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Climate change and technology adoption with a large informal sector

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ABSTRACT

What are the aggregate consequences of policies that target adopting more efficient technologies in an economy with a large informal sector? Using a heterogeneous agents model with endogenous occupation choice between workers and formal and informal entrepreneurs and calibrated to Mexico, we found that in economies with a large informal sector, a decrease in the overall tax rate increases by more the adoption of advanced technologies than in economies with a low informal sector. Furthermore, the burden on government revenues is lower in a highly informal economy. In addition, we find that such policies are more efficient than those that target adopting more advanced technologies because they tackle two distortionary problems: the informality rate and the low adoption of advanced technologies. Such policies become relevant, as we estimate that climate change can reduce aggregate production by up to 6.6% in the long-run.

1. Introduction

Mexican establishments are smaller and less productive than their counterparts in developed countries. Recent research has offered explanations for that low productivity, such as scarce workers' schooling (Banco de México, 2023), low-quality institutions (Algazi, 2018), idiosyncratic costs imposed by crime on establishments (Mascarúa, 2022), gender disparities (Mascarúa, 2023), and distortions associated with a sizeable informal sector (Leal-Ordóñez, 2014), among others. In addition, since a significant fraction of Mexican firms operates in the informal sector, the lack of credit access may further distort their productivity levels (Moll, 2014). In this context, the effects associated with climate change have the potential to impose additional distortions on the Mexican economy, for example, by reducing firms' access to inputs (e.g., with less fertile soil and reduced water supply) or increasing their production costs, as a large share of firms are not profitable enough or lack credit access to acquire more efficient technologies that reduce input usage. Therefore, it becomes relevant for establishments to adopt more productive technologies that reduce the use of inputs.

In this paper, we study the long-run aggregate effects of climate change on Mexican establishments and how policymakers can support appropriate technology adoption of Mexican establishments to mitigate such impacts. To do it, we develop a heterogeneous agents model with an endogenous occupational choice between workers and entrepreneurs and a selection of two different technologies: one more productive that requires a lower input use but has higher operating costs than the other.

The model builds on Lucas (1978) span-of-control model and Guner et al. (2008). Agents become workers or entrepreneurs based on their talent. Entrepreneurs operate firms in the formal or informal sector, as in Leal-Ordóñez (2014). Also, firms may adopt a

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more efficient technology that reduces input use but has higher fixed costs (Hübler and Schwerhoff, 2023; Tsomocos and Khemka, 2023). Alternatively, firms may operate a technology that requires more inputs but with lower fixed costs. Climate change costs are modeled as changes in input availability and prices. Two main mechanisms distort aggregate productivity and provide a rationale for policy intervention. First, changes in production costs and adopting different production technologies have compositional effects (either from workers switching from formal to informal jobs or firms using the inefficient technology). Second, higher input costs directly affect firms' production levels. We calibrate the model using data on Mexican firms from the Establishments Census of INEGI and calibration values from other studies, such as Algazi (2018) and Leal-Ordóñez (2014).

To estimate the aggregate effects of climate change, we feed into our model the results of Dasgupta et al. (2021), who count a reduction of 5.6% in the effective labor supply resulting from an increase of 2.0° Celsius in average temperatures in the Americas. In addition, we feed into the model a hypothetical increase in the rental rate of capital of 10%, as Buhr et al. (2018) estimated due to climate change. In such a scenario, the adoption of advanced technologies that require lower inputs declines. Moreover, steady-state output would decrease by 6.6%. Such results motivate adopting policies that aim to reduce the use of simple and inefficient technologies that require more inputs to mitigate the adverse effects of climate change.

We consider a policy that aims to increase the adoption of more advanced technologies in which the government changes the overall tax rate for all establishments. The reason to target all establishments instead of the less efficient ones is that, with the presence of a sizeable informal sector, such as in Mexico, it becomes difficult to target firms using less efficient technologies since many of them operate under the authorities' radar. Due to the government surveillance, the adoption of less effective technologies tends to more labor-intensive production. In Sajid et al. (2021), it is suggested how labor can lead to a higher volume of carbon emissions regardless of the economic development level, compared to that of fixed capital. While high-skilled labor can reduce net emissions (Chen et al., 2021), informality in the workforce hinders its incorporation into the production process. On the other hand, advanced entrepreneurs benefit from more skilled labor and the adoption of technologies or regulations with the potential diminishing of environmental impact. For instance, more stringent environmental regulations are associated to better production output (Berman and Bui, 2001), or compensate their economic costs without taking into account the improvement in life quality externality (Dechezleprêtre et al., 2019). We find that in economies with a large informal sector, a decrease in the overall tax rate boosts the adoption of advanced technologies and expands output considerably more than in economies with a low informal sector. This is because such policy tackles simultaneously informality (tax evasion) and the adoption of advanced technologies. Furthermore, the burden on government revenues is lower in the high informality economy.

In addition, we consider an alternate policy in which the government subsidizes the use of the advanced technology in the formal sector (the sector that, by definition, is the only one under the authorities' radar.) To run a balanced budget, the government increases the tax rate for the formal sector. We find that partially subsidizing the use of the advanced technology increases the adoption of the advanced technology and aggregate output. However, such policies considerably increase the tax burden of the private formal sector and may decrease informality levels. Thus, this study provides evidence that overall tax rate policies may be more efficient than targeted policies in economies with a large informal sector.

This paper contributes to the distributional consequences of climate change and the aggregate effects of the adoption of different technologies; green and brown technologies as in Tsomocos and Khemka (2023), efficient and less efficient technologies as in Li and Sun (2015) and Hübler and Schwerhoff (2023). We extend the knowledge in the literature by studying a channel not thoroughly studied, the informal sector. In addition, this paper contributes to the literature of the consequences of climate policies using macroeconomic models tailored for emerging economies, such as Bento et al. (2018), Reidt (2021), and Finkelstein Shapiro and Nuguer (2023)

2. A model with costly adoption of technology

The model extends Lucas (1978) *span-of-control* framework by including an endogenous distribution of informal and formal workers, similar to Antón and Leal (2015), and costly technological adoption as in Hübler and Schwerhoff (2023). Finally, the model is represented dynamically, as in Guner et al. (2008).

2.1. Environment

The economy comprises a representative household formed by a continuous population of mass 1 of individuals endowed with entrepreneurial talent z , as in Guner et al. (2008). Talent is drawn from a time-invariant distribution with a density function $g(z)$, and a CDF $G(Z)$ for $z \in [z_{\min}, z_{\max}]$. In addition, each house member has one unit of time each period.

The household utility function over a sequence of consumption is given by:

$$\sum_{t=0}^{\infty} \beta^t u(C_t), \quad (1)$$

where β is the subjective discount factor, and C_t is the representative consumption good in period t . In addition, the household accumulates capital by making investments of X_t , with K_0 units of capital at the initial period 0. The law of motion of capital is, hence:

$$K_{t+1} = X_t + (1 - \delta)K_t. \quad (2)$$

Household members can select their occupation from entrepreneurs or workers, and from the formal or the informal sector. Entrepreneurs form establishments to produce and have access to two decreasing returns-to-scale technologies: a more productive technology (Advanced Technology, denoted by the subscript a) but with higher fixed operating costs f_a and, in contrast, a less productive one (Simple Technology, denoted by the subscript s) but with lower fixed operating costs f_s . The functional form of the production function $g_j(z, k, l)$ is:

$$g_j(z, k, l) = \eta_j z k^{\theta_k} l^{\theta_l}, \tag{3}$$

where η_j is the deterministic specific efficiency (technology j equals s or a), k is the capital the establishment rents, l represents the workers hired, and the decreasing returns to scale assumption implies $0 < \theta_k + \theta_l < 1$ and ensures in equilibrium the existence of a distribution of establishments (instead of the most productive establishment producing all goods in the economy). Algebraically, the advanced and the simple technologies differ in the parameters $\eta_a > \eta_s$ and $f_a > f_s$. The government levies output at a rate τ_y and returns the revenues R_t to the household as a lump-sum transfer. The rate τ_y taxes simultaneously labor, capital, and profits. Such simplification reduces the complexities of the Mexican tax system into a single average value and allows us to calibrate the related parameters more easily. The government can only tax establishments that rent high levels of capital. The government detection probability $p(k(z))$ is given by:

$$p(k(z)) = \begin{cases} 0, & k(z) \leq b \\ 1, & \text{else,} \end{cases} \tag{4}$$

where $b > 0$ is the capital threshold.¹

2.2. Economic problems of agents

2.2.1. Workers

Workers supply inelastically their unit of labor. Their earnings are, hence, the wage rate w .

2.2.2. Formal entrepreneurs

An entrepreneur z who operates in the formal sector F with technology j will maximize their profits according to:

$$\pi_j^F(z; w, r) = \max_{\{l_F, k_F\}} \left\{ (1 - \tau_y) \eta_j z k_F^{\theta_k} l_F^{\theta_l} - w l_F - r k_F - f_j \right\}, \tag{5}$$

where r is the price of capital.

2.2.3. Informal entrepreneurs

An informal entrepreneur with talent z who uses technology j maximizes profits according to:

$$\pi_j^I(z; w, r) = \max_{\{l_I, k_I\}} \left\{ (1 - p(k_I)) \left(\eta_j z k_I^{\theta_k} l_I^{\theta_l} - w l_I - r k_I - f_j \right) \right\} \tag{6}$$

Since informal entrepreneurs lose all their profits whenever they exceed the detection capital threshold, the previous equation can be restated as follows:

$$\pi_j^I(z; w, r) = \max_{\{l_I, k_I\}} \left\{ \eta_j z k_I^{\theta_k} l_I^{\theta_l} - w l_I - r k_I - f_j \right\} \quad \text{s.t.} \quad k_I \leq b. \tag{7}$$

2.2.4. Household

Total household earnings correspond to the earnings of the workers and the entrepreneurs operating on both the informal and formal sector, the lump-sum transfers T_t and capital earnings rK_t .

$$\begin{aligned} E(w, r) &= \int_{z_{\min}}^{z_{\max}} w(1 - I_s(z) - I_a(z) - F_s(z) - F_a(z)) dG(z) \\ &+ \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} I_j(z) \pi_j^I(z; w, r) dG(z) \\ &+ \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} F_j(z) \pi_j^F(z; w, r) dG(z) + T_t + rK_t \end{aligned} \tag{8}$$

where $I_j(z)$ and $F_j(z)$ are the index functions for the entrepreneurs employing technology j , either simple or advanced.

The household maximizes its utility by choosing C_t , K_t , $I_t(z)$, and $F_t(z)$, given the wage w and the cost of capital r :

$$\max_{\{C_t, K_t, I_t(z), F_t(z)\}} \left\{ \sum_{t=0}^{\infty} \beta^t u(C_t) \right\}, \tag{9}$$

¹ Ihrig and Moe (2001) argue that capital is more challenging to hide. First, the labor informality rate is lower in the manufacturing sector than in the service sector, which hints that authorities detect less informal labor than capital. Second, output is also challenging to hide in the manufacturing sector when firms engage in international trade because of regulations, tariffs, and other government controls.

and subject to the budgetary restriction:

$$C_t(z) + K_{t+1} - (1 - \delta)K_t = r_t K_t + E(w_t, r_t; \tau_y, b) + T_t, \quad \forall t, \tag{10}$$

for a given initial capital K_0 .

By solving the optimization problem of the household, the rental rate of capital is pinned down:

$$r = \frac{1}{\beta} - (1 - \delta) \tag{11}$$

2.3. Government policies

The government has a balanced budget each period.

$$R_t = T_t, \quad \forall t \tag{12}$$

2.4. Market clearing

The supply of labor equals its demand for all sectors and technologies. The condition is:

$$\begin{aligned} \int_{z_{\min}}^{z_{\max}} W(z; w_t, r_t) dG(z) &= \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} I_j(z; w_t, r_t) l_{I_j}(z; w_t, r_t) dG(z) \\ &+ \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} F_j(z; w_t, r_t) l_{F_j}(z; w_t, r_t) dG(z), \end{aligned} \tag{13}$$

where $I_j(z)$ and $F_j(z)$ are the index functions for the entrepreneurs employing technology j , either simple or advanced, and W is the index function for workers, given by:

$$W = 1 - I_a(z; w_t, r_t) - I_s(z; w_t, r_t) - F_a(z; w_t, r_t) - F_s(z; w_t, r_t). \tag{14}$$

Additionally, capital markets are cleared considering the following condition:

$$\begin{aligned} K_t &= \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} I_j(z; w_t, r_t) k_{I_j}(z; w_t, r_t) dG(z) \\ &+ \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} F_j(z; w_t, r_t) k_{F_j}(z; w_t, r_t) dG(z) \end{aligned} \tag{15}$$

Finally, goods' market are cleared with the following condition:

$$\begin{aligned} C_t + K_{t+1} - (1 - \delta)K_t &= \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} I_j(z; w_t, r_t) y_{I_j}(z; w_t, r_t) dG(z) \\ &+ \sum_{j=s,a} \int_{z_{\min}}^{z_{\max}} F_j(z; w_t, r_t) y_{F_j}(z; w_t, r_t) dG(z) \end{aligned} \tag{16}$$

For the analysis of the next section, we will focus on a steady-state equilibrium.

2.5. Calibration

We calibrate the parameters to replicate the aggregate productivity of the Mexican economy, its distribution of establishments and the size of the informal sector.

We assume the entrepreneurial ability to follow a truncated Pareto distribution with parameters z_{\min} , z_{\max} and *shape*. That is, the talent z has the CDF:

$$G(z) = \frac{1 - \left(\frac{z_{\min}}{z}\right)^{shape}}{1 - \left(\frac{z_{\min}}{z_{\max}}\right)^{shape}} \tag{17}$$

There are two sets of parameters that need to be calibrated. We take the values for the first set from [Leal-Ordonez \(2014\)](#) and jointly calibrate the other one using computational methods. For the first set, the parameter θ_k that represents the share of capital in the production function is set to 0.33. The depreciation rate, δ , is 0.05. The lowest talent value, z_{\min} , and the fixed cost to produce using the simple technology, f_s , are normalized to the unity. Finally, the tax rate τ_y is 0.25. To determine the simple and advanced technologies, we follow [Hübler and Schwerhoff \(2023\)](#) and set $\eta_a = 1.3$ and $\eta_s = 1.0$.

We jointly calibrate the other parameters, β , θ_l , z_{\max} , *shape*, b and f_a , using the `BlackBoxOptim.jl` of Julia 1.9.1 that minimizes the Euclidean distance between some observed moments and their model counterparts. We take the observed moments from [Leal-Ordonez \(2014\)](#), and consist of the informality share, the establishment size (i.e. the average number of workers), the establishment size of establishments with more than 100 workers, the share of establishments with more than 100 workers, and the capital-output ratio.

Table 1
Calibration targets.

Targeted variables		Data	Model
(1)	Informality size	0.45	0.44
(2)	Mean size	5.5	5.6
(3)	Mean size by employment size category (+100)	360	348
(4)	Worker share by employment size category (+100)	0.30	0.29
(5)	Capital–output ratio	2.0	2.0
(6)	Share of production from simple technologies	0.40	0.41

Note. Data moments (1) to (5) are from [Leal-Ordóñez \(2014\)](#) and moment (6) from [Hübler and Schwerhoff \(2023\)](#).

Table 2
Calibrated parameter values.

Parameter	Benchmark	Counterfactual	Source
β	0.9353	0.9404	Computational simulations
θ_l	0.2408	0.2101	
z_{\max}	80.45	80.45	
<i>shape</i>	2.77	2.75	
b	15.16	2.06	
f_a	21.74	16.65	
f_s		1.00	Hübler and Schwerhoff (2023)
η_a		1.30	
η_s		1.00	
θ_k		0.33	Leal-Ordóñez (2014)
δ		0.05	
z_{\min}		1.00	
τ_y		0.25	

Note. The table shows the calibrated parameters for the Benchmark economy and a Counterfactual one consistent with an informality rate like that of the United States. We calculated the first group of parameters with computational simulations that minimize the Euclidean distance between the observed and the model moments in [Table 1](#). We take the other set of parameters from [Hübler and Schwerhoff \(2023\)](#) and [Leal-Ordóñez \(2014\)](#).

As the model is highly nonlinear and because of the interaction of general equilibrium effects, all parameters may affect various moments simultaneously. However, some parameters may play a higher direct effect on the value of the moments. Specifically, the parameter β determines the rental rate of capital in the steady state and, as a consequence, the capital–output ratio. The parameters θ_l , z_{\max} and *shape* determine the productivity of the production function and the distribution of establishments; hence, the three parameters directly affect the establishment size and the share of establishments with more than 100 workers. Parameter b , the maximum capital level that informal establishments can rent without being caught, determines the informality rate. Finally, the fixed cost f_a of using the advanced technology determines the share of establishments using the advanced (or simple) technology. [Table 1](#) shows the observed moments and their model counterparts. In general, the model replicates reasonably well the chosen moments.

Finally, [Table 2](#) presents a summary of the jointly calibrated parameter values (Benchmark column).

3. Results

In this section, we present an estimate of the aggregate effects of climate change and two policies. The first policy adjusts the overall tax rate of all establishments, regardless of the technology they use. The second policy subsidizes the use of the advanced technology.

3.1. Aggregate effects of climate change

In [Table 3](#), we show three long-run scenarios for the Mexican economy that arise from an increase in the rental rate of capital, a reduction in the effective labor supply, and the combined effects. We relate such differences to climate change. In particular, [Dasgupta et al. \(2021\)](#) estimate that countries in the Americas would face a reduction of 5.6% in effective labor supply in the long run under a climate-change scenario consistent with an increase in average temperatures of 2.0° Celsius. In addition, [Buhr et al. \(2018\)](#) estimate that climate change would increase global interest rates by up to 10% in the long run.

3.1.1. Decrease in labor supply

In column (b) of [Table 3](#), we show the steady-state effects of a decrease in labor supply of 5.6%, as [Dasgupta et al. \(2021\)](#) estimated for countries in the Americas due to climate change. For comparison purposes, we present the Benchmark economy in column (a) that resulted from the calibration in [Section 2.5](#).

Notice that the decrease in labor supply of 5.6% does not result in a steady-state reduction of the same magnitude. The reason is that the decline in labor supply further raises wages and, hence, some former entrepreneurs become workers. Also, the

Table 3
Aggregate effects associated with a change in inputs by climate change.

Variable	(a) Benchmark	(b) Labor effect	(c) Capital effect	(d) Both effects
Informality share	43.8	43.3	45.5	45.3
Entrepreneurship rate (%)	17.7	21.8	17.2	21.3
Production shares (%)				
(1) Simple technology (informals)	36.6	36.4	38.5	38.3
(2) Simple technology (formals)	4.0	4.0	3.0	3.0
(3) Advanced technology (formals)	59.4	59.6	58.5	58.7
Simple technology (1) + (2)	40.6	40.4	41.5	41.3
Advanced technology (3)	59.4	59.6	58.5	58.7
Capital	100.0	97.6	87.8	85.7
Labor	82.3	78.2	82.8	78.7
Output	100.0	97.8	95.5	93.4
Mean size	5.6	4.4	5.8	4.5
Wage	100.0	102.8	95.5	98.1

Note. The Table shows different steady-state equilibria from the model presented in Section 2. Column (a) depicts the estimated values from the initial calibration (Benchmark) from Section 2.5. Column (b) shows the aggregate values from a counterfactual economy in which effective labor decreases by 5.6% in the long run (Labor effect), as in Dasgupta et al. (2021). Column (c) shows a counterfactual economy in which the cost of capital increases by 10% in the long run (Capital effect), as in Buhr et al. (2018). Finally, column (d) shows the aggregate values in which both labor decreases and the cost of capital increases in the long run (both effects).

entrepreneurship rate increases mechanically because of compositional effects: as the labor supply decreases, the entrepreneurship rate becomes larger in relative terms.

Reducing labor supply does not alter the adoption of advanced technology as a mechanism to cope with the reduction in available workers. The production share by the advanced technology increases from 59.4% to 59.6%. As capital and labor are complements in the production function (3), the aggregate use of capital decreases by 2.4%. The combined effect results in that average productivity decreases, as proxied by the establishment mean size (a reduction from 5.6 to 4.4), and aggregate output decreases by 2.2% in the long run.

3.1.2. Increase in the rental rate of capital

In the second scenario, in column (c) of Table 3, we increased the cost of capital by 10%, as in Buhr et al. (2018). We use that value in our model as a proxy for a hypothetical increase in the capital rental rate associated with climate change.

With the increase in the rental rate of capital, there is a slight decrease in the entrepreneurship rate. That is, some entrepreneurs become workers with higher production costs. Although wages decrease, such a decrease does not compensate for the increase in capital costs. Similarly, the informality rate increases because, as capital becomes more expensive, some firms on the edge of profitability switch to the informal sector to remain profitable.

The share of formal establishments using the simple production technology decreases from 4.0% to 3.0%. However, there is an increase in such rate for the informal establishments (from 36.6% to 38.5%). The reason is that some previous formal entrepreneurs switch to the informal sector and use the same technology. The share of formal establishments that use the advanced technology to produce decreases from 59.4 to 58.5%.

With the exit of some less productive establishments, the average establishment size slightly increases from 5.6 to 5.8. In addition, the aggregate use of capital is considerably lower, with a decrease of 12.2%. With the higher cost of capital, some establishments substitute capital for labor. In addition, some previous entrepreneurs become workers, so the labor supply increases by 0.5 percentage points (from 82.3 to 82.8%). The net effect is that steady-state output decreases by 4.5%.

3.1.3. Decrease in labor supply and an increase in the rental rate of capital

Column (d) of Table 3 shows a third counterfactual scenario in which we introduced the combined effects on inputs: a decrease of 5.6% in labor supply and an increase of 10% in the cost of capital. The mechanisms that affect the aggregate variables combine the ones described in the previous subsections.

In this scenario, the informality rate increases from 43.8 to 45.3%. The share of production of the simple technology rises from 40.6 to 41.3%; hence, the share of advanced technology production decreases from 59.4 to 58.7%. The aggregate use of capital decreases by 14.3%, and the labor supply decreases by 0.6 percentage points (from 82.3 to 78.7%). As a consequence, aggregate output has the highest contraction in this scenario, with 6.6%

3.1.4. Discussion

The three scenarios point in the direction that, according to our model, with a temperature increase of 2° Celsius, as the authors have pointed out, the aggregate decrease in aggregate output can range from 2.2% to 6.6%. Since our simple model only considers consumption to provide utility, the decline in production also approximates a decrease in welfare. Such numbers are significant. Therefore, there is a rationale for policy interventions. In addition, although our model does not incorporate pollution in the

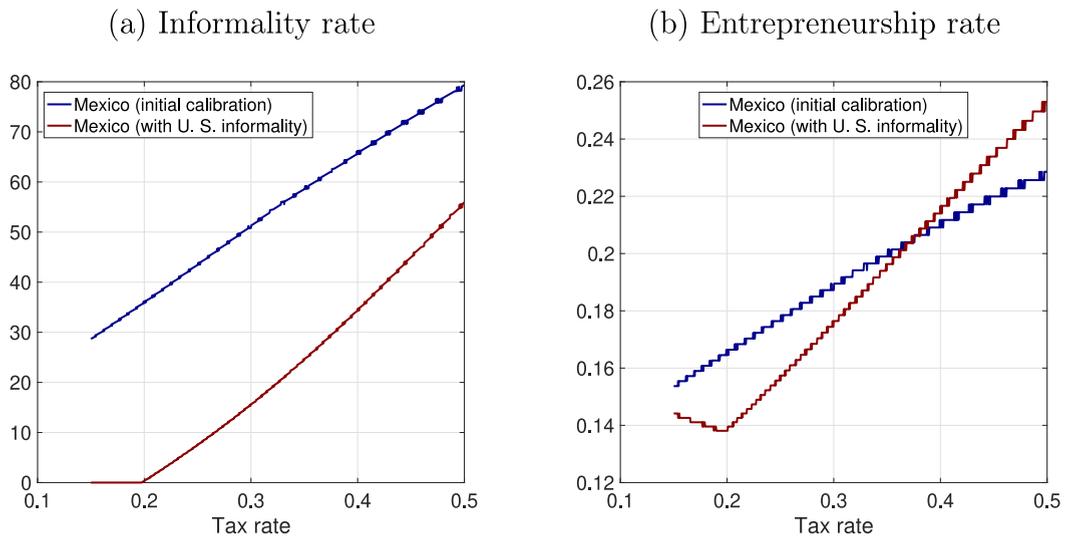


Fig. 1. Informality and entrepreneurship rates as the tax rate changes (%). *Note.* The figure shows the results from different steady-state equilibria that result from changing the tax rate τ_y . The blue line represents the calibrated economy presented in Section 2.5 and the red line represents a counterfactual Mexican economy with low levels of informality, as those present in the United States. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

production function, if we relate the simple technology to inefficient pollutant industries, a policy to reduce the use of inputs becomes even more relevant.

However, in a country with high informality, such as Mexico, targeted policies that either subsidize the adoption of advanced technology or tax the use of inefficient simple technologies may not be effective, as an outstanding share of establishments is outside the scope of the authorities. With that in mind, we study the aggregate effects of policies that aim at all establishments by varying the overall tax rate.

3.2. Tax policy for all establishments

We numerically solve the model for a range of tax rates τ_y , from 0.15 to 0.50. In addition, we recalibrated the model using the moments presented in Section 2.5, except the size of the informal sector, that we set it to 7.3%, which is the informality rate of the United States. We present the parameter values in the column Counterfactual of Table 2. We do such exercise to compare how the presence of a large informal sector changes the effects of the policies compared to a counterfactual Mexican economy with a small informal sector (similar to the United States).

Fig. 1 shows the percentage of workers in the informal sector as the tax rate changes. Remember that in the benchmark scenario, the tax rate is 0.25. The graph displays two lines. The blue line represents the scenario that arises from the calibration described in Section 2.5, and the red line represents the counterfactual scenario of the Mexican economy with the informality rate of the U. S. The model predicts in both cases that as the tax rate increases, the informality rate increases as well, and vice versa. The reason is that with a higher tax rate, the operating costs of the formal establishments will be higher, and some will switch to the informal sector to counteract the increase in the tax burden. The decrease in the size of the formal sector decreases aggregate productivity, wages decline, and some workers will form establishments after the decrease in their wage income (Fig. 1b).

Fig. 2 displays the production of formal and informal establishments using simple and advanced technologies. Similarly to the previous graphs, the blue line represents the scenario from the initial calibration, and the red line represents the counterfactual Mexican economy with the U. S. informality rate. Notice that informal establishments only use the simple technology. If they use it, they will increase their capital usage and get caught by the government.

The graphs show two effects. If the tax rate decreases (from its benchmark value of 0.25), the share of the production of the simple technology decreases for informal establishments and increases for formal establishments. The reason is that with a decrease in the tax rate, some informal establishments will become formal but produce using the simple technology because they are less productive in adopting the advanced technology. With a decrease in the tax rate, more formal establishments will adopt the advanced technology. Notice, however, that in the benchmark case with higher informality (blue line), the increase in the share of the production with the advanced technology is higher.

The aggregate effects are summarized in Fig. 3. In the presence of a large informal sector (blue lines), the changes in the tax rate bring large swings in the use of the simple and advanced technologies. By contrast, with low values of informality (red lines), the changes in the usage of both technologies remain relatively constant, with tax rates between 0.15 and 0.35. The results indicate that in countries with a large informal sector, such as Mexico, the decrease in the overall tax rate may increase the adoption of more efficient technologies.

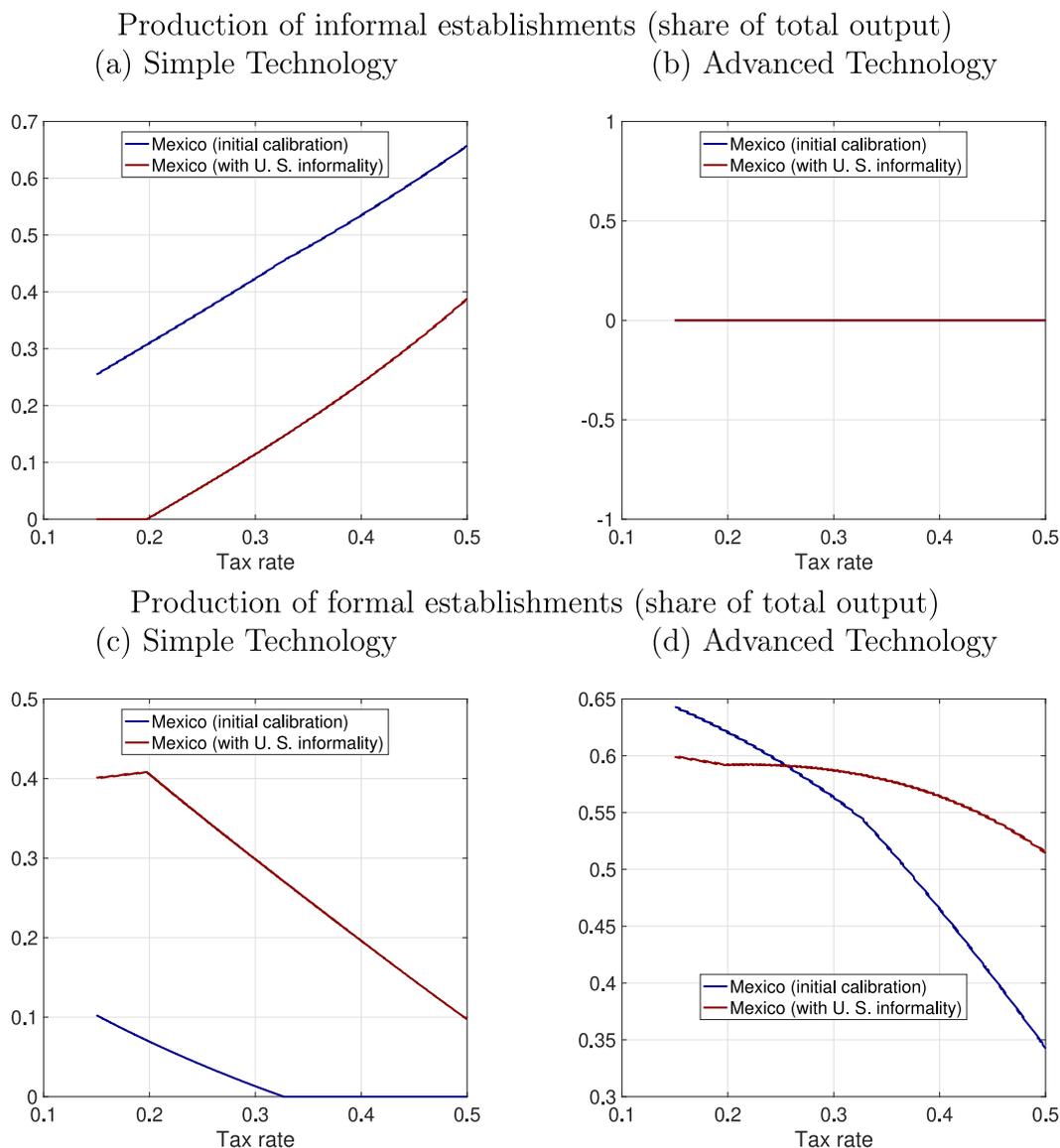


Fig. 2. Share of output produced using the simple (S) and advanced (A) technology by informality status. *Notes* The figure shows the share of output produced by formal and informal establishments using advanced (a) or simple (s) technology. Each quadrant represents a steady-state equilibrium from a different tax rate (x-axis). The blue line represents the Benchmark calibration, and the red line represents a counterfactual economy of Mexico with the informality rate of the United States. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The previous Figure showed that in the high-informality economy, the decrease in the tax rate results in a more significant adoption of the advanced technology than in the low-informality economy. The reason is that establishments have more disposable income to adopt it, and some informal establishments switch to the formal sector and adopt the advanced technology. However, the decrease in the tax rate may alter government revenues.

Fig. 4 shows the tax revenues for several tax rates. Government revenues decrease less in an economy with a large informal sector (blue line) than in one with a small informal sector (red line).

3.3. Subsidy policy for formal establishments

In this section, we study a policy that subsidizes the operation of the advanced technology in the formal sector. We focus on the formal sector since, by definition, it is the only sector under the scope of the authorities. We present several scenarios where the government subsidizes a fraction of the fixed costs to operate the advanced technology. To pay for this subsidy, the government taxes the formal establishments (those that operate simple and advanced technologies.) We further assume that the government

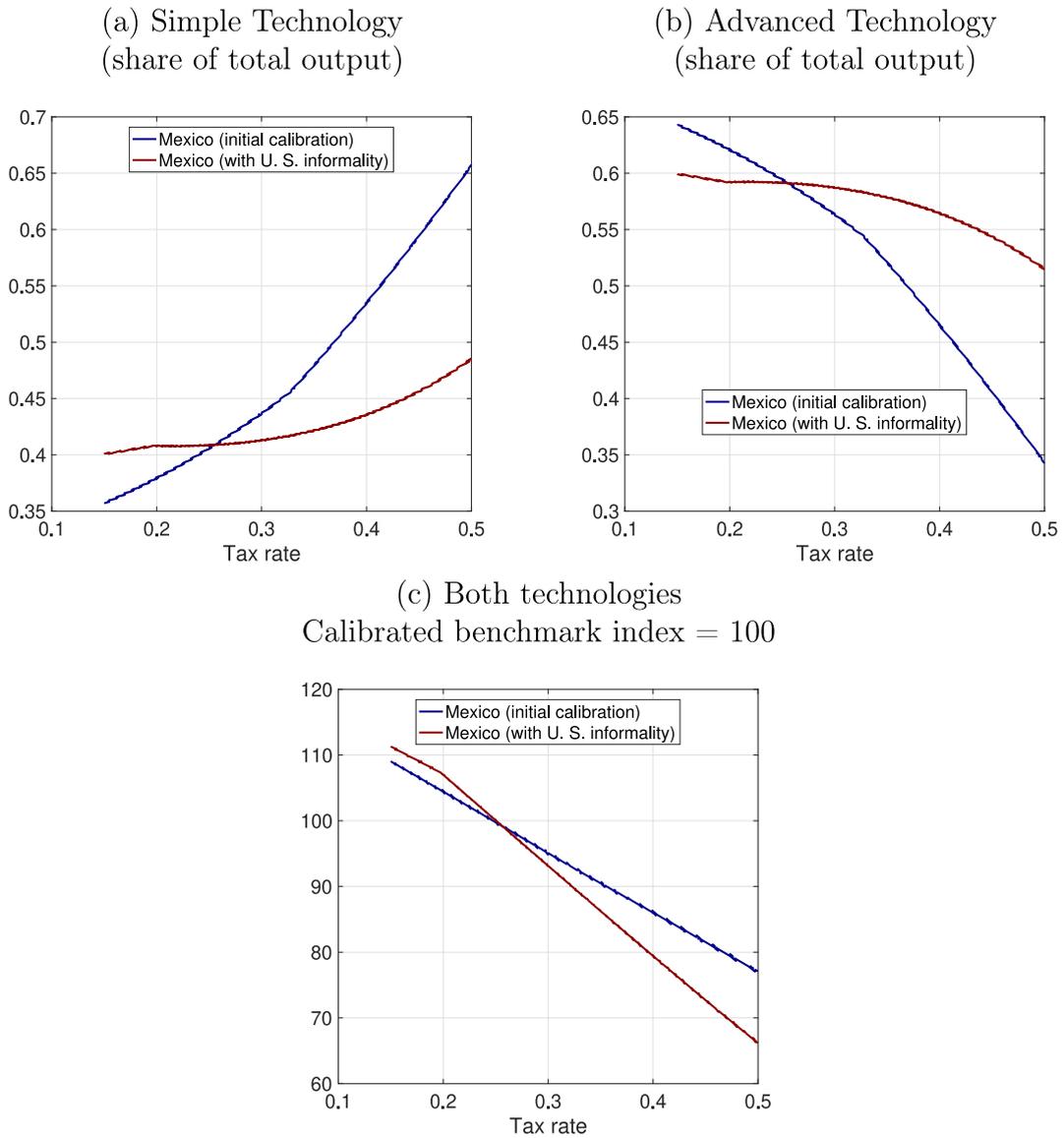


Fig. 3. Share of output produced using the simple (S) and advanced (A) technology. *Note.* The figure shows the results from different steady-state equilibria that result from changing the tax rate τ_y . The blue line represents the calibrated economy presented in Section 2.5 and the red line represents a counterfactual Mexican economy with low levels of informality, as those present in the United States. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

runs a balanced budget on this policy; that is, the tax revenues are equal to the cost of the subsidies. To calculate the additional tax burden on the formal sector, we set a grid from zero to one representing the fraction of the fixed cost f_a that the government subsidizes and then find the tax rate that balances the budget.

Fig. 5a plots the fraction of the subsidy and the increase in τ_y . As the Figure shows, subsidizing the operation of advanced technology is costly for the formal sector: its tax rate increases between 0 and 12 percentage points depending on the size of the subsidy (from a benchmark value of 25%.)

As Fig. 5b shows, and as expected, the adoption of the advanced technology increases with a larger subsidy. However, one consequence is that the informality rate rises with a small fraction of the subsidy (from a to 20%) because the extra tax burden pushes some formal establishments to the informal sector. However, with subsidy fractions from 25% to nearly 80%, the informality rate decreases since the subsidy encourages some former informal establishments to adopt the advanced technology and operate in the formal sector (Fig. 5c). Eventually, with high subsidy values (fractions above 80%), the informality rate increases as the tax burden increases.

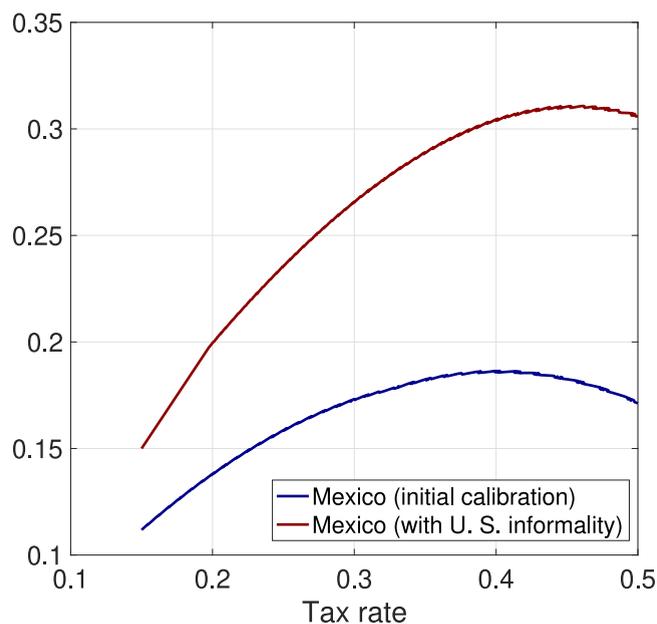


Fig. 4. Government revenues as the tax rate changes (%). *Note.* The figure shows the results from different steady-state equilibria that result from changing the tax rate τ_s . The blue line represents the calibrated economy presented in Section 2.5 and the red line represents a counterfactual Mexican economy with low levels of informality, as those present in the United States. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Finally, Fig. 5d shows that total output may decrease with high and low subsidies (because of the informal sector changes due to the extra tax burden). In conclusion, this exercise shows that a government may obtain similar results if its goals are to increase both the adoption of the advanced technology and output with a policy that decreases the tax rate for all establishments (as the one presented above). In addition, a general reduction in the tax rate considerably reduces the informal sector's size and further increases efficiency.

4. Conclusion

Using a structural model calibrated to the distribution of establishments in Mexico, we found that in economies with a large informal sector, a decrease in the overall tax rate increases the adoption of advanced technologies more than in economies with a low informal sector. Furthermore, the burden on government revenues is lower in a highly informal economy. Additionally, we compared such a policy with one that subsidizes the use of advanced technologies and found that both policies achieve similar results in terms of the adoption of technology and increases in output.

However, decreasing the overall tax rate is more efficient, as it tackles labor informality and technological adoption. If the simple technology is also the one that pollutes more, a decrease in the overall tax rate, although it does not directly target adopting a more efficient technology, may increase efficiency without posing a high burden on government revenues. In a scenario in which climate change may decrease output by up to 6.6%, such a policy becomes relevant to mitigate the adverse effects of climate change.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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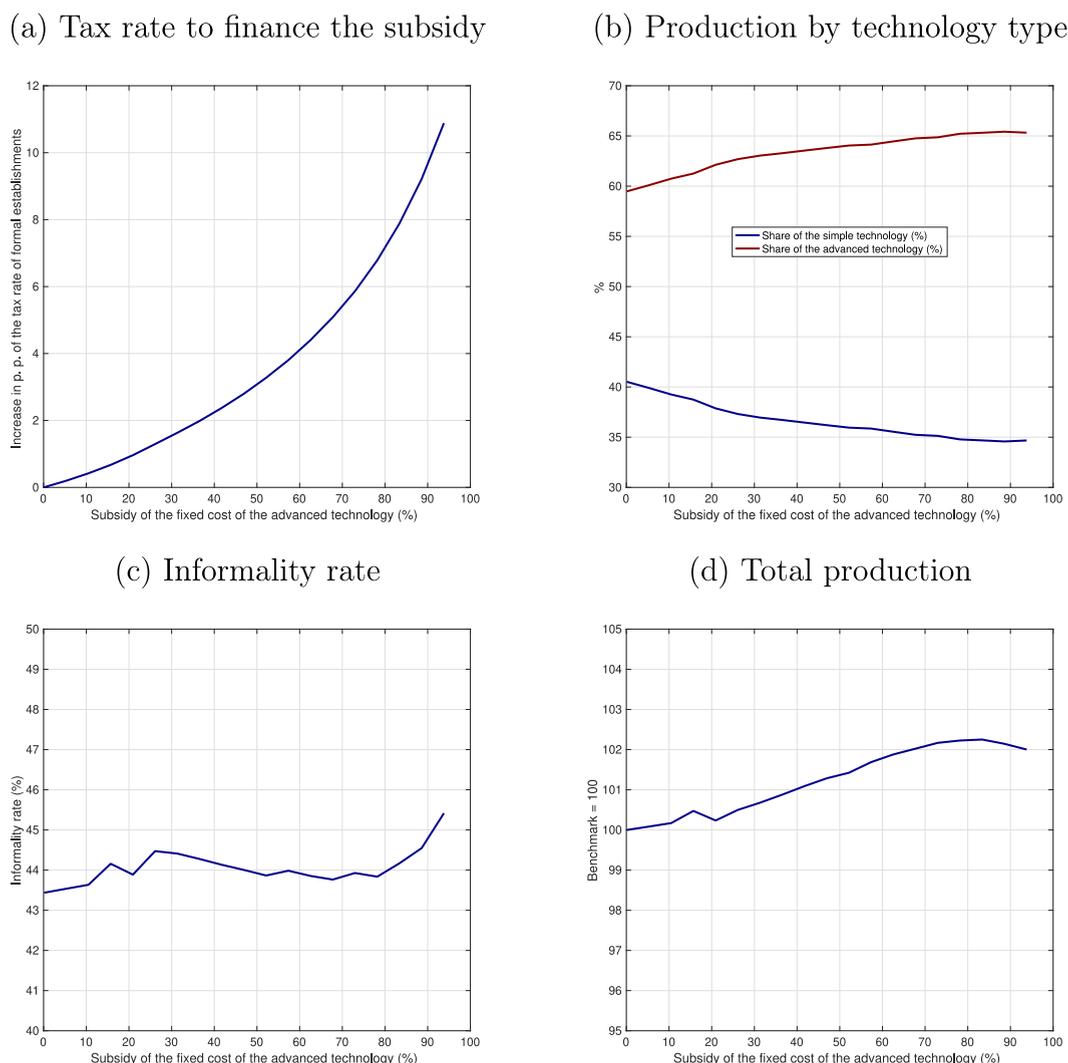


Fig. 5. Changes in the aggregates by changes in the subsidy to operate the advanced technology. *Notes* The Figure shows the different scenarios in which the government subsidizes the use of the advanced technology in the formal sector. Panel (a) shows the tax rate needed to finance the corresponding share of the subsidy. Panel (b) shows the production share of the advanced and simple technologies. Panel (c) shows the informality rate as a function of the share of the subsidy. Panel (d) shows the aggregate output as a function of the share of the subsidy.

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