

DESIGN AND PERFORMANCE OF MINING AND PETROLEUM FISCAL REGIMES IN LATIN AMERICA AND THE CARIBBEAN

SURVEY OF CURRENT PRACTICES,
LESSONS LEARNED, AND BEST PRACTICES

**Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library**

Davis, Graham A.

Design and performance of mining and petroleum fiscal regimes in Latin America and The Caribbean: survey of current practices, lessons learned and best practices / Graham A. Davis, James L. Smith.
p. cm. — (IDB Monograph ; 831)

Includes bibliographic references.

1. Mineral industries-Taxation-Latin America. 2. Mineral industries-Taxation-Caribbean Area. 3. Mineral oils-Taxation-Latin America. 4. Mineral oils-Taxation-Caribbean Area. 5. Fiscal policy-Latin America. 6. Fiscal policy-Caribbean Area. 7. Land use-Effect of taxation on-Latin America. 8. Land use-Effect of taxation on-Caribbean Area. I. Smith, James L. II. Inter-American Development Bank. Infrastructure and Energy Sector. III. Title. IV. Series.
IDB-MG-831

JEL Codes: H21, L71, L72, Q3, Q38, Q32

Keywords: Oil, gas, mining, taxes, royalty, fiscal framework, tax policy

Copyright © 2020 Inter-American Development Bank. This work is licensed under a Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives (CC-IGO BY-NC-ND 3.0 IGO) license (<http://creativecommons.org/licenses/by-nc-nd/3.0/igo/legalcode>) and may be reproduced with attribution to the IDB and for any non-commercial purpose. No derivative work is allowed.

Any dispute related to the use of the works of the IDB that cannot be settled amicably shall be submitted to arbitration pursuant to the UNCITRAL rules. The use of the IDB's name for any purpose other than for attribution, and the use of IDB's logo shall be subject to a separate written license agreement between the IDB and the user and is not authorized as part of this CC-IGO license.

Note that link provided above includes additional terms and conditions of the license.

The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its Board of Directors, or the countries they represent.



DESIGN AND PERFORMANCE OF MINING AND PETROLEUM FISCAL REGIMES IN LATIN AMERICA AND THE CARIBBEAN

SURVEY OF CURRENT PRACTICES, LESSONS LEARNED, AND BEST PRACTICES

Graham A. Davis, Ph.D.
Professor Emeritus
Division of Economics and Business
Colorado School of Mines
Golden, Colorado

James L. Smith, Ph.D.
Professor Emeritus
Department of Finance
Southern Methodist University
Dallas, Texas

With modeling support from CRU Group and Eugenio Domínguez.

**This report is dedicated
to Ramón Espinasa (1952-2019)**

We would like to thank Estefanía Marchán, Osmel Manzano, Gerardo Reyes-Tagle, Andrew Powell, and Gustavo García for the fruitful discussions and valuable feedback while producing this report.

CONTENTS

| | |
|------|---|
| p 9 | Glossary |
| p 13 | Executive Summary |
| p 15 | 1. Introduction |
| p 18 | 2. Method of Analysis |
| p 23 | 3. Fiscal Regimes for Oil, Gas, and Mining in LAC |
| p 23 | 3.1. Petroleum Fiscal Regimes |
| p 25 | 3.2. Mining Fiscal Regimes |
| p 28 | 4. Impacts of Existing Fiscal Regimes in LAC |
| p 29 | 4.1. Physical Impacts of Existing Fiscal Regimes in LAC |
| p 30 | 4.1.1. Exploration Effort (Petroleum Only) |
| p 31 | 4.1.2. Investment at the Development Stage |
| p 32 | 4.1.3. Peak Rate of Production |
| p 35 | 4.1.4. Enhanced Recovery (Petroleum Only) |
| p 36 | 4.1.5. Resource Recovery Factor |
| p 38 | 4.1.6. Project Life and Abandonment |
| p 40 | 4.2. Impacts of Taxes on Project Economics and Government Benefits |
| p 40 | 4.2.1. Government Take |
| p 44 | 4.2.2. Deadweight Loss |
| p 47 | 4.2.3. Fiscal Yield |
| p 50 | 4.2.4. Fiscal Inefficiency |
| p 53 | 5. Additional Insights, Lessons Learned, and Proposed Good Practices |
| p 53 | 5.1. Additional Insights |
| p 53 | 5.1.1. Royalties Are Prevalent and Highly Distortionary |
| p 56 | 5.1.2. LAC's Fiscal Regimes Are Not Neutral |
| p 59 | 5.1.3. The Impact of a Fiscal System is Sensitive to Each Project's Profitability |
| p 60 | 5.2. Lessons Learned |
| p 60 | 5.2.1. Fiscal Regime Performance Varies by Project |
| p 63 | 5.2.2. Higher Effective Tax Rates Lead to Higher Distortions |
| p 64 | 5.2.3. High Deadweight Losses Associated With High Government Takes Are Mainly Due to Special Taxes Levied on Top of Corporate Income Tax |
| p 64 | 5.2.4. At All Levels of Government Take, LAC's Petroleum Taxes Are More Distortive Than Mining Taxes |

| | | | |
|------|-------|--------|--|
| p 64 | | 5.2.5. | Government Take Is a Poor Indicator of Fiscal Performance |
| p 65 | | 5.2.6. | Taxes That Are Too High Can Actually Decrease Tax Revenue |
| p 68 | | 5.3. | Proposed Good Practices in Oil, Gas, and Mining Taxation |
| p 69 | | 5.3.1. | Tax Petroleum in the Same Way and at the Same Level as Mining |
| p 69 | | 5.3.2. | Taxes That Target Rent Are the Least Distortionary |
| p 70 | | 5.3.3. | Systems With a Resource Surtax and Rapid Expensing Are a Second-Best to Rent Taxes |
| p 72 | | 5.3.4. | Royalties Levied on Production Volume or Gross Revenue, Asset and Dividend Taxes, and Profit-oil Sharing Rates Should Be as Low as Possible |

p 74 **6. Conclusions**

p 77 **Appendix I. Technical Methodology**

| | |
|------|------------------------------------|
| p 77 | Methodological Limitations |
| p 77 | Simplifying Assumptions |
| p 77 | Restrictions on the Scope of Study |

p 90 **Appendix II. Individual Country Highlights**

| | |
|-------|------------------------------------|
| p 90 | Argentina |
| p 91 | Bolivia (petroleum only) |
| p 92 | Brazil |
| p 93 | Chile (mining only) |
| p 94 | Colombia |
| p 95 | Dominican Republic (mining only) |
| p 96 | Ecuador |
| p 97 | Guyana (petroleum only) |
| p 98 | Mexico |
| p 99 | Panama (mining only) |
| p 100 | Peru |
| p 101 | Trinidad & Tobago (petroleum only) |
| p 102 | Venezuela (petroleum only) |

p 103 **References**

List of Tables

| | |
|------|--|
| p 23 | Table 3.1: High-Level Summary of Petroleum Fiscal Regimes in LAC as of 2018 |
| p 25 | Table 3.2: Petroleum Scenarios Examined in This Report |
| p 26 | Table 3.3: High-Level Summary of Mining Fiscal Regimes in LAC as of 2018 |
| p 27 | Table 3.4: Mining Projects Examined in This Report |
| p 28 | Table 4.1: Performance of Existing LAC Fiscal Regimes, All Measured Relative to No-Tax Benchmark |
| p 54 | Table 5.1: Specific Sources of Distortion and Deadweight Loss in Petroleum Fiscal Regimes |
| p 56 | Table 5.2: Average Physical and Fiscal Results for the Projects in the Five Mining Countries That Include Royalties in Their Fiscal Systems |
| p 57 | Table 5.3: Mining Fiscal Regime Regressivity at the Time of Investment |
| p 58 | Table 5.4: Mining Fiscal Regime Regressivity Post Investment |
| p 58 | Table 5.5: Petroleum Fiscal Regime Regressivity Post Investment |

List of Figures

| | |
|------|--|
| p 20 | Figure 2.1: Illustration of Tax-Induced Distortions |
| p 31 | Figure 4.1: Exploration Intensity (Petroleum) |
| p 32 | Figure 4.2: Half-Cycle Capital Investment (Petroleum) |
| p 33 | Figure 4.3: Half-Cycle Capital Investment (Mining) |
| p 34 | Figure 4.4: Peak Production Rate (Petroleum) |
| p 35 | Figure 4.5: Peak Production Rate (Mining) |
| p 36 | Figure 4.6: Enhanced Oil Recovery |
| p 37 | Figure 4.7: Resource Recovery Factor (Petroleum) |
| p 38 | Figure 4.8: Resource Recovery Factor (Mining) |
| p 39 | Figure 4.9: Project Lifetime (Petroleum) |
| p 40 | Figure 4.10: Project Lifetime (Mining) |
| p 41 | Figure 4.11: Full-Cycle Government Take (Petroleum) |
| p 43 | Figure 4.12: Half-Cycle Government Take (Petroleum) |
| p 43 | Figure 4.13: Half-Cycle Government Take (Mining) |
| p 44 | Figure 4.14: Full-Cycle Deadweight Loss (Petroleum) |
| p 45 | Figure 4.15: Half-Cycle Deadweight Loss (Petroleum) |
| p 46 | Figure 4.16: Half-Cycle Deadweight Loss (Mining) |
| p 48 | Figure 4.17: Full-Cycle Fiscal Yield (Petroleum) |
| p 49 | Figure 4.18: Half-Cycle Fiscal Yield vs. Government Take (Petroleum) |
| p 49 | Figure 4.19: Half-Cycle Fiscal Yield vs. Government Take (Mining) |
| p 51 | Figure 4.20: Full-Cycle Fiscal Inefficiency (Petroleum) |
| p 52 | Figure 4.21: Half-Cycle Fiscal Inefficiency (Petroleum) |
| p 52 | Figure 4.22: Half-Cycle Fiscal Inefficiency (Mining) |

| | |
|------|---|
| p 59 | Figure 5.1: Deadweight Loss and Government Take From Panama's Fiscal Regime for the Cobre Panama Copper Mining Project Under Various No-Tax Present Value Indexes |
| p 60 | Figure 5.2: Half-Cycle Government Take for Mining Projects as a Function of Their No-Tax Present Value Index |
| p 60 | Figure 5.3: Half-Cycle Fiscal Inefficiency for Mining Projects as a Function of Their No-Tax Present Value Index |
| p 62 | Figure 5.4: The Impact of Brazil's Fiscal Regime on Two Iron Ore Projects in Brazil, Compared With the Mining Sample Average |
| p 63 | Figure 5.5: Deadweight Loss vs. Government Take: Half-Cycle Cash Flows, Petroleum |
| p 63 | Figure 5.6: Deadweight Loss vs. Government Take: Half-Cycle Cash Flows, Mining |
| p 66 | Figure 5.7: Fiscal Yield vs. Government Take, Full-Cycle Cash Flows, Petroleum |
| p 66 | Figure 5.8: Fiscal Yield vs. Government Take, Half-Cycle Cash Flows, Petroleum |
| p 66 | Figure 5.9: Fiscal Yield vs. Government Take, Half-Cycle Cash Flows, Mining |
| p 67 | Figure 5.10: Fiscal Yield vs. No-Tax PVI for the Cobre Panama Copper Project |
| p 67 | Figure 5.11: Fiscal Inefficiency vs. Government Take, Full-Cycle Cash Flows, Petroleum |
| p 68 | Figure 5.12: Fiscal Inefficiency vs. Government Take, Half-Cycle Cash Flows, Petroleum |
| p 68 | Figure 5.13: Fiscal Inefficiency vs. Government Take, Half-Cycle Cash Flows, Mining |

GLOSSARY

Average Effective Tax Rate (AETR):

The average tax rate for a project, measured as the present value of Government net cash flows as a share of total before-tax project worth.

Concessionary System:

A legal framework under which the Operator obtains by lease the right to conduct exploration and development within a given area in exchange for the payment of a royalty, income taxes, and perhaps a lump-sum cash bonus payment and other levies.

Deadweight Loss (DWL):

The difference between potential economic rent that would be generated but for distortions caused by the fiscal regime and actual economic rent generated when the investment is subject to that regime.

Dry Hole:

An exploratory well that fails to establish a commercial deposit of oil or gas.

Economic Rent:

The difference between the net present value of revenues generated by an investment and the net present value of all economic costs required to complete that investment, including a risk-adjusted return on invested capital but excluding taxes and transfer payments.

Enhanced Oil Recovery (EOR):

Investments and operations designed to stimulate and revive an aging oil or gas field to raise the rate of production and increase profits.

Efficient Tax:

A tax regime that collects rent from the resource project without distorting the investment and production decisions of the Operator, and as such does not diminish the Economic Rent projected to be generated by the project.

Exploration Intensity:

As used in this report, the maximum number of dry holes an Operator would tolerate before abandoning exploration in a given area.

Fiscal Inefficiency (FI):

The ratio of total DWL created by a given fiscal regime to the total present value of Government net cash flows generated by that regime.

Fiscal Yield (FY):

The share of the potential economic rent that would be generated by a non-distorted, tax-free investment that Government actually captures with the fiscal regime in place.

Full-Cycle:

Financial analysis that incorporates all cash flows beginning from the exploration phase and continuing through to project abandonment.

Government Take (GT):

The share of actual economic rents generated by an investment that Government captures over the life of a project, measured in terms of present value of Government net cash flows. GT may be calculated on the basis of either Full-Cycle or Half-Cycle cash flows.

Half-Cycle:

Financial analysis that incorporates cash flows beginning with initial development of a known mining resource or oil or gas field and continuing through to project abandonment. Exploration costs are excluded, but EOR in oil and gas production is not.

Internal Rate of Return (IRR):

The discount rate at which the net present value of Operator's net cash flow equals zero, roughly approximating the annually compounded profit rate earned on Operator's investment.

Marginal Effective Tax Rate (METR):

The ratio of returns to capital (IRR in a discounted cash flow model) gross of tax and net of tax, calculated as $(IRR_G - IRR_N)/(IRR_G)$. It is a measure of the impact of taxation on the returns to capital, and thereby the incentive to invest.

Net Present Value (NPV):

The value of project cash flows (revenues and expenses) that are discounted according to their risk and the time value of money, used to express the current value of future returns. NPV may be calculated on the basis of the entire project, or on the basis of the Operator's or Government's net cash flows treated separately.

Peak Production:

The maximal rate of extraction from a given project, which in our analysis is assumed to occur in all but the final year of production in a mining project and the third year of production in an oil and gas project.

Present Value Index (PVI):

The present value of post-development cash flows divided by the present value of development cash flows. An index of 1.0 indicates a zero-NPV project, and an index greater than one indicates a positive-NPV project. The greater the index above 1.0, the more profitable the project.

Production Sharing Contract (PSC):

An alternative to the Concessionary System of resource leasing under which the Operator signs a legal contract with Government setting forth specific financial terms and operating conditions under which exploration and development may be conducted.

R-Factor:

A ratio used to raise or lower the prevailing rate of tax or other levies, calculated at any given time by dividing the Operator's cumulative revenues by the Operator's cumulative costs.

Recovery Factor (RF):

The portion of original resource-in-place that is actually produced over the life of a given oil or gas field or mining project.

Reserves:

The volume of energy or mineral that can be economically produced from a given deposit based on current price projections and available technology.

Resource-in-Place:

The entire physical volume of oil and/or gas originally contained in a given deposit, regardless of its recoverability, measured at standard temperature and pressure.

Royalty:

A levy calculated as a percentage of the value of produced resources, with or without deductions for the costs incurred.

Sliding Scale:

A schedule whereby a tax rate or other levy increases as certain production or profitability milestones are achieved during the life of a project.

EXECUTIVE SUMMARY

There has long been interest over fiscal mechanisms by which governments can appropriate rents from mining and petroleum operations. Typical mechanisms include royalties, income taxes, and carried interests. For many Latin American and Caribbean (LAC) countries these revenues can be important sources of funding for social programs and development. Yet economic policy with respect to mineral wealth poses a series of challenges. Primarily, fiscal arrangements need to ensure that governments benefit from the financial gains associated with natural resource exploitation without adversely impacting private sector exploration and investment, without which these resources would produce no value. Of interest, therefore, is optimal taxation design. This report examines the performance of mining and petroleum taxation policies in thirteen Latin American and Caribbean countries, across 26 petroleum projects and 15 mining projects representative of the region. We focus on the ability of each country's system of taxation to foster development of these projects in a manner that efficiently exploits the resource while allowing appropriate flows of project rents to the Government.

Each country included in the study has developed its own, very unique fiscal regime for petroleum and mining—no two are alike, not even across the two sectors. Some are quite simple, but many are complicated. For oil and gas, both Production-Sharing contracts and traditional Concessionary systems are in common usage. Indeed, some individual countries employ both types of fiscal regimes. In mining, there is no production-sharing or bonus bids, but instead up to six different types of taxes by which rents are transferred to the Government.

Of utmost importance is the ability of each fiscal regime to efficiently capture economic rents for the nation without unduly discouraging exploration and resource development. Equally important is the robustness of the chosen regime to perform well under a range of economic circumstances, including high versus low prices and high versus low costs, as well as under a range of project specifics, such as deep water versus shallow water oil and different metals and types of mines.

We have examined the performance of each regime with respect to these factors via the optimization of an engineering-economic model of each project both before taxation and after taxation using the methodology in Smith (2014). All the regimes induce Operator distortions, with subsequent deadweight loss. In general, the petroleum fiscal regimes tend to be more distortionary than the mining regimes. In fact, for the average dollar raised by the Government through petroleum taxation, 45 cents of project rent are lost. The worst petroleum systems that we modeled lose more than \$1.00 of rent per \$1.00 of tax revenue raised. With the tax burden extinguishing private sector investment completely at 3 of the 26 projects. This is in large part because of the petroleum regime's extensive reliance on less efficient fiscal instruments like royalties.

The Government Take of total project rents averages well over 50% across all the mining and petroleum projects we examined, with the highest Government Takes generally causing the most distortions and, as a result, being less efficient. This indicates that the conventional measure of Government Take is a poor indicator of fiscal performance because it overlooks distortions that are created by the fiscal regime and fails to measure the potential rents that might have been captured but are lost due to poor fiscal design.

Instead, we introduce the Fiscal Yield measure, which is the percentage of the no-tax project rent that is actually captured by the fiscal system. A higher Fiscal Yield reveals higher absolute government revenues for a given project. Average Fiscal Yield for projects at the development stage is 56% for petroleum and 58% for mining. Average Fiscal Yield for petroleum projects including the exploration and development stages is 53%. Fiscal Yield is a more useful measure of a fiscal system's performance as it reveals just how much of a project's inherent value flows to the Government.

Another notable result of our analysis is that the impact of a fiscal regime depends greatly on the specifics of the project being taxed. That is, the distortionary effects within a fiscal system are not uniform across the projects to which the system is applied, and incorrect inferences could be drawn by passing the fiscal system through a single "representative" project. Nor are the distortionary effects independent of project economics, with more distortions as economic and physical conditions change to create lower pre-tax profit margins and higher effective tax rates.

The literature on effective resource taxation is plentiful and generally advises in favor of neutral taxes like cash flow taxes or resource rent taxes. No LAC country that we examined has attempted to design a neutral taxation system. The lowest inefficiencies were found in Chile (for mining) and Guyana (for petroleum), largely because of their relatively low rate of taxation and their emphasis on profit taxes rather than sales or production royalties. The simplest way to reduce the existing distortions in the other LAC countries is to reduce the rate of resource taxation, as was done in Argentina from 2017 to 2018. That modification reduced the deadweight loss on the two Argentinian mining projects that we modeled by 50%. The petroleum fiscal regimes within each country could be modified to more closely resemble the mining fiscal regimes, which tend to contain less distortionary fiscal instruments and apply lower rates of taxation. Alternatively, there is the more sophisticated path of replacing the existing fiscal systems with rent taxes.

An intermediate step for both the petroleum and mining fiscal regimes would be to place more weight on corporate income taxation as a way of taxing resource projects, as with special surtaxes above and beyond the global corporate income tax rates such that the desired level of government revenue is achieved. Our simulations show that when corporate income taxes allow for unlimited loss carryforwards and accelerated depreciation combined with intangibles expensing, these instruments perform quite well. The cost may be an absence of income to the government during the early years of a project. Yet, when we tested this in our models of the mining projects (which tend to rely more heavily than petroleum projects on income taxes for government revenue), 13 of the 15 projects had income tax flowing to the government in the first year of production.

1. INTRODUCTION

There has long been interest over fiscal mechanisms by which governments can appropriate rents from mining and petroleum operations. Typical mechanisms include royalties, income taxes, and carried interests. For many Latin American and Caribbean (LAC) countries these revenues can be important sources of funding for social programs and development. Yet economic policy with respect to mineral wealth poses a series of challenges. Primarily, fiscal arrangements need to ensure that governments benefit from the financial gains associated with natural resource exploitation without adversely impacting private sector exploration and investment, without which these resources would produce no value.

Of particular interest, therefore, is optimal taxation design. Optimality includes considering the effects of taxation on operating decisions. Does taxation sterilize reserves? Does it affect the speed of extraction? How efficient is a given suite of fiscal terms within a country at capturing the greatest economic rents without distorting investments and operations in ways that reduce the potential value of the resource? And, given that tax revenues often fund important social programs and development, when does the government begin to receive payments from the project?

Over the last few decades, thinking on natural resource taxation has evolved in many leading mining and hydrocarbons producing countries towards developing non-distortionary fiscal tools.¹ Distortions can be measured as Deadweight Loss (DWL), which is the difference between the potential economic rent that could be generated by a project and the actual rent that is generated once taxes are applied and an Operator shifts its behavior to avoid the levies and maximize its private return.

In the late 1970s and early 1980s, several studies of Canadian mining tax policy were undertaken which evaluated a fiscal system by testing how an Operator of an actual or hypothetical mine might re-optimize operations given taxes.² These studies found that traditional fiscal

1. See Smith (2013) for a comprehensive review of this literature.

2. Examples include Helliwell (1978), Bradley et al. (1981), and Slade (1984).

instruments like royalties could be highly distortionary. Similarly, studies of Norwegian oil and gas taxation in the 1980s found that a simulated field would suffer very high DWLs due to Norway's fiscal policies at the time (Nystad 1985, Kemp and Rose 1985).³ The result has been resource tax reforms in Canada, Norway,⁴ and other countries that reduce the inefficiency of traditional tax instruments, along with a continued push to replace these instruments with a pure rent tax or resource rent tax. Rent taxes are levied not on accounting measures of revenue or net income but on a measure of the economic surplus generated by a project over and above a competitive rate of return.⁵

The fiscal systems applied to mining and oil and gas in LAC have largely escaped such comprehensive and comparative analyses.⁶ Given that, a practical analysis of LAC's fiscal regimes is required in order to evaluate their fiscal effectiveness and identify good practices. This report examines the performance of mining and petroleum taxation policies in thirteen Latin American and Caribbean mineral and energy producing countries. We focus on the ability of each country's system of taxation (i.e., fiscal regime) to foster development of mining and petroleum resources in a manner that efficiently exploits the resource while allowing appropriate flows of project rents to the Government. Depending on the country and the fiscal regime in place, these flows may take the form of income tax and/or special tax revenues, production royalties, participation in production and profits, cash bonus bids, land-use and licensing fees, and mandated contributions to various socially-oriented funds. This study does not model special tax agreements such as an Investment Agreement between a specific Operator and the Government.

Each country included in the study has developed its own, very unique fiscal regimes for petroleum and mining—no two are alike, not even across these two sectors. Some are quite simple, but many are complicated. For oil and gas, both Production-Sharing contracts (PSC) and traditional Concessionary systems are in common usage. Indeed, some individual countries employ both types of fiscal regimes. In mining, there is no production-sharing or bonus bids,⁷ but instead up to six different types of taxes by which rents are transferred to the Government or to approved social programs. By contrasting these regimes and the results they produce, we attempt to identify problems (tax provisions that severely distort or impede investment and production decisions), as well as good practices that maximize the value of a country's resource endowment while allowing the Government to capture a fair share of the benefits.

Of utmost importance is the ability of each fiscal regime to efficiently capture economic rents for the nation without unduly discouraging exploration and resource development. Equally important is the robustness of the chosen regime to perform well under a range of economic circumstances, including high versus low prices and high versus low costs, as well as under a range of project specifics, such as deep water versus shallow water oil, and different metals and types of mines.

3. See also Lund (1992) and Blake (2013) for fiscal analyses that include oil field design endogeneity.

4. Norway undertook additional revisions in 1992, 2002, and 2005 intended to further reduce distortions (Lund 2014a). The government currently has a policy of achieving 78% or more of project rents with no project distortions, though whether this has been achieved is subject to debate (Lund 2018a).

5. See Land (2010) and Chen and Perry (2015) for examples. While pure rent taxes are indisputably non-distortionary, Smith (1999) notes that resource rent taxes can still induce Operator distortions.

6. Chen and Perry (2015) review mining taxation in Colombia and make theoretical suggestions for improvements. Blake and Roberts (2006) evaluate the Trinidadian post-1995 PSC, but only via a generic oil field model that does not represent the geology found in the country. They conclude that the Trinidadian system is the most distortionary of the five that they examine. Mintz and Chen (2012) estimate METR's for a number of countries, including Brazil, and find that Brazil has the highest METR in the sample. Manzano et al. (2017) review the fiscal systems in Chile, Peru, and Venezuela.

7. Lump-sum cash payments due at the time an Operator acquires rights to exploit a resource are referred to as cash bonuses. In some systems, the size of the bonus is determined by auction, in which case the payments are referred to as bonus bids.

We have examined the performance of each regime with respect to these factors and found that all the regimes induce Operator distortions. Some have a much stronger effect (are more distortionary) than others because of their use of less efficient fiscal instruments like royalties. Although the petroleum and mining sectors are very different, some similar learnings emerge. A surprising result is that the impact of a fiscal regime depends greatly on the specifics of the project being taxed. That is, the distortionary effects within a fiscal system are not uniform across projects. We also find that petroleum tends to be taxed more heavily than mining, both in terms of rates and in terms of the number of fiscal instruments used to tax the project. Petroleum projects generally have, as a result, greater distortionary responses to the fiscal systems than mining projects. Finally, the Government Take (GT) averages well over 50% for the projects we examined, with the highest GTs generally causing the most distortions and, as a result, being the least efficient. The simplest way to reduce distortions is to reduce GT. A more sophisticated approach would be to place more emphasis on the less distortionary traditional instruments, like income surtaxes, or to replace existing traditional fiscal instruments with less distortionary instruments like rent taxes. This could potentially create a win-win outcome, where the additional project rent from the decreased distortions provides more rent to both the Operator and the Government.

The rest of this report is structured as follows: Section 2 summarizes our method of analysis, and Section 3 presents the main components of the existing fiscal regimes applied to oil, gas, and mining projects in the Latin American and Caribbean countries analyzed. Section 4 presents the physical and economic impacts of existing fiscal regimes on representative oil, gas, and mining projects across the region. Section 5 presents some additional insights, distills the lessons learned from our analysis and proposes some thoughts on good practices for fiscal regime design based on these lessons. Section 6 provides some concluding thought. Technical information on our methodology, sources, and individual country highlights can be found in the Appendices to this report.

2. METHOD OF ANALYSIS

The design of mineral and energy tax systems is no simple matter. In mineral and energy extraction, there is intertemporal optimization of the extraction of a finite resource by an Operator, broadly called the Hotelling problem. When operating margins are not expected to improve greatly over time, as is usually the case, the solution to that problem has the Operator extracting the resource as quickly as possible, as limited by the capacity constraints imposed by prior investment in pressure (in the case of petroleum) and mine design (in the case of mining) and in plant and equipment.⁸ A fiscal regime may affect the intensity of exploration, the scale of development and speed of extraction of known resources, the timing and scope of investment midway through the project (as in mine expansions and enhanced oil recovery), and the date of ultimate abandonment and decommissioning of all operations.

We use the term “distortion” to describe any deviation from the pattern of investment and operations that would be undertaken by the Operator but for the burden of taxation, which comprises our “No-Tax” benchmark. While in theory it is possible to tax resource rents in a non-distortionary way (Smith, 2013), in practice such distortions are unavoidable due to practical difficulties in measuring the size of resource rents generated by any given project. The resulting reliance on available accounting measures that are loosely related to the size of resource rents (e.g., production quantity, sales revenue, net income) explains many of the rather blunt tax instruments in use.

Distortions cause waste – or lost rent – at the project, since they deflect the operation from its optimal and efficient plan. The waste is formally called Deadweight Loss (DWL). The distortions arise due to the Operator’s attempt to re-optimize the after-tax return when facing various levies. For example, a fiscal regime that imposes a simple 20% royalty on sales is likely to reduce the scale of investment, which is determined at the margin where the after-tax value of the incremental unit of reserves is equal to its cost. The royalty reduces the after-tax value of the incremental unit of reserves but not its cost of extraction, which therefore limits investment relative to the No-Tax benchmark. Likewise, a fiscal regime that imposes progressively higher (sliding-scale) tax rates as the rate of production from a given resource increases may create incentives to avoid the higher rates by limiting the rate of extraction while extending the life of the operation.

Each distortion caused by the fiscal regime impacts the size, timing, and net present value (NPV) of revenues that Government will derive from the private investments that are undertaken to develop its resource base. Judging the overall impact and effectiveness of a given fiscal regime, therefore, requires a modeling framework that captures the private Operator’s behavioral response to the specific tax provisions included in the regime. That response will be specific to each project given that different projects have different investment and operating choices that can be influenced by a distortionary fiscal regime.

The present study was conducted using a peer-reviewed, state-of-the-art economic optimization model that considers a petroleum or mining Operator’s incentive to tailor their investment and production decisions in a way that maximizes the after-tax value of the project.⁹ For hydrocarbons, this includes adapting the intensity of exploration, determining the scope of primary resource recovery, the rate of extraction, the timing and scope of

8. Cairns and Davis (1998), Litzenger and Rabinowitz (1995).

9. The model is described and fully documented in Smith (2014). The model was adapted to apply to mining. See Appendix I for complete methodological details. Berg et al. (2018) apply this same approach to evaluate fiscal regime design for oil production in Norway.

enhanced recovery operations, as well as the point of abandonment. For mining, this includes production capacity and ore grade, which in turn affect the selection of average grade, quantity of reserves, stripping ratio, and life of mine. We have not modeled the option to invest in mid-life expanded production in the mining projects because an expansion option in mining is not parallel to an EOR option in petroleum. EOR extends the life of a known deposit, while expansion options in mining are typically exercised only once an unexpected increase in reserves materializes. In this modeling exercise we do not consider reserve uncertainty. For both hydrocarbons and mining the operating decisions affect investment costs and operating costs.

There are many ways in which projects can be designed or tweaked in the face of taxes, so tax provisions play an important part in the Operator's final choice. Our model is structured to reveal the tendency of a given fiscal regime to influence or distort the Operator's most important decisions. We start by building a cash flow model of the project in Microsoft Excel. Within the model are grids representing the investment and operating decision tradeoffs that the Operator faces. The model searches over the grid space to find the decisions that maximize the project NPV attributable to the Operator. Based on those decisions, the model then calculates total project NPV, Operator NPV, GT, total resource recovery factors, DWL, and other project metrics. Appendix I includes complete methodological details.

Based on an accounting of cash flows with and without taxes, we measure the Fiscal Inefficiency (FI) of the tax regime applied to each project as the ratio of total DWL created by the regime to the total present value of Government net cash flows generated.

We also measure the Fiscal Yield (FY) achieved by the regime, the portion of potentially available economic rents in a no-tax environment that are actually captured by Government with taxation. These are superior metrics to GT for assessing a fiscal regime because they indicate the inefficiency of the regime, whereas GT simply denotes the portion of the inefficient outcome distributed to the Government.

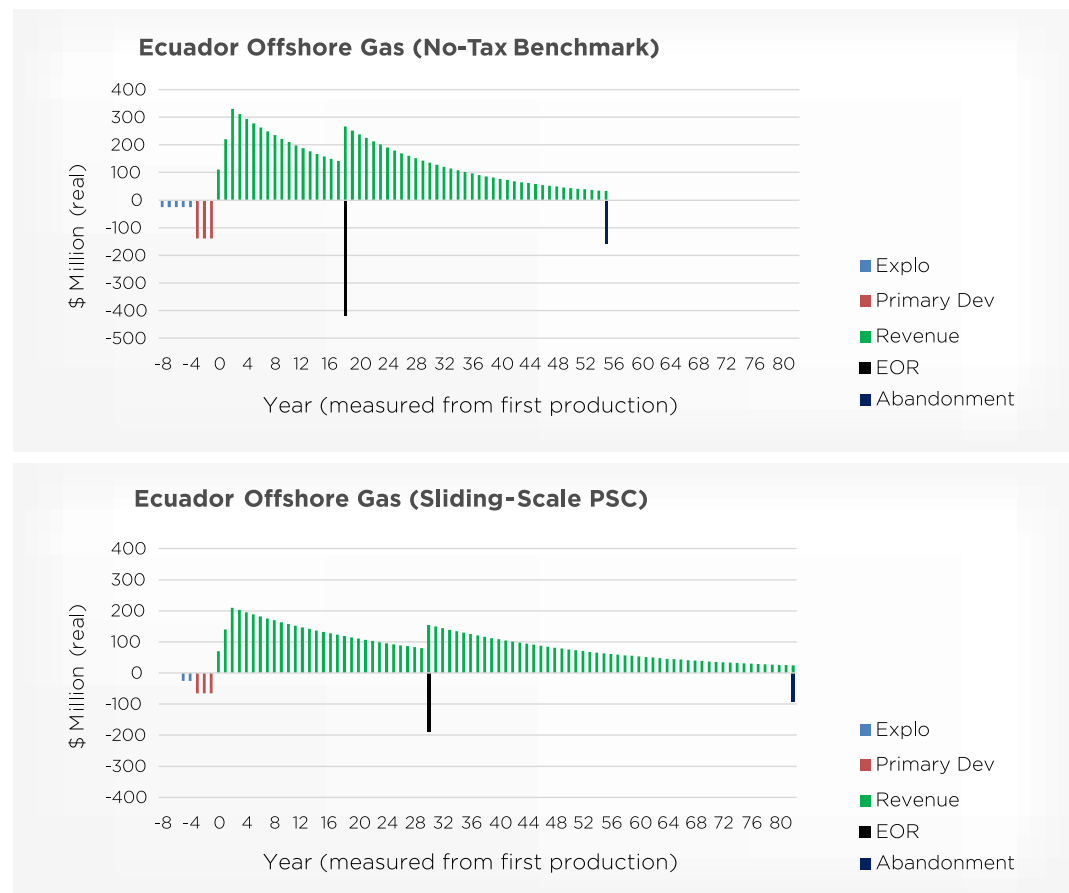
Figure 2.1 indicates the types and potential scope of tax-induced distortions that are identified by our modeling approach. The two panels plot the results of our analysis of Ecuador's PSC regime for offshore gas at the exploration stage. Time is measured relative to the date of first production along the horizontal axis, and the magnitudes of positive and negative cash flows are reflected in the height of the bars. The upper panel reports the No-Tax case, where the Operator would drill as many as five dry exploratory wells before giving up the campaign and develop the resulting discovery (if any) with sufficient investment to achieve a 5.5% extraction rate (per annum). A major investment in enhanced recovery would be taken in the 19th year of production, and the field would finally be abandoned 37 years later, after having recovered some 46% of the original gas-in-place. The project's total economic rent under this scenario would amount to US\$613 million, all of which would accrue to the Operator.

On the other hand, the lower panel in Figure 2.1 shows the adjustments a profit-maximizing Operator would make to the No-Tax plan in order to reduce the burden of current Ecuadorian taxation. Exploration intensity is reduced as the maximum number of dry holes decreases from five to two. The scale of development is also reduced, which results in slower extraction, lower revenues, and increased discounting of the Operator cash flows and production taxes received by the Government. Enhanced recovery is delayed by 15 years, and the life of the

field is extended by about 30 years. Despite that longer life, the Operator extracts only 43% of the original oil-in-place versus 46% in the No-Tax scenario. Thus, given the Operator's optimal investment strategy under the Ecuadoran PSC regime, the project's total economic rent is reduced from US\$613 million to US\$545 million, of which the Operator retains \$143 million and the Government captures US\$402 million. The difference between the two scenarios, US\$68 million, is the DWL from taxation. Put differently, for each dollar of rent captured by the Government, 17 cents of economic rent inherent in the deposit are foregone. Those 17 cents are not available for taxation by the Government, nor do they flow to the Operator. They are either left in the ground or consumed via inefficiencies (higher costs and more delayed cash flows) during production.

Whereas the conventional measure of GT for this regime equals 74%, its FY is only 66%. The lower yield is due to the Government's inability to collect any taxes on the portion of potential profits that are extinguished as a result of the DWL created by the tax. Those \$68 million in DWL thus account for the regime's FI index of 0.17, or 17 cents of DWL per dollar of raised taxes.

Figure 2.1: Illustration of Tax-Induced Distortions



Source: Authors' calculations.

Figure 2.1 encompasses all investments made during the life of the project, beginning with the exploration phase. We refer to this comprehensive view of investment decisions as the Full-Cycle approach. Once a discovery has been made and those exploration costs are sunk, the Operator's decisions regarding whether and how to develop the resource are based only on the incremental cost of moving forward, which constitutes what we call the Half-Cycle approach. In the remainder of this report, we analyze the impact of taxes on both Full-Cycle

and Half-Cycle (HC) investment decisions. The former is applied only to petroleum fiscal regimes, while the latter is applied to both petroleum and mining fiscal regimes. Full Cycle analysis was not applied to the mining projects because of lack of data on initial exploration potential for the various projects studied.

There is substantial variation between and within countries regarding the geology and the specific fiscal regime applied to oil, gas, and mining projects. Our analysis handles this variation by incorporating one or more representative scenarios for each of the 13 countries studied. Because of different extraction technologies, data availabilities, and prior research efforts, the oil and mining analyses are not symmetric. In oil, for example, there are differences between and within countries with respect to geological resource potential (as reflected in exploration risk and the expected range of field sizes) and to capital and operating costs (due mainly to differences in operating environments: coastal plain vs. jungle vs. deep water, etc.). Moreover, a different tax system or simply different rates may apply to different projects within the same country. Thus, for oil and gas, a scenario includes the type of project (e.g., deep water gas), a hypothetical resource specific to that project and country, a hypothetical commodity price environment, Full-Cycle and Half-Cycle analysis, plus the specific fiscal regime that applies to that case given the rules adopted by the subject country in 2018. During our research we examined many separate scenarios for each country. The scenarios encompass a variety of geological and operating factors that potentially influence the impact of taxes. These factors include onshore versus offshore locations, deep water versus shallow water, oil-rich versus dry gas reservoirs, and sensitive environmental siting.

There are also wide-ranging types of mining projects undertaken in LAC. For this reason, the study selected one or more representative mining scenarios for each of the countries studied. Unlike the modeling of hypothetical projects in oil and gas, each mining scenario involved the modeling of an actual private sector metal mining project that has been or is being undertaken in that country, assuming its development started in 2018, and imposing upon the project the 2018 fiscal rules for that type of metal in that subject country.¹⁰ The projects range from advanced exploration stage projects to mature operating projects. As mentioned earlier, due to lack of exploration data for these projects only Half-Cycle decisions could be modeled. For each scenario sensitivities over the price environment (-50% to +50%), CIT tax rate (-30 percentage points to +30 percentage points), and royalty rate (none to +30 percentage points, where applicable) were investigated.

The comparison of hydrocarbon outcomes with mining outcomes is informative as to how different fiscal regimes within the same country create different fiscal outcomes. And by comparing the two fiscal systems we get a feel for just how the fiscal system for one industry might be restructured given the political possibilities evident in the fiscal system for the other industry.

As with any modeling exercise our approach has limitations. We have included a comprehensive discussion of these limitations in Appendix I, where the principal simplifying assumptions are listed, and restrictions on the scope of enquiry are identified.

10. Given the complex combination of commodity, geology, economics, and fiscal regime of each project, modeling of scenarios was done by CRU. See Appendix I for more details.

As this discussion reveals, there is considerable complexity in taxation design and analysis. This complexity has had the disadvantage of inhibiting comprehensive taxation analysis, whereby researchers consider only individual components in isolation, or produce extremely simplified models that enable tractable analyses. Our approach has been to include a considerable degree of complexity with respect to Operator decisions, but to abstract from what we consider to be the special cases enumerated in Appendix I. One should, as a result, only take broad inferences from our analysis; the actual numerical results are, at best, illustrative. Nevertheless, we feel that these inferences are valid given the details of the production decisions that we have chosen to include and the rigor of the modeling exercise.

3. FISCAL REGIMES FOR OIL, GAS, AND MINING IN LAC

In this section we outline the fiscal regimes for each of the countries studied. We begin with the petroleum fiscal regimes and then outline the mining fiscal regimes. Of note is the significant degree of difference in taxation that Governments impose on petroleum operators compared with mining operators, even though both are extracting a finite resource over which nations have sovereignty.

3.1. Petroleum Fiscal Regimes

The basic characteristics of the petroleum fiscal regimes in the eleven petroleum-producing countries under study are listed in Table 3.1. The taxes in the table are listed in three sections, from instruments that are known from tax theory to be least distortionary to instruments that are known to be most distortionary, left to right.

Table 3.1: High-Level Summary of Petroleum Fiscal Regimes in LAC as of 2018

| | CORPORATE INCOME TAX THAT DISTORTS INVESTMENTS | | | | | | | | ADDITIONAL TAXES THAT DISTORT INVESTMENT | | | | ADDITIONAL TAXES THAT DISTORT BOTH PRODUCTION AND INVESTMENT | | |
|-------------------|--|-----------------------|----------|-------|-------------------|----------------------------|--------------|--------|--|-------------|---------------|-------------|--|---------|-----|
| | CIT | Worker Profit Sharing | Deprec. | Bonus | Loss Carryforward | Limit on Loss Carryforward | Intan-gibles | Uplift | Reg. Tax. | Surface Fee | Training Fees | Govt. Part. | SPT | Roy | PSC |
| Argentina | 30% | - | UOP | - | 5 years | - | Amortize | - | YES | YES | - | - | - | 12% | - |
| Bolivia | 25% | YES | 5 YR SL | - | Infinite | - | Amortize | - | - | YES | - | - | - | 50% | YES |
| Brazil | 34% | - | UOP | YES | Infinite | 30% | Amortize | - | - | YES | - | 30% | WPT | 15% | YES |
| Colombia | 33% | - | 5 YR SL | - | 12 years | - | Amortize | - | - | YES | - | 10%-20% | WPT | 8%-12% | - |
| Ecuador | 25% | YES | 10 YR SL | - | 5 years | 25% | Expense | - | - | - | - | - | WPT | - | YES |
| Guyana | 45% | - | EXPENSED | - | Infinite | - | Expense | - | - | YES | YES | - | - | 2% | YES |
| Mexico | 30% | YES | 4 YR SL | - | 10/15 years* | - | Expense | - | - | YES | - | - | WPT | 7.5% | YES |
| Peru | 31% | YES | 5 YR SL | - | Infinite | 50% | Expense | - | - | - | YES | - | - | 15%-35% | - |
| Trinidad & Tobago | 35% | YES | 50:30:20 | - | Infinite | - | Expense | - | - | YES | - | - | WPT | 12.5% | YES |
| Venezuela | 50% | - | 10 YR SL | YES | 3 years | 25% | Expense | YES | - | - | - | 60% | - | 33% | - |

* 15 years for deepwater projects

Sources: Authors' calculations based on Wood Mackenzie, EY, Deloitte, BNamericas, and various trade press reports.

All of the countries studied levy a basic corporate income tax (CIT) on profits earned from upstream petroleum operations. Some add worker profit sharing, which is like a CIT surtax. Depreciation of tangible capital expenditures typically ranges from five to ten years, straight-line (SL), while a few countries base depreciation on units of production (UOP). Intangible capital expenditures (e.g., drilling costs) are typically expensed, but there are exceptions on the treatment of tangibles as well as intangibles. Only a few regimes permit “uplift” of capital expenditures, which amounts to deductions in excess of the original expenses. In addition, there are usually periodic rental payments in proportion to the area under contract, and various social, training, and/or technology fees. Since these are similar to the imposition of fixed costs, they tend to distort investment decisions but not subsequent production decisions. The additional taxes in the last section of the table induce both investment and production distortions, and are for that reason thought to be highly distortionary.

The fiscal regimes in four countries are based on the Concession system, wherein the Operator is licensed to undertake exploration and development within a certain territory. The Operator takes all resulting production and markets it to generate income, a portion of which is taxed by the Government. Alternatively, six of the countries offer PSCs, in which the Government is entitled to a fixed or variable share of the production that remains after the Operator’s costs have been fully or partially recouped. Many of the countries also employ special petroleum-specific taxes (SPT) that apply when prices (or production, or profits) reach high levels. These are known as windfall price/production/profits taxes (WPT).

In addition to substantial between-country variation in fiscal regimes, there is significant within-country variation. One fiscal regime may apply to a country’s offshore resources and another to onshore resources. A different system (or simply different rates) may apply to natural gas fields than to oil fields. Deep water resources may be offered under a regime altogether different than what applies to shallow water resources. Additionally, as was discussed in the previous section, there is significant variation regarding the geological conditions of each oil and gas project. Table 3.2 lists the twenty-six different representative scenarios analyzed in this report across the ten countries in our sample.

Table 3.2: Petroleum Scenarios Examined in This Report

| | Country/Scenario | Regime Type |
|----|--|-------------|
| 1 | Argentina w/ export price index | Concession |
| 2 | Argentina w/o export price index | Concession |
| 3 | Bolivia, Frontier | PSC |
| 4 | Bolivia, Mature Areas | PSC |
| 5 | Brasil, Post-Salt Deep Water | Concession |
| 6 | Brasil, Pre-Salt (Operator Profit Share = 25%) | PSC |
| 7 | Brasil, Pre-Salt (Operator Profit Share = 50%) | PSC |
| 8 | Colombia, Offshore Oil | Concession |
| 9 | Colombia, Offshore Oil w/ Free Trade Zone | Concession |
| 10 | Colombia, Onshore Gas | Concession |
| 11 | Ecuador, Offshore Gas | PSC |
| 12 | Ecuador, Onshore Oil | PSC |
| 13 | Ecuador, Onshore Oil, w/ WPT | PSC |
| 14 | Guyana, Deep Water | PSC |
| 15 | Guyana, Shallow Water | PSC |
| 16 | México, Deep Water Oil | Concession |
| 17 | México, Deep Water Oil (Operator 50%) | PSC |
| 18 | México, Deep Water Oil (Operator 75%) | PSC |
| 19 | Perú, Offshore Oil (High Upside Geology) | PSC |
| 20 | Perú, Offshore Oil (Low Upside Geology) | PSC |
| 21 | Perú, Onshore Gas | PSC |
| 22 | Trinidad & Tobago, Offshore Gas, Deep Water | PSC |
| 23 | Trinidad & Tobago, Offshore Gas, Shelf | PSC |
| 24 | Trinidad & Tobago, Onshore Oil | Concession |
| 25 | Venezuela, Heavy Oil, with Alternative Min. Tax | Concession |
| 26 | Venezuela, Heavy Oil, without Alternative Min. Tax | Concession |

Source: Authors' estimations.

3.2. Mining Fiscal Regimes

As a parallel to Table 3.1, Table 3.3 lists the basic characteristics of the mining fiscal regimes in the nine countries studied.¹¹ The taxes in the table are again listed in three sections, from instruments that are least distortionary to instruments that are most distortionary, left to right. In the case of Argentina, we have added the regime in place in 2017 to examine the effect of the 2018 tax reforms. The difference between the 2017 and 2018 fiscal regimes in Argentina is a lower CIT rate and a lower dividend tax in 2018. With the exception of Chile, the fiscal regimes in place in the other countries studied are very complex in their calculations of taxes and allowances.

All countries levy a basic corporate income tax on profits earned from operations, though its features vary substantially across countries. Some countries offer accelerated depreciation, while others do not. They also vary greatly in their allowance of loss carryforwards. Because investment is not fully deductible and there are no uplift allowances, all CIT regimes reduce investment. Chile and Peru impose variable income surtaxes for mining operations. Many countries also impose

11. The tax treatment of intangibles is not included as the mining case does not consider exploration spending, which is the main item subject to either expensing or itemization.

a worker profit sharing tax, which is an additional income tax.¹² In some cases the worker profit sharing tax is deductible when calculating the CIT, and in other cases it is not.

Many countries then add royalties on net operating income, taxes on dividends taken out of the project, and taxes on the worth of the asset. Because these allow for deductions of operating costs, they will further distort investment but not production.¹³ Globally, mining taxation does not tend to include production sharing or government participation (IMF 2012), and that is the case here. Some countries then add revenue or production-based royalties. In Ecuador there is a 70% windfall profits tax when metal prices rise above a benchmark. Because these instruments do not allow deductions of operating costs, they will distort both production decisions and investment decisions. Some countries offer fiscal stability regimes, though sometimes at a cost; in Peru the corporate income tax rate is increased by 2 percentage points for any company wishing to avail themselves of fiscal security. Both the petroleum and mining studies assumed this increased CIT rate for Peru.

As with petroleum, there can be significant within-country variation. Different surtax and royalty rates may be applied to different metals, and royalties can vary by State, as in the case of Brazil. Table 3.4 lists the 15 different representative projects analyzed in this report. Each mining project, save for Fruta del Norte, is an open-pit operation. Copper, gold, iron ore, and nickel, the metals produced by these projects, are the predominant metals mined in these countries. Many of the projects are substantial in size; the average project rent available for taxation is \$5 billion, with a maximum of \$22 billion at Colombia's Cerro Matoso nickel project.

Table 3.3: High-Level Summary of Mining Fiscal Regimes in LAC as of 2018

| | CORPORATE INCOME TAXATION THAT DISTORTS INVESTMENT | | | | | | ADDITIONAL TAXES THAT DISTORT INVESTMENT | | | ADDITIONAL TAXES THAT DISTORT BOTH PRODUCTION AND INVESTMENT | | | Fiscal Stability Regime |
|------------------|--|-----------------------|-----------------------|----------|-------------------|----------------------------|--|--------------|-----------|--|---------------|----------------------|-------------------------|
| | CIT | Worker Profit Sharing | Special Mining Surtax | Deprec. | Loss Carryforward | Limit on Loss Carryforward | Net Income Royalty | Dividend Tax | Asset Tax | Gross Royalty | Prod. Royalty | Windfall Profits Tax | |
| Argentina | 30% | - | - | 4 YR SL | 5 Years | - | 3% | 7% | - | 1,5% | - | - | 30 Years |
| Argentina (2017) | 35% | - | - | 4 YR SL | 5 Years | - | 3% | 10%-45% | - | 1,5% | - | - | 30 Years |
| Brazil | 25% | 9% | - | 6 YR SL | Infinite | 30% | 1%-3%* | - | - | - | Varies | - | - |
| Chile | 35% | - | 0%-14% | 3 YR SL | Infinite | - | - | - | - | - | - | - | - |
| Colombia | 33% | - | - | 8 YR SL | 12 Years | - | 4%-12% | 5% | - | - | - | - | 20 Years |
| Rep. Dominicana | 27% | 10% | - | 7 YR SL | Infinite | - | - | - | 1% | 5% | - | - | 25 Years |
| Ecuador | 25% | 15% | - | 11 YR SL | 5 Years | 25% | - | 5% | 0.15% | 3%-8% | - | 70% | Yes |
| Mexico | 30% | 10% | - | 77:16:7 | 10 Years | - | 7,5%-8% | 10% | 1.25% | - | - | - | - |
| Panama | 25% | - | - | 10 YR SL | 5 Years | - | - | 5% | 2% | 4%-8% | - | - | 10 Years |
| Peru | 31,5% | 8% | 3%-12% | 6 YR SL | Infinite | 50% | - | 5% | 0.4% | - | - | - | 15 Years |

*Regional Tax

Source: Authors' calculations based on CRU, PWC, EY, and Deloitte tax summaries.

12. For the mining analysis we have included a 10% worker profit sharing tax in Dominican Republic. Firms can cap the worker tax as a percentage of annual salaries.

13. Boadway and Keen (2015) provide a simple analytical model of how CIT and royalties will affect investment and production decisions in resource extraction.

Table 3.4: Mining Projects Examined in This Report

| | Country | Project | Commodity |
|----|--------------------|-----------------|------------|
| 1 | Argentina | Taca Taca | Copper |
| 2 | Argentina | Veladero | Gold |
| 3 | Brazil | Corumba | Iron Ore |
| 4 | Brazil | Minas Río | Iron Ore |
| 5 | Chile | Sierra Gorda | Copper |
| 6 | Chile | Zaldivar | Copper |
| 7 | Colombia | Cerro Matoso | Nickel |
| 8 | Colombia | Gramalote | Gold |
| 9 | Dominican Republic | Pueblo Viejo | Gold |
| 10 | Ecuador | Fruta del Norte | Gold (u/g) |
| 11 | Mexico | Noche Buena | Gold |
| 12 | Mexico | Piedras verdes | Copper |
| 13 | Panama | Cobre Panamá | Copper |
| 14 | Peru | Constancia | Copper |
| 15 | Peru | Lagunas Norte | Gold |

Source: Authors' estimations

4. IMPACTS OF EXISTING FISCAL REGIMES IN LAC

In this section, we summarize the effects of existing fiscal regimes on various project-level performance criteria. Relevant criteria encompass physical as well as financial outcomes, and reflect impacts felt at the exploration stage of investment (for oil and gas) as well as during the development and production stages of operations (for both mining and oil and gas).¹⁴ Summary statistics are presented in Table 4.1. The first panel refers to the mine modeling, while the last three panels refer to the oil and gas modeling. To facilitate comparisons, the averages over the total sample for oil and gas and mining have been highlighted in the Table. We will first review the effect of fiscal regimes on physical project design. We then review the fiscal outcomes. To summarize, however, we point out that, at 72%, the average Half-Cycle GT for petroleum is significantly higher than it is for mining, at 60%. This means that petroleum projects are taxed more heavily than mining projects. That higher degree of taxation creates more distortions and a higher DWL (18% vs. 4%). The net result is a Half-Cycle FY of 56% for petroleum and 58% for mining. The higher degree of taxation in petroleum has yielded no additional capture of project rents due to its inefficiency.

Table 4.1: Performance of Existing LAC Fiscal Regimes, All Measured Relative to No-Tax Benchmark

| | (1) Maximum Number of Dry Holes | (2) Half-Cycle Capex | (3) Peak Rate of Production | (4) Onset Of EOR ¹ | (5) Resource Recovery Factor | (6) Overall Project Lifetime | (7) Full-Cycle Government Take | (8) Half-Cycle Government Take | (9) Full-Cycle Deadweight Loss | (10) Half-Cycle Deadweight Loss | (11) Full-Cycle Fiscal Yield | (12) Half-Cycle Fiscal Yield | (13) Full-Cycle Fiscal Inefficiency ² | (14) Half-Cycle Fiscal Inefficiency |
|--|--|----------------------------|--------------------------------------|--|---------------------------------------|---------------------------------------|---|---|---|--|---------------------------------------|---------------------------------------|---|--|
| All Countries/Fiscal Scenarios (Mining) | | | | | | | | | | | | | | |
| Average: | n/a | 80% | 79% | n/a | 93% | 121% | n/a | 60% | n/a | 4% | n/a | 58% | n/a | 7% |
| Maximum: | n/a | 98% | 97% | n/a | 100% | 156% | n/a | 82% | n/a | 20% | n/a | 74% | n/a | 30% |
| Minimum: | n/a | 59% | 59% | n/a | 67% | 103% | n/a | 46% | n/a | 0% | n/a | 46% | n/a | 0% |
| All Countries/Fiscal Scenarios (Petroleum) | | | | | | | | | | | | | | |
| Average: | 58% | 38% | 63% | 238% | 80% | 143% | 71% | 72% | 33% | 18% | 53% | 56% | 45% | 38% |
| Maximum: | 100% | 73% | 88% | 663% | 100% | 250% | 99% | 93% | 100% | 52% | 75% | 71% | 161% | 158% |
| Minimum: | 0% | 3% | 21% | 114% | 48% | 85% | 0% | 51% | 6% | 3% | 0% | 38% | 10% | 5% |
| Concessionary Systems Only (Petroleum) | | | | | | | | | | | | | | |
| Average: | 63% | 36% | 66% | 203% | 75% | 129% | 79% | 69% | 26% | 17% | 58% | 53% | 50% | 41% |
| Maximum: | 75% | 54% | 88% | 350% | 94% | 177% | 95% | 93% | 61% | 33% | 68% | 62% | 161% | 158% |
| Minimum: | 33% | 3% | 21% | 145% | 48% | 85% | 68% | 54% | 11% | 8% | 38% | 38% | 19% | 14% |
| PSC Regimes Only (Petroleum) | | | | | | | | | | | | | | |
| Average: | 55% | 39% | 61% | 255% | 82% | 152% | 66% | 74% | 38% | 19% | 49% | 58% | 42% | 36% |
| Maximum: | 100% | 73% | 86% | 663% | 100% | 250% | 99% | 92% | 100% | 52% | 75% | 74% | 109% | 123% |
| Minimum: | 0% | 7% | 29% | 114% | 62% | 105% | 0% | 51% | 6% | 3% | 0% | 42% | 10% | 5% |
| Note 1: | Excluding four fiscal regimes under which EOR is never initiated. | | | | | | | | | | | | | |
| Note 2: | Excluding three inefficient fiscal regimes that extinguish exploration incentives altogether, which means the denominator would be zero. | | | | | | | | | | | | | |

Source: Authors' calculations.

14. An overview of results is also provided in CRU (October 2018), though the results for Constancia, Fruta Del Norte, Lagunas Norte, Piedras Verdes, Zaldivar, Corumba, Taca Taca, and Veladero have been updated.

4.1. Physical Impacts of Existing Fiscal Regimes in LAC

We begin with an examination of the impacts of the fiscal regimes on project design. It is useful to point out that the differences in physical impacts of fiscal regimes are due to four primary factors: the fiscal regime's components; the taxation rates applied through those components; taxation's effective intensity at a project given that project's profitability and the absence of neutrality of these fiscal regimes; and an Operator's flexibility over project design and operation in response to taxation.

As we noted above, fiscal regimes are very different from country to country. Even within a country the fiscal regime can vary depending on which State (or region) the project is in and what product (type of metal or hydrocarbon) the project produces. Within our sample, the impact of a pure difference in fiscal regime can be seen by comparing Argentina's mining projects for 2017 and 2018, where the difference is a decrease in the CIT rate and a decrease in dividend taxes. The projects have a higher investment level under the reduced tax rates. For petroleum, a similar comparison can be seen in the case of Ecuador, where the country has used two onshore regimes, one with a WPT and one without. Investment decreases dramatically when the fiscal regime includes a WPT.

As we will show in later sections, none of the LAC fiscal regimes that we study are neutral. Instead, they are either progressive or regressive, meaning that their effective rate of taxation on a project varies with profit margin. Therefore, taxation's effective intensity on a given project affects the level of distortions. In a regressive regime, a low margin (high cost) project will be exposed to a higher effective tax rate and exhibit larger design distortions than the same project with a higher margin (lower costs) within the same country.

Moreover, different projects have different technical specifications that may or may not allow the Operator much flexibility in design. By definition, the more the design varies in response to a given fiscal regime, the more flexibility the project Operator has. In the mining case studies, each project's specific technical opportunities are modeled. Some projects have more flexibility in design than others. Brazil's two iron ore mining projects are a case in point, with Minas Rio being a more flexible project than Corumba and therefore experiencing less investment in response to taxation. In petroleum, because of the use of hypothetical as opposed to actual project scenarios, all similar scenarios within a country (e.g., onshore oil and gas) have the same project margins and same design flexibility. Any difference in investment between two such scenarios within the same country is completely due to the difference in fiscal regime between the two scenarios (e.g., the Ecuadorian example mentioned above). But when scenarios from different countries are compared, differences in fiscal design, operating margin, and project flexibility all come into play, just as they do in the mining scenarios.

A comparison of Mexico's two mining projects is of interest in teasing out these effects given that they, for the most part, bookend the rest of the project results presented in this section. The fiscal regime in Mexico has almost no effect on Noche Buena's gold reserves but substantial effect on Piedras Verdes' copper reserves (see Figure 4.8). The fiscal regime is virtually the same for these two projects, so it cannot be causing the difference.¹⁵ On the other hand, Noche Buena is the more marginal project and, given Mexico's regressive fiscal regime (see Section 5.1.2), its rate of taxation will be higher than Piedras Verdes (see Figure 4.13). In this case it is possible to deduce that Noche Buena's specific design and operating flexibility is limited compared with Piedras Verdes. As a result, even though it has a higher effective rate of taxation it has fewer distortions and suffers less DWL.

15. In Mexico there is a special mining tax that differs according to the metal produced. Copper has a 7.5% rate, whereas gold has an 8% rate. This difference is too small to be of significance in this comparison.

This example emphasizes that the spread in outcomes in the physical impacts of fiscal regimes in LAC can be as much due to project idiosyncrasies (in the case of mining) as they are due to the differences in the fiscal regimes studied (in the case of petroleum). That said, a common theme in the rest of this section is that, whether due to more distortionary fiscal design, decreased operating margins, or more operating flexibility, petroleum design decisions are more impacted by the applicable fiscal regimes than mining design decisions.

4.1.1. Exploration Effort (Petroleum Only)

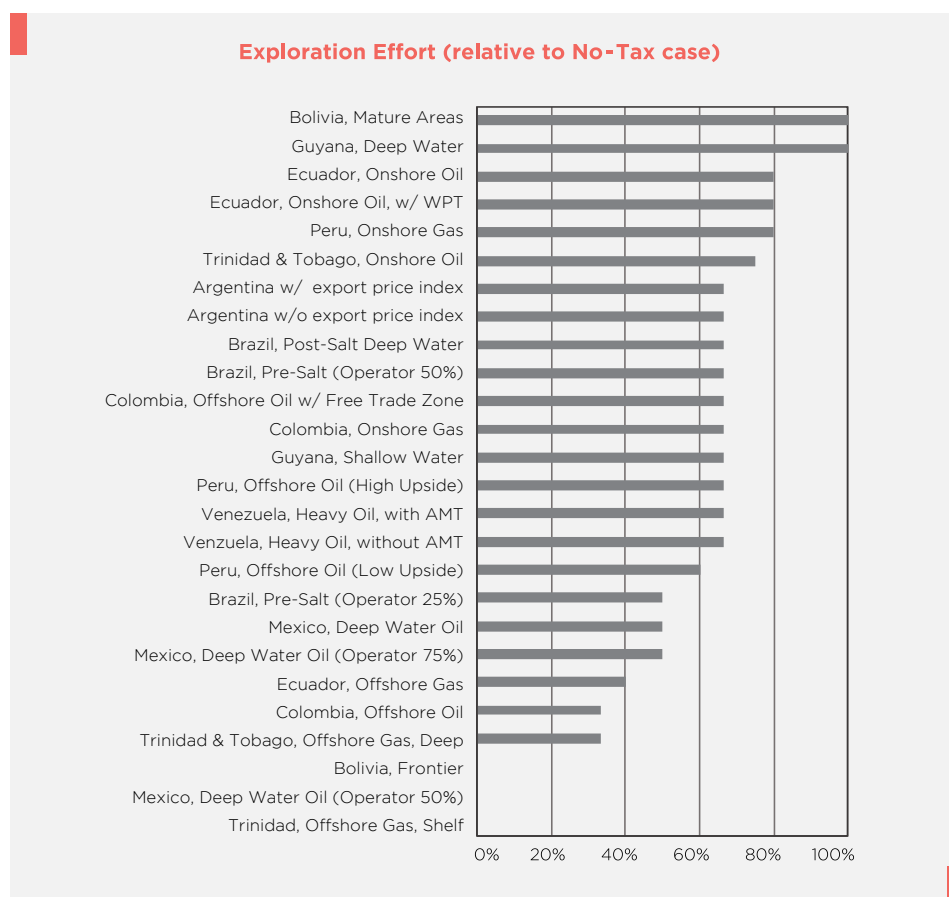
Because of the hypothetical nature of the petroleum projects selected, we were able to perform an analysis for these projects of the effects of taxation on the exploration stage of investment. The intensity of exploration can be measured by the number of dry holes an Operator would tolerate before abandoning the exploration campaign within a given block or concession. We refer to this as the “maximum number of dry holes” and measure the extent to which each of the existing tax regimes reduces the maximum number of dry holes relative to the No-Tax benchmark. This type of analysis is based on the principle that another exploration well will follow a dry hole as long as the expected value of that next well (including both the reduced chance of subsequent success and the after-tax expected value of a successful well) remains positive.¹⁶ The more punitive the tax, the less likely additional wells will be drilled.

On average, the existing LAC fiscal regimes reduce the intensity of oil and gas exploration by 42% relative to the No-Tax benchmark (see Table 4.1). Nevertheless, there is substantial variation between the several regimes studied, as illustrated in Figure 4.1, where countries and regimes are ranked in terms of the extent to which taxes distort exploration intensity. In the best cases, exploration at the marginal well in Bolivia’s mature areas and Guyana’s deep water fields is not deterred by taxation, given their high probability of success. But in the worst cases, several countries’ fiscal regimes completely extinguish the incentive to drill even the first exploratory well (i.e., Bolivia’s frontier areas regime, Mexico’s deep water oil regime (Operator 50%), and Trinidad & Tobago’s offshore shelf gas regime). On average, the PSC regimes tend to reduce the intensity of exploration to a larger extent (45% reduction relative to the No-Tax benchmark) than the Concessionary regimes (37% reduction).

Reduced exploration has the probabilistic impact of decreasing the expected oil and gas recovery from a field. This leads to inefficiencies and DWL as a result of profitable oil and gas being left undeveloped when, on average, it would be developed had the correct amount of exploration effort been undertaken. This lost resource is the reason that the DWLs for the Full-Cycle analysis double on average those of the Half-Cycle analysis (see Table 4.1). While we were not able to estimate the Full-Cycle effects for mining, there is no reason to believe that the DWL for mining would not also be substantially greater were we to include exploration effects.

16. Probability of success is assumed to decline after each dry hole according to Bayes’ Law. The probabilistic mechanism is explained in Smith (2005).

Figure 4.1: Exploration Intensity (Petroleum)



Source: Authors' calculations.

To emphasize the differing impacts the same fiscal system can have on different projects – a key finding of this report – Bolivia's fiscal regime has dramatically different impacts on the two types of geological resource. Exploration in the frontier area project is completely extinguished by the fiscal system, while exploration in the mature area project is not affected due to the very low cost of completing additional wells there. It does not take a large after-tax profit from subsequent development to justify exploration in Bolivia's mature areas, but a large after-tax profit is required to justify the high cost of exploration in frontier areas.

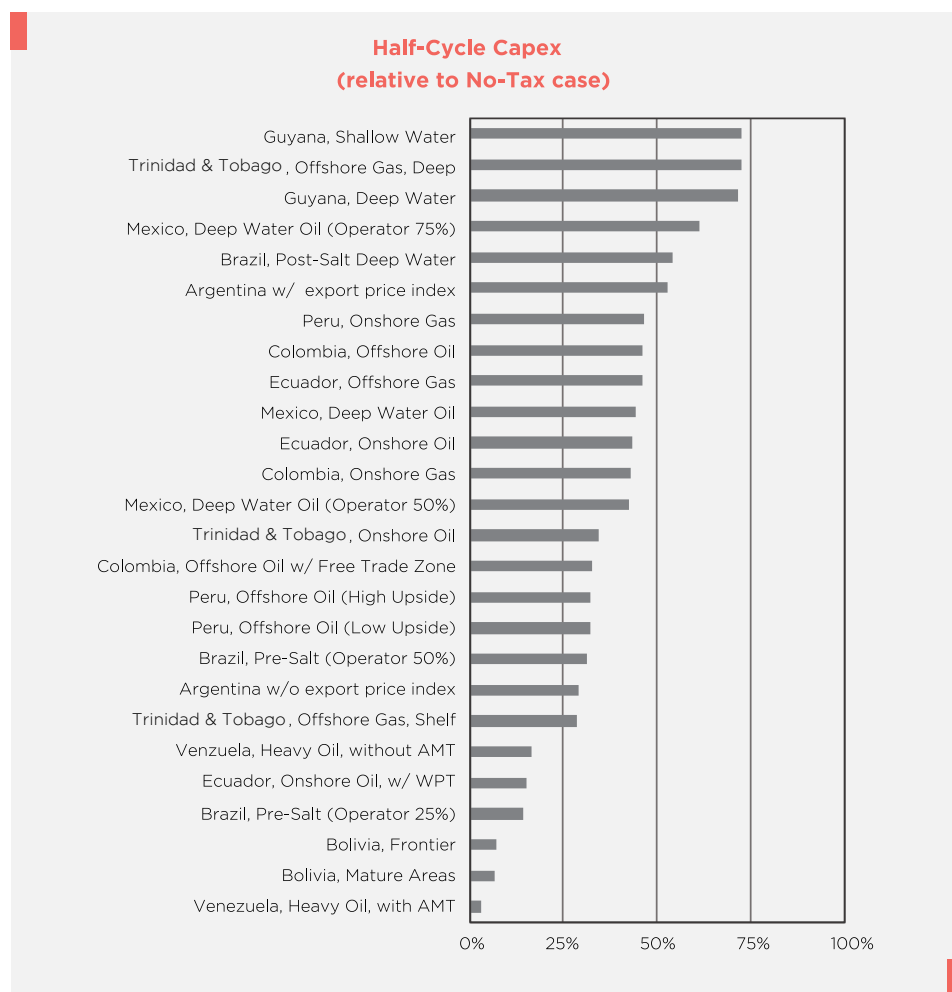
4.1.2. Investment at the Development Stage

Governments tend to spend considerable resources to attract investment in mining, oil, and gas because of the sectors' various economic and social benefits. Reduced investment results in fewer construction jobs, fewer ancillary and support jobs, and a reduced stock of national physical capital. Column 2 in Table 4.1 shows the impact of LAC's fiscal regimes on investment in project development, conditional on prior exploration efforts being successful. All the existing LAC fiscal regimes suppress the level of investment relative to their No-Tax benchmarks.

On average, the tax burden from existing LAC petroleum fiscal regimes reduces Half-Cycle investment to 38% of the No-Tax benchmark. However, the size of this distortion varies significantly across individual countries and regimes, as illustrated in Figure 4.2. In the best cases, Guyana's shallow water and Trinidad & Tobago's deep water gas regimes reduce investment by only 27%. But in the worst cases, Venezuela's heavy oil (with or without the Alternative Minimum Tax or AMT), Bolivia's mature and frontier areas regimes, Brazil's Pre-Salt

Regime (Operator 25%), and Ecuador's Onshore Oil regime with Windfall Profits Tax all reduce investment by more than 75% compared to the No-Tax benchmark.

Figure 4.2: Half-Cycle Capital Investment (Petroleum)



Source: Authors' calculations.

For mining fiscal regimes, investment in project development is, on average, 20% lower than the No-Tax case, with a worst-case reduction of 41% and a best-case reduction of 2% (Table 4.1 and Figure 4.3). Because of economies of scale in mining, decreased investment serves to increase operating costs. This serves to dampen an Operator's incentives to reduce investment in the face of taxes and may explain in part the reduced distortions seen in mining compared with the petroleum Half-Cycle analysis.

Figure 4.3: Half-Cycle Capital Investment (Mining)



Source: Authors' calculations.

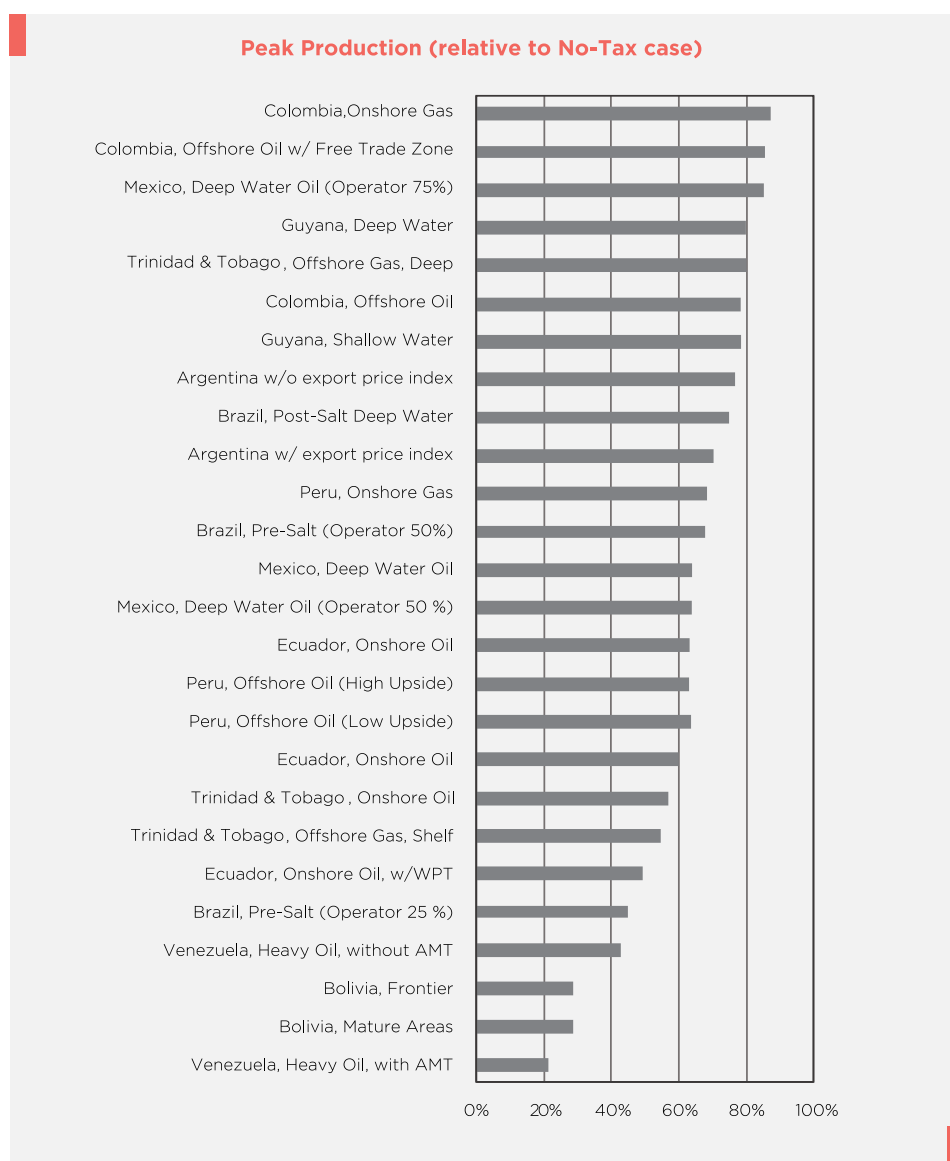
4.1.3. Peak Rate of Production

Table 4.1 also reports the impact of fiscal regimes on the Peak Rate of Production for projects relative to the No-Tax case. The Peak Rate of Production measures the rate of extraction of a project and is also an indicator of the scale of its initial installed production capacity. A lower Peak Rate results from a lower initial investment in project development. All petroleum and mining fiscal regimes in LAC incentivize slower production relative to the No-Tax case due to the decreased investment noted above. In the oil and gas models, natural decline will also cause production to decline over the life of the field. In the mining models, the Peak Rate is maintained until the resource is abandoned, at which point production falls to zero.

A reduction in the rate of production marks a slowdown in the cash flows received from a project by both the Operator and Government. A lower rate of production also typically extends the life of a project. It is important to note that, for both petroleum and mining, an extended project life does not necessarily mean that more resources will be extracted – something we will discuss in more detail in the following sections.

On average, the tax burden from existing LAC petroleum fiscal regimes reduces the Peak Rate of Production by 37% relative to the No-Tax benchmark. But, again, there is substantial variation between countries and scenarios, as illustrated in Figure 4.4. In the best-performing cases – including Colombia's regimes, Mexico's deep water oil regime, Guyana's regimes, and Trinidad & Tobago's deep water gas regime – the Peak Rate is reduced by roughly 20% or less. Yet, in the worst-performing case, Venezuela's regime reduces the Peak Rate by 79%. On average, concessionary systems and PSC regimes both have a similar effect, reducing the Peak Rate of production by 34% and 39% respectively.

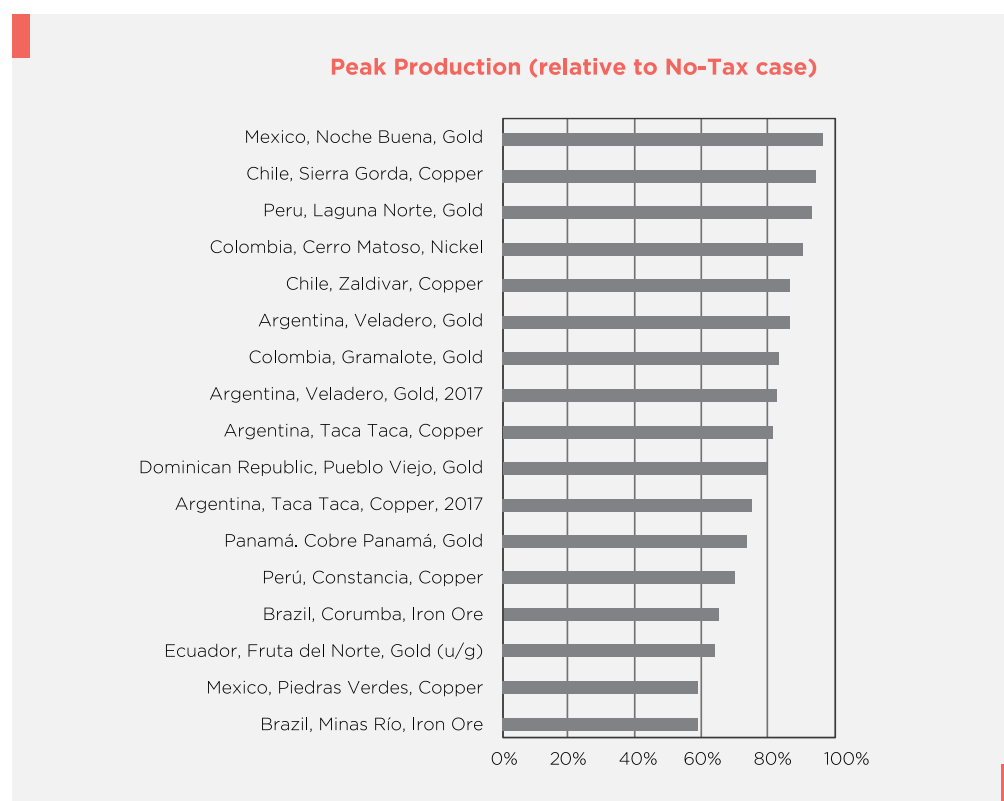
Figure 4.4: Peak Production Rate (Petroleum)



Source: Authors' calculations.

For mining, the rate of production is on average reduced by 21% compared with the No-Tax case, with a range from 3%, represented by Mexico's relatively inflexible Noche Buena gold project, to 41%, represented by Brazil's Minas Rio iron ore project, as shown in Figure 4.5.

Figure 4.5: Peak Production Rate (Mining)



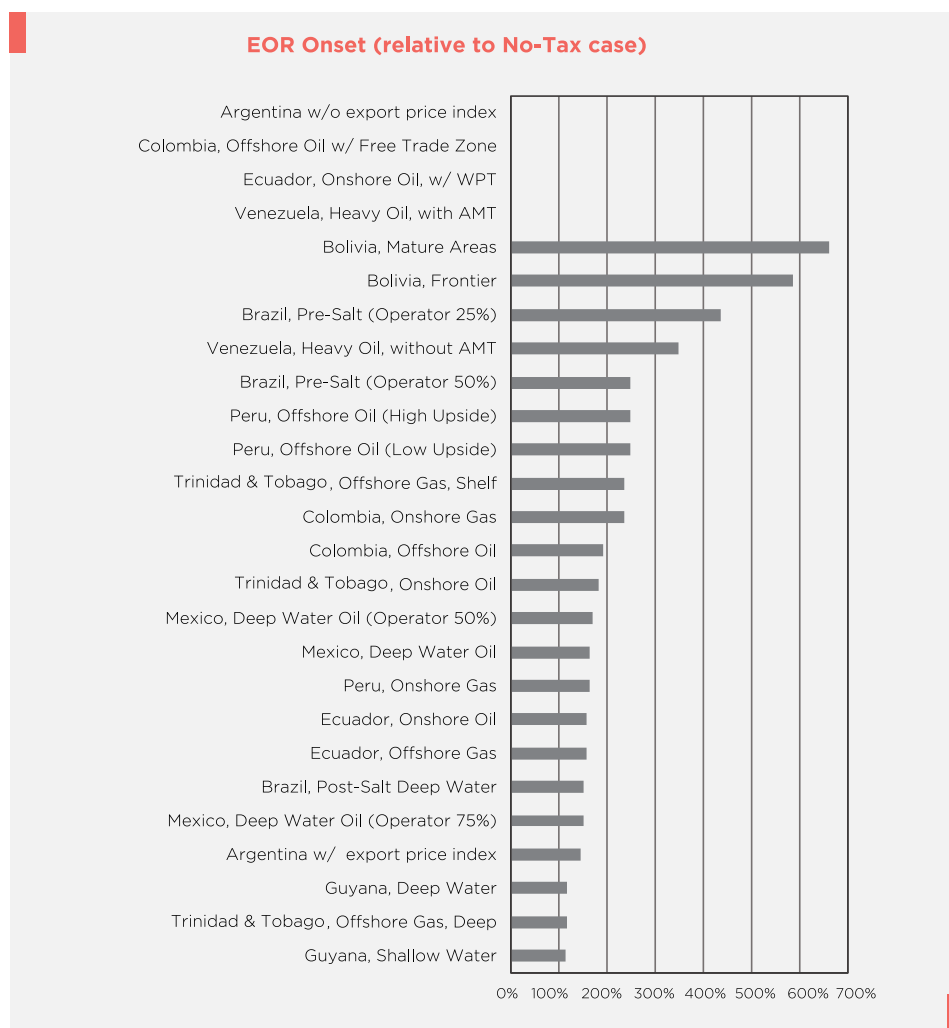
Source: Authors' calculations.

4.1.4. Enhanced Recovery (Petroleum Only)

The petroleum models allow for the option of investment spending on enhanced oil recovery (EOR). The LAC petroleum fiscal regimes tend to cause a delay in the application of enhanced oil recovery, as shown in Column 4 of Table 4.1. On average, the time period of primary production, which precedes EOR, more than doubles relative to the No-Tax case. In Argentina's regime without export price indexing, Colombia's offshore oil regime with a Free Trade Zone, Ecuador's offshore oil regime with a Windfall Profit Tax and Venezuela's heavy oil regime with an Alternative Minimum Tax, the tax burden imposed by existing LAC fiscal regimes eliminates investments in EOR altogether. Those cases are not included in the summary statistics shown in Table 4.1 but are reflected in Figure 4.6.

The delay in pursuing EOR is substantially longer in the case of PSC regimes than in the case of Concessionary systems. The apparent vulnerability of EOR to PSC regimes has much to do with the limitations placed on the Operator's ability to recover capital expenditures expeditiously. Most PSC regimes in LAC are characterized by having a low Cost Oil share of project revenues. This means that the portion of sales revenue from which the Operator is allowed to recover capital and operating costs under a PSC regime is relatively low. When the magnitude of revenues is also low, as is typical of the late-in-life circumstances in which EOR would be considered, the burden of carrying forward unreimbursed capital expenditures may be enough to forfeit EOR altogether. The range of variation in the distortion to EOR across countries and regimes is shown in Figure 4.6.

Figure 4.6: Enhanced Oil Recovery



Source: Authors' calculations.

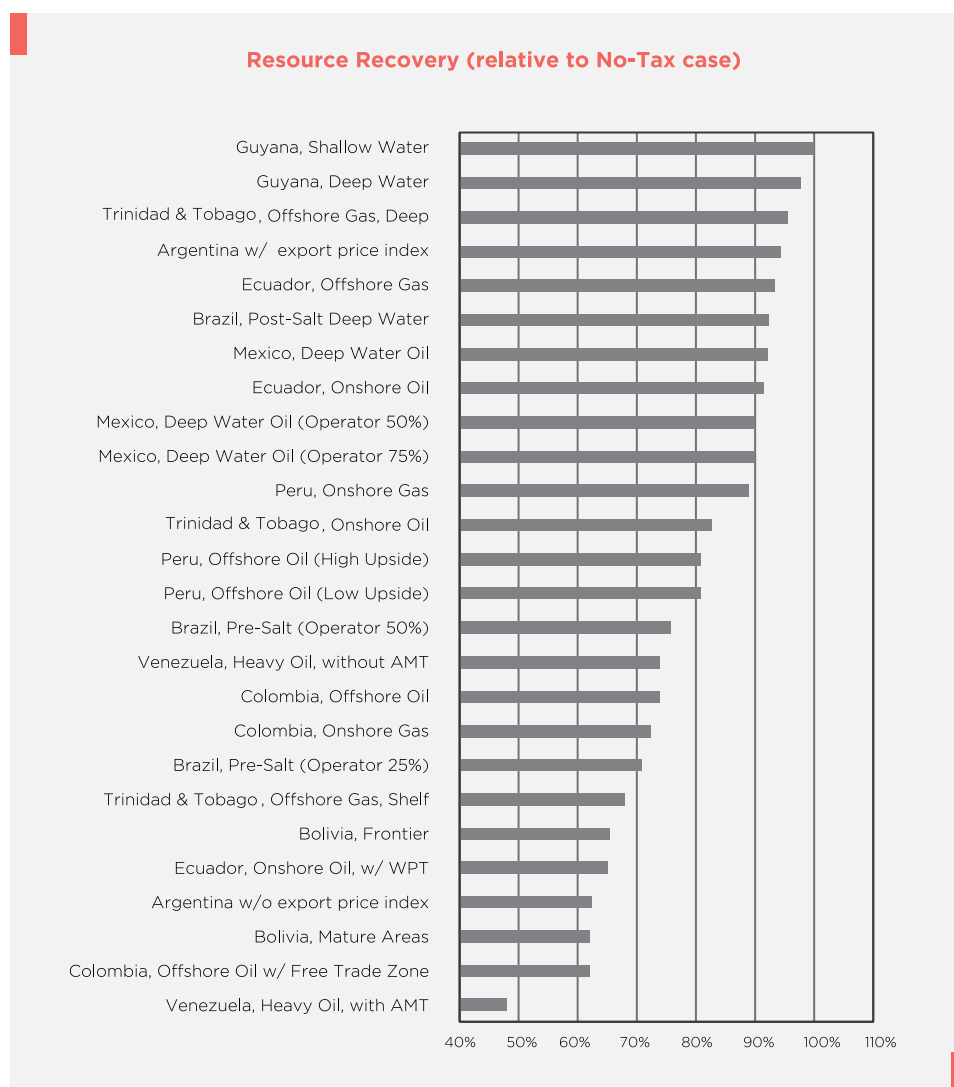
4.1.5. Resource Recovery Factor

The fiscal regimes also result in “high grading” at the mining projects (lower mineral grades become uneconomic to produce) and a higher “economic limit” (the rate of production at which operations are abandoned) at oil and gas projects. EOR is also curtailed in some of the petroleum fiscal regimes (see previous section). The nearly universal result is that fewer reserves are extracted. On average, the existing LAC fiscal regimes reduce the volume of known reserves by 20% for oil and gas projects and 7% for mining projects (see Column 5 of Table 4.1) though, again, there is substantial variation between countries and between scenarios within countries in this regard. Once again, the distortions in petroleum are greater than those in mining.

In the worst cases, the burden of taxation potentially reduces the volume of petroleum reserves for Argentina’s regime without export price index, Bolivia’s regime for mature areas, and Colombia’s offshore oil regime with Free Trade Zone provisions by more than one-third, and for Venezuela’s heavy oil regime with Alternative Minimum Tax by more than half. On average, Concessionary systems and PSC regimes have a similar impact on the volume of recoverable petroleum reserves (25% and 18% reduction, respectively). The loss of reserves makes clear that, while the reduced peak rate of production that we saw in our results often

extends the life of a project, it does not add enough volume of production at the tail end of the project's life to compensate for the slower initial rate of extraction.

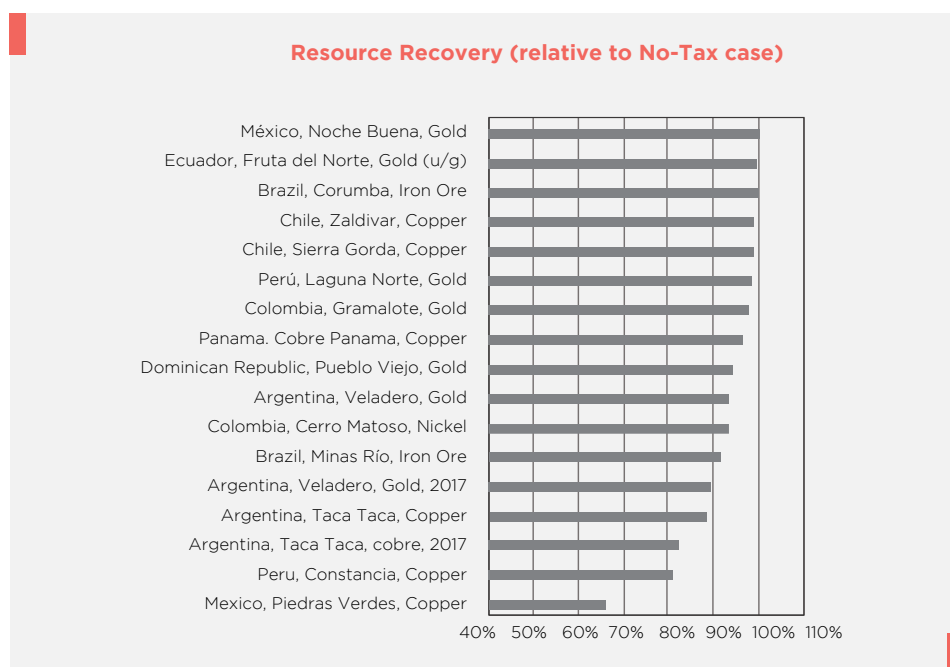
Figure 4.7: Resource Recovery Factor (Petroleum)



Source: Authors' calculations.

In mining, unlike petroleum, the reduction in investment and resultant slower production caused by the fiscal regimes tends to increase production costs, as mining projects are subject to economies of scale. Lower production levels increase the unit operating costs across the projects in our sample by an average of 6%, as compared to the No-Tax case. This incentivizes “high grading” across the mining projects which is the practice of mining only the orebody with the highest grade of material. The lower grade material is left unmined given that higher operating costs, combined with taxes, make it uneconomic to extract. This results in fewer overall reserves being extracted over the lifetime of the project. On average, the existing LAC fiscal regimes reduce the volume of recovered reserves by 7% for mining projects (see Column 4 of Table 4.1). Figure 4.8 shows the decreased resource recovery factor for each mining project in the sample.

Figure 4.8: Resource Recovery Factor (Mining)



Source: Authors' calculations.

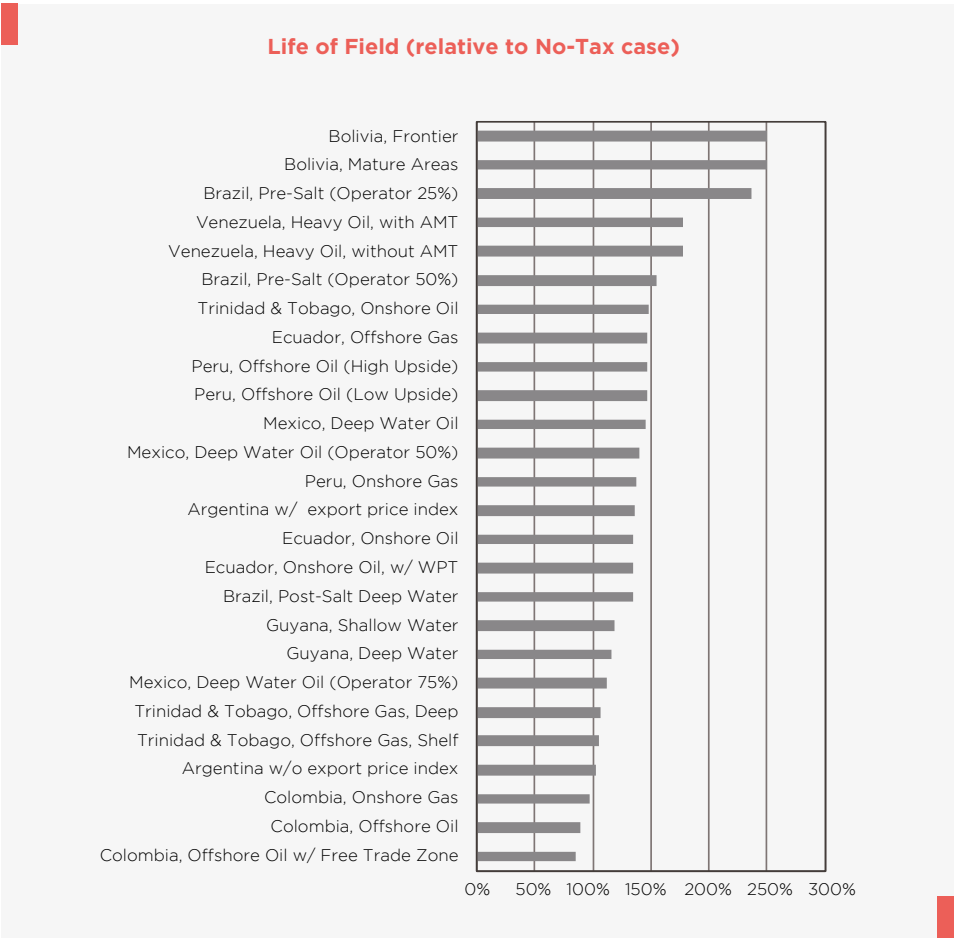
4.1.6. Project Life and Abandonment

Because the existing LAC fiscal regimes tend to reduce the rate of extraction from typical projects, they also reduce the rate of resource depletion. Even though there are fewer resources to begin with compared to the No-Tax case in most of the cases studied, this results in an extension of the life of the project in all the mining and most of the petroleum projects studied. Project life increases by 43% on average for petroleum projects and 19% on average for mining projects relative to the No-Tax case, as shown in Column 6 of Table 4.1. Variations in the size of tax-induced distortions of the life of petroleum and mining projects in the various countries and regimes are shown in Figures 4.9 and 4.10, respectively.

For oil and gas, PSC regimes tend to extend field life somewhat longer than do Concessionary systems. This is a consequence of the tendency for lower initial investment and slower extraction under the existing PSC regimes, as discussed above. In extreme cases, such as in Bolivia's Frontier and Mature Areas regimes and Brazil's Pre-Salt (25% operator) regime, the life of the project is more than doubled. Nevertheless, we emphasize that longer project lives are not per se beneficial. Slower depletion may keep the asset alive longer, but it also reduces the present value of operating profits and GT. This would be true even if the project remains in production long enough to produce the same cumulative volume of resources over the course of its lifetime as compared to the No-Tax case.

A decreased project life can also be detrimental. In the case of Colombia, for example, the existing fiscal regimes (onshore gas and offshore oil, with or without a Free Trade Zone) increase the breakeven level of production (where the field hits the economic limit and is abandoned) so much that, in conjunction with decreased efforts at EOR, abandonment occurs up to 15% earlier than in the No-Tax case. This leaves an even greater portion of the original resource-in-place lost forever in the ground and represents a doubling down in terms of inefficiency because fewer resources are produced each year over the abbreviated lifetime of the field.

Figure 4.9: Project Lifetime (Petroleum)



Source: Authors' calculations.

In mining, none of the project lives are shortened in this way because reserves are exogenous to the rate of production; slowing the rate of production cannot augment reserves as it can in petroleum. As a consequence of this exogeneity, while resources are reduced as a result of taxes, the coincident reduction in production rate due to decreased investment necessarily causes mine life to be extended in each case. Ecuador's Fruta del Norte gold project is the most affected, while Colombia's Cerro Matoso's nickel project is the least affected.

Figure 4.10: Project Lifetime (Mining)



Source: Authors' calculations.

The fact that in Section 4.1 the distortions to the projects vary in severity depending on the physical measure used reinforces the idea that each project responds differently, across different project facets, to a fiscal regime. One cannot hope to predict with any reliability how a specific project attribute will respond to taxation without first modeling the project (which includes engineering tradeoffs in project design and cost) and then imposing a specific fiscal regime on that project, as we have done.

4.2. Impacts of Taxes on Project Economics and Government Benefits

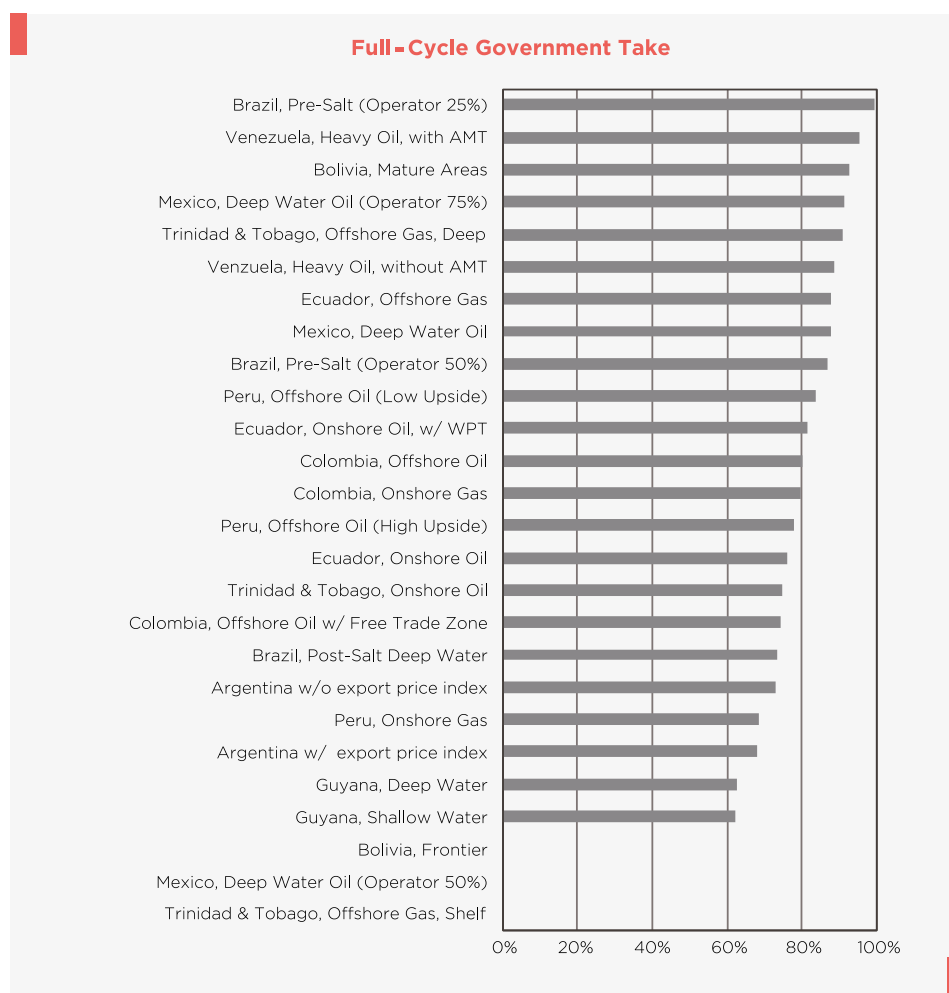
The remaining columns of Table 4.1 report the financial impact that existing LAC fiscal regimes have on the “size of the pie” to be shared between Operator and Government, and on the share of that pie captured by Government. The “pie” consists of economic rents generated through exploration, development, and production. These rents reflect economic profits in excess of the costs incurred to exploit the resource, as typically enumerated by a positive project NPV. Any tax-induced distortions will reduce the size of pie, but the impact on Government also depends on whether distortive tax provisions direct a substantially greater share of the reduced rents to Government.

4.2.1. Government Take

Government Take, shown in the seventh and eighth columns of Table 4.1, is the conventional measure of fiscal performance that many studies (and governments) have focused on. It is calculated as the share of total post-tax Project NPV (total rents) that accrue to Government and workers (Government NPV) through taxation. For the twenty-six oil and gas scenarios analyzed here, on average, the existing LAC petroleum fiscal regimes generate a GT of 71%, or roughly US\$456 million per project, based on Full-Cycle analysis of the project that counts all cash flows beginning at the exploration stage.¹⁷ This means that, on average, 29% of the

17. These figures are based on the unweighted average of Government Take calculated across all twenty-six scenarios.

Figure 4.11: Full-Cycle Government Take (Petroleum)



Source: Authors' calculations.

rents produced in the upstream petroleum sector, or US\$196 million per project, are retained by the Operator. However, many countries' regimes deviate significantly from the average, as shown in Figure 4.11.

On the high end, Full-Cycle GT reaches 99% of rents in Brazil's Pre-Salt (Operator 25%) regime while, on the low end, Full-Cycle GT is stuck at 0% for Bolivia's frontier regime, Mexico's deep water oil (Operator 50%) regime, and Trinidad & Tobago's offshore shelf gas regime because the applicable taxes in those scenarios completely extinguish the Operator's exploration incentives in the first place; no economic rents are generated so there are none to share.

This result highlights the crucial impact that fiscal burdens place on the exploration stage of the upstream enterprise. Without those initial investments, development of substantial new resources is impossible, and the potential benefits of resource development will not materialize. Too stringent taxation of the profits that are expected to accrue at the production stage directly reduces the return to exploration — potentially to an extent that deters the whole enterprise, as we see in a few of the existing LAC regimes. This is a particular problem for PSC regimes, where incentives to exploration are lower than for Concessionary systems (see the first column of Table 4.1 and Section 3.1). Consequently, Full-Cycle GT averages only 66% of the No-Tax benchmark for PSC regimes, in contrast to an average of 79% across the Concessionary systems.

Once a discovery has been made, exploration costs are sunk and should not significantly affect subsequent development decisions.¹⁸ To isolate and identify fiscal impacts that affect the development and production of known resources, we consider Half-Cycle economics and analyze how the investment decisions an Operator would make to develop a known resource under the prevailing tax regime compare to the No-Tax benchmark. Column 8 in Table 4.1 shows Half-Cycle GT.

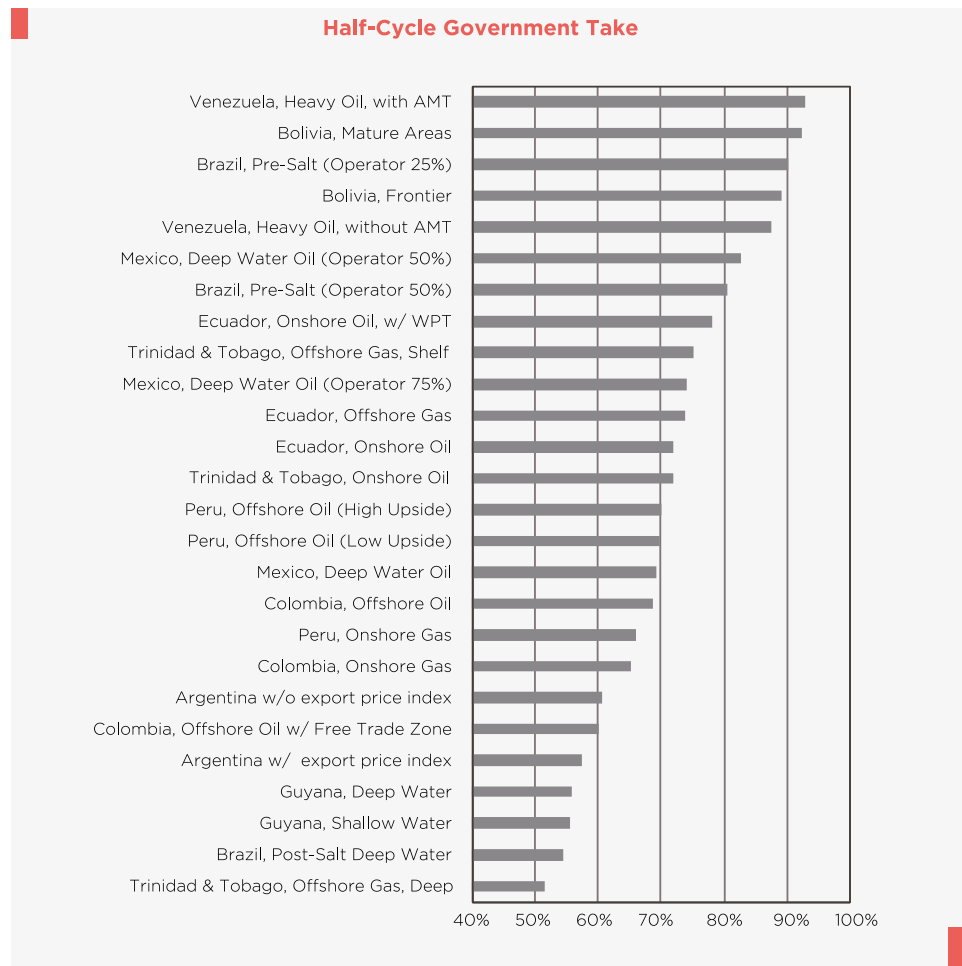
For oil and gas regimes, Half-Cycle GT averages 72% of available rents, or US\$ 936 million per project, only marginally higher than the average Full-Cycle GT of 71%. On the lowest end, Half-Cycle GT is 51% in Trinidad & Tobago's offshore deep water gas regime. In a number of cases, including in Venezuela's heavy oil (with AMT) and Bolivia's mature areas, the Government manages to capture more than 90% of Half-Cycle economic rents, as shown in Figure 4.12. However, it is important to repeat that this is contingent on an Operator already having made the initial investment in exploration, which seems difficult in the case of the Bolivian and Venezuelan regimes due to the lack of incentives seen in the Full-Cycle results.

It is obvious that measuring and reporting only Half-Cycle GT can mask important deficiencies related to exploration incentives. In general, Full-Cycle GT might tend to exceed Half-Cycle GT since most exploration costs fall on the Operator, not the Government. Offsetting this, however, is the possibility that high taxation might extinguish exploration altogether, in which case Full-Cycle GT falls to zero, although the hypothetical Half-Cycle GT, based on the assumption a discovery has already been established through exploration, could still be positive. Unfortunately, Half-Cycle GT is often what gets reported when fiscal regimes are being evaluated. Due to missing data, it is also the only measure of GT we have been able to calculate for the mining fiscal regimes.

At 60%, or US\$ 2,756 million, average Half-Cycle GT is proportionally lower for mining than for the corresponding oil and gas regimes. On the low end, Chile's Sierra Gorda copper project has a 46% Half-Cycle GT while, on the high end, Brazil's Minas Rio iron ore project has an 82% Half-Cycle GT, as shown in Figure 4.13. The higher GT seen in the oil and gas regimes is a result of the more numerous petroleum tax instruments applied in LAC, at often higher tax rates.

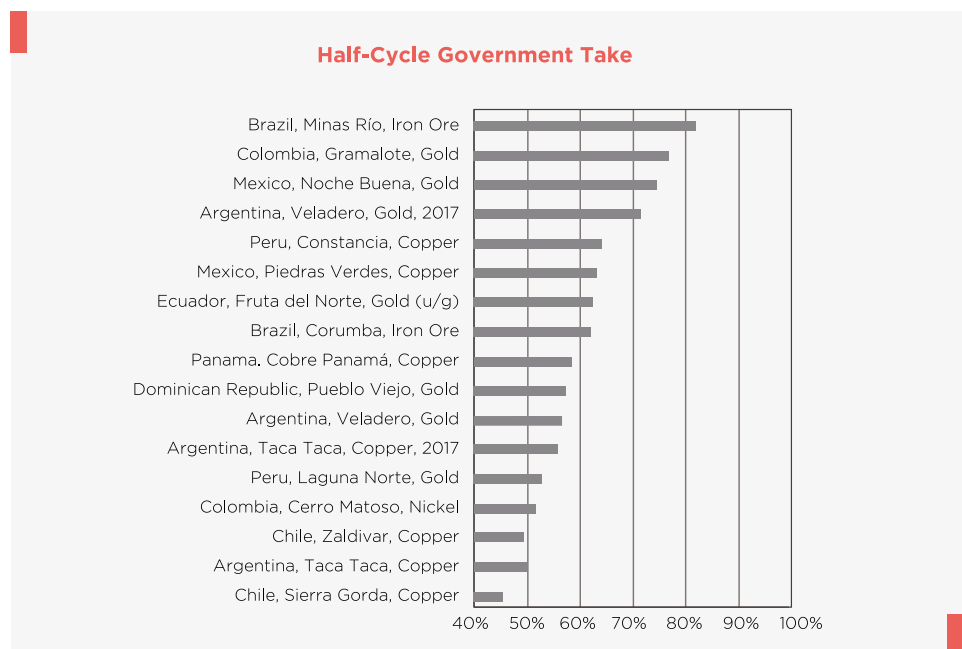
18. Costs incurred at the exploration stage impact decisions at the development stage only to the extent that unrecovered exploration costs can be used to offset taxable income from production. We exclude from our subsequent analysis of Half-Cycle economics the sunk cost of initial exploration investments but for petroleum include the impact of whatever tax shield each fiscal regime allows for the recovery of those costs at the production stage. The mining project analysis does not include these tax shields.

Figure 4.12: Half-Cycle Government Take (Petroleum)



Source: Authors' calculations.

Figure 4.13: Half-Cycle Government Take (Mining)



Source: Authors' calculations.

4.2.2. Deadweight Losses

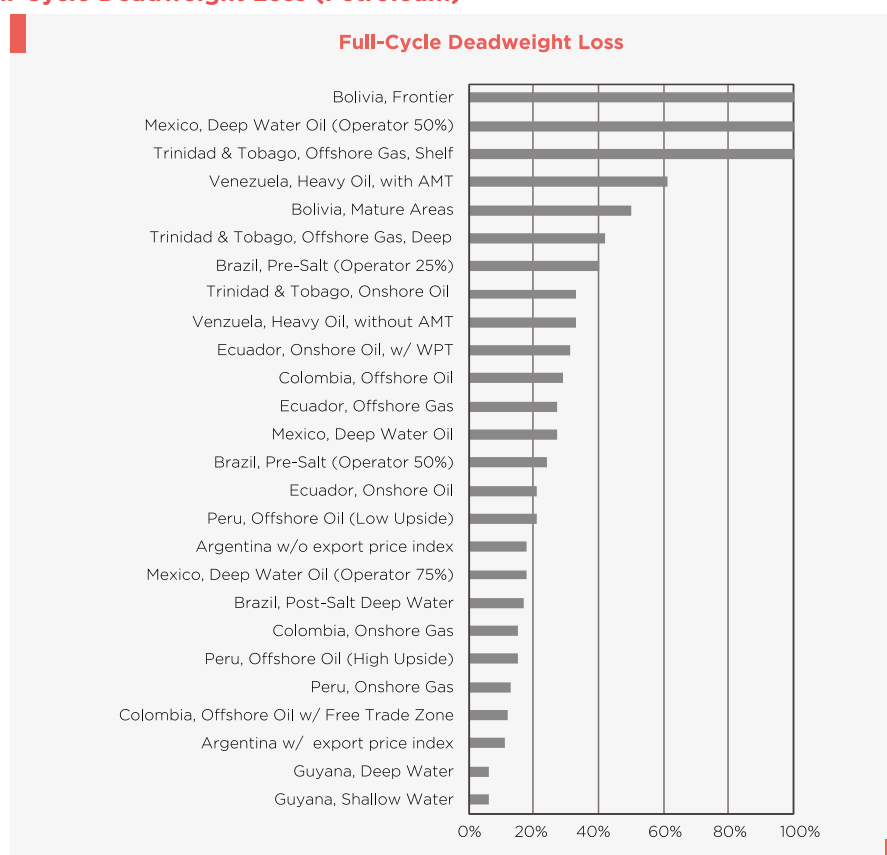
The physical project distortions we have outlined above create DWLs that, to various degrees, shrink the size of the rent or pie available to be shared by the Operator and Government. DWLs represent the social inefficiencies of taxation. In particular, the reduced recovery of reserves and the slowdown of cash flow receipts from the reserves that are recovered are the main drivers of the DWLs observed in our analysis. In some cases, the DWLs created by the existing LAC fiscal regimes are large relative to the potential value of the underlying resources, which limits the benefits that LAC nations can derive from their domestic resource endowments.

Full-Cycle DWLs for oil and gas projects can be particularly high, as seen in column 9 of Table 4.1 and Figure 4.14 below. On average, one-third (33%) of the potential value of the petroleum resource endowments is lost due to tax-induced distortions at the exploration, development, and production levels. Of course, there are many more than the twenty-six projects we have analyzed within the LAC region that are at risk of DWLs of this magnitude.

Again, the variation between countries and scenarios is large. The best performing regimes, including both of Guyana's regimes, have Full-Cycle DWLs of less than 10% of the potential value of the resources. But, on the high end, Bolivia's frontier regime, Mexico's deep water oil (operator 50%) PSC regime and Trinidad & Tobago's offshore shelf gas regime all produce DWLs of 100%, as all the value of the resource is potentially sacrificed due to the deterrent to exploration.

Concessionary systems tend to be somewhat more efficient than PSC regimes, sacrificing an average of only 26% of the value of the Full-Cycle resource endowment versus 38%. As we have previously mentioned, the main difference between the two systems is that the deterrent to exploration tends to be smaller under the Concessionary regimes. Nevertheless, as Figure 4.14 indicates, a poorly designed Concessionary system – as in the case in Venezuela's heavy oil (with AMT) regime – may still sacrifice over 60% of the value of the resource base. In Venezuela's case, this is because the concessionary regime includes all the usual components of a corporate income tax, but also a special alternative minimum tax that bears no relation to project profitability.

Figure 4.14: Full-Cycle Deadweight Loss (Petroleum)

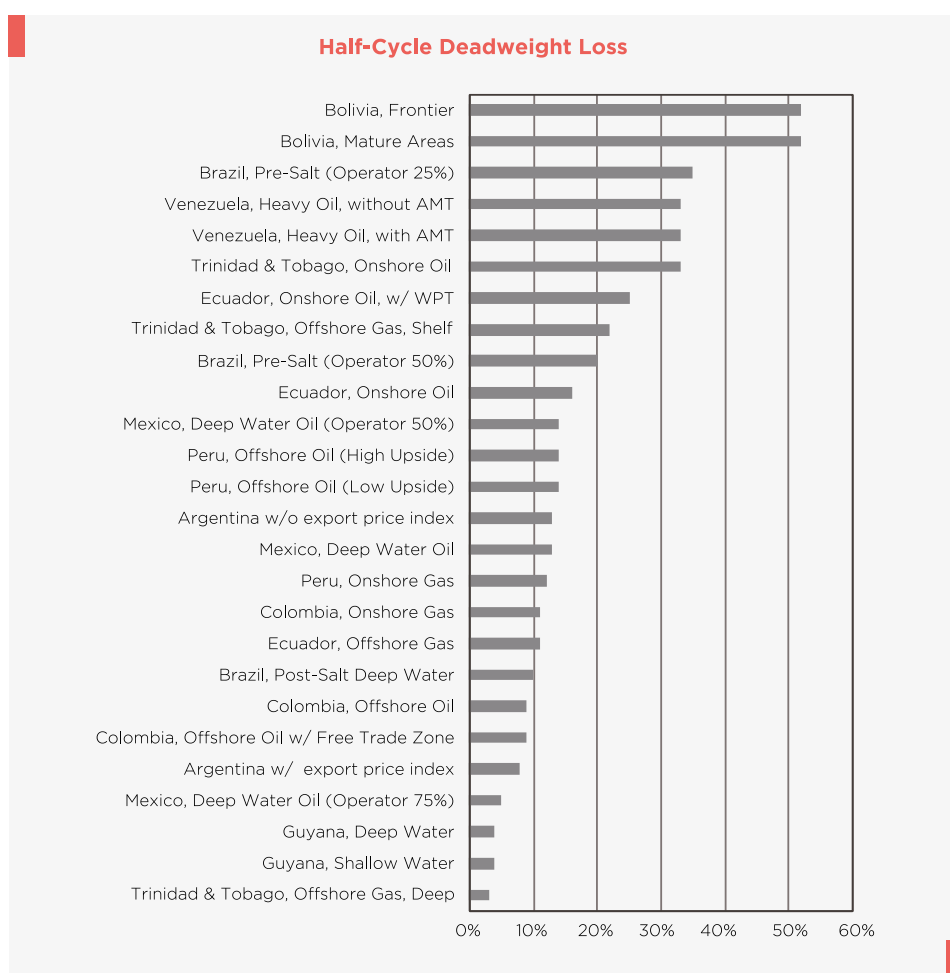


Source: Authors' calculations.

Half-cycle DWLs, which have been estimated for both petroleum and mining, are much smaller proportionally than Full-Cycle DWLs but still significant (see Figures 4.15 and 4.16). Losses are smaller because the Half-Cycle measure excludes any losses due to the suppression of exploration. On average, Half-Cycle DWLs for oil and gas regimes amount to 18% of the potential value of a known field (see column 10 of Table 4.1), though there is great variation amongst the regimes analyzed. Trinidad & Tobago's offshore deep water gas regime is the best performing, generating DWL of only 3%, while Bolivia's frontier and mature regimes are the worst performing, generating DWL of 52%. Again, the total DWLs at stake in the region are many times greater as there are many more oil and gas projects subject to taxation in LAC than as modeled here.

Most of these DWLs result from less intensive development of the resource, which in turn is a result of an Operator's decision to alter a project's design in response to taxes. Initial investment is smaller, peak production is lower, and the resource is extracted more slowly relative to the No-Tax case. Investments in enhanced oil recovery are also delayed, downsized, or foregone altogether. As we have already seen, fewer reserves are produced over the life of the asset. Concessionary systems and PSC regimes are not much different when evaluated on a Half-Cycle basis, producing 17% versus 19% DWLs respectively. This parity, unlike the Full-Cycle result, is due to the exclusion of the large distortions to exploration that the PSC regimes tend to create.

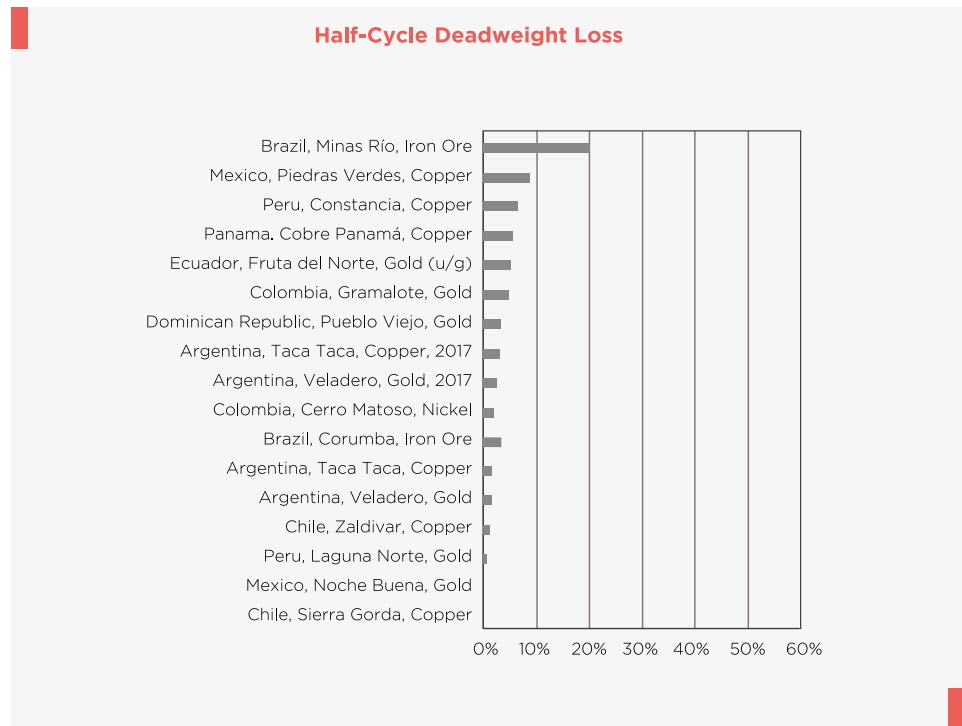
Figure 4.15: Half-Cycle Deadweight Loss (Petroleum)



Source: Authors' calculations.

At 4%, average Half-Cycle DWLs are proportionally lower for mining than petroleum. This is in part a result of the fewer and lower taxes imposed on mining (and consequent reduced distortionary impact), but could also be that the technology used in our sample of mining projects offers less opportunity for Operators to make changes to project design in the face of taxes. The absence of an expansion option similar to EOR is an example of what might be reduced flexibility. As it was also noted earlier, the reduction in investment and in the consequent scale of production of mining projects (Columns 2 and 3 in Table 4.1) increases mine project unit operating costs by an average of 6%, which contributes to the DWLs measured for these projects.

Figure 4.16: Half-Cycle Deadweight Loss (Mining)



Source: Authors' calculations.

Though mining DWL represents only 4% of the total Economic Rent available from these projects, some of this lost rent could be shared between the Government, society, and the Operator under more efficient fiscal systems. To be sure, the total DWLs at stake in the region are also many times the \$2.6 billion measured here as there are currently over 100 substantive mining operations in production and subject to taxation in South America alone.

Overall, as seen in Figure 4.16, all but five of the mining regimes studied (Minas Río, Piedras Verdes, Constancia, Cobre Panamá, Fruta del Norte) produced Half-Cycle DWLs of 5% or less. Chile's Sierra Gorda copper project, Mexico's Noche Buena gold project, and Peru's Lagunas Norte gold project produce close to zero DWL. With DWL of roughly 20%, Brazil's Minas Río iron ore project is an outlier. Brazil's Corumba iron ore project faces the same fiscal terms as Minas Río, save for a reduced production royalty, yet it only produces DWL of 3%. Even when that State royalty is removed for both projects, the tax regime affects Minas Río much more than it does Corumba. The reason for the difference between the two Brazilian mining projects' response to the same fiscal period regime must be their relative design flexibility. Section 5.2.1 takes up this analysis in more detail.

4.2.3. Fiscal Yield

As we have seen, a very high share of GT from a petroleum or mining project is not necessarily beneficial to a Government or society if it must be captured by a system of taxation that dramatically shrinks the size of the pie and the attendant benefits that come from a thriving industry. Yet, there are several existing LAC fiscal regimes – particularly in the petroleum sector – that can create this problem. In this section, we advance the measure of FY, which paints a more complete picture of the performance of a given regime across various projects and can help policymakers avoid the illusion of a tax system that takes a large slice of a small pie.

FY is defined as the NPV of total Government revenues captured under the given regime divided by the NPV of total project rents under the No-Tax benchmark. The denominator measures the total rents that would be available but for distortions caused by the fiscal regime. The ratio therefore measures the percentage of potential rents that are actually captured by the regime in question. Because some distortions and DWLs are probably inevitable in the presence of taxes, we would not expect FY to reach 100%. However, getting close to that benchmark means the fiscal regime is especially effective at avoiding most distortions while capturing most rents.

Full-Cycle FY (column 11 of Table 4.1) includes the calculation of the cost of exploration. Half-Cycle FY (column 12 of Table 4.1) excludes those costs.¹⁹ As long as there are DWLs, the FY of a given regime will be lower than the reported GT. And, the larger the DWLs, the greater will be that difference. On average, the FY of existing LAC regimes is much lower than the reported GT.

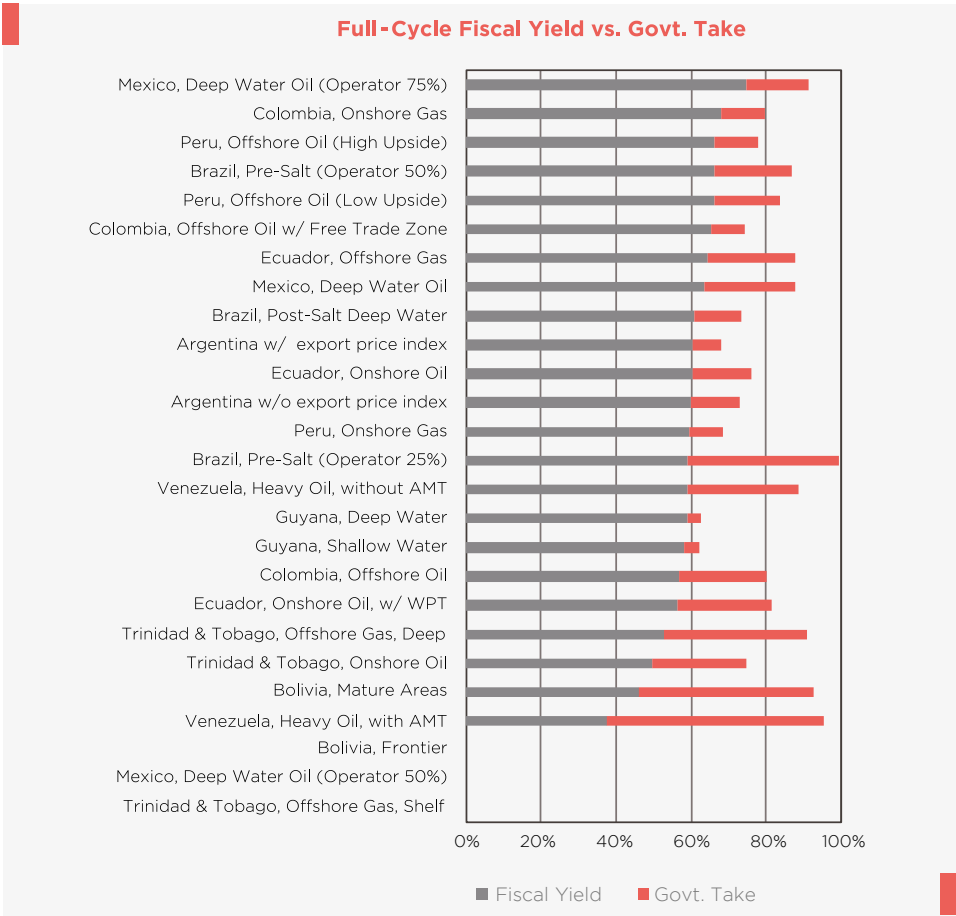
For petroleum, this is true of both the Full-Cycle measure (53% versus 71%) and the Half-Cycle measure (56% versus 72%), as can be seen in Table 4.1. Figures 4.17 and 4.18 below show this breakdown for each of the scenarios analyzed. The importance of considering the estimated FY of a regime in addition to the estimated GT can be illustrated by Venezuela. Full-Cycle GT for Venezuela's heavy oil (with AMT) regime reaches 95% of actual profits, but that amounts to only 38% (FY) of the potential rents that would accrue if the Operator were not deterred from investing more due to the Alternative Minimum Tax, which is not related to profitability. Half-Cycle GT for the same regime reaches 93% compared to a FY of 38%. For the Government, this results in the receipt of a large slice of a much smaller pie.

For mining, the Half-Cycle measures of FY and GT are not much different on average (58% versus 60%) because of the lower degree of distortion created by LAC's existing mining fiscal regimes. In fact, the average GT for mining is lower than petroleum's (60% versus 72%) as a result of less burdensome taxation, but its average FY is higher than petroleum's (58% versus 56%) as a result of this lower rate of taxation and the less distortionary instruments used (see Table 4.1). Nevertheless, in the cases where distortions are large a similar dynamic prevails: a very large share of GT can actually translate into a much lower measure of FY. In the case of Brazil's Minas Rio iron ore project, for example, a Half-Cycle GT of 82% is reduced to a FY of 66% due to the many distortions created by the fiscal regime. The result is a larger slice of a smaller pie.

It seems reasonable, then, for policymakers to estimate both GT and FY in order to ensure that any given regime is not leaving behind potential profits due to high distortions. Focusing on FY does not mean that weak taxation should be favored to eliminate distortions. Rather it should serve as a tool to analyze the impact of a given fiscal regime on both the size of the pie and the relative size of a Government's slice of that pie. For example, suppose a Government considered reforms that would lower a project's fiscal burden and remove almost all distortions. Suppose that regime generates a GT of only 50%. It follows that the calculated value of FY would also be close to 50%. Thus, our measure of FY seems a straightforward way to gauge the real impact of a fiscal regime.

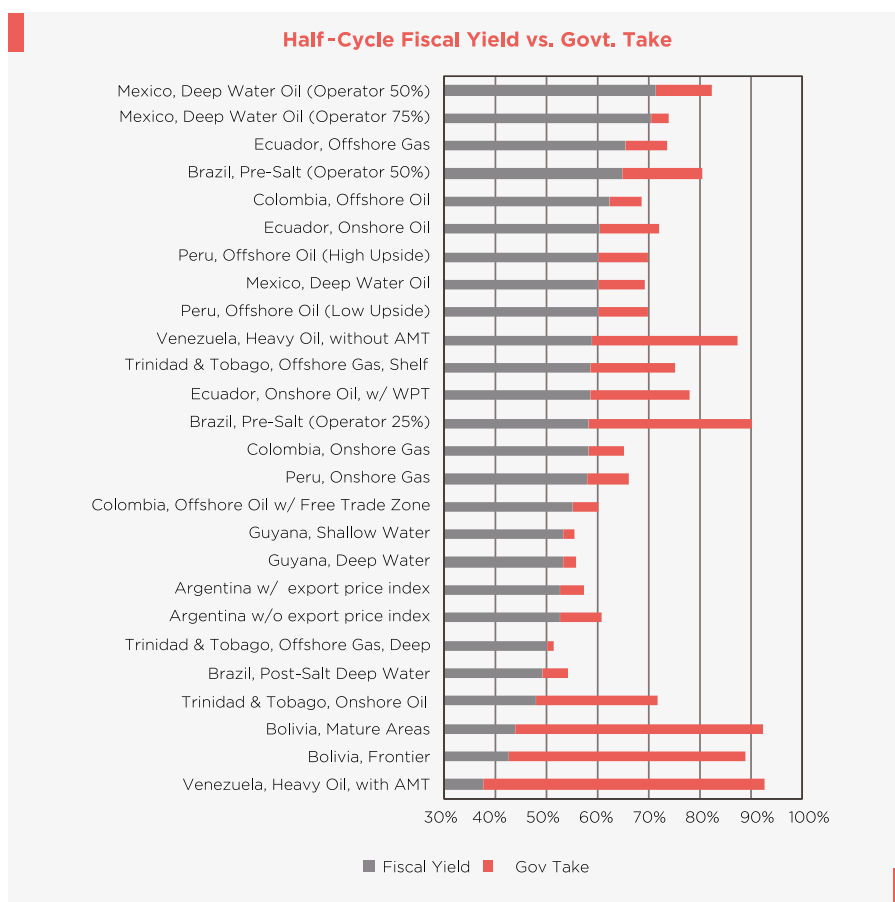
19. As has been previously mentioned, in the case of petroleum it does incorporate their impact as a future tax shield.

Figure 4.17: Full-Cycle Fiscal Yield (Petroleum)



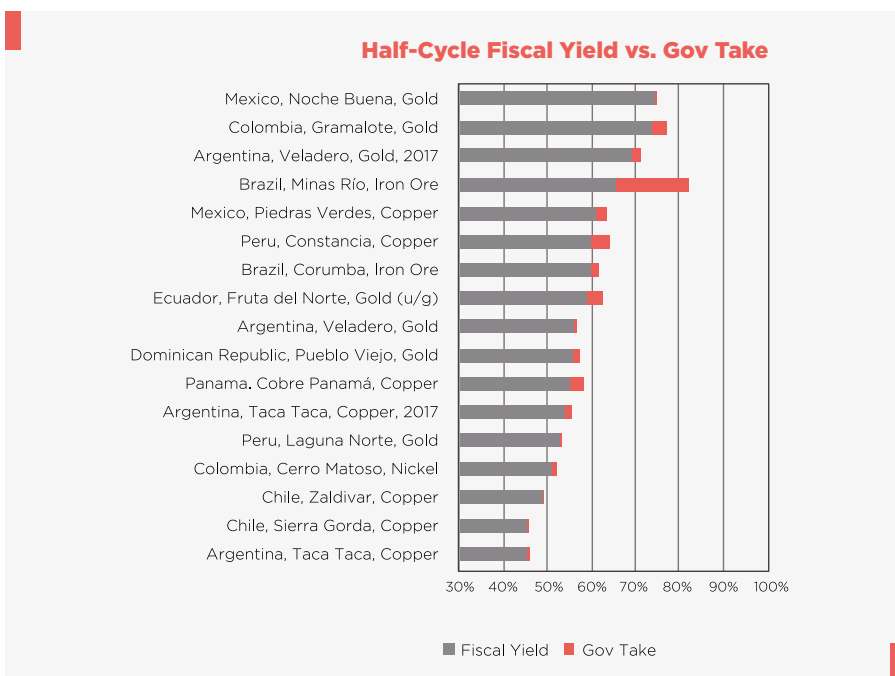
Source: Authors' calculations.

Figure 4.18: Half-Cycle Fiscal Yield vs. Government Take (Petroleum)



Source: Authors' calculations.

Figure 4.19: Half-Cycle Fiscal Yield vs. Government Take (Mining)



Source: Authors' calculations.

4.2.4. Fiscal Inefficiency

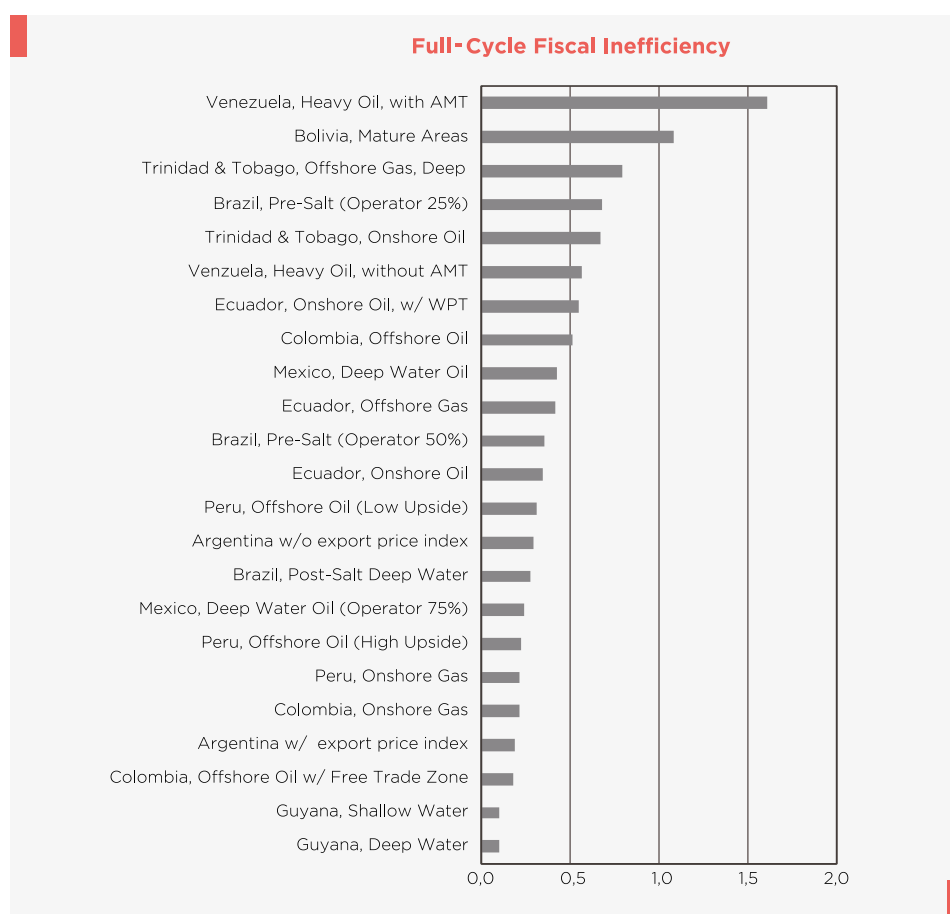
We have noted that DWLs represent the social cost of taxation. They are rents that theoretically could be captured by Government under a less distortionary tax regime. The estimated size of those losses relative to the NPV of Government revenues produced by a given regime provides a simple measure by which the performance of different regimes may be compared. We define our final index of fiscal performance, FI, as the size of DWLs divided by the NPV of Government net cash flows. A ratio of 25%, for example, indicates that for every dollar captured by the Government, the size of the pie (total project NPV) shrinks by 25 cents due to tax-induced distortions. The FI of existing LAC regimes is reported in columns 13 and 14 of Table 4.1, using Full-Cycle and Half-Cycle cash flows respectively.

In the case of oil and gas, the Full-Cycle size of the pie shrinks by 45 cents on average for every dollar that LAC Governments raise through petroleum taxes. However, as is the case for the other indicators that have been presented, the degree of inefficiency varies significantly across regimes, as shown in Figure 4.20. In the best case, Guyana's deep and shallow waters oil regimes shrink the size of the pie by only 10 cents. In the worst case, Venezuela's heavy oil (with AMT) regime shrinks the size of the pie by \$1.61 for every dollar raised. In addition to the Venezuelan regime, Bolivia's mature areas oil regime falls into this category.²⁰ From the Full-Cycle perspective, the Concessionary systems appear somewhat more inefficient than the PSC regimes. However, this is mainly due to the fact that the three worst-performing PSC regimes (those which extinguish exploration altogether) were excluded from the statistics reported in Table 4.1.

Half-Cycle FI measures for existing LAC oil and gas regimes appear lower than Full-Cycle because the cost of many distortions is treated as sunk. On average, the size of the petroleum pie shrinks by about 38 cents for every dollar of Half-Cycle cash flows raised through taxes (Figure 4.21). Yet, even when considering only Half-Cycle investments, the higher DWLs caused by the Venezuelan heavy oil (with AMT) and the Bolivian regimes for mature and frontier areas regimes during the resource development phase exceed the amount of tax revenue actually captured by those Governments. Here the Half-Cycle FI measure surpasses 100%, which means the social cost of raising money is greater than the amount of money raised. On the other hand, Guyana's deep and shallow water regimes perform well, only shrinking the pie by about 10 cents for every dollar raised. Mexico's deep water oil (operator 75%) and Trinidad & Tobago's offshore deep water gas regimes appear the most efficient when exploration losses are not accounted for.

20. Not shown in Figure 4.20 are three regimes (Bolivia frontier regime, Mexico deep water oil PSC with Operator 50%, and Trinidad & Tobago offshore shelf gas) where the tax burden extinguishes exploration completely. This is the most extreme form of inefficiency because the entire Deadweight Loss is incurred in return for no Government revenues. These regimes simply put the resource off limits.

Figure 4.20: Full-Cycle Fiscal Inefficiency (Petroleum)



Source: Authors' calculations.

The average Half-Cycle FI measure for LAC's mining regimes is much lower than seen in petroleum, averaging 7 cents per dollar raised, with a range of 0 cents to 30 cents, as shown in Figure 4.22. Chile's Sierra Gorda copper project, Mexico's Noche Buena gold project, and Peru's Laguna's Norte gold project produced close to zero DWL and hence do not lower the size of the pie for every dollar raised in taxes. On the other hand, Brazil's Minas Rio iron ore project had much higher DWL, and thus lowers the size of the pie by 30 cents for every dollar raised.

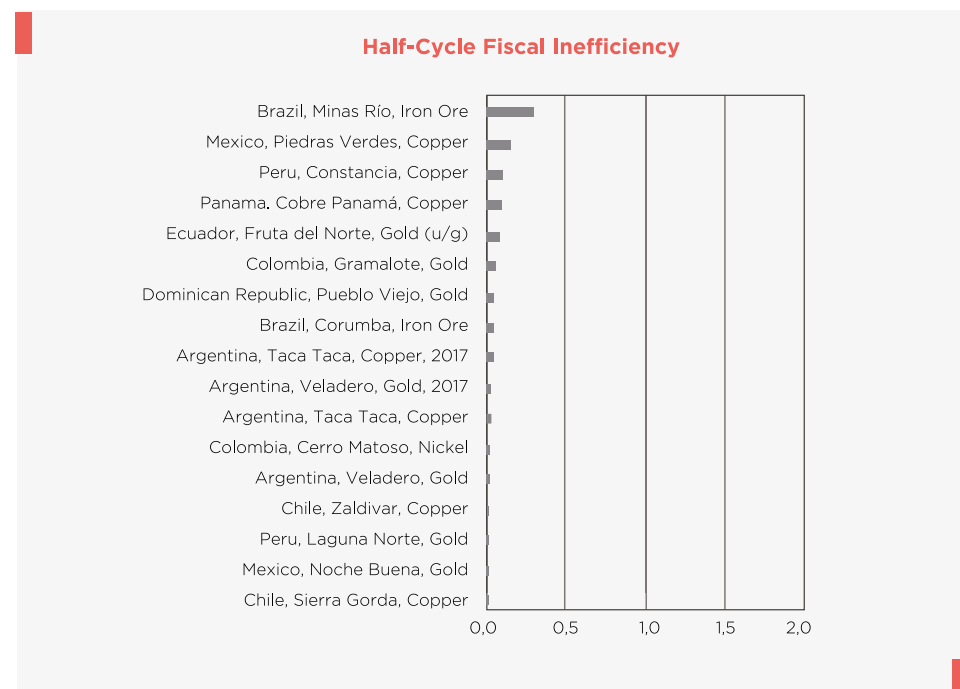
Once again, the overall higher efficiency of mining fiscal regimes compared with petroleum regimes comes from two sources: the fewer and lower taxes applied to the sector and the fewer options mining Operators have to change project design in the face of taxes. Similar to the FY measure, it would benefit policymakers to estimate the FI metric in order to gauge the costs versus the benefits of raising money through a specific fiscal regime applied to a particular project.

Figure 4.21: Half-Cycle Fiscal Inefficiency (Petroleum)



Source: Authors' calculations.

Figure 4.22: Half-Cycle Fiscal Inefficiency (Mining)



Source: Authors' calculations.

5. ADDITIONAL INSIGHTS, LESSONS LEARNED, AND PROPOSED GOOD PRACTICES

The analysis in the previous sections included modeling investment and operating choices over a number of hypothetical (in the case of petroleum) and actual (in the case of mining) project designs, and investigating the effect of the specific fiscal regimes in place in each country on those design decisions. We then compared those likely responses across projects using a number of physical measures, like investment undertaken, and economic measures, like DWL. The degree of distortion induced by taxation at each project is a result of an indeterminate combination of the tendency of given fiscal instruments within a regime to distort design decisions, each instrument's fiscal rate, and other fiscal design characteristics such as depreciation rules, project operating margins that affect the intensity of taxation given non-neutrality, and the degree to which the project Operator has the flexibility to alter project design. In this section, we suggest some additional insights and distill the lessons learned from our analysis.

5.1. Additional Insights

5.1.1. Royalties Are Prevalent and Highly Distortionary

Because each of the existing LAC fiscal regimes consists of various tax provisions and instruments, it is not apparent from the analysis reported so far which provisions are mostly responsible for the distortions and DWLs that have been reported in each country. To gain further insight using the petroleum scenarios, here we examine the impact of seven hypothetical “pure” petroleum fiscal regimes, each of which incorporates only a single tax instrument, e.g., income tax or royalty or PSC. This allows the type and size of distortions characteristic of each tax instrument to be better identified. The seven generic regimes are as follows:

1. ROY: Royalty regime consists of a fixed royalty levied as a simple percentage of gross revenue.
2. CIT: Corporate income tax regime consists of a conventional tax on net income after allowing for ten-year straight line depreciation of capital expenditures.
3. PSC: Production Sharing Contract consists of a fixed government share in profit oil, where cost oil is limited to 60% of total production.
4. PSC+i: Production sharing as in #3, with interest accruing on Operator's unrecovered costs, where the interest rate corresponds to the nominal discount rate.
5. PSC RF: R-factor based production sharing where Government's share of profit oil increases as Operator recovers more of the cumulative costs incurred in the project, and where cost oil is limited to 60% of total production.

6. PSC RF+i: R-factor based production sharing as in #5, with interest accruing on Operator's unrecovered costs, where the interest rate corresponds to the nominal discount rate.

7. PSC IRR: Internal Rate of Return (IRR)-based production sharing, where Government's share of profit oil increases as Operator achieves higher internal rates of return on cumulative project cash flows, and where cost oil is limited to 60% of total production.

Each of these generic regimes is applied to a hypothetical benchmark upstream project similar to the projects used earlier in this report to evaluate the actual LAC petroleum fiscal regimes. To ensure comparability across regimes, the tax rate in each regime is calibrated to produce equal "tax effort." In other words, subject to a \$60 per barrel price of oil, the NPV of Government revenues captured under each of these seven regimes is the same, resulting in a 55% Fiscal Yield, which is the average of the Full-Cycle and Half-Cycle Fiscal Yields of the existing petroleum regimes (see Table 3.1).²¹ Therefore, it cannot be said that the greater distortions caused by one regime versus another are due to heavier or more aggressive taxation.

The results of this analysis of the comparative effects that emanate from the individual tax provisions appear in Table 5.1 below. The table reports tax-induced distortions in the initial rate of production, in the lead time before onset of EOR, the percentage of resource in place that is ultimately recovered, and the overall life of the project. The table also reports GT as a percentage of overall profits generated by the project, DWL as a percentage of the potential value of the resource, and most importantly, the FY and FI of each generic regime. The table reports results based on both Full-Cycle and Half-Cycle analysis of cash flows.

Table 5.1: Specific Sources of Distortion and Deadweight Loss in Petroleum Fiscal Regimes

| | Roy | CIT | PSC | PSC+i | PSC RF | PSC RF+i | PSC IRR |
|--|------|------|------|-------|--------|----------|---------|
| (Impact of fiscal regime relative to the No-Tax benchmark) | | | | | | | |
| Initial Production | 57% | 79% | 79% | 79% | 86% | 86% | 107% |
| Onset of EOR | 279% | 129% | 129% | 136% | 121% | 229% | 250% |
| Resource Recovery | 78% | 98% | 94% | 92% | 94% | 78% | 73% |
| Project Life | 156% | 129% | 115% | 113% | 104% | 117% | 96% |
| (Half-Cycle fiscal performance) | | | | | | | |
| HC Govt. Take | 69% | 58% | 58% | 58% | 56% | 59% | 58% |
| HC Fiscal Yield | 55% | 55% | 55% | 55% | 55% | 55% | 55% |
| HC Fiscal Inefficiency | 38% | 9% | 9% | 10% | 5% | 14% | 10% |
| HC DWL | 21% | 5% | 5% | 6% | 3% | 8% | 6% |
| (Full-Cycle fiscal performance) | | | | | | | |
| FC Govt. Take | 74% | 59% | 61% | 61% | 59% | 63% | 62% |
| FC Fiscal Yield | 57% | 56% | 57% | 57% | 57% | 58% | 58% |
| FC Fiscal Inefficiency | 40% | 10% | 10% | 12% | 7% | 14% | 11% |
| FC DWL | 23% | 6% | 6% | 7% | 4% | 8% | 7% |
| Exploration Effort | 63% | 75% | 75% | 75% | 75% | 75% | 75% |

21. The fiscal regimes compared by Deacon (1993), Bradley (1998), and Cairns and Smith (2019) were calibrated similarly to achieve equal tax effort.

The royalty is clearly the most distortive element that can be imposed on upstream petroleum projects in LAC. The royalty creates DWLs that are several times larger than any of the other tax instruments. The FI of the royalty is more than double that of any other tax instrument. Compared to the royalty, all of the other tax instruments are more or less similar—but with some important differences. The simple PSC regime based on a progressive R-Factor division of profit oil is overall the least inefficient among these generic regimes. That regime comes closest to reproducing the physical outcomes of the No-Tax benchmark and carries a very low FI score relative to the other regimes. Somewhat less efficient is the corporate income tax regime and the PSC regimes based on fixed or IRR-progressive sharing of profit oil. Note that the FY of all of these regimes is roughly the same by construction to achieve equal “tax effort,” which means that they all raise more or less the same amount of revenue but at greater or lower cost to society. The royalty imposes by far the greatest cost on society.

Another systematic result observed in the table is that the R-factor version of production sharing tends to reduce DWLs relative to PSC regimes based on either fixed profit shares or profit shares tied to an Operator’s IRR. The R-factor is a form of progressive taxation that taxes more heavily as the profitability of a project increases, so it is not surprising that it might perform better than a fixed PSC regime that is blind to profitability. What is notable about the result is the comparison to the IRR-based PSC, which is also progressive and based directly on an Operator’s profit rate. In this regard, we note that, unlike the result under all other regimes, the level of initial investment and the initial rate of production under the IRR-based PSC regime are even higher than the No-Tax benchmark. It appears that an Operator is induced to push investment past the optimal level because this reduces IRR and consequent tax rates during the early stages of an operation when production and income are high. This type of distortion is unique to the IRR-based production sharing system.

It is also important to note that the generic regimes that are assumed to allow interest to accrue on the Operator’s unrecovered costs (PSC+i and PSC RF+i) create even greater DWLs than the same regimes without this provision. On its face, this result is a paradox since allowing the Operator to recover interest on invested capital brings the tax base closer to the ideal of economic rent. However, these regimes are calibrated to generate equal tax effort. In this example, this means that a Government that grants interest on carryforwards must also raise the underlying tax rates to replace the tax revenues that would otherwise be lost. Our results indicate that this particular “cure” for tax-induced distortions may be worse than the disease. The distortions induced by an even higher basic tax rate outweigh the benefit that may accrue when interest is allowed on deductions that must be carried forward. There are many forms of investment “uplift” in the real world that are similar to allowing interest on carryforwards, and our result casts all of them in some doubt if they cause Government to attempt to recoup in the form of higher rates what it gives away in the form of uplift (or interest on accruals).

A similarly detailed analysis was not undertaken for the mining sector. However, further analysis shows that royalties are the most distortionary components of the mining projects analyzed. Here, we take each of the projects within the five countries that imposed royalties on mine production (see Table 3.3) and remove those royalties while leaving the other fiscal instruments in place. We then average the results and report the respective distortions in initial investment, production, resource recovery and project life relative to the No-Tax benchmark. We also report the respective average Half-Cycle GT, FY, FI, and DWL. Table 5.2 tabulates the results. The royalties in the fiscal regimes that use them are an important component of GT, increasing it from 51% to 62%, and increasing FY from 50% to 58%. But the royalties are highly distortive of the physical project measures, and because of this more than double the FI and DWL of

the regimes. In other words, as with petroleum, they are a highly inefficient means of raising government revenues. While the petroleum and mining regimes provide the same FYs for the government (see Table 4.1), the higher royalty rates for petroleum compared with mining and their increased prevalence (see Tables 3.1 and 3.3 above) are no doubt a large part of the reason why the overall FI of the petroleum regimes is much higher (see Table 4.1).

Table 5.2: Average Physical and Fiscal Results for the Projects in the Five Mining Countries That Include Royalties in Their Fiscal Systems

| | Royalty | No Royalty |
|------------------------|---------|------------|
| Initial Investment | 77% | 85% |
| Initial Production | 76% | 84% |
| Resource Recovery | 96% | 98% |
| Project Life | 129% | 117% |
| HC Govt Take | 62% | 51% |
| HC Fiscal Yield | 58% | 50% |
| HC Fiscal Inefficiency | 9% | 4% |
| HC DWL | 5% | 2% |

Source: Authors' calculations.

5.1.2. LAC's Fiscal Regimes Are Not Neutral

Each of the projects that we model will only be undertaken if prices are high enough to produce a non-negative NPV. At some low price the project NPV is just marginally above zero and the project is undertaken with the small amount of rent going to the owner. All of the fiscal regimes we have studied would stop that marginal project from going ahead at the time of investment since they all reduce the benefits of investing at the margin. At this low price GT goes towards 100%, making the regimes regressive at the margin.

Some of the fiscal regimes continue to be regressive at higher prices, while others turn progressive due to taxation components whose rates escalate with price. Whether or not the fiscal regime is progressive or regressive at these higher prices can be project dependent. Table 5.3 shows this type of analysis for the mining cases studied, where metal prices were increased by 20%. Government Take at that higher price is compared with GT at the base case price. Chile exhibits the only neutral tax regime within this price range, a result of its sliding scale progressive mining income surtax. That progressive income tax component serves to make taxation at the Sierra Gorda copper project neutral, while taxation is regressive at the Zaldivar copper project. The difference is due to the relative inability of the Sierra Gorda project to flex its design in order to avoid the progressive taxation at higher prices.²²

There are several implications of tax regressivity at the margin. One, as we mentioned above, is that marginal projects are not undertaken due to taxation. Another is that government revenues do not increase proportionally with project profits, which can be difficult politically. On the other hand, regressivity tends to smooth government income from taxation over the price cycle. It also results in a fiscal system that is least punitive, and therefore least

22. This is evident in the Figures in Section 4.1 and Section 4.2, where the Sierra Gorda project has relatively less physical and economic distortions in response to taxation.

distortionary, for high margin, high rent projects. From an efficiency standpoint this is preferable to a progressive system. Where taxation turns progressive at higher margins, government income starts to increase more than proportionally with project profits – a desirable political outcome that helps stem the pressure to nationalize natural resource projects. But this comes at the cost of higher overall deadweight losses since the high margin projects have higher GTs and are more distorted than low margin projects.

Table 5.3: Mining Fiscal Regime Regressivity at the Time of Investment

| Country | Type |
|--|------------|
| Argentina, Taca Taca, Copper | Regressive |
| Argentina, Veladero, Gold | Regressive |
| Brazil, Corumba, Iron Ore | Regressive |
| Brazil, Minas Rio, Iron Ore | Regressive |
| Chile, Sierra Gorda, Copper | Neutral |
| Chile, Zaldivar, Copper | Regressive |
| Colombia, Cerro Matoso, Nickel | Regressive |
| Colombia, Gramalote, Gold | Regressive |
| Dominican Republic, Pueblo Viejo, Gold | Regressive |
| Ecuador, Fruta del Norte, Gold (u/g) | Regressive |
| Mexico, Noche Buena, Gold | Regressive |
| Mexico, Piedras Verdes, Copper | Regressive |
| Panama, Cobre Panama, Copper | Regressive |
| Peru, Constancia, Copper | Regressive |
| Peru, Lagunas Norte, Gold | Regressive |

Source: Authors' calculations.

Another way of investigating tax neutrality is to examine whether GT increases when prices increase by 20% after a project has been designed and built based on a projection that base case prices would maintain. We undertook this analysis for both the mining projects and the petroleum projects in our sample. As shown in Tables 5.4 and 5.5, the fiscal regimes in petroleum tend to have more progressively scaled fiscal components than in mining, and so are more frequently progressive. In all but one of mining scenarios studied the fiscal regime is regressive. Chile's regime applied to Sierra Gorda is neutral because of its progressive special mining tax. It is not neutral when applied to the Zaldivar project. In petroleum the results are also project specific. For example, Brazil's pre-salt projects with a 50% operator stake are progressive, while they are regressive with a 25% operator stake.

The dependence of regressivity or progressivity on project specifics is an interesting result, as usually regimes are described as progressive or regressive based on whether they have regressively or progressively scaled rates of taxation in their design. Our analysis shows that all of the components of the taxes and their interactions within a project must be considered before declaring regressivity or progressivity.

Table 5.4: Mining Fiscal Regime Regressivity Post Investment

| Country | Type |
|--|------------|
| Argentina, Taca Taca, Copper | Regressive |
| Argentina, Veladero, Gold | Regressive |
| Brazil, Corumba, Iron Ore | Regressive |
| Brazil, Minas Rio, Iron Ore | Regressive |
| Chile, Sierra Gorda, Copper | Regressive |
| Chile, Zaldivar, Copper | Regressive |
| Colombia, Cerro Matoso, Nickel | Regressive |
| Colombia, Gramalote, Gold | Regressive |
| Dominican Republic, Pueblo Viejo, Gold | Regressive |
| Ecuador, Fruta del Norte, Gold (u/g) | Regressive |
| Mexico, Noche Buena, Gold | Regressive |
| Mexico, Piedras Verdes, Copper | Regressive |
| Panama, Cobre Panama, Copper | Regressive |
| Peru, Constancia, Copper | Regressive |
| Peru, Lagunas Norte, Gold | Regressive |

Source: Authors' calculations.

Table 5.5: Petroleum Fiscal Regime Regressivity Post Investment

| Country/Regime | Type |
|---|-------------|
| Argentina w/ export price index | Regressive |
| Argentina w/o export price index | Progressive |
| Bolivia, Frontier | Regressive |
| Bolivia, Mature Areas | Regressive |
| Brazil, Post-Salt Deep Water | Progressive |
| Brazil, Pre-Salt (Operator 25%) | Regressive |
| Brazil, Pre-Salt (Operator 50%) | Progressive |
| Colombia, Offshore Oil | Regressive |
| Colombia, Offshore Oil w/ Free Trade Zone | Regressive |
| Colombia, Onshore Gas | Regressive |
| Ecuador, Offshore Gas | Regressive |
| Ecuador, Onshore Oil | Regressive |
| Ecuador, Onshore Oil, w/ WPT | Progressive |
| Guyana, Deep Water | Progressive |
| Guyana, Shallow Water | Regressive |
| Mexico, Deep Water Oil | Regressive |
| Mexico, Deep Water Oil (Operator 50%) | Progressive |
| Mexico, Deep Water Oil (Operator 75%) | Progressive |
| Peru, Offshore Oil (High Upside) | Regressive |
| Peru, Offshore Oil (Low Upside) | Regressive |
| Peru, Onshore Gas | Regressive |
| Trinidad & Tobago, Offshore Gas, Deep | Regressive |
| Trinidad & Tobago, Offshore Gas, Shelf | Regressive |
| Trinidad & Tobago, Onshore Oil | Progressive |
| Venezuela, Heavy Oil, with AMT | Regressive |
| Venezuela, Heavy Oil, without AMT | Regressive |

Source: Authors' calculations.

5.1.3. The Impact of a Fiscal System Is Sensitive to Each Project's Profitability

When tax regimes are regressive, less profitable projects tend to be exposed to a higher GT, and higher GTs lead to greater design distortions and a consequently higher DWL. In progressive tax regimes, less profitable projects will have a lower GT and less DWL. An important determinant of a project's response to taxation is, then, its profitability.

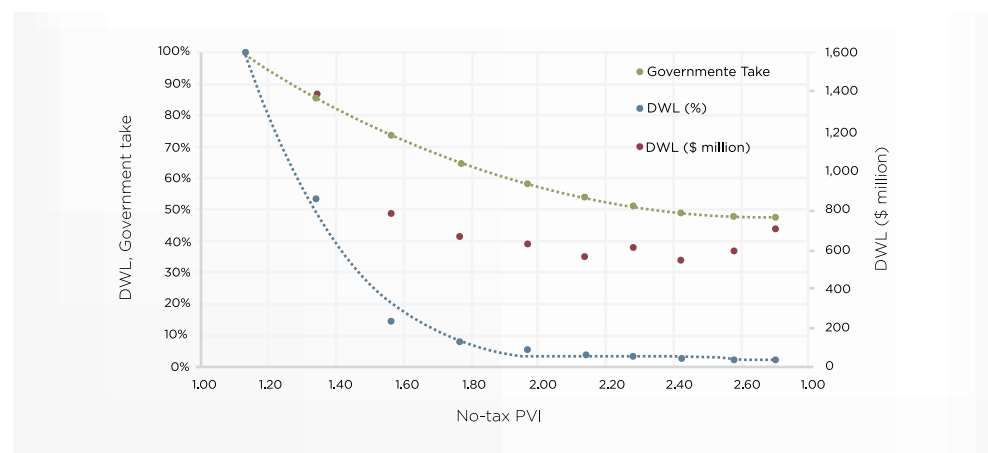
Project margin is one of the four factors that we mentioned earlier that determine the degree of project distortion under taxation. All of the fiscal regimes that we examine are regressive at the margin, with some of the petroleum regimes becoming progressive at higher prices. This means that as a project's Present Value Index (PVI) gets closer to 1.00 (denoting a project with an NPV of zero), GT increases severely, as does DWL and FI.

Figure 5.1 provides a controlled example for the Cobre Panama copper mining project, whereby we flex the base case copper price to create different No-Tax PVIs. Due to the regressivity of the Panamanian tax regime, as the PVI of the project decreases the GT from the fiscal regime increases. The DWL increases correspondingly.²³ The DWLs are increasing because the higher GT serves to cause Operators to increasingly distort the physical project design. When prices fall sufficiently the DWL goes to 100% as the otherwise profitable project is no longer undertaken given the tax regime.²⁴

For the mining projects as a whole, Figures 5.2 and 5.3 show that GT and FI tend to be higher the more marginal the project, with Minas Rio being the outlying data point in Figure 5.3. In Figure 5.3 FI goes to infinity as PVI goes to 1.00, since marginal projects are completely extinguished by these regressive fiscal systems.

While all of the petroleum regimes are regressive at the margin, some turn progressive as prices increase (see Table 5.5). Once again, the effective GT and corresponding DWL caused by a fiscal regime will depend on project profitability, with more profitable projects having higher percent DWL in the progressive regimes.

Figure 5.1: Deadweight Loss and Government Take From Panama's Fiscal Regime for the Cobre Panama Copper Mining Project Under Various No-Tax Present Value Indexes

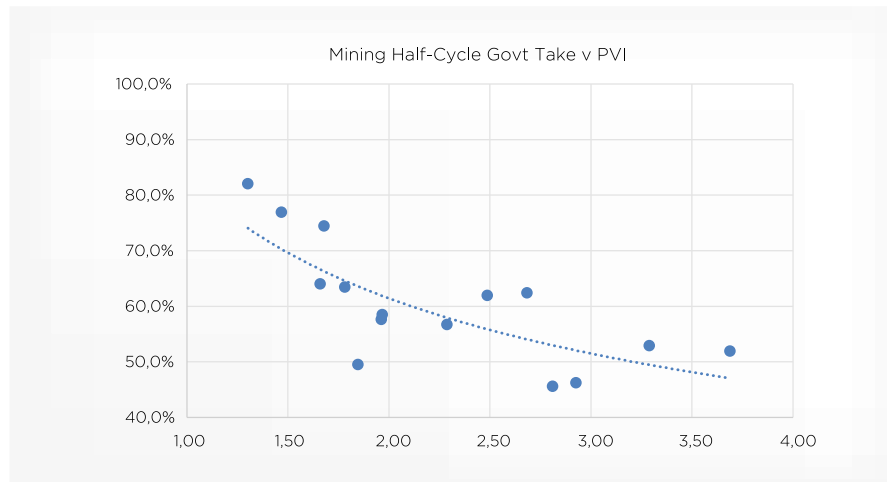


Source: Authors' calculations.

23. Smith (2014) also noticed this effect for petroleum projects.

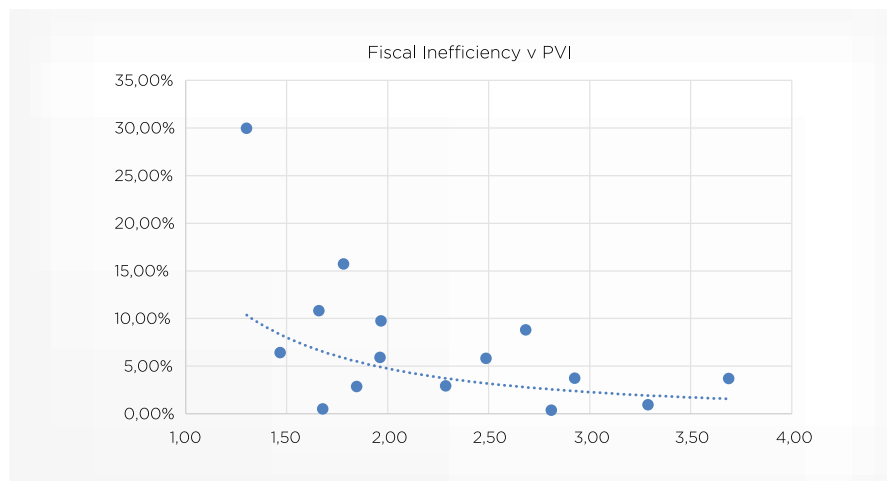
24. Government Take goes to 100% in the limit: at the point where Deadweight Loss is 100%, Government Take is precisely \$0/\$0, or 100%.

Figure 5.2: Half-Cycle Government Take for Mining Projects as a Function of Their No-Tax Present Value Index



Source: Authors' calculations.

Figure 5.3: Half-Cycle Fiscal Inefficiency for Mining Projects as a Function of Their No-Tax Present Value Index



Source: Authors' calculations.

5.2. Lessons Learned

5.2.1. Fiscal Regime Performance Varies by Project

A fundamental finding to emerge from this study is that an Operator's potential response to the specific provisions in a given fiscal regime is important and must be considered when assessing how that regime will perform in practice. Operators will adjust the scale and timing of investments in response to taxation where possible. Our modeling has identified numerous margins of investment that are responsive to taxes, including the intensity of exploration, the scale of initial investments to develop a project, along with the rate of extraction and depletion. For oil and gas, the timing and scope of enhanced recovery have also been shown to be highly sensitive to tax rates and the associated provisions for cost recovery. Finally, in the case of petroleum projects, the decision to abandon a project was found to be based not only on the dwindling level of production but also on the proportion of that production that is taxed by Government.

An example illustrates this point: It may be supposed that a high royalty rate would cause early abandonment of an oil field and reduce total production. That conclusion is undoubtedly correct if investment across all other margins is held constant. But a high royalty may also reduce the scope of the Operator's initial development program, which may in turn cause production to decline at a slower pace, thereby extending the life of the field. At the same time, the high royalty may discourage application of enhanced recovery as the field ages, and an investor who anticipates this may elect to increase investment in initial capacity as a more profitable alternative to enhanced oil recovery (EOR). The total impact of the royalty on resource recovery, the Operator's return, and Government revenues depend on the resolution of these interrelated investment problems and may actually result in longer field life and a higher recovery factor.²⁵ The outcome depends on the specific design alternatives available at the project.

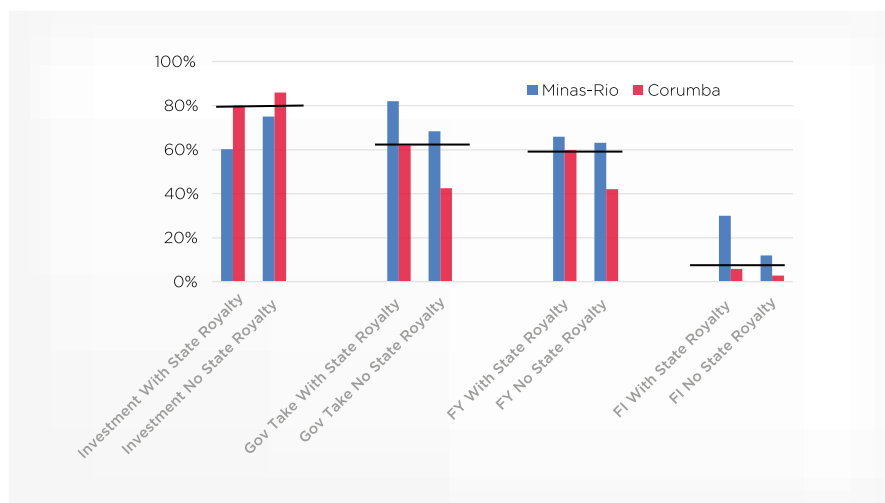
Up to now, the most prevalent form of fiscal regime analysis has been to specify a fixed exploration or development scenario in terms of the timing and level of investment and production, and then to subject the resulting cash flows to an accounting-based determination of tax liabilities.²⁶ Yet that type of analysis begs the question of how the chosen fiscal regime may affect the level and timing of investment and production. Tax-induced distortions of exploration and development can only be identified by applying optimization models that identify the specific investment scenarios that are most successful in avoiding the burden of taxation imposed by a specific regime. Our model of exploration and production was developed for this specific purpose. Although our model is a simplification of the complex decision-making that Operators confront when planning real world investments, it captures many of the tradeoffs that link major investments at the various margins of exploitation.

In the end, and given this finding, the efficacy of a fiscal regime can only be measured by investigating its performance over a range of projects so that a variety of possible outcomes can be observed. Our analysis of the fiscal regime for mining in Brazil is illustrative of this. Figure 5.4 shows the GT, DWLs, FY, and FI of Brazil's fiscal regime for Minas Rio and Corumba, the two open-pit iron ore mining projects studied, compared with the sample average. The projects face identical fiscal terms save for a production royalty that varies by State. At 82%, GT for Minas Rio is the highest in our sample for mining, while, at 62%, GT for Corumba is below the sample average. This reflects the more marginal nature of Minas Rio, with taxation being regressive. The FYs for the two projects are roughly the same, but the FI at Minas Rio is well above average, and well below average at Corumba.

25. The tension between changes in investment and production decisions in response to a change in the commercial environment in which a mining or petroleum project operates was noted by Gordon in 1966. Bohn and Deacon's (2000) is a more recent examination of such tensions.

26. Passing various fiscal regimes through a few "representative" resource projects is a longstanding technique for assessing the comparative competitiveness of various tax regimes. See, for example, Otto et al. (2006), Mining Association of Canada (2008), Nakhle (2008), Tordo (2007), Daniel et al. (2010), and IMF (2012). As previously discussed, a further limitation of the modeling techniques applied in these studies is the assumption that the Operator does not reoptimize the project given the fiscal regime the project is exposed to. They are fiscal flow accounting exercises rather than fiscal assessment exercises.

Figure 5.4: The Impact of Brazil's Fiscal Regime on Two Iron Ore Projects, Compared With the Mining Sample Average



Source: Authors' calculations.

In Section 5.1.1 we noted that royalties were particularly distortionary for most projects. If one were interested in the impact of removing royalties in Brazil, there is still the need to model the impact over a variety of projects. Here, we remove the royalty applied to each of these two mining projects and redo the analysis. The royalty provided the majority of the government revenue at Corumba. Because of its project inflexibility Corumba's investment level and reserve quantity barely increases when the royalty is removed, while Minas Rio's investment and reserves increase substantially. The GT necessarily decreases at both projects due to the decreased taxation, but the increased investment at Minas Rio causes its FI to decline. As a result, its FY remains almost the same, while Corumba's decreases. Reducing the royalty at Minas Rio has positive outcomes for the Government (same FY with reduced FI), while the reduction at Corumba has a negative outcome (reduced FY and a small decrease in FI given that the royalty did not particularly distort decisions at that project).

If one were to evaluate the Brazilian system using only the smaller Corumba project, it would look to be a fiscal system with an average GT, inducing few distortions and inefficiencies despite its high reliance on royalty income. It might serve as a model for other countries. Conversely, if only the larger Minas Rio project was analyzed, the Brazilian system would be revealed to be the most distortionary in the sample – a fiscal model to avoid. In our view the appropriate way to assess a fiscal system is to measure its worst possible impact on projects, as in the Minas-Rio case. This is because a government cannot control the types of projects that are developed, and there is every reason to believe that flexible projects like Minas Rio are just as likely to be developed as inflexible projects like Corumba.

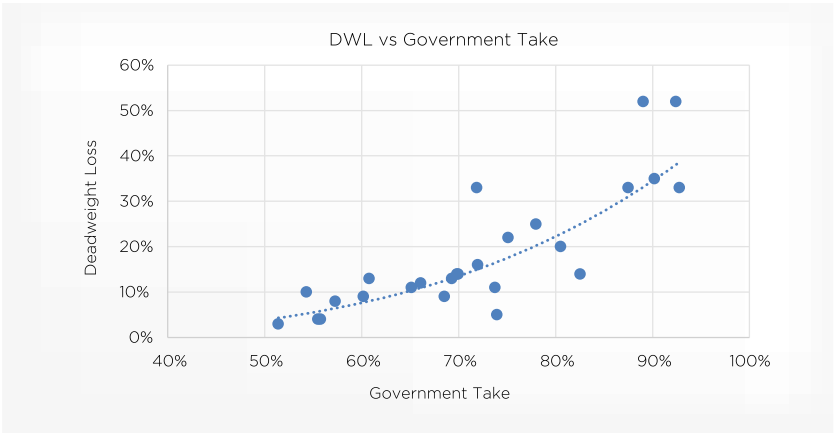
This same type of comparison can be made for some of the petroleum scenarios. Bolivia's petroleum fiscal regime hardly impacts an Operator's decisions over exploration in mature areas, but it extinguishes exploration in frontier areas (see Figure 4.1 above). Selecting either one of these as a case through which Bolivia's fiscal regime would be analyzed would not provide a reliable indication of how other projects would behave. Peru is a middle case, where exploration effort at the high prospect project is distorted somewhat less than the low prospect case.

5.2.2. Higher Effective Tax Rates Lead to Higher Distortions

Across our sample, we find that higher average effective tax rate (i.e., GT) is predictive of greater distortions and inefficiencies in the projects studied. This is clearly visible when we plot the DWL created by each of the existing LAC fiscal regimes against the corresponding GT, as in Figures 5.5 and 5.6. There is a clear positive association between DWL and GT across the entire range of regimes. We have shown the trend as nonlinear since DWL rises to 100% as GT rises towards 100%.

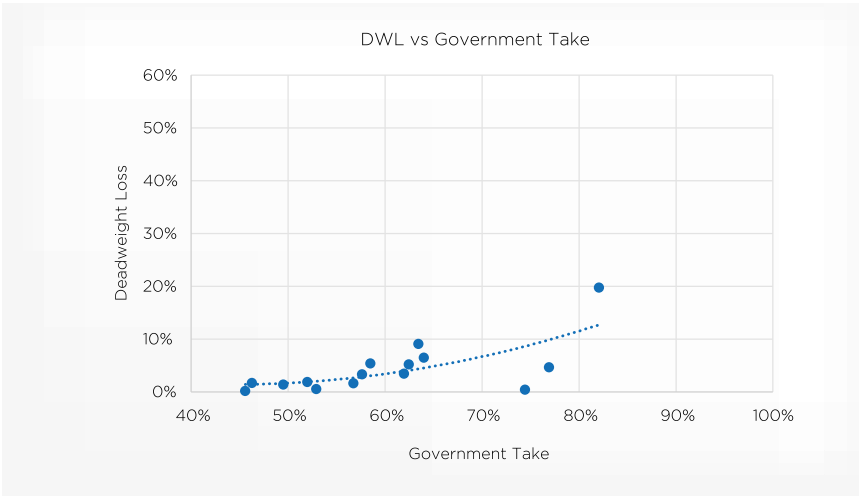
The higher GT at some projects is the result of two forces. The first is a more aggressive tax regime, and the second is the non-neutrality of that tax regime. In all of our regimes GT rises for the marginal project. In the progressive petroleum regimes GT can also rise for the highly profitable projects.

Figure 5.5: Deadweight Loss vs. Government Take: Half-Cycle Cash Flows, Petroleum



Source: Authors' calculations.

Figure 5.6: Deadweight Loss vs. Government Take: Half-Cycle Cash Flows, Mining



Source: Authors' calculations.

5.2.3. High Deadweight Losses Associated With High Government Takes Are Mainly Due to Special Taxes Levied on Top of Corporate Income Tax

The high DWLs in certain of the oil and gas and mining projects studied are due to royalties and special taxes that are levied in addition to the general and relatively efficient corporate income tax. As shown in Section 5.1.1 using the generic forms of petroleum tax systems, CIT could by itself produce a GT of roughly 60% while creating DWLs that amount to roughly 5%. This same relative efficiency of CIT holds for mining: when we eliminated all but the CIT on the most inefficient mining project but increased the income tax surtax from 10% to 26% to maintain the GT at 82%, the DWL fell by 25%.²⁷ Notably, the decrease in DWL results in higher project value for both the Operator and the Government – a win-win outcome indicative of efficient fiscal system reform.

5.2.4. At All Levels of Government Take, LAC's Petroleum Taxes Are More Distortive Than Mining Taxes

It is clear from our analysis that the physical and economic dimensions of petroleum projects are impacted more by taxation in LAC than are mining projects. Figures 5.5 and 5.6 in Subsection 5.2.2 compare DWLs and GT in both sectors. For oil and gas regimes, Half-Cycle GT averages 73% of available profits, with a corresponding DWL that averages 18%.²⁸ At 60%, average Half-Cycle GT is lower for mining, as is the corresponding average DWL, at 4%. The higher DWL in petroleum is in part due to the higher GT.

But petroleum taxes are also more distortionary in and of themselves. Based on the trend lines drawn on Figures 5.5 and 5.6, at a GT of 70% the typical DWL for petroleum is about 13%, while it is only about 7% for mining. The trend line for mining is in fact everywhere below the trend line for petroleum.

Given our previous findings, it should be no surprise that the reason for this is a combination of one known factor and one possible factor: (1) oil and gas projects in Latin America and the Caribbean are subject to more distortionary types of taxes than are mining projects, and (2) Operators may have a greater degree of design flexibility in the development and exploitation of petroleum deposits than do mining Operators, though even if they have less flexibility the impact of (1) could still result in increased project distortions and higher DWL. Evidence of (1) is the fact that CIT and worker profit sharing represent only 20% of GT for the oil and gas projects modeled, whereas they average 66% of GT for the mining projects modeled, the difference reflecting the tendency for petroleum regimes to place much more reliance on royalties and special taxes. With this increased reliance on relatively inefficient tax instruments comes the higher inefficiencies in the petroleum projects that we have seen repeatedly to this point.

5.2.5. Government Take Is a Poor Indicator of Fiscal Performance

Our results indicate that the conventional measure of GT, although seen as critical by policymakers and the literature, is a poor indicator of fiscal performance because it overlooks virtually all distortions and DWLs that are created by the fiscal regime in place. Although GT

27. Minas Rio has a DWL of \$742 million under the current fiscal regime and a DWL of \$568 million under the enhanced CIT rate.

28. Full-Cycle Government take is 70%, while DWL is 35%.

dutifully reflects the portion of actual economic rents captured by Government, it fails to measure potential rents that might have been captured but are lost due to poor fiscal design. We have seen that it is important to distinguish between the size of the pie and the size of the slice. GT only focuses on the size of the slice. For the existing hydrocarbons and mining fiscal regimes, GT ranges from 46% to 93% of actual rents generated during the resource exploitation phase—and even higher when exploration expenditures are accounted for. But even 93% of a small pie is still a small slice. In Figure 5.1 the GT in the limit went to 100% as the project shut down due to low prices. Yet 100% of nothing is nothing.

As we have seen, we propose two alternative measures to address this limitation: FY and FI. Both measures reflect the size of a Government's slice as well as the size of the DWLs that reduce the total size of the pie. FY measures the share of potential rents that are actually captured by a given fiscal regime. The larger the DWLs, the greater will be the difference between FY and GT. The average Full-Cycle FY of an oil and gas project in our sample is 52%, compared to a much higher average GT of 70%. Similarly, the average Half-Cycle FY of an oil and gas project is 58%, versus an average GT of 73%. For mining, the difference is smaller, reflecting the lower average DWLs in the sector. The average Half-Cycle FY of a mining project in our sample is 58%, compared to a 60% GT.

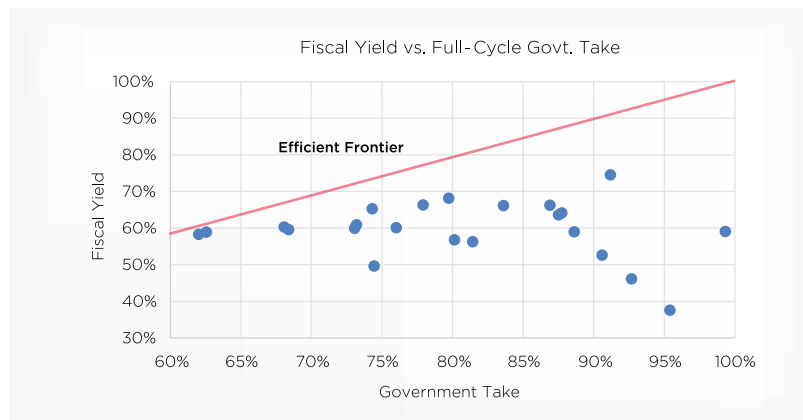
FI, on the other hand, measures by how much a fiscal regime reduces the size of the pie. It is calculated by dividing DWLs by the NPV of Government net cash flows. Across the oil and gas projects in our sample, the Full-Cycle size of the pie shrinks by an average of 67 cents for every dollar that LAC Governments raise through taxes, while the Half-cycle pie is reduced 35 cents on average. For mining, the Half-Cycle size of the pie is reduced by an average of 7 cents per dollar raised.

5.2.6. Taxes That Are Too High Can Actually Decrease Tax Revenue

Our results also show that the “Laffer Curve”, which predicts that income tax receipts can fall if the rate of taxation is too high, applies to the mining and petroleum taxes levied within LAC. An effective tax rate, or GT, that is too high discourages investment and reduces the tax base (or the size of the pie), and therefore decreases tax revenue. Some governments that aspire to a high GT tend to fare worse in terms of tax revenues than those that impose lower rates.

FY provides a direct signal of this relationship. FY measures the percentage of potential rents (or of the potential pie) that is actually captured by the regime in question. A lower FY indicates lower absolute revenues to the Government. Figure 5.7 plots the Full-Cycle FY for each of the petroleum regimes studied versus their corresponding GT. The Efficient Frontier, which is the 45-degree line shown in the graph, reflects a non-distortionary tax system, such as a pure rent tax, imposed with varying degrees of GT. Since such a regime is free of distortion, GT and FY are the same. Its maximum is 100% at a 100% GT. It is against this perfectly efficient tax system that we evaluate the actual fiscal systems employed in LAC. The figure shows that all the fiscal regimes create inefficiencies, with that inefficiency (the distance between the frontier and the actual data points) growing as GT grows. With few exceptions, when GT is pushed above 85%, FY declines precipitously. This reflects declining absolute government revenues as GT increases. The highest FYs are generally achieved at GTs below 85%.

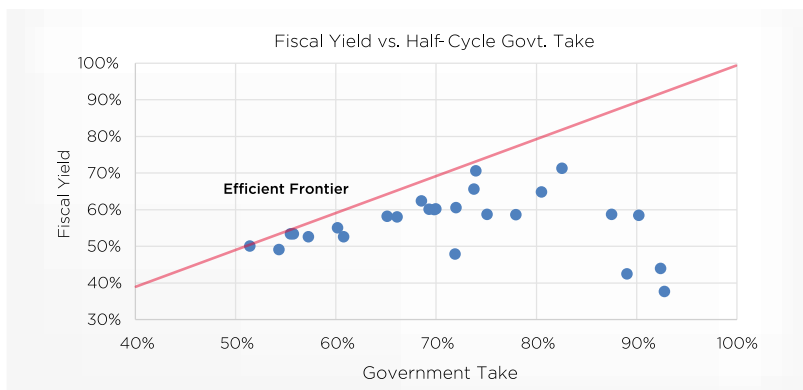
Figure 5.7: Fiscal Yield vs. Government Take, Full-Cycle Cash Flows, Petroleum



Source: Authors' calculations.

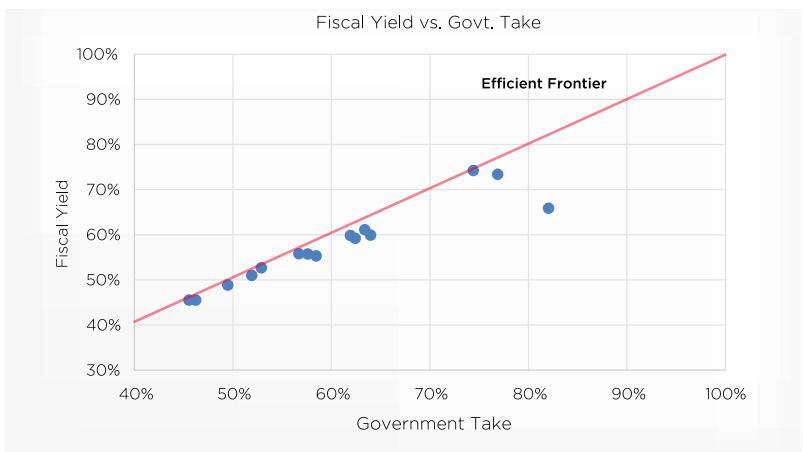
Figures 5.8 and 5.9 provide the Half-Cycle analysis for petroleum and mining regimes respectively, as compared against the Efficient Frontier. This again shows a declining FY as GT increases. In keeping with our observation that the fiscal regimes for petroleum are more distortionary than those for mining, the FYs for mining are closer to the Efficient Frontier.

Figure 5.8: Fiscal Yield vs. Government Take, Half-Cycle Cash Flows, Petroleum



Source: Authors' calculations.

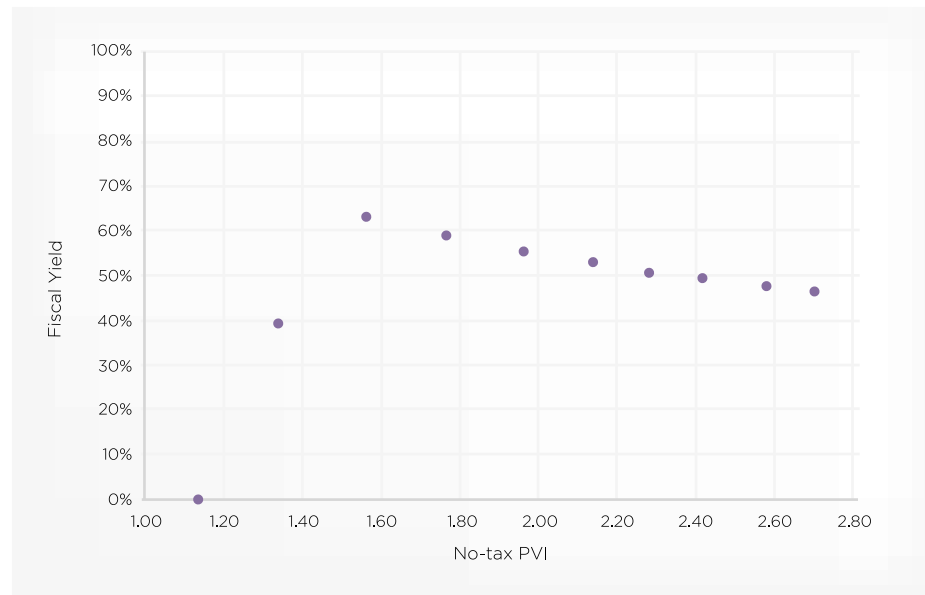
Figure 5.9: Fiscal Yield vs. Government Take, Half-Cycle Cash Flows, Mining



Source: Authors' calculations.

While most of the mining projects are reasonably close to the Efficient Frontier, a downturn in prices would substantially increase the GT and decrease the FY for these projects due to the regressivity of the mining tax regimes. Figure 5.10 extends the analysis of the Cobre Panama project depicted in Figure 5.1 above in this way and shows that FY declines when copper prices drop (recall that GT is increasing to 100% as prices drop). When the PVI falls below 1.2 the project is abandoned by the Operator in the face of taxes (it would otherwise continue for any $PVI > 1.00$) and the FY goes to zero as the tax base is extinguished.

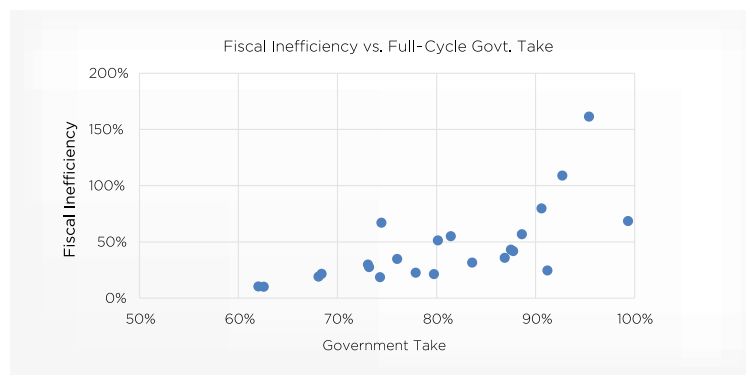
Figure 5.10: Fiscal Yield vs. No-Tax PVI for the Cobre Panama Copper Project



Source: Authors' elaborations from own calculations.

The reason for the tendency towards declining FY with increasing GT in these figures is the increase in FI. This relationship is pictured in Figure 5.11 based on Full-Cycle analysis of the existing LAC petroleum regimes. The figure plots GT against our measure of FI. It is clear that regimes that employ very high tax rates increase inefficiency considerably. The Figure excludes three highly distortive regimes that preclude exploration, including the Bolivian regime for frontier areas, the Mexican regime for deep water oil (Operator 50%), and the Trinidad & Tobagoregime for offshore shelf gas. These regimes have a Full-Cycle GT of zero.

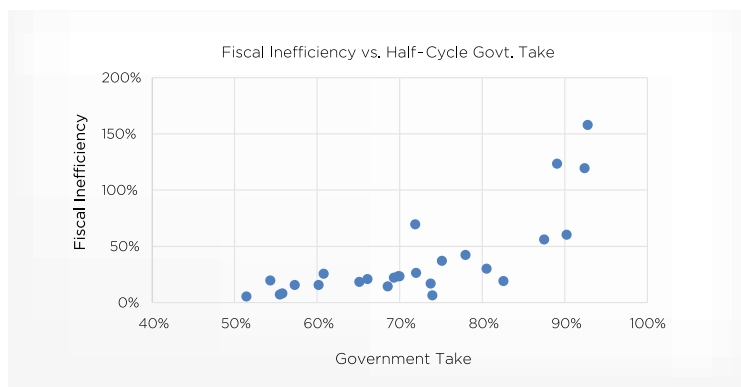
Figure 5.11: Fiscal Inefficiency vs. Government Take, Full-Cycle Cash Flows, Petroleum



Source: Authors' calculations.

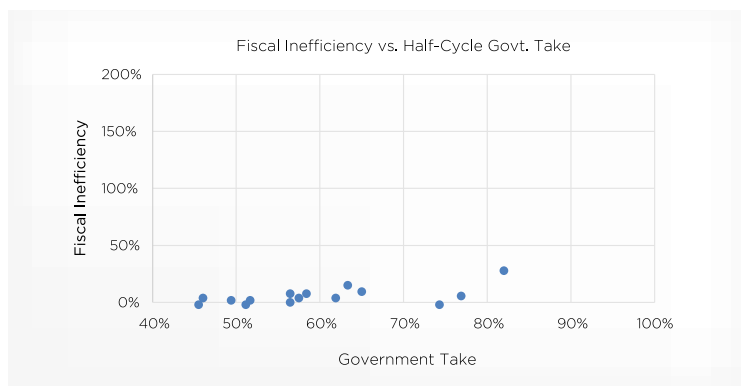
The same conclusions apply when the petroleum regimes are analyzed on the basis of Half-Cycle cash flows, as shown in Figure 5.12. The lower the GT, the more efficient the fiscal system is. As shown in Figure 5.13, mining fiscal inefficiencies are a fraction of those created by the petroleum regimes, yet the same tendency applies.

Figure 5.12: Fiscal Inefficiency vs. Government Take, Half-Cycle Cash Flows, Petroleum



Source: Authors' elaborations from own calculations.

Figure 5.13: Fiscal Inefficiency vs. Government Take, Half-Cycle Cash Flows, Mining



Source: Authors' elaborations from own calculations.

5.3. Proposed Good Practices in Oil, Gas, and Mining Taxation

The existing fiscal regimes applied to mining and petroleum contain fiscal instruments that have been shown in theory to be distortionary. Our analysis shows that in practice they are indeed distortionary, and in some cases so distortionary that governments are losing cash flows due to the induced project inefficiencies. The taxation literature over the past several decades has identified good practice in resource taxation, much of that stemming from the seminal work of Brown (1948) and Garnaut and Clunies Ross (1975) and ensuing research including Fane (1987), Bond and Devereux (1995), Smith (1999), Lund (2009), Boadway and Keen (2010), Smith (2013), Boadway and Keen (2015), and many of the papers included in the volume edited by Daniel, Keen, and McPherson (2010). There is no reason that such practice cannot be recommended for LAC. In this section we relate much of the advice of that theoretical taxation literature as being applicable to LAC given the distortions that we have estimated.

5.3.1. Tax Petroleum in the Same Way and at the Same Level as Mining

As we have shown, the Government Take for the average petroleum project is 73%, while the average for mining is 60% (Table 4.1). There is no economic reason why a country or region would want to tax petroleum differently or more heavily than mining. The goal in both should be to tax rents at the desired rate while creating no distortions. That rate could be anywhere from 1% to 100%, depending on what the government deems fair.

A direct result of the higher rate of taxation of petroleum given the use of distortionary tax instruments is higher physical distortions of petroleum projects and higher FI. At a minimum, by our analysis targeting petroleum GT at 70% or less, as effected by the fiscal regimes in Peru, Argentina, Colombia, and Guyana, would greatly reduce FI in the other countries while not dramatically reducing government revenues as these countries back down the Laffer Curve. The relatively higher efficiency of the mining regimes also recommends that the fiscal instruments used there (and specifically, the higher reliance on income taxes and surtaxes and decreased reliance on production royalties) are worthy of consideration for application to petroleum.

5.3.2. Taxes That Target Rent Are the Least Distortionary

Our analysis has shown that royalties and income taxes with incomplete depreciation allowances in use in LAC are distortionary. Theory suggests that for whatever GT desired, pure rent taxes and other tax systems that target rent are neutral, as they do not distort investment and operating decisions (Smith, 2013). Rent is defined as the surplus that remains after all fixed and variable costs have been recovered by an Operator, including a risk-adjusted return on invested capital from the initiation of exploration through to the development of a project, and after the rents to entrepreneurial talent (Cairns 1985, Land 2010, Chen and Perry 2015).²⁹ After-tax income provides an imperfect measure of return on capital invested and does not fully compensate the Operator for investments undertaken. Taxing it will lead to distortions, as we have shown. Production and revenues include no allowance for capital invested, and taxing these items via royalties severely dissuades the Operator from investing capital.

Income tax systems specially designed to target rent can produce relatively neutral results. Norway, for example, has an explicit goal of neutral petroleum project taxation and appears to approximately achieve that goal through an allowance for depreciation that goes above and beyond that normally included in a CIT (Lund 2018a). That additional allowance causes the income tax to fall purely on rent.

A fiscal regime based strictly on taxing net cash flows rather than accounting income (e.g., the so-called “Brown Tax,” named after the economist who first proposed it) is in principle also neutral and free of distortion, a means by which to implicitly implement a pure rent tax. However, such a tax effectively converts the Government into an equity partner in the upstream enterprise, which includes obligations to participate in up-front investments as well as subsequent production revenues, and to participate in losses as well as profits. It is understandable that such arrangements may not be attractive to any Government.

After noting the distortions in Colombia’s existing mining fiscal regime, Chen and Perry (2015) provide a path forward for adding resource rent-based taxation to the CIT tax base in

29. Rent is intended to mean surplus, or excess profit. A fair rate of profit includes in it the concept of an adequate return to capital invested. In a net present value analysis this is incorporated in the analysis via a risk-adjusted discount rate. Entrepreneurial talent is often not a cost that is included in the computation of rent, and yet that cost exists and needs to be accounted for.

Colombia. We would echo the merit of the LAC countries in our study investigating revision of their fiscal regimes towards resource rent taxation, though suggest in the next section some relatively simple second-best options.

5.3.3. Systems With a Resource Surtax and Rapid Expensing Are Second-Best to Rent Taxes

None of the countries analyzed in this study seek to impose a non-distortionary rent tax.³⁰ As such, the tax systems that they use create distortions. Distortions may be inevitable given the set of tax systems that seem both practicable and politically acceptable for developing countries, but that only highlights the importance of identifying the distortions likely to be induced by any specific fiscal regime, quantifying their cost, and searching for more efficient fiscal regimes if needed.

The idiosyncrasy of project responses to taxation makes such an exercise difficult. Helliwell (1978), who was a pioneer in modeling project-level responses to tax systems, suggests that the way around the idiosyncrasy of Operators' responses to taxes is a complete cataloguing of a nation's current and potential resource deposits, and to build a fiscal system that best suits the nations' goals. In our view, this is impractical. So is the idea of designing individual fiscal systems suited to the specifics of each project, or types of projects, as suggested by Boadway and Keen (2010, pp. 24-25). Logistical issues aside, because of the non-neutrality of most fiscal systems, what may be optimal at one price level will not be optimal at another.

Even though the modeled responses to taxes are largely idiosyncratic and complex, our analysis does reveal that the existing corporate income tax systems by themselves are relatively efficient across all types of projects. This is because they allow the Operator a deduction for investment spent. Theory tells us that CIT with rapid investment cost expensing is a reasonable second-best ideal to a non-distortionary rent tax. As seen in Tables 3.1 and 3.3, some LAC fiscal systems allow for relatively rapid investment depreciation, and even immediate expensing of investment in the case of Guyana. In the oil and gas PSC regimes, high limits on the proportion of production that is deemed Cost Oil provides a better proxy for the taxation of economic rent. For example, setting the Cost Oil limit in a PSC regime at 75% (as is the case in Guyana) rather than 50% (as in Brazil) provides a better approximation of economic rent. Moreover, none of the existing LAC regimes permit an Operator to deduct interest on costs carried forward for future recovery. This tends to artificially inflate "economic profit" and the tax base, causing reduced investment since it decreases its rewards.

Rapid expensing of investment, though increasing efficiency, would decrease GT. A special income surtax that increases the overall rate of CIT can allow for GT to be restored to desired levels. The analysis in Section 5.1.1 showed the relative efficiency of an increased rate of CIT for a hypothetical petroleum project, even with relatively slow 10-year depreciation recovery. It is also important to index the tax base for inflation, because inflation tends to increase recorded revenues over time while leaving real economic rents unchanged. Some of the existing petroleum fiscal regimes do this via "uplift," which allows the Operator to deduct from the tax base an amount over and above actual capital expenditures, but none of the mining regimes do.

30. This is not unusual. According to the IMF (2012), only Norway and Italy impose resource rent taxes on top of CIT. The Special Lease Agreement between Dominican Republic and the Pueblo Viejo mining project includes a 28.75% Net Profits Interest, which is a form of rent tax. But this does not appear to be a statutory fiscal instrument in the Dominican Republic. Five mining countries and five petroleum countries surveyed by the IMF allow uplift on accumulated losses, which seeks to neutralize the inefficiency of the CIT itself.

Given these considerations, Guyana's fiscal regime is an example of a relatively efficient petroleum taxation system. Petroleum producers are effectively exempted from the income tax and production royalties because under the law Government pays those levies on behalf of the Operator, taking the money out of the Government's share of Profit Oil collected under the PSC. That means the Operator is really just subject to production sharing, and the Guyanese PSC is among the simplest and most straightforward to be found in Latin America. The Cost Oil limit is high (75%), which permits an Operator to rapidly recover sunk costs. Also, the Government share of Profit Oil is relatively low (50%) and fixed over the life of the field. These characteristics combine to produce fiscal burdens on upstream petroleum investment that are light in comparison to many other LAC countries, and as we mentioned above proxy a tax on economic rent. As a result of this and the low GT, Guyana has the lowest FI of the petroleum scenarios studied, both for shallow and deep water fields.

The low GT of the Guyanese system also produces a below-average FY compared to the other LAC regimes. The IMF has reportedly identified the relatively low GT in Guyana as being problematic, and is urging the country to implement a more aggressive tax regime by making the regime more progressive, removing interest as a tax-deductible expense, and tightening ring fencing to deter profit-shifting.³¹ An additional consideration would be to reduce or eliminate the exemption on income tax, Guyana's income tax being relatively non-distortionary compared with other income taxes given Guyana's allowance of immediate expensing of investment and unlimited loss carryforwards.³²

In the case of mining, Chile's fiscal regime is exemplary. It relies exclusively on a CIT supplanted by an additional progressive profits surtax to tax mining projects that produce more than 12,000 tonnes per year of copper equivalent metal. The CIT, at a relatively high rate of 35% for foreign-owned projects, allows for accelerated depreciation and imposes no limits on loss carryforwards. The surtax has similar allowances, except for the allowance of accelerated depreciation. In this way, they approximate a tax on economic rents, and the DWLs from the current regime on the Sierra Gorda and Zaldivar copper projects are among the lowest studied. In fact, the DWLs at Sierra Gorda are close to zero, making the move to a resource rent tax on that project unwarranted.

Chile's regime could be improved by allowing uplift on loss carryforwards and allowing accelerated depreciation in calculating the tax base for the surtax. Any reduction in GT could be made up by increasing the income surtax. Moreover, since the tax approximates a rent tax, there is no reason to exclude smaller mining projects from the surtax. Extending the surtax to the smaller projects that are currently exempted would broaden the tax base and allow for a reduction in the overall tax rate and a resultant decrease in FI.

31. "Exxon Sparks IMF Concern with Weighty Returns in Tiny Guyana," Bloomberg, April 9, 2018, <https://www.bloomberg.com/news/articles/2018-04-09/exxon-sparks-imf-concern-with-weighty-returns-in-tiny-guyana>

32. Were Guyana to provide tax subsidies in proportion to losses, the income tax would be non-distortionary. Likewise, were the loss carryforwards in other countries to include a risk-free rate of interest, with guarantees of payoffs for unrecovered losses at the end of the project, the income tax would be non-distortionary.

5.3.4. Royalties Levied on Production Volume or Gross Revenue, Asset and Dividend Taxes, and Profit-oil Sharing Rates Should Be as Low as Possible

It is in theory best practice to avoid royalties levied on volume or gross revenue because gross revenue is a poor measure of rent. Royalties are as a result highly distortive (see Section 5.1.1). By our analysis, the least distortionary fiscal regimes in both sectors tend to follow this practice. In oil and gas, PSC regimes avoid royalties altogether—at least in theory. Yet, the Government's share of Profit Oil, which denotes the portion of sales revenue that an Operator and Government will divide among themselves according to the prevailing profit-sharing rate in a PSC regime, is equivalent to a royalty and creates similar distortions. The PSC regimes that postpone large Government participation in Profit Oil until after an Operator has recovered sunk costs, on the other hand, tend to reduce the extent to which economic rents are overstated for tax purposes.³³ Mexico's deep water oil PSC is an example that does this, whereas Brazil's Pre-Salt PSC regime and Guyana's PSC regime don't.

Most concessionary systems in LAC rely heavily on outright royalties, many of which are levied at fixed rates over the life of the field. A few regimes, as in Colombia where the royalty rate varies from 8% to 25% or Peru where the royalty rate varies between 15% and 35%, include variable royalty rates that increase with the rate of production, R-factor, oil price, or other criteria.³⁴ These systems also have the potential to reduce the overstatement of economic rents (relative to fixed-rate royalty systems) because the progressive royalty rates are at least indirectly related to economic rent through their linkage to financial and/or productivity measures. Distortions are made much worse in the few countries (as in Mexico's deep water oil concessionary system or in Brazil's Pre-Salt PSC regimes) that make royalty rates or profit-sharing rates the criterion by which rivals compete among themselves in auctions to win petroleum licenses.

In mining, Argentina, Brazil, Dominican Republic, Ecuador, and Panama all make use of royalties as a fiscal instrument (see Table 3.3). Ecuador and Panama have the highest rates. Brazil's royalty is on production, which is more distortionary than a royalty on sales because production is only remotely related to rent.³⁵

Royalties are applied in part because of Government's desire to obtain project revenues from the start of production, whereas income taxes may not flow for several years due to the tax shields afforded by the recovery of initial investment (depreciation). In the petroleum regimes, those that lack a royalty are based on some form of PSC contract, in which the government revenues commence with first production and are received in the form of government's share in profit oil. Yet, in the mining case studies the corporate tax systems generated government cash flow from year 1 of the project in 13 of the 15 cases.³⁶ Moreover, if a country has a portfolio of projects operating at the same time, as is the case in all of the countries studied, it is not vital that any single project produce tax cash flows from its first year of production. It is therefore our opinion that the path to a more efficient

33. They do this through rates that are linked to R-factors, IRR, or similar.

34. The R-Factor varies through time according to the ratio of Operator's cumulative revenues to cumulative expenditures.

35. Rent is revenues minus costs, minus return to investment, in present value terms. A royalty on revenues includes at least a part of this formula. A royalty on production excludes the effect of price on revenues, and is thus even further from a tax on rent.

36. The two cases for which this does not hold are Zaldivar and Minas Rio. This outcome of course depends on the economic environment – should prices drop income taxes may well not accrue for several years due to operating income being lesser than tax shields.

system of taxation is away from royalties and towards the theoretically ideal pure rent tax or second-best corporate income taxes.

If a combined royalty/profits tax system is nevertheless employed, our advice is to have royalties that apply to value rather than production, since this is less distortionary, and to limit the royalty component and consequent overall GT attributable to royalties to the lowest practicable level in preference for a wide national tax base at a low rate as compared with a narrow resource-based tax base at a high rate (Poterba 2010). This will serve to reduce the distortions to investment and production and increase the social and economic benefits that such investment creates.³⁷ This is directly contrary to popular conceptions of mining and oil and gas as special class of assets that warrants, and indeed can often accommodate, a relatively aggressive royalty system. We have shown that such a system can be highly inefficient and wasteful of the country's scarce natural resources.

37. Poterba (2010) discusses mechanisms by which the broadening of the tax base can be achieved.

6. CONCLUSIONS

This report has reviewed the taxation of oil, gas, and mining sectors by the governments of the major Latin American and Caribbean producing countries. We found the fiscal regimes in place to be complex and widely divergent in terms of form and structure. We also found most of the existing regimes tend to unintentionally discourage investment, limit production, and create deadweight losses that impede the governments' ability to realize the full value and benefits of their resource endowments.

These conclusions are based on an analysis of deadweight losses using a model of resource exploration and development that recognizes and incorporates investors' likely reactions to various fiscal provisions in the attempt to maximize private operator value via the minimization of the burden of taxation. This behavioral approach to the investor's reaction to taxes is designed to identify potential distortions to the plan of exploitation—distortions that may to some extent impair benefits (revenues, jobs, production) that the government would hope to capture through the fiscal regime.

Our model focuses, in particular, on distortions to the extent of exploration for new resources, the scope of investment in the development of newly discovered resources, the initial rate of production and subsequent efforts to increase production using enhanced methods of resource recovery, the overall resource recovery factor, and the expected lifetime of the project. Each type of distortion contributes to the overall deadweight loss attributed to the tax system.

Certain of the existing fiscal regimes come closer to the theoretic ideal of a “neutral” tax system that does not create incentives to alter what would otherwise be the most efficient investment plans. In the worst cases, where several distortive tax instruments are stacked up in combination against the investor, we find the prospective deadweight losses effectively destroy over half of the total potential value of the resource. In other words, an ill-structured fiscal regime may effectively cut a country's resource endowment by half. The mining fiscal regimes that we investigated, as applied to our selection of mining projects, tend to come closer to an optimal tax, while the petroleum regimes tend to be highly distortionary. In this report, we have identified workable fiscal reforms that may restore a significant fraction of the potential losses that would otherwise be incurred.

It is important to understand that the performance of a fiscal regime should not be assessed using the conventional measure of Government Take. Although that measure represents the fraction of realized profit from a given project that is captured by the government, it fails to account for investments that are not made and potential government revenues that are never generated due to tax-induced distortions. Our measure of Fiscal Inefficiency quantifies this negative aspect of the fiscal regime by comparing the amount of deadweight loss generated by a given regime to the amount of revenue that regime will actually capture.

That information is complemented by our measure of Fiscal Yield, which summarizes the financial performance and effectiveness of the fiscal regime by measuring the fraction of potential profits (that would be generated but for tax-induced distortions) the regime is able to capture. Unless the fiscal regime is completely neutral (no distortions), the Fiscal Yield will always be smaller than Government Take. In many of the LAC countries, the Fiscal Yield of existing regimes is significantly smaller than the reported level of Government Take. We emphasize that the Government's slice of the pie can never result in a large revenue stream if the pie itself is small. To the extent that the fiscal regime makes the pie small, reforms that accord with the recent literature on efficient fiscal regimes may be in order. Failing that, a move to a heavier weighting on corporate income tax and less weighting on production royalties would serve many LAC economies well.

APPENDIX I.

TECHNICAL METHODOLOGY

Methodological Limitations

Simplifying Assumptions

i. In each model we have assumed that the project is managed on a stand-alone basis, meaning that tax losses cannot be written off against income from other projects. Instead, tax losses are carried forward, and any unused losses or capital depreciation at the end of the project life is written off. This will cause distortionary taxes like the Corporate Income Tax to have a higher distortionary impact than in cases where tax losses at one project might be used to offset taxable income at another.

ii. The No-Tax case is a theoretical scenario, where Operators have complete freedom to build the design of their choosing. In all cases the No-Tax design requires more investment than the design with taxes. Yet many Operators will face capital budgeting constraints that prevent or constrain their decisions in this regard. We ignore these constraints. To the extent that Operators would not build an optimal design in the absence of taxes due to capital constraints, our analysis overestimates the distortions and consequent DWL caused by the fiscal systems.

iii. Taxation is a form of risk sharing between Government and the Operator. Most tax systems reduce the riskiness of the cash flows accruing to the Operator. It is well known that firms adjust their effective project discount rates, in this case downwards, depending on the tax system the project faces (Samis et al. 2007, Lund 2014b, Davis and Lund 2018). We have used the same discount rate to evaluate all scenarios, including the No-Tax case, and so do not include this nuance in our analysis. Nor do we use different after-tax discount rates for projects with different profitability, even though under most valuation models more marginal projects warrant higher discount rates due to increased operating leverage (Samis et al. 2007). This introduces error into our estimation of DWLs for each project tax scenario.

iv. In this vein, taxation of a project exposes Government to that project's risk. Different fiscal systems create different risk exposures. Royalties on production are the least risky, while windfall taxes are the most risky (Samis et al. 2007). Our analysis does not take a government's risk tolerance into account and uses the same discount rate for Government cash flow streams as is used for Operator streams. This again introduces error into the analysis, since Government and Operator streams should be discounted at special rates appropriate to the risks of each of those cash flow streams.

v. Many fiscal systems allow deductions of interest payments on debt. This incentivizes firms to take on debt. Such debt will reduce GT and will reduce the distortionary impacts of the fiscal regime. Our analysis assumes 100% equity financing, and so does not take into account the interactions between fiscal regime, project financing, and project distortions.

vi. We assume perfect competition. There is evidence that producers of nickel, copper, iron ore, lead, tin, and zinc behave oligopolistically, which can imply that they extract resources at a slower rate than socially optimal (Ellis and Halvorsen 2002, Zhang and Lin Lawell 2017). We do not consider how taxes may incentivize an imperfectly competitive firm to behave even less competitively by further slowing the rate of extraction, or how governments may wish to affect world prices to their advantage through tax policy (Boadway and Keen

2010). These nuances would add another layer to the analysis of how tax regimes affect Government and Operator welfare.

vii. Our analysis presumes that firms are rational, profit-maximizing entities, and simulates how such entities would respond to taxation of their projects at the stage of investment and design. It does not measure and is not calibrated by actual Operator responses to changes in taxation. Empirical work analyzing actual mining Operator responses to changes in tax systems shows that they do behave in a way that is consistent with our presumption of rationality, though it is impossible to know if their responses would be precisely those that we model here (Harchaoui and Lasserre 1995). While an assumption of Operator rationality appears reasonable, not all Operators will necessarily act in this way. Where the choices of private Operators are inefficient, a distortionary royalty may be an optimal tax policy.³⁸ Again, we do not take these effects into account.

Restrictions on the Scope of Study

i. Each country's fiscal regime is highly complex, with detailed interactions between each fiscal component in the form of deductions and offsets. There may also be investment agreements and allowances negotiated between a Government and an Operator tailored to the special nature of that project. Our assumption of the tax regime of each project includes only the most impactful fiscal components and interactions as generally laid out in the publicly available literature. Tax regimes are also continually shifting; the regimes we assume were in effect on January 1, 2018.

ii. We do not evaluate tax policies under information asymmetries between Government and Operator, which would favor production and revenue-based taxes over profit or rent-based taxes (Boadway and Keen 2015).

iii. We do not include the possibility that there are other distortionary influences, like expropriation risk, that would cause the Operator to extract slower or faster than modeled here (Bohn and Deacon 2000). In this situation there is the possibility that the distortions from the tax systems that we investigate offset these other distortions, so that the after-tax design is approximately optimal after all. In other words, the distortions that the tax systems create may accidentally drive investment and operations back to what they would be in a No-Tax scenario.

iv. Resource extraction may also have negative externalities, like pollution, and taxation that slows extraction and reduces the amount of resource produced may in part correct for these externalities.³⁹ We do not take these costs into account. In this sense, the DWL measured here is biased high. Or, it may be that resource extraction has positive externalities in the form of technology spillovers (Bjørnland and Thorsrud 2015), and the DWL from taxation systems that slow production and even stop projects altogether is larger than estimated here.

v. We do not focus on the parsing of government revenues amongst the various government and social entities within a fiscal regime. Nor do we include considerations of distortions from taxation beyond DWL. Lilford (2017) suggests that such additional considerations include lost wages, the income taxes on those wages, increased welfare payments, knock-on effects to service providers, community impacts, and equity market impacts.

38. See Boadway and Keen (2015) for a summary of the use of royalties to offset privately suboptimal extraction decisions.

39. Though as Lund (2018b) points out, there are more efficient ways for governments to correct this than through the usual fiscal instruments designed to provide the state with income. Slowing the rate of oil leasing is an example.

vi. Taxation is not only a way for governments to raise revenue, it is also a form of public policy. We are aware that countries may want to increase the GT in order to raise revenue, and that any decrease in a resource property's GT may require an increase in even more distortionary taxes of other productive activities. Taxation is also a tool that governments use to manage natural resources. The fact that taxation halts low profit projects or keeps resources in the ground may be exactly what is desired. We abstain from commenting on fiscal regimes as public policy, and instead limit our analysis to a purely positive approach that focuses on efficiency.

vii. We have not considered commercial and technical uncertainty, or an Operator's responses to such uncertainty. Tax systems can have different influences on project optimization once these forms of uncertainty are modeled. This is especially true in cases of windfall profits taxes under uncertain price paths (as in Ecuador) and where tax rates vary with operating margin (Chile and Peru) (Samis et al. 2007). The general non-neutrality of the tax systems we analyze will mean that under uncertainty the distortionary effects will be lower (in the case of progressive taxes) or higher (in the case of regressive taxes) than those that we measure.

viii. We have not evaluated the stability of the various fiscal regimes nor the fact that some regimes allow for fiscal stability contracts. Fiscal instability is a deterrent to natural resource investments and can increase DWL beyond that which we measure, due to firms expecting higher taxes than stated in the statutes and higher discounting of risky tax deductions (Davis and Lund 2018). In the mining industry fiscal stability is one of the top ten company decision criteria for investment in a region (Mitchell 2009).

ix. We have not assessed the relative distortions of mining and oil and gas taxes due to their differences from the level of taxation of other sectors. Where marginal effective tax rates (METR) differ across sectors and across products within a sector, national and international efficiency in the allocation of capital is diminished.⁴⁰

x. Profit shifting, whereby multinational companies shift profits from higher-tax jurisdictions to lower-tax jurisdictions, has been shown to be significant for multinational oil and gas companies given their high tax burden (Beer and Loeprick 2017). We have not modeled these influences, and on this basis our estimates of GT for each project may be exaggerated.

40. This was the emphasis in the analysis of Colombian mine taxation by Chen and Perry (2015) (see fn 6).

Methodology

Petroleum

Our analysis of oil and gas fiscal regimes is adapted from Smith's (2014) model of petroleum exploration, development, and production. The model integrates exploration and development decisions to produce a "full-cycle" analysis of investments and returns. We begin by focusing on a reservoir where the volume of original oil-in-place is fixed and denoted OIP. Where oil and gas are both present, we state resource volumes in terms of barrels of oil equivalent with gas converted at the rate of 6 mcf per barrel (boe).

Primary Production Phase

Recovery of reserves during the initial (primary) phase of production is primarily governed by the initial capital investment (number of wells) and geological properties of the reservoir:

$$R_0 = s \times OIP, \quad (1)$$

where R_0 represents the volume of primary recovery and s represents the primary recovery factor. According to Total Exploration and Production (2009), the primary recovery factor is typically around 33% and we adopt that value.

During the primary phase of production, output declines exponentially from the initial level at a fixed rate, a , over time:

$$Q_t = Q_0 \times e^{-at} \text{ for } t \geq 0, \quad (2)$$

where Q_t represents the instantaneous flow of production at time t . The volume of primary reserves is by definition the integral of (2):

$$R_0 = s \times OIP = \int_0^\infty Q_t dt = \frac{Q_0}{a}. \quad (3)$$

It follows that $Q_0 = a \times R_0$, which means the rate of decline and the rate of extraction are the same. Likewise, the volume of primary reserves remaining in the reservoir at time t is given by:

$$R_t = \frac{Q_t}{a} = R_0 \times e^{-at}. \quad (4)$$

The required investment to realize this production profile depends on the rate of extraction (a), which is chosen by the investor, and the size of the field (OIP) and local conditions as reflected in a regional calibration factor (A), which are fixed exogenously:

$$I(a) = A \times s \times OIP \times a^{1.68}, \quad (5)$$

where the elasticity with respect to rate of extraction exceeds one, indicating diminishing returns. Investment requirements may be expressed alternatively in terms of the "capital coefficient," which measures the amount of investment in primary development required per initial daily barrel of production:

$$CC(a, A) \equiv \frac{I(a)}{Q_0/365} = 365 \times A \times a^{0.68}. \quad (6)$$

We assume the capital investment is spread equally across three years. Operating costs are of two types. We assume the investor incurs a variable cost (VC) per barrel as production occurs, plus an additional annual fixed operating cost (FOC) that is proportional to the installed capital investment.

Enhanced Production Phase

At a time, T , of their choosing the investor can make an additional investment in enhanced recovery techniques, which are assumed to augment the volume of remaining reserves by the factor λ :

$$Q_t^e = \lambda \times Q_t \text{ for } t \geq T. \quad (7)$$

The extent to which reserves are augmented through EOR depends on the timing of EOR and the state of previous reservoir depletion, as well as on λ . The extent of reservoir depletion is measured by the ratio of remaining primary reserves to the initial volume:

$$d_t = 1 - \frac{R_t}{R_0} = 1 - e^{-at}. \quad (8)$$

The additional investment required for enhanced oil recovery is assumed to depend on the volume of remaining reserves to which EOR is applied ($\lambda \times R_p$) and the state of depletion at the time the EOR investment is made:

$$J(\lambda, T, a) = \frac{Aa^{1.68}\lambda R_T}{d_T}. \quad (9)$$

This is the same functional form that applied to investment in the primary phase of recovery, but scaled inversely by the state of depletion.

Optimal Development

At the time of initial development, and based on the investor's choice of rate of extraction (a) and the onset of EOR (T), and the time at which the field is decommissioned (\bar{T}) the present value of the oil field net of taxes is given by:

$$\begin{aligned} \pi^e(a, T, \bar{T}) = & \int_0^T (P_t - VC) \times Q_t \times e^{-rt} dt + \int_T^{\bar{T}} (P_t - VC) \times Q_t^e \times e^{-rt} dt - \int_0^{\bar{T}} [I_t(a) + \\ & FOC_t(a)] e^{-rt} dt - \int_0^{\bar{T}} \tau_t(a, T, \bar{T}) \times e^{-rt} dt - \frac{e^{-(a+r)\bar{T}}}{1-e^{-a\bar{T}}} \times \lambda \times I(a) - D \times e^{-r\bar{T}}, \end{aligned} \quad (10)$$

where $\tau_t(a, T, \bar{T})$ reflects the net payment of taxes under a given fiscal regime, D represents decommissioning costs incurred at the end of field life, \bar{T} represents the time at which the field is decommissioned, and $I_t(a)$ represents the portion of total primary capex, $I(a)$, expended at time t . Optimal development of the field is identified by maximizing Equation 10 with respect to the three choice parameters (a, T, \bar{T}) using the method of grid search.

Exploration Phase

The investor is assumed to hold the right to drill a sequence of exploratory wells that target a given prospect. Each well is assumed to cost X , of which a fixed percentage (δ) represents intangible costs. We let RF be a 0/1 indicator that determines whether, according to the given fiscal regime, intangible costs may be expensed against the corporate income tax. After-tax cash flow for the period in which the exploratory well is drilled is then given by: $-X \times [1 - \delta \times CIT \times (1 - RF)]$, where CIT represents the marginal corporate income tax rate.

Tangible exploration costs are carried forward to offset future income. Thus, total exploration costs (tangible and intangible) carried forward after a series of n wells has been drilled is given by:

$$CF(n) = n \times X \times [1 - \delta \times (1 - RF)]. \quad (11)$$

Success of each exploratory well is predicted by a physical discovery process in which there are assumed to be four possible outcomes in terms of the size of deposit:

$$\begin{aligned} \text{Small Field:} & \quad OIP = OIP_1 \\ \text{Medium Field:} & \quad OIP = OIP_2 \\ \text{Large Field:} & \quad OIP = OIP_3 \\ \text{Dry Hole:} & \quad OIP = 0 \end{aligned}$$

Drilling of the prospect is assumed to continue until a discovery is made or the investor gives up, whichever comes first. The probability of outcome i from well j is denoted p_j^i and is determined according to the discovery model of Smith (2005) which entails increasing dry hole risk after each successive failure. Let α represent the conditional probability that any given exploratory well will find a commercial field given that the prospect is charged with hydrocarbons, and let β represent the unconditional probability that the prospect has been charged with hydrocarbons. Dry hole risk then must increase with each additional failure according to:

$$p_n^4 = \frac{\alpha(1-\alpha)^{n-1}\beta}{(1-\alpha)^{n-1}\beta + (1-\beta)} \quad \text{for } n = 1, 2, \dots \quad (12)$$

We assume the relative likelihoods of the three commercial field types are given by q_1, q_2, q_3 , the complete set of discovery probabilities at each stage of exploration is then established:

$$p_n^i = (1 - p_n^4) \times q_i, \quad \text{for } i = 1, 2, 3. \quad (13)$$

The expected net present value of any individual exploratory well in the sequence is given by:

$$V^n = \sum_{j=1}^3 \frac{p_n^j \times \Pi^e(a^*, T^*, \bar{T}^* | OIP_j)}{e^{-r\Delta t}} - X \times [1 - \delta \times CIT \times (1 - RF)], \quad (14)$$

where the present value is computed relative to the date of drilling, $\Pi^e(a^*, T^*, \bar{T}^* | OIP_j)$ represents the optimized present value of the field as determined from the development phase, r represents the investor's annual discount rate, and Δt represents the elapsed time between exploration and field development.

Integration of Exploration and Development

The full-cycle, after-tax net present value of the complete exploratory sequence is given by the value of each of the N wells that constitute the exploration "campaign" (V^n for $n=1, 2, \dots, N$) multiplied by the probability that each of those wells gets drilled, denoted ϕ^n . Each of the N wells is drilled if and only if all preceding wells in the sequence were dry. Thus:

$$\phi^n = \prod_{j=0}^{n-1} p_j^4, \quad (15)$$

where for convenience we define $p_j^4 = 1$. The expected full-cycle, after-tax net present value of an exploration campaign that would be abandoned after N dry holes is then given by:

$$NPV^{FC}(N) = \sum_{j=1}^N \frac{V^j \phi^j}{(1+r)^{j+\Delta w}}, \quad (16)$$

where Δw represents the time elapsed between each exploration well. Thus, the value of the Investor's right to exploit the prospect in question is given by:

$$\max_N NPV^{FC}(N). \quad (17)$$

Calibration to Individual LAC Scenarios

The method of analysis outlined above is applied to each of the country-specific scenarios after calibrating economic and geological parameters based on values that are judged to be representative of the countries in question. All scenarios are based on a discount rate (r) of 10% real, 2% inflation rate, annual fixed operating cost (FOC) equal to 2% of the capital investment, and an enhanced recovery factor (*if EOR is initiated*) of $\lambda = 2.0$. Other parameters vary across the scenarios according to the following table.

Table 1: Specification of Geological and Economic Parameters of the Respective LAC Scenarios

| Country/Scenario | | Regime Type | X | CC | VC | OIP_1 | OIP_2 | OIP_3 | Gas | α | β |
|------------------|--|-------------|-----------|------------------|--------|---------|---------|---------|------------|----------|---------|
| | | Concession | \$mm/well | \$m/daily boe | \$/boe | mm boe | mm boe | mm boe | % of Total | % | % |
| 1 | Argentina w/ export price index | Concession | 100 | 20 | 25 | 300 | 900 | 3,000 | 0% | 70% | 50% |
| 2 | Argentina w/o export price index | Concession | 100 | 20 | 25 | 300 | 900 | 3,000 | 0% | 70% | 50% |
| 3 | Bolivia, Frontier | PSC | 1 | 10 | 12 | 100 | 300 | 900 | 90% | 70% | 70% |
| 4 | Bolivia, Mature Areas | PSC | 50 | 10 | 12 | 100 | 300 | 900 | 90% | 70% | 99% |
| 5 | Brazil, Post-Salt Deep Water | Concession | 75 | 25 | 16 | 300 | 900 | 3,000 | 11% | 70% | 50% |
| 6 | Brazil, Pre-Salt (Operator Profit Share = 25%) | PSC | 75 | 20 | 8 | 300 | 900 | 3,000 | 15% | 60% | 75% |
| 7 | Brazil, Pre-Salt (Operator Profit Share = 50%) | PSC | 75 | 20 | 8 | 300 | 900 | 3,000 | 15% | 60% | 75% |
| 8 | Colombia, Offshore Oil | Concession | 100 | 25 | 25 | 300 | 900 | 3,000 | 100% | 70% | 50% |
| 9 | Colombia, Offshore Oil w/ Free Trade Zone | Concession | 100 | 25 | 25 | 300 | 900 | 3,000 | 0% | 70% | 50% |
| 10 | Colombia, Onshore Gas | Concession | 20 | 12 | 15 | 100 | 300 | 900 | 0% | 70% | 50% |
| 11 | Ecuador, Offshore Gas | PSC | 25 | 25 | 12 | 300 | 500 | 900 | 100% | 50% | 70% |
| 12 | Ecuador, Onshore Oil | PSC | 25 | 38 | 25 | 300 | 900 | 3,000 | 0% | 70% | 90% |
| 13 | Ecuador, Onshore Oil, w/ WPT | PSC | 25 | 38 | 25 | 300 | 900 | 3,000 | 0% | 70% | 90% |
| 14 | Guyana, Deep Water | PSC | 100 | 38 | 25 | 300 | 900 | 3,000 | 0% | 80% | 90% |
| 15 | Guyana, Shallow Water | PSC | 30 | 25 | 25 | 300 | 500 | 900 | 0% | 50% | 70% |
| 16 | Mexico, Deep Water Oil | Concession | 100 | 25 | 25 | 300 | 900 | 3,000 | 0% | 50% | 60% |
| 17 | Mexico, Deep Water Oil (Operator 50%) | PSC | 100 | 25 | 25 | 300 | 900 | 3,000 | 0% | 50% | 60% |
| 18 | Mexico, Deep Water Oil (Operator 75%) | PSC | 100 | 25 | 25 | 300 | 900 | 3,000 | 0% | 50% | 60% |
| 19 | Peru, Offshore Oil (High Upside Geology) | PSC | 25 | 25 | 25 | 300 | 900 | 3,000 | 20% | 50% | 70% |
| 20 | Peru, Offshore Oil (Low Upside Geology) | PSC | 25 | 25 | 25 | 300 | 500 | 900 | 20% | 50% | 70% |
| 21 | Peru, Onshore Gas | PSC | 25 | 12 | 15 | 300 | 900 | 3,000 | 70% | 70% | 90% |
| 22 | Trinidad & Tobago, Offshore Gas, Deep Water | PSC | 100 | 25 | 10 | 300 | 900 | 3,000 | 100% | 50% | 70% |
| 23 | Trinidad & Tobago, Offshore Gas, Shelf | PSC | 50 | 20 | 10 | 100 | 300 | 900 | 100% | 50% | 70% |
| 24 | Trinidad & Tobago, Onshore Oil | Concession | 2 | 16 | 15 | 10 | 30 | 90 | 100% | 80% | 80% |
| 25 | Venezuela, Heavy Oil, with Alternative Min. Tax | Concession | 10 | 25 | 25 | 100 | 300 | 900 | 0% | 95% | 95% |
| 26 | Venezuela, Heavy Oil, without Alternative Min. Tax | Concession | 10 | 25 | 25 | 100 | 300 | 900 | 0% | 95% | 95% |

Data Sources

- Agencia EFE
- BBVA
- Brazil ANP
- Compelo Energy
- Columbia Center on Sustainable Development
- Drilling Contractor Magazine
- Ernst & Young
- Guyana, Ministry of Natural Resources
- JWNEnergy.com
- Mayer Brown Taui Chequer Law Firm
- Offshore Energy Today
- Oil and Gas Journal
- Oil Price.com
- Petroleum Intelligence Weekly
- Reuters
- Shell Oil
- Total, S.A.
- Trinidad & Tobago, Ministry of Energy and Energy Industries
- World Oil Magazine
- Americas Quarterly
- BNamericas
- Canales Auty
- CMS LawNow.com
- Deloitte
- Eco (Atlantic) Oil & Gas Ltd.
- ExxonMobil
- Juan Pablo Sarmiento Michel
- Latin American Herald Tribune
- Newsbase.com
- Offshore Magazine
- Oil Now
- PeruReports.com
- Price Waterhouse Coopers
- Rigzone
- Simmons & Company, International
- US Energy Information Administration
- Wall Street Journal
- Wood-MacKenzie

Mining

Our analysis of mining regimes is adapted from Smith's (2014) model of petroleum exploration, development, and production to suit the physical and economic aspects to mine design and production (Davis and Domínguez 2017).⁴¹ The 15 mining projects and 9 countries were selected by CRU and IDB (CRU October 2017) for their representativeness of the types of mines and metals produced in each country. Some of the projects are currently under production, while others are in the design stage. Each project was modeled as starting investment in 2018 based on the project's initial engineering design.

In each of the 15 cases modeled the orebody has already been defined through exploration, and only design and development needs to be undertaken. This is what we call Half-Cycle Analysis. The Excel discounted cash flow model assumes that a profit-maximizing mine owner chooses investment and production decisions over the life of the asset in the face of the tax regime facing the project as of 2018. The cash flow models have reasonable detail, with over 100 cash flow line items in each, including an accounting for each metal produced and sold, mining operating costs, plant operating costs, sales costs, complete tax calculations including depreciation and loss carryforwards, closure costs, and mine and plant capital costs. In these models the owner has choices over a constant production rate and a constant cut-off grade. Cut-off grade determines the quantity of reserves and the mill feed grade (see Table 2). Mill feed grade in turn determines the stripping ratio in the case of open pit mines (see Table 3). The so-called "tonnage-grade curves" and "stripping ratio curves" provided on those tables were determined by CRU either from project technical reports or the observation of actual operations, and are customized for each particular project. Life of mine is simply reserves divided by production rate.

41. An overview of the methodology and model parameterization is contained in CRU (February 2018). Spreadsheet models were provided to the authors in a private communication from CRU.

Table 2: Grade/Tonnage Curves

| Project | Average Grade/Cutoff Grade Curve | Reserve Tonnage/Cutoff Grade Curve |
|-----------------|---|---|
| Cerro Matoso | $\text{Grade}(\% \text{Ni}) = 1.67 \exp[21.5 \text{COG}(\% \text{Ni})]/100$ | $\text{Reserve}(\text{Mt}) = 368 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Ni})) - 0.37}{\sqrt{2} * 0.59} \right] \right)$ |
| Corumba | $\text{Grade}(\% \text{Fe}) = 42.06 \exp[0.64 \text{COG}(\% \text{Fe})]/100$ | $\text{Reserve}(\text{Mt}) = 42.14 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln 100 \text{COG}(\% \text{Ni}) - 3.96}{\sqrt{2} * 0.12} \right] \right)$ |
| Minas-Rio | $\text{Grade}(\% \text{Fe}) = 28.1 \exp[0.99 \text{COG}(\% \text{Fe})]/100$ | $\text{Reserve}(\text{Mt}) = 3688 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln 100 \text{COG}(\% \text{Ni}) - 3.46}{\sqrt{2} * 0.14} \right] \right)$ |
| Fruta del Norte | $\text{Grade}(\text{g/t Au}) = 0.52 \text{COG}(\text{g/t Au}) + 4.50$ | $\text{Reserve}(\text{Mt}) = 26.6 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au}) - 2.04}{\sqrt{2} * 0.13} \right] \right)$ |
| Gramalote | $\text{Grade}(\text{g/t Au}) = 1.12 \text{COG}(\text{g/t Au}) + 0.30$ | $\text{Reserve}(\text{Mt}) = 719.5 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au}) + 1.70}{\sqrt{2} * 0.94} \right] \right)$ |
| Lagunas Norte | $\text{Grade}(\text{g/t Au}) = \text{Min} \left[\text{Max} \left(\frac{1.3 + 0.24 \text{COG}(\text{g/t Au})^2}{-3.39 + 2.52 \text{COG}(\text{g/t Au})}, 0 \right) + 0.16 \right]$ | $\text{Reserve}(\text{Mt}) = 316.9 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au}) - 0.29}{\sqrt{2} * 0.45} \right] \right)$ |
| Noche Buena | $\text{Grade}(\text{g/t Au}) = 0.57 \text{COG}(\text{g/t Au}) + 0.63$ | $\text{Reserve}(\text{Mt}) = 114.5 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au}) + 0.59}{\sqrt{2} * 0.42} \right] \right)$ |
| Pueblo Viejo | $\text{Grade}(\text{g/t Au Eq}) = 2.32 \exp[0.22 \text{COG}(\text{g/t Au Eq})]$ | $\text{Reserve}(\text{Mt}) = 308.1 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au Eq}) - 0.64}{\sqrt{2} * 0.56} \right] \right)$ |
| Veladero | $\text{Grade}(\text{g/t Au}) = 0.66 \exp[0.61 \text{COG}(\text{g/t Au})]$ | $\text{Reserve}(\text{Mt}) = 563.4 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln \text{COG}(\text{g/t Au}) + 0.22}{\sqrt{2} * 0.45} \right] \right)$ |
| Sierra Gorda | $\text{Grade}(\% \text{Cu}) = (0.18 + 1.07(100 \text{COG}(\% \text{Cu})) - 0.79(100 \text{COG}(\% \text{Cu}))^2 + 1.07(100 \text{COG}(\% \text{Cu}))^3)/100$ | $\text{Reserve}(\text{Mt}) = 3000 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu})) + 1.22}{\sqrt{2} * 0.70} \right] \right)$ |
| Taca Taca | $\text{Grade}(\% \text{Cu}) = 0.28 \exp[151 \text{COG}(\% \text{Cu})]/100$ | $\text{Reserve}(\text{Mt}) = 2336.9 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu})) + 0.86}{\sqrt{2} * 0.49} \right] \right)$ |
| Zaldívar | $\text{Grade}(\% \text{Cu Eq}) = (38 \text{COG}(\% \text{Cu Eq}) + 0.77)/100$ | $\text{Reserve}(\text{Mt}) = 1316.9 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu Eq})) + 0.26}{\sqrt{2} * 0.28} \right] \right)$ |
| Piedras Verdes | $\text{Grade}(\% \text{Cu}) = (123 \text{COG}(\% \text{Cu}) + 0.12)/100$ | $\text{Reserve}(\text{Mt}) = 1137 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu})) + 1.96}{\sqrt{2} * 0.78} \right] \right)$ |
| Constancia | $\text{Grade}(\% \text{Cu}) = (73 \text{COG}(\% \text{Cu}) + 0.18)/100$ | $\text{Reserve}(\text{Mt}) = 1296.3 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu})) + 1.53}{\sqrt{2} * 0.49} \right] \right)$ |
| Cobre Panamá | $\text{Grade}(\% \text{Cu}) = (76 \text{COG}(\% \text{Cu}) + 0.27)/100$ | $\text{Reserve}(\text{Mt}) = 3520 * 0.5 * \left(1 - \text{erf} \left[\frac{\ln(100 \text{COG}(\% \text{Cu})) + 1.21}{\sqrt{2} * 0.56} \right] \right)$ |

Source: CRU spreadsheet models

Table 3 Stripping Ratio Curves

| Project | Stripping Ratio Curve |
|-----------------|---|
| Cerro Matoso | Stripping Ratio= $161\text{Grade}(\%\text{Ni})-2.09$ |
| Corumba | Stripping Ratio= $1.1 \times 10^{-12} \exp[47.6\text{Grade}(\%\text{Fe})]$ |
| Minas-Rio | Stripping Ratio= $1.5 \times 10^{-6} \exp[35.4\text{Grade}(\%\text{Fe})]$ |
| Fruta del Norte | Stripping Ratio= 0.00 (underground mine) |
| Gramalote | Stripping Ratio= $0.91 \exp[2.03\text{Grade}(\text{g/t Au})]$, grade $\leq 0.50\text{g/t Au}$ Stripping Ratio= $0.37 \exp[3.84\text{Grade}(\text{g/t Au})]$, grade $> 0.50\text{g/t Au}$ |
| Lagunas Norte | Stripping Ratio= $4.99-6.48\text{Grade}(\text{g/t Au})+2.33\text{Grade}(\text{g/t Au})^2$ |
| Noche Buena | Stripping Ratio= $0.43 \exp[2.61\text{Grade}(\text{g/t Au})]$ |
| Pueblo Viejo | Stripping Ratio= $0.15\text{Grade}(\text{g/t Au Eq})+0.46$ |
| Veladero | Stripping Ratio= $1.32 \exp[0.95\text{Grade}(\text{g/t Au})]$ |
| Sierra Gorda | Stripping Ratio= $0.17 \exp[745\text{Grade}(\%\text{Cu})]$ |
| Taca Taca | Stripping Ratio= $107\text{Grade}(\%\text{Cu})+1.28$ |
| Zaldívar | Stripping Ratio= $95\text{Grade}(\%\text{Cu Eq})+0.30$ |
| Piedras Verdes | Stripping Ratio= $-344\text{Grade}(\%\text{Cu})+3.82$ |
| Constancia | Stripping Ratio= $404\text{Grade}(\%\text{Cu})-0.09$ |
| Cobre Panamá | Stripping Ratio= $1128\text{Grade}(\%\text{Cu})-3.28$ |

Source: CRU spreadsheet models

The physics of mining is that the selection of a lower cut-off grade results in more reserves and a longer mine life, but at a lower average grade. Lower grade material yields less metal per tonne processed, and so is less economic to process in the mill. Yet lower grade material requires less mining capital costs and reduces mining costs per tonne of mill feed via a reduced stripping ratio. The task is to select the optimum cut-off grade, which requires the application of economic parameters.

The higher the selected production rate for a given cut-off grade, the lower the unit costs (when there are economies of scale) and the less discounting of cash flows given a shorter mine life. Yet a higher production rate requires higher initial mine and mill capital costs, which are not salvaged at the end of the mine life and therefore considered to be irreversibly sunk. The task is to select the optimum production rate, which again requires the application of economic parameters.

The economic parameters in the models include nominal prices, real costs, cost inflation dependent on type of costs, and a nominal discount rate. The nominal discount rate is representative of industry practice for each particular metal, as determined by CRU.⁴² Prices are taken to be those prevailing in mine project design as of 2018, as determined by CRU. Costs are related to the engineering design and operating rates taken by the operator, as determined by CRU using their proprietary “bottom up” cost models. Operating costs include wages, consumables, fuels, electricity, and raw materials. Unit plant operating costs are a function of mill production rate, ore grade, and, for iron ore, mass recovery rates. Unit mine costs are a function of mined tonnes per year. The mine and plant operating cost functions allow for variable economies of scale.

42. 8.9% for nickel, copper, and iron ore, and 8.1% for gold.

Capital costs include facilities, infrastructure and mine development, and equipment. Inflation is applied to mine capital, plant capital, shipping, and operating costs, at rates determined to be appropriate by CRU. Plant capital costs are a function of mill production rate and ore grade, and, for iron ore, the mass recovery rate. Mine capital costs are a function of mined tonnes per year. The mine and plant capital cost functions again allow for variable economies of scale. Each of the 20 cost function functional forms used in the models is formulated and parameterized based on the engineering studies, as estimated by CRU. Each mine model then uses one plant operating cost function, one mine operating cost function, one plant operating cost function, one plant capital cost function, and one mine capital cost function, as is appropriate for that specific project and as calibrated by CRU. Tables 4 and 5 provide the details of operating and capital cost functions used in the modeling for each project. In those tables SR is stripping ratio, Q_0 is annual milled tonnage (Mt/yr.), and $M_0 = Q_0(1+SR)$ is annual mined tonnage (Mt/yr.).

Table 4: Operating Cost Formulas

| Project | Plant Operating Cost (2016 \$/t ore) | Mine Operating Cost (2016 \$/t ore) |
|-----------------|---|---|
| Cerro Matoso | $\text{Cost}(\$/t) = 107.8 \exp[11.13 \text{Grade}(\% \text{Ni}) - 0.13 Q_0]$ | $\text{Cost}(\$/t) = (1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = (1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Corumba | $\text{Cost}(\$/t) = 0.2(-40.26 - 17.85 \text{Grade}(\% \text{Fe}) / 0.64 * 0 + 60.17 Q_0 - 0.083.74 \ln(Q_0 \text{Grade}(\% \text{Fe}) / 0.64 * 0.66))$ | $\text{Cost}(\$/t) = 2(1+SR)(4.78 M_0^{-0.67} + 1.25)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 2(1+SR)(0.0037 M_0 + 1.30)$, $M_0 \geq 64.5$ |
| Minas-Rio | $\text{Cost}(\$/t) = 40.26 - 17.85 \text{Grade}(\% \text{Fe}) / 0.695 * 0.842 + 60.17 Q_0^{-0.08} + 3.74 \ln(Q_0 \text{Grade}(\% \text{Fe}) / 0.695 * 0.842)$ | $\text{Cost}(\$/t) = (1+SR)(4.78 M_0^{-0.67} + 1.25)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = (1+SR)(0.0037 M_0 + 1.30)$, $M_0 \geq 64.5$ |
| Fruta del Norte | $\text{Cost}(\$/t) = 1.77(47.82 Q_0^{-0.81} + 10.22)$ | $\text{Cost}(\$/t) = 1.09(77.03 Q_0^{-0.56})$ |
| Gramalote | $\text{Cost}(\$/t) = 1.21(47.82 Q_0^{-0.81})$ | $\text{Cost}(\$/t) = 1.1(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 1.1(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Lagunas Norte | $\text{Cost}(\$/t) = 4(47.82 Q_0^{-0.81})$ | $\text{Cost}(\$/t) = 4(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 4(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Noche Buena | $\text{Cost}(\$/t) = 0.9(47.82 Q_0^{-0.81})$ | $\text{Cost}(\$/t) = 0.9(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 0.9(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Pueblo Viejo | $\text{Cost}(\$/t) = 1.04 * (47.82(Q_0^{-0.81}) + 10.22)$ | $\text{Cost}(\$/t) = 0.5(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 0.5(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Veladero | $\text{Cost}(\$/t) = 0.98(47.82 Q_0^{-0.81})$ | $\text{Cost}(\$/t) = 2.57(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 4.5$ $\text{Cost}(\$/t) = 2.57(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Sierra Gorda | $\text{Cost}(\$/t) = 53.66 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{0.33}$ | $\text{Cost}(\$/t) = (1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = (1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Taca Taca | $\text{Cost}(\$/t) = 1.66(53.66 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{0.33})$ | $\text{Cost}(\$/t) = 1.49(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 1.49(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Zaldívar | $\text{Cost}(\$/t) = 2(1973 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{1.01})$ | $\text{Cost}(\$/t) = (1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = (1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Piedras Verdes | $\text{Cost}(\$/t) = 1973 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{1.01}$ | $\text{Cost}(\$/t) = (1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = (1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Constancia | $\text{Cost}(\$/t) = 0.89(53.66 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{0.33})$ | $\text{Cost}(\$/t) = 0.59(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 0.59(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |
| Cobre Panamá | $\text{Cost}(\$/t) = 0.89(53.66 Q_0^{-0.14} \text{Grade}(\% \text{Cu})^{0.33})$ | $\text{Cost}(\$/t) = 0.77(1+SR)(4.78 M_0^{-0.67} + 0.94)$, $M_0 < 64.5$ $\text{Cost}(\$/t) = 0.77(1+SR)(0.0037 M_0 + 0.99)$, $M_0 \geq 64.5$ |

Table 5: Capital Cost Formulas

| Proejct | Plant Capital Cost (million 2016 \$) | Mine Capital Cost (million 2016 \$) |
|-----------------|--|---|
| Cerro Matoso | $\text{Cost}(\text{M}\$)=263.6\exp[0.328Q_0]$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)$ |
| Corumba | $\text{Cost}(\text{M}\$)=52.7+13.2Q_0^{108.8}\ln(\text{Grade}(\%\text{Fe})/0.64*0.66)$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+2.84)-0.50M_0$ |
| Minas-Rio | $\text{Cost}(\text{M}\$)=52.7+108.9Q_0^{108.8}\ln(Q_0\text{Grade}(\%\text{Fe})/0.695*0.842)$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+2.84)8.4M_0$ |
| Fruta del Norte | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86}+110.24)71.1Q_0$ | $\text{Cost}(\text{M}\$)=72.60\exp[-0.09Q_0]+3.99Q_0$ |
| Gramalote | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86})+27.03Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+0.7M_0$ |
| Lagunas Norte | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86})+12.0Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+12.0M_0$ |
| Noche Buena | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86})$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)$ |
| Pueblo Viejo | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86}+110.24)+323.9Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+31.8M_0$ |
| Veladero | $\text{Cost}(\text{M}\$)=Q_0(218.38Q_0^{-0.86})1.7Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+2.6M_0$ |
| Sierra Gorda | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))+4.95Q_0$ | $\text{Cost}(\text{M}\$)=M_0^{-0.79}+(5.89M_0^{-0.79}+4.11)+0.8M_0$ |
| Taca Taca | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))+12.5Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+2.6M_0$ |
| Zaldívar | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))+40Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)$ |
| Piedras Verdes | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)$ |
| Constancia | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))+30.96Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+6.4M_0$ |
| Cobre Panamá | $\text{Cost}(\text{M}\$)=Q_0(20.12+23.08Q_0^{-0.89}-103.58\text{Grade}(\%\text{Cu}))+34.94Q_0$ | $\text{Cost}(\text{M}\$)=M_0(5.89M_0^{-0.79}+4.11)+7.3M_0$ |

Source: CRU spreadsheet models

In the No-Tax case the maximization of the project's value is notionally:

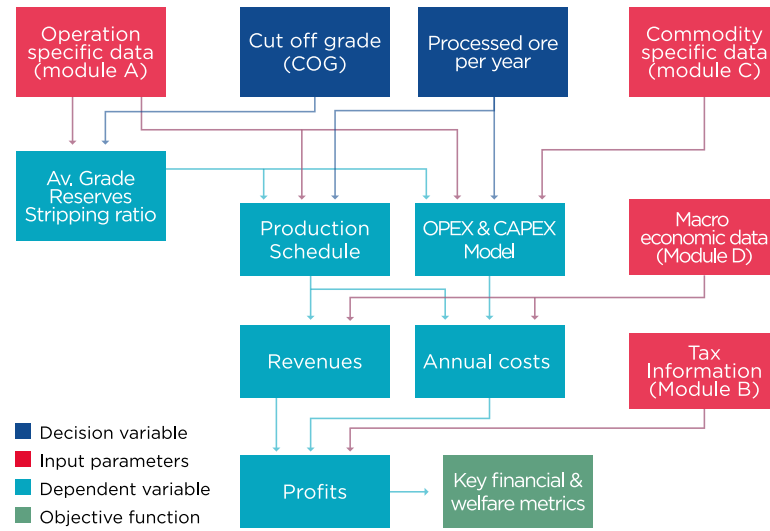
$$\max_{Q_0, COG} NPV = -\sum_{t=1}^3 \left[\frac{I_t(Q_0, COG)}{(1+r)^t} \right] + \sum_{t=4}^T \left[\frac{P_t Q_m(Q_0, COG) - c_t(Q_0, COG) Q_0}{(1+r)^t} \right] - \frac{\gamma \sum_{t=1}^3 [I_t(Q_0, COG)]}{(1+r)^{T+1}}$$

where I is investment in mine, plant and equipment, which takes place in the first three years of the project, P is mineral price and Q_m is metal quantity produced in each year of operations, c is unit mining and milling cost in each year of operations, and Q_0 is the annual mill production. Mine life is T , determined by production rate and total reserves. Reclamation costs are denoted by the last term in the equation, and are calculated as a percentage, γ of the initial cumulative mine and mill investment cost escalated through time at cost inflation rate π . Reclamation takes one year starting at the end of mine life.

The Excel models conduct a grid search over possible combinations of discrete increments in initial mill production rate, Q_0 , and mine cut-off grade, COG , such that net present value is maximized. Production rate and cut-off grade affect investment through mine stripping ratio and plant size, affect metal produced through production rate and mill feed grade, affect costs through stripping ratio, mill production rate, and mill feed grade, and affect reclamation cost via mine and mill capital cost.

Figure 1 provides a schematic of the Excel models (CRU February 2018).

Figure 1: Model Schematic



When taxes are applied, they influence cash flows via a net tax charged to each year of the project. The operator is then assumed to choose mill production rate Q_0 and cut-off grade COG such that after-tax net present value is maximized. These choices, when different from the No-Tax choices, represent tax-induced distortions that create DWL for the project. We track and take present values of the various tax streams so that the GT, FY, and FI can be calculated.

Data Source

- CRU
- Deloitte on-line tax summaries
- Ernst & Young on-line tax summaries
- Price Waterhouse Coopers on-line tax summaries

APPENDIX II. INDIVIDUAL COUNTRY HIGHLIGHTS

Here we report on the impacts of the resource tax regimes in effect as of 2018 within the respective countries of the LAC region. The results and conclusions presented here are drawn from the comprehensive set of individual country studies that were completed during our research. Most of these countries host both mining and petroleum activities, but subject them to different tax rates and instruments. Therefore, the results and conclusions vary by sector as well as by country. We take the individual countries in turn and distinguish between sectors as needed.



ARGENTINA

- Argentina recently reduced its corporate income tax rate from 35% to 30%, with plans to reduce it further, to 25%, in 2020. We have used a CIT rate of 30% for this exercise. It also reduced its dividends withholding tax from 45% to 7%. Our mining examples apply the 7% withholding tax.

- Argentina's petroleum fiscal regime creates incentives for an Operator to significantly reduce the rate of production from conventional oil fields, and to delay the application of enhanced recovery techniques. The potential loss of reserve volumes is substantial.

- The petroleum fiscal regime also somewhat impedes exploration; the maximum number of wells drilled prior to abandoning the search is cut by a third.

- These impacts potentially reduce the value of Argentina's conventional oil reserves by about 18%, assuming that oil export duties are levied at rates that are not indexed by inflation. Indexing the oil export duty stimulates the type of investment that would restore a large part of that lost value, primarily by encouraging investments in enhanced oil recovery.

- Argentina's shale oil and shale gas industry suffers both from high costs (relative to the U.S.) and high taxation. The tax regime fails to make adequate allowance for the current high cost level and renders many potential shale prospects uneconomic.

- Argentina's mining sector is not taxed as much as petroleum, resulting in below-average GT. From an efficiency standpoint it fares well in our analysis of Taca Taca and Veladero given the new, lower CIT rate and reduced dividend tax, though it is potentially more inefficient for less profitable projects given the fiscal system's regressivity. The CIT system itself is relatively efficient given its accelerated depreciation, though it does limit loss carryforwards to 5 years. This will penalize less profitable projects than those we analyze. The two distortionary additions to CIT are dividends taxes and royalties. In the two projects that we analyze the dividends tax and royalties share approximately equally in the incremental DWL beyond the minimal inefficiencies created by the CIT in the base case.

- The main profits royalty, at 3%, allows for deduction of operating costs, and is set at a relatively low rate. It will create investment inefficiencies. A second minor royalty at 1.5% is based on revenue and thereby creates production inefficiencies as well as investment inefficiencies.

- Our analysis shows that a proportionally higher combined royalty rate would severely increase project DWL, reflecting the potential production and investment distortions from these forms of royalty. Argentina has done well to limit these distortionary instruments to a low rate.

- The mining fiscal regime in Argentina is regressive, providing some stability of Government tax revenues during commodity price swings. While the high profitability of the two projects that we analyze results in modest GT and minimal DWL, the regressivity means that the observed low percent DWL would increase for projects that are less profitable than Taca Taca (No-Tax PVI = 2.95) and Veladero (No-Tax PVI = 2.29), since a general result of our analysis is that the higher the GT, the higher the project percent DWL. By our estimation, even at the relatively low base case royalty rates the DWL at Taca Taca rises from 2% to 5% as long-term copper prices fall by 50% and Taca Taca's GT increases to 62%.

- The regressivity affects Veladero to a greater degree, and this is the better project by which to judge Argentina's fiscal regime. Veladero's viability is more sensitive to metal price than Taca Taca as a result of its lower profitability. In a No-Tax case it is not viable at a long-term gold price that is 30% below the base case. Under taxation it is not developed by the Operator if gold prices fall by 20% from the base case, reflecting a DWL of 100% of the \$89 million of available No-Tax project rent at that price. This reveals the potential of the distortionary elements in Argentina's fiscal regime to do more damage than is shown in our base case results for Taca Taca, since it can halt the development of projects altogether should long-term prices drop.

- We have also analyzed the mining fiscal system that was in place in 2017. As shown in the regional analysis in Section 4.2, the new system is more efficient and has a lower GT than the old system. The efficiency comes in part from the significantly reduced dividends tax rate, which was as high as 45% for dividends in early project years where taxable income was shielded by depreciation.

- In September 2018 Argentina imposed a temporary export duty that is in effect an additional 7.5% gross royalty on mining companies.⁴³ We have not evaluated the effect of this royalty, or the effect of the ongoing fiscal instability, on project design and investment decisions.



BOLIVIA (petroleum only)

- Bolivia's existing petroleum fiscal regime creates large distortions in private investment decisions and field development decisions, relative to the No-Tax case.

- The distortions most likely to result from Bolivia's fiscal regime take the form of a much slower rate of extraction during the primary phase of production, delayed onset of enhanced oil recovery, and in the case of frontier areas, a very substantial (possibly total) reduction in the potential exploratory effort of all but the most promising prospects.

- Due to these distortions, DWLs under the existing fiscal regime range between 50% and 100% of the potential economic value of the underlying resources, which is extremely high relative to the fiscal regimes of most other countries.

43. "Yamana Gold says Argentina's new export tax could hurt cash flow," Reuters, September 12, 2018.

- Due to the heavy hand and aggressive structure of Bolivia's fiscal regime, which draws heavily from gross revenues rather than profits, the Government captures 90% or more of any profits generated by fields that enter the development stage. It is that prospect of high GT, however, that also has the potential to extinguish risky investments in exploration.

- Both the average and marginal tax rates on profits generated during the development phase (after exploration costs are sunk) are high by international standards, ranging around 90%. It should be noted that the high marginal tax rates create some of the weakest incentives for cost control within Latin America, since Operator is incentivized by the fact that most of any cost savings redound to the Government rather than shareholders (through taxation of the additional profits). They also impose on the Government more of the inherent price risk associated with crude oil, compared with most other Latin American countries, because most of the incremental profits and losses that occur as oil prices fluctuate will accrue to the Government.



BRAZIL

- Brazil's two petroleum fiscal regimes, Concession and PSC, perform quite differently due to differences that begin at the bid round, where rivals competing to win blocks set the terms on which Government revenues are generated. Under Concession, competition that leads to elevated bonus bids is innocuous. Under PSC, competition that leads to elevated Government profit shares is harmful.

- Both regimes impose tax burdens and disincentives that distort investments relative to the No-Tax case, and these distortions create substantial DWLs. Under the Concession regime, the distortions sacrifice roughly one-sixth of the potential value of the resources. Under the PSC regime, the losses are much higher, 24% in the case of a 50% Government profit share and up to 40% in the case of a 75% profit share.

- A higher Government profit share does not ensure higher Government profits. Indeed, the Brazilian government would capture larger profits with a 50% profit share than with 75%. High profit shares tend to backfire because they create distortions that reduce the size of the pie.

- Principal distortions take the form of less extensive exploration relative to the No-Tax case, slower extraction of the resource, delayed and less effective application of EOR, and lower ultimate recovery factors. All of these distortions are more severe under the PSC regime than under the Concession regime, and more severe under the PSC regime when aggressive bidding pushes the winning profit share rate from 50% up to 75%.

- Under the Concession regime with bonus bids typical of recent auctions, GT is roughly 75% of total full-cycle profits, in line with international benchmarks. Under the PSC regime with bonus bids typical of recent auctions, GT is much higher, approaching 90% and more, which is high by international standards.

- Both versions of Brazil's petroleum fiscal regime (Concession and PSC) are relatively neutral in their effect. They take roughly the same share of profits regardless of field size, profitability, or rate of production.

- Brazil's mining fiscal regime is highly complex, with overlapping taxation at the Federal and State level. It has also the potential to be highly inefficient, as shown in the case of Minas Rio.

- Within the CIT, which has a base tax rate of 15% and a 10% surtax, carryforwards of tax losses are limited to 30% of taxable income, which causes Brazil's CIT to be relatively distortionary towards investment. Worker profit sharing, which is assessed on the same basis as CIT, causes the effective CIT rate to be 34%.

- Royalties on net income and royalties on production are both distortionary. The production royalty rates vary by State. The production royalties in Minas Gerais are high and severely distort its large Minas Rio iron ore mine, which has the highest FI in the mining sample. The distortions at Corumba are lower due in part to the lower production royalty in Mato Grosso, where Corumba is located.

- Royalties that vary by State will cause locational distortions as well. Mines will preferentially locate in States where there are lower or no production royalties. We do not evaluate this distortion.

- Because of the royalty on production volume and the limited loss carryforwards, the regime is highly regressive for the two mines that we model. Regressivity causes severe distortions at marginal mines. Minas Rio is a case in point. The low profitability of Minas Rio (No-Tax PVI = 1.30) causes the regressive nature of the production royalty to impose a high base case GT and also severe distortions on the project. By our estimation the project could not survive a 10% decrease in iron ore price due to the high GT, causing a DWL of \$1.1 billion in No-Tax project rent at that lower price. Any reduction in GT, either through reduced rates of taxation or through improved project economics, would dramatically decrease the DWL at this project. For example, simply removing the State production royalty reduces the project DWL by \$458 million (from 20% DWL to 8% DWL) in the base case. Even then, an 8% DWL is the second highest in the mining sample.

- Corumba, a more profitable iron ore mine in Brazil, has less distortions due to its higher profitability (No-Tax PVI = 2.49). GT is also lower, in part due to the State's lower production royalty. Our analysis shows, however, that Corumba's geological and cost structure does not allow substantial design flexibilities that can create DWL in the face of aggressive taxation. As a result, the fiscal system when applied to Corumba shows good efficiency. The fiscal system does cause the project to become uneconomic at an iron ore price 30% below the base case price, causing a 100% DWL of \$150 million in project value at that price. But for higher prices DWL remains below 3%.

- The effectiveness of Brazil's fiscal regime should be evaluated on its potential for distortion, as reflected in our modeling of Minas Rio. By that, the regime is the most inefficient of the nine mining-country regimes that we studied.



CHILE (mining only)

- Chile's mining fiscal regime is the most efficient of those studied. It is royalty-free and relies only on corporate income taxes and income surtaxes. It is the only fiscal system of the nine countries reviewed that has this property.

- Within the CIT there are no limits to loss carryforwards, and accelerated depreciation is allowed. This makes the corporate income tax system amongst the most efficient of those studied. Because of the progressive rates of taxation in the special mining tax the fiscal system is almost neutral with respect to commodity prices and project profitability.⁴⁴

- The special mining tax provides a relatively minor ~15 percentage point increase to GT for the two Chilean projects that we modeled. As a result, the two projects have the lowest total GT of those studied.

- Because the special mining surtax does not allow accelerated depreciation deductions, it is more distortionary than the CIT. Raising the rate of surtax by 30 percentage points causes the DWL at Zaldivar to rise from 1.4% to 14.3%. Raising the CIT by the same amount only causes DWL to rise by only 7.2%.

- Of the two Chilean projects studied, Zaldivar is marginal, not being able to withstand a price decrease of 30% in the absence of taxes. The distortionary effects of the income tax system cause the project not to be built at a price decrease of 20%, causing \$97 million in DWL at that price. This indicates that there is room for improvement in the Chilean system. One recommendation would be to allow the special mining surtax to be calculated based on accelerated depreciation.

- Nevertheless, the fact that this marginal project only has a DWL of 1.4% in the base case is indicative of the superiority of this fiscal regime compared with the others studied.



COLOMBIA

- Colombia's petroleum fiscal regime creates incentives for Operator to significantly reduce the rate of production of both oil and gas, to delay the application of enhanced recovery techniques, and to reduce the volume of hydrocarbons recovered over the life of the field.

- The fiscal regime also serves to impede exploration; the maximum number of wells drilled prior to abandoning the search is cut in half.

- These impacts reduce the overall value of Colombia's upstream hydrocarbon endowment by about 15% in the case of onshore gas, and by 30% in the case of offshore oil—although the latter is reduced to 11% if the special Free Trade Zone provisions are employed.

- Despite the relatively high number of distinct taxes and levies imposed on upstream development, Colombia's GT is no higher than in some other countries that apply much simpler forms of taxation.

- Colombia's petroleum fiscal regime is regressive. The Government captures a smaller share of profits on the most valuable fields and a higher share of profits on the least valuable fields.

44. Whenever there is a base tax that is not neutral it is impossible to create complete neutrality through the addition of a progressive tax. This is evident by the fact that Government Take rises to 100% just before the point where the price is so low as to make the project unviable from the Operator's perspective.

- Colombia's simple mining fiscal regime includes a corporate income tax, a dividend tax and a royalty on net operating income whose rate varies by commodity. The royalty rate is relatively low for gold (4%), limiting the distortions from the royalty. It is high for nickel (12%), but Cerro Matoso's extreme profitability (pre-tax PVI = 3.69) limits the DWL from this due to the regressive nature of the taxation, causing a low base-case GT for this project. Unprofitable projects would be severely affected by this level of taxation (see Gramalote below).

- Like Chile, Colombia has no taxes that distort both production and investment. Its CIT loss carryforwards are generous, making the CIT relatively efficient.

- The regime is regressive as a result of the royalty and dividend tax structure, and so less profitable projects will see increased GT and increased DWL. Gramalote, which is a marginal gold project, provides an example of this. Its GT, at 78%, is much higher than that of the more profitable Cerro Matoso (52%). The DWL for Gramalote project rises from 4.7% to 100% for a 10% decrease in gold price, since at that price the tax system prevents the project from moving forward. \$321 million in pre-tax project rent is lost. At base case prices a 5 percentage point increase in the profits royalty would increase the DWL from 4.7% to 9%, reflecting the inefficiency of this tax instrument. Raising it by 10 percentage points, to 14% (similar to the nickel royalty at Cerro Matoso), would cause the project not to be built, at a loss of \$767 million in pre-tax rents.

- Colombia's regime therefore has the potential for significant project distortions at low margin projects, though the regime seems to be relatively efficient for higher-margin projects as a result of their low GT arising from the tax regime's severe regressivity.⁴⁵



DOMINICAN REPUBLIC

(mining only)

- Dominican Republic's mining fiscal regime includes a CIT regime that is exemplary due to its infinite allowance for loss carryforwards, without limitation. To this the country adds a worker profits sharing tax, an asset tax, and a royalty on gross revenues. The additions to CIT combine to create a highly regressive tax regime with a potential for high tax inefficiency.

- Pueblo Viejo is a profitable gold project whose base case DWL is 3.3%, with a below-average FI of 6%. At first glance this may be seen to indicate an efficient tax system. But as project margins narrow (as implemented in our model by a decrease in metal price) the DWL rises substantially due to the rising GT associated with Dominican Republic's tax regressivity. At a 40% drop in gold price the DWL rises to 26%, and at a 50% drop in price an otherwise viable project (NPV = \$141 million) is terminated as a result of the tax regime's high GT.

- Dominican Republic's gross revenue royalty is highly inefficient, creating 18 cents in DWL for each dollar it raises at Pueblo Viejo, three times the FI of the entire tax package. The country would be well served to eliminate the gross royalty and maintain its fiscal revenues through a CIT surtax similar to Chile's.

45. Chen and Perry (2015) have previously noted the high regressivity of the Colombian mining fiscal regime.



ECUADOR

- Ecuador's production-sharing rates escalate as the rate of production in the field rises. This creates a strong incentive for Operator to limit investment and avoid the higher and more onerous PSC tiers. The result: less oil is produced, and it is extracted more slowly, which creates a substantial DWL for society.
- The imposition of a special tax on incremental oil revenues created at high prices tends to backfire. The volume and rate of production are both further slowed by this provision, which causes Government NPV to decline relative to the case without the special tax.
- Although more lenient, the legacy PSC fiscal terms that date back to 1994 produce outcomes that in many respects are more favorable than the current regime. In the case of Sur Oriente oil basin, the old regime would generate more exploration, reduce DWLs substantially, and generate a higher Government NPV than the updated PSC regime with price cap and special tax.
- Ecuador's legacy 1994 PSC regime also performs well regarding offshore gas. It would potentially generate twice as much exploration as the updated regime and therefore deliver almost the same Government NPV.
- Attempts to make Ecuador's PSC regime more progressive, by instituting a finer and more substantial graduated production-sharing schedule might backfire. This is because Operator's attempt to increase production by more intensive investment and development triggers higher taxes. It is in Operator's interest to settle for a slower extraction, even though that reduces total revenue, because it also reduces the effective tax rate and generates higher overall Operator NPV.
- Under the PSC variants explored here, GT ranges between 60%-88%. The upper end of this range clearly meets Government's stated objective of capturing 75% of the rent generated through private investment. But this measure of Government welfare is flawed by ignoring the impact of distortions that tend to reduce the total size of the pie to be shared.
- Of the four small mines in our sample, which tend to have reduced inefficiencies from a given level of taxation, Ecuador's Fruta del Norte has by far the highest FI.
- Ecuador's mining fiscal regime includes a relatively distortive corporate income tax, a high worker profit tax, a dividend tax, an asset tax, royalties on gross revenues that vary by commodity, and a windfall profits tax. The CIT is relatively inefficient because it does not allow accelerated depreciation, carryforwards of tax losses are limited to 25% of taxable income, and carryforwards are limited to 5 years. All of this combines to cause Ecuador's CIT to be the most distortionary towards investment of any of the countries modeled.
- Fruta del Norte appears to have a relatively inflexible project design. This causes less distortion for this fiscal regime than would likely be the case for other projects. Even so, DWL does rise to 7.5% as the gold price falls by 30%, and at a 40% price drop the project's No-Tax NPV of \$440 million is lost due to negative Operator NPV.
- These distortions would be higher for a flexible design project, and so Ecuador's fiscal regime could be more inefficient for other projects.

- Ecuador is the only mining economy studied to have a windfall profits tax. It is designed as a windfall revenue tax, being based on revenues rather than profits. Uniquely to this regime, the tax causes GT to increase when gold prices rise sufficiently. Kinross Gold Corp., Fruta del Norte's previous owner, reportedly halted development at the project in 2013 and took a \$700 million write down as a result of its inability to negotiate downwards the windfall profits tax.⁴⁶

- The windfall profits tax does not bite in Fruta Del Norte's base case because we do not model price uncertainty over the life of the project. It does have minor distortionary effects at higher base case prices. The effect is not substantial given the higher profit margins at those prices. In the case of Fruta del Norte, at a 50% higher gold price the FI of the windfall profits tax is only 1%. Equivalently, the 75% GT at a 50% higher gold price has an overall FI of only 3.3%.



GUYANA (petroleum only)

- Guyana's existing fiscal regime creates relatively little distortion in private investment decisions and field development decisions, relative to the No-Tax benchmark.

- The distortions most likely to result from Guyana's fiscal regime take the form of a somewhat slower rate of extraction during the primary phase of production, delayed onset of enhanced oil recovery (by only 2-4 years), and in the case of shallow water fields, a substantial reduction (by one-third) in the potential exploratory effort.

- Despite these distortions, DWLs under the existing fiscal regime in no case exceed 6% of the potential economic value of the underlying resources, which is small relative to the fiscal regimes of most other countries.

- Despite the relatively light impact of Guyana's fiscal regime on the Operator, the Government is still able to capture nearly two-thirds of full-cycle total profits generated in the upstream sector.

- Both the average and marginal tax rates on profits generated during the development phase (after exploration costs are sunk) are low by international standards, ranging between 52% and 57%. GT is accordingly also low by international standards. It should be noted, however, that the low marginal tax rates create some of the strongest incentives for cost control within Latin America, since Operator is incentivized by the fact that roughly half of any cost savings rebound to shareholders rather than Government (through taxation of the additional profits). They also impose on the Government less of the inherent price risk associated with crude oil, compared with most other Latin American countries.

46. Reuters market news, "Canada's Kinross Cancels Ecuador Gold Project," June 10, 2013.



MEXICO

- Both versions of Mexico's existing petroleum fiscal regime (concession and PSC) rely heavily on competition among bidders to establish royalty rates and profit shares. But high royalties and profit shares are a disincentive for investment that ultimately detracts from the value of the resources. The highest royalty rate is not the best royalty rate—which brings into question whether firms should be required to compete on this basis. The same is true of the profit share.

- The distortions most likely to result from Mexico's fiscal regime take the form of a much slower rate of extraction during the primary phase of production, moderately delayed onset of enhanced oil recovery, and in the case of the PSC system, a very substantial (possibly total) reduction in the potential exploratory effort.

- Depending on the royalty rates and profit shares that result from the competitive bidding, DWLs can range anywhere between 10% and 100% of the potential economic value of the underlying resources. Mexico therefore must trust the self-restraint of the bidders it is attempting to attract.

- Mexico captures nearly as much profit from a PSC contract that conveys a relatively low percentage of profit oil to the Government, as it does from a similar contract that conveys a higher percentage to the Government. This paradox is explained by the fact that Operator has a strong incentive to increase investment and accelerate revenues under the former (less stringent) contract. This delivers Government's profit share earlier, thereby increasing its present value.

- Under the PSC system, both the average and marginal tax rates on profits generated during the development phase (after exploration costs are sunk) are high by international standards, approaching 90%. It should be noted that the high marginal tax rates create some of the weakest incentives for cost control within Latin America, since Operator is incentivized by the fact that most of any cost savings redound to the Government rather than shareholders (through taxation of the additional profits). They also impose on the Government more of the inherent price risk associated with crude oil, compared with most other Latin American countries, because most of the incremental profits and losses that occur as oil prices fluctuate will accrue to the Government.

- Marginal tax rates under the concession form of license are lower (60%-70%) and in line with international norms.

- Mexico's mining fiscal regime includes a CIT, worker profit sharing, a variable profits royalty, a dividend tax, and an asset tax. The CIT regime allows accelerated depreciation and limits loss carryforwards to 10 years. The portfolio of taxes causes the system to be regressive.

- Mexico is another case where one must look at the potential for the tax system to distort production and investment. Mexico's Noche Buena gold mine is one of the least distorted in our sample, and if only this mine were modeled one might see Mexico's fiscal system as representing best practice. Yet the same system is highly distortive of the Piedras Verdes copper mine, reducing investment and production by 41% and reducing reserves by 33%.

- Our analysis shows that Noche Buena is a mine with very little design flexibility. As a result of the project's low margins, GT under this regressive tax regime is relatively high, at 74%. But because of the inflexible project design DWL and FI remain low no matter what price or royalty scenario we apply to the project. The only case where DWL rises is at a 20 percentage point lower gold price, where the tax system makes the project uneconomic for the private Operator. This is because the tax system does not allow full recapture of initial investment, as would a rent tax. At that point DWL rises to 100% of the \$86 million in project rent foregone.

- Piedras Verdes, on the other hand, has considerable design flexibility in the face of taxes. Base case FI, at 16%, is twice the sample average. As the profit margin at the project declines via a 20 percentage point price decrease, DWL rises from the base case level of 9% to 18%, and GT rises from 66% to 78%. FI at this point is 25%. At a further 10 percentage point price drop the tax system causes the private Operator to forego what would otherwise be a viable project. Again, at this point, DWL rises to 100%, with \$10 million in project rent foregone.

- This is another indication that to evaluate a fiscal regime one must look at its potential for inefficiency across different projects. As a result of the relatively large number of taxes that do not allow across different projects deductions of investment via depreciation, Mexico's regime is heavily weighted towards distortionary taxes that have little effect on the small and inflexible Noche Buena project, but the potential to cause large inefficiencies for flexible projects like Piedras Verdes.



PANAMA (mining only)

- Panama's corporate income tax does not allow accelerated depreciation and limits loss carryforwards to 5 years. It has a dividend tax and an asset tax. Panama also has a royalty on gross income. This results in a highly regressive fiscal regime and, as with any regressive regime, in the potential for large inefficiencies at low margin projects.

- This potential for inefficiency can be seen using our model of Cobre Panama. Cobre Panama, a relatively profitable project, has a base case DWL of 5.4% and a slightly above-average FI of 10%. That DWL rises rapidly when copper prices fall and GT increases (see Figure 7.1). For a 30% decrease in price the DWL rises to 54%. For a 40% drop in copper price the project is stalled, even though in the absence of taxes it could withstand a 50% drop in price.

- The gross royalty is highly inefficient as a taxation mechanism, creating 21 cents in DWL for each royalty dollar raised from the Cobre Panama project. By simply removing that tax the DWL at Cobre Panama would be halved.



PERU

- We have assumed in our analysis that oil and mining companies avail themselves of a stability agreement, increasing the CIT by two percentage points to 31.5% per the terms of such agreements. Investments made without resort to the stability agreement would, under Peruvian law, qualify for a 2 percentage point lower corporate income tax rate, but would face increased uncertainty regarding future changes in that rate.
- Peru's royalty-based petroleum fiscal regime is a blunt instrument that creates significant distortions at both the exploration and development stages of investment. Because royalties are levied on gross revenues, rather than profits or economic rents, such distortions are not unexpected, but they are large. The largest distortions impact potential investments in the yet-to-be developed oil sector.
- Although the R-Factor increases the royalty rate as revenues accumulate, this does not result in progressive taxation. Government captures about the same share of rents on large and more lucrative gas fields than on smaller and more marginal gas fields. As applied to oil fields, the system is actually regressive. This result is due to two aspects of the R-factor royalty system. First, royalties are not levied on profits or rents and royalties per se represent a regressive form of taxation. Second, the criterion for increasing the royalty rate (R-Factor) is a poor measure of a field's profitability. Even sub-economic fields may eventually produce high R-Factors as revenues continue to accumulate, which triggers for the Government a larger share of an unprofitable revenue stream.
- A simple modification to the current Peruvian fiscal regime, basing the sliding-scale royalty rate on IRR (which is a better measure of profitability) rather than the R-factor, would produce better outcomes for both the Government and Operator. Economic distortions would be reduced, oil and gas would be extracted from developed fields more quickly, and Government and Operator profits would increase.
- The IRR-based royalty regime does not solve all problems with the existing regime, and this is due to the fact that taxes would still be levied as a percentage of gross revenues rather than profits or economic rents. Although the IRR-based regime reduces DWLs by increasing the level of investment at the development stage and therefore increasing the rate of extraction, it still imposes disincentives on exploratory investments.
- Both forms of the sliding-scale royalty regime create strong disincentives for investments in enhanced resource recovery, which may be delayed by 20-30 years in the case of oil fields—or in some cases eliminated entirely. This distortion is smaller in the case of gas fields, but still significant.
- GT under either form of the royalty regime is well within the international norm (75%-80%), but this measure of Government welfare is flawed by ignoring the impact of distortions that tend to reduce the total size of the pie to be shared.
- Peru's complex mining fiscal regime is comprised of a corporate income tax with a 50% limit on loss carryforwards, a worker profit tax, a CIT surtax, a dividend tax, and an asset tax. The CIT surtax is progressive. Even so, the overall fiscal regime is highly regressive, causing lower margin projects to have higher DWL.
- The regressivity is because of the high tax burden caused by dividend and asset taxes that are in addition to the relatively low CIT and that do not allow recovery of investment. Because of this regressivity it is likely that the regime is curtailing or severely distorting low margin projects.

- The Constancia copper project's base case decrease in investment (26%) and loss of reserves (19%) reflects these tax distortions given its relatively low profitability (pre-tax PVI = 1.66) and high GT (64%). Though its base case DWL is just above average, at 5.4%, that DWL rises to 24% for a 20% drop in copper price. Below that the tax system causes the Operator to forego the project.

- Lagunas Norte is a large gold project that has high profitability (pre-tax PVI = 3.29, No-Tax rent of \$5.2 billion) and correspondingly lower GT (53%) given the regressivity of Peru's tax regime. It appears to be relatively inflexible in project design given its extraordinarily low base-case DWL (0.5%) that does not change substantially as we vary royalty rates and prices. Still, at a 40 percentage point lower price the tax system causes the project to be uneconomic for the Operator, with a 100% DWL of \$679 million in lost project rent.

- Once again, we evaluate Peru's fiscal regime based on its potential for high tax-inefficiencies at projects like Constancia.



TRINIDAD & TOBAGO

(petroleum only)

- Trinidad & Tobago's concession regime acts to deter exploration somewhat relative to the No-Tax benchmark. The number of viable exploration wells is reduced by one-third.

- The concession regime poses a much stronger deterrent to timely production and implementation of EOR. Production rates are cut almost in half relative to the No-Tax case and EOR is substantially delayed. The volume of reserves is thereby reduced, and the value of those reserves reduced even more due to the delayed sales.

- The Government can be expected to capture roughly 70%-75% of available profits from onshore oil fields developed under the concession regime.

- Trinidad & Tobago's PSC regime, as applied to offshore gas resources in shallow water, may be too aggressive. Although the regime captures some 75%-85% of profits generated at the development stage, it doesn't leave enough to compensate for Operator's expense incurred at the exploration stage, including the risk and expense of dry holes. This poses a very strong deterrent to offshore exploration.

- The PSC regime applied to shallow water resources also poses a very strong deterrent to the intensity of resource development, rate of production, and application of EOR. The end result is a substantial reduction in total recovery of resource-in-place relative to the No-Tax case.

- The special incentives offered to deep water projects are critical. DWLs incurred in field development are mostly eliminated by these provisions, although the strong deterrent to exploration remains if the sliding-scale profit-sharing schedule is not indexed for inflation.

- But the special deep water incentives are costly in terms of reduced GT, which may dip below 50% in some cases. This is low relative to most Latin American peers.



VENEZUELA (petroleum only)

- Venezuela's fiscal regime creates incentives for Operator to significantly reduce the rate of production from heavy oil fields, and to delay or shelve the application of enhanced recovery techniques. The potential loss of reserve volumes is substantial.
- The fiscal regime also somewhat impedes exploration; the maximum number of unsuccessful wells drilled prior to abandoning the search is cut by a third.
- These impacts potentially reduce the value of Venezuela's remaining heavy oil reserves by about 61%. Much of this impact stems from the country's Alternative Minimum Tax (AMT), which reserves at least 50% of gross oil revenues for the Government. Elimination of the AMT would not only mitigate investment distortions and restore approximately half of the lost reserves; it would also increase the absolute amount of profits captured by the Government.
- Despite the substantial impediments to international investment that are posed by Venezuela's fiscal regime, much larger impediments devolve from the current social, economic, and political instability within the country. It will take more than reform of the petroleum tax system to restore the confidence of outside investors.

REFERENCES

- Beer, Sebastian, and Jan Loeprick. "Taxing Income in the Oil and Gas Sector – Challenges of International and Domestic Profit Shifting." *Energy Economics*, 61 (2017), 186-198.
- Berg, Magnus, Øyvind Bøhren, and Erik Vassnes. "Modeling the Response to Exogenous Shocks: The Capital Uplift in Petroleum Taxation." *Energy Economics*, 69 (2018), 442-455.
- Bjørnland, Hilde C., and Leif A. Thorsrud. "Boom or Gloom? Examining the Dutch Disease in Two-Speed Economies." *The Economic Journal*, 126 (2016), 2219-2256.
- Blake, Andon J., and Mark C. Roberts. "Comparing Petroleum Fiscal Regimes under Oil Price Uncertainty." *Resources Policy*, 31 (2006), 95-105.
- Blake, Andon J. "Investigating Tax Distortions: An Applied Model of Petroleum Exploration and Extraction Decisions." *Natural Resource Modeling*, 26:1 (2013), 66-90.
- Boadway, R., and N. Bruce. "A General Proposition on the Design of a Neutral Business Tax." *Journal of Public Economics*, 24 (1984), 231-239.
- Boadway, R., and M. Keen. "Theoretical Perspectives on Resource Tax Design." In *The Taxation of Petroleum and Minerals: Principles, Problems and Practice*, P. Daniel, M. Keen, and C. McPherson (eds.), New York: Routledge (2010), 13-74.
- Boadway, R., and M. Keen. "Rent Taxes and Royalties in Designing Fiscal Regimes for Nonrenewable Resources." In *Handbook on the Economics of Natural Resources*, R. Halvorsen and D.F. Layton (eds.), Cheltenham, UK: Edward Elgar (2015), 97-139.
- Bohn, Henning, and Robert T. Deacon. "Ownership Risk, Investment, and the Use of Natural Resources." *American Economic Review*, 90:3 (2000), 526-549.
- Bond, Stephen R., and Michael P. Devereux. "On the Design of a Neutral Business Tax under Uncertainty." *Journal of Public Economics*, 58:1 (1995), 57-71.

- Bradley, Paul G. "On the Use of MAP for Comparing Alternative Royalty Systems for Petroleum Development Projects." *The Energy Journal*, 19:1 (1998), 47-81.
- Bradley, Paul G., John F. Helliwell, and John R. Livernois. "Efficient Taxation of Resource Income: The Case of Copper Mining in British Columbia." *Resources Policy*, September (1981), 161-170.
- Brown, E. Cary. "Business-Income Taxation and Investment Incentives." In *Income, Employment and Public Policy: Essays in Honour of Alvin Hansen*, New York, Norton (1948), 300-316.
- Cairns, Robert D. "Reform of Exhaustible Resource Taxation." *Canadian Public Policy*, February (1985), 649-658.
- Cairns, Robert D., and Graham A. Davis. "On Using Current Information to Value Hard-Rock Mineral Properties." *Review of Economics and Statistics*, 80:4 (1998), 658-663.
- Cairns, Robert D., and James L. Smith. "The Green Paradox, A Hotelling Cul de Sac." *Economics of Energy and Environmental Policy*, 8:2 (2019), 161-180.
- Chen, Duanjie, and Jack Mintz. "Repairing Canada's Mining-Tax System to be Less Distorting and Complex." *University of Calgary SPP Research Papers*, 6:18 (2013).
- Chen, Duanjie, and Guillermo Perry. "Mining Taxation in Colombia." *University of Calgary SPP Research Papers*, 8:7 (2015).
- CRU. "Mining Tax Regimes in Latin America-Phase II: Cases Selection and Preliminary Technical Data Analysis." October 26, 2017.
- CRU. "Mining Tax Regimes in Latin America-Phase II: Cases Selection and Methodological Handbook." February 19, 2018.
- CRU. "Mining Tax Regimes in Latin America-Phase II: Modeling Results." October 13, 2018.
- Daniel, Philip, Michael Keen, and Charles McPherson (eds.). *The Taxation of Petroleum and Minerals: Principles, Problems, and Practice*. New York: Routledge (2010a).
- Daniel, Philip, Brenton Goldsworthy, Wojciech Maliszewski, Diego Mesa Puyo, and Alistair Watson. "Evaluating Fiscal Regimes for Resource Projects: An Example from Oil Development." In *The Taxation of Petroleum and Minerals: Principles, Problems, and Practice*, P. Daniel, M. Keen, and C. McPherson (eds.), New York, NY: Routledge (2010b), 187-240.
- Davis, Graham A., and Eugenio L. Domínguez. "A Discounted Cash Flow Model of Tax Avoidance and Distortions in Mining Projects." May 16, 2017.
- Davis, Graham A., and Diderik Lund. "Taxation and Investment Decisions in Petroleum." *The Energy Journal*, 39:6 (2018), 189-208.

- Deacon, Robert T. "Taxation, Depletion, and Welfare: A Simulation Study of the U.S. Petroleum Resource." *Journal of Environmental Economics and Management*, 24 (1993), 159-187.
- Ellis, Gregory M., and Robert Halvorsen. "Estimation of Market Power in a Nonrenewable Resource Industry." *Journal of Political Economy*, 110:4 (2002), 883-899.
- Fane, G. "Neutral Taxation under Uncertainty." *Journal of Public Economics*, 33 (1987), 95-105.
- Garnaut, Ross, and Anthony Clunies Ross. "Uncertainty, Risk Aversion, and the Taxing of Natural Resource Projects." *The Economic Journal*, 85:338 (1975), 272-287.
- Gordon, Richard L. "Conservation and the Theory of Exhaustible Resources." *Canadian Journal of Economics and Political Science*, 32:3 (1966), 319-326.
- Harchaoui, Tarek M., and Pierre Lasserre. "Testing the Impact of Taxation on Capacity Choice: A 'Putty Clay' Approach." *Journal of Public Economics*, 56 (1995), 377-411.
- Helliwell, John F. "Effects of Taxes and Royalties on Copper Mining Investment in British Columbia." *Resources Policy*, March (1978), 35-44.
- International Monetary Fund. "Fiscal Regimes for Extractive Industries: Design and Implementation." Fiscal Affairs Department (2012).
- Kemp, Alexander G., and David Rose. "The Effects of Petroleum Taxation in the United Kingdom, Norway, Denmark, and the Netherlands: A Comparative Study." *The Energy Journal*, 6 (Special Tax Issue) (1985), 109-123.
- Land, Bryan C. "Resource Rent Taxes: A Re-Appraisal." In *The Taxation of Petroleum and Minerals: Principles, Problems, and Practice*, P. Daniel, M. Keen, and C. McPherson (eds.), New York, NY: Routledge (2010), 241-262.
- Lilford, Eric. "Quantitative Impacts of Royalties on Mineral Projects." *Resources Policy*, 53 (2017), 369-377.
- Litzenberger, Robert H., and Nir Rabinowitz. "Backwardation in Oil Futures Markets: Theory and Empirical Evidence." *Journal of Finance*, 50:5 (1995), 1517-1545.
- Lund, Diderik. "Petroleum Taxation under Uncertainty: Contingent Claims Analysis with Application to Norway." *Energy Economics*, January (1992), 23-31.
- Lund, Diderik. "State Participation and Taxation in Norwegian Petroleum: Lessons for Others?" *Energy Strategy Reviews*, 3 (2014a), 49-54.

- Lund, Diderik. "How Taxes on Firms Reduce the Risk of After-tax Cash Flows." *FinanzArchiv*, 70 (2014b), 567-598.
- Lund, Diderik. "Increasing Resource Rent Taxation When the Corporate Income Tax is Reduced?" Memorandum No. 3/2018, Department of Economics, University of Oslo (2018a).
- Lund, Diderik. "Current Issues in Taxation of Nonrenewable Natural Resources." Unpublished manuscript, University of Oslo (2018b).
- Manzano, Osmel E., Fernando Navajas, and Andrew Powell, eds. *The Economics of Natural Resources in Latin America*. Routledge (2017).
- Mining Association of Canada. *Comparative Review of the Rate of Royalty in the Canada Mining Regulation, as Relates to National and International Competitiveness* (2008).
- Mintz, Jack, and Duanjie Chen. "Capturing Economic Rents from Resources through Royalties and Taxes," University of Calgary SPP Research Papers, 5:30 (2012).
- Mitchell, Paul. "Taxation and Investment Issues in Mining." In *Advancing the EITI in the Mining Sector: A Consultation with Stakeholders*, C. Eads, P. Mitchell, and F. Paris (eds.), Extractive Industries Transparency Initiative (2009), 27-31.
- Nakhle, Carole. *Petroleum Taxation: Sharing the Oil Wealth: A Study of Petroleum Taxation Yesterday, Today, and Tomorrow*. London and New York, Routledge (2008).
- Nystad, Arild N. "Petroleum Taxes and Optimal Resource Recovery." *Energy Policy*, August (1985), 381-401.
- Otto, James, Craig Andrews, Fred Cawood, Michael Doggett, Pietro Guj, Frank Stermole, John Stermole, and John Tilton. *Mining Royalties: A Global Study of Their Impact on Investors, Government, and Civil Society*. The World Bank, Washington DC (2006).
- Poterba, James. "The Challenge of Tax Reform and Expanding the Tax Base." *Economic and Social Review*, 41:2 (2010), 133-148.
- Samis, Michael R., Graham A. Davis, and David G. Laughton. "Using Stochastic Discounted Cash Flow and Real Option Monte Carlo Simulation to Analyse the Impacts of Contingent Taxes on Mining Projects." *Proceedings, AusIMM Project Evaluation Conference*, Melbourne, Australia, (2007), 127-137.
- Slade, Margaret E. "Tax Policy and the Supply of Exhaustible Resources: Theory and Practice." *Land Economics*, 60:2 (1984), 133-147.
- Smith, Ben. "The Impossibility of a Neutral Resource Rent Tax." *Working Papers in Economics and Econometrics* No. 380 (1999), Australian National University.

- Smith, James L. "Petroleum Prospect Valuation and the Option to Drill Again." *The Energy Journal*, 26:4 (2005), 53-68.
- Smith, James L. "Issues in Extractive Resource Taxation: A Review of Research Methods and Models," *Resources Policy*, 38 (2013), 320-331.
- Smith, James L. "A Parsimonious Model of Tax Avoidance and Distortions in Petroleum Exploration and Development." *Energy Economics*, 43 (2014), 140-157.
- Tordo, Silvana. *Fiscal Systems for Hydrocarbons: Design Issues*. Washington: World Bank (2007).
- Total Exploration and Production, 2009. "EOR: Maximizing Recovery Factors," *The Know How Series*. Total S.A., Paris. https://www.bomobile.total.com/uploads/gestion_media/TOTAL_EORbis-GB2.pdf.
- Zhang, Wei, and C.-Y. Cynthia Lin Lawell. "Market Power in Nonrenewable Resource Markets: An Empirical Dynamic Model." *Land Economics*, 93:1 (2017), 74-86.

