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Abstract

This paper examines the impact of implementing a carbon tax on aggregate total factor productivity in the Dominican Republic through the resource allocation channel. It incorporates energy inputs—electricity and fuel—into firms' production functions, allowing predictions of potential changes in resource allocation due to the carbon tax. The theoretical implications of the model indicate that the carbon tax has a heterogeneous effect on firms' input choices, contingent on the level of firms' existing input market distortions. Moreover, the model suggests that in economies in which more productive firms are less distorted, the carbon tax can decrease aggregate total factor productivity. In contrast, when more productive firms are more distorted, the carbon tax can increase or decrease aggregate total factor productivity. Utilizing detailed firm-level data from 2009 to 2018, covering up to 118,000 firms, this paper finds that a carbon tax is more effective when levied on fuels rather than electricity. For the majority of sectors in the sample, the paper finds that existing distortions in energy consumption are positively correlated with firm-level productivity. Moreover, the quantitative results show that the introduction of the carbon tax shifts the burden of market distortions from high productivity firms to low productivity ones, generating aggregate total factor productivity gains for most sectors in the Dominican Republic. Overall, this study underscores the importance of considering existing input market distortions when analyzing the impact of environmental taxes.

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The Effect of Carbon Taxes on Aggregate Productivity: the Case of the Dominican Republic

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1 Introduction

In 2015, in correspondence of the Paris Agreement, the Government of the Dominican Republic (DR) submitted its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change.[1] In its NDC, the Dominican Republic has pledged to reduce its greenhouse gas (GHG) emissions by 27% by 2030, relative to the levels recorded in 2010. Despite the effort to meet this commitment,[2] the DR is still an economy which relies heavily on fossil-fuel sources.[3] In similar contexts, countries have considered large-scale regulatory interventions, such as the introduction of a carbon tax.[4] The regulation would provide a strong price incentive for firms to reduce consumption of fossil-fuels and switch to lower carbon alternatives. While contributing to reducing emissions, the introduction of a carbon tax would also affect energy costs, which indicates that it would also have an impact on the allocation of factor inputs across firms.

In this paper, we analyze the impact of a hypothetical carbon tax on aggregate total factor productivity (TFP) through the resource allocation channel. We begin by developing a model in which a carbon tax affects firms' consumption of energy inputs. In this model, the carbon tax is levied on firms' total emissions from the use of electricity and fuel in the production process. Consequently, the introduction of this tax alters the cost of energy inputs, thereby changing firms' demand for all factor inputs, modifying their emission intensities, and affecting aggregate TFP through resource reallocation.[5] Utilizing data from all formal firms in the Dominican Republic between 2009 and 2018, we calibrate the model at the sector level and quantify changes in firm-level emission intensities and aggregate sector TFP under two carbon tax scenarios. Our findings indicate that a carbon tax is more effective when levied on fuels rather than electricity. Additionally, this tax is likely to positively impact aggregate sector TFP for most industries by reducing distortions for high-productivity firms relative to low-productivity ones, thereby reallocating resources from the latter to the former within these sectors. Overall, the study highlights the importance of considering existing input market distortions when analyzing the introduction of environmental taxes.

[1] The Paris Agreement, adopted by 196 Parties in Paris in December 2015, is a legally binding international treaty that aims to limit global warning. It entered into force on November 4, 2016.

[2] Among other initiatives, in 2021 the DR signed a landmark agreement with the World Bank to subsidize reduction of emissions through preventing deforestation.

[3] The GHG footprint of the DR comes from the production and consumption of energy (from fossil-fuels for heating or lighting, for industrial processes, and transport) and partly from the agriculture sector (enteric fermentation and manure left on pasture). Aggregate information can be found on the International Energy Agency (IEA) website, while information at the economic sector level is reported in Sections 2 and 3.

[4] For the case of the DR, see for example the 2018 Collaborative Instruments for Ambitious Climate Action (CI-ACA) Dominican Republic or the 2020 carbon pricing instrument road map. A carbon tax entails imposing a levy on every unit of pollution emitted.

[5] A firm's emission intensity is defined as the emissions produced by its consumption of an energy input per unit of output revenue.

The introduction of carbon taxes is advocated to reduce the carbon footprint of firms and households (Stavins [2020]; Metcalf [2019]). One argument in support of the introduction of this environmental tax is the provision of a direct economic incentive for reducing carbon emissions, alongside revenue generation for climate mitigation initiatives (Allan, Lecca, McGregor, and Swales [2014]). Additionally, these Pigouvian taxes facilitate the internalization of costs connected to adverse externalities arising from pollution, and can potentially drive innovation aimed at reducing carbon emissions (Goulder and Mathai [2010]). On the other hand, a typical concern is *carbon leakage*,[6] that is, the transfer of emissions from the local (regulated) jurisdiction to non-regulated ones as a result of the firms' response to the policy. This concern is limited for small economies such as the DR, which contribute marginally to the global stock of carbon emissions generated worldwide. Other concerns regard the equity, distributional impact, and costs of the implementation of carbon mitigating policies, especially in developing countries. Additionally, the imposition of an environmental tax could bring negative impacts on economic growth, employment, and competitiveness (see, among others, Zhang, Guo, Zheng, Zhu, and Yang [2016]). Negative welfare effects could also arise as firms may pass on the increased energy costs to customers (Fabra and Reguant [2014], Marion and Muehlegger [2011]). Lastly, the efficacy of carbon taxes likely varies given institutional characteristics. For example, Allen, Barbalau, and Zeni [2023] argue that the development of financial market instruments contingent on carbon emissions shapes the optimal level of a carbon tax.

Numerous studies examine the effects of implementing carbon taxes from various perspectives.[7] Köppl and Schratzenstaller [2023] offer an overview of their impact on diverse outcomes including macroeconomic effects, competitiveness, innovation, and distributional implications. The majority of these studies do not identify adverse effects of a carbon tax introduction on GDP growth, employment, competitiveness, or innovation. Some studies aim at uncovering the determinant of emissions and related firm choices (Haller and Murphy [2012]). Firm idiosyncratic characteristics are important in discerning the relationship between firm climate adaptation and performance. In this regard, Capelle, Kirti, Pierri, and Villegas Bauer [2023] provide direct evidence of the positive link between productivity-enhancing investments and lower emission intensity. Similarly, Lanteri and Rampini [2023] prove the importance of financing frictions in determining firm-level emissions. Yet the extant literature scarcely addresses the potential trade-off between TFP and environmental taxes (see, for example, Yamazaki [2022]) or attempts to model directly the change in firms' production process brought by the introduction of such taxes. We fill this void by developing a theoretical framework that incorporates energy consumption as a crucial input within the production function. This

[6]See, among others, Fowlie and Reguant [2022].

[7]The World Bank [2023b] provides the latest information on carbon pricing schemes introduced around the world.

framework enables us to analyze the allocative efficiency consequences of implementing a hypothetical carbon tax at the firm level. Moreover, our model emphasizes the pivotal role of pre-existing distortions within the input market and their implications on the efficacy of such a policy measure.

In our paper, we extend the theoretical framework from Hsieh and Klenow [2009] to allow for differentiated energy inputs such as fuels and electricity and simulate the within-sector interactions of a carbon tax with existing market frictions. We hypothesize the introduction of a carbon tax levied on firms according to their total emissions from the consumption of fuels and electricity. A key insight gleaned from the model is the heterogeneous impact on firms of the carbon tax, contingent on the correlations between the energy distortions with the output and capital wedges, and the correlations between the energy distortions with firm productivity. Specifically, when more productive firms face lower distortions in the energy input markets and when there exists a positive correlation between the capital and output wedges with the energy wedges, the introduction of an environmental tax will decrease aggregate TFP. This occurs because introducing the carbon tax distorts higher-productivity firms more than lower-productivity ones, given that the former initially faced lower distortions. Consequently, resources are shifted from more productive to less productive firms, increasing misallocation and decreasing aggregate TFP. In contrast, if more productive firms face higher distortions or the correlations between the capital and output wedges with the energy wedges are non-positive, then the introduction of a carbon tax can either increase or decrease aggregate TFP.

Using detailed data on firms' tax declarations and energy expenditures from the Direccion General de Impuestos Internos (DGII) of the Dominican Republic and aggregate information from the National Energy Information System (SIEN) between 2009 and 2018, we calibrate the model at the sector level. Using this data, we first provide a back-of-the envelope calculation of the revenues generated by the introduction of a carbon tax rate using plausible scenarios.[8] We find that, based on the most recent estimates in 2018, a tax of \$110/tCO_2 would generate carbon tax revenues approximately of \$920 millions, or roughly 10% of total taxes collected in 2018.[9] On average, this represents roughly 20% of the total earnings reported by the firms in our sample in the same year, although there is substantial variation across sectors. The sectors with the highest carbon emissions footprint and that are also likely to be particularly impacted by the policy in the short term are transport, cement, and hospitality.

We conduct our main counterfactual exercise on the impact of a carbon tax in the DR accounting for input market frictions within sectors. We do not estimate frictions explicitly, but infer them from observed

[8] The estimated carbon prices are the output of an independent analysis on the DR, and are based on the REMIND-MAgPIE 3.0-4.4 model. For more information, see `https://www.ngfs.net/ngfs-scenarios-portal/explore`.

[9] The percentage of total taxes collected in 2018 is computed using an average exchange rate of 49.54 DOP/USD and 430,629 million DOP of total taxes collected in 2018.

output and input choices of firms, in a similar spirit as in Hsieh and Klenow [2009]. We find that for most economic sectors, the most productive firms face the highest levels of distortions. Consequently, for most of these sectors in which this relationship holds, our counterfactual examination predicts that the impact on aggregate sector TFP is projected to be positive. Furthermore, we show that the tax is more effective if it is levied on fuels - which are substantially more emission intensive - rather than electricity.

2 Theoretical Framework

In this section, we build on the theoretical framework developed in Hsieh and Klenow [2009] to determine the impact of a carbon tax on aggregate TFP in presence of market distortions. We assume a single-sector economy in which the final good is produced from a set of intermediate goods in the economy. Producers of the intermediate goods act monopolistically and choose the optimal combination of labor, capital, electricity, and fuel to maximize profits. The production of the intermediate goods generates carbon emissions through consumption of fossil-fuel energy sources. Carbon emissions are taxed at a fixed rate which accounts for the social damage generated by releasing carbon in the atmosphere.

Denote y as the final good produced by a representative firm facing a perfectly competitive output market. The firm combines output from a set of m intermediate goods $\{y_i\}_{i=1,...m}$ using a Cobb-Douglas production technology:

$$y = (\sum_{i=1}^{m} y_i^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

with $\sigma > 1$. The firm solves the following profit maximization problem:

$$\max_{i=1,...m} py - \sum_{i=1}^{m} p_i y_i, \tag{2}$$

with p and p_i defined as the prices of the final good y and of the intermediate good y_i, respectively, and satisfying the zero profit condition $py = \sum_{i=1}^{m} p_i y_i$. Each intermediate good, y_i is produced from capital, k_i, labor, l_i, electricity, x_i, and fuel, f_i as:

$$y_i = a_i k_i^{\beta_k} l_i^{\beta_l} x_i^{\beta_x} f_i^{\beta_f}, \tag{3}$$

with the coefficients of output elasticities sufficing $\beta_l + \beta_k + \beta_x + \beta_f = 1$. Firm i's quantity-based total factor productivity is denoted as a_i and represents how efficient firm i is at transforming its demanded inputs into a unit of the intermediate good. The production of output y_i generates emissions from the consumption of electricity and fuel, e_{xi} and e_{fi}, respectively, given by:

$$e_{xi} = \eta_x x_i, \quad e_{fi} = \eta_f f_i, \tag{4}$$

with η_x as the carbon content of the fuel mix used to generate electricity x_i, and η_f as the carbon content of the fuel f_i used as direct input for producing y_i, both taken as given.[10] We assume that emissions e_{xi} and e_{fi} are taxed at a fixed rate λ. Furthermore, we denote the cost of capital, labor, electricity, and fuel as r, w, z_x, and z_f respectively.

Intermediate Good Producer's problem. Each intermediate good i is produced by a monopolist which chooses the optimal combination of inputs $\{k_i, l_i, x_i, f_i\}$ to maximize profits:

$$\max_{k_i,l_i,x_i,f_i} p_i(1-\tau_{yi})y_i - wl_i - r(1+\tau_{ki})k_i - z_x(1+\tau_{xi})x_i - z_f(1+\tau_{fi})f_i - \lambda(e_{xi}+e_{fi}). \tag{5}$$

The first three terms in (5) are the same as in Hsieh and Klenow [2009]. The output price $p_i = y^{\frac{1}{\sigma}} y_i^{-\frac{1}{\sigma}} p$ is such that to maximize the representative producer's profits in (2),[11] whereas the wedges τ_{yi} and τ_{ki} are interpreted as distortions in the output and capital markets, which alter the optimal input choices of producer i. Output distortions τ_{yi} reflect government size restrictions, output subsidies or transportation costs, whereas capital distortions τ_{ki} are likely the result of credit constraints or subsidized access to credit.

The fourth and fifth terms represent the additional energy input costs. The wedges τ_{xi} and τ_{fi} are existing distortions in the electricity and fuel markets. In practice, firms facing higher (lower) wedges τ_{xi} or τ_{fi} have a higher (lower) cost of energy for each unit of production, resulting in under-consumption (over-consumption) of fossil fuels. Those wedges may capture information asymmetries regarding energy efficient technologies, bounded rationality, and/or managerial myopia or incentives to adopt energy efficiency measures (DeCanio [1993], Howarth, Haddad, and Paton [2000]). Importantly, the wedges $\{\tau_{yi}, \tau_{ki}, \tau_{xi}, \tau_{fi}\}$ can be generally correlated within firms. For example, recent research in Iovino, Martin, and Sauvagnat [2021] has documented a positive relationship between subsidized access to debt financing and higher emissions intensity, whereas a work by Shapiro [2021] has shown that emissions intensive industries are more protected by import trade policies. In the case of the DR, the energy market suffers from significant energy losses due to poor infrastructure and electricity theft, which effectively increase operating costs. A compounding

[10] Note that η_x and η_f are kept constant across intermediate goods' production functions $i = 1, \dots m$. In the calibration section, we let η_x and η_f vary across industries and regions.

[11] That is, each producer i acts monopolistically, anticipating the effect of its production choices on the intermediate good price p_i. This specification is taken from Hsieh and Klenow [2009].

effect is also the heavy reliance on imported fossil fuels, which introduces cost volatility. Additionally, a lack of investment in electrical infrastructure perpetuates poor service quality and ongoing dependence on subsidies, affecting firms heterogeneously.

Finally, the sixth term represents the total carbon tax expenditure incurred by the producer, which is given by the carbon tax λ applied to total emissions from consumption of electricity and fuel respectively. This last term appears uniquely if the economy is subject to a carbon tax.

In summary, the allocation of resources across firms depends not only on the firms' productivity, a_i, but also on the output, capital, and energy distortions they face. Hsieh and Klenow [2009] show that to the extent that resource allocation is driven by distortions rather than productivity, this will result in differences in the marginal revenue products of capital, labor, and energy. These marginal revenue products are as defined:

$$\begin{aligned} mrpl_i = \beta_l \frac{\sigma-1}{\sigma}\frac{p_i y_i}{l_i}, \quad mrpk_i = \beta_k \frac{\sigma-1}{\sigma}\frac{p_i y_i}{k_i} \\ mrpx_i = \beta_x \frac{\sigma-1}{\sigma}\frac{p_i y_i}{x_i}, \quad mrpf_i = \beta_f \frac{\sigma-1}{\sigma}\frac{p_i y_i}{f_i} \end{aligned} \tag{6}$$

Outcomes of interest. Our model allows us to evaluate the implications of introducing the carbon tax λ on firm-level emissions intensities, market structure, and aggregate TFP. To this end, we define producer i's emission intensity from electricity and fuel as the total emissions produced by their consumption per unit of output revenues

$$\xi_{xi}^{\lambda} = \frac{e_{xi}}{p_i y_i} \quad \text{and} \quad \xi_{fi}^{\lambda} = \frac{e_{fi}}{p_i y_i}. \tag{7}$$

Furthermore, we study the market structure leveraging firms' market shares, which are defined as the share of firm i's output revenue in aggregate output revenues:

$$s_i = \frac{p_i y_i}{\sum_{i=1}^{m} p_i y_i} = \frac{p_i y_i}{py}. \tag{8}$$

Lastly, aggregate TFP of the economy is defined by:

$$\text{TFP} = \frac{y}{K^{\beta_k} L^{\beta_l} X^{\beta_x} F^{\beta_f}}, \tag{9}$$

with aggregate output, y, as in (1) and where $K = \sum_{i=1}^{m} k_i$, $L = \sum_{i=1}^{m} l_i$, $X = \sum_{i=1}^{m} x_i$ and $F = \sum_{i=1}^{m} f_i$ are the aggregate demand of capital, labor, and energy inputs in the economy

Absence of distortions. In what follows, we first want to assess the equilibrium effect of the tax λ on the endogenous emissions intensities in (7), the market share in (8), and aggregate TFP in (9) respectively in absence of distortions, i.e. when the wedges equal 0 $\{\tau_{yi} = 0, \tau_{ki} = 0, \tau_{xi} = 0, \tau_{fi} = 0\}$ for each $i = 1, \dots m$. We prove in the Appendix the following:

Proposition 1. *In absence of distortions, producer i's optimal emissions intensities, ξ^{λ}_{xi} and ξ^{λ}_{fi}, in* (7) *are constant across firms and decrease with the carbon tax, λ, as:*

$$\xi^{\lambda}_{xi} = (\frac{\sigma}{\sigma - 1})\frac{\eta_x \beta_x}{z_x}\frac{1}{1 + \alpha^{\lambda}_x}, \quad and \quad \xi^{\lambda}_{fi} = (\frac{\sigma}{\sigma - 1})\frac{\eta_f \beta_f}{z_f}\frac{1}{1 + \alpha^{\lambda}_f}, \tag{10}$$

where $\alpha^{\lambda}_x = \lambda\eta_x/z_x$ and $\alpha^{\lambda}_f = \lambda\eta_f/z_f$ are the ratios of the energy inputs' tax relative to the energy inputs' costs.

Corollary 1.. *Producer i's market share, s^{λ}_i, in* (8) *and aggregate total factor productivity, TFP^{λ}, in* (9) *are the same as in a frictionless economy without a carbon tax.*

Proposition 1 and Corollary 1 offer a useful set of predictions regarding the benchmark impact of the carbon tax absent distortions in the input and output markets. Equation 10 implies that each producer i's emissions intensity ξ^{λ}_{ix} (ξ^{λ}_{if}) is reduced by a higher amount the higher the fuel tax α^{λ}_x (α^{λ}_f). This means that for a given carbon tax λ, the higher carbon content of the energy source, η, and the lower the unregulated price of the energy source, z, the higher the effect of the tax on the producer i's input choices. Importantly, such effect is constant across producers i in the economy since each producer faces the same energy price.

Furthermore, Corollary 1 states that, absent distortions, we should not expect the tax to alter the market structure nor the efficient allocation of resources within the economy. Indeed, the unique effect of the tax λ is that of reducing aggregate demand of fossil-fuel inputs X and F, and therefore total carbon emissions in such a way as to account for the negative externality.

Importantly, Proposition 1 also offers a testable implication to detect the presence of distortions in the energy markets. Specifically, absent distortions, and in absence of the carbon tax $\lambda = 0$, the proposition implies that all firms should have the same baseline emissions intensities, which we denote as $\xi^{*}_{xi} = (\frac{\sigma}{\sigma-1})\frac{\eta_x \beta_x}{z_x}$ and $\xi^{*}_{fi} = (\frac{\sigma}{\sigma-1})\frac{\eta_f \beta_f}{z_f}$. Consequently, according to the model, any variation in the baseline emissions intensities that we observe in the economy should be attributed to the presence of distortions.

We now move to the general case in which the economy presents distortions as represented by $Var(\tau_{ji}) > 0$ for $j = y, k, x, f$. We prove in the appendix the following

Proposition 2. *In presence of distortions, producer i's optimal emissions intensities, ξ^{λ}_{xi} and ξ^{λ}_{fi} in* (7), *are heterogeneous across firms and decrease with the carbon tax, λ, as:*

$$\xi_{xi}^{\lambda} = (\frac{\sigma}{\sigma-1})\frac{\eta_x \beta_x}{z_x}\frac{(1-\tau_{yi})}{1+\tau_{xi}+\alpha_x^{\lambda}}, \qquad \xi_{fi} = (\frac{\sigma}{\sigma-1})\frac{\eta_f \beta_f}{z_f}\frac{(1-\tau_{yi})}{1+\tau_{fi}+\alpha_f^{\lambda}}. \tag{11}$$

Corollary 2.. *Producer i's market share, s_i^{λ}, in* (8) *and aggregate total factor productivity, TFP^{λ}, in* (9) *are different from the economy with distortions and no carbon tax.*

Proposition 2 highlights that, setting $\lambda = 0$, the presence of market distortions generate heterogeneity in emissions intensities across producers i. Specifically, producers who experience a cheaper (more expensive) access to the output market and or a cheaper (more expensive) access to the energy market, as reflected in lower (higher) wedges τ_{yi}, τ_{xi}, and τ_{fi} respectively, have a higher (lower) emission intensity.

Second, we note that introducing a tax λ would now reduce emissions intensities heterogeneously across producers. Specifically as we show in the appendix, the marginal effect of the tax on emissions intensities depends on the initial energy wedges τ_{xi} and τ_{fi}. The lower the wedges, the higher the marginal impact of the tax, and thus the relative decrease in the producer's emissions intensity.

Corollary 2 implies that the impact of λ on emissions intensities ξ_{xi}^{λ} and ξ_{fi}^{λ} will also be reflected in the market structure, i.e., in each firm's market share s_i^{λ}. As we detail in the model Appendix, the market share of producers i with cheaper (more expensive) access to energy markets will be reduced (increased) respectively. This is an important feature of the tax as it reallocates resources from less energy constrained to more energy constrained firms.

Whether such alteration ultimately has a positive or a negative effect on aggregate TFP depends on the correlation between the energy distortions $\{\tau_{xi}, \tau_{fi}\}$ and the capital and output distortions $\{\tau_{ki}, \tau_{yi}\}$, as well as on the correlation between the energy distortions $\{\tau_{xi}, \tau_{fi}\}$ and firm quantity-based TFP, a_i. When a_i and $\{\tau_{xi}, \tau_{yi}, \tau_{ki}, \tau_{fi}\}$ are jointly log-normal, following Hsieh and Klenow [2009], we derive in the Appendix an explicit expression for the aggregate TFP, which allows us to introduce the following:

Corollary 3.. *Let a_i and $\{\tau_{xi}, \tau_{yi}, \tau_{ki}, \tau_{fi}\}$ be jointly log-normally distributed. Then a sufficient condition for the carbon tax, λ, to decrease aggregate TFP with respect to the distorted economy without a tax is that, for each energy wedge τ_{ji} with $j = x, f$:*

$$Corr(\tau_{ji}, a_i) < 0, \quad Corr(\tau_{ji}, \tau_{ki}) \geq 0 \quad \text{and} \quad Corr(\tau_{ji}, \tau_{yi}) \geq 0. \tag{12}$$

Furthermore, under such condition, the higher the output elasticities of electricity and fuel β_x and β_f, the *higher the reduction in aggregate TFP generated by the tax. If the inequalities in* (12) *are not jointly verified, then the impact of the tax, λ, on aggregate TFP is ambiguous and depends on the magnitude of the tax, λ, relative to the energy prices, z_f and z_x, the output elasticities, β_x and β_f, and the correlation between the energy wedges, $\{\tau_{fi}, \tau_{xi}\}$, and $\{a_i, \tau_{ki}, \tau_{yi}\}$.*

Corollary 3 outlines a sufficient condition for a homogeneous carbon tax to negatively affect aggregate TFP in presence of distortions. Intuitively, when more productive firms face lower energy distortions, i.e. when $Corr(\tau_{ji}, a_i) < 0$, we can expect the tax to decrease aggregate TFP in equilibrium. This is because when $Corr(\tau_{ji}, a_i) < 0$, then firms that are more productive have cheaper access to energy markets, which implies that distortions tend to favour more productive firms over less productive ones. Introducing the tax would increase such distortions for more productive firms relative less productive firms in the economy. Vice versa, when $Corr(\tau_{ji}, a_i) > 0$, then we should expect that the effect of the tax on aggregate TFP is at least ambiguous, implying that the tax, λ, has the potential to increase it. This is because the tax alleviates market distortions in favor of more productive firms in the economy. Lastly, the higher the output elasticities of energy, the stronger the positive/negative impact of the tax on aggregate TFP.

3 Construction of the Dataset

The empirical exercises carried out in this paper combine firm-level data and an energy balance matrix to estimate emissions at the firm level in the Dominican Republic. The first source of firm-level information is the tax forms from the Direccion General de Impuestos Internos (DGII), which compiles tax declarations for the universe of formal firms required to file taxes in the Dominican Republic between 2007 and 2021. The number of firms each year averages around 90,000, ranging from 55,000 in 2007 to close to 129,000 in 2021. Through these tax declarations, we have the necessary information to track and compute several firm performance variables, including sales, production, value added, and productivity. Also key to our analysis is firms' expenses and liabilities, as this will be the conduit through which a CO2 tax affects firms. The database also includes relevant firm characteristic variables such as the economic sector of activity and geographical location. We complement this information with data from the National Energy Information System (SIEN). SIEN reports energy consumption and energy generation by type of source and economic activity, as well as CO2 emissions by aggregate sectors. SIEN also details how energy is used in the main areas of consumption. This is complemented by data on supply flows, including supply, transformation centers, and final energy consumption. With this information, it is possible to estimate total emissions related to purchase of energy by fuel type and by economic activity. Aggregate information from SIEN is provided between 2009 and 2018, whereas firm-level information from the DGII is available between 2007 and 2021. Our analysis refers to the combined dataset relative to the period 2009–2018. Summary statistics at the activity level are reported in Appendix B.1.

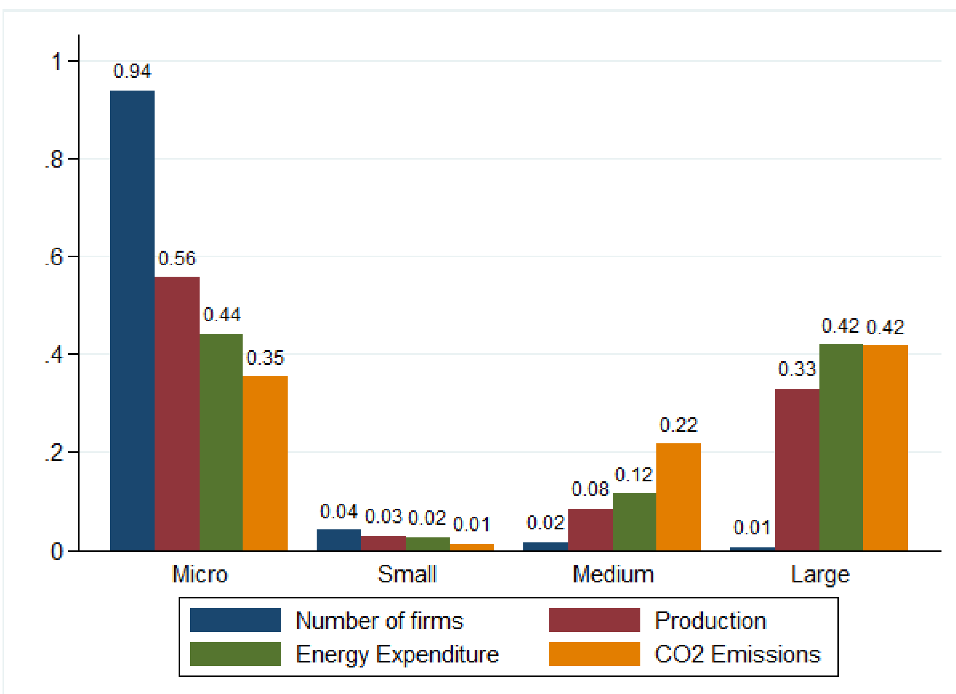
Estimation of CO2 emissions. Form 606 provides the link between DGII firm data and SIEN emissions data, which enables us to estimate energy consumption and CO2 emissions by firm. Form 606 is a monthly report submitted by companies to DGII that provides information on the purchase of goods and services that include a tax receipt number (NCF). To quantify the energy consumption and CO2 emissions by firm, we leverage on the information on purchases of different fuels for energy generation as well as electrical energy purchases. The energy activities reported in Form 606 are displayed in Appendix B.2.

Emissions from Electricity Consumption. A firm's expenditure in electricity is equated to a firm's expenditure reported in Form 606 in sectors 4011 (electric energy generation), 4012 (transportation of electric energy), and 4013 (distribution and sale of electric energy). Using a firm's location, it is possible to assign a price per KWh to each firm based on the average price reported by the Dominican Republic's electricity distribution companies: EDESUR, EDENORTE, and EDEESTE (EDEs). Each of the EDEs serves a specific region in the country, and there is variation in the average electricity price across regions. Dividing the firm's electricity expenditure by its location's average electric price, we estimate the firm's energy consumption in kilowatt-hour (kWh). To estimate CO2 firms' emissions from electricity consumption, it is necessary to estimate a conversion factor from kWh consumed to kilogram (kg) of CO2 emissions. BNE provides information on the total Gigawatt hour (GWh) of electricity produced, with the SIEN representing nearly 93.3 percent of the 21.7 thousand GWh of electricity generated, isolated systems accounting for 5 percent, and auto producers for the remaining 1.7 percent. Dividing the total electricity generated in GWh by the total emissions of CO2 in kg, we obtain the conversion factor needed to transform firms' electricity consumption into firms' emissions of CO2.

Emissions from Fuel Consumption. In addition to electricity consumption, many firms produce emissions through consumption of different types of fossil fuels in their production and transportation processes. Ideally, we would want to know a firm's expenditure on each type of fuel so that we can perform a similar exercise as with electric consumption to estimate firms' emissions from fuel consumption; however, the information provided in Form 606 is aggregated by energy sector as described in Appendix B.2. To estimate emissions from fuel consumption, we compare the International Standard Industrial Classifications (ISICs) reported for each firm by DGII to the economic activity sectors reported in SIEN's CO2 emissions tables. We then estimate firms' emissions by distributing the economic activity's emissions reported by SIEN based on firms' proportion of non-electric energy expenditure from Form 606 for that economic activity. For example, SIEN reports that the agriculture sector emitted 220,000 tons of CO2 in 2018. These 220 tons of CO2 get assigned to all firms for which their activity reported by DGII is agriculture, and a firm's share of those 220,000 tons of CO2 is equal to each firm's share of total non-electric energy expenditure reported by Forms 606 for the agriculture sector in 2018. Detailed information on the estimation process is reported in the Appendix B.2.

Statistics. According to the universe of close to 118,000 firms reported in DGII data in 2018, nearly 97 percent of Dominican firms are micro or small (1 to 19 employees), with the remainder being medium or large. Microfirms are responsible for 56 percent of production, 44 percent of energy spending, and 35 percent of total CO2 emissions in the Dominican Republic. On the other side of the spectrum, even though large firms only represent 1 percent of total firms, they concentrate an important share of economic activity, including 33 percent of aggregate production, 42 percent of total energy spending, and 42 percent of total CO2 emissions.

Figure 1. Economic activity by firm size

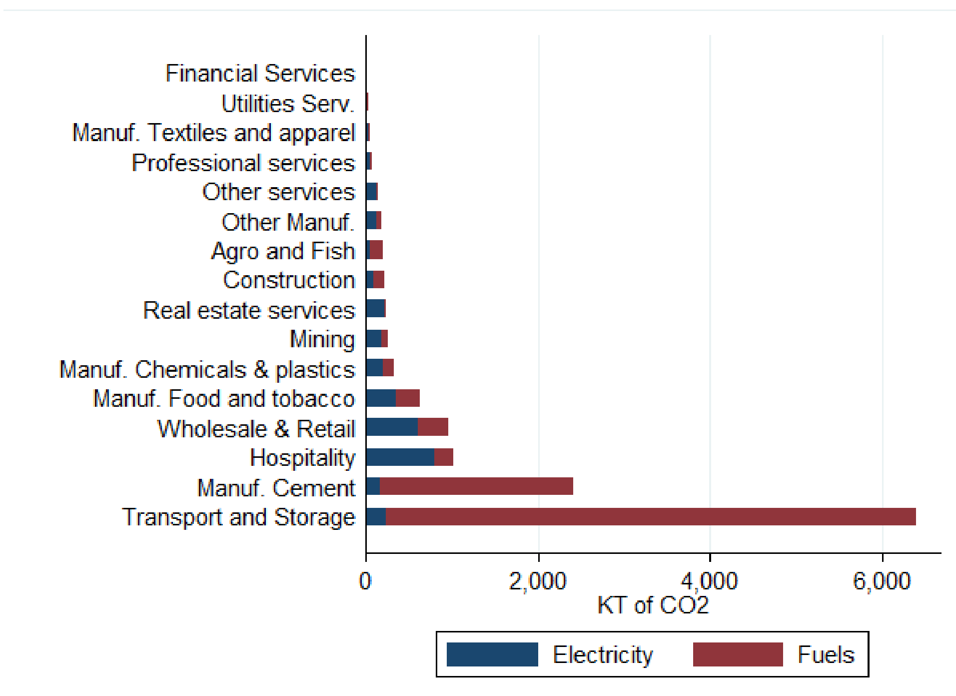


Note: This graph shows the distribution of firms, economic activity, and CO2 emissions by firms' size. Firms' size is based on employment and is categorized as follows: microfirms are firms with less than 5 employees, small firms are those with 5 to 19 employees, medium firms have 20 to 99 employees, and large firms have 100 or more employees.

Tables B2 through B5 in the appendix report the mean, median, minimum, and maximum values for production, EBIT, energy expenditure, and total CO2 emissions for each economic activity in 2018, respectively. The pattern that is consistent with all four variables is that there is a large dispersion between firms in the same economic activity, with large firms (in terms of the respective variable) driving the mean away from the median, resulting in a skewed distribution. The statistics suggest that there are few large firms that drive economic activity and emissions in the country. Table B5, for example, shows that the median emission for most economic activities is equal to zero, but the maximum values tend to be large for most activities, especially transport and storage, manufacturing of cement, lime, and plaster, and mining and quarrying.

The highest CO2 emitting sectors in 2018 were transport and storage (6,397 KT), cement manufacturing (2,408 KT), and hospitality services (1,016 KT) with the difference that close to 95 percent of transport and storage, and cement manufacturing emissions are produced by the burning of fuels, whereas 80 percent of emissions from hospitality services arise from the consumption of electricity (see Figure 2).

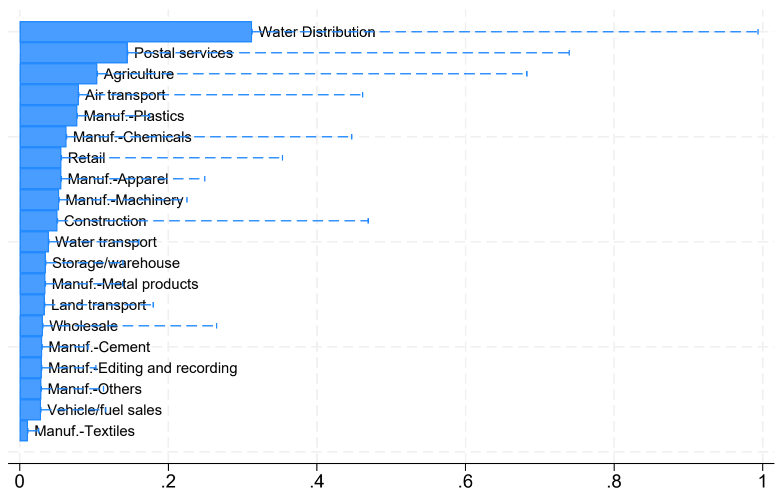
Figure 2. Emissions by economic sector



Note: This figure shows total firms' emissions of CO2 by energy type in 2018. The majority of CO2 emissions are produced by the consumption of fuels in the transport and storage sector. The hospitality services sector, on the other hand, is an important emitter of CO2 from the consumption of electricity.

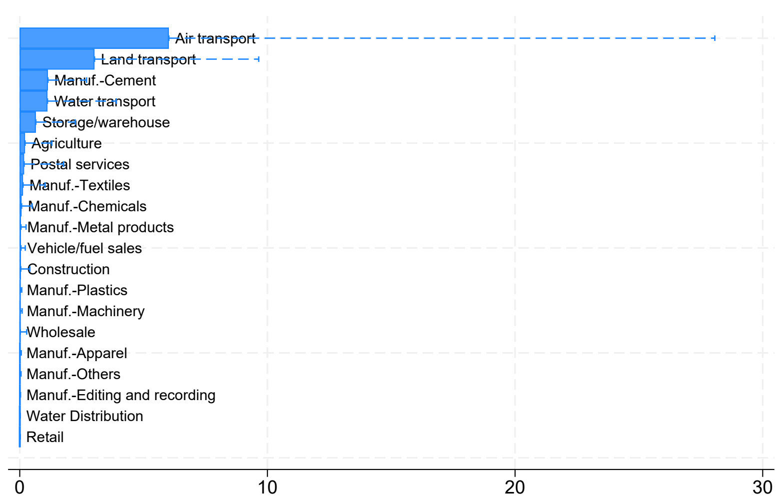
The distribution of emissions intensity (i.e., firm emissions/value added) among the different types of firms and sources of energy is a key element in understanding the possible effects of the tax on misallocation of resources within sectors. In practice, we observe substantial variation in electricity and fuel emissions across and within sectors. Among the most intensively emitting sectors based on their consumption of electricity are water distribution, postal services, and agriculture, whereas the most intensively emitting sectors based on their consumption of fuels are air transport, land transport, and the manufacturing of cement (see Figure 3 and Figure 4).

Figure 3. Electricity Emission Intensity



Note: The bar plot shows the average emissions intensity from electricity consumption by economic sector. Emissions intensity is computed as total emissions by electricity consumption divided by value added. Data are from DGII and SIEN and are relative to 2018. Dotted blue lines refer to standard deviations within sectors.

Figure 4. Fuels Emission Intensity



Note: The bar plot shows the average emissions intensity from fuels consumption by economic sector. Emissions intensity is computed as total emissions by fuels consumption divided by value added. Data are from the combined sources DGII and SIEN and are relative to 2018. Dotted blue lines refer to standard deviations within sectors.

Existing carbon pricing and fuel taxes. Our methodology for estimating emissions at the firm level lies on the assumption that firms within sectors face the same price of fuel and electricity. While this may be a strong assumption in some countries, it does seem to apply fairly well in the case of the firms in our sample. Fuel prices are announced weekly by the Ministry of Industry, Commerce, and SMEs (MICM);

there is a slight price differential for electricity prices based on firms' locations on the island.

Liquid fuels in the DR are priced according to an import parity price rule, whereby the Ministry for Industry, Commerce, and SMEs (MICM) updates weekly the official prices to match the supply cost (import parity plus commercialization margins), an excise-specific tax (Ley 112-00), and an ad-valorem tax (set at 16 percent by Ley 495-06). A similar system applies to natural gas prices. According to the The World Bank [2023a], this pricing system does not provide subsidies for liquid fuels on a regular basis, which are common in other countries in the region. However, since March 2022, the Dominican government has implemented a policy of extraordinary fuel subsidies to curb inflation, resulting in frozen prices for premium gasoline at 293.60 pesos per gallon and regular gasoline at 274.50 pesos per gallon. The government also provides subsidies to shield consumers from high electricity costs, which amounted to US 1.5 million in 2024 (about 1.2 percent of GDP). In 2021 and 2022, government spending on electricity subsidies increased by 63% and 52% due to rising global fuel prices.

As far as carbon taxes are concerned, the DR does not have an explicit carbon taxation mechanism, which varies within or across sectors, but a system of excise taxes applied at the fuel level. Gasoline, diesel, and petrol are the fuels subject to comparatively higher tax rates, whereas LPG and coal for electricity generation are tax-exempt. Revenues from fuel taxes are low (1.5 percent of GDP on average between 2005 and 2022) and should be raised considerably to help meet the decarbonization goals.

We now take the model to the data. We first set the tax level $\lambda = 0$, reflecting the fact that the Dominican Republic does not currently have a carbon tax, and estimate output elasticities, firm-level productivities a_i as well as wedges $\{\tau_{xi}, \tau_{yi}, \tau_{ki}, \tau_{fi}\}$ across different sectors. We then use these estimates to evaluate the effects of different taxes λ on our outcomes of interest.

4 Model Calibration

The theoretical model indicates that existing distortions would predict a heterogeneous response to the carbon tax and an ambiguous effect on aggregate TFP, depending on the correlation of wedges and firm-level productivity. In order to quantify the potential gains/losses introduced by different carbon taxes λ, we infer the wedges $\{\hat{\tau}_{ji}\}_{j=k,y,x,f}$ and quantity-based productivity $\hat{a}_i$ using firm-level data.

In particular, wedges are identified using the following equations that arise from the first-order conditions of firm i's profit maximization problem.

$$
\begin{aligned}
(1-\hat{\tau}_{yi}) &= \frac{\sigma}{\sigma-1}\frac{1}{\hat{\beta}_l^s}\frac{wl_i}{p_i y_i} \\
(1+\hat{\tau}_{ki}) &= \frac{\sigma-1}{\sigma}\hat{\beta}_k^s\frac{p_i y_i}{rk_i}(1-\hat{\tau}_{yi}) \\
(1+\hat{\tau}_{xi}) &= \frac{\sigma-1}{\sigma}\hat{\beta}_x^s\frac{p_i y_i}{z_x^s x_i}(1-\hat{\tau}_{yi}) \\
(1+\hat{\tau}_{fi}) &= \frac{\sigma-1}{\sigma}\hat{\beta}_o^s\frac{p_i y_i}{z_f^s f_i}(1-\hat{\tau}_{yi}).
\end{aligned} \tag{13}
$$

The productivity $\hat{a}_i$ is also inferred from the data and equal to:

$$
\hat{a}_i = \kappa_s \frac{(p_i y_i)^{\frac{\sigma-1}{\sigma}}}{k_i^{\beta_k} l_i^{\beta_l} x_i^{\beta_x} f_i^{\beta_f}} \tag{14}
$$

with $\kappa_s = w^{\beta_l} * (py)^{-\frac{1}{\sigma-1}}/p$. Note that, as in Hsieh and Klenow [2009], the sector-level constant κ_s is not observable. However, the constant does not affect changes in market share with respect to the baseline economy or changes in aggregate sector TFP, so it can be normalized to 1.

To estimate these wedges and $\hat{a}_i$, we follow a similar approach to Hsieh and Klenow [2009]. This requires measuring firms' output, capital, labor, fuel expenditures, and electricity expenditures from the data, as well as calibrating factor prices, the elasticity of substitution between varieties, and the output elasticities of inputs. As explained in the previous section, we measure firms' expenditures on oil and electricity using firm fuel and electrical energy purchases, deflated by sectoral GDP deflators reported by the Dominican Republic's Central Bank. Also, we calculate firms' value added, $p_{si}y_{si}$, as the difference between gross revenue and intermediate inputs. We use aggregate sector value-added deflators, provided by the Dominican Republic's Central Bank, to deflate our estimate of firms' value-added. The capital input, k_i, is measured as the book value of fixed assets, which we deflate using the aggregate sector gross revenue deflators. As Hsieh and Klenow [2009] we control for differences in human capital and rent sharing across firms by using firm wage bill as the labor input l_i deflated by the intermediate input industry deflator.

To calibrate factor prices, we assume that the price of capital is $r = 0.1$ and the price of labor is $w = 1$.[12] We set the elasticity of substitution between varieties i to $\sigma = 3$, implying a 50 percent markup reflected in firms' output price, p_i^*. The output elasticities of inputs are estimated at the 2-digit ISIC sector level using a

[12] We abstract from making assumptions on fuel (z_o) and electricity (z_x) input prices that might bias results, as these prices likely vary at the firm-level and we do not observe them. Furthermore, since the calculation of fuel and electricity input distortions requires only information on fuel ($z_o o_i^*$) and electricity ($z_x x_i^*$) input expenditures, and not of input prices, this approach does not affect our computations.

linear regression of value added on the four input factors, with the following constraint: $\beta_l + \beta_k + \beta_x + \beta_f = 1$. In this manner, we assume that firms' production function is constant returns to scale.

There is substantial data attrition in the estimation of the production function. On average, in a given year, only 21 percent of firms provide sufficient information to DGII in order to estimate the production function. The data required includes: total sales, total intermediate inputs, finished product and intermediate input inventories, wage bill, electricity expenditure, and fuel expenditure. Furthermore, for some 2-digit industries, we obtain negative elasticities for some factor inputs. Industries with negative elasticities are dropped from our analysis.[13] As a result of this data attrition, the sample of firms used for our quantitative analyses is substantially smaller, representing only 5.3 percent of firms in 2018. However, this sample still accounts for a substantial share of economic activity and firm emissions, representing 31.6 percent of value added and 27.6 percent of total firm emissions, as displayed in Table 1.

5 Existing Misallocations in the Dominican Republic

This section presents evidence of allocative inefficiencies of factor inputs across firms in the Dominican Republic, including fuel and electricity inputs. Figure 5 displays large dispersion in marginal revenue products of inputs, computed as in (6). This reflects the variation in the estimated wedges $\{\hat{\tau}_{ji}\}_{j=k,y,x,f}$, including electricity and fuel inputs, which suggests the presence of energy frictions in the Dominican Republic. Furthermore, there is also substantial dispersion of firm revenue-based total factor productivity in the Dominican economy. As derived in the Appendix A, revenue-based TFP is defined as:

$$tfpr_i = \frac{\sigma}{\sigma - 1} (\frac{mrpl_i}{\beta_l})^{\beta_l} (\frac{mrpk_i}{\beta_k})^{\beta_k} (\frac{mrpx_i}{\beta_x})^{\beta_x} (\frac{mrpf_i}{\beta_f})^{\beta_f}, \tag{15}$$

implying that heterogeneity in $tfpr_i$ reflects the combined variation in the estimated wedges $\{\hat{\tau}_{ji}\}_{j=k,y,x,f}$. As explained by Hsieh and Klenow [2009], in the absence of distortions, revenue TFP would equalize across firms. Furthermore, differences in the input quantities demanded by firms would only depend on quantity-based TFP, so that firms that are more productive capture a larger share of factor inputs. Conversely, the presence of distortions may cause factors to be allocated not towards more productive firms (higher a_i), as demanded input quantities would also depend on distortions. In turn, this can lead to a lower level of aggregate TFP, as the most efficient firms would not necessarily capture the largest shares of factor inputs in comparison to the frictionless economy.

[13] Service industries with a 2-digit ISIC code greater than 64 are excluded from our analysis as these are sectors with very low emissions. These sectors include financial services, real estate services, professional services, public administration, education services, health services, social services, arts and entertainment, and private home services.

Table 1
Share of economic activity by calibration model sample (Year 2018)

Economic activity	**PY**	**Firms**	**Electricity Expenditure**	**Fuel Expenditure**	**Total emissions**	**Electricity emissions**	**Fuel emissions**
Agriculture	66.7%	8.4%	62.4%	45.0%	73.3%	88.3%	66.5%
Manuf.-Textiles	28.9%	12.0%	60.7%	19.2%	53.0%	79.9%	26.0%
Manuf.-Apparel	24.0%	12.7%	73.7%	50.1%	92.7%	97.2%	66.7%
Manuf.-Editing and recording	71.5%	14.6%	58.4%	50.2%	74.0%	76.9%	66.7%
Manuf.-Chemicals	70.1%	17.5%	65.9%	60.1%	91.1%	95.5%	87.0%
Manuf.-Plastics	68.3%	30.6%	72.7%	58.5%	92.3%	95.9%	77.1%
Manuf.-Cement	75.5%	22.4%	73.7%	64.8%	86.5%	97.3%	85.7%
Manuf.-Metal products	90.0%	11.8%	40.3%	41.7%	54.5%	54.1%	55.7%
Manuf.-Machinery	23.6%	13.8%	44.6%	24.7%	45.0%	57.7%	32.6%
Manuf.-Others	57.3%	11.7%	61.0%	28.2%	66.4%	80.6%	37.3%
Water Distribution	33.7%	9.6%	61.5%	15.5%	78.1%	80.6%	20.2%
Construction	72.1%	5.6%	34.3%	31.0%	59.6%	62.8%	57.0%
Vehicle/fuel sales	75.5%	10.7%	52.8%	46.6%	77.8%	84.4%	74.1%
Wholesale	53.2%	11.5%	57.4%	50.9%	87.4%	91.9%	81.0%
Retail	50.7%	10.9%	57.9%	30.9%	90.9%	92.7%	49.2%
Land transport	27.6%	5.6%	38.2%	24.3%	46.1%	70.8%	46.0%
Water transport	40.3%	8.2%	51.7%	47.5%	88.3%	96.3%	88.1%
Air transport	7.1%	5.5%	50.6%	9.6%	18.1%	94.6%	17.8%
Storage/warehouse	47.9%	10.1%	46.8%	6.7%	13.6%	86.8%	12.4%
Postal services	44.7%	12.5%	44.4%	39.2%	82.5%	84.4%	74.2%
Total (2018)	31.6%	5.3%	8.8%	39.9%	27.6%	13.4%	42.0%

Note: This table reports the share of economic activity attributed to the calibration sample for those industries with only positive output elasticities of factor inputs and with an ISIC sector code below or equal to 64. Among the sectors omitted are financial services, real estate services, professional services, public administration, education services, health services, social services, arts and entertainment, and private home services. The economic activity variables considered from left to right are: value added (PY), number of firms, electricity expenditure, fuel expenditure, total emissions, electricity emissions, and fuel emissions.

Figure 5. Distribution of MRPs of inputs

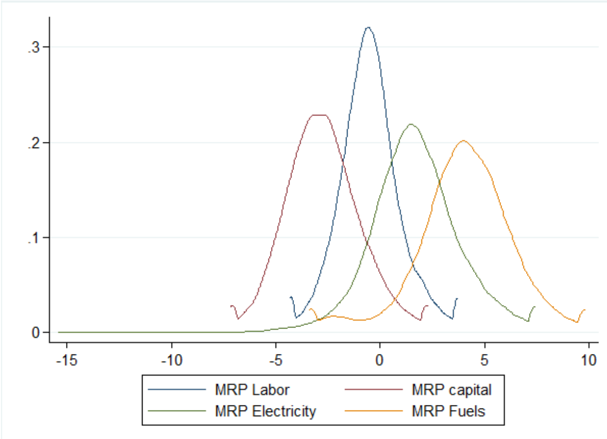
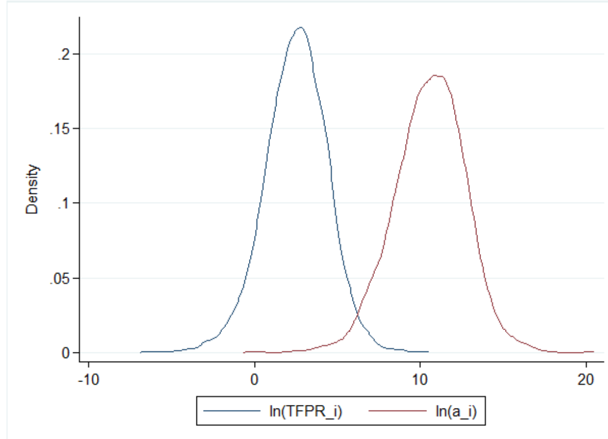


Figure 6. Distribution of revenue-based TFP



Note: Figure 5 reports the kernel density of firms' marginal revenue products of factor inputs. Figure 6 plots the kernel density of revenue TFP and quantity TFP. Both estimates are relative to 2018, which is the latest year for which combined DGII-SIEN data are available. The distributions have been demeaned by the 2-digit ISIC sector mean.

As anticipated from Proposition 2, in the presence of heterogeneous wedges, the tax λ will also impact the baseline market structure s_i^λ by reducing (increasing) the market share of firms i with cheaper (more expensive) access to energy markets respectively. Such alteration can have an ambiguous effect on aggregate TFP depending on the correlation between distortions $\{\tau_{ki}, \tau_{yi}, \tau_{xi}, \tau_{fi}\}$ and quantity-based TFP, a_i. Corollary 3 outlines a sufficient condition for a homogeneous carbon tax to negatively affect aggregate TFP in the presence of distortions: when more productive firms face lower distortions in the energy input markets, $Corr(\tau_{ji}, a_i) < 0$, and the capital and output wedges are positively correlated with the energy wedges, we can expect the tax to reduce aggregate TFP in equilibrium. Otherwise, the tax can potentially increase aggregate TFP. We take the model to the data by testing its implications at the 2-digit sector level, so that market shares and aggregate TFP are calculated at the sectoral level. Table 2 shows the percentage of industries with positive correlations between distortions $\{\tau_{ki}, \tau_{xi}, \tau_{fi}\}$ and quantity-based TFP, a_i. This positive correlation between energy distortions and productivity is important as it means that more productive firms have a higher cost of energy, resulting in higher frictions.

6 Counterfactual: Impact of a Carbon Tax on TFP

The DR government is considering tax reform proposals, including the introduction of a carbon tax. This measure would involve levying a tax on energy sources in proportion to their carbon emissions content, thereby incentivizing businesses to adopt more environmentally friendly practices and reduce their carbon footprint.

Table 2
Share of industries with positive correlations between firm distortions and firm quantity-based TFP

Year	Capital	Electricity	Fuels
2009	83.3%	64.3%	53.3%
2010	42.1%	71.4%	64.3%
2011	38.9%	94.1%	85.7%
2012	44.4%	68.8%	66.7%
2013	31.6%	56.3%	53.3%
2014	44.4%	76.5%	60.0%
2015	50.0%	64.7%	80.0%
2016	38.9%	76.5%	75.0%
2017	42.1%	83.3%	62.5%
2018	36.8%	64.7%	75.0%

Note: Each column shows the share of industries that report a positive correlation between quantity-based TFP, a_i, the column's respective distortion, τ_{ji}, where $j = k, x, f$.

Estimation of aggregate tax revenues. In a first exercise, we depart from the theoretical model to give a back-of-the-envelope estimate of the revenues collected by the Dominican Republic for different levels of the carbon tax. Such figure may be useful to assess the potential relevance of a carbon tax on the government budget and public spending. The total revenues collected in each sector by the regulator are estimated as:[14]

$$R^{\lambda} = \sum_{i=1}^{m} \lambda(\hat{e}_{ix} + \hat{e}_{if}) \tag{16}$$

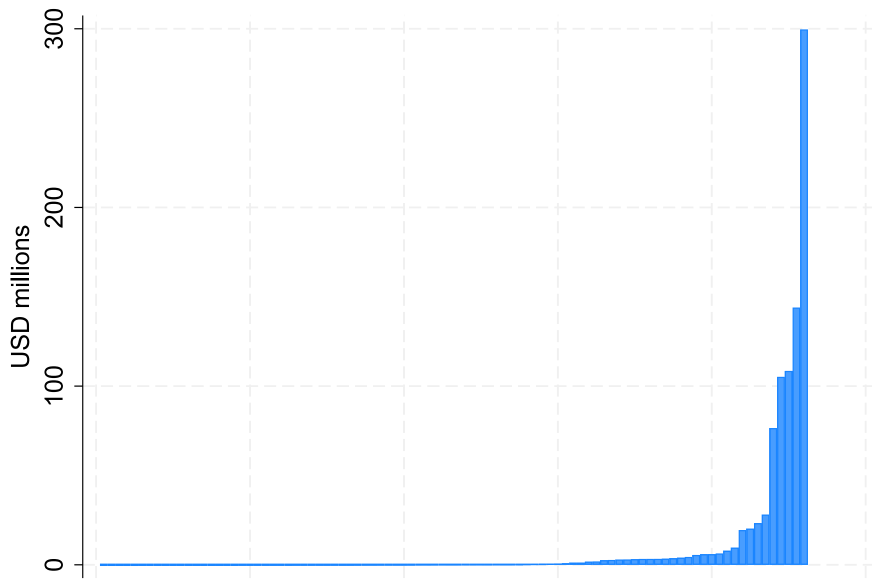
with $\hat{e}_{ix}$ and $\hat{e}_{if}$ representing the historical emissions from electricity and fuel, respectively, as summarized in the data section. For the choice of the tax levels, we refer to two scenarios consistent with the First NGFS Comprehensive Report. In the first scenario (National Determined Contributions - NDCs) the carbon price is calibrated to include all pledged targets, even if they are not yet backed up by effective policies. For the Dominican Republic, this implies a carbon price of 52.31 USD/tCO2 by 2025. The second scenario (Net Zero 2050) assumes a more ambitious goal of limiting global warming to 1.5°C and reaching net zero emissions by 2050. This would imply a carbon price of around 109.13 USD/tCO2 by 2025.[15]

Figure 7 shows the carbon tax revenues across different sectors upon the introduction of a 110\$/tCO_2 tax applied to electricity and fossil-fuel bills. The blue bars refer to cumulative revenues across the two fuel sources. The five most polluting sectors are transport and storage, cement and lime, other manufacturing,

[14]This amounts to evaluating the impact of the tax in a static setting where each producer i cannot adjust its production decisions in response to the tax λ.

[15]The estimated prices are the output of an independent analysis on the DR, and are based on REMIND-MAgPIE 3.0-4.4 model. For more information, see `https://www.ngfs.net/ngfs-scenarios-portal/explore`.

Figure 7. Carbon Tax Revenues



Note: The plot shows in $ millions the total carbon tax revenues generated by a $110/tCO2 tax applied to the firms' combined fuels and electricity bills sorted from the least polluting to the most polluting sector. Data refer to 2018.

other commercials, and hotels, bars, and restaurants, respectively. We estimate that the cumulative tax revenues amount to $920 millions. This corresponds to 20 percent of the firms' total earnings and about 3 percent of their reported total income. A $52/tCO_2$ carbon tax would generate, on the other hand, cumulative revenues of about $434 millions. Documenting such figures is important to provide a sense of the impact of the regulation. However, as discussed, it is important take into account firm-level adjustments to the policy, as well as equilibrium adjustments in the input markets. We now perform counterfactual exercises on our model to derive the effect of the tax on our outcomes of interest, which are firm-level emissions intensities across fuel sources, and TFP across sectors.

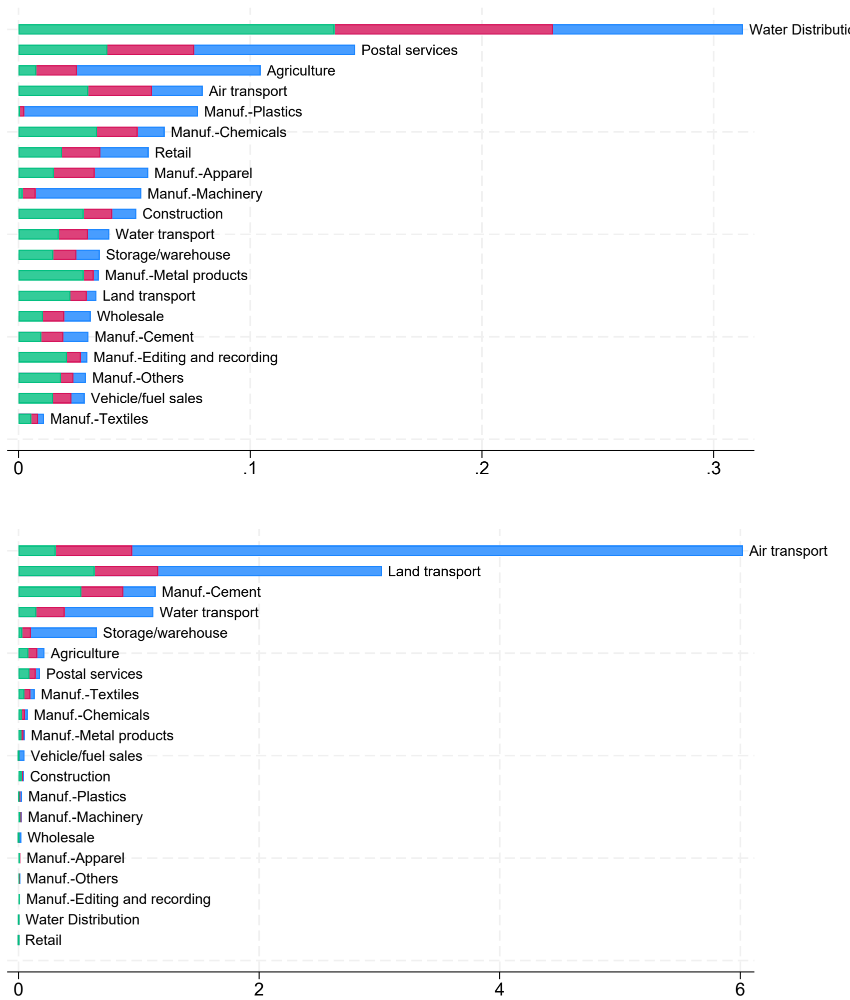
Effect of the tax on emissions intensities. Following Proposition 2, the new emissions intensities become:

$$\hat{\xi}_{xi}^{\lambda} = \hat{\xi}_{xi} \frac{1 + \hat{\tau}_{xi}}{1 + \hat{\tau}_{xi} + \alpha_x^{\lambda}}, \quad \hat{\xi}_{fi}^{\lambda} = \hat{\xi}_{fi} \frac{1 + \hat{\tau}_{fi}}{1 + \hat{\tau}_{fi} + \alpha_f^{\lambda}}. \tag{17}$$

with $\hat{\xi}_{xi}$ and $\hat{\xi}_{fi}$ the historical emissions intensities, summarized in the Data Section, and $\hat{\tau}_{ix}$ and $\hat{\tau}_{if}$ the estimated historical price wedges in the electricity and fuel markets, summarized in the calibration Section.[16]

[16]Expression (17) holds true taking energy prices z_x and z_f as fixed at the historical benchmark. Lower (higher) prices would result in an overestimation (underestimation) of the tax effect respectively.

Figure 8. Impact of the Tax on Average Emission Intensity



Note: The bar plots show the baseline emissions intensities (in blue) against the counterfactual emissions intensities deriving from the introduction of a carbon tax representing 10% (red bar) and 50% (green bar) of the baseline energy prices respectively. The top plot refers to the case of electricity. The bottom plot refers to the case of fuel.

Figure 8 compares the new average emissions intensities against the computed emissions intensities (see Figure 3 and Figure 4) across different fuel sources and sectors. We have chosen to plot two levels of the carbon tax which correspond to an increase of 10% (red bar) and 50% (green bar) of the baseline energy prices respectively. As observed, there is an heterogeneous response to the tax across sectors and fuel sources. As predicted by the model, the tax is far more effective if applied on fuels than on electricity. This because the carbon content of the fuel sources are much higher than that of the fuels used to produce electricity. Particularly interesting is the case of air transport, whose average emissions intensity is reduced by more than 90% in the case of a fuel tax increasing fuel prices of 50%. After the tax, according to the model, the representative firm in this sector will be less polluting than the land transport or cement sectors. Clearly, as our model abstracts from the opportunity to change the production technology, the ultimate costs of such tax have to take into account the availability of greener technologies.

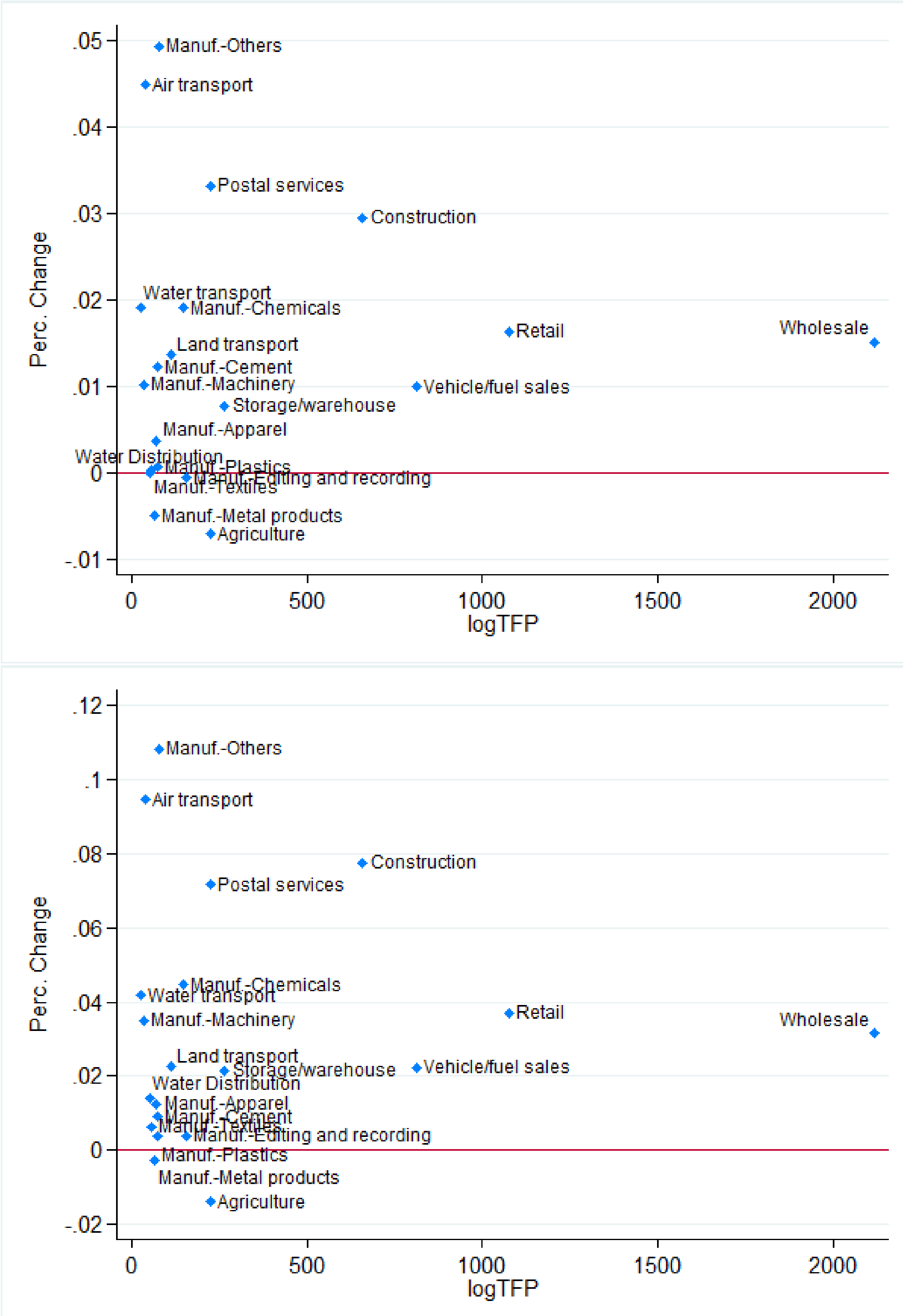
Effect of the tax on aggregate TFP. To derive the counterfactual effect of the tax on aggregate sector TFP, we make use of the Corollary 3's assumption that the wedges $\{\hat{\tau}_{iy}, \hat{\tau}_{ix}, \hat{\tau}_{ik}, \hat{\tau}_{if}\}$ as well as the firm-level productivity a_i follow a log-normal distribution. Under such assumption, we show in the Appendix that the logarithm of aggregate TFP subject to a tax λ is:

$$log(\widehat{\text{TFP}}^{\lambda}) = m + \mathbb{E}[ln(\hat{a}_i)] + \frac{\sigma - 1}{\sigma}\Big(Var[ln(\hat{a}_i)] + Var[ln(t\hat{fpr}_i^{\lambda})] - 2Cov[ln(\hat{a}_i), t\hat{fpr}_i^{\lambda}]\Big) \tag{18}$$

with $\hat{a}_i$ the estimated historical firm-level productivity, $\sigma = 3$ set as in the calibration section, m equal to the historical number of firms in the sector, and the total revenue productivity $t\hat{fpr}_i^{\lambda}$ estimated from the historical one using the formula provided in the appendix. We compare the expression in equation (18) with the historical total productivity computed as in equation (18) assuming $\hat{\lambda} = 0$.

Figure 9, y-axis, shows the percentage changes in aggregate sector TFP generated by a tax λ that increases the energy prices by 10 percent (left plot) and by 50 percent (right plot), respectively. These are compared against the baseline aggregate sector TFP as estimated from our model. In line with the model prediction and with the evidence that the majority of sectors have energy wedges that are positively correlated with firm-level productivity, we conclude that the impact of the tax is primarily positive. Specifically, with the exception of a few sectors, among them agriculture and metal manufacturing, the majority of sectors are positively impacted by the tax, given our estimated frictions. Clearly, the higher the tax, the higher the positive/negative impact on productivity, as illustrated by the differences between the top and bottom plots.

Figure 9. Effect of the tax on aggregate sector TFP



Note: The scatter plots show the aggregate sector TFP (x-axis) against the percentage changes in productivity induced by a carbon tax representing 10% (top plot) and 50% (bottom plot) of the baseline energy prices respectively.

7 Conclusion

In this paper we study the distributional effects at the sector level of the introduction of a hypothetical carbon tax in the Dominican Republic. We first extend the theoretical framework in Hsieh and Klenow [2009] and introduce the consumption of energy and fuels as production inputs. We then take the model to the data using information on the universe of formal firms in the Dominican Republic between 2009 and 2018.

We provide two main sets of results. First, the theoretical model provides a framework to understand the effect of the introduction of a hypothetical carbon tax. A key insight gleaned from the model is the heterogeneous impact on firms, contingent on the correlation between distortions in the input market and firm-level productivity. Specifically, when more productive firms encounter fewer distortions and there exists a positive correlation between the capital and output wedges with the energy wedges, the introduction of an environmental tax can lead to a reduction in aggregate TFP. If these correlations do not hold, then aggregate TFP can either increase or decrease.

Second, our empirical analyses shed light into the anticipated consequences of implementing a carbon tax in the Dominican Republic. We find that the most productive firms across various economic sectors face the highest levels of distortions. Consequently, the introduction of a carbon tax could potentially elevate aggregate TFP in these sectors. Through a counterfactual examination where we hypothesize different levels of the carbon tax, we demonstrate a notable decrease in emission intensity, particularly for fuel consumption. Moreover, the impact on aggregate TFP is projected to be positive, as the most productive firms tend to be burdened by the highest wedges in the majority of sectors.

Our study presents some limitations that may be the focus of future research. The theoretical model does not capture the dynamic adjustment of firms following the introduction of the carbon tax. Firms may upgrade their technology to face the challenge posed by the introduction of the tax. The carbon tax may also be levied differently, affecting industrial factors heterogeneously. We are also not able to differentiate between energy sources to include renewable and clean energy production which would not be affected by the carbon tax. These may be useful starting points for future work.

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Appendix A Model Appendix

Model Solution. Deriving the representative producer problem in (2) by y_i gives

$$p_i = py^{\frac{1}{\sigma}} y_i^{-\frac{1}{\sigma}} \tag{B.1}$$

plugging (B.1) into producer i's problem in (5), and deriving with respect to $\{k_i, l_i, x_i, f_i\}$ gives, after some rearrangement,

$$\begin{aligned}
\frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{k_i^\lambda}\beta_k &= \frac{r(1+\tau_{ki})}{(1-\tau_{yi})} \\
\frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{l_i^\lambda}\beta_l &= \frac{w(1+\tau_{li})}{(1-\tau_{yi})} \\
\frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{x_i^\lambda}\beta_x &= \frac{z_x(1+\tau_{xi})+\lambda\eta_x}{(1-\tau_{yi})} \\
\frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{o_i^\lambda}\beta_o &= \frac{z_f(1+\tau_{fi})+\lambda\eta_f}{(1-\tau_{yi})}
\end{aligned} \tag{B.2}$$

Following Hsieh and Klenow [2009], we define the marginal revenue product of capital, labor, and energy as:

$$\begin{aligned}
\{mrpk_i^\lambda\} &:= \frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{k_i^\lambda}\beta_k = \frac{r(1+\tau_{ki})}{(1-\tau_{yi})} \\
\{mrpl_i^\lambda\} &:= \frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{l_i^\lambda}\beta_l = \frac{w(1+\tau_{li})}{(1-\tau_{yi})} \\
\{mrpx_i^\lambda\} &:= \frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{x_i^\lambda}\beta_x = \frac{z_x(1+\tau_{xi})+\lambda\eta_x}{(1-\tau_{yi})} \\
\{mrpf_i^\lambda\} &:= \frac{\sigma-1}{\sigma}\frac{p_i^\lambda y_i^\lambda}{o_i^\lambda}\beta_f = \frac{z_f(1+\tau_{fi})+\lambda\eta_f}{(1-\tau_{yi})}
\end{aligned} \tag{B.3}$$

Note that the marginal revenue product of capital and labor are independent of the tax, and we call them henceforth $mrpk_i^\lambda = mrpk_i$ and $mrpl_i^\lambda = mrpl_i$. Emissions intensity is given by

$$\begin{aligned}
\xi_{xi}^\lambda &= \frac{e_{ix}^\lambda}{p_i^\lambda y_i^\lambda} = \frac{\sigma-1}{\sigma}\frac{\beta_x\eta_x}{z_x}\frac{1-\tau_{iy}}{1+\tau_{ix}+\frac{\lambda\eta_x}{z_x}} = \frac{\sigma-1}{\sigma}\frac{\beta_x\eta_x}{z_x}\frac{1-\tau_{iy}}{1+\tau_{ix}+\alpha_x^\lambda}, \\
\xi_{fi}^\lambda &= \frac{e_{if}^\lambda}{p_i^\lambda y_i^\lambda} = \frac{\sigma-1}{\sigma}\frac{\beta_f\eta_f}{z_f}\frac{1-\tau_{iy}}{1+\tau_{if}+\frac{\lambda\eta_f}{z_f}} = \frac{\sigma-1}{\sigma}\frac{\beta_f\eta_f}{z_f}\frac{1-\tau_{iy}}{1+\tau_{if}+\alpha_f^\lambda},
\end{aligned} \tag{B.4}$$

which proves in Propositions 1 and 2. The expression for the market share is

$$s_i^\lambda = \frac{p_i^\lambda y_i^\lambda}{p^\lambda y^\lambda} = \frac{p_i^\lambda(y^\lambda(p_i^\lambda)^{-\sigma}(p^\lambda)^\sigma)}{p^\lambda y^\lambda} = \frac{(p_i^\lambda)^{1-\sigma}}{(p^\lambda)^{1-\sigma}} \tag{B.5}$$

from the zero profit condition $p^\lambda y^\lambda = \sum_i p_i^\lambda y_i^\lambda$, one can easily derive that the final price $p^\lambda = (\sum_i (p_i^\lambda)^{1-\sigma})^{\frac{1}{1-\sigma}}$. Substituting this expression into (B.5), one gets

$$s_i^\lambda = \frac{(p_i^\lambda)^{1-\sigma}}{\sum_i (p_i^\lambda)^{1-\sigma}} \tag{B.6}$$

Dividing the FOCs for $\{l_i, x_i, f_i\}$ in (B.2) by the FOC for k_i, and recalling that $y_i = a_i k_i^{\beta_k} l_i^{\beta_l} o_i^{\beta_o} x_i^{\beta_x}$ and that $\beta_k = 1 - \beta_l - \beta_x - \beta_o$, we get

$$p_i^\lambda = \frac{1}{a_i}\frac{\sigma}{\sigma - 1}(\frac{mrpl_i}{\beta_l})^{\beta_l}(\frac{mrpk_i}{\beta_k})^{\beta_k}(\frac{mrpx_i^\lambda}{\beta_x})^{\beta_x}(\frac{mrpf_i^\lambda}{\beta_f})^{\beta_f} \tag{B.7}$$

which is the expression in Hsieh and Klenow [2009] extended to account for the introduction of energy inputs and the tax. Defining $tfpr_i^\lambda = \frac{\sigma}{\sigma-1}(\frac{mrpl_i^\lambda}{\beta_l})^{\beta_l}(\frac{mrpk_i^\lambda}{\beta_k})^{\beta_k}(\frac{mrpx_i^\lambda}{\beta_x})^{\beta_x}(\frac{mrpf_i^\lambda}{\beta_f})^{\beta_f}$, the price can be written as

$$p_i^\lambda = \frac{1}{a_i} tfpr_i^\lambda \tag{B.8}$$

Substituting (B.8) into (B.6), we get

$$s_i^\lambda = \frac{(p_i^\lambda)^{1-\sigma}}{\sum_i (p_i^\lambda)^{1-\sigma}} = (\frac{a_i}{tfpr_i^\lambda})^{\sigma-1}\frac{1}{\sum_i (\frac{a_i}{tfpr_i^\lambda})^{1-\sigma}} \tag{B.9}$$

which proves the first result of Corollaries 1 and 2 noticing that when $\lambda \neq 0$, then $s_i^\lambda \neq s_i$ if and only if $\tau_{ix} \neq 0$ (and/or $\tau_{if} \neq 0$) since $mrpx_i^\lambda \neq mrpx_i$ (and/or $mrpf_i^\lambda \neq mrpf_i$) therefore $tfpr_i^\lambda \neq tfpr_i$.

Finally, define the aggregate TFP as

$$TFP^\lambda = \frac{y^\lambda}{(k^\lambda)^{\beta_k}(l^\lambda)^{\beta_l}(x^\lambda)^{\beta_x}(f^\lambda)^{\beta_f}} = (\frac{y^\lambda}{k^\lambda})^{\beta_k}(\frac{y^\lambda}{l^\lambda})^{\beta_l}(\frac{y^\lambda}{x^\lambda})^{\beta_x}(\frac{y^\lambda}{f^\lambda})^{\beta_f} \tag{B.10}$$

with $k^\lambda = \sum_i k_i^\lambda$, $l^\lambda = \sum_i l_i^\lambda$, $f^\lambda = \sum_i f_i^\lambda$, and $x^\lambda = \sum_i x_i^\lambda$. Rearranging the FOCs in (B.2), one has

$$k_i^\lambda = \frac{\sigma - 1}{\sigma} p_i^\lambda y_i^\lambda \frac{\beta_k}{r(1 + \tau_{ki})} = \frac{\sigma - 1}{\sigma} p^\lambda y^\lambda s_i^\lambda \frac{\beta_k}{mprk_i} \tag{B.11}$$

so that aggregate demand of capital reads

$$\begin{aligned} k^\lambda &= \sum_{i=1}^m k_i^\lambda = \frac{\sigma - 1}{\sigma} p^\lambda y^\lambda (\sum_{i=1}^m s_i^\lambda \frac{1}{mprk_i}) \\ \rightarrow \frac{k^\lambda}{y^\lambda} &= \frac{\sigma - 1}{\sigma} p^\lambda \frac{\beta_k}{mrpk^\lambda} \end{aligned} \tag{B.12}$$

with $\frac{1}{mrpk^{\lambda}} = \big(\sum_i s_i^{\lambda} \frac{1}{mprk_i}\big)$. Applying this to all other inputs we get

$$TFP^{\lambda} = \frac{\sigma}{\sigma-1}\frac{1}{p^{\lambda}}(\frac{mrpk^{\lambda}}{\beta_k})^{\beta_k}(\frac{mrpl^{\lambda}}{\beta_l})^{\beta_l}(\frac{mrpx^{\lambda}}{\beta_x})^{\beta_x}(\frac{mrpf^{\lambda}}{\beta_f})^{\beta_f} = \frac{1}{p^{\lambda}}tfpr^{\lambda} \tag{B.13}$$

now recalling that $\frac{1}{p^{\lambda}} = ((\sum_i (p_i^{\lambda})^{1-\sigma})^{1/1-\sigma})^{-1} = (\sum_i (\frac{a_i}{tfpr_i^{\lambda}})^{\sigma-1})^{1/(\sigma-1)}$, we get

$$TFP^{\lambda} = \Big(\sum_{i=1}^{m}(a_i\frac{tfpr^{\lambda}}{tfpr_i^{\lambda}})^{\sigma-1}\Big)^{\frac{1}{\sigma-1}} \tag{B.14}$$

this proves the second result in Corollaries 1 and 2 noticing that if $\{\tau_{ik}, \tau_{il}, \tau_{ix}, \tau_{if}\} \neq 0$, then when $\lambda \neq 0$ $\frac{tfrp^{\lambda}}{tfpr_i^{\lambda}} \neq \frac{tfrp}{tfpr_i}$ hence $TFP^{\lambda} \neq TFP$.

Corollary 3 [Proof]. Assume that a_i and $tfpr_i$ are jointly log-normally distributed. Define

$$\chi_i = (a_i\frac{\overline{tfpr}}{tfpr_i})^{\sigma-1}, \tag{B.15}$$

recalling that the product of log-normal distributions is still a log-normal distribution, the logarithm of χ_i is a normal distribution of mean and variance

$$log(\chi_i) \sim \mathcal{N}(\mu, \Sigma^2) \tag{B.16}$$

with

$$\begin{aligned} \mu &= (\sigma-1)(\mathbb{E}[log(a_i)] + \mathbb{E}[log(\overline{tfpr})] - \mathbb{E}[log(tfpr_i)]) = (\sigma-1)\mathbb{E}[log(a_i)] \\ \Sigma^2 &= (\sigma-1)^2(Var[log(a_i)] + Var[log(tfpr_i)] - 2Cov[log(a_i), log(tfpr_i)]). \end{aligned} \tag{B.17}$$

From the expression for the aggregate TFP, with m large enough, one has

$$TFP = \frac{m}{m}\Big(\sum_{i=1}^{m}(a_i\frac{tfpr}{tfpr_i})^{\sigma-1}\Big)^{1/(\sigma-1)} = m\mathbb{E}[\chi_i]^{1/(\sigma-1)} \tag{B.18}$$

which applying the logarithm on both sides gives

$$logTFP = m + \frac{1}{\sigma-1}log(\mathbb{E}[\chi_i]). \tag{B.19}$$

From the properties of the log-normal distribution, recalling (B.16), one has

$$\mathbb{E}[\chi_i] = e^{\mu + \frac{1}{2}\Sigma^2} \tag{B.20}$$

and so substituting into (B.19)

$$\begin{aligned} logTFP &= m + \frac{1}{\sigma - 1}(\mu + \frac{1}{2}\Sigma^2) \\ &= m + \mathbb{E}[log(a_i)] + \frac{(\sigma - 1)}{2}(Var[log(a_i)] + Var[log(tfpr_i)] - 2Cov[log(a_i), log(tfpr_i)]). \end{aligned} \tag{B.21}$$

This implies that the differences in TFP with and without the tax

$$log(TFP) - log(TFP^{\lambda}) = \frac{\sigma - 1}{2}\Big(V[log(tfpr_i)] - V[log(tfpr_i^{\lambda})] - 2(Cv[log(a_i), log(tfpr_i)] - Cv[log(a_i), log(tfpr_i^{\lambda})])\Big). \tag{B.22}$$

where $V = Var$ and $Cv = Cov$. From the definition of $tfpr_i$, we have

$$\begin{aligned} log(tfpr_i) &= \kappa + \beta_l log(mrpl_i) + \beta_k log(mrpk_i) + \beta_x log(mrpx_i) + \beta_f log(mrpf_i) \\ &= \kappa + \beta_k log(1 + \tau_{ki}) + \beta_x log(1 + \tau_{xi}) + \beta_f log(1 + \tau_{fi}) - log(1 - \tau_{yi}). \end{aligned} \tag{B.23}$$

with κ a constant which we disregard, and where one notes that we applied $\beta_l + \beta_k + \beta_f + \beta_x = 1$. Applying the first-order Taylor approximation, we get

$$log(tfpr_i) \approx \kappa + \beta_k\tau_{ki} + \beta_x\tau_{xi} + \beta_f\tau_{fi} + \tau_{yi}. \tag{B.24}$$

Following the same steps for $log(tfpr_i^{\lambda})$, we get

$$log(tfpr_i^{\lambda}) = \kappa + \beta_k log(1 + \tau_{ki}) + \beta_x log(1 + \tau_{xi} + \alpha_x^{\lambda}) + \beta_f log(1 + \tau_{fi} + \alpha_f^{\lambda}) - log(1 - \tau_{yi}). \tag{B.25}$$

and applying the first-order Taylor approximation, we get

$$log(tfpr_i^{\lambda}) \approx \kappa + \beta_k\tau_{ki} + \beta_x\frac{1}{1 + \alpha_x}\tau_{xi} + \beta_f\frac{1}{1 + \alpha_f}\tau_{fi} + \tau_{yi}. \tag{B.26}$$

We therefore have that the first difference in (B.22) reads

$$V[log(tfpr_i)] - V[log(tfpr_i^\lambda)] \approx \beta_x^2 V[\tau_{xi}](1-(\frac{1}{1+\alpha_x^\lambda})^2) + \beta_f^2 V[\tau_{fi}](1-(\frac{1}{1+\alpha_f^\lambda})^2) + ..$$
$$+2\beta_f\beta_x Cv[\tau_{xi},\tau_{fi}](1-\frac{1}{(1+\alpha_f^\lambda)}\frac{1}{(1+\alpha_x^\lambda)}) + 2\beta_x\beta_k Cv[\tau_{xi},\tau_{ki}](1-\frac{1}{(1+\alpha_x^\lambda)}) + 2\beta_x Cv[\tau_{xi},\tau_{yi}](1-\frac{1}{(1+\alpha_x^\lambda)}) + ..$$
$$+2\beta_f\beta_k Cv[\tau_{fi},\tau_{ki}](1-\frac{1}{(1+\alpha_f^\lambda)}) + 2\beta_f Cv[\tau_{fi},\tau_{yi}](1-\frac{1}{(1+\alpha_f^\lambda)}). \tag{B.27}$$

Note that the first two terms are always positive since α_x^λ and α_f^λ are positive provided that $\lambda > 0$. On the other hand, note that the remainder of the terms can be positive or negative depending on the sign of the covariances between τ_{x_i} and $\{\tau_{ki}, \tau_{yi}\}$, the covariances between τ_{f_i} and $\{\tau_{ki}, \tau_{yi}\}$ and the covariance between τ_{xi} and τ_{fi}. If these wedges are all positively correlated, then introducing the tax has the unambiguous effect of reducing the variance of $tfpr_i$, otherwise, it could increase it as well.

The second difference in (B.22) reads

$$Cov[log(a_i), log(tfpr_i)] - Cov[log(a_i), log(tfpr_i^\lambda)] \approx \beta_x Cov[log(a_i),\tau_{xi}](1-\frac{1}{1+\alpha_x^\lambda}) + \beta_f Cov[log(a_i),\tau_{xi}](1-\frac{1}{1+\alpha_f^\lambda}) \tag{B.28}$$

Note that this term is positive (negative) is both the wedges τ_{xi} and τ_{fi} are positively (negatively) correlated with a_i. Putting together the first and second terms, we obtain the sufficient condition for which the tax $\lambda > 0$ reduces aggregate TFP, that is for which

$$log(TFP) - log(TFP^\lambda) > 0. \tag{B.29}$$

Appendix B Data Appendix

B.1 Summary statistics

Table B1

Activity Summary Statistics - 2018

Activity	Firms (Number)	Production (USD Million)	EBIT (USD Million	Energy Exp. (USD Million	CO2
Cereal Crops	109	80.6	2.4	3.1	8.92
Traditional Crops	1,004	761.2	12.9	18.3	39.47
Agricultural Services	880	180.6	4.5	6.9	14.67
Forestry	50	4.4	-0.2	0.7	1.39
Cattle raising	297	156.3	-1.5	5.9	16.45
Breeding Other Animals	239	658.2	11.0	27.0	79.29
Fishing	50	18.5	1.1	0.8	1.57
Mining and quarrying	165	400.2	-35.5	74.3	251.96
Production and Processing of Meat	93	684.7	34.3	29.0	78.71
Manuf. of Oils and Fats	19	466.7	24.6	13.8	24.67
Manuf. of Dairy Products	128	338.5	22.6	15.2	35.07
Manuf. of grain mill products	88	407.3	10.6	23.2	83.56
Manuf. of bakery	386	117.6	7.2	6.7	16.87
Sugar Processing	8	433.2	49.1	12.8	19.77
Cocoa, Chocolate and Confectionery	43	169.3	6.0	3.4	10.51
Manuf. of Beverages	146	1,336.5	303.8	58.9	151.31
Manuf. of Tobacco Products	165	804.4	101.9	6.4	14.45
Manuf. of Textiles and Clothing	676	652.2	58.5	16.3	24.96
Manuf. of Wood, Paper, Cardboard	269	400.3	23.4	11.3	26.51
Editing, Recording, Printing	966	290.7	8.9	11.5	29.07
Manuf. Petroleum Refining Products	14	1,476.7	38.2	3.0	5.17
Plastic processing	229	826.6	53.7	46.6	147.31
Manuf. Chemicals	274	527.3	46.2	16.2	38.67
Manuf. of Pharmaceuticals	229	897.9	143.8	13.7	37.90
Manuf. of soaps and detergents	241	363.0	24.6	15.7	27.24
Manuf. of Glass Products	44	12.9	0.6	0.2	0.28
Manuf. of Ceramic Products	26	49.5	-0.9	3.9	101.07
Manuf. of Cement, Lime, Plaster	13	442.7	79.2	66.5	1,657.51
Manuf. of basic iron and steel	74	562.4	11.0	31.3	44.75
Manuf. of Furniture	432	137.6	7.6	3.8	8.54
Other Manufacturing	2,210	3,719.0	423.8	86.0	672.79
Electricity, Gas and Water	856	5,262.5	96.6	2,056.7	429.66
Construction	11,403	3,625.2	144.5	128.3	166.92
Trade-Vehicles	6,732	2,877.8	88.4	123.0	34.53
Trade others	26,278	15,890.1	705.8	360.6	405.37
Trade-Fuel	1,380	5,543.7	119.1	3,961.9	342.53
Hotels, Bars and Restaurants	3,591	2,891.1	-11.0	266.3	345.39
Transport and Storage	5,396	2,885.8	285.4	287.6	6,188.94
Banks, Associations, Credit Corp., etc.	4	0.0	0.0	0.0	0.00
Exchange agents, remittance agents	7	0.2	18.4	0.0	0.00
Insurance	4	0.2	0.0	0.0	0.01
Home rental	13,134	1,398.6	215.3	93.6	128.26
Communications	1,412	2,409.6	89.5	64.4	167.72
Teaching Services	1,431	164.7	6.5	4.7	8.82
Health services	2,586	833.5	64.2	28.3	78.85
Other services	20,447	3,458.3	149.0	106.5	86.44
Public administration	22	3.7	0.5	0.0	0.04
Others	5,632	586.0	515.3	27.5	37.26

Table B2

Production (Thousand of USD, 2018)

Activity	Average	Median	Min.	Max.
Crop of Cereals	739.3	0.3	-141.4	24,383
Traditional Crops	758.2	2.0	0.0	76,627
Agricultural Services	205.2	2.4	-19.7	20,371
Forestry	87.3	0.0	0.0	1,718
Cattle raising	526.2	0.0	0.0	28,720
Breeding Other Animals	2,754.0	30.8	0.0	119,552
Fishing	369.6	0.0	0.0	6,196
Mining and quarrying	2,425.6	0.0	0.0	204,127
Production and Processing of Meat	7,362.2	362.4	0.0	273,884
Manuf. of Oils and Fats n	24,565.1	263.7	0.0	381,624
Manuf. of Dairy Products	2,644.5	3.0	-1.5	240,810
Manuf. of grain mill products	4,628.1	140.2	0.0	70,121
Manuf. of bakery	304.7	38.6	0.0	14,132
Sugar Processing	54,147.9	1,525.7	0.0	304,088
Cocoa, Chocolate and Confectionery	3,936.2	7.3	0.0	43,023
Manuf. of Beverages	9,154.3	12.6	-0.2	730,760
Manuf. of Tobacco Products	4,874.9	22.1	-128.3	156,299
Manuf. of Textiles and Clothing	964.8	24.0	0.0	91,115
Manuf. of Wood, Paper, Cardboard	1,488.0	28.2	0.0	62,555
Editing, Recording, Printing	301.0	21.2	0.0	21,251
Manuf. of Petroleum Refining Products	105,476.2	290.9	0.0	1,447,129
Plastic processing	3,609.8	243.6	0.0	134,342
Chemical Manufacturing	1,924.5	36.3	-3.6	135,110
Manuf. of Pharmaceuticals	3,920.8	37.0	0.0	103,875
Manuf. of soaps and detergents	1,506.3	5.9	0.0	182,034
Manuf. of Glass Products	293.1	43.4	0.0	5,076
Manuf. of Ceramic Products	1,902.5	17.8	0.0	28,093
Manuf. of Cement, Lime and Plaster	34,050.8	682.2	0.0	187,442
Manuf. of basic iron and steel	7,600.0	86.9	0.0	389,404
Manuf. of Furniture and Mattresses	318.6	17.5	0.0	35,838
Other Manufacturing Industries	1,682.8	24.1	-288.1	235,356
Electricity, Gas and Water	6,147.7	1.7	-54.5	718,690
Construction	317.9	0.0	-606.4	375,795
Trade-Vehicles	427.5	20.8	0.0	180,014
Trade others	604.7	14.5	-25.4	787,542
Trade-Fuel	4,017.2	299.2	-17.6	658,773
Hotels, Bars and Restaurants	805.1	21.4	0.0	140,839
Transport and Storage	534.8	7.2	0.0	141,077
Banks, Associations, Credit Corp., etc.	2.1	0.0	0.0	8
Exchange agents, remittance agents	29.7	0.0	0.0	194
insurance	54.5	33.6	0.0	151
Home rental	106.5	0.0	-44.3	269,700
Communications	1,706.5	9.4	0.0	867,094
Teaching Services	115.1	16.6	0.0	7,803
Health services	322.3	12.1	0.0	40,364
Other services	169.1	3.1	-133.5	72,137
Public administration	169.7	0.0	0.0	2,839
Others	104.0	0.0	0.0	73,364

Table B3
EBIT (Thousand of USD, 2018)

Activity	Average	Median	Min.	Max.
Crop of Cereals	22.1	0.0	-299.5	1,730.3
Traditional Crops	12.9	0.0	-1,506.5	4,081.0
Agricultural Services	5.1	0.0	-3,506.7	2,661.4
Forestry	-5.0	0.0	-256.7	106.5
Cattle raising	-4.9	0.0	-964.1	722.4
Breeding Other Animals	46.2	0.0	-6,364.7	5,834.3
Fishing	22.0	0.0	-84.1	453.6
Mining and quarrying	-216.5	0.0	-29,217.6	4,264.4
Production and Processing of Meat	368.5	0.0	-5,011.7	30,135.4
Manuf. of Oils and Fats n	1,295.9	11.4	-81.3	20,475.1
Manuf. of Dairy Products	176.5	0.0	-307.6	16,537.7
Manuf. of grain mill products	120.5	0.0	-474.4	4,503.5
Manuf. of bakery	18.8	0.0	-526.3	5,339.0
Sugar Processing	6,140.0	0.0	-11,802.8	51,405.5
Cocoa, Chocolate and Confectionery	139.8	0.0	-1,946.8	3,555.8
Manuf. of Beverages	2,080.8	0.0	-5,416.6	264,395.7
Manuf. of Tobacco Products	617.8	0.0	-1,509.7	22,812.6
Manuf. of Textiles and Clothing	86.6	0.0	-5,497.3	22,595.3
Manuf. of Wood, Paper, Cardboard	87.0	0.0	-1,212.3	4,140.6
Editing, Recording, Printing	9.2	0.1	-1,873.0	3,008.1
Manuf. of Petroleum Refining Products	2,729.6	16.7	-126.5	33,899.7
Plastic processing	234.6	1.0	-4,915.5	12,173.6
Chemical Manufacturing	168.7	0.0	-1,335.9	11,675.7
Manuf. of Pharmaceuticals	628.1	0.0	-770.0	56,136.8
Manuf. of soaps and detergents	102.0	0.0	-2,799.8	12,964.4
Manuf. of Glass Products	14.7	0.0	-98.8	537.9
Manuf. of Ceramic Products	-32.8	0.0	-2,562.0	1,348.3
Manuf. of Cement, Lime and Plaster	6,091.5	7.9	-145.8	25,713.0
Manuf. of basic iron and steel	148.9	0.9	-2,219.0	11,048.0
Manuf. of Furniture and Mattresses	17.7	0.0	-421.7	1,625.5
Other Manufacturing Industries	192.1	0.0	-10,064.8	107,040.1
Electricity, Gas and Water	113.0	0.0	-146,160.9	99,607.8
Construction	12.7	0.0	-155,016.1	101,828.3
Trade-Vehicles	13.1	0.0	-2,657.5	23,431.2
Trade others	26.9	0.0	-4,730.6	28,280.3
Trade-Fuel	86.3	3.0	-2,204.3	15,387.3
Hotels, Bars and Restaurants	-3.1	0.0	-18,151.1	25,664.5
Transport and Storage	53.0	0.0	-3,962.2	81,116.6
Banks, Associations, Credit Corp., etc.	-2.4	-1.3	-7.1	0.0
Exchange agents, remittance agents	2,623.4	0.0	-5.0	18,161.5
insurance	3.1	1.9	-2.8	11.3
Home rental	16.4	0.0	-3,655.5	42,838.3
Communications	63.5	0.0	-282,579.1	283,824.7
Teaching Services	4.6	0.0	-640.6	572.0
Health services	24.8	0.0	-2,146.1	7,272.5
Other services	7.3	0.0	-12,884.1	7,463.3
Public administration	24.9	0.0	-9.6	502.8
Others	91.6	0.0	-166,057.1	185,847.6

Table B4

Energy Expenditure (Thousand of USD, 2018)

Activity	Average	Median	Min.	Max.
Crop of Cereals	28.5	0.0	0.0	917.7
Traditional Crops	18.2	0.0	0.0	1,702.0
Agricultural Services	7.8	0.0	0.0	713.4
Forestry	14.1	0.0	0.0	487.4
Cattle raising	20.0	0.0	0.0	938.5
Breeding Other Animals	113.1	0.1	0.0	9,101.7
Fishing	15.6	0.0	0.0	161.7
Mining and quarrying	450.3	0.0	0.0	48,362.7
Production and Processing of Meat	311.5	9.2	0.0	11,604.0
Manuf. of Oils and Fats n	724.4	5.0	0.0	9,249.2
Manuf. of Dairy Products	118.7	0.0	0.0	10,271.6
Manuf. of grain mill products	263.5	7.9	0.0	9,592.2
Manuf. of bakery	17.4	1.2	0.0	637.4
Sugar Processing	1,601.6	72.5	0.0	7,218.1
Cocoa, Chocolate and Confectionery	78.7	0.0	0.0	1,285.2
Manuf. of Beverages	403.8	0.7	0.0	27,224.8
Manuf. of Tobacco Products	38.6	0.0	0.0	1,837.1
Manuf. of Textiles and Clothing	24.1	0.3	0.0	8,266.9
Manuf. of Wood, Paper, Cardboard	42.1	0.7	0.0	1,404.2
Editing, Recording, Printing	11.9	0.4	0.0	1,193.3
Manuf. of Petroleum Refining Products	214.0	30.7	0.0	1,678.3
Plastic processing	203.5	8.4	0.0	5,109.9
Chemical Manufacturing	59.1	0.2	0.0	4,077.4
Manuf. of Pharmaceuticals	60.0	0.7	0.0	1,700.7
Manuf. of soaps and detergents	65.0	0.1	0.0	12,027.9
Manuf. of Glass Products	3.5	0.5	0.0	26.9
Manuf. of Ceramic Products	150.4	0.8	0.0	1,760.6
Manuf. of Cement, Lime and Plaster	5,116.5	201.6	0.0	29,574.9
Manuf. of basic iron and steel	423.5	2.9	0.0	14,708.3
Manuf. of Furniture and Mattresses	8.8	0.2	0.0	699.9
Other Manufacturing Industries	38.9	0.5	0.0	3,548.3
Electricity, Gas and Water	2,402.6	0.0	0.0	511,608.7
Construction	11.3	0.0	0.0	13,277.1
Trade-Vehicles	18.3	0.4	0.0	56,261.7
Trade others	13.7	0.0	0.0	22,701.3
Trade-Fuel	2,870.9	137.9	0.0	347,621.2
Hotels, Bars and Restaurants	74.2	0.5	0.0	14,668.7
Transport and Storage	53.3	0.0	0.0	117,148.4
Banks, Associations, Credit Corp., etc.	0.7	0.0	0.0	2.9
Exchange agents, remittance agents	0.4	0.0	0.0	2.1
insurance	2.9	1.1	0.0	9.3
Home rental	7.1	0.0	0.0	8,986.2
Communications	45.6	0.0	0.0	28,184.8
Teaching Services	3.3	0.1	0.0	699.0
Health services	11.0	0.1	0.0	1,489.0
Other services	5.2	0.0	0.0	3,844.9
Public administration	0.7	0.0	0.0	10.1
Others	4.9	0.0	0.0	7,160.0

Table B5

Total CO_2 Emissions (kt, 2018)

Activity	Average	Median	Min.	Max.
Crop of Cereals	0.08	0.00	0.00	3.43
Traditional Crops	0.04	0.00	0.00	4.08
Agricultural Services	0.02	0.00	0.00	1.73
Forestry	0.03	0.00	0.00	0.98
Cattle raising	0.06	0.00	0.00	3.16
Breeding Other Animals	0.33	0.00	0.00	26.37
Fishing	0.03	0.00	0.00	0.40
Mining and quarrying	1.53	0.00	0.00	205.45
Production and Processing of Meat	0.85	0.01	0.00	24.00
Manuf. of Oils and Fats n	1.30	0.01	0.00	17.01
Manuf. of Dairy Products	0.27	0.00	0.00	19.76
Manuf. of grain mill products	0.95	0.01	0.00	43.81
Manuf. of bakery	0.04	0.00	0.00	2.41
Sugar Processing	2.47	0.13	0.00	11.37
Cocoa, Chocolate and Confectionery	0.25	0.00	0.00	5.19
Manuf. of Beverages	1.04	0.00	0.00	55.59
Manuf. of Tobacco Products	0.09	0.00	0.00	6.40
Manuf. of Textiles and Clothing	0.04	0.00	0.00	9.90
Manuf. of Wood, Paper, Cardboard	0.10	0.00	0.00	3.84
Editing, Recording, Printing	0.03	0.00	0.00	3.69
Manuf. of Petroleum Refining Products	0.37	0.04	0.00	2.89
Plastic processing	0.64	0.01	0.00	20.71
Chemical Manufacturing	0.14	0.00	0.00	12.18
Manuf. of Pharmaceuticals	0.17	0.00	0.00	5.06
Manuf. of soaps and detergents	0.11	0.00	0.00	18.41
Manuf. of Glass Products	0.01	0.00	0.00	0.09
Manuf. of Ceramic Products	3.89	0.02	0.00	45.70
Manuf. of Cement, Lime and Plaster	127.50	4.98	0.00	736.43
Manuf. of basic iron and steel	0.60	0.00	0.00	30.57
Manuf. of Furniture and Mattresses	0.02	0.00	0.00	2.38
Other Manufacturing Industries	0.30	0.00	0.00	80.29
Electricity, Gas and Water	0.51	0.00	-0.03	168.91
Construction	0.01	0.00	0.00	23.18
Trade-Vehicles	0.01	0.00	0.00	5.99
Trade others	0.02	0.00	0.00	66.15
Trade-Fuel	0.25	0.01	0.00	29.22
Hotels, Bars and Restaurants	0.10	0.00	0.00	25.72
Transport and Storage	1.15	0.00	0.00	2,511.41
Banks, Associations, Credit Corp., etc.	0.00	0.00	0.00	0.00
Exchange agents, remittance agents	0.00	0.00	0.00	0.00
insurance	0.00	0.00	0.00	0.01
Home rental	0.01	0.00	0.00	19.45
Communications	0.12	0.00	0.00	73.09
Teaching Services	0.01	0.00	0.00	0.92
Health services	0.03	0.00	0.00	4.24
Other services	0.00	0.00	0.00	7.49
Public administration	0.00	0.00	0.00	0.04
Others	0.01	0.00	0.00	14.19

B.2 Emissions from Electricity and Fuel Consumption

Table B6

Form 606 – Energy Industries

ISIC Code – Energy Sectors	Related Fuels
401301-Electrical power distribution 401302-Sale of electricity to the user	Electricity
402001-Manufacture and distribution of gas (Not incl. transportation by gas pipelines) 402002-Manufacture of gaseous fuels with a calorific value 402003-Sale of gas to users	Natural Gas
505001-Retail sale of fuel for motor vehicles and motorcycles (Incl. Service Stations)	Gasoline, diesel, biodiesel
505002-Retail sale of lubricant products and cooling products for motor vehicles	Lubricants
514111-Wholesale of charcoal, coal, coke, fuel wood, naphtha	Mineral coal, charcoal, cane bagasse, other primaries, coke, vegetable coal
514112-Wholesale refined petroleum products	Other non-energetic, asphalts
514191-Fractioning and distribution of liquefied gas	Liquefied petroleum gas, refinery gases
514199-Wholesale of fuels and lubricants, except for automotive, firewood and coal	Kerosene, avtur, fuel oil

Emissions from Electricity Consumption. A firm's expenditure in electricity is equated to a firm's expenditure reported in Form 606 in sectors 401301 and 401302 (see Table B6). Using a firm's location reported to DGII, it is possible to assign an average price per KWh to each firm, based on the average price reported by the Electricity Distribution Companies of the Dominican Republic: EDESUR, EDENORTE and EDEESTE (EDEs) that serve a specific location in a specific year. Dividing the firms' electricity expenditure data by the assigned average price, based on the firm location, we obtain the firm's energy consumption in KWh. To estimate CO2 emissions from electricity consumption it is necessary to estimate a conversion factor from KWh consumed to kg of CO2 emissions. To obtain a KWh to Kg of CO2 conversion factor we use SIEN's Energy Balance Information. The Energy Balance Information matrix reports the quantities of fuels used in the generation of electric energy. In 2021 there were three main fuels used in the generation of electricity in the Dominican Republic, natural gas (41 percent), mineral carbon (31 percent), and fuel oil (11 percent). The remaining electricity is produced through hydropower (7 percent) and other renewable sources (10 percent), in previous years diesel also was an important source of energy for electricity generation. Each of these fuels produce different amounts of CO2 when they are transformed in the energy generation process. We use the U.S. Environmental Protection Agency, Inventory of Greenhouse Gas Emissions and

Sinks: 1990-2020 CO2 emissions coefficients. In this manual it is reported that for every cubic meter of natural gas burnt 1.9 Kgs of CO2 are produced; for every ton of mineral carbon burnt 2,030.1 Kgs of CO2 are produced, and for every gallon of fuel oil burnt 10.19 Kgs of CO2 are produced. With this conversion factors we can estimate the total CO2 emissions generated in electricity generation. Additionally, BNE provides information on total GWh of electricity produced, with the Sistema Electrico Nacional Interconectado (SENI), representing nearly 93.3 percent of the 21.7 thousand GWh of electricity generated, isolated systems accounted for 5 percent, and auto producers for the remaining 1.7 percent. Dividing the total electricity generated in KWh by the total emissions of CO2 in Kgs we obtain the conversion factor needed to transform firms' electricity consumption into firms' emissions of CO2.

Emissions from Fuel Consumption. Besides firms' CO2 emissions through their electric consumption, many also use different types of fuels in their production and transportation processes which also emit CO2. As mentioned before, we would ideally want to know a firm's expenditure on each type of fuel so that we can perform a similar exercise as with electric consumption to estimated firms' emissions from fuel consumption; however, the information provided in Form 606 is aggregate by energy sector as described in Table B6. Thus, in each energy sector (in some more than others) there is a mix of fuels traded that is undetermined and that we have assigned specific fuels to each sector to best match their activity description. For example, retail sale of fuel for motor vehicles and motorcycles including service stations (ISIC 505001) was matched to gasoline, diesel, and biodiesel. A share of these fuels could also potentially be traded in the energy sector wholesale of fuels and lubricants, except for automotive, firewood and coal (ISIC 514199) but without further information we cannot assign better shares of each fuel to the different energy sectors reported in Form 606. Thus, to rely less on this ad hoc distribution for the estimation of fuel emissions at the firm level we alternatively use the emissions data reported by SIEN. In order to do this, we match the ISICs reported for each firm by DGII to the activity sectors reported in SIEN's CO2 emissions tables and estimate firm emissions by assigning total activity emissions reported by SIEN to all firms in that specific activity. We then assign the emissions share corresponding to each firm based on their share of total non-electric energy expenditure from Form 606 for that activity. For example, SEIN reports that the agriculture sector emitted 220 thousand tons of CO2 in 2018. These 220 tons of CO2 get assigned to all firms for which their activity reported by DGII is agriculture, and a firm's share of those 220 thousand tons of CO2 is equal to each firm's share of total non-electric energy expenditure reported by Forms 606 for the agriculture sector in 2018. It is important to highlight that with this methodology we do to exploit the variation in firm expenditure patterns observed in Form 606, as not all firms in the same activity sector (i.e., agriculture) have the same expenditure patterns, (i.e., some might spend more or less in energy sector “sale of gas to users [ISIC 402003]” and others might spend more or less in energy sector “retail sale of fuel [ISIC 505001]”).

B.3 Relation between the level of productivity of each industry and the correlation between productivity and distortions in each input market

An important stylized fact is that there is no significant relation between the level of productivity of each industry and the correlation between productivity and distortions in each input market. In other words, industries with higher levels of productivity do not necessarily have higher correlations between the level of productivity and its inputs (see Figure B1, B2, B3, B4) .

Figure B1. Output

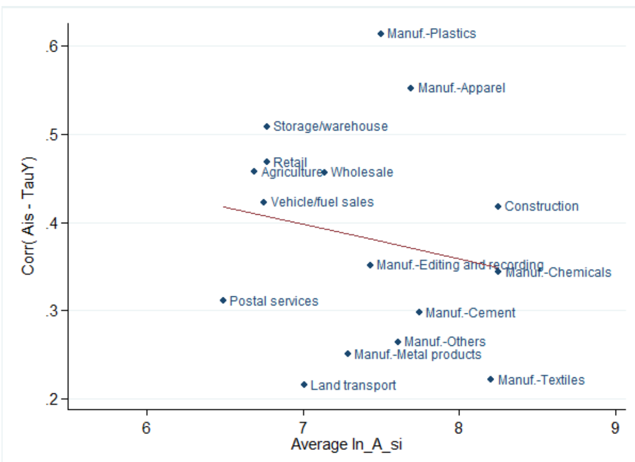


Figure B2. Capital

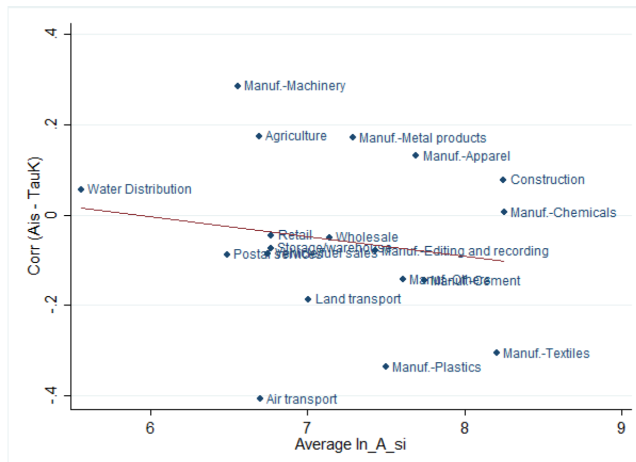


Figure B3. Electricity

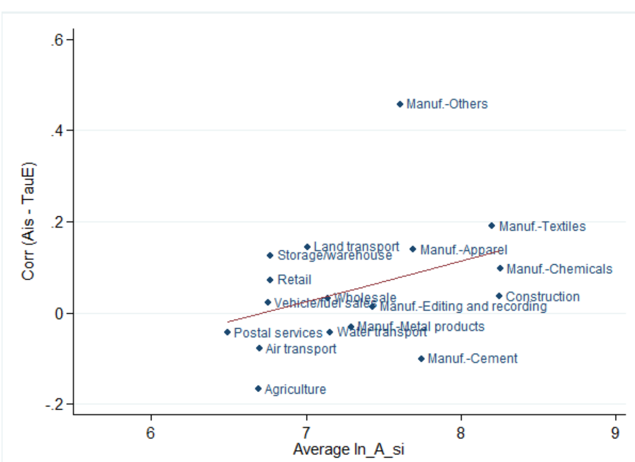
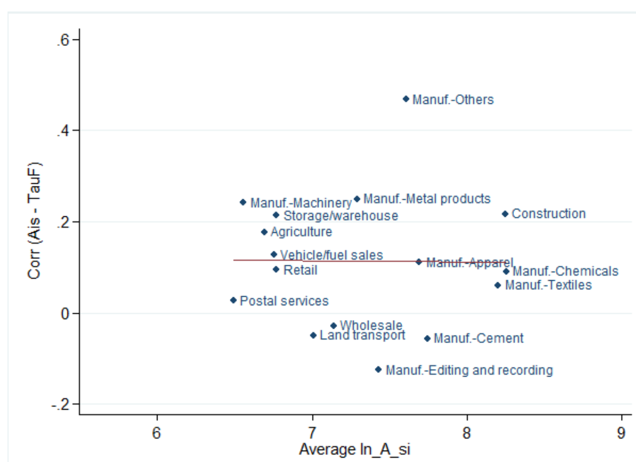


Figure B4. Fuel



B.4 Production function estimated results

Figure B7 displays the results for the estimation of the production function as stated in Equation (3). The estimated β_s for each of the production function inputs represent how intensively each input is used in the generation of value added in each of the sectors of the economy. The constant elasticity of substitution assumption in the model, restricts the inputs elasticities to add up to one, $\beta_l + \beta_k + \beta_x + \beta_f = 1$. The estimation of the production function with four inputs of production and one constraint, generates negative coefficients for some of the sectors' inputs, such as manufacturing of food, manufacturing of footwear, manufacturing of electrical and medical equipment, hospitality services, among others. Thus, these sectors are omitted in the calibration of the model, as explained in previous sections. Among the sectors with the largest electricity elasticity we find manufacturing of metal products, editing and recording, and land transport services. Among the sectors with the smallest but positive electricity elasticity we find manufacturing of plastics, manufacturing of machinery, and agriculture. On the other hand, the sectors with largest fuel elasticities are manufacturing of cement, construction, and manufacturing of textiles. Among the sector with lowest fuel elasticities are storage and warehousing services, manufacturing of plastics, and vehicle sales.

Table B7

Output Elasticities of Inputs: β_s

ISIC code	Industry name	β_l	β_k	β_x	β_f
01	Agriculture	0.4858	0.3787	0.0061	0.1293
15	Manuf.-Food	0.4802	0.4892	**-0.1042**	0.1347
16	Manuf.-Tobacco	0.1542	0.5122	**-0.0242**	0.3578
17	Manuf.-Textiles	0.2714	0.4939	0.0225	0.2122
18	Manuf.-Apparel	0.4786	0.3474	0.0495	0.1246
19	Manuf.-Footwear	0.3847	0.3570	**-0.1135**	0.3717
20	Manuf.-Wood products	0.6096	**-0.0281**	0.2853	0.1332
21	Manuf.-Paper products	0.4711	0.5511	0.2122	**-0.2344**
22	Manuf.-Editing and recording	0.4304	0.2256	0.1604	0.1835
24	Manuf.-Chemicals	0.5357	0.3003	0.1074	0.0566
25	Manuf.-Plastics	0.3924	0.5820	0.0020	0.0236
26	Manuf.-Cement	0.3494	0.2857	0.0392	0.3257
27	Manuf.-Basic metals	0.3681	0.4753	**-0.0073**	0.1639
28	Manuf.-Metal products	0.2613	0.4444	0.1672	0.1270
29	Manuf.-Machinery	0.6641	0.1719	0.0022	0.1618
31	Manuf.-Electrical equip.	0.7960	0.1631	**-0.0299**	0.0708
33	Manuf.-Medical equip.	0.4857	0.9383	**-0.1449**	**-0.2791**
36	Manuf.-Others	0.4550	0.2811	0.1357	0.1283
40	Electricity	0.4953	0.3848	**-0.1168**	0.2367
41	Water Distribution	0.4578	0.3456	0.1123	0.0844
45	Construction	0.4336	0.1930	0.1359	0.2375
50	Vehicle/fuel sales	0.7118	0.1474	0.1038	0.0370
51	Wholesale	0.7236	0.1667	0.0525	0.0572
52	Retail	0.6904	0.1632	0.0622	0.0842
55	Hospitality	0.6235	0.1403	**-0.0091**	0.2453
60	Land transport	0.5595	0.1796	0.1529	0.1081
61	Water transport	0.6093	0.2160	0.0973	0.0774
62	Air transport	0.6163	0.2118	0.1069	0.0649
63	Storage/warehouse	0.8020	0.0797	0.1071	0.0112
64	Postal services	0.6004	0.2495	0.0389	0.1113

Note: This table reports the estimates of the output elasticities of inputs. These elasticities are estimated at the 2-digit ISIC sector level using a linear regression of value added on the four input factors, with the following constraint: $\beta_l + \beta_k + \beta_x + \beta_f = 1$.