t)P_t - C) \) that increases the private marginal cost of extraction. In the second case, cumulative profit is
below normal, and the company does not pay rent tax. Regardless, it is obviously that, in either case,

\[ q_t^R = 1 - \frac{c}{p_t} = q_t^N \]  

(4-4a)

The formulation of the rent tax allowance is such that it preserves the equality between marginal revenue and marginal cost of extraction at the pre-tax level, thus preserving neutrality. This is the critical feature that contributes to the rent tax’s much accredited neutrality on mining operation decisions.

If the project continues,

\[
\pi^{R,C}_t (P_t; T) = \left( \frac{P_t^2 - C^2}{2P_t} \right) - C + \frac{C^2}{P_t} - F - T \max \left\{ \left( \frac{P_t^2 - C^2}{2P_t} \right) - C + \frac{C^2}{P_t} - F - D_t^0, 0 \right\} 
+ \beta E[\pi^{R}_t+1]
\]

An abandonment cost \( A \) is incurred at termination, but the company will receive a refund equivalent to the tax value of the normal profit allowance.

\[
\pi^{R,T}_t = R_t - (1 - T)A = TD_t^0 - (1 - T)A.
\]

At the price threshold for closure, the company is indifferent between continuing and terminating the project:
\[ \pi_t^{R,C}(P_t^R; T) - \pi_t^{R,T} = 0, \text{ or} \]

\[
\left( \frac{P_t^R - C}{2P_t^R} \right) - C + \frac{C^2}{P_t^N} - F - T \max \left\{ \left( \frac{P_t^R - C}{2P_t^R} \right) - C + \frac{C^2}{P_t^R} - F - D_t^0, 0 \right\}
\]

\[ + \beta \mathbb{E}[\pi_{t+1}^R] - (TD_t^0 - (1 - T)A) = 0 \tag{4-4b} \]

If time \( t \) is the last period, Equation (4-4b) can be simplified to

\[ \frac{P_t^R - C}{2P_t^R} - C + \frac{C^2}{P_t^R} - F + (1 - \beta)A = 0.55 \tag{4-4b'} \]

For all periods before the last,

\[
\left\{ \left( \frac{P_t^R - C}{2P_t^R} \right) - C + \frac{C^2}{P_t^R} - F \right\} + \beta \mathbb{E}[\pi_{t+1}^N] + A = 0.56 \tag{4-4b''} \]

Since Equation (4-4b') is identical to Equation (4-1b'), and Equation (4-4b'') is identical to Equation (4-1b''), the price thresholds under a rent tax regime is identical to the without-tax threshold, that is, \( P_t^R = P_t^N \) for any period.

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55 See Proposition 2 in Annex C.
56 See Proposition 3 in Annex C.
4.2.4 Distortions under Royalty and Ad-Valorem Tax

A project liable to royalty or ad-valorem tax will extract less ore deposits than if it is liable to the rent tax; recall \( g^O_t, g^V_t < g^R_t \), for \( \{\tau, \varphi\} > 0 \). A price-taking firm chooses a cut-off grade such that the marginal cost of extraction and processing equals the mineral price. Consequent to the mining taxes raising the private marginal cost of extraction, the company leaves underground resources that is otherwise economical to extract without these taxes.\(^{57}\) Since the ore grade are uniformly distributed, the cut-off grade under royalty is greater than that under the rent tax at any mineral price level, \( \{(1 - g^O_t), (1 - g^V_t)\} > (1 - g^R_t) \). In this setup, reduced extraction is akin to the standard high-grading effect in the mining taxation literature.

Note that if ore deposits are recoverable, the choice of extraction quantity will have a bearing on the Hotelling rent. This introduces a distortion of royalty or ad-valorem tax on the extraction profile over the project life, an additional dimension of distortion that is not considered here. However, since irrecoverability implies that unmined resources are lost forever, it actually leads to greater efficiency loss than if the resources are recoverable. Based on the irrecoverability assumption, the simulation as described in Section 4.3 establishes the upper limit of efficiency loss of royalty and ad-valorem tax, vis-à-vis the rent tax.

\(^{57}\) More realistically, depending on the actual mine configuration the company may be able to salvage the unextracted ore or the unprocessed tailing at a later date when market conditions renders this profitable, notwithstanding the taxes. Irrecoverability establishes an upper bound for the potential loss induced by royalty and ad-valorem taxes.
The price threshold for termination is also higher under royalty or ad-valorem tax than is under the rent tax, \( \{P_t^Q, P_t^V\} > \overline{P_t^R} \). When mineral price is between the thresholds, the company will choose to terminate a project (since \( \{P_t^Q, P_t^V\} \geq P_t \)) that it would rather continue under a rent tax regime (since \( P_t > \overline{P_t^R} \)). The immediate conclusion may be that royalty and ad-valorem tax also distort the closing decision.

However, when mineral price is above royalty or ad-valorem tax’s price thresholds, the company will choose to continue regardless of the tax regimes (since \( P_t > \{P_t^Q, P_t^V\} > \overline{P_t^R} \)). Similarly, when mineral price is below the rent tax’s threshold, the project will terminate (since \( \{P_t^Q, P_t^V\} > \overline{P_t^R} > P_t \)). Royalty and ad-valorem tax create no distortion on the firm’s closure decision if either condition is met, although each condition entails a very different fiscal implication for the host government.\(^{58}\) Unlike the distortion on extraction quantity, the distortion on the closing decision is not categorical.

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\(^{58}\) When mineral price is low, the company makes less than normal profit. Upon project termination the government is to reimburse to the company share of the normal profit proportional to the rent tax rate. In comparison, under a royalty or ad-valorem regime, the government has no such obligation. Conversely, high mineral price earns the company more economic rent. The government collects more revenues with a rent tax than with a royalty or ad-valorem tax.
Note: Distortion on the closing decision only occurs at the region between $\overline{P}_t^R$ and $\{P_t^O(\tau), \overline{P}_t^V(\varphi)\}$. When mineral price falls outside this region, the firm will make the same decision regardless of the mining tax regimes. Note that the region will expand when the royalty and ad-valorem tax rates ($\tau, \varphi$) increase.

4.2.5 Other Considerations on the Rent Tax

When both aspects of distortions are considered, the rent tax is non-distortionary on mining operations, and is thus preferred to royalty or ad-valorem tax on efficiency grounds. This notwithstanding, the rent tax suffers from several drawbacks that are not often considered in a standard theoretical model.

First, it is well known that the complexity in monitoring and verifying the rent tax base translates into higher compliance and administration costs. Secondly, the rent tax distorts the capital structure decision. When a project is partially debt-financed, the appropriate financial discount rate used for discounting seems to be the weighted average cost of capital (WACC), which is lower than the equity discount rate. Since the imputed economic rent is less at the (higher) equity discount rate, resource companies react to the rent tax by relying more heavily on equity. The tax incentive that encourages debt-financing under a corporate income tax now encourages equity-financing under the rent tax.

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59 Bond and Devereux (1995) consider that both rates would reduce to a single (default-free) interest rate, “under the conditions of certainty with no bankruptcy risk and no distortionary personal taxes”. In practice, borrowing constraint alone is sufficient to raise the return on equity above the prevailing (default-free) interest rate.
In practice, mining companies can establish special purpose subsidiaries for individual projects. The subsidiary finances a project entirely with equity provided by the parent company, which borrows funds from capital markets. Although the true cost of capital is still the WACC, for tax purposes it is the subsidiary’s nominal equity discount rate that will be used to compute the economic rent. This technique allows the parent company to maintain a desired debt-equity ratio, but reduces tax liabilities at the expense of the host government.

Lastly and in the same vein of argument, the rent tax is vulnerable to common tax avoidance measures such as transfer pricing and income or cost shifting. Transfer pricing opportunities may be more limited for natural resources that are benchmarked and traded in commodities markets, but cost-shifting is difficult to confirm due to information asymmetry and the many opportunities that the subsidiary can award supplier and service contracts to the parent company or its affiliates. When a tax is levied on economic rent, the rent vanishes from account books.

The possibility of tax avoidance is discussed in Garnaut and Clunies Ross (1975). Osmundsen (1995) and Lund (2002) propose principal-agent contracts to determine the appropriate tax schedule in the presence of information asymmetry. However, Boadway and Keen (2008) points out that principal-agent contracts by necessity concede information rent to resource companies and negatively affect government revenue. Instead, Boadway and Keen (2008) find solution in a functioning tax audit system to prevent abuses. Even so, such a system inevitably adds to the compliance and
administration costs. In comparison, tax administration for royalty and ad-valorem tax is simple, and the tax bases are less susceptible to tax management techniques.\textsuperscript{60}

The efficiency argument for the rent tax often focuses on distortions on the cut-off grade or closing decisions. However, when considerations are extended beyond these operations decisions, to financing and tax compliance issues, the advantages of the rent tax become less absolute. The question is an empirical one that cannot be adequately addressed by a theoretical model. Given that the rent tax’s potential distortions are not directly quantifiable, an indirect approach to test for the rent tax’s relative merits would be to quantify, through simulation, the efficiency loss of royalty and ad-valorem tax resulted from highgrading (or equivalently reduced extraction) and premature mine closure. As discussed, royalty and ad-valorem tax indeed distort mining operation decisions, but what is the magnitude of the distortions? If the efficiency loss is significant, the rent tax is likely to outperform. On the other hand, if the loss is marginal, the rent tax loses its relative advantages, and its vulnerability to tax-avoidance may weigh against it.

The next section describes the simulation setup and Section 4.4 reports the simulation results. To anticipate the findings, the efficiency loss of royalty and ad-valorem tax is limited for many scenarios.

\footnote{\textsuperscript{60} The ad-valorem tax is equally susceptible to the transfer pricing, but is immune to the income or cost shifting; a royalty regime is immune to both.}
4.3 Simulation Setup

This simulation attempts to quantify royalty and ad-valorem tax’s distortions at two levels. The first is on the cut-off grade, and the second on the closing decision. The cut-off grade depends on three variables: 1) mineral prices \( (P_t, P_{t+1}, \ldots) \) that affects the current and expected operating profits; 2) variable costs \( C \); and 3) tax burden \( (\tau, \varphi) \). The higher the mineral price, or the lower the operating costs and the tax burden, the less the magnitude of distortion on the cut-off grade. By influencing the project’s current and future operating profits, these three variables also influence the closing decision, alongside the periodic fixed cost \( F \) and the abandonment cost \( A \).

Since the total distortion depends on tax burden, the tax burden must be equivalent for the taxes to be comparable. Henceforth, mining taxes are referred to as revenue-equivalent if they yield the same expected tax revenues for the government in present value terms.\(^{61}\) Recall that the government is assumed to be risk-neutral and has the same discount rate as the mining company. In principle, even at the same price level, taxes that are ex-ante revenue equivalent may induce different behavior.

The spreadsheet financial model implements the theoretical model in Section 4.2.\(^{62}\) It retains the identical set of assumptions and the profit functions:

\[
\pi_t^{Q,C} = \max_{q \in [0,1]} \int_0^q (1-x)dx (P_t - \tau) - qC + \beta E[\pi_{t+1}^Q];
\]

\(^{61}\) This is ex-ante revenue-equivalence. While revenue-equivalence can be defined in the ex-post sense, this definition is not useful as two taxes are rarely revenue-equivalent ex-post.

\(^{62}\) The spreadsheet model will be downloadable at JDI website.
\[ \pi^V_{t,C} = \max_{q \in [0,1]} \int_0^q (1-x)dx \; P_t(1 - \varphi) - qC + \beta E[\pi^V_{t+1}]; \]

\[ \pi^R_{t,C} = \max_{q \in [0,1]} \int_0^q (1-x)dx \; P_t - qC \]

\[ -T \max\{\int_0^q (1-x)dx \; P_t - qC - D_t^0, 0\} + \beta E[\pi^R_{t+1}]. \]

The NPVs at termination are as follows:

\[ \pi^Q_{t,T} = \pi^V_{t,T} = -A \]

\[ \pi^R_{t,T} = TD_t^0 - (1 - T)A. \]

The spreadsheet separately models mining operations under each of the three tax instruments under consideration. There are thus three worksheets, each containing several modules. First of all, there is a mineral price module. Starting from an initial level, the path of mineral price fans out over time as it increases or decreases by a certain percentage every period. This is the only uncertain variable in the model.

Secondly, a cash flow module computes the equity cash flows for each period and at all price levels over the project’s maximum mine life, as if the project cannot be terminated prematurely. In each period, the company optimizes on the extraction quantity depending on the mineral price. This determines the revenues and variable operating costs. Mining tax liabilities is also computed for different tax regimes. The equity cash flows are derived from subtracting variable and fixed operating costs, capital investment and mining tax liabilities from revenues.
Several simplifications are made in this module. First, the project is not subject to corporate income tax, against which royalty or ad-valorem tax are often deductible and is non-existent in an ideal rent tax regime. Secondly, mine development is instantaneous – there is no delay between the mine construction and extraction phase. Lastly, debt financing is omitted, and so are working capital requirement and the economic depreciation and replacement of physical capital. Although it requires little effort to incorporate these missing elements into the spreadsheet model, realism gives way to simplicity to draw crisp comparisons between mining tax regimes.\(^{63}\)

Thirdly, based on the stream of equity cash flows, the project’s NPVs is computed for each period and price scenario over the maximum mine life. Conjoining this is a real options module that compares the NPV if the project continues, against the NPV if it is terminated:

\[
\pi^*_t = \max\{\pi^{*C}_t, \pi^{*T}_t\}.
\]

Since a firm’s current NPV depends on future prices and contingent actions, the firm’s closing decision can only be solved backward and sequentially, beginning from the last period.

---

\(^{63}\) Section 4.5 (Discussions and Robustness of Simulation Results to Model Specifications) assessed the impact of each of the omitted item on the analysis results.
As indicated, for a fair comparison the taxes must be revenue-equivalent. In the simulations, this is achieved by first specifying a rent tax rate, and then finding a royalty levy and an ad-valorem tax rate that, when both types of distortion are accounted for, generate equivalent expected tax revenues as the rent tax.

It is expected that distortion destroys project value. The purpose of the simulation is to gauge how value-destructive royalty and ad-valorem taxes can be. From the perspective of the government, the mining taxes are identical on fiscal grounds. The comparison will thus be on financial grounds, as the taxes may affect mineral operation decisions differently and resulting in different (net of tax) equity NPVs for the company.

In principle, there are three major stakeholders in mining projects: the host government that claims the mining tax revenue, the company shareholders that retains the after-tax cash flows, and lastly the downstream industries that make use of the mineral output. An indicator of economic wellbeing, the economic NPV is the sum of the stakeholder NPVs. For a single mining project, the demand curve it faces is extremely if not perfectly elastic. This implies that the mineral price equals willingness to pay – there is no consumer surplus for the downstream industries. In other words, the economic NPV is simply the sum of the government and equity NPVs. Royalty and ad-valorem tax’s efficiency loss can thus be measured by the difference in equity NPV alone, since tax revenue is held constant by design.
4.3.1 Parameters in Base Case

The following table presents the parameters that populate the spreadsheet model. The parameters are calibrated to yield certain benchmarks, including the operating margin, the payback period, and the project NPV. The parameters’ absolute values are less meaningful than the benchmarks they produce.

<table>
<thead>
<tr>
<th>Table 4-1: Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum project life</strong></td>
</tr>
<tr>
<td><strong>Financial parameters</strong></td>
</tr>
<tr>
<td>Initial mineral price</td>
</tr>
<tr>
<td>Opex - variable costs</td>
</tr>
<tr>
<td>Opex - fixed costs</td>
</tr>
<tr>
<td>Capex</td>
</tr>
<tr>
<td>Abandonment cost</td>
</tr>
<tr>
<td>Financial discount rate</td>
</tr>
<tr>
<td><strong>Benchmarks</strong></td>
</tr>
<tr>
<td>Operating margin</td>
</tr>
<tr>
<td>Payback period</td>
</tr>
<tr>
<td>Project NPV</td>
</tr>
<tr>
<td><strong>Tax parameters</strong></td>
</tr>
<tr>
<td>Rent tax</td>
</tr>
</tbody>
</table>

Project life is assumed to be 16 years, after which the project must terminate.\(^{64}\) Ore grade is uniformly distributed in each of the 16 mining blocks. The initial mineral price is normalized to $100.0 per ton of mineral output, the variable operating cost of extraction and processing is $43.0 per ton of ore extracted, and the fixed costs is $4.0 per period in

\(^{64}\) Although a maximum mine life of 16 years may seem arbitrary, extending it does not overturn the simulation results. The reason is that, for a longer mine life; the parameter values should be re-calibrated to produce comparable project benchmarks.
operation. In the absence of distortion, 57.0 tons of ore will be extracted. The revenues and operating costs are $40.7 and $28.5 ($24.5 for variable cost, $4.0 for fixed cost), respectively. The project generates $12.2 of profits each period. The operating margin, defined here as the ratio between the free cash flow and revenue, is 30.0% (12.2/40.7). The total undiscounted profit is $195.6 over the project life, against an initial capital investment of $68.3 and an abandonment cost of $20.0. The payback period is 5.6 years (68.3/12.2). Altogether, these figures yield a project NPV of $0 at a 20% financial discount rate. In other words, the project earns no economic rent.

For this base case, mineral price is held constant at $100.0 per ton, and there is no mining tax. In subsequent simulations, however, there is a 50% chance that the mineral price moves upward, and a 50% chance that it moves downward. Price volatility varies by scenarios and is a common knowledge. The rent tax rate is set at 40%.

4.3.2 Simulation Scenarios
Since the project does not earn economic rent, revenue-equivalence requires that the royalty be set to zero, which renders the base case uninteresting. The simulation considers six scenarios that alter the base case parameters.

---

65 The extraction and processing cost of $43.0 is calibrated to yield an operating margin of 30% for the base case. In subsequent scenarios, this cost figure will be adjusted upward to keep a higher margin at 60%.
66 This quantity is derived from the first order condition in Equation (4-1a), and corresponds to a cut-off grade of 0.43. The cut-off grade is a direct result of the uniform ore grade distribution assumption and is not realistic.
67 As a robustness check, Section 5 presents simulation results when the financial discount rate is at 10%.
The six scenarios build on each other but introduce one variation at a time. The first scenario (Average Margin) retains all base case assumptions, except that mineral price fluctuates by 15% each year. In the second scenario (High Margin), the before-tax operating margin increases from 30% to 60%. This is achieved by resetting the base case variable operating cost. In the third scenario (High Fluctuation), annual price fluctuation increases from 15% to 30% per year. In the fourth scenario (Halved Capex), the capital investment is halved. In the last two scenarios (Convex and Concave), the ore grade distribution function takes a convex and concave shape, respectively.

The magnitude of distortion increases with tax burden, which is tied to the size of economic rent. Therefore, by increasing the economic rent, the first four scenarios create an environment that renders royalty and ad-valorem tax progressively more distortive. In the fifth scenario, it is hypothesized that the cut-off grade rule that is derived from a convex distribution function should become more sensitive to taxes, also resulting in greater distortion. A concave distribution in the last scenario however is expected to reduce distortion.
4.4 Simulation Results

This section presents the simulation results.

4.4.1 Average Margin

In the first simulation, the annual price fluctuation is 15%. To recapitulate, contingent on the mineral price, the company decides on whether to continue operations, and if so optimizes on the extraction quantity. Once the project is terminated, the mine is closed permanently. Any unmined ore is irrecoverable. From the company’s decisions, the project NPV, mining tax revenues, and the expected project life can be determined. These figures are then weighted by probabilities and discounted to compute their present values at the start of the project.

Simulation results are presented in Column A of Table 4-1 for the rent tax, Column B for royalty, and Column C for ad-valorem tax. Columns D and E present the absolute and percentage differences.

Under the rent tax regime (Column A), the ex-ante project NPV is $5.25. The amount is split between the company (an equity NPV of $3.15 or 60%) and the host government (tax revenue of $2.10 or 40%), proportional to the rent tax rate.

The state of the project over its maximum project life is best described by a series of probabilities that the project will be in operation. For reporting purposes, however, a summary metrics is constructed in the interest of succinctness. Denote the maximum life
of the project by $M$, and the probability that the project be in operation at time $t$ by $p_t$.

The expected duration ($L$) of a project is the sum of the probabilities that the project is in operation: $L = \sum_{t=1}^{M} p_t$. For the rent tax regime, the expected project life is 15.0 of the maximum 16 years. Over the project life, the total expected quantity of ore extraction is 794.7 tons, and the quantity of mineral output is 595.8 tons.

Under the royalty regime (Column B), a royalty levy of $0.99 per ton of mineral output yields the equivalent expected tax revenues for the government. The government NPV remains constant at $2.10 because of revenue-equivalence, while other metrics reduce very negligibly – equity NPV by $0.01, expected mine life by 0.13 year, and mineral output quantities by 5.10 tons, respectively. The ad-valorem regime (Column C) returns similar results.

<table>
<thead>
<tr>
<th>Table 4-3: Simulation Results for Average Margin Scenario</th>
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<tbody>
<tr>
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<tr>
<td><strong>Scenario highlights</strong></td>
</tr>
<tr>
<td>Annual price fluctuation - 15%</td>
</tr>
<tr>
<td>Initial free cash flow as % of revenue – 30%</td>
</tr>
<tr>
<td>(variable opex = $43.0/kg of ore extracted)</td>
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<tr>
<td>Capex – full ($68.3)</td>
</tr>
<tr>
<td>Ore grade distribution – uniform</td>
</tr>
<tr>
<td><strong>Payback period:</strong> 5.6 years</td>
</tr>
<tr>
<td><strong>Mining tax</strong></td>
</tr>
<tr>
<td>40% rent</td>
</tr>
<tr>
<td>$0.99/kg mineral</td>
</tr>
<tr>
<td>0.93% price</td>
</tr>
<tr>
<td><strong>NPVs</strong></td>
</tr>
<tr>
<td>Project</td>
</tr>
<tr>
<td>Equity</td>
</tr>
</tbody>
</table>

68 This metric assigns equal weights to each of the year that the project can be in operation. In addition, note that $p_t \geq p_{t+1}$. 111
<table>
<thead>
<tr>
<th>Government</th>
<th>$ 2.10</th>
<th>2.10</th>
<th>2.10</th>
<th>0.00</th>
<th>0.00</th>
<th>0.0%</th>
<th>0.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mining operation</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected project life (L) year</td>
<td>15.98</td>
<td>14.85</td>
<td>14.98</td>
<td>-0.13</td>
<td>0.00</td>
<td>-1.2%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Ore extracted ton</td>
<td>794.69</td>
<td>784.76</td>
<td>788.14</td>
<td>-9.93</td>
<td>-6.55</td>
<td>-1.2%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Mineral output ton</td>
<td>595.83</td>
<td>590.73</td>
<td>592.53</td>
<td>-5.10</td>
<td>-3.29</td>
<td>-0.9%</td>
<td>-0.6%</td>
</tr>
</tbody>
</table>

Although the company’s mine development decision as a real option is not explicitly modelled, from the minute difference in equity NPVs ($0.01 for royalty and less for ad-valorem tax) it must be the case that the price thresholds for mine development be almost identical across tax regimes. In other words, a tax-free project that is marginally profitable is likely to remain so under royalty or ad-valorem tax.

Recall that the efficiency loss of royalty or ad-valorem tax is measured by the reduction in the equity NPV, when government revenue is held constant and there is no consumer surplus for the downstream industries. Although the loss is nominally incurred by the company, the government may internalize it if the company acquires the mining concession through open tender, in which case its bid would be $0.01 less under the royalty or ad-valorem tax.

For this scenario, the monetized efficiency loss is quite minimal, but the magnitude of distortion will grow as economic rent increases. For present purposes it suffices to introduce the metrics in order to facilitate interpretation of the summary tables in other scenarios.
4.4.2 High Margin

In the second simulation, the variable operating cost decreases from $43.0/kg of ore extracted to $18.8/kg, resulting in an increase in the initial operating margin from 30% to 60% at a fixed mineral price level of $100/kg. Increasing margin shortens the payoff period reduces from 5.6 to 2.4 years.

Under the rent tax regime, the economic rent increases from $5.25 to $95.9. Ore extraction is 1,240 tons and mineral output is 759 tons. Naturally, a higher margin enables the firm to operate at lower mineral prices, thus extending the expected mine life from 15.0 to 16.0 years.

Revenue equivalence calls for the mining taxes to be adjusted upward, to $14.7/kg of mineral output for royalty, and 14.3% of mineral price for ad-valorem tax. The expected tax revenue is $38.35.

In terms of mineral output, 733 tons of mineral will be produced under royalty, and 744 tons under the ad-valorem tax. The reduction in mineral production translates into a reduction in the equity NPV by $0.71 (1.2%) and $0.31 (0.5%).

<table>
<thead>
<tr>
<th>Scenarios highlights</th>
<th>Rent (A)</th>
<th>Royalty (B)</th>
<th>Ad-valorem (C)</th>
<th>Abs. Diff (D)</th>
<th>% Diff (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual price fluctuation - 15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial free cash flow as % of revenue - 60%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Variable cost = $18.8/kg of ore)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Capex – full ($68.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ore grade distribution - uniform

**Payback period:** 2.4 years

<table>
<thead>
<tr>
<th>Mining tax</th>
<th>40% rent</th>
<th>$14.67/kg mineral</th>
<th>14.27% price</th>
</tr>
</thead>
</table>

**NPVs**
- **Project** $ 95.88 95.17 95.57 -0.71 -0.31 -0.7% -0.3%
- **Equity** $ 57.53 56.82 57.22 -0.71 -0.31 -1.2% -0.5%
- **Government** $ 38.35 38.35 38.35 0.00 0.00 0.0% 0.0%

**Mining operation**
- **Expected mine life (L) year** 15.95 15.64 15.91 -0.32 -0.04
- **Ore extracted** ton 1,240.15 1,142.56 1,180.36 -97.58 -59.79 -7.9% -4.8%
- **Mineral output** ton 759.08 733.12 744.35 -25.96 -14.72 -3.4% -1.9%

### 4.4.3 High Price Fluctuation

Greater price volatility increases project NPV because the company can capture the upside potential by increasing output when mineral price is high, and limit losses by terminating the project when the price falls below a threshold. In the third simulation, the annual price fluctuation increases to 30%. The project’s economic rent increases slightly to $100.0. However, the expected project life decreases.\(^{69}\)

The expected mine life under the royalty and the ad-valorem tax regimes are 13.5 and 14.2 year, respectively. The equity NPV is $57.6 under royalty and $59.6 under ad-valorem tax. The loss in the equity NPV represents 6.2% (2.5/40.0) and 1.0% (0.4/40.0)

---

\(^{69}\) The overall effect of increasing price volatility on the closing decision threshold (or equivalently the project life) is ambiguous. On the one hand, it lowers the price threshold, because the reward of a future price rebound is now greater. On the other hand, volatility implies a higher probability that the mineral price falls below the (adjusted) threshold. In this simulation, the second effect dominates.
of government revenues. Starting from this scenario, royalty’s distortion is becoming significant, while the ad-valorem tax’s distortion remain rather modest.

<table>
<thead>
<tr>
<th>Scenario highlights</th>
<th>Rent (A)</th>
<th>Royalty (B)</th>
<th>Ad-valorem (C)</th>
<th>Abs. Diff (D)</th>
<th>% Diff (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual price fluctuation - 30%</td>
<td></td>
<td></td>
<td></td>
<td>A-B</td>
<td>B/A-1</td>
</tr>
<tr>
<td>Initial free cash flow as % of revenue - 60%</td>
<td></td>
<td></td>
<td></td>
<td>A-C</td>
<td>C/A-1</td>
</tr>
<tr>
<td>(Variable cost = $18.8/kg of ore)</td>
<td></td>
<td></td>
<td></td>
<td>B/A-1</td>
<td></td>
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<tr>
<td>Capex – full ($68.3)</td>
<td></td>
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<tr>
<td>Ore grade distribution – uniform</td>
<td></td>
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</tr>
</tbody>
</table>

**Payback period:** 2.4 years

**Mining tax**
- 40% rent
- $17.89/kg mineral
- 15.14% price

**NPVs**
- Project: $100.06, $97.60, $99.65
- Equity: $60.04, $57.57, $59.63
- Government: $40.02, $40.02, $40.02

<table>
<thead>
<tr>
<th>Mining operation</th>
<th>Expected project life (L) year</th>
<th>Ore extracted</th>
<th>Mineral output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.63</td>
<td>1,042.22</td>
<td>695.17</td>
</tr>
<tr>
<td></td>
<td>13.51</td>
<td>867.79</td>
<td>621.74</td>
</tr>
<tr>
<td></td>
<td>14.20</td>
<td>966.75</td>
<td>666.42</td>
</tr>
</tbody>
</table>

**Mining operation**
- Expected project life (L) year
- Ore extracted
- Mineral output

<table>
<thead>
<tr>
<th>4.4.4 Halved Capital Investment</th>
</tr>
</thead>
</table>

In this simulation, the initial capital investment is reduced by half, from $68.3 to $34.2. This implies a payback period of only 1.2 years if mineral price is constant. The project NPV increases instantaneously by the same amount as the reduction in capital investment, to $134.2 ($100.1 + $34.2). The rent tax transfers $53.68 of economic rent to the government, leaving $80.5 to the company. The reduction in capital investment is a windfall gain that affects only the project NPV, and has no impact on the company’s cut-off grade and closing decisions once the project is launched. Therefore, for the rent tax
regime, the mineral output and the expected project life are identical to the third simulation.

To capture the extra economic rent, a revenue-equivalent royalty levy must be set at $25.7/kg of mineral. In this extreme case with high economic rent (as indicated by the payback period of 1.2 years), the royalty has significant distortion on the company’s decision. The expected project life reduces by almost 2 years (from 14.6 to 12.7 years), and the mineral output reduces by 16.0% (from 695 to 584 tons). The resulting equity NPV is $74.8, $5.7 less than that under the rent tax regime ($80.5). The loss in equity NPV is equal to 10.7% of tax revenue (5.7/53.7).

By contrast, a revenue-equivalent ad-valorem tax rate at 20.5% of mineral output price has very modest impact. Expected project life reduces by 0.5 year (to 14.1 years), and mineral output by 41 tons, 5.9% less than the quantity under the rent tax regime. These notwithstanding, the equity NPV is at $79.7, $0.8 less than under the rent tax regime. The decrease in equity NPV is equivalent to 1.6% (0.8/53.7) of expected government revenue.

<table>
<thead>
<tr>
<th>Scenario highlights</th>
<th>Rent (A)</th>
<th>Royalty (B)</th>
<th>Ad-valorem (C)</th>
<th>Abs. Diff (D) A-B</th>
<th>% Diff (E) B/A-1</th>
<th>C/A-1</th>
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<tbody>
<tr>
<td>Annual price fluctuation - 30%</td>
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<tr>
<td>Initial free cash flow as % of revenue - 60%</td>
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<tr>
<td>(Variable cost = $18.8/kg of ore)</td>
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<tr>
<td>Capex – halved ($34.15)</td>
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<tr>
<td>Ore grade distribution - uniform</td>
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<tr>
<td>Payback period: 1.2 years</td>
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<td>Mining tax</td>
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<tr>
<td></td>
<td>40%</td>
<td>$25.69/kg</td>
<td>20.49%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>rent</td>
<td>mineral</td>
<td>price</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPVs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td>$ 134.21</td>
<td>128.49</td>
<td>133.37</td>
<td>-5.72</td>
<td>-0.84</td>
<td>-4.3%</td>
</tr>
<tr>
<td>Equity</td>
<td>$ 80.53</td>
<td>74.81</td>
<td>79.68</td>
<td>-5.72</td>
<td>-0.84</td>
<td>-7.1%</td>
</tr>
<tr>
<td>Government</td>
<td>$ 53.68</td>
<td>53.68</td>
<td>53.68</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>Mining operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected project life (L) year</td>
<td>14.63</td>
<td>12.72</td>
<td>14.11</td>
<td>-1.91</td>
<td>-0.52</td>
<td></td>
</tr>
<tr>
<td>Ore extracted</td>
<td>ton 1,042.22</td>
<td>790.33</td>
<td>936.59</td>
<td>-251.89</td>
<td>-105.63</td>
<td>-24.2%</td>
</tr>
<tr>
<td>Mineral output</td>
<td>ton 695.17</td>
<td>584.22</td>
<td>654.23</td>
<td>-110.94</td>
<td>-40.94</td>
<td>-16.0%</td>
</tr>
</tbody>
</table>

4.4.5 Convex Ore Grade Distribution

All simulations thus far assume the ore grade (g) follows a uniform distribution. With a more convex distribution function, the cut-off grade would become more sensitive to tax burden, thereby leading to greater distortion. In this simulation, the ore grade distribution function is assumed to be convex: \( g = (1 - q)^2 \). Convexity implies that less mineral can be recovered for any level of ore extraction \( q \). The profit functions become

\[
\pi_t^{Q,C} = \max_{q \in [0,1]} \int_0^q (1 - x)^2 dx \ (P_t - \tau) - qC + \beta E[\pi_{t+1}^Q];
\]

\[
\pi_t^{V,C} = \max_{q \in [0,1]} \int_0^q (1 - x)^2 dx \ P_t(1 - \phi) - qC + \beta E[\pi_{t+1}^V];
\]

\[
\pi_t^{R,C} = \max_{q \in [0,1]} \int_0^q (1 - x)^2 dx \ P_t - qC
\]

\[-T \max\left\{\int_0^q (1 - x)^2 dx \ P_t - qC - D_t^0, 0\right\} + \beta E[\pi_{t+1}^R].\]

The cut-off grade decision is governed by the following relationships:
\[
q_t^Q = 1 - \sqrt[Q]{\frac{C}{P_t - r}};
\]
\[
q_t^V = 1 - \sqrt[Q]{\frac{C}{P_t(1 - \omega)}};
\]
\[
q_t^R = 1 - \sqrt[Q]{\frac{C}{P_t}}.
\]

As before, the closing decision is based on a comparison between the profit if the project is continued, and the profit if it is terminated. In order to maintain the initial operating margin at 60%, the variable costs for this simulation is reduced from $18.8/kg of ore extracted to $13.8/kg. The payback period increases slightly to 1.8 years.

Under the rent tax regime, the project NPV reduces to $75.7 because the mine contains less mineral content. The equity NPV is $45.4, and the expected tax revenue is $30.3. Over the 14.6 years of expected project life, 610 tons of mineral will be produced.

Under the royalty regime, the revenue-equivalent levy is $20.5/kg of mineral produced. The expected project life is 13.3 years, and mineral production is 527 tons. The equity NPV is $43.3. The reduction in equity NPV is $2.1, or 6.9% (2.1/30.3) of tax revenues. An unanticipated result is that, as compared to the previous scenario (Halved Capex), the magnitude of distortion actually decreases. This is due to the fact that, with lower economic rent ($75.7 in this scenario against $134.2 in the previous), the royalty levy can be reduced from 25.69/kg to $20.5/kg. The resulting reduction in distortion dominates the opposing effect of a convex distribution function. In determining the magnitude of distortion, the sensitivity of the cut-off grade decision rule to tax burden is less influential.
than the size of the tax burden itself. Nevertheless, an efficiency loss of 6.9% (2.1/30.3) of government tax revenues is significant.

Under the ad-valorem tax, the expected project life is 14.3 years. 576 tons of mineral will be produced. The equity NPV is $45.1, only $0.3 less than that under the rent tax regime. The loss is 1.1% (0.3/30.3) of mining tax revenue.

<table>
<thead>
<tr>
<th>Table 4-7: Simulation Results for Convex Ore Grade Distribution Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario highlights</strong></td>
</tr>
<tr>
<td>- Annual price fluctuation - 30%</td>
</tr>
<tr>
<td>- Initial free cash flow as % of revenue - 60%</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>- Capex – halved ($34.15)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Payback period:</strong> 1.8 years</td>
</tr>
<tr>
<td><strong>Mining tax</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Project</td>
</tr>
<tr>
<td>Equity</td>
</tr>
<tr>
<td>Government</td>
</tr>
<tr>
<td><strong>NPVs</strong></td>
</tr>
<tr>
<td>- Project</td>
</tr>
<tr>
<td>- Equity</td>
</tr>
<tr>
<td>- Government</td>
</tr>
<tr>
<td><strong>Mining operation</strong></td>
</tr>
<tr>
<td>- Expected project life (L) year</td>
</tr>
<tr>
<td>- Ore extracted</td>
</tr>
<tr>
<td>- Mineral output</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

4.4.6 Concave Ore Grade Distribution
This scenario assumes a concave ore grade distribution: \( g = \sqrt{1 - q} \). In view of the last simulation, a concave distribution should lead to greater distortion as compared to the fourth simulation (Halved Capex). The profit functions are as follows:

\[
\pi_{t}^{Q,C} = \max_{q \in [0,1]} \int_{0}^{q} \sqrt{1 - x} \, dx \left( P_{t} - \tau \right) - qC + \beta E[\pi_{t+1}^{Q}];
\]
\[
\pi_{t}^{V,C} = \max_{q \in [0,1]} \int_{0}^{q} \sqrt{1 - x} \, dx \, P_{t}(1 - q) - qC + \beta E[\pi_{t+1}^{V}];
\]
\[
\pi_{t}^{R,C} = \max_{q \in [0,1]} \int_{0}^{q} \sqrt{1 - x} \, dx \, P_{t} - qC - T \max\left\{ \int_{0}^{q} \sqrt{1 - x} \, dx \, P_{t} - qC - D_{t}^{0}, 0 \right\} + \beta E[\pi_{t+1}^{R}]. \tag{70}
\]

These yield the cut-off grade decision rules:

\[
q_{t}^{Q} = 1 - \left( \frac{C}{P_{t} - \tau} \right)^{2};
\]
\[
q_{t}^{V} = 1 - \left( \frac{C}{P_{t}(1 - q)} \right)^{2};
\]
\[
q_{t}^{R} = 1 - \left( \frac{C}{P_{t}} \right)^{2}.
\]

The variable costs is re-calibrated to $23.6/kg of ore extracted in order to preserve the initial operating margin at 60\%, while the capex is still halved (at $34.15). The payback period is 0.9 years.

\[\text{Note that the integral represents the quantity of mineral produced each period. Let } M(q) = \int_{0}^{q} \sqrt{(1 - x)} \, dx = \left( \frac{-2}{3} \right) (1 - q)^{\frac{3}{2}} + C \text{ for some constant } C. \text{ When no ore is extracted, the mineral produced must be zero: } M(0) = 0. \text{ This implies } C = \left( \frac{2}{3} \right), \text{ and thus } M(q) = \left( \frac{2}{3} \right) \left( 1 - (1 - q)^{\frac{3}{2}} \right).\]
The without-tax project NPV is $195.0, which is also the project NPV under the rent tax. At a 40% rent tax rate, the amount is split into $117.0 and $78.0 which accrues respectively to the investor and the government.

Under the royalty regime, a unit levy of $28.5/kg of mineral production will yield the equivalent amount of tax revenue ($78.0) to the government. The equity NPV is $107.3, and the sum of the government and equity NPVs is the project NPV, at $185.3. As compared to the rent tax, the royalty induces a loss of 12.4% (9.7/78). This is greater than the 10.7% loss in the fourth scenario (Halved Capex), and is consistent with the findings in the fifth scenario (Convex). Lastly, under the ad-valorem tax regime with a 22% charge on mineral price, the project NPV is $193.7, and the equity NPV is $115.7. The total distortion is 1.7% (1.3/78.0).

Table 4-8: Simulation Results for Concave Ore Grade Distribution Scenario

<table>
<thead>
<tr>
<th>Scenario highlights</th>
<th>Rent (A)</th>
<th>Royalty (B)</th>
<th>Ad-valorem (C)</th>
<th>Abs. Diff (D)</th>
<th>% Diff (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback period: 0.9 years</td>
<td></td>
<td></td>
<td></td>
<td>A-B</td>
<td>A-C</td>
</tr>
<tr>
<td>Mining tax</td>
<td>40%</td>
<td>$28.52/kg</td>
<td>22.00%</td>
<td>rent</td>
<td>mineral</td>
</tr>
<tr>
<td>NPVs</td>
<td>Project</td>
<td>$194.99</td>
<td>$185.30</td>
<td>$193.66</td>
<td>-9.69</td>
</tr>
<tr>
<td></td>
<td>Equity</td>
<td>$116.99</td>
<td>$107.31</td>
<td>$115.66</td>
<td>-9.69</td>
</tr>
<tr>
<td></td>
<td>Government</td>
<td>$78.00</td>
<td>$78.00</td>
<td>$78.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
### Mining operation

<table>
<thead>
<tr>
<th></th>
<th>Expected project life (L) year</th>
<th>Ore extracted</th>
<th>Mineral output</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.47</td>
<td>12.72</td>
<td>13.60</td>
<td>-1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,191.58</td>
<td>878.12</td>
<td>-313.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,063.97</td>
<td>-127.61</td>
<td>-15.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-313.46</td>
<td>-127.61</td>
<td>-15.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-313.46</td>
<td>-127.61</td>
<td>-15.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-313.46</td>
<td>-127.61</td>
<td>-15.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-313.46</td>
<td>-127.61</td>
<td>-15.92</td>
</tr>
</tbody>
</table>

#### 4.5 Discussions and Robustness of Simulation Results to Model Specifications

The simulations consider multiple scenarios. The different mine characteristics are representative of a wide range of actual mines from a financial standpoint. The first scenario is descriptive of a marginal mine that earns low economic rent. Gradually, the mine characteristics are changed in the direction of increasing the rent.

While the magnitude of distortion under royalty can be sizable when a mine earns high economic rent, ad-valorem tax’s distortion is insignificant. For all the scenarios considered, the ad-valorem tax generates an equivalent amount of tax revenues without giving rise to much distortion. If the rent tax incurs an additional tax compliance and administration costs of as little as 2% of tax revenue, or induces tax avoidance measures resulting in the loss of tax revenue of similar amount, the rent tax’s efficiency gain vis-à-vis the ad-valorem tax will be negated.

Not only are the results for the ad-valorem tax robust for different levels of profitability and ore grade distributions, the distortion estimates are at their upper limits given the irrecoverability and permanent closure assumptions. Moreover, the simulations assume a fixed ad-valorem tax rate. If the tax rate is structured as a sliding scale, the distortion can
be further reduced. Despite its simplistic design, a fixed-rated ad-valorem tax mimics the rent tax well on account of the high positive correlation between the tax bases. High mineral prices translate to high economic rent, and the government can collect approximate revenues using either instrument. On the other hand, the tax bases of both are reduced at low price levels. In this case the ad-valorem tax’s burden is insufficient to alter the decisions drastically. The high correlation of tax base is a key feature that underlies the simulation results.

The remaining of this section accesses the relevance of alternate model specifications, namely a lower financial discount rate; an increasing variable cost function that depends on existing ore stock; and imperfect information. The simulation results hold out against the first two alternate specifications, but are called into question when information is imperfect. Imperfect information being a fact of life, this limitation may suggest a case for the rent tax in practical applications.

First, the simulations assume a financial discount rate of 20%. At a lower discount rate, the economic rent increases. The tax rate of royalty and ad-valorem tax are adjusted upward to preserve revenue equivalence, resulting in greater distortions. A supplementary simulation is run using a lower discount rate of 10%. Aside from this change, the scenario is identical to that described in the last (Concave). Table 4-9 reports the simulation results. For the ad-valorem tax, a distortion of 2.0% (2.43/119.74) is insignificant, and the parametric specification on the financial discount rate is immaterial.
Table 4-9: Simulation Results Low Discount Rate Scenario

<table>
<thead>
<tr>
<th>Scenario highlights</th>
<th>Rent (A)</th>
<th>Royalty (B)</th>
<th>Ad-valorem (C)</th>
<th>Abs. Diff (D)</th>
<th>% Diff (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A-B</td>
<td>B/A-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A-C</td>
<td>C/A-1</td>
</tr>
<tr>
<td>Payback period:</td>
<td>0.9 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining tax</td>
<td>40%</td>
<td>$32.99/kg</td>
<td>22.62%</td>
<td>-20.62</td>
<td>-6.9%</td>
</tr>
<tr>
<td></td>
<td>rent</td>
<td>mineral</td>
<td>price</td>
<td>-2.43</td>
<td>-0.8%</td>
</tr>
<tr>
<td>NPVs</td>
<td></td>
<td></td>
<td></td>
<td>-11.5%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>Project $</td>
<td>299.36</td>
<td>278.74</td>
<td>296.93</td>
<td>-20.62</td>
<td>-6.9%</td>
</tr>
<tr>
<td>Equity $</td>
<td>179.62</td>
<td>159.00</td>
<td>177.19</td>
<td>-2.43</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Government $</td>
<td>119.74</td>
<td>119.74</td>
<td>119.74</td>
<td>0.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>Mining operation</td>
<td></td>
<td></td>
<td></td>
<td>-18.4%</td>
<td>-5.9%</td>
</tr>
<tr>
<td>Expected project life (L) year</td>
<td>13.77</td>
<td>11.93</td>
<td>12.90</td>
<td>-1.84</td>
<td>-0.88</td>
</tr>
<tr>
<td>Ore extracted ton</td>
<td>1,175.63</td>
<td>825.88</td>
<td>1,043.51</td>
<td>-349.75</td>
<td>-29.7%</td>
</tr>
<tr>
<td>Mineral output ton</td>
<td>729.29</td>
<td>594.87</td>
<td>685.98</td>
<td>-134.42</td>
<td>-18.4%</td>
</tr>
</tbody>
</table>

In the simulations, the marginal extraction and processing cost is constant and independent of existing ore stock. When the cost increases with depleting ore stock, complexity grows exponentially since the extraction quantity at present would have a bearing on future profitability that in turns influences the present termination decision. A simulation will not be attempted, but deduction from previous findings lends weight to the view that efficiency loss would reduce with this functional specification. Recall the size of the economic rent has a first-order impact on the magnitude of distortion. When operating costs increase with depleting ore stock, the economic rent necessarily decreases. Consequently, the revenue-equivalent ad-valorem tax rate can be lowered. Reduced tax burden thus translates to reduced distortions.
Recall the simulations make several simplifications, including (i) corporate income tax, (ii) instantaneous mine development, and omissions of (iii) debt financing, (iv) working capital requirements, and (iv) depreciation and replacement of physical capital. The impact of each of these on the analysis results can be assessed by examining their individual impact on the size of total economic rent and the sensitivity of operations (cut-off grade and closing) decisions to the tax rates. To recapitulate, the former dominates the latter in determining the change in the magnitude of distortion.

In practice, royalty and ad-valorem tax are typically treated as an operating expense and deductible against corporate income tax. This reduces the sensitivity of the operation decisions to the statutory tax rate of royalty and ad-valorem tax, leading to less distortion. When mine development is not instantaneous, mineral prices during the extraction phase becomes more uncertain as price paths diverge during mine development. For reasons discussed in Section 4.3.3, the economic rent will increase with greater price fluctuation, leading to more distortion since the revenue-equivalent tax rate is set at a higher level.

The assessment of debt financing requires qualifications. If it is assumed the calculation of economic rent is based on the true cost of capital, then debt financing would reduce the WACC, thereby increasing the economic rent and thus the ad-valorem tax’s distortion. However, as discussed, a company subject to the rent tax can invest through a special purpose subsidy, in which case there will be no change to the imputed economic rent and distortion. The effect of working capital requirements on distortion is ambiguous and in
any case is unlikely to be significant. Lastly, economic depreciation necessitates periodic capital replacement, which reduces economic rent and distortion.

Comparisons between the mining taxes are established on the principle of revenue equivalence, which in turn is predicated on some knowledge about the project’s economic rent. In the simulations, the only fluctuating variable is mineral price. In reality the unknown price is better characterized as an uncertainty than as a risk. Except for rare occasions in which the project company enters fixed price sales agreements, price fluctuation is highly unpredictable to the degree that it cannot be assigned with a probability distribution. As such, a revenue-equivalent ad-valorem tax would be infeasible. The ad-valorem rate may be too low such that the tax fails to secure for the government as much tax revenue as the rent tax, or too high that it leads to distortions exceeding the 1.7%.

4.6 Conclusions
This paper first develops a stylized theoretical model that demonstrates the royalty and ad-valorem tax’s distortions on the cut-off grade and mine closure decisions. Neither is the theoretical model nor its conclusions innovative by any means. However, it provides a framework for simulations which return unconventional results. The simulations quantify the magnitude of the distortions by comparing the performance of royalty and ad-valorem tax against the rent tax. The former’s distortion losses are from reduced mineral production, but the measurement is expressed in monetary terms. Given revenue
equivalence, the ad-valorem tax’s efficiency loss is limited to 1.7% of expected tax revenue. The simulation results are robust in different project profitability scenarios and model specifications.

It is important to emphasize that the result are obtained under extreme circumstances – unextracted ores are non-recoverable, and the project is highly profitable as indicated by the payback period. Since actual resource projects rarely achieve this level of profitability, distortions on the real projects should be greatly limited – so much so that even the royalty may become a comparably efficient tax instrument as in Scenarios 1 (Average Margin) and 2 (High Margin). That said, it is equally important to emphasize that the simulations presumes some level of predictability on the economic rent in order to set revenue-equivalent tax rates. This assumption is however rarely satisfied in reality.

By itself and in the highly stylized manner put forward in the theoretical literature, the standard efficiency argument is sufficiently challenged by the simulation findings. What little efficiency gain the rent tax may yield, it is likely to be negated by the rent tax’s higher tax administration costs and susceptibility to tax avoidance measures that lead to a loss of set government revenue. However, as an ad-valorem tax may be substantially distortionary in practice. This methodological limitation suggests that an alternative efficiency argument for the rent tax can still be made, based on an information problem which renders revenue-equivalence infeasible, and not on the rent tax’s inherent non-distortionary properties.
Bibliography


Appendix A

A Stylized Explanation on How Eroded Traceability Will Reduce Coffee Export Price

Suppose there are two coffee types, A and B in Ethiopia. Outside Ethiopia, there are two groups of overseas coffee buyers whose respective client groups are partial to a particular coffee type.\textsuperscript{71} Clients of the first group prefer Coffee A, and those of the second prefer Coffee B, with both willing to pay a higher price for the preferred coffee. As intermediaries in the global coffee supply chain, overseas buyers’ valuations of coffees derive from their client’s valuations. Thus, the first group’s valuation of Coffee A is higher than its valuation of Coffee B. Conversely, the second group’s valuation of Coffee B is higher than its valuation of Coffee A. Let \( V_{IJ} \) be buyer of type I’s valuation of Coffee J, where I and J can be A or B. Overseas buyer’s valuation of the two types of coffee can be expressed as follows:

\[
V_{AA} > V_{AB}, \quad \text{Assumption (1)} \\
V_{BB} > V_{BA}. \quad \text{Assumption (2)}
\]

It can be assumed that overseas buyers have equal valuation of their preferred coffee, that is,

\[
V_{AA} = V_{BB}. \quad \text{Assumption (3)}
\]

\textsuperscript{71} The number of buyers in each group should be sufficiently large such that their price offers to exporters will be competitive.
\[ V_{AB} = V_{BA}. \] Assumption (4)

The immediate implications, that \( V_{AA} > V_{BA} \) and \( V_{BB} > V_{AB} \) are necessary to prevent one group of buyers outbidding the other group for both coffees.\(^72\)

Ethiopian exporters may either accept or reject the overseas coffee buyers’ offers. Let \( P_I \) be buyer of type I’s price offer to exporters that supply Coffee J. Should the exporters accept the offers, the payoffs would be \( V_{IJ} - P_I \) and \( P_I \), respectively for the successful buyers of type I and exporters that supply coffee of type J. Should the exporters reject all the offers, the payoff for both would be zero.\(^73\)

Now consider two coffee export systems. In the first system, there are mechanisms that 1) reveal to buyers the types of coffee that exporters are holding before the actual purchases; and 2) guarantee that the information on coffee type is credible. In other words, buyers have complete information about coffee types, and type-specific contracts are enforceable.

\(^72\) In itself, one group buying all coffees does not lead to a fallacious argument but merely creates inconvenience in the narration. In place of Assumptions (3) and (4), alternative sets of assumptions can be used: \( V_{AA} > V_{BB} > V_{BA} \) or \( V_{AA} > V_{BB} > V_{AB} > V_{BA} \). Note that Assumptions (1) and (2) are preserved.

\(^73\) Although a simplifying assumption, that exporters have no outside option may not be far from reality given that exporter licenses permit holders only to export coffee. Supplying coffee to the domestic market would require a different license, and it is illegal to sell export-grade coffee domestically. In addition, stockpiling is considered a criminal offense. In March 2009, boarding coffee and depriving Ethiopia of its much needed foreign exchange earnings. The ECX trading licenses of these six exporters were also suspended (Reuters, Mar 2009). In May 2011, the government issued a directive which forbids exporters holding more than 54 tonnes of coffee without a legal shipment contract signed for it, on pain of being banned from the ECX for two months. Those found holding in excess of 500 tonnes will be banned for three months (Bloomberg, May 2011). Considering these restrictions, the outside option for exporters may even be negative.
Figure A-1: Extensive Form Game with Complete Information

Given a sufficiently large number of buyers to rule out cartels, open biddings between buyers ensures their price offers would approach their true valuation, $P_{IJ} = V_{IJ}$, for $I$ and $J$ equal to A or B. Furthermore, given Assumptions (1) to (4), the first group of buyers’ price offer for Coffee A will be higher than that of the second group, and the second group’s price offer for Coffee B will be higher than that of the first group:

$$P_{AA} > P_{BA}, \text{ and } P_{BB} > P_{AB}.$$  

Drawn by a higher price, the exporter of Coffee A will supply to the first group of buyers, and the exporter of Coffee B to the second group. The outcome of this game is characterized by spontaneous matching of exporters and buyers by coffee type.
The second system mingles the coffees before delivery such that neither exporters nor buyers can creditably identify the coffee types. Figure A-2 illustrates the structure of this game:

**Figure A-2: Extensive Form Game with Incomplete Information**

This game is similar to the previous one, except that chance or “nature” determines the type of coffees an exporter will receive. To guide bidding decisions, overseas buyers form a priori belief about the coffee being type A with probability $\rho$ and being type B with probability $(1-\rho)$.

Two types of equilibrium are plausible. A separating equilibrium however is infeasible since non-traceability renders type-specific contracts non-enforceable. The second, pooling equilibrium is one where the two types fetch the same price that equals to the
average of $P_{AA}$ and $P_{AB}$, or of $P_{BB}$ and $P_{BA}$, weighted by buyers’ belief about coffee type. Let $P_I$ denote this price, and

$$P_I = \rho P_{AA} + (1-\rho)P_{AB} = \rho P_{BA} + (1-\rho)P_{BB}. $$

Non-traceability limits the outcome of this game to just one: Coffee A and Coffee B will be sold at a common price $P_I$, as defined above. The common price is less than what is otherwise attainable if coffee types are ascertain, $P_I < P_{AA}$ and $P_I < P_{BB}$. This outcome ensues not from the mismatch between buyer preference and coffee type at delivery. Even when overseas buyers receive the preferred coffee in actuality, their valuation would remain at $P_I$ in the absence of credible information about the coffee type.
Appendix B

Key Financial and Economic Parameters on Peru LNG

Financial Parameters

**Project life:** The project life is for 20 years, inclusive of two years of construction period starting 2008.

**Investment cost:** According to capital budgeting, the total investment for the LNG plant, the gas pipeline and the marine facilities was estimated to be 3.97 billion USD (IFC, 2008). However, credit reports reveal the actual investment to be 3.17 billion. The total investment cost is taken to be 3.17 billion USD in this study.

**Loan structure:** PLNG obtained loans from several institutions that totaled 2.25 billion USD. IDB alone lent 400 million and arranged another 400 million of syndication loan. IFC also contributed 300 million. The average loan life is around 17 years, with two year grace period; the weighted (nominal) interest rate is 4.27 percent per annum. Annual principal repayment begins in 2011 and averages 150 million. The following table presents projected investment costs and the financing plan.

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Table B.1: PLNG Uses and Sources of Fund Statement

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74 Own derivation based on Equilibrium (2012a).
75 The discrepancy of 0.8 billion can be reconciled by the facts that capital budgeting makes allowances for contingencies; at a 15% cost overrun factor the contingencies is around 475 million. In addition, capital budgeting includes 245 million for interest during construction (IDC) and a debt service reserve account (DSRA) of 134 million. The credit reports may not include these items as investment expenses.
76 Own derivation based on Apoyo and Associates (2011) and Apoyo and Associates (2012a).
### Project Costs

<table>
<thead>
<tr>
<th>Construction costs</th>
<th>million USD</th>
<th>%</th>
<th>Financing Plan</th>
<th>million USD</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG plant</td>
<td>2,363</td>
<td>59%</td>
<td>IFC</td>
<td>300</td>
<td>7.6%</td>
</tr>
<tr>
<td>PLNG pipeline</td>
<td>785</td>
<td>20%</td>
<td>USEXIM</td>
<td>400</td>
<td>10.1%</td>
</tr>
<tr>
<td>Management costs</td>
<td>221</td>
<td>6%</td>
<td>IDB A Loan</td>
<td>400</td>
<td>10.1%</td>
</tr>
<tr>
<td>G&amp;A</td>
<td>96</td>
<td>2%</td>
<td>IDB B Loan</td>
<td>250</td>
<td>6.3%</td>
</tr>
<tr>
<td><strong>Total construction costs</strong></td>
<td><strong>3,465</strong></td>
<td><strong>87%</strong></td>
<td>Local Bond</td>
<td>350</td>
<td>8.8%</td>
</tr>
<tr>
<td>Financing costs</td>
<td>128</td>
<td>3%</td>
<td>SACE</td>
<td>250</td>
<td>6.3%</td>
</tr>
<tr>
<td>Interest during construction</td>
<td>245</td>
<td>6%</td>
<td>Total debt</td>
<td><strong>2,250</strong></td>
<td><strong>56.6%</strong></td>
</tr>
<tr>
<td>Debt service reserve account</td>
<td>134</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total financing costs</strong></td>
<td><strong>507</strong></td>
<td><strong>13%</strong></td>
<td>Equity</td>
<td><strong>1,722</strong></td>
<td><strong>43.4%</strong></td>
</tr>
<tr>
<td><strong>Total project cost</strong></td>
<td><strong>3,972</strong></td>
<td><strong>100%</strong></td>
<td>Total project funding</td>
<td><strong>3,972</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Source: IFC (2008)

### Revenue:

The PLNG plant has an installed capacity to produce LNG that is equivalent to 218 trillion British thermal units (TBtu) in energy unit. The entire LNG output of 218 TBtu is sold and loaded to tankers operated by Repsol CG Commercialización de Gas S.A. (hereafter Repsol CG), under an 18-year term LNG sales and purchase agreement (LSPA).

Since the LNG sales price is set as a function of the price Repsol CG receives from its clients, it is necessary to mention how the latter disposes of the LNG. Repsol CG had a gas supply agreement with Mexico’s state-owned power company for up to 18 years,

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77 To be technically precise, the LNG plant has a nominal capacity of 4.4 million metric tons per annum (MMTA), as it is an industry practice to express LNG output in weight unit. However, for the purpose of this paper, gas quantity is more conveniently expressed either in energy unit (Btu) or in volume unit (cubic feet), depending on the context. Energy unit is preferable for gauging the monetary value of the gas, since gas price is quoted in US dollars per million British thermal unit (USD/MMBtu). Volume unit is preferable when comparing gas quantity with the country’s available reserves, which is given in cubic feet (or cubic meter). While all three measures are convertible, this paper drops the weight unit to avoiding adding to the confusion.

78 Repsol CG is a subsidiary of a key consortium member (Repsol SA) with a stake interest in Consorcio Camisea and PLNG.
beginning 2011. Mexico’s initial uptake per annum was 10.8 TBtu but will increase to 144 TBtu in 2015. Mexico’s peak uptake being two third of that supplied by PLNG, Repsol CG sells the surplus in Asian and European markets on an ad hoc basis. The gas to Mexico is priced at 0.03 USD less than 91% of the Henry Hub index, which is expressed in USD per million British thermal unit (USD/MMBtu). Sales in other markets are determined by spot price. It is assumed in this study that the remaining one third is sold to the Asian market where gas price has been the highest.

Regardless of the destinations, the price that PLNG will receive from Repsol CG is determined as follows:

<table>
<thead>
<tr>
<th>LNG price in overseas markets (P_{OM})</th>
<th>LNG sales price (P_{LSPA})</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{OM} ≤ 4</td>
<td>43% of P_{OM} + 0.57</td>
</tr>
<tr>
<td>4.5 &lt; P_{OM} &lt; 7.5</td>
<td>70.75% of P_{OM} - 0.72</td>
</tr>
<tr>
<td>7.5 ≤ P_{OM} &lt; 10</td>
<td>72% of P_{OM} - 0.76</td>
</tr>
<tr>
<td>P_{OM} ≥ 10</td>
<td>78.75% of P_{OM} - 1.4</td>
</tr>
</tbody>
</table>

Source: Equilibrium (2011)

To facilitate understanding, consider the first line in the table. When LNG price in overseas markets (P_{OM}) is 4.5 USD/MMBtu or less, PLNG would receive 43% of the overseas price, plus 57 US cents. The gas sales price is hereafter referred to as the LNG sales and purchase agreement price (P_{LSPA}).

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79 The contract has a 15-year fixed term with a potential extension for three more years. If extended, the gas supply agreement will perfectly overlap the project life.
80 Since Repsol CG began shipping LNG in June 2010, the common destinations have included Mexico, Spain, the United States and Japan.
81 To give a numerical example, if the Henry Hub price is 1 USD/MMBtu, Repsol CG would receive 88 US cents for the LNG that is shipped to Mexico.
**Gas purchase:** PLNG has an 18-year gas supply agreement with Consorcio Camisea, which provides gas at a volume of 620 MCF per day, totaling 4.2 TCF over the project life. The gas supply agreement price (P_{GSA}) is a function of overseas price (P_{OM}), as follows:

![Table B.3: Determination of Gas Purchase Price for PLNG (USD/MMBtu)]

<table>
<thead>
<tr>
<th>Overseas price (P_{OM})</th>
<th>2.00</th>
<th>3.00</th>
<th>4.00</th>
<th>5.00</th>
<th>6.00</th>
<th>7.00</th>
<th>8.00</th>
<th>9.00</th>
<th>10.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSA price (P_{GSA})</td>
<td>0.06</td>
<td>0.12</td>
<td>0.15</td>
<td>0.16</td>
<td>0.24</td>
<td>2.03</td>
<td>2.34</td>
<td>2.96</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Source: Equilibrium, 2012

PLNG pays to Consorcio Camisea a minimum price of 0.06 USD/MMBtu, if the overseas price (P_{OM}) is no more than 2 USD/MMBtu. If instead the overseas price is above 10 USD/MMBtu, the gas purchase price is 3.57 USD, plus 61 US cents for every dollar of the overseas price exceeding 10 USD.

**Gas transportation:** PLNG has an agreement with the consortium that was awarded the transportation concession, for the transportation of gas from Camisea to PLNG’s own feedstock pipeline. Recall that both consortiums as well as Consorcio Camisea are owned by essentially the same group of international oil and gas companies. The service fee follows a scheme similar to the one above and is not transcribed here (Equilibrium, 2012).
Other operating costs: G&A costs, LNG plant and pipeline operating costs are expected to be 10 percent and 2.5 percent of income, respectively.82

Corporate income tax (CIT): Peru’s statutory CIT rate is 30 percent.

Tax depreciation rule: Peruvian tax law applies the straight line depreciation method. For the extractive industries (mineral, oil and gas), the maximum depreciation allowance is 20% of cost per year for tangible assets, and 10% for intangible assets (RLNA, 2010). It is assumed that PLNG claims the maximum capital allowance to defer CIT payments.

Royalty: The determination of royalties follows an elaborate scheme. In essence, royalties for each LNG shipment is derived by multiplying the royalty rate by the tax base.

The royalty rate is a function of the overseas price (P_OM). For 4 USD/MMBtu or less, the rate is 30%; for 5 USD/MMBtu or above, the rate is 38%. For intermediate values, the rate (τ%) is determined by the linear interpolation method.

Table B.4: Determination of Royalties Rate (%)

<table>
<thead>
<tr>
<th>Overseas price (P_OM, USD/MMBtu)</th>
<th>≤ 4</th>
<th>∈ (4.5)</th>
<th>≥ 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Royalties rate (%)</td>
<td>30%</td>
<td>τ%</td>
<td>38%</td>
</tr>
</tbody>
</table>

Source: Block 56 License Agreement, Section 8.3.3.

82 Own derivation based on Pacific Credit Rating (2012).
The tax base is the maximum of the gas supply agreement price \( (P_{\text{GSA}}) \), and a minimal reference value \( (\text{MRV}) \) that is indexed to the overseas price \( (P_{\text{OM}}) \): 

| Table B.5: Determination of Royalties Base (USD/MMBtu) |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Oversea price \( (P_{\text{OM}}) \) | 3.5 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 |
| Minimum reference value \( (\text{MRV}) \) | 0.50 | 0.53 | 0.63 | 0.79 | 0.97 | 1.18 | 1.47 | 1.76 |
| GSA price \( (P_{\text{GSA}}) \) | 0.14 | 0.15 | 0.16 | 0.24 | 2.03 | 2.34 | 2.96 | 3.57 |
| Royalties base, \( \text{Max}\{P_{\text{GSA}},\text{MRV}\} \) | 0.50 | 0.53 | 0.63 | 0.79 | 2.03 | 2.34 | 2.96 | 3.57 |

Source: Own derivation based on Block 56 License Agreement, Section 8.2.9.

In summary, the royalty payment for each MMBtu of gas extracted is determined as follows:

\[
\text{Royalties payments} = \begin{cases} 
30\% \text{ of } \max\{P_{\text{GSA}}, \text{MRV}\}, & P_{\text{OM}} \leq 4 \text{ USD/MMBtu} \\
\tau\% \text{ of } \max\{P_{\text{GSA}}, \text{MRV}\}, & P_{\text{OM}} \in (4, 5)\text{USD/MMBtu} \\
38\% \text{ of } \max\{P_{\text{GSA}}, \text{MRV}\}, & P_{\text{OM}} \geq 5 \text{ USD/MMBtu}
\end{cases}
\]

where \( \tau \) is determined by the linear interpolation method. As a reminder, the offtaker Repsol CG has arranged to sell two third of the LNG to Mexico, at a price that is indexed to the Henry Hub index. Price fluctuations at Henry Hub thus have a significant impact on royalty collection.

PeruPetro, a state-owned enterprise responsible for negotiating oil and gas projects on the government’s behalf, regularly releases information about the overseas price and royalty collection from each LNG export shipment. Given a published overseas price, the
model’s royalty estimate closely matches that in PeruPetro’s report (to the first decimal place). This gives confidence that royalty payment is modelled precisely.

**Economic Parameters**

The outcome of the economic analysis hinges critically on a set of parameters, including energy price forecasts, projected domestic demand and mostly importantly the size of Peru’s natural gas reserves. This study considers three scenarios that vary in this set of parameters.

**Economic discount rate**: An economic discount rate of 8 percent (real) is assumed throughout the analysis.

**Energy price forecasts**: IDB commissioned Apoyo Consultoria to conduct a study on the economic impact of the Camisea project on Peru. Although the Apoyo report gives brief treatment to Camisea II, it contains information on oil price and domestic demand forecasts at that time. In this study, the price forecasts for various petroleum products (gasoline, diesel, LPG and residual oil) are taken from the Apoyo report. Since the report does not provide gas price forecasts, they are taken from U.S. Energy Information Agency’s (EIA) 2008 report for Scenarios 1, and its 2013 report for Scenarios 2 and 3, respectively.
**Natural gas reserve estimates:** The Ministry of Energy and Mines (MEM) releases annual reports on the country’s natural gas reserves.

**Domestic gas demand forecasts:** The demand forecast for Scenario 1 is taken from the Apoyo report. The forecast for Scenarios 2 and 3 is from MEM’s latest report on this matter (MEM, 2012). The forecast period is from 2010 to 2033 in the former, and from 2013 to 2040 in the latter. Beyond the forecasted periods, it is assumed that demand will grow at the respective long term average rates. In both reports, the total demand is disaggregated by the type of users: public utilities that run power plants, industrial users, residential households and natural gas vehicles. Approximately 60% of the demand stems from public utilities, 30% from industrial users and 10% from other types of users. The Apoyo report did not foresee a strong demand springing from the petrochemical industry. While the MEM report predicts a total demand of 3.4 TCF from the petrochemical sector, the figure is not included in this analysis for Scenarios 2 and 3.83

**Future oil import duration:** Natural gas being a non-renewable resource, the depletion of reserves is inevitable. Its eventual occurrence, however, can be deferred in the absence of LNG export. In this analysis, the duration of oil import is the period between when depletion is expected to occur in the with-project scenario, and when depletion is expected to occur in the without-project scenario.

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83 Adding potential demand from the petrochemical industry would only hasten gas depletion.
**Future oil import estimate**: The quantity of oil import required is computed by first identifying the energy content released by natural gas in the ways it is used by domestic consumers, and secondly by determining the number of barrels of oil required to produce the same amount of energy.

Natural-gas-fired power plants are typically more efficient than fuel-oil-fired plants. It takes around 8,200 Btu of natural gas to generate one kilowatt-hour (kWh) of electricity, as compared to 11,000 Btu of petroleum products (EIA, 2011).\(^{84}\) Since each MMCF of natural gas contains around 1,100 MMBtu, and each barrel of fuel oil contains about 5.98 MMBtu, it can be inferred that, for the purpose of electricity generation, replacing one MMCF of natural gas would require approximately 247 barrels of fuel oil.\(^{85}\) Multiplying MEM’s forecasted demand from public utilities (MMCF) in any year by 247 (barrel/MMCF) would yield the volume of oil replacement (barrels) for that year.

For residential and industrial consumers, the predominant usage of natural gas is as a heating fuel. The heating value measures the amount of heat released by an energy source when combusted. The higher heating value (HHV) of natural gas is 1,100 Btu per cubic feet, and that for petroleum products (gasoline, diesel, LPG and residual oil) range between 12,500 Btu to 150,000 Btu per gallon.\(^{86}\) The number of oil barrel replacement for each type of users can be determined in a similar manner as described above: first by

\[ \frac{11000 \text{ MMBtu}}{\text{MMCF}} \times \frac{0.0082 \text{ MMBtu}}{\text{kWh}} \times \frac{0.011 \text{ MMBtu}}{\text{kWh}} \div \frac{5.98 \text{ MMBtu}}{\text{barrel}} = 246.8 \text{ barrels/MMCF}. \]

\(^{84}\) The amount of energy required to generate one kWh of electricity is called the heat-rate and is expressed in Btu/kWh.

\(^{85}\) Own derivation based on Beychok (2012).

\(^{86}\) Own derivation based on Beychok (2012).
converting the user’s gas demand (MMCF) into energy unit (MMBtu), and secondly into barrels of oil replacement using a weighted average of heating values for various petroleum products, with the weights corresponding to the composition of the user’s petroleum consumption.\(^{87}\)

**Structure of the economic model:** An economic model is built upon the financial model. The model keeps track of the reserves remaining and the earliest depletion year for the with-project scenario and the without-project scenario. It also computes the barrels of oil replacement and the associated costs, under different reserves and price scenarios. During PLNG’s project life, the net benefit for Peru is positive because of CIT and royalties; the economic cost of future oil import will only be realized after the date of reserve depletion. The economic NPV is derived from the discounted stream of benefits and costs.

\(^{87}\) For example, according to Apoyo (2007), the industrial sector’s petroleum consumption consists of 60% residual oil, 30% LPG and 10% diesel. The heating value used for conversion is a weighted average of the heating values of residual oil, LPG and diesel.
Appendix C

Relations between Price Thresholds

**Proposition 1 (Section 4.2.2)**

**Claim:** $\overline{P}_t^N < \{\overline{P}_t^Q, \overline{P}_t^V\}$. This is most apparent when the current period $t$ is also the last.

Observe the following:

1. at termination the abandonment cost is identical, that is, $\pi_t^{*,T} = -A$
2. $\pi_t^{Q,C}(P_t; \tau) = \max_{q \in [0,1]} \int_0^q (1-x)dx \ (P_t - \tau) - qC - F - \beta A$
   
   $= \max_{q \in [0,1]} \int_0^q (1-x)dx \ P_t - qC - F - \beta A - \int_0^q (1-x)dx \ \tau$
   
   $= \pi_t^{N,C}(P_t) - \int_0^q (1-x)dx \ \tau$
   
   $< \pi_t^{N,C}(P_t), \forall \tau > 0$
3. $\frac{\partial \pi_t^{Q,C}}{\partial P_t} > 0$

That $\overline{P}_t^N < \overline{P}_t^Q$ can be demonstrated by the following:

$\pi_t^{N,C}(\overline{P}_t^Q) > \pi_t^{Q,C}(\overline{P}_t^Q; \tau)$ by Observation (2);

$= \pi_t^{Q,T}$ by definition of price threshold;

$= -A = \pi_t^{N,T}$ by Observation (1);

$= \pi_t^{N,C}(\overline{P}_t^N)$ by definition of price threshold

Given $\pi_t^{N,C}(\overline{P}_t^Q) > \pi_t^{N,C}(\overline{P}_t^N)$, this implies
\[
\overline{p_t^Q} > \overline{p_t^N}
\]
by Observation (3).

From Observation (2), it can be shown that \( E[\pi_t^{N,C}(P_t)] > E[\pi_t^{Q,C}(P_t; \tau)] \) for all periods. Repeating the above steps will show that the inequality holds for all periods, for \( \overline{p_t^Q} \) as well as for \( \overline{p_t^I} \).

**Proposition 2 (Section 4.2.3)**

**Claim:** \[
\frac{p_t^R - C^2}{2p_t^R} - C + \frac{C^2}{p_t^R} - F + (1 - \beta)A = 0 \text{ if time } t \text{ is the last period.}
\]

Since \( t \) is the last period, the project will terminate at time \( t + 1 \). The future value is

\[
\pi_{t+1}^R = TD_{t+1}^0 - (1 - T)A
\]

\[
= T(1 + r)D_t^1 - (1 - T)A \quad \text{by definition of } D_{t+1}
\]

\[
= T(1 + r) \max\{D_t^0 - \left( \int_0^{q_t^R} (1 - x) dx \right) P_t - q_t^R C - F \}, 0\} - (1 - T)A
\]

by definition of \( D_t^1 \)

\[
= T(1 + r) \max\{D_t^0 - \left( \frac{p_t^R - C^2}{2p_t^R} - C + \frac{C^2}{p_t^R} - F \right), 0\} - (1 - T)A
\]

Substituting the term \( \pi_{t+1}^R \) into Equation (4-4b) yields

\[
\left( \frac{p_t^R - C^2}{2p_t^R} \right) - C + \frac{C^2}{p_t^N} - F - T \max\left\{ \left( \frac{p_t^R - C^2}{2p_t^R} \right) - C + \frac{C^2}{p_t^R} - F - D_t^0, 0 \right\}
\]

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Proposition 3 (Section 4.2.3)

Claim: \[ \{ \left( \frac{p_t^R - C}{2p_t^R} \right) - C + \frac{C^2}{p_t^R} - F \right\} + \beta E [\pi_{t+1}^N] + A = 0 \] if time \( t \) is the not the last.

To arrive at Equation (4-4b”), first solve for \( E[\pi_{t+1}^R] \) in Equation (4-4) for different price scenarios. Without loss of generality, suppose the current period \( t \) is the second last period, and the next period \( t + 1 \) is the last.

First, suppose the future mineral price is below the price threshold: \( p_{t+1} < \overline{p}_{t+1}^R \), in which case the project will terminate at \( t + 1 \).

\[
\pi_{t+1}^R = \max\{\pi_{t+1}^{R,C}(p_{t+1}; T), \pi_{t+1}^{R,T}\}
\]

\[
= \pi_{t+1}^{R,T} = TD_{t+1}^0 - (1 - T)A = T(1 + r)D_t^1 - (1 - T)A
\]

\[
= T(1 + r)\max\{D_t^0 - \left( \int_0^{q_t^R} (1 - x) dx P_t - q_t^R C - F \right), 0\} + (1 - T)\pi_{t+1}^{N,T}
\]

Substituting the term \( \pi_{t+1}^R \) into Equation (4-4b)

\[
\int_0^{q_t^R} (1 - x) dx P_t - q_t^R C - F - T\max\{\int_0^{q_t^R} (1 - x) dx P_t - q_t^R C - F - D_t^0, 0\}
\]

\[
+ \beta \left[ T(1 + r)\max\{D_t^0 - \left( \int_0^{q_t^R} (1 - x) dx P_t - q_t^R C - F \right), 0\} + (1 - T)\pi_{t+1}^{N,T} \right]
\]

\[-TD_t^0 + (1 - T)A = 0.\]
This yields Equation (4-4b") after simplification, for \( P_{t+1} < \bar{P}_{t+1}^R \).

Secondly, suppose the future mineral price is below the price threshold: \( P_{t+1} > \bar{P}_{t+1}^R \), in which case the project will continue in the final period \( t + 1 \).

\[
\pi_{t+1}^R = \max\{\pi_{t+1}^{R,C}(P_{t+1}; T), \pi_{t+1}^{R,T}\} = \pi_{t+1}^{R,C}(P_{t+1}; T)
\]

\[
= \left( \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F \right)
\]

\[-T \max\left\{ \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F - D_{t+1}^0, 0 \right\} + \beta E[\pi_{t+2}^R]\]

\[
= \left( \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F \right)
\]

\[-T \max\left\{ \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F - D_{t+1}^0, 0 \right\} + \beta(TD_{t+2}^0 - (1 - T)A)\]

\[
= \left( \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F \right)
\]

\[-T \max\left\{ \int_0^{q_{t+1}^N}(1 - x)dx P_{t+1} - q_{t+1}^N C - F - D_{t+1}^0, 0 \right\}
\]

\[+ \beta((1 + r)TD_{t+1}^1 - (1 - T)A)\]

\[
= (1 - T) \left( \int_0^{q_{t+1}^R}(1 - x)dx P_{t+1} - q_{t+1}^R C - F - \beta A \right) + TD_{t+1}^0 \quad \text{after simplification}
\]

\[
= (1 - T) \left( \int_0^{q_{t+1}^N}(1 - x)dx P_{t+1} - q_{t+1}^N C - F - \beta A \right) + TD_{t+1}^0 \quad \text{since } q_t^R = q_t^N \forall t
\]

\[
= (1 - T)\pi_{t+1}^{N,C}(P_{t+1}) + TD_{t+1}^0.
\]

Substituting this into Equation (4-4b) yields

\[
\int_0^{q_t^R}(1 - x)dx P_t - q_t^R C - F - T \max\left\{ \int_0^{q_t^R}(1 - x)dx P_t - q_t^R C - F - D_t^0, 0 \right\}
\]

\[+ \beta \left( (1 - T)\pi_{t+1}^{N,C} + TD_{t+1}^0 \right) - (TD_t^0 - (1 - T)A) = 0\]
This yields Equation (4-4b'') after simplification.