Energy Prices, Energy Efficiency, and Structural Change: Evidence from Latin America

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Abstract

We study how energy prices drive decoupling in Latin America through two channels: energy efficiency and structural change. We develop a multisector model and test its predictions using historical decomposition and panel fixed-effects analysis. Our findings reveal a sharp dichotomy. The region's decline in energy intensity has been dominated by efficiency gains, and our econometric results confirm this channel is highly responsive to price signals. In contrast, we find no evidence that energy prices induce short-term structural change. This suggests that while price-based policies effectively foster efficiency, guiding the more inertial process of structural transformation requires a broader policy toolkit.

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1 Introduction

The global challenge of reducing greenhouse gas emissions while sustaining economic growth requires policies that promote cleaner technologies and structural transformations across all regions. Latin America faces unique challenges in decarbonizing its economies due to its heavy reliance on fossil fuel exports, large share of emissions from changes in land-use practices and agriculture, and vulnerability of its population to climate change. Understanding how economic forces shape structural change and energy efficiency is essential for designing effective decarbonization strategies in the region. We seek to answer: *What are the primary drivers of the long-term decline in energy intensity in Latin America, and how do energy prices influence the key channels of energy efficiency and structural change?*

Climate policies, such as carbon taxes, aim to reduce CO_2 emissions by incentivizing the adoption of energy-saving technologies and cleaner energy sources. This shift, often driven by Directed Technical Change, entails adaptation costs for firms and workers, potentially affecting economic sectors differently (Nordhaus, 1991; Pearce, 1991). The effectiveness of such policies in achieving decoupling – separating economic growth from emissions – depends fundamentally on their ability to reduce overall energy intensity (energy use per unit of GDP). This reduction can occur through improvements in energy efficiency[1] within sectors or through structural change[2] towards less energy-intensive economic activities (Kaya *et al.*, 1997). In the Latin American context, factors such as labor market informality, inequality, and fiscal dependence on natural resources add complexity to this transition (Ivanova *et al.*, 2024).

We examine the relationship between energy prices, structural change, and energy efficiency in Latin America (LATAM). Our analysis pursues three main objectives: (1) to develop a theoretical model that elucidates how policies influencing energy prices affect energy intensity via efficiency and structural channels; (2) to descriptively decompose historical changes in energy intensity into these two components; and (3) to econometrically estimate the responsiveness of each channel to energy price signals using a comprehensive panel dataset for the region.

In our multisector theoretical model, we show how sectors dependent on non-renewable energy are most affected by policies that increase energy prices. We identify three key mechanisms: incentives for within-sector energy-saving innovation, relative price changes driving resource reallocation between sectors based on energy efficiency, and indirect effects stemming from capital-energy complementarity influencing interest rates and output composition.

To empirically evaluate these mechanisms, we employ a two-part strategy. First, a Fisher

[1] Energy efficiency refers to the reduction in energy use per unit of output within a given sector, often achieved through technological upgrades or process optimization.

[2] Structural change refers to a shift in the composition of the economy from more energy-intensive sectors (e.g., mining or heavy industry) toward less energy-intensive sectors (e.g., services).

ideal index decomposition provides a robust historical perspective on the drivers of energy intensity changes in the region over the past three decades. Second, to test the predictions of our model, we use a panel fixed-effects regression framework. This approach allows us to estimate the relationship between energy prices and our two key outcomes—sectoral energy intensity and sectoral GDP shares—while controlling for unobserved country- and time-specific heterogeneity.

Our main findings reveal a tale of two distinct channels. Descriptively, we find that energy efficiency improvements have been the dominant long-term driver of decarbonization in Latin America, while the contribution of structural change has been more modest and varied. Our econometric results reinforce this distinction: higher energy prices are robustly associated with significant reductions in energy intensity across most sectors, confirming a responsive efficiency channel. In contrast, we find no statistically significant evidence that short-term energy price fluctuations induce large-scale structural change. This suggests that while price signals are effective at incentivizing technological and operational efficiency, the economic structure of a country is far more inertial and responds to deeper, long-run development forces.

We contribute to the literature by providing a unified theoretical and empirical analysis of the two primary channels of energy decoupling in Latin America. Our contribution is twofold. First, we develop a multisector model that formally distinguishes between the energy efficiency and structural change channels. Second, using a comprehensive panel dataset, we provide robust empirical evidence on the differential responsiveness of these two channels to price signals. By highlighting the dichotomy between a responsive efficiency channel and an inertial structural one, our work offers insights for designing effective and realistic climate policies in the region.

The rest of this paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the theoretical model. Section 4 describes our data sources and provides descriptive statistics. Section 5 outlines our decomposition and econometric methodology. Section 6 discusses the empirical findings. Finally, Section 7 concludes.

2 Literature Review

This study connects two distinct but related bodies of literature: the long-run drivers of structural transformation and the analysis of energy intensity. By integrating insights from both, we investigate how energy prices influence the primary channels of decarbonization in Latin America.

First, a vast literature explains long-term structural transformation—the shift from agriculture to manufacturing and then to services—through mechanisms such as non-homothetic preferences and differential productivity growth across sectors (Buera & Kaboski, 2012;

Kongsamut *et al.*, 2001; Matsuyama, 2002). This economic evolution is intrinsically linked to energy use. As economies shift toward less physically intensive services, aggregate energy intensity tends to decrease, contributing to the decoupling of economic growth from environmental pressures (de Groot & Mulder, 2012; Metcalf, 2008). While phenomena like premature deindustrialization can complicate this path in developing regions (Rodrik, 2016), the general link between economic structure and energy use is well-established.

Second, a parallel stream of research uses Index Decomposition Analysis (IDA) to disentangle the historical drivers of changes in aggregate energy intensity. These studies consistently identify two main components: within-sector efficiency gains (the "technique effect") and shifts between sectors (the "structural effect"). For developed countries, studies like Metcalf (2008) find that efficiency improvements are the dominant driver. The evidence for developing regions is more mixed; while some find a similar pattern (Jimenez & Mercado, 2014), the relative importance of each channel often depends on the specific country and time period. Our work contributes to this literature by applying a Fisher index decomposition to provide a comprehensive historical account for Latin America, a region where such detailed, long-term analysis remains scarce.

While these two streams of literature describe the "what" and "how" of energy intensity changes, they often do not explicitly model or estimate the role of market forces, such as energy prices, as a primary driver. Some studies have explored the impact of energy prices on energy consumption, but often at an aggregate level or without distinguishing clearly between the efficiency and structural channels. For instance, Sterner (1985) showed that subsidized energy prices in Mexico led to higher energy intensity primarily through technological choices within industries, suggesting a responsive efficiency channel but an inert structural one. However, there is a gap in the literature that provides a unified framework and panel data evidence on the differential sensitivity of these two channels to price signals across a broad set of developing countries.

This paper aims to fill this gap. We build a multisectoral theoretical model that formally distinguishes between the price-induced efficiency and structural change channels. We then test the predictions of this model using a panel fixed-effects approach for 20 Latin American countries. By doing so, we provide, to our knowledge, one of the first systematic empirical assessments of the differential responsiveness of these two fundamental decoupling mechanisms to energy price changes in the region.

3 Theoretical model

This section presents a multisectoral static general equilibrium model designed to isolate the key mechanisms through which an energy price shock, such as that induced by a carbon tax, affects sectoral output, energy use, and factor prices.

Consumers are assumed to be homogeneous, and there are N productive sectors, each producing a distinct consumption good. Production in each sector utilizes capital, labor, and energy.

3.1 Consumers

Households own the factors of production (capital and labor) and generate energy (though we treat the energy price as exogenous to the household's decision here). The consumer maximizes utility subject to a budget constraint. The representative consumer receives income in the form of wages, w, interest rates, r, and sells of energy, $p_{e,t}\bar{e}_t$. Where $p_{e,t}$ is the price of energy at time t and $\bar{e}_t$ is the amount of energy sold by the representative household at time t.The income of the household is completely devoted to consume the N goods available in the economy. Thus, the consumer's problem is as follows:

$$\max_{c_{i,t}} \sum_{i=1}^{N} \lambda_i \ u(c_{i,t}) \ s.t. \ a_t r_t + w_t + p_{e,t}\bar{e}_t = \sum_{i=1}^{N} p_{i,t} c_{i,t}$$

where N is the number of goods in the economy (as well as the number of sectors) $c_{i,t}$ is the consumption of good i at time t, $p_{i,t}$ is its price, λ_i is the weight of good i in the utility function, β is the discount factor, a_t is the stock of financial assets, and r_t and w_t are the interest rate and the wage at time t. Solving this problem, we find the ratio of expenditure between any two pair of goods.

$$\frac{u'(c_j)}{u'(c_{i,t})} = \frac{p_{j,t}}{p_{i,t}} \frac{\lambda_i}{\lambda_j} \tag{1}$$

Assumption 1: The elasticity of substitution between consumption goods is higher than one.

Lemma 3.1 *For any pair of goods, i and j an increase in the relative price of good i, $\frac{p_{i,t}}{p_{j,t}}$, generates a re-composition of expenditure in favor of good j and against good i:*

$$\frac{\partial \left(\frac{p_{i,t} c_{i,t}}{p_{j,t} c_{j,t}}\right)}{\partial \left(\frac{p_{i,t}}{p_{j,t}}\right)} < 0$$

Proof: It follows directly from equation 1 and Assumption 1.

3.2 Firms

Total GDP is the sum of all the sectoral products, $Y_t = \sum_{i=1}^{N} p_{i,t} Y_{i,t}$, and firms, in each sector, maximize profits:

$$\max_{K_{i,t}, L_{i,t}} \left\{ p_{i,t} A_{i,t} \left(\min\left[K_{i,t}, \gamma_{i,t} e_{i,t}\right]\right)^{\alpha} L_{i,t}^{1-\alpha} - r_t K_{i,t} - w_t L_{i,t} - p_{e,t} e_{i,t} \right\}$$

where $A_{i,t}$ is the total factor productivity (TFP) of sector i at time t, $K_{i,t}$ is capital, $L_{i,t}$ is labor, and $e_{i,t}$ is energy used in sector i. The parameter $\gamma_{i,t}$ represents the energy efficiency of capital utilization in sector i, indicating how many units of energy ($e_{i,t}$) are required per effective unit of capital ($K_{i,t}$).

The choice of functional forms aims to capture economic features relevant to energy policy. The Leontief function $\min[K_{i,t}, \gamma_{i,t}e_{i,t}]$ specification models capital and energy as perfect complements for a given technology $\gamma_{i,t}$. This is justified by the observation that much capital equipment requires a certain flow of energy to operate. Firms are efficient and choose a combination of energy and capital such that $K_{i,t} = \gamma_{i,t}e_{i,t}$. Therefore, the maximization problem can be rewritten in the following way:

$$\max_{K_{i,t},L_{i,t}} \left\{ p_{i,t}A_{i,t}\left(K_{i,t}\right)^{\alpha} L_{i,t}^{1-\alpha} - r_t K_{i,t} - w_t L_{i,t} - p_{e,t}\frac{K_{i,t}}{\gamma_{i,t}} \right\}$$

From the first order conditions of this problem, we find the relation between factor prices and the value of the marginal productivity of each factor.

$$r_t + \frac{p_{e,t}}{\gamma_{i,t}} = p_{i,t}\alpha A_{i,t}(k_{i,t})^{\alpha-1} \tag{2}$$

$$w_t = p_{i,t}(1-\alpha)A_{i,t}(k_{i,t})^{\alpha} \tag{3}$$

Therefore, $r_t K_{i,t} + p_{e,t}e_{i,t} = p_{i,t}\alpha A_{i,t}(K_{i,t})^{\alpha}L_{i,t})^{1-\alpha}$, $w_t L_{i,t} = p_{i,t}(1-\alpha)A_{i,t}K_{i,t})^{\alpha}L_{i,t})^{1-\alpha}$ and

$$r_t K_{i,t} + p_{e,t}e_{i,t} + w_t L_{i,t} = p_{i,t}A_{i,t}K_{i,t}^{\alpha}L_{i,t}^{1-\alpha} \tag{4}$$

Assuming perfect factor mobility, wages and the risk-adjusted required return on capital will be equalized across sectors. However, the total cost of employing capital ($r_t + p_{e,t}/\gamma_{i,t}$) varies across sectors depending on their energy efficiency. We find the relationship, for any two sectors, between relative prices, relative capital-labor ratios, and the cost of energy per unit of capital and relative prices.

$$\frac{p_{i,t}}{p_{j,t}} = \frac{A_{j,t}}{A_{i,t}}\left(\frac{k_{j,t}}{k_{i,t}}\right)^{\alpha} = \left(\frac{k_{i,t}}{k_{j,t}}\right)^{1-\alpha}\frac{A_{j,t}}{A_{i,t}}\left(\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{r_t + \frac{p_{e,t}}{\gamma_{j,t}}}\right) \tag{5}$$

where $k_{i,t} = K_{i,t}/L_{i,t}$ is the capital-labor ratio in sector i.

Solving $\frac{k_{j,t}}{k_{i,t}}$ in equation 5

$$\frac{k_{j,t}}{k_{i,t}} = \left(\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{r_t + \frac{p_{e,t}}{\gamma_{j,t}}}\right) \tag{6}$$

and

$$\frac{p_{i,t}}{p_{j,t}} = \frac{A_{j,t}}{A_{i,t}}\left(\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{r_t + \frac{p_{e,t}}{\gamma_{j,t}}}\right)^{\alpha} \tag{7}$$

Therefore, holding the rest constant, the capital-labor ratio of any sector is a decreasing function of the cost of the energy needed to operate one unit of capital. Moreover, the relative price of two goods depends on the TFP and the cost of operating one unit of capital with energy in each sector. While the rest remain constant, an increase in productivity in the sector i generates a reduction in the price of the good i, and an innovation in energy saving (increase in $\gamma_{i,t}$) reduces the price of good i.

3.3 Equilibrium

In equilibrium, goods markets, and factor markets clear. Combining equations (1) and (7), for any two goods, the relative consumption is a function of: (i) the relative cost of capital, including the cost of the energy needed to operate one unit of capital, (ii) the relative TFP and the relative weight of the goods in the utility function.

$$\frac{u'(c_{i,t})}{u'(c_{j,t})} = \frac{\lambda_j}{\lambda_i}\frac{A_{j,t}}{A_{i,t}}\left(\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{r_t + \frac{p_{e,t}}{\gamma_{j,t}}}\right)^{\alpha} \tag{8}$$

Lemma 3.2 *For any pair of goods, i and j, where good j is more energy-efficient than good i (i.e., $\gamma_{j,t} > \gamma_{i,t}$), an increase in the price of energy, $p_{e,t}$, leads to a reallocation of consumption in favor of good j and against good i:*

$$\frac{\partial\left(\frac{c_{i,t}}{c_{j,t}}\right)}{\partial p_{e,t}} < 0$$

Proof: It follows directly from equation (8) and Assumption 1.

Finally, we assume that the capital market is perfect so all financial assets become capital, $a_t = k_t$. Therefore, from the first-order conditions of the firm and the household budget constraint, it follows that

$$r_tK_t + w_tL_t + p_{e,t}E_t = \sum_{i=1}^{N} p_{i,t}C_{i,t} = \sum_{i=1}^{N} p_{i,t}Y_{i,t} \tag{9}$$

where $L_t = \sum_{i=1}^{N} L_{i,t}$, $K_t = \sum_{i=1}^{N} K_{i,t}$, $E_t = \sum_{i=1}^{N} e_{i,t}$ and $C_{i,t} = c_{i,t}L_t$. We are considering a closed economy, and each sector i produces its corresponding consumption good i. Therefore, for every sector i total output and total consumption are identical.

Proposition 1: *$C_{i,t} = Y_{i,t}$ for every $i \epsilon N$.*

Corollary 3.1 *An increase in the relative price of good i (a decrease in the price of good j)*

leads to a redistribution of output in favor of sector j and against good i:

$$\frac{\partial\left(\frac{p_{i,t}Y_{i,t}}{p_{j,t}Y_{j,t}}\right)}{\partial\left(\frac{p_{i,t}}{p_{j,t}}\right)} < 0$$

Proof: It follows directly from 3.1 and Proposition 1.

3.3.1 Factor prices

Lemma 3.3 *In equilibrium, the interest rate and the wage are given by* $r_t = \alpha\frac{Y_t}{K_t} - \frac{p_{e,t}}{\gamma_t}$ *and* $w_t = (1-\alpha)\frac{Y_t}{L_t}$*, where* $\gamma_t = \frac{K_t}{E_t}$*.*

Proof:
Claim 1: $r_t = \alpha\frac{Y_t}{K_t} - \frac{p_{e,t}}{\gamma_{i,t}}$

(i) $Y_t = \sum_{i=1}^{N} p_{i,t}Y_{i,t}$ so $\frac{Y_t}{K_t} = \sum_{i=1}^{N}\frac{K_{i,t}}{K_t}p_{i,t}\frac{Y_{i,t}}{K_{i,t}}$

(ii) $p_{i,t}\frac{Y_{i,t}}{K_{i,t}} = \frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{\alpha}$

(iii) $\gamma_t = \frac{K_t}{E_t}$ so $\gamma_t = K_t\sum_{i=1}^{N}\frac{1}{e_{i,t}}$ and $\frac{1}{\gamma_t} = \frac{1}{K_t}\sum_{i=1}^{N}\frac{K_{i,t}}{\gamma_{i,t}}$

(iv) There is full capital utilization so $\sum_{i=1}^{N}\frac{K_{i,t}}{K_t} = 1$.

From (i) and (ii)

$$\frac{Y_t}{K_t} = \sum_{i=1}^{N}\frac{K_{i,t}}{K_t}\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}}{\alpha}$$

so

$$\alpha\frac{Y_t}{K_t} = r_t\sum_{i=1}^{N}\frac{K_{i,t}}{K_t} + \frac{p_{e,t}}{K_t}\sum_{i=1}^{N}\left(\frac{K_{i,t}}{\gamma_{i,t}}\right)$$

Combining with (iii) and (iv) $\alpha\frac{Y_t}{K_t} = r_t + \frac{p_{e,t}}{\gamma_t}$. Therefore, $r_t = \alpha\frac{Y_t}{K_t} - \frac{p_{e,t}}{\gamma_t}$.

Claim 2: $w_t = (1-\alpha)\frac{Y_t}{L_t}$.

(v) $Y_t = \sum_{i=1}^{N} p_{i,t}Y_{i,t}$ so $\frac{Y_t}{L_t} = \sum_{i=1}^{N}\frac{L_{i,t}}{L_t}p_{i,t}\frac{Y_{i,t}}{L_{i,t}}$.

(vi) $p_{i,t}\frac{Y_{i,t}}{L_{i,t}} = \frac{w_t}{1-\alpha}$

(vii) There is full employment, so $\sum_{i=1}^{N}\frac{L_{i,t}}{L_t} = 1$

From (v), (vi), and (vii), it follows that $w_t = (1-\alpha)\frac{Y_t}{L_t}$.

Corollary 3.2 *Keeping the rest constant, an increase in the price of energy generates a reduction in the interest rate:* $\frac{\partial(r_t)}{\partial p_{e,t}} = -\frac{1}{\gamma_t}$.

Proof: it follows directly from 3.2.

3.3.2 Decoupling

Decoupling is the process of separating economic growth from environmental degradation. In the context of the model, decoupling is a reduction in the ratio $\frac{E_t}{Y_t}$. In the following lines we identify different ways to affect this ratio. For this purpose, it is useful to define the value of aggregate consumption, c_t, and the share $\sigma_{i,t}$ in sector i in t, GDP: $c_t = \sum_{i=1}^{N} p_{i,t}c_{i,t}$ and $\sigma_{i,t} = \frac{p_{i,t}Y_{i,t}}{Y_t} = \frac{p_{i,t}C_{i,t}}{Y_t}$.

We can also see the effects of labor-saving innovations, energy-saving innovations, changes in the price of energy, and changes in decoupling. Now, notice that energy consumption per unit of GDP can be written as the changes in sectoral composition of output on energy consumption per unit of output, in the following way $\frac{E_t}{Y_t} = \sum_{i=1}^{N} \frac{e_{i,t}}{Y_t}$ so

$$\frac{E_t}{Y_t} = \sum_{i=1}^{N} \left(\frac{Y_{i,t}}{Y_t} \frac{K_{i,t}}{A_{i,t}(K_{i,t})^{\alpha}(L_{i,t})^{1-\alpha}} \frac{1}{\gamma_{i,t}} \right)$$

and

$$\frac{E_t}{Y_t} = \sum_{i=1}^{N} \left(\frac{p_{i,t}Y_{i,t}}{Y_t} \frac{1}{p_{i,t}A_{i,t}(k_{i,t})^{\alpha-1}} \frac{1}{\gamma_{i,t}} \right) \tag{10}$$

Lemma 3.4 *Energy consumption per unit of output can be affected by: (i) Energy-saving innovations in any sector, (ii) increases in the price of energy, (iii) an exogenous sectoral recomposition of output in favor of sectors with low energy intensity (low $\gamma_{i,t}$), (iv) an increase in the interest rate.*

Proof: Recall that $p_{i,t}\alpha A_{i,t}(k_{i,t})^{\alpha-1} = r_t + \frac{p_{e,t}}{\gamma_{i,t}}$, so $p_{i,t}A_{i,t}(k_{i,t})^{\alpha-1} = \frac{1}{\alpha}\left(r_t + \frac{p_{e,t}}{\gamma_{i,t}}\right)$. Therefore, equation (10) implies $\frac{E_t}{Y_t} = \sum_{i=1}^{N} \left(\frac{p_{i,t}Y_{i,t}}{Y_t} \frac{\alpha}{r_t + \frac{p_{e,t}}{\gamma_{i,t}}} \frac{1}{\gamma_{i,t}} \right) = \sum_{i=1}^{N} \left(\alpha \frac{p_{i,t}Y_{i,t}}{Y_t} \frac{1}{\gamma_{i,t}r_t + p_{e,t}} \right)$

Now, define $\sigma_{i,t} = \frac{p_{i,t}Y_{i,t}}{Y_t}$. Therefore,

$$\frac{E_t}{Y_t} = \alpha \sum_{i=1}^{N} \frac{\sigma_{i,t}}{\gamma_{i,t}r_t + p_{e,t}}$$

$$\frac{\partial(E_t/Y_t)}{\partial\gamma_{i,t}} = -\alpha r_t \frac{\sigma_{i,t}}{(\gamma_{i,t}r_t + p_{e,t})^2} < 0 \tag{11}$$

$$\frac{\partial(E_t/Y_t)}{\partial p_{e,t}} = -\alpha \sum_{i=1}^{N} \frac{\sigma_{i,t}}{(\gamma_{i,t}r_t + p_{e,t})^2} < 0 \tag{12}$$

$$\frac{\partial(E_t/Y_t)}{\partial\sigma_{i,t}} = \alpha \frac{1}{\gamma_{i,t}r_t + p_{e,t}} > 0 \tag{13}$$

$$\frac{\partial(E_t/Y_t)}{\partial r_t} = -\sum_{i=1}^{N} \frac{\sigma_{i,t}\gamma_{i,t}}{(\gamma_{i,t}r_t + p_{e,t})^2} < 0 \tag{14}$$

From equations (11), (12), (13) and (14) energy consumption per unit of output can be affected by: (i) Energy saving innovations in any sector (the more efficient the sector the less energy used to produce one unit of the good), (ii) increases in the price of energy, (iii) sectoral redistribution of output (the greater the share of a sector in the economy, the greater its energy consumption), (iv) changes in the interest rate (the higher the interest rate of a sector, the lower its energy consumption).

Now, from equation (12) it follows that given a change in energy prices, for any two sectors i and j, if $\gamma_{i,t} > \gamma_{j,t}$, then $\frac{\partial(e_{i,t}/Y_{i,t})}{\partial p_{e,t}} < \frac{\partial(E_{j,t}/Y_{j,t})}{\partial p_{e,t}}$, so a sectoral re-composition of output in favor of sector i and against sector j reduces the consumption of energy per unit of production.

3.4 Carbon Tax and Energy Efficiency

So far, we have expressed the energy consumption per unit of product as a function of sectoral shares, the intensity with which energy is used in different sectors, the price of energy, and the relative intensity of capital (concerning labor). The next question is: How does environmental policy affect each of these determinants of decoupling? To answer this question, we make three simplifying assumptions that help to carry out a simple and tractable analysis.

- Assumption 2: Carbon tax (τ) directly affects the price of energy, $\frac{\partial p_{e,t}}{\partial \tau} > 0$
- Assumption 3: $\gamma_{i,t}$ is an increasing function of $p_{e,t}$. Therefore, $\frac{\partial \gamma_{i,t}}{\partial \tau} > 0$
- Assumption 4: α does not depend on $p_{e,t}$. Therefore, $\frac{\partial \alpha}{\partial \tau} = 0$

With these results, it is possible to revisit equations (11), (12), (13) and (14) and analyze the effects of a carbon tax.

$$\frac{\partial(E_t/Y_t)}{\partial \tau} = \alpha \left\{ \begin{array}{l} -\sum_{i=1}^{N} \frac{\sigma_{i,t}}{(\gamma_{i,t} r_t + p_{e,t})^2} \frac{\partial p_{e,t}}{\partial \tau} \\ - r_t \sum_{i=1}^{N} \frac{\sigma_{i,t}}{(\gamma_{i,t} r_t + p_{e,t})^2} \frac{\partial \gamma_{i,t}}{\partial \tau} \\ + \sum_{i=1}^{N} \frac{1}{\gamma_{i,t} r_t + p_{e,t}} \frac{\partial \sigma_{i,t}}{\partial \tau} \\ - \sum_{i=1}^{N} \frac{\gamma_{i,t}\sigma_{i,t}}{(\gamma_{i,t} r_t + p_{e,t})^2} \frac{\partial r_t}{\partial \tau} \end{array} \right\} \tag{15}$$

However, recall that, from Corollary 3.2, $\frac{\partial(r_t)}{\partial p_{e,t}} = -\frac{1}{\gamma_t}$. Therefore, $\sum_{i=1}^{N} \frac{\gamma_{i,t}\sigma_{i,t}}{(\gamma_{i,t} r_t + p_{e,t})^2} \frac{\partial r_t}{\partial \tau} = -\sum_{i=1}^{N} \frac{\sigma_{i,t}}{(r_t + p_{e,t})^2} \frac{\gamma_{i,t}}{\gamma_t} \frac{\partial p_{e,t}}{\partial \tau}$ and

$$\frac{\partial(E_t/Y_t)}{\partial\tau} = \alpha \left\{ \begin{array}{l} \displaystyle\sum_{i=1}^{N} \frac{\sigma_{i,t}}{(\gamma_{i,t}r_t + p_{e,t})^2}\left(\frac{\gamma_{i,t}}{\gamma_t} - 1\right)\frac{\partial p_{e,t}}{\partial\tau} \\ \displaystyle - r_t\sum_{i=1}^{N} \frac{\sigma_{i,t}}{(\gamma_{i,t}r_t + p_{e,t})^2}\frac{\partial\gamma_{i,t}}{\partial\tau} \\ \displaystyle + \sum_{i=1}^{N} \frac{1}{\gamma_{i,t}r_t + p_{e,t}}\frac{\partial\sigma_{i,t}}{\partial\tau} \end{array} \right\} \tag{16}$$

Thus, there are three mechanisms through which the carbon tax affects energy consumption per unit of output:

(i) The demand for capital and energy are closely linked. The tax generates an increase in the price of energy, prompting firms to reduce their usage of this input. However, a reduction in energy consumption dampens capital demand, leading to a decrease in interest rates, which, in turn, stimulates the use of both capital and energy. The net effect on each sector depends on its energy efficiency relative to the average efficiency of the economy. More efficient sectors are likely to increase their use of capital and energy in response to the higher energy prices. Therefore, the net effect in the aggregate depends on the relative size of the efficient sectors. If they are relatively big, then the net effect is an increase in energy consumption per unit of output.

(ii) The increase in energy prices stimulates energy-saving innovations, allowing increased production without the corresponding increase in energy consumption.

(iii) The energy price increase affects the prices of final goods differently across sectors, leading to a heterogeneous impact and stimulating a sectoral redistribution of output. If this redistribution favors sectors that are more efficient in energy usage, the overall energy consumption per unit of GDP decreases.

What is the effect of a carbon tax on the sectoral distribution of output? Perhaps the easiest way to answer this question is by analyzing the sectors pairwise to determine the effect of the tax on the relative size of two sectors. Take two sectors, j and i, and use equation (7) to express the relative price as a function of the tax,

$$\frac{p_{i,t}}{p_{j,t}} = \frac{A_{j,t}}{A_{i,t}}\left(\frac{r_t + \frac{p_{e,t}}{\gamma_{i,t}}(1+\tau)}{r_t + \frac{p_{e,t}}{\gamma_{j,t}}(1+\tau)}\right)^{\alpha} \tag{17}$$

Now, recall that $r_t = \alpha\frac{Y_t}{L_t} - \frac{p_{e,t}}{\gamma_{i,t}}$ so $r_t + \frac{p_{e,t}}{\gamma_{i,t}} = \alpha\frac{Y_t}{L_t}$ and

$$\frac{p_{i,t}}{p_{j,t}} = \frac{A_{j,t}}{A_{i,t}}\left(\frac{\alpha\frac{Y_t}{L_t} + \frac{p_{e,t}}{\gamma_{i,t}}\tau}{\alpha\frac{Y_t}{L_t} + \frac{p_{e,t}}{\gamma_{j,t}}\tau}\right)^{\alpha} \tag{18}$$

Thus,

$$\frac{\partial(\frac{p_{i,t}}{p_{j,t}})}{\partial\tau} = \alpha\frac{A_{j,t}}{A_{i,t}}\left(\frac{\alpha\frac{Y_t}{L_t}+\frac{p_{e,t}}{\gamma_{i,t}}\tau}{\alpha\frac{Y_t}{L_t}+\frac{p_{e,t}}{\gamma_{j,t}}\tau}\right)^{\alpha-1} p_{e,t}\frac{\alpha\frac{Y_t}{L_t}}{\left(\alpha\frac{Y_t}{L_t}+\frac{p_{e,t}}{\gamma_{j,t}\tau}\right)^2}\left(\frac{1}{\gamma_i}-\frac{1}{\gamma_j}\right) \tag{19}$$

Therefore, if $\gamma_{j,t} > \gamma_{i,t}$ then $\frac{\partial\sigma_{j,t}}{\partial\tau} > 0$

Proposition 2: *An increase in energy prices leads to a redistribution of output in favor of sectors with higher energy efficiency and against sectors with lower energy efficiency.*

Proof: It follows from Corollary 3.1 and equation 19.

In summary, the theoretical model indicates that carbon taxes influence energy consumption per unit of output, which occurs through three mechanisms: (i) incentives for energy-saving innovations within sectors, (ii) encouragement of sectoral restructuring in favor of sectors with higher energy efficiency, and (iii) discouragement of capital use, which affects sectors more heavily reliant on energy. Due to data limitations, it is not possible to separately estimate mechanisms (ii) and (iii). However, we can estimate the aggregate effect, distinguishing between the within-sector innovation mechanism—hereafter referred to as "energy efficiency" (i)—and a combined structural change effect that pools mechanisms (ii) and (iii).

4 Data and Descriptive Statistics

To empirically analyze the drivers of energy intensity, we construct a balanced panel dataset covering 20 Latin American countries over the period 1990–2020. This dataset, comprising 620 country-year observations, provides the foundation for both our descriptive decomposition and our econometric analysis.

The primary data sources are twofold. Annual Gross Domestic Product (GDP) data, disaggregated by economic activity (ISIC Rev.4), were sourced from CEPALSTAT (ECLAC, 2023). Energy statistics, including detailed final energy consumption balances by end-use sector, were obtained from the Latin American Energy Organization (OLADE) via its SIELAC platform (sielac.olade.org).

An important step in our data preparation involved a detailed harmonization of these sources. We aggregated the granular economic and energy data into five consistent productive sectors for our analysis: (1) Agriculture & Mining, (2) Manufacturing, (3) Construction, (4) Transport, and (5) Services. The detailed mapping is provided in Appendix Table 1, which allows for the precise calculation of sectoral energy intensity (energy consumption per unit of sectoral GDP). Macroeconomic control variables, such as real gasoline prices and inflation, were sourced from the World Bank's World Development Indicators.

Table 1: Sectoral Mapping for Energy Intensity Analysis

Final Aggregated Sector (for Intensity)	**GDP Components (CEPAL)**	**Energy Component (SIELAC)**
1. Agro-Fishing-Mining	Agriculture, hunting and forestry + Mining and quarrying	(Agriculture, fishing and mining)
2. Manufacturing	Manufacturing (excludes Electricity, gas and water)	Industrial
3. Construction	Construction	Construction and others
4. Transport	Transport minus Post and telecommunications	Transport
5. Services	Post/telecom., Finance, Public admin., Trade, Hotels	Commercial, services, public
Sectors excluded from productive energy intensity calculation:		
- Electricity, Gas & Water GDP	Electricity, gas and water supply	Mainly "Own consumption" or "Losses"
- Residential Consumption	Not a productive GDP sector	Residential

Note: Mapping between sectoral GDP (CEPALSTAT) and energy consumption (SIELAC). Backticks denote variables aggregated via R script.

Table 2 presents the summary statistics for the key variables used in our analysis. Several stylized facts emerge from the data, highlighting the region's heterogeneity. Panel A shows vast differences in economic scale, energy consumption, and macroeconomic conditions, with particularly high variance in inflation rates across countries and over time. The average aggregate energy intensity is 9.43 TJ per million USD of GDP, but the large standard deviation (5.82) underscores the diverse energy profiles within Latin America.

Panel B confirms the well-established structural pattern of the region's economies: on average, the Services sector accounts for the majority of GDP (53.7%), while Agriculture (15.9%) and Industry (16.4%) hold smaller yet significant shares. The sectoral energy intensities shown in Panel C reveal a stark hierarchy. The Transport sector is by far the most energy-intensive (45.9 TJ/$GDP), followed by Industry (16.5) and Agriculture (3.9). In contrast, the Services sector, despite its large economic weight, is the least energy-intensive (0.9 TJ/$GDP). This heterogeneity is fundamental to our study, as it implies that shifts in economic structure toward services can significantly lower aggregate energy intensity.

Finally, Panel D provides a first look at our main dependent variables, showing that on average, both the efficiency and structural effects have contributed negatively to energy intensity over the period, confirming the long-term decoupling trend. The substantial variation in these effects across the panel provides the necessary statistical leverage for our subsequent econometric analysis.

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	N
Panel A: Socioeconomic and Energy Variables					
GDP Total (Million USD)	154,091.18	343,244.67	1,022.81	2,357,484.79	620
Final Energy Consumption (TJ)	941,526.27	1,859,576.03	11,209.84	9,948,009.59	620
Total GHG Emissions (kt CO2e)	118,526.27	224,165.25	2,291.32	1,127,554.01	620
Population (thousands)	24,758.53	43,953.89	258.87	213,196.30	620
Renewable Energy Share (%)	29.89	18.54	0.35	74.95	620
Electricity Sector Efficiency (%)	48.25	15.73	13.12	108.72	620
Gasoline Price (USD/bbl)	114.89	60.28	18.05	379.97	351
Inflation (Consumer Price Index) (%)	37.33	357.95	-1.55	7,481.66	573
Energy Intensity (TJ/Million USD)	9.43	5.82	2.15	32.79	620
Carbon Intensity (kt/TJ)	0.1405	0.0588	0.0513	0.3551	620
CO2 per GDP (kt/Million USD)	1.2565	0.8830	0.2345	6.5340	620
Panel B: GDP Sector Shares (%)					
GDP Agriculture	15.90	9.80	1.55	56.25	620
GDP Industry	16.35	4.99	4.53	33.12	620
GDP Construction	6.56	2.55	1.18	20.30	620
GDP Transport	7.47	3.42	2.15	19.33	620
GDP Services	53.73	10.89	24.21	79.41	620
Panel C: Energy Intensity by Sector (TJ/$GDP)					
Energy Intensity Agriculture	3.90	7.14	0.03	58.42	620
Energy Intensity Industry	16.48	14.13	3.27	88.60	620
Energy Intensity Construction	2.21	4.44	0.00	31.23	620
Energy Intensity Transport	45.93	24.64	7.58	156.37	620
Energy Intensity Services	0.90	0.64	0.03	4.07	620
Panel D: Decomposition Effects (rel. 1990)					
Structural Effect	-1.31	1.49	-8.56	3.73	620
Efficiency Effect	-2.07	2.63	-10.36	5.05	620
Intensity Effect	-3.38	3.13	-13.27	4.21	620

Note: The table reports descriptive statistics for 20 Latin American countries over the period 1990–2020 (31 years), totaling 620 observations unless otherwise indicated due to missing data (351 for gasoline prices and 573 for inflation). GDP is expressed in millions of constant USD. Final energy consumption is measured in terajoules (TJ). GHG emissions are expressed in kilotonnes of CO_2 equivalent (kt CO_2e). *Energy Intensity* represents the ratio of total energy consumption to economic output, measured in terajoules (TJ) per unit of GDP. *Carbon Intensity* refers to the amount of CO_2 emissions per unit of energy consumed, measured in kilotonnes per terajoule (kt/TJ). CO_2 per GDP indicates kilotonnes of CO_2 per USD. The decomposition effects are calculated relative to the base year 1990 using a Fisher index logarithmic decomposition: (i) the *Structural Effect* captures changes in aggregate carbon intensity due to shifts in the economic structure—i.e., changes in the share of GDP across sectors with different energy intensities; (ii) the *Efficiency Effect* reflects changes in the energy intensity within each sector, indicating technological improvements or deterioration in efficiency; and (iii) the *Intensity Effect* is the sum of structural and efficiency effects, representing the total change in aggregate energy or emissions intensity relative to 1990. Missing values are due to incomplete records for specific years or countries.

5 Empirical Strategy

Our empirical strategy is designed to test the key predictions of our theoretical model regarding the drivers of energy intensity. We employ a two-part approach. First, we use a descriptive decomposition analysis to quantify the historical contributions of the energy efficiency and structural change channels to the evolution of aggregate energy intensity in Latin America. Second, we use a panel fixed-effects regression framework to econometrically estimate the relationship between energy prices and these two channels.

5.1 Decomposition Analysis: Disentangling Historical Drivers

To separate the historical influence of technological progress from that of economic restructuring, we perform an Index Decomposition Analysis (IDA). Aggregate energy intensity (I_t) at time t is the sum of sectoral energy intensities ($I_{s,t}$) weighted by their respective shares in total output ($S_{s,t}$):

$$I_t = \frac{E_t}{Y_t} = \sum_{s}^{N} \frac{Y_{s,t}}{Y_t} \cdot \frac{E_{s,t}}{Y_{s,t}} = \sum_{s}^{N} S_{s,t} \cdot I_{s,t} \tag{20}$$

Simple decomposition methods often leave a large, uninterpretable residual or interaction term, complicating the attribution of change. To overcome this limitation and achieve a "perfect" decomposition with no residuals, we employ an additive decomposition based on the generalized Fisher ideal index. This approach is widely recognized in the energy economics literature for its theoretical consistency and accuracy (Ang & Zhang, 2000). The Fisher index is considered a superlative index because it uses an average of base-year (Laspeyres) and end-year (Paasche) weights, thus providing a more accurate measure of change that is robust to substitution bias, a method successfully applied in similar contexts by Metcalf (2008).

This method attributes the total change in aggregate energy intensity, $\Delta I_{tot} = I_t - I_0$, to two components.

The first is the *Energy Efficiency Effect* (ΔI_{int}), which isolates the impact of within-sector changes in energy use per unit of output ($I_{s,t}$), holding the economic structure constant. This effect directly corresponds to the impact of energy-saving innovations ($\Delta\gamma_{i,t}$) in our theoretical model.

The second component is the *Structural Change Effect* (ΔI_{str}), which measures the impact of reallocating economic activity across sectors ($S_{s,t}$) with different energy intensities, holding within-sector efficiencies constant. This empirically captures the sectoral recomposition ($\Delta\sigma_{i,t}$) predicted by our model. The total change is thus the sum of these two effects:

$$\Delta I_{tot} = \Delta I_{str} + \Delta I_{int} \tag{21}$$

This decomposition provides a robust historical account of the primary forces driving the evolution of energy intensity in Latin America.

5.2 Econometric Model: Estimating the Price Response

While decomposition analysis is powerful for historical attribution, it does not identify the underlying drivers of efficiency and structural change. To test the core prediction of our theoretical model—that energy prices influence both channels—we employ a panel fixed-effects regression model. This approach allows us to exploit the variation in energy prices across countries and over time to estimate their relationship with our outcomes of interest, while controlling for unobserved time-invariant heterogeneity.

We estimate variants of the following baseline specification:

$$Y_{c,t} = \beta_0 + \beta_1 \log(\text{EnergyPrice}_{c,t}) + \alpha_c + \delta_t + \epsilon_{c,t} \tag{22}$$

where $Y_{c,t}$ is the outcome variable for country c in year t. The main independent variable is the logarithm of real energy prices, for which we use real gasoline prices as a consistent and widely available proxy. The terms α_c and δ_t represent country and year fixed effects, respectively. Country fixed effects control for all time-invariant country characteristics (e.g., geography, institutional quality), while year fixed effects account for common shocks affecting all countries in a given year (e.g., global recessions, technological trends).

The coefficient of interest, β_1, captures the average within-country relationship between energy prices and the outcome variable, after netting out these confounding factors. Standard errors are clustered at the country level to account for potential serial correlation.

We apply this model to two sets of outcome variables to test each channel separately.

To analyze the *Energy Efficiency Channel*, the dependent variable $Y_{c,t}$ is energy intensity, estimated at both the aggregate and sectoral levels. A negative and significant β_1 in these regressions would support the hypothesis that higher energy prices are associated with improved energy efficiency.

To test the *Structural Change Channel*, the dependent variables are the GDP shares of each productive sector. A significant β_1 for any of these shares would indicate that energy prices are correlated with the reallocation of economic activity across the economy.

Finally, we extend this baseline model by including interaction terms to explore whether the effect of energy prices is conditional on other factors, such as the existing level of energy efficiency or the macroeconomic environment (inflation). This allows for a more nuanced understanding of the conditions under which price-based policies are most effective.

6 Results

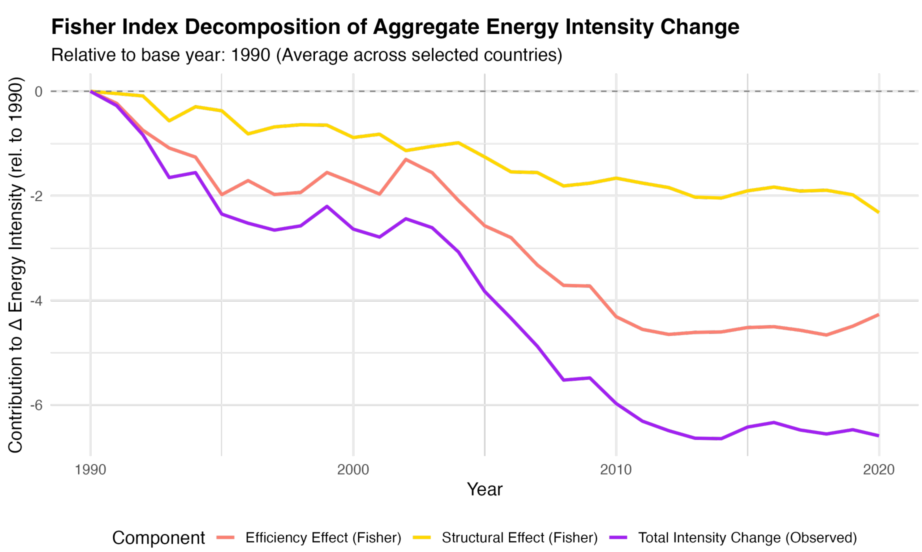
This section presents the empirical results of our study, organized to build a comprehensive narrative from broad trends to specific mechanisms. We begin by descriptively analyzing the evolution of energy intensity in Latin America over the past three decades, using a Fisher index decomposition to disentangle the contributions of the energy efficiency and structural change channels.

We then delve into the sectoral dynamics that underpin these aggregate trends. Finally, we employ a panel fixed-effects methodology to econometrically test the predictions of our theoretical model, specifically examining how energy prices influence both energy intensity and structural change across the region.

6.1 Decoupling Energy Intensity in Latin America

To understand the historical drivers of energy intensity in Latin America, we first note an overall downward trend of 40% from 1990 to 2020. To dissect this trend, we decompose the aggregate change into two main components: the *Energy Efficiency Effect*, which captures within-sector technological improvements, and the *Structural Change Effect*, which reflects the reallocation of economic activity. Figure 1 illustrates the cumulative contribution of these effects to the total change in energy intensity from the 1990 baseline.

Figure 1: Decomposition of Cumulative Change in Energy Intensity



Notes: This figure shows the cumulative change in aggregate energy intensity for Latin America, averaged across 20 countries, relative to the 1990 baseline. The total change in energy intensity (purple line) using an additive Fisher index into the *Energy Efficiency Effect* (pink line) and the *Structural Change Effect* (yellow line). The *Efficiency Effect* captures changes due to within-sector efficiency gains, while the *Structural Change Effect* captures the impact of reallocating economic activity between sectors with different energy intensities.

The results reveal that while both channels contributed to the decline, their relative importance has evolved significantly. The sharpest drop in aggregate energy intensity occurred between 2000 and 2010, a period where, as shown in Figure 1, the *Energy Efficiency Effect* (the red line) clearly emerged as the primary driver of decarbonization. Its contribution deepened consistently and accelerated after 2005, suggesting that as economies in the region modernized, the adoption of more efficient production processes became a dominant force. In contrast, the *Structural Change Effect* (the yellow line), while still contributing to the overall decline, saw its impact plateau from the mid-2000s onwards.

This pattern closely resembles trends observed in developed economies. For instance, Metcalf (2008) found that roughly three-quarters of the decline in U.S. energy intensity since 1970 was driven by efficiency improvements rather than structural changes. Our findings suggest a similar dynamic at play in Latin America, where technological progress within sectors, rather than a fundamental shift in economic structure, has been the primary factor behind the region's most significant decarbonization progress in recent decades.

The quantitative contributions, detailed in Table 3, confirm this evolving dynamic. While efficiency gains were the dominant long-term driver, accounting for over 80% of the total intensity reduction, their relative importance peaked in the 2000s. During this decade, efficiency improvements were so strong they contributed 111% to the decline, compensating for a structural shift that temporarily worked against decarbonization. However, the immense cross-country variation, evidenced by the large standard deviations, suggests that these aggregate trends mask diverse national experiences.

Table 3: Efficiency and Activity Contributions to Changes in Intensity

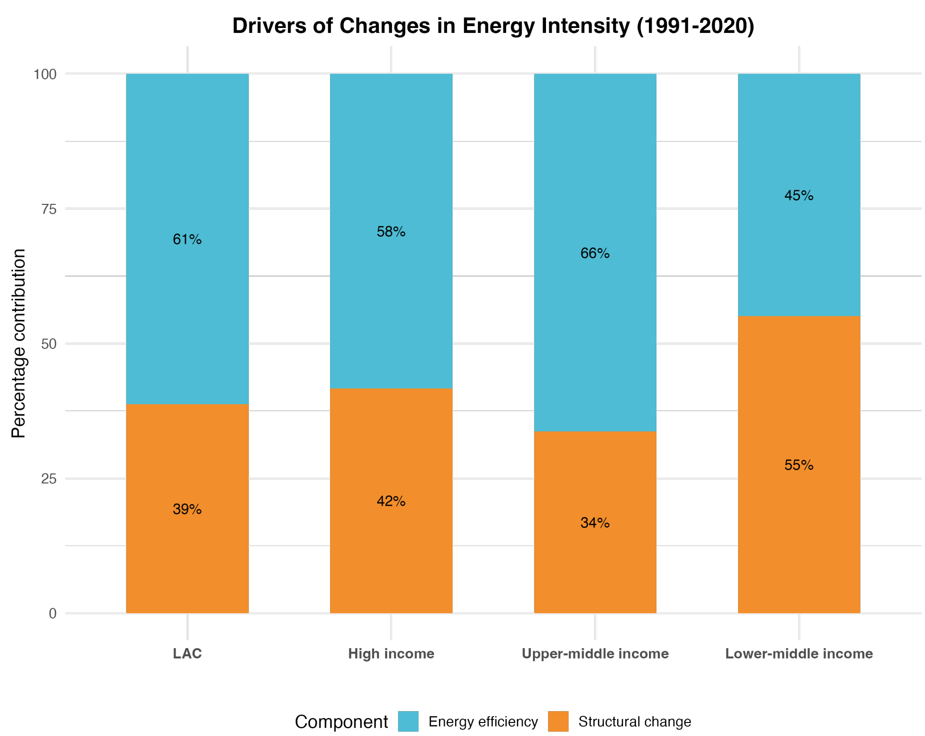
	Mean	**SD**	**Min**	**Max**
Panel A: Full Sample				
Efficiency (%)	80.8	348	-2757	5318
Activity (%)	19.2	348	-5218	2857
Panel B: By Period				
1991–2000				
Efficiency (%)	72.0	515	-2757	5318
Activity (%)	28.0	515	-5218	2857
2001–2010				
Efficiency (%)	111	310	-551	3800
Activity (%)	-11.2	310	-3700	651
2011–2020				
Efficiency (%)	59.1	33.2	-103	99.5
Activity (%)	40.9	33.2	0.453	203

Note: Author's calculations. Values represent the percentage contribution of each component (*Efficiency* or *Activity*) to the total change in energy intensity. Negative values indicate that the component contributed opposite to the overall change. Panel A shows the full sample (1990–2020), and Panel B breaks it into subperiods.

While on aggregate Latin America's decarbonization has been driven by energy efficiency, a disaggregation by country income level reveals distinct development pathways, as shown in Figure 2. For high-income and upper-middle-income countries, the pattern mirrors the regional average: energy efficiency improvements are the dominant factor, accounting for 58% and 66% of the reduction in energy intensity, respectively. This suggests that as countries reach higher levels of development, they are better able to invest in and adopt advanced, energy-saving technologies within their existing economic sectors.

In stark contrast, for the lower-middle-income group, structural change is the primary driver, contributing a majority 55% to the decline. This indicates that for these economies, the main path to reducing energy intensity has not been through technological upgrades within sectors, but rather through a fundamental shift of the economy away from energy-intensive activities (like heavy industry or primary resource extraction) towards less-intensive sectors, such as services. This finding highlights that the strategies for decoupling economic growth from energy use are not uniform and depend heavily on a country's stage of economic development.

Figure 2: Relative Contribution of Decoupling Drivers by Income Group (1990–2020)



Notes: This figure shows the percentage contribution of the *Energy Efficiency Effect* and the *Structural Change Effect* to the total reduction in aggregate energy intensity for the period 1990–2020. The contributions are calculated for the entire Latin America and Caribbean (LAC) sample and for three income groups based on the World Bank classification: High income (5 countries), Upper-middle income (10 countries), and Lower-middle income (5 countries).

6.2 Sectoral Drivers of Decoupling

To understand the underlying dynamics of the aggregate efficiency and structural change effects, we now turn to a sectoral analysis. Figures 3 and 4 disaggregate these two drivers, showing the evolution of each sector's contribution relative to the 1990 baseline.

Figure 3 illustrates the profound structural transformation that has characterized Latin American economies over the past three decades. The most prominent trend is the sustained rise of the *Services* sector, which expanded its share of GDP by approximately 15 percentage points by 2020. This tertiarization of the economy is a hallmark of modernization and a key component of the structural effect. Conversely, the shares of traditionally dominant sectors like *Manufacturing* and *Agro-Mining* have persistently declined, shrinking by roughly 7 and 8 percentage points, respectively. The *Transport* sector also saw a consistent, albeit smaller, contraction in its economic share. These shifts collectively represent a move towards a less physically intensive economic structure, aligning with the positive contribution of the structural effect to decarbonization observed in our aggregate analysis.

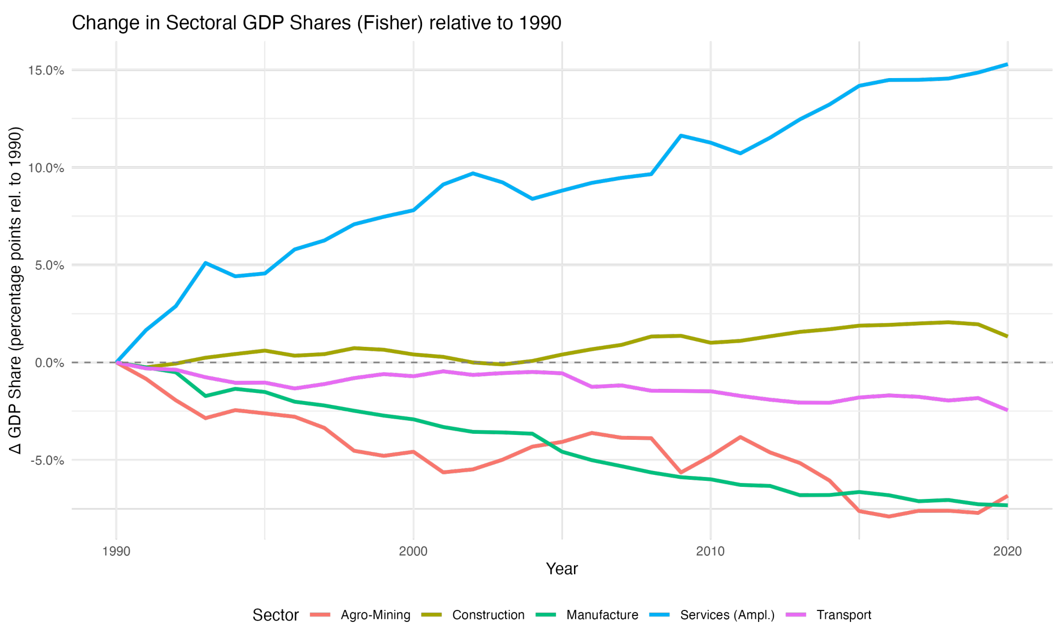


Figure 3: Structural change by sector: change in GDP share relative to 1990.

Meanwhile, Figure 4 reveals the sectoral contributions to the energy efficiency effect, measured as the change in within-sector energy intensity. The story here is one of widespread, albeit uneven, progress. The *Manufacturing* and *Transport* sectors have been the clear leaders in decarbonization, achieving dramatic and sustained reductions in their energy intensity. By 2020, manufacturing had reduced its energy use per unit of output by nearly 15 units, while transport achieved a reduction of over 16 units relative to 1990. These significant gains in traditionally energy-intensive sectors have been the powerhouse behind the aggregate efficiency effect.

The *Agro-Mining* sector also shows a consistent, though more modest, improvement in efficiency over the period. In contrast, the *Services* and *Construction* sectors exhibit much flatter trends, indicating that their energy intensity has remained relatively stable. This highlights an insight: while the economy has shifted towards services (structural effect), the most significant technological efficiency gains have occurred within the industrial and transport sectors.

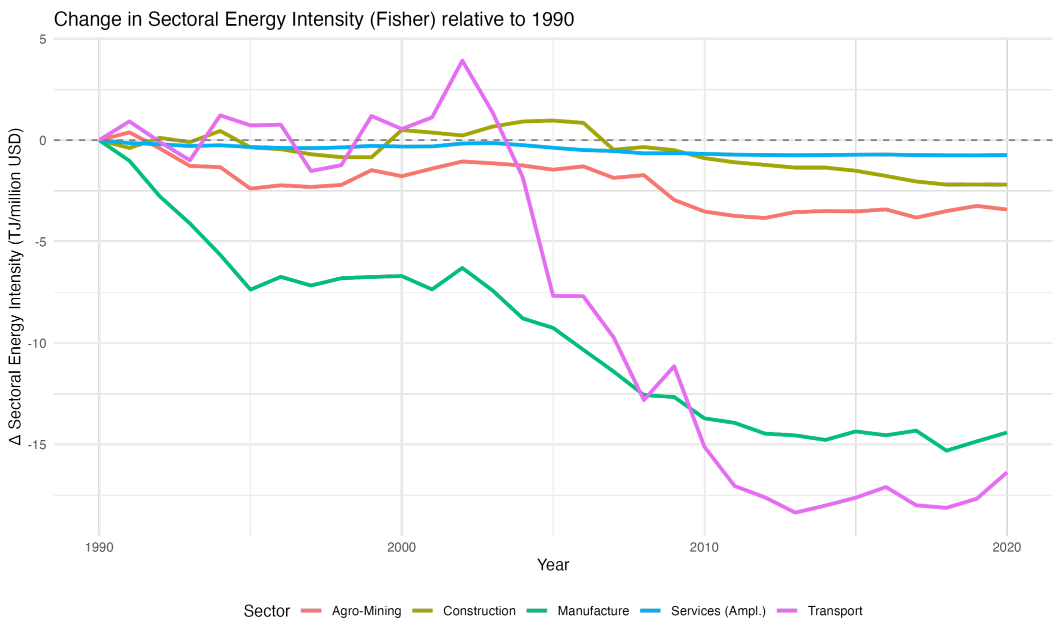


Figure 4: Energy efficiency gains by sector: change in energy intensity relative to 1990.

6.3 Econometric Analysis of Decoupling Channels

Our descriptive analysis reveals that Latin America's decarbonization has been primarily driven by energy efficiency gains, while structural change has followed longer-term development patterns. To empirically test the mechanisms linking energy prices to these two channels, we now employ a panel fixed-effects methodology, using real gasoline prices as a proxy for economy-wide energy costs.

6.3.1 The Energy Efficiency Channel: A Responsive Mechanism

We first test the prediction from our theoretical model that higher energy prices incentivize within-sector efficiency improvements. The results, presented in Table 4, provide strong support for this channel.

Table 4: Effect of Gasoline Prices on Energy Intensity (Aggregate and by Sector)

	Aggregate (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	-0.253**	-0.747***	-0.210*	0.067	-0.270*	-0.391***
	(0.077)	(0.226)	(0.107)	(0.577)	(0.126)	(0.120)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	351	351	351	324	351	351
Adjusted R^2	0.908	0.892	0.866	0.558	0.837	0.755

*p<0.1; **p<0.05; ***p<0.01

Notes: This table presents fixed-effects regressions estimating the impact of gasoline prices on energy intensity at the aggregate level and across sectors. The dependent variables are: Aggregate Energy Intensity (column 1), and Sectoral Energy Intensity for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). The key independent variable is the logarithm of real gasoline prices. All models include country fixed effects and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. The sample includes a balanced panel of countries from [insert years if needed]. Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels.

At the aggregate level, we find a statistically significant elasticity of -0.25, indicating that a 10% increase in real gasoline prices is associated with a 2.5% reduction in overall energy intensity (Column 1). This confirms that higher energy costs ($p_{e,t}$) compel firms to become more efficient, which is equivalent to investing in a higher $\gamma_{i,t}$ in our model.

The sectoral results show this effect is widespread, with particularly strong and significant responses in the *Agriculture & Mining* (-0.75) and *Services* (-0.39) sectors.

To explore this relationship further, Table 5 investigates whether the impact of prices is conditional on existing efficiency levels. The results reveal a synergy: the price effect is significantly amplified in more energy-efficient economies. The joint marginal effect for *Agriculture*, *Transport*, and *Services* is negative and significant, suggesting that price signals are most effective when firms already have the technological capacity or incentive to improve. This highlights a powerful complementarity between price-based policies and direct investments in technology.

Table 5: Effect of Gasoline Prices on Energy Intensity with Interaction in Energy Efficiency

	Aggregate (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	-0.174	0.116	-0.603*	-0.047	0.052	-0.074
	(0.201)	(0.292)	(0.303)	(2.581)	(0.302)	(0.170)
Energy Efficiency (%)	1.020	7.919**	-2.850	-0.626	2.592	3.240**
	(1.351)	(3.579)	(2.190)	(17.926)	(2.471)	(1.180)
log(Gasoline Price) $\times$ *Efficiency*	-0.122	-1.636*	0.822	0.251	-0.647	-0.569**
	(0.313)	(0.767)	(0.473)	(4.051)	(0.568)	(0.259)
Joint Marginal Effect	-0.418	-1.520**	0.218	0.204	-0.595*	-0.643***
	(0.443)	(0.524)	(0.244)	(1.529)	(0.306)	(0.174)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	351	351	351	324	351	351
Adjusted R^2	0.915	0.901	0.882	0.555	0.842	0.773

*p<0.1; **p<0.05; ***p<0.01

Notes: This table reports fixed-effects regressions estimating the impact of gasoline prices, energy efficiency, and their interaction on energy intensity at both aggregate and sectoral levels. The dependent variables are: Aggregate Energy Intensity (column 1), and Sectoral Energy Intensity for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). *Energy Efficiency (%)* represents the percentage of energy efficiency improvement relative to baseline levels. The interaction term captures how the effect of gasoline prices on energy intensity varies with efficiency levels. The **Joint Marginal Effect** corresponds to the combined effect of gasoline prices when energy efficiency is set at 1 (i.e., 100%). All regressions include country and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels.

6.3.2 The Structural Change Channel: A Story of Long-Term Inertia

In contrast, our empirical evidence for a short-term, price-driven structural change channel is considerably weaker. Table 6 examines the direct impact of gasoline prices on sectoral GDP shares. The coefficients are small and statistically insignificant across all productive sectors (Columns 2–6). This suggests that year-to-year fluctuations in energy prices, while sufficient to alter energy use within sectors, do not trigger immediate, large-scale reallocation of economic activity between them.

This finding aligns with the notion that structural change is a slow-moving, inertial process. The vast investments in capital, labor skills, and infrastructure that define a country's economic structure are not easily repurposed in response to short-term price signals. While our descriptive analysis confirmed a decades-long shift towards services, the econometric results imply this transformation is driven by deeper, long-run forces rather than a direct, contemporaneous reaction to energy prices.

Table 6: Effect of Gasoline Prices on Aggregate GDP and Sectoral GDP Shares

	GDP (log) (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	0.200*	-0.015	-0.005	-0.005	-0.001	0.025
	(0.093)	(0.022)	(0.009)	(0.007)	(0.006)	(0.030)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	351	351	351	351	351	351
Adjusted R^2	0.985	0.905	0.851	0.523	0.838	0.894

*p<0.1; **p<0.05; ***p<0.01

Notes: This table presents fixed-effects regressions estimating the impact of gasoline prices on aggregate GDP and sectoral GDP shares. The dependent variables are: aggregate GDP in logarithms (column 1) and sectoral GDP shares for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). All regressions include country and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. Asterisks denote statistical significance at the 10% (*), 5% (**), and 1% (***) levels. Interpretation: A positive coefficient in column (1) indicates that higher gasoline prices are associated with higher aggregate GDP (in logs). Coefficients in columns (2)–(6) capture how sectoral GDP shares respond to changes in gasoline prices.

Even when interacting prices with efficiency levels (Table 7) or inflation, we find no consistent evidence of price-induced structural change. While higher prices in more efficient economies are associated with stronger aggregate GDP growth, this does not translate into significant shifts in sectoral shares.

Table 7: Effect of Gasoline Prices on Aggregate GDP and Sectoral GDP Shares with Interaction in Energy Efficiency

	GDP (log) (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	-0.072	-0.072	0.002	-0.026	0.008	0.088*
	(0.166)	(0.046)	(0.022)	(0.026)	(0.012)	(0.046)
Energy Efficiency (%)	-2.798**	-0.455	0.084	-0.174	0.098	0.447
	(0.896)	(0.322)	(0.174)	(0.182)	(0.111)	(0.372)
log(Gasoline Price) × Efficiency	0.487*	0.117	-0.013	0.041	-0.014	-0.131
	(0.179)	(0.077)	(0.037)	(0.039)	(0.026)	(0.092)
Joint Marginal Effect	0.903***	0.044	-0.011	0.016	-0.006	-0.044
	(0.213)	(0.041)	(0.019)	(0.015)	(0.016)	(0.060)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	351	351	351	351	351	351
Adjusted R^2	0.987	0.912	0.853	0.537	0.852	0.908

*p<0.1; **p<0.05; ***p<0.01

Notes: This table presents fixed-effects regressions estimating the effect of gasoline prices, energy efficiency, and their interaction on aggregate GDP (log) and sectoral GDP shares. The dependent variables are: Aggregate GDP in logarithms (column 1) and sectoral GDP shares for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). *Energy Efficiency (%)* represents the percentage improvement in energy efficiency relative to a baseline. The interaction term captures how the effect of gasoline prices on GDP varies with the level of energy efficiency. The **Joint Marginal Effect** represents the total effect of gasoline prices on GDP when energy efficiency is set at 1 (i.e., 100%). All models include country and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. Asterisks indicate significance at the 10% (*), 5% (**), and 1% (***) levels.

In summary, our empirical analysis robustly validates the efficiency channel as a responsive mechanism linking energy prices to decarbonization. However, it suggests the structural change channel, while crucial in the long run, is largely inelastic to short-term energy price movements.

6.4 Robustness Checks

To ensure the validity of our main findings, we conduct a series of robustness checks, focusing on the potential confounding influence of the macroeconomic environment. High inflation, in particular, can obscure price signals and alter firms' investment and consumption behavior. Therefore, we re-estimate our main specifications including the annual inflation rate and its interaction with the logarithm of gasoline prices.

The detailed results of these regressions are presented in the Appendix. For the energy efficiency channel, the findings remain highly consistent. As shown in Appendix Table 8, the negative and statistically significant relationship between gasoline prices and energy intensity holds even after controlling for inflation. The joint marginal effect remains negative and significant at the aggregate level and for key sectors, confirming that our main conclusion about the responsiveness of energy efficiency is robust.

Similarly, for the structural change channel, the results are unchanged. The inclusion of inflation and its interaction with prices does not reveal any significant relationship between gasoline prices and sectoral GDP shares (see Appendix Table **??**). This reinforces our conclusion that short-term energy price movements are not a primary driver of economic restructuring.

Overall, these checks increase our confidence that the distinction between a responsive efficiency channel and an inertial structural channel is a robust feature of the data and not an artifact of specific macroeconomic conditions.

7 Conclusion

This study investigates the primary drivers of the long-term decline in energy intensity in Latin America, focusing on the distinct roles of energy efficiency and structural change. By combining a multisectoral general equilibrium model with a comprehensive empirical analysis of 20 countries over three decades, we provide a nuanced understanding of the mechanisms through which energy prices shape the path to decarbonization. Our theoretical model predicts that an increase in energy prices can reduce aggregate energy intensity through two main channels: by incentivizing within-sector energy-saving innovation (the efficiency channel) and by encouraging a reallocation of economic activity towards less energy-intensive sectors (the structural change channel). Our empirical findings reveal a tale of two distinct channels with different temporal dynamics. Descriptively, we show that the long-term decline in energy intensity has been predominantly driven by improvements in energy efficiency. Econometrically, our panel fixedeffects analysis validates this distinction: we find robust evidence for a responsive efficiency channel, where higher real energy prices are consistently associated with lower energy intensity across most sectors. This effect is even amplified in economies that are already more energy-efficient, suggesting a synergy between price signals and technological capacity. In stark contrast, we find limited evidence for a price-driven structural change channel in the short to medium term. The long-term shift towards services appears to be driven by deeper, secular development trends rather than a direct response to year-to-year price fluctuations, suggesting that a country's economic structure is highly inertial. These findings have profound policy implications. Price-based instruments—such as carbon taxes or the removal of fossil fuel subsidies—can be expected to be effective tools for encouraging energy efficiency and can yield relatively quick returns. However, policymakers should have realistic expectations about their ability to engineer rapid structural transformation. Fostering a fundamental shift towards a less energy-intensive economy requires a more patient and holistic policy toolkit that includes long-term industrial strategy, public investment in new sectors, and education to build the necessary human capital. Our work highlights that while putting a price on energy is a fundamental first step, it is most powerful as a catalyst for technological change within the existing economic framework, rather than as a primary driver of its wholesale reinvention. Our analysis is subject to certain limitations that open avenues for future research. We use gasoline prices as a proxy for economy-wide energy costs; future work could incorporate more granular, sector-specific energy prices to refine these estimates. Furthermore, our static model does not capture the dynamic feedback between capital accumulation and energy innovation. A dynamic general equilibrium framework could provide deeper insights into these long-run interactions. Finally, while our panel analysis identifies average relationships, country-specific case studies using quasi-experimental methods could further illuminate how institutional quality and local policy design mediate the effects we identify, especially in countries that have implemented explicit carbon pricing.

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A Robustness Checks: Additional Tables

This appendix contains the detailed results of the robustness checks discussed in Section 6.4.

Table 8: Effect of Gasoline Prices on Energy Intensity with Interaction in Inflation

	Aggregate (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	-0.176***	-0.887**	-0.124	-0.817	-0.196	-0.308**
	(0.049)	(0.214)	(0.106)	(0.787)	(0.129)	(0.110)
Inflation (%)	0.007	-0.021	0.016	-0.287***	0.016**	0.015
	(0.006)	(0.019)	(0.014)	(0.064)	(0.005)	(0.012)
log(Gasoline Price) × Inflation	-0.001	0.006	-0.004	0.068***	-0.002*	-0.002
	(0.001)	(0.004)	(0.003)	(0.014)	(0.001)	(0.002)
Joint Marginal Effect	-0.178***	-0.881***	-0.128	-0.749	-0.199	-0.310**
	(0.049)	(0.213)	(0.106)	(0.774)	(0.129)	(0.110)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	309	309	309	309	309	309
Adjusted R^2	0.918	0.893	0.858	0.620	0.850	0.736

*p<0.1; **p<0.05; ***p<0.01

Notes: This table presents fixed-effects regressions estimating the effect of gasoline prices, inflation, and their interaction on energy intensity at both the aggregate and sectoral levels. The dependent variables are: Aggregate Energy Intensity (column 1), and Sectoral Energy Intensity for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). *Inflation (%)* refers to the annual percentage change in the consumer price index (CPI). The interaction term captures how the effect of gasoline prices on energy intensity changes with inflation levels. The **Joint Marginal Effect** corresponds to the combined effect of gasoline prices when inflation is set at 1%. All models include country and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.

Table 9: Effect of Gasoline Prices on Aggregate GDP and Sectoral GDP Shares with Interaction in Inflation

	GDP (log) (1)	**Agriculture** (2)	**Manufacturing** (3)	**Construction** (4)	**Transport** (5)	**Services** (6)
log(Gasoline Price)	0.079	0.002	0.005	-0.015	0.000	0.008
	(0.076)	(0.021)	(0.010)	(0.011)	(0.007)	(0.027)
Inflation (%)	-0.019**	0.002	0.002*	-0.003**	0.000	-0.001
	(0.007)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
log(Gasoline Price) × *Inflation*	0.003*	-0.001*	-0.000	0.001**	-0.000	0.000
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Joint Marginal Effect	0.086	0.001	0.005	-0.015	0.000	0.009
	(0.074)	(0.021)	(0.010)	(0.011)	(0.007)	(0.027)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	309	309	309	309	309	309
Adjusted R^2	0.984	0.903	0.897	0.642	0.856	0.908

*p<0.1; **p<0.05; ***p<0.01

Notes: This table presents fixed-effects regressions estimating the impact of gasoline prices, inflation, and their interaction on aggregate GDP (log) and sectoral GDP shares. The dependent variables are: Aggregate GDP in logarithms (column 1) and sectoral GDP shares for Agriculture and Mining (2), Manufacturing (3), Construction (4), Transport (5), and Services (6). *Inflation (%)* represents the annual percentage change in the consumer price index (CPI). The interaction term captures how the effect of gasoline prices on GDP varies with inflation levels. The **Joint Marginal Effect** represents the total effect of gasoline prices when inflation is set at 1 percentage point. All models include country and year fixed effects. Standard errors, clustered at the country level, are reported in parentheses. Asterisks indicate significance at the 10% (*), 5% (**), and 1% (***) levels.