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Measuring the Effects of an Optimization in Brazilian Environmental Regulation in the Oil and Gas Sector

Thiago Costa Monteiro Caldeira, Mathias Schneid Tessmann*, Rogerio Boueri Miranda, Danny de Castro Soares

Brazilian Institute of Education, Development and Research - IDP, Brazil. *Email: mathias.tessmann@idp.edu.br

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ABSTRACT

This paper aims to investigate the oil and gas sector in Brazil by assessing how much its results would improve if there were an optimization in environmental regulation. To this end, data from 5 companies traded on the São Paulo stock exchange, the capital asset price model, and input-output matrices are considered. The difference between the CAPM betas of Brazilian firms and firms from benchmark countries is used to estimate the weighted average cost of capital with more efficient environmental governance in the country, which is then used to perform simulations in the input-output matrices. The results indicate that the destruction of the value of investments can vary between 33 and 110 billion reais in 5 years for delays in licensing of 6 and 24 months, respectively, and negative effects on GDP can reach 70 billion reais in 5 years for delays of 6 months in the licensing process. These findings underscore the importance of effective environmental governance for the country and are valuable for policymakers, investors, and supply chain agents who consider the sector in their decision-making.

Keywords: Oil and Gas, Capital Asset Price Model, Input-Output Matrix, Brazilian Oil and Gas Sector
JEL Classifications: Q48, K32, N76, O13

1. INTRODUCTION

The oil and gas sector in Brazil is structured in different interdependent links. The upstream level includes research, exploration, and production of oil and natural gas; the midstream includes processing, treatment, and movement infrastructure; while the downstream includes the processing, refining, and distribution of its derivatives. The oil and natural gas production phase occurs after research activities and exploratory campaigns to verify the presence of hydrocarbons in certain areas and the subsequent assessment of the feasibility of their exploration. That is, before production begins, investments are made and risks are assumed to achieve this.

Oil and natural gas production can occur in different environments, onshore and offshore, in the latter case, in shallow and deep waters (post- and pre-salt). In addition, some fields may be specific to natural gas or involve the extraction of both types of hydrocarbons. There are currently 441 oil and natural gas fields in production in the country, in 17 different basins, in 10 states of the Federation. Of the total oil produced in the country, 77.09% comes from fields contracted under the concession model, 14.03% in the sharing format and 8.88% in the onerous transfer modality, while 49.54% comes from fields in the pre-salt environment, 45.53% in the post-salt and 4.93% in onshore fields, operated by more than 40 companies.

Until 1998, only Petrobras produced oil and natural gas in Brazil, but in 1997 a constitutional amendment regulated the participation of other companies in extraction and production activities, which significantly changed the functioning of the sector and began to be structured based on the policy formulated by the National Energy Policy Council (CNPE) and the regulation of the National Agency of Petroleum, Natural Gas and Biofuels (ANP).

Over the past 25 years, the average oil production in Brazil was 2,202,267.48 bbl/d and 83,624 million m^3/d of natural gas. In 2000, oil production in the country was around 1,230,600.42 bbl/d and 36,326 million m^3/d of natural gas. It took the country 10 years to surpass the 2MM bbl/d mark, which, in 2010, produced 2,054,343.29 bbl/d and 62,834 MM m^3/d of natural gas. The following 10 years were also marked by constant growth in oil production, especially due to the increase in volume in pre-salt fields; the 3 million bbl/d mark of oil was reached for the 1st time in December 2019. Over the last 4 years, the sector has continued to show stability in the growth of the volume produced; in November 2023, the sector produced 3,677,940.33 bbl/d of oil, representing the largest volume ever produced.

On the other hand, there are signs of a reduction in the growth process observed in recent years, especially due to the beginning of the decline of some pre-salt fields, such as the Tupi field, the largest in terms of volume among these, which began the decline phase of its production increase in 2023. The oil and gas production fields in the pre-salt environment were and are fundamental to the development of the sector, expanding investments, technologies, and the competitiveness of production in the country. Their importance is reflected in the evident difference in production growth in these fields compared to those in the post-salt and onshore areas.

Another possible option for increasing oil and natural gas production in Brazil is the revitalization of mature and marginal fields, in order to increase the field recovery factor and increase their marginal production. There are 211 marginal production fields, of which 90% are located onshore. In addition, of the 206 mature fields, 85% are also onshore, according to information from the ANP. However, oil production from mature and marginal fields comes mostly from offshore basins, with 85% of total production in 2024 coming from offshore fields.

About natural gas, 60% of production from mature fields is onshore, with the North and Northeast regions concentrating a significant portion of mature and marginal fields, with more than 180 fields in onshore production. In the offshore sector, the state of Rio de Janeiro stands out with 16 mature fields that, in June 2024, exceeded 240 thousand bpd of oil production, representing approximately 70% of the country's total production (FIRJAN, 2024).

However, the production recorded by fields classified as mature has shown a downward trend in recent years, with a reduction of around 49% between 2018 and 2024. The potential of these fields to increase oil and gas production in the country is due to Brazil's low recovery factor (around 11%) compared to the world average (around 30%). Norway, for example, has a recovery factor of around 47%, and for some fields, this percentage has reached values of around 60% (FIRJAN, 2024).

Thus, considering only mature and marginal fields, if these reach the global average recovery rate of 30%, an additional production of approximately 4.8 billion barrels from these fields is estimated, which could result in more than R$92 billion in royalties. In a more optimistic scenario, where the Brazilian oil industry approaches Norway's performance, with a recovery rate of 47%, the potential for additional production could exceed 12 billion barrels, resulting in the payment of approximately R$230 billion in royalties (FIRJAN, 2024).

For comparison purposes, in 2022 it was reported that the proven oil reserves of pre-salt fields are in the order of 11,478 (MM/bbl), the highest number ever recorded since the beginning of operations in this environment, and consisted of a 19.30% increase in the proven reserves in 2021 (ANP, 2023). Incentive policies to increase production in mature and marginal fields were implemented from 2016 onwards, increasing the recovery factor of the incentivized field, reversing the decline in production, and extending its useful life. Mature fields have an average recovery factor slightly higher than the national average, around 19%, but still far from the global average and that of oil-producing countries.

Oil production in fields with benefits grew by 23%, while that of mature fields without incentives declined by 35% in the period 2020-2024. Of the mature and marginal fields in the country, only 59 are included in the incentive regime by the ANP (FIRJAN, 2024). The incentive for mature and marginal fields is one of the measures aimed at avoiding the imminent decline of the growth period of the country's current oil and natural gas fields. In addition, other exploration frontiers are also studied by energy policy, such as the equatorial margin, and onshore oil and natural gas production.

However, the delay and uncertainty regarding the international benchmark in environmental licensing processes in Brazil generate at least two types of devaluation in oil and gas exploration projects. First, the delay shifts the flows to future periods, which are then discounted more heavily when brought to current value, which causes a decrease in their total. Second, the uncertainty about the conditions of approval increases the risk of the project and, consequently, the discount rate to be used in its pricing. This increase in the discount rate also reduces the present value of the financial flow corresponding to the project.

Therefore, this paper seeks to assess the economic effects that would be generated by the Brazilian oil and gas sector resulting from an optimization in environmental regulation. To this end, data from 5 publicly traded companies operating in the sector, the Capital Asset Price Model, and input-output matrices are considered. CAPM betas are estimated considering a more efficient regulatory environment, and compared with actual betas, the difference between them is then incorporated into the calculation of the weighted average cost of capital to simulate shocks in the input-output matrices.

The results indicate that the destruction of investment value could range from R$33 billion to R$110 billion over 5 years for delays in licensing of 6 and 24 months, respectively, and negative effects on GDP could reach R$70 billion over 5 years for delays of 6 months in the licensing process. In addition, the simulations estimate that the loss in gross production value could reach R$126 billion, with a possible reduction in economic remuneration of R$7.9 billion, while 210,000 formal jobs would not be created and R$10.7 billion would not be collected on the product over 6 years.

Several recent studies have investigated the productivity of the sector and its economic effects, such as Aidarova et al., (2024), Ajayi and Pollitt (2025), Kellogg and Reguant (2021), Benatti et al. (2024), Huseynli (2023), Bogmans et al. (2024), Amahalu and Okudo (2023), Acheampong and Kemp (2022) and Grodzicki (2024) and, with these findings, we contribute to this scientific literature by providing estimates of how the oil and gas sector could benefit from the implementation of a more efficient environmental regulatory governance system, with the relevance of these insights extending to assisting policymakers, investors, and supply chain agents in decision-making.

In addition to this introduction, the work has four more sections. The second section explains the methodology used, Section 3 presents and discusses the results, and, finally, Section 4 concludes.

2. METHODOLOGY

2.1. Data

When comparing the weighted costs of capital of companies operating in different countries, it is necessary to consider the general conditions of the economic environment. A company operating in Brazil will probably have a higher cost of capital than a similar company operating in the United States or Europe due to the various relative inefficiencies in the national business environment. The set of these inefficiencies is commonly called the Brazil Cost and is measured by the difference in interest rates on Brazilian and American sovereign bonds.[1].

Since the objective of this report is to assess the impact of deficiencies in the environmental licensing process on the current value of investment flows associated with projects to be implemented in Brazil, adjustments are made so that Brazil Risk can be considered in this calculation. This is done by obtaining the beta of international companies considered as benchmarks, and their weighted costs of capital will be calculated using the risk-free rate (r_f) and the market rate of return (r_m) of Brazilian companies. This incorporates the difference in sovereign interest rates into the cost of capital of international companies.

The average of the adjusted betas of the United States (0.7291) and Europe (0.6901) is obtained in Damodaran (2025), and established with a benchmark (β_{fe}^{B} = 0.7096). In the case of the United States, 147 companies are considered, and, in the case of Europe, 82 companies from the countries of the European Union, the United Kingdom, Switzerland, and Scandinavian countries. This value will be considered fixed during the analysis period that includes the years between 2025 and 2031.

For the sector in Brazil, the estimated betas are considered[2] ($\hat{\beta}_e$), gross debt amounts (D), net worth (E), cash positions (C), and market value (V) of the five main companies in the sector, being Azevedo and Travassos Energia S.A. (AZEV3), Brava Energia S.A. (BRAV3), Petróleo Brasileiro S.A. PETROBRAS (PETR4), Petrorecôncavo S.A. (RECV3), and PRIO S.A. (PRIO3).

The information is obtained from Economatica, and all values are based on the date of December 31, 2024. The tax burden (T) of the sector is obtained by adding income tax (25%) to the Social Contribution on Net Income (9%), resulting in 34%. Royalties are not included as a component of the sectoral tax burden, since the international bases would not be comparable in this case, since Damodaran (2025) does not include this expense. Table 1 presents the variables considered.

For the intertemporal analysis of the economic impacts of regulatory optimization in the oil and gas sector, a series of annual input-output matrices (IPM) covering the period from 2010 to 2021 is used. The matrices adopted reflect the productive structure of the Brazilian economy in the pattern of 67 economic sectors and were extracted from estimates compatible with the System of National Accounts (SNA, 2010), according to a methodology consolidated in the Brazilian literature on structural analysis (Passoni and Freitas, 2022).

Considering that the original input-output matrices are expressed at current prices, that is, subject to inflation and variation in relative prices over time, it was necessary to apply a deflation process to allow comparison between different years. To this end, all relevant monetary values - such as total output and income - were transformed to constant 2021 prices, using a specific deflation index for each year, chained from the implicit price index of the gross production value.

This procedure aims to isolate the purely quantitative effects of economic variables, eliminating distortions associated with inflation or changes in the relative prices of products between sectors. Deflation thus allows the simulation results to be interpreted in real terms, reflecting only changes in the volumes produced, income generation, and employment, and not nominal variations induced by price changes over time. Nevertheless, this practice is in line with Balk and Reich (2008).

2.2. Capital Asset Price Model

The capital asset pricing model provides a methodology for calculating the discount rate to be applied in calculating the discounted value of project cash flows:

$$r_e = r_f + \beta_e (r_m - r_f) \quad (1)$$

Where r_e is the discount rate specific to a company, industry or project, r_f is the return on government bonds of corresponding

Table 1: Variables for calculating adjusted betas[3]

Company	$\hat{\beta}_e$	T (%)	D	E	C	V
AZEV4	0.63	34	109.446	136.381	0.003	0.491
BRAV3	0.17	34	18,944.060	10,523.671	3.172	7.998
PETR4	0.80	34	371,934.573	366,006.000	20.254	425.779
RECV3	0.93	34	1,792.321	4,235.277	0.296	3.957
PRIO3	0.79	34	22,433.677	25,924.192	3.993	27.776

Source: Elaborated by authors

1 The Brazil Cost can be assessed directly by the interest rate differential (EMBI) or by the cost of the swap between the rates of the two countries (CDS).

2 Values or April 2025 are estimated from data from the previous 48 months.

3 The values of D, E, C, and V are in millions of R$.

duration, r_m is the market return, usually measured as the long-term return of the stock market index and β_e is the level of sensitivity of the company's (or sector's, or project's) value to variations in the stock market index.

The value of β is usually estimated by regression between the market risk premium, $(r_m – r_f)$, and the company's risk premium $(r_e – r_f)$. Like this:

$$(r_e - r_f)_t = \hat{\beta}_e (r_m - r_f)_t + \mu_t \qquad (2)$$

Where the subscript t denotes the period of assessment of market and company risk, $\hat{\beta}_e$ is the estimated beta of the company, and μ_t it's white noise.

Once the company's beta has been estimated, it is inserted into Equation 1 to obtain an estimate of the company's risk-weighted cost of capital, which is used as a discount rate in assessing the viability of the company's projects. Thus:

$$WACC_e = r_f + \beta_{fe} (r_m – r_f) \qquad (3)$$

Where β_{fe} is the company's adjusted beta obtained, the estimated beta $\hat{\beta}_e$ must be adjusted to specific company conditions, so that the business risk can be isolated from other risks that are present but are not based on the attractiveness of the sector. For example, the company's debt ratio, that is, the relationship between the company's debt and its net equity, must be considered in this adjustment, since the more indebted the company, the greater its risk and, consequently, its beta.

However, this increase in risk is not due to the business itself, but rather to the company's effective capital structure. Therefore, it is necessary to adjust the beta so that it does not capture the risk of the company's capital structure. In addition, the influence of taxes in this equation must be recognized, since taxes act as amortizers for the variation in company profits. The adjustment is then made as:

$$_{de} \qquad \frac{\hat{\ }}{1+\left(1-\quad\right)-} \qquad (4)$$

Where β_{de} is the company's beta adjusted for its capital structure, also called unlevered beta, T is the company's tax burden, D is the indebtedness, and E is your net worth.

There is still an adjustment to obtain the final beta to be used due to the company's cash position. The greater the company's cash, the lower its risk. Thus, the cash position works inversely to the company's debt, and must also be adjusted (realeveraged) so that it does not mix with the risk of the enterprise itself.

$$\beta_{fe} = \frac{\beta_{de}}{1 - \frac{C}{V}} \qquad (5)$$

Where β_{fe} is the company's adjusted beta, C is your cash and equivalents position and V is its market value. In possession of the β_{fe} it is possible, according to Equation 3, to obtain the weighted cost of capital to be used as a discount rate in projects.

2.3. Input-Output Matrix

The Input-output matrix is a table that describes, in monetary terms, who buys and who sells within the economy. The rows show the sales of each sector; the columns show the purchases of inputs necessary for production. The simultaneous arrangement of rows and columns allows us to see the economy as an integrated system, in which any change in the production of one sector triggers chained responses in the others.

Since the methodology is based on National Accounts, the results are replicable and auditable, which provides transparency and legitimacy to public policy studies. As a result, the input-output matrix provides a detailed view of the production structure and intersectoral links, allowing us to identify how an increase or reduction in production in one sector impacts this same sector and others.

One of the main advantages of the input-output matrix lies in its structural transparency and its ability to capture production chains, even based on aggregated data. Among the practical applications of the input-output model, we can mention its use in economic policy analyses, assessment of the impacts of demand shocks, and sectoral development planning.

The main analytical tool of the Input-output matrix is the inverse of Leontief[4], which allows estimating the systemic impacts of exogenous variations in final demand. This matrix represents the interdependencies between productive sectors and, based on an initial shock - such as an increase or reduction in investment or production in a given sector - allows calculating the repercussions across the economy as a whole. These impacts are distributed across three distinct levels: Direct, indirect, and induced.

The direct effect refers to the initial response of the sector affected by the shock, that is, how much its production varies immediately due to the change in final demand. The indirect effect corresponds to the repercussions of this variation on the supplying sectors, which need to expand (or reduce) their production to meet the new level of demand from the impacted sector. The induced effect captures the dynamics of household consumption, considering that increases (or decreases) in production generate variations in workers' income, which alter the consumption pattern of the economy as a whole. This effect is relevant because it increases the spread of impacts by incorporating the response of the domestic sector, which is responsible for a significant part of aggregate demand.

4 Wassily Leontief initially developed the idea of the input-output matrix in the 1930s, influenced by previous ideas from Quesnay (Tableau Économique) and Walras (general equilibrium). This methodology gained prominence from the 1960s onwards, when more than 40 countries began to use it in their economic planning.

3. RESULTS

Table 2 presents the adjusted beta values for each firm in the sector considered. The arithmetic mean of the adjusted betas is used as a parameter for calculating the sector's cost of capital, since the disparity in the size of the companies would lead to an excessive prevalence of Petrobras' numbers if the weighted average were used.

The average return of Brazilian stock markets between 1993 and 2023 (r_m^{BR}) was 17%. They are used as a proxy for the Brazilian risk-free interest rate ($r_{f,t}^{BR}$) the forecasts obtained from the market expectations system of the Central Bank of Brazil regarding the basic interest rate (SELIC) for the years 2025-2029. Table 3 presents for the next 5 years the average market return, interest expectations, the average cost of capital weighted by risk for the sector in Brazil ($WACC_{BR}$), and the risk-weighted average cost of capital of American and European companies if they were subject to the Brazil Cost ($WACC_{bench}$).

Table 2: Firms' adjusted betas

Company	β_{fe}
AZEV4	1.082
BRAV3	1.113
PETR4	0.526
RECV3	0.939
PRIO3	0.573
Média	0.847

Source: Elaborated by authors

Table 3: Calculation of the risk-weighted cost of capital for the sector

T	$r_{f,t}^{BR}$ (%)	r_m^{BR} (%)	$WACC_{BR}$ (%)	$WACC_{bench}$ (%)
2025	15.00	17.00	16.96	16.46
2026	12.50	17.00	16.92	15.78
2027	10.50	17.00	16.88	15.24
2028	10.00	17.00	16.88	15.10
2029	9.75	17.00	16.87	15.04

Source: Elaborated by authors

Table 4: Estimated investment flows for the sector

Year	R$	US$
2025	139,948,610,786	27,586,697,250
2026	153,242,985,286	30,487,549,882
2027	127,454,647,365	25,807,983,930
2028	107,758,217,388	22,114,599,970
2029	81,140,601,776	16,790,030,730

Source: Elaborated by authors with data from the oil national agency (ANP)

The risk-weighted average cost of capital values will be used to discount the expected investment flow for the sector. The National Agency of Petroleum, Natural Gas and Biofuels provides the expected flows for oil and gas exploration and production activities in Brazil over the next 5 years (2025-2029). Table 4 presents the estimated investment flows for the sector.

The expected flow of investments for the sector in Brazilian Reais is then discounted by the weighted average cost of capital of the benchmark ($WACC_{bench}$), and the weighted average cost of Brazilian capital ($WACC_{BR}$) to measure the loss of current value due to the higher cost of capital faced by Brazilian companies due to inefficiencies in the regulatory governance process in Brazil. In addition to the higher discount rate, there are also delays in the release of investments, which also lead to losses in the discounted value of the investment flow. Table 5 presents simulations with delays of 6, 12, 18, and 24 months in the investment flow and their consequences for the current value of the flows.

The values that appear for the years 2023 and 2031 are the result of delays in investment flows that were not suppressed, but rather carried forward to subsequent months and discounted by the weighted average cost of Brazilian capital ($WACC_{BR}$) 2029.

Given the losses in the net present value of oil and gas exploration and production projects due to delays in the flow of investments, Input-Output Matrix models are developed to estimate the indirect and induced impacts of these delays on the Brazilian economy, focusing on the effects on the gross production value, income generation, employment and taxes generated. The analysis uses sectoral multipliers derived from the 2021 matrix, the most recent year available with reliable data, and considers the average delay of 6 months in investments as the reference scenario.

Initially, the marginal economic impact of investments in oil and gas exploration and production activities is measured based on the 2021 inverse Leontief matrix. Three specific multipliers are estimated for the oil and gas sector, namely the gross production value multiplier, the income multiplier, and the employment multiplier. These coefficients represent, respectively, how much total production, wage bill, and jobs are generated for each real investment in the sector, considering the direct, indirect, and induced effects along the production chains.

Table 5: Investment flow with delays

Year	Investment	Flow benchmark	Flow delay 6 month	Flow delay 12 month	Flow delay 18 month	Flow delay 24 month
2025	139.95	120.21	59.96	0.00	0.00	0.00
2026	153.24	113.78	108.01	103.11	51.56	0.00
2027	127.45	82.21	89.14	97.33	93.11	88.89
2028	107.76	60.45	64.43	69.83	76.89	83.96
2029	81.14	39.62	44.65	50.94	55.60	60.25
2030	0.00	0.00	16.62	33.23	38.68	44.13
2031	0.00	0.00	0.00	0.00	14.39	28.79
Loss of added value			33.46	61.83	86.04	110.25
Loss of added value %			8.04	16.88	26.79	39.78

Source: Elaborated by authors

To estimate the impacts on production value, employment, and income, the inverse Leontief coefficient of the open model is applied, along with the respective multipliers, which incorporate direct and indirect effects resulting from purchase and sale relationships between sectors. In order to measure the effects induced by the increase (or elimination of the loss) in household consumption, the model was closed by endogenizing the consumption account; in this way, the increase in income obtained at the first moment feeds back into demand, generating new cycles of production and employment. After estimating the total effect of the postponement of investments on the gross production value, the average sectoral coefficients of incidence of taxes on production are applied, as recorded in the input-output matrix, to measure the losses in tax revenue.

To measure the shock to the sector, the difference between the investment flows estimated in the benchmark scenario (without delays) and the flows adjusted to reflect an average delay of 6 months is used. This difference represents the annualized loss of investments between 2025 and 2030, in values discounted by the weighted average cost of Brazilian capital. The impact is not limited to a simple temporal postponement, as there are significant losses in value in the 1st years (2025-2026), only partially offset by marginal increases in flows in the following years (2027-2030), when investments finally occur. Table 6 presents the annual investment losses.

Although the shock only affects the oil and gas segment, the multipliers automatically capture the interdependencies with the supply chain and with other sectors of the economy. It is assumed that the technical structure of the sector, highly capital-intensive and relatively stable, remains valid throughout the projection horizon, a common assumption in studies that use input-output matrices in a short- and medium-term context.

It is worth noting that, since this is an exercise based on multipliers from 2021, the estimated effects should be interpreted as an approximation of the economic reality under the productive structure of that year. However, since the intersectoral structure is relatively stable in the short term, this approximation is methodologically valid for estimates up to 2030, especially under the assumption that delayed investment is distributed in subsequent years in proportion to the simulation carried out in the previous section.

This approach incorporates an intertemporal view of the impact of regulatory inefficiency over the following years. Even if part of the investment is made later, the initial negative effects are not fully recovered, given the opportunity cost associated with postponing economic stimulus, especially in periods of low utilization of productive capacity and high unemployment, as the effects are not concentrated in the year of delay, but propagate throughout the remaining years in the analysis - until 2030 - in terms of output, income, employment and taxes.

The oil and gas sector, identified in the Brazilian input-output matrix by code 0680, occupies a strategic position in the national production structure. Based on the annual matrices compatible with the National Accounts System (format of 67 sectors), it is noted that this activity combines high capital intensity with a strong capacity to radiate demand throughout the chain, since its disbursements are concentrated in metallic capital goods, land transportation, energy utilities, and specialized support services. The sector's average share between 2010 and 2021 is 1.9%, with a maximum of 2.5% of the gross value of production in 2021. Figure 1 shows the sector's share in the gross value of total production.

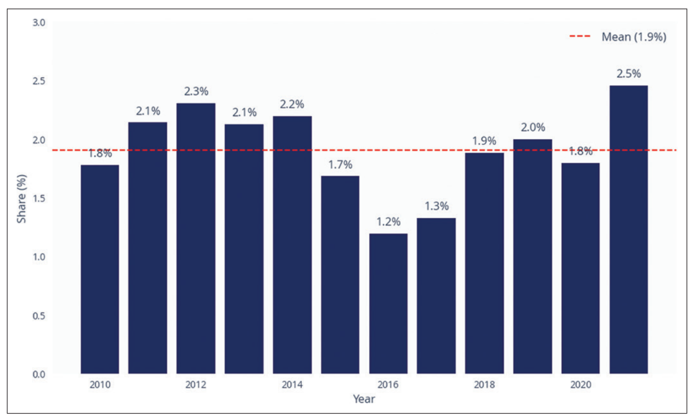
Based on the inverse Leontief (L) applied to the annual matrices from 2010 to 2021, the contribution of the oil and gas sector to the gross value of production is estimated, both in the open model and in the closed model. The results presented in Figure 2 reveal

Table 6: Annual investment losses

Year	Investment	Flow benchmark	Fluxo 6 months	Loss
2025	139,948.61	120,210.98	59,964.17	−60,246.81
2026	153,242.99	113,775.48	108,008.01	−5,767.47
2027	127,454.65	82,205.74	89,139.52	6,933.77
2028	107,758.22	60,453.78	64,432.74	3,978.95
2029	81,140.60	39,619.80	44,651.11	5,031.31
2030	0.00	0.00	16,615.08	16,615.08
Total	609,545.06	416,265.79	382,810.62	−33,455.17

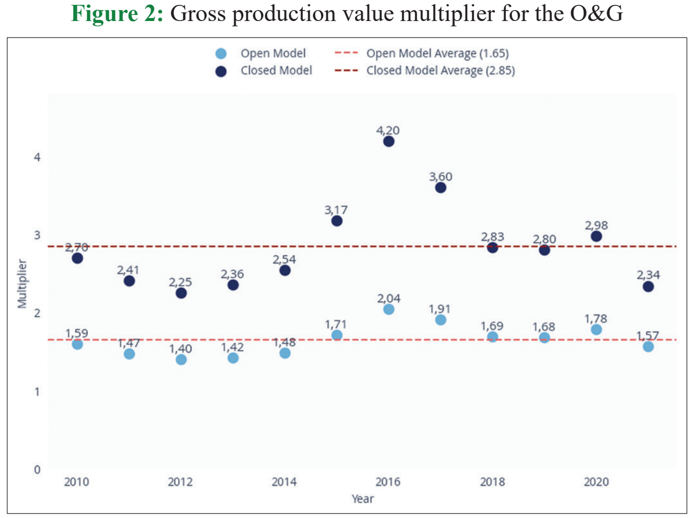
Source: Elaborated by authors

Figure 1: Percentage share of the sector in the gross value of total production



Source: Elaborated by authors

Figure 2: Gross production value multiplier for the O&G



Source: Elaborated by authors

that each real added to the segment's production translates into a significant additional gain for the economy, due to its ability to activate metalworking suppliers, logistics services, and energy utilities, in addition to stimulating household consumption when the income generated is diffused.

The historical average of the production multiplier in the oil and gas sector is 1.65 in the open model and reaches 2.85 when the model is closed for household consumption. These values mean that, for every R$1 added to the sector's production, the cascading effect on the economy generates, on average, R$1.65 in production in other sectors when only direct and indirect links are considered. When the income effect is included - that is, the increase in consumption resulting from wages and other income distributed -, the total boost rises to R$2.85, an aggregate impact on the Gross Production Value. This positive chain confirms the strategic relevance of the sector as a driver of value throughout the national production chain.

Therefore, investments or efficiency gains that increase the segment's production have a multiplied impact on the metalworking, transportation, and specialized services chains, and, subsequently, on household consumption. This coefficient reinforces the sector's strategic position as a driver of economic dynamism, as it demonstrates that the value generated is not restricted to exploration and production activities, but is disseminated widely, expanding the productive base and national income.

By breaking down the columns of the input-output matrix, it is possible to identify which activities absorb oil and gas production as an intermediate input. Between 2010 and 2021, three sectoral groups accounted for most of this demand. The first is oil refining and coking, where, when processing crude oil, this segment directly uses approximately one-third of the value produced by the oil and gas sector, a ratio that intensifies in years when installed refining capacity operates closer to its limit.

The second group - formed by electricity, natural gas, and other utilities - joins the third - water, sewage, and waste management - whose dependence arises from the consumption of derivatives, especially fuel oil, in pumping stations and treatment processes, in addition to the use of gas in industrial boilers. Figure 3 presents the sectors demanding the oil and gas sector in percentage terms.

It is possible to verify the strong self-consumption of the oil and gas sector itself, especially before the 2015 crisis. This characteristic comes from the reinvestment of part of the production in artificial lift operations, gas reinjection, and platform maintenance, creating an internal circuit that keeps a relevant portion of the value generated within the chain itself. Understanding this map of demanders is essential to assessing the effects of a possible regulatory optimization. A positive shock that accelerates investments in exploration has repercussions, first of all, on refining, increasing the refinery utilization rate, and stimulating expansion or unit conversion projects.

Following this, the increase in the supply of natural gas reduces the marginal costs of thermoelectric plants, influencing prices in the energy market and strengthening the utilities segment. Finally, water and sewage services capture economies of scale and reductions in energy costs, improving their operating margins. In this way, the mitigation of regulatory obstacles boosts oil and gas production and radiates concrete benefits to activities essential to infrastructure and collective well-being.

From the opposite perspective, the input-output matrix allows us to measure the volume of intermediate purchases made by the oil and gas sector and, thus, identify which activities act as its

Figure 3: Demanders from the O&G sector in terms of participation

Source: Elaborated by authors

main suppliers. Between 2010 and 2021, the demand structure for inputs remained diversified, combining high-technology-intensive metallic capital goods, large-scale logistics services, and specialized corporate support contracts. This range of supplies reflects the capital-intensive nature of exploration and production, which requires structural materials, robust transportation operations, and continuous technical-administrative support, in addition to a significant percentage of self-consumption of oil and gas to maintain its operations. Figure 4 shows the percentage of suppliers to the oil and gas sector.

When oil and gas production accelerates, the positive effect falls directly on this group of suppliers, which also includes wholesale trade, industrial maintenance, engineering, insurance, and financial services linked to the management of large projects. The increase in orders generates new industrial orders, increases the occupancy of the transport fleet, expands the demand for specialized consultancy, and, ultimately, injects additional income into the entire production network. In this way, reductions in regulatory deficiencies can increase the revenue of the energy chain, but also strengthen a broad group of suppliers, distributing gains in production, employment, and revenue across various segments of the national economy.

The impact of regulatory improvements on the Gross Production Value is projected through the shock that eliminates the average 6-month delay in investments in the sector. By returning these disbursements to the original schedule, the inverse Leontief of the input-output matrix is applied to simultaneously measure the initial loss caused by the postponement - 2025/2026 - and the subsequent gain that propagates between 2027 and 2030 when the capital flow returns to its expected pace. This procedure allows us to quantify, in real terms, the amount of production that is no longer generated throughout the production chain due to regulatory inefficiency. Table 7 presents the direct, indirect, and total effects of a regulatory improvement.

The simulation results in Table 7 indicate that the 1st year of delay, 2025, accounts for most of the economic cost of regulatory inefficiency. In the open model, which considers only direct and indirect effects, the estimated loss amounts to R$94.4 billion in gross production value. When the model is closed to endogenize household consumption, the induced impact increases this amount to R$126.8 billion. This difference illustrates the weight of the income effect, where the initial decline in wages and profits in the oil and gas sector reduces household purchasing power and, consequently, the demand for goods and services throughout the

Figure 4: Suppliers in the O&G sector by share

Source: Elaborated by authors

Table 7: Effects on production

Year	Direct effect	Indirect effect	Induced effect	Total effect (open model)	Total effect (closed model)
2025	−18,591.81	−75,832.41	−32,350.83	−94,424.22	−126,775.05
2026	−1,779.81	−7,259.49	−3,096.97	−9,039.30	−12,136.26
2027	2,139.72	8,727.51	3,723.24	10,867.23	14,590.47
2028	1,227.88	5,008.29	2,136.59	6,236.17	8,372.76
2029	1,552.63	6,332.89	2,701.67	7,885.53	10,587.20
2030	5,127.31	20,913.32	8,921.82	26,040.64	34,962.46
Added in 6 years	−10,324.07	−42,109.88	−17,964.48	−52,433.95	−70,398.42

Source: Elaborated by authors

economy. Figure 5 shows the annual effect of delays on gross production value.

From 2026 onwards, the results indicate that the trajectory of losses softens. Since capital expenditures were only postponed and, in principle, not canceled, part of the postponed investment begins to be made, which gradually reactivates the supply chain and mitigates the negative impact on the gross value of production. Even so, the production gap is not fully offset, since each delayed real failure fails to generate simultaneous repercussions in other sectors at a time when the economy could absorb them with a greater multiplier effect.

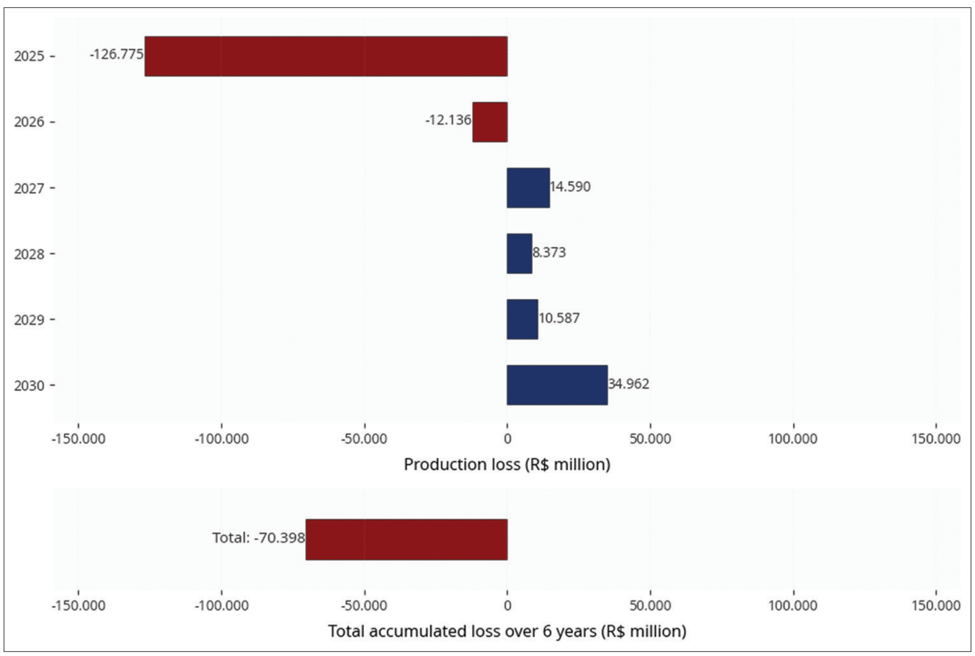
This partial recovery dynamic continues until 2030, the last year of the analysis horizon. At the end of the 5 years, the flow of investments returns to normal, but the time elapsed between the original planning and the effective execution implies permanent losses of opportunity. Figure 6 presents the direct, indirect, and induced effects due to the delay caused by regulatory inefficiency in the sector.

The Gross Production Value lost due to the average delay of 6 months in investments in the oil and gas sector is concentrated in the oil and gas segment itself. However, the impact of the shock is significantly broader, with approximately half of the estimated decline spreading outside the sector, highlighting the high degree of interconnection and production chains in the Brazilian economy. In other words, the regulatory inefficiency that postpones strategic investments not only harms the core of the energy sector but also reverberates across several supply and service chains, compromising the generation of added value throughout the production structure.

The greatest indirect impacts fall on three sectors: Wholesale and retail trade - with a loss of R$4.2 billion in production due to the drop in demand for intermediate and consumer goods; iron and derivatives production - which loses R$2.8 billion due to its dependence on orders linked to the oil infrastructure; and land transportation - with a decline of R$2.3 billion, reflecting the lower flow of inputs and products in the logistics chain. Figure 7 presents the direct, indirect, and induced sectoral effects on the gross value of production due to delays caused by regulatory inefficieny in the sector.

The average 6-month postponement of investments in the oil and gas sector has a direct impact on the mass of remuneration distributed to the economy. In the open scenario, the accumulated net loss reaches R$4.7 billion, in the closed scenario - which

Figure 5: Annual effect on gross production value (R$ million)



Source: Elaborated by authors

Figure 6: Effects on gross production value in 6 years (R$ million)

Source: Elaborated by authors

incorporates induced family consumption - the impact deepens to R$7.9 billion (2021 values), highlighting the importance of the income-consumption-production chain for the diffusion of regulatory shocks. Table 8 presents the direct, indirect, and total effects on income.

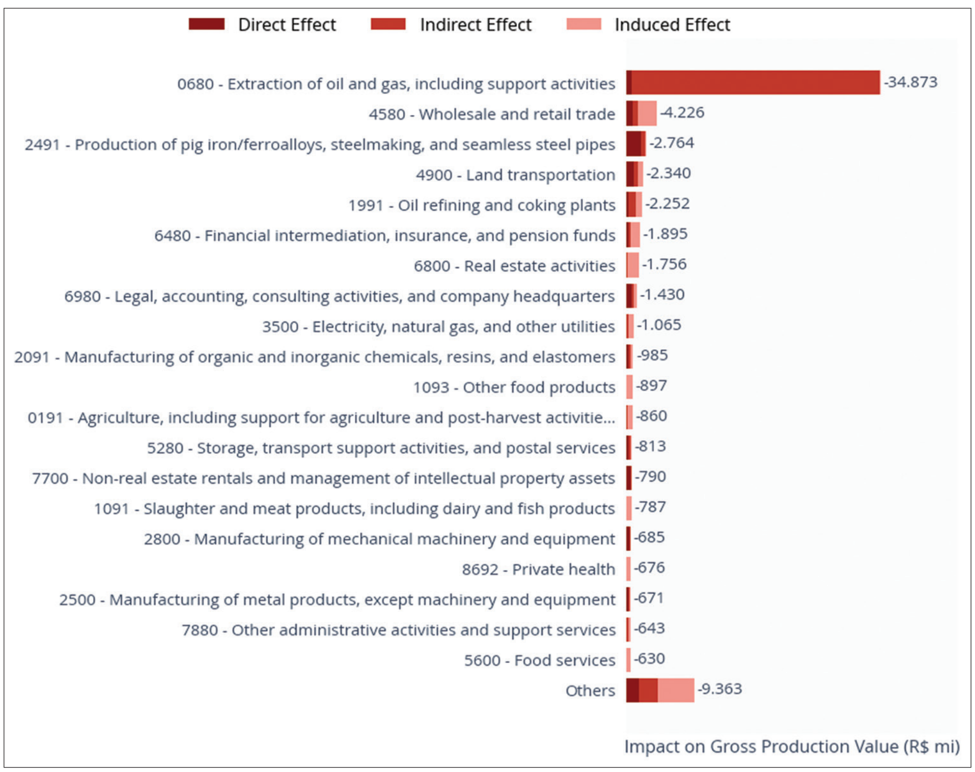
The time trajectory mirrors the behavior observed in the gross value of production, where in the first 2 years (2025-2026) income suffers a sharp contraction, while the gains recorded from 2028 onwards, when investments finally occur, do not fully compensate for the initial losses. In net terms, aggregate household income remains R$7.9 billion below what would be seen in a regulatory environment aligned with international benchmarks. Figure 8 shows the annual effect on income due to delays caused by regulatory inefficiency in the sector.

The decomposition by the inverse Leontief matrix shows that R$1.7 billion of the loss is due to wages paid directly by oil and gas companies - direct effect, R$3.0 billion is canceled in the supply chain - indirect effect, and R$3.2 billion is no longer circulated through household consumption - induced effect. This last component reveals the multiplier role of income, in which the smaller payroll restricts purchasing power and consequently compresses the production of goods and services aimed at the domestic market. Figure 9 presents the direct, indirect, and induced effects on income due to delays in the 6-year horizon.

From an intersectoral perspective, only 22% of the loss - approximately R$1.8 billion - is concentrated in the oil and gas sector itself. The remaining R$6.1 billion is spread across dozens of sectors, with emphasis on wholesale and retail trade, land transportation, and basic industries, where dependence on orders and services from the oil cluster is high. The asymmetric distribution reinforces that the social cost of regulatory delays falls mainly on workers and companies outside the core of the sector. Figure 10 shows the sectoral effects due to delays.

The results in Figure 10 show that the postponement of strategic investments not only compromises the direct generation of qualified jobs in the energy sector but also reduces household

Figure 7: Sectoral effects on gross production value



Source: Elaborated by authors

Table 8: Effects on income

Year	Direct effect	Indirect effect	Induced effect	Total effect (open model)	Total effect (closed model)
2025	−3,146.69	−5,313.38	−5,727.28	−8,460.07	−14,187.35
2026	−301.24	−508.65	−548.28	−809.89	−1,358.16
2027	362.15	611.51	659.15	973.66	1,632.81
2028	207.82	350.92	378.25	558.74	936.99
2029	262.79	443.73	478.29	706.51	1,184.81
2030	867.81	1,465.34	1,579.49	2,333.15	3,912.64
Total (6 years)	−1,747.36	−2,950.53	−3,180.37	−4,697.89	−7,878.26

Source: Elaborated by authors

Figure 8: Annual effects on income

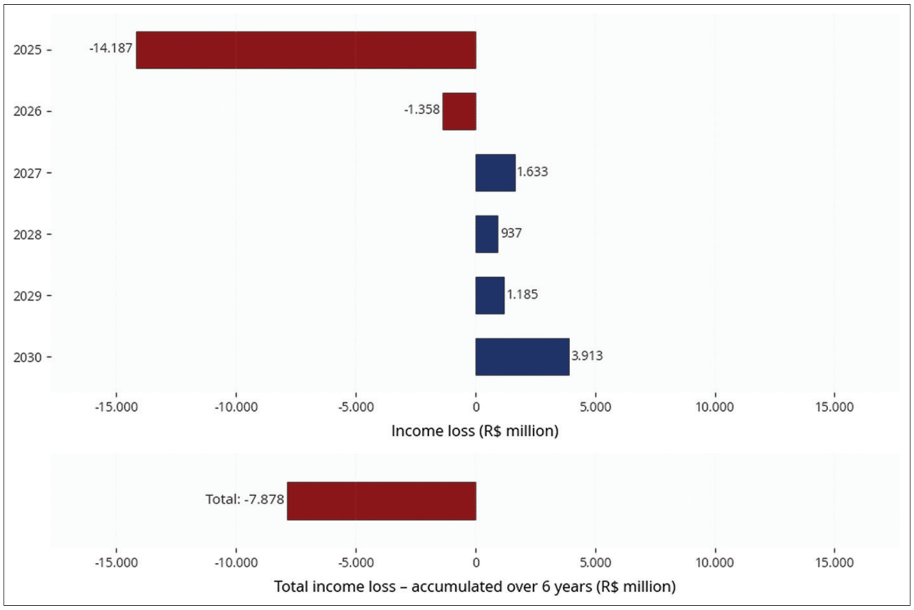


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Figure 9: Effects on income in 6 years

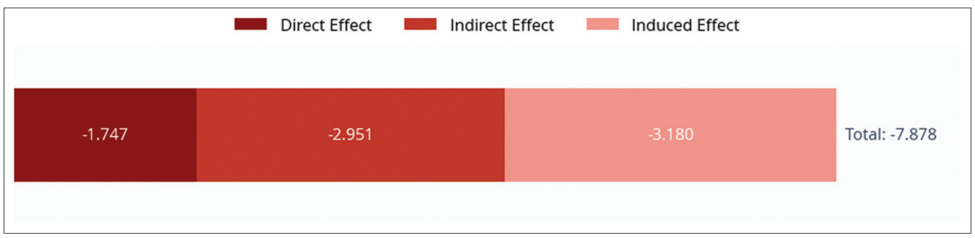

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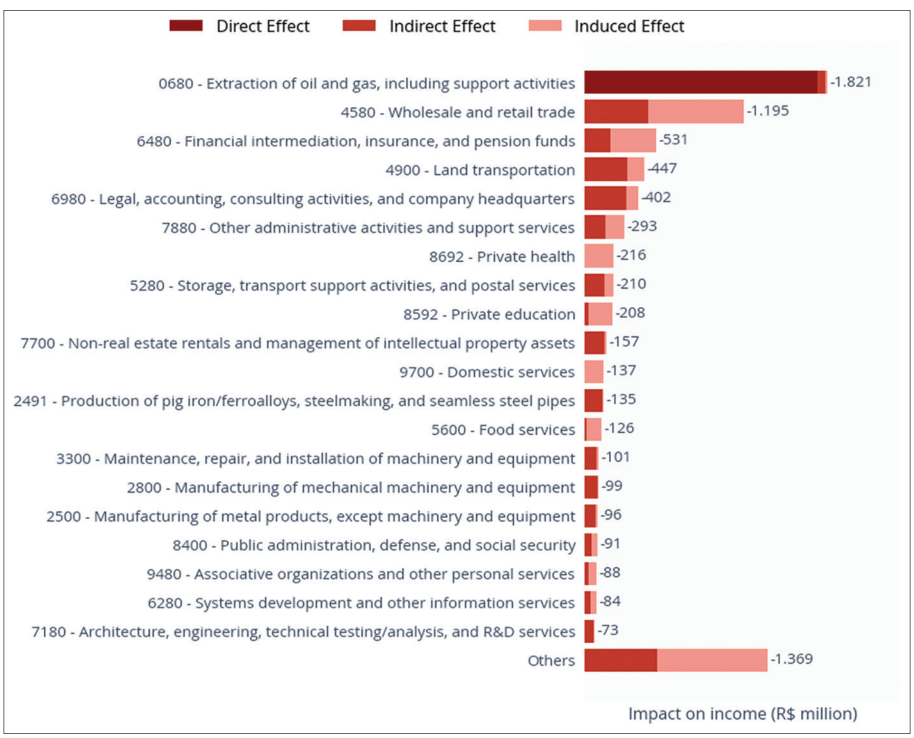
Figure 10: Sectoral effects



Source: Elaborated by authors

income across the entire production network, prolonging the effects of an initially sectoral shock and widening the aggregate welfare gap. The 6-month postponement of investments in the sector also translates into a sharp decline in formal employment. In the open scenario, the expected net elimination amounts to a reduction of 86,000 jobs.

When the effects induced by lower household consumption are considered, the closed impact deepens to a reduction of 210,000 formal employment relationships in the period 2025-2030. These numbers, measured in absolute terms, indicate the social cost of regulatory delays. Table 9 presents the direct, indirect, and total effects on jobs.

As in the estimated results for gross production value and income, the employment time curve shows significant losses in the first 2 years, followed by partial recovery with the late realization of investments. Even so, the net balance at the end of the 5-year horizon remains negative, reflecting the inability of the return effects to fully compensate for the gap generated by the initial postponement. Figure 11 shows the annual effect on the number of jobs caused by the regulatory inefficiency of the sector.

The sectoral analysis reveals that the direct impact on the oil and gas segment itself is relatively modest, with approximately 4.7 thousand jobs not being created or eliminated. However, the high density of backward and forward linkages means that supply chains and related services absorb the largest share of the shock.

In wholesale and retail trade, the estimated contraction amounts to a reduction of 47 thousand jobs, as a result of the lower turnover of goods caused by the fall in income and the decline in industrial orders. Land transportation loses approximately 19 thousand jobs, due to the reduced volume of cargo to be moved. Figure 12 shows the direct, indirect, and induced sectoral effects on employment.

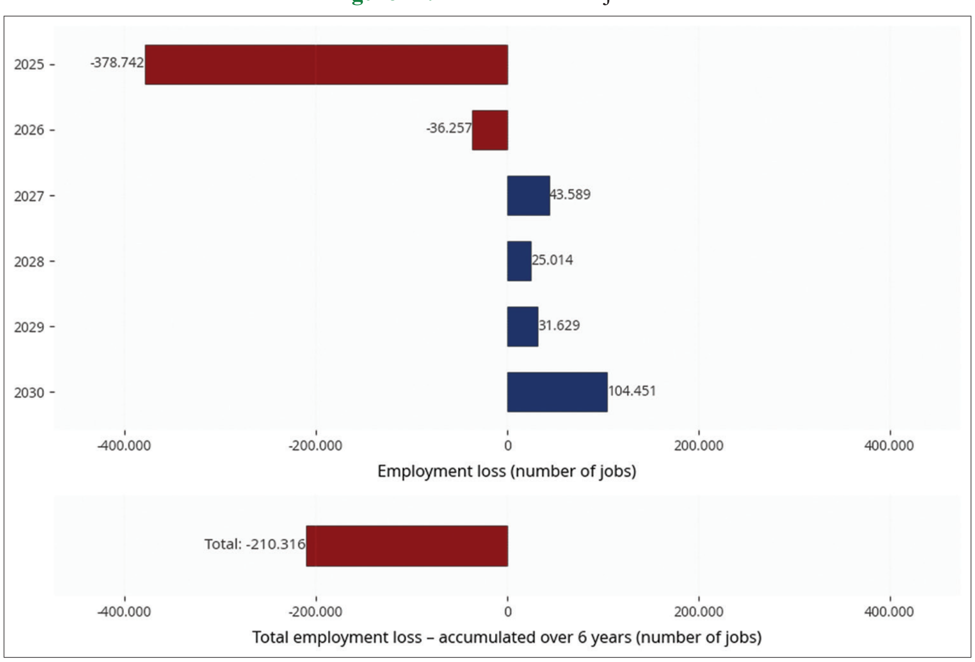
The dispersion of the shock also affects segments such as livestock, food, and agriculture which, although showing smaller losses in absolute terms, suffer a significant decline in locations where the agribusiness depends on energy inputs and the demand for food products from workers in the oil complex. In short, the delay in licensing not only limits direct hiring of highly qualified workers in the oil and gas sector but also triggers a chain reaction that reduces job opportunities in labor-intensive and lower-paying sectors. The

Table 9: Effects on jobs

Year	Direct effect	Indirect effect	Induced effect	Total effect (open model)	Total effect (closed model)
2025	−8,176	−147,944	−222,622	−156,120	−378,742
2026	−783	−14,163	−21,312	−14,945	−36,257
2027	941	17,027	25,621	17,968	43,589
2028	540	9,771	14,703	10,311	25,014
2029	683	12,355	18,592	13,038	31,629
2030	2,255	40,800	61,395	43,055	104,451
Total (6 years)	−4,540	−82,153	−123,622	−86,694	−210,316

Source: Elaborated by authors

Figure 11: Annual effect on jobs



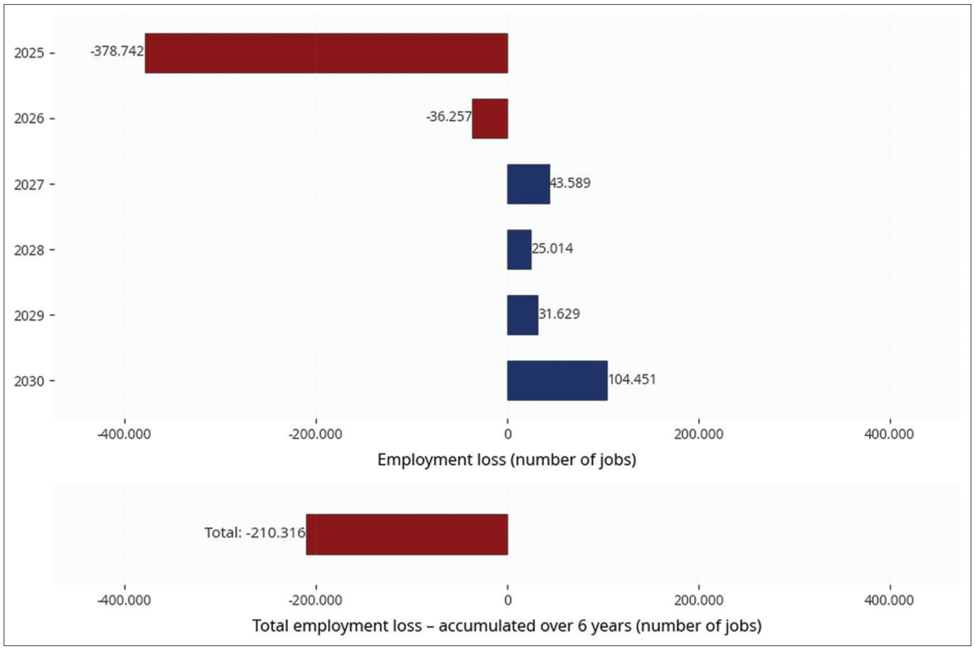
Source: Elaborated by authors

final result of 210,000 formal jobs that are no longer created shows that regulatory efficiency is crucial to preserving the dynamism of the labor market throughout the economy.

The average 6-month delay in investments in the oil and gas sector has a significant impact on tax collection and royalty revenue, with immediate effects as early as 2025. Based on the closed modeling based on the input-output matrix, a loss of R$10.7 billion in taxes on the product is estimated over 6 years, a direct reflection of the retraction in economic activity triggered by regulatory inefficiency that affects the execution of projects in the sector. Table 10 shows the effects on taxes.

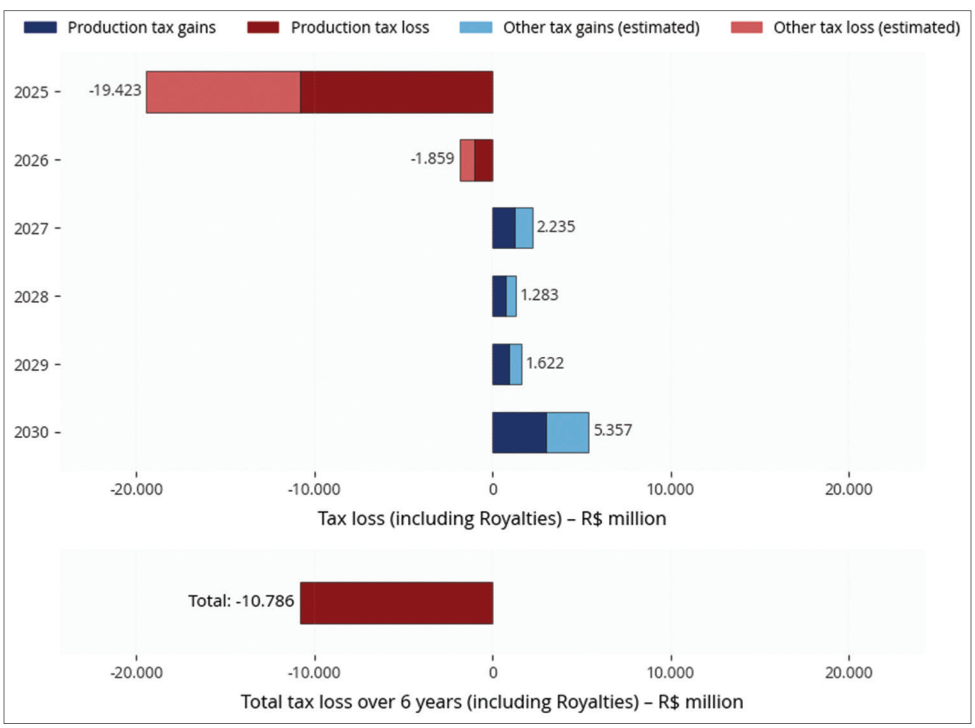
The methodology adopted to estimate this impact considered the total effect of the postponement of investments on the gross value of production. The aggregate shock accumulated over 6 years totals a reduction of R$70.4 billion in the gross value of production, distributed among all sectors of the economy. Based on this

Figure 12: Sectoral effects on jobs



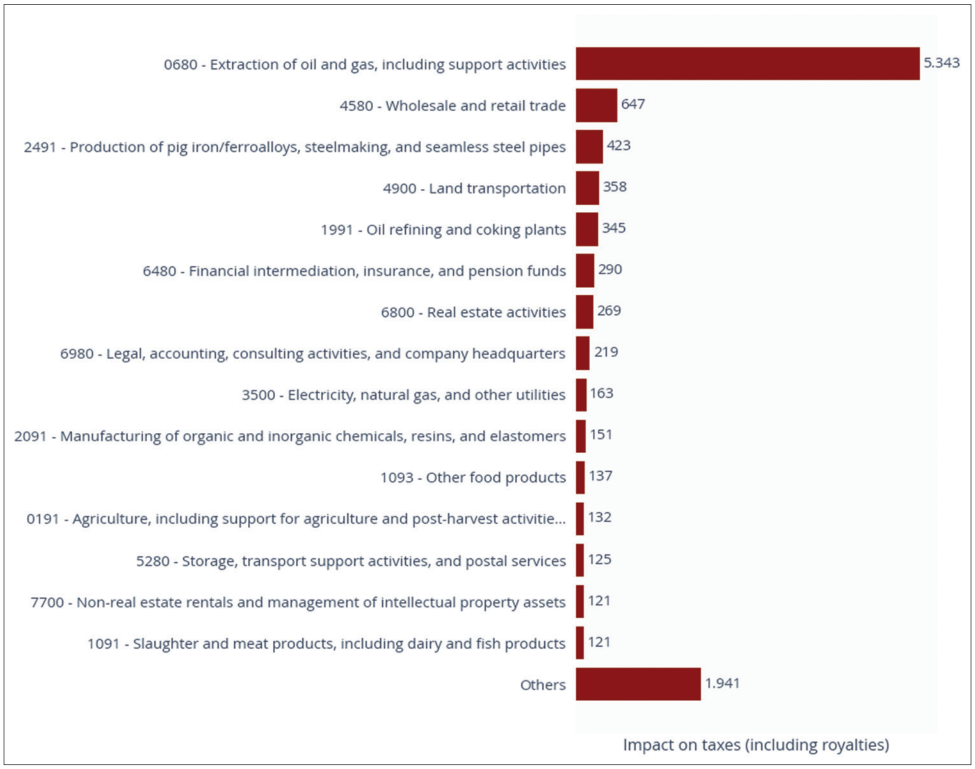
Source: Elaborated by authors

Figure 13: Annual effect on tax collection



Source: Elaborated by authors

Figure 14: Sectoral tax losses



Source: Elaborated by authors

Table 10: Effects on taxes

Year	Effect on tax levels
2025	−19,423.19
2026	−1,859.40
2027	2,235.40
2028	1,282.79
2029	1,622.06
2030	5,356.59
Total (6 years)	−10,785.73

Source: Elaborated by authors

value, the average sectoral coefficients of incidence of taxes on production - as recorded in the input-output matrix - are applied to measure the losses in tax collection. This approach allows us to observe the fiscal impacts arising from institutional distortions that delay productive investments in strategic sectors. Figure 13 shows the annual effect on tax collection due to delays caused by regulatory inefficiency in the sector.

It is important to highlight that the input-output matrix only captures taxes on products, not including relevant taxes such as income tax and contributions on net profit. Thus, to estimate the remaining taxes in the sectors, especially on income and contributions on profit, it was decided to estimate the difference in taxation due to the levels of value-added taxes, as established in studies on the gross tax burden by the Fiscal Policy Observatory of FGV/IBRE (Schymura, 2022). Thus, it is believed that, even though there may be occasional changes in the tax composition between sectors, the estimated total impact becomes more reliable with the Brazilian tax reality. Figure 14 shows the sectoral tax losses due to delays caused by regulatory inefficiency in the sector.

Furthermore, the effects of the postponement of investments in the oil and gas sector are not restricted to the sector itself. It is estimated that, on average, approximately 50% of the reduction in tax losses occurs outside the sector of origin. The impacts spread to interdependent sectors, such as trade, transportation, and the industrial intermediate goods chain, with emphasis on the segments of production of machinery, equipment, and metal structures. This chain reinforces the role of the oil and gas sector as a demand driver in key sectors of the economy and shows that delays caused by regulatory inefficiency also compromise the fiscal health of a wide range of adjacent economic activities.

4. CONCLUSION

This paper investigated the oil and gas sector in Brazil in an attempt to identify the possible economic gains resulting from an optimization in environmental regulation. To this end, data from companies in the sector listed on the São Paulo stock exchange, the Capital Asset Price Model, and input-output matrices are considered. The resulting loss is measured by the difference between the CAPM betas of Brazilian firms and those of benchmark countries, which is incorporated into the weighted average cost of capital, in order to simulate shocks in production, employment, and tax collection in the input-output matrices.

The results indicate that the destruction of investment value could range from R$33 billion to R$110 billion over 5 years for delays in licensing of 6 and 24 months, respectively, and negative effects on GDP could reach R$70 billion over 5 years for delays of 6 months in the licensing process. In addition, the simulations estimate that the loss in gross production value could reach R$126 billion, with a possible reduction in economic remuneration of R$7.9 billion, while 210,000 formal jobs would not be created, and R$10.7 billion would not be collected on the product over 6 years.

Therefore, this work provides valuable insights into the importance of efficient environmental governance and the optimization of its processes, in which the expanded results of the oil and gas sector would benefit the entire country. These findings contribute to the scientific literature by highlighting the relevance of the sector for the Brazilian economy, as well as for policymakers, investors, and supply chain agents who consider the oil and gas sector in their decisions.

For future research, the differences arising between the real CAPM betas and the estimated betas could have their influence measured on production, employment, and revenue through computable general equilibrium models for the oil and gas sector and, for the Brazilian economy in aggregate, with Dynamic Stochastic General Equilibrium.

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