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Mexico: Reducing Energy Subsidies and Analyzing Alternative Compensation Mechanisms

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Abstract

Energy subsidies are politically sensitive. In Mexico they include subsidies to electricity, gasoline, diesel, and liquefied petroleum gas. Between 2005 and 2009, subsidies were, on average, equal to Mex$200.4 billion per year. Subsidies to electricity represent roughly 1% of GDP. Subsidies to gasoline are equivalent to 25% of revenues collected from the value-added tax. These subsidies have fiscal, distributional, and environmental implications. This paper analyzes the impact that energy subsidy reductions and alternative compensating mechanisms might have in Mexico. We use a computable general equilibrium model of the Mexican economy to see the effects of removing such subsidies, looking at possible compensation mechanisms and analyzing the impact on the income groups that may be affected by the reduction of energy subsidies. As an example, we simulate the effect of allocating these resources to expanding healthcare coverage that is not readily available to all workers in Mexico. The main results are an increase in GDP, investment and capital accumulation, significant and progressive gains in welfare, and an increase in production and consumption across the board, even though some of the energy sectors take time to recover from the energy subsidy removal. Expanded healthcare promotes formality and leads to a more productive economy,

Resumen

Los subsidios a la energía son un tema políticamente sensible. En México estos subsidios se otorgan a la electricidad, gasolina, diésel y gas licuado de petróleo. Entre 2005 y 2009 los subsidios fueron, en promedio, equivalentes a $200.4 miles de millones de pesos anuales. Los subsidios a la electricidad representan aproximadamente 1% del PIB y los subsidios a la gasolina al 25% de los ingresos del IVA. Estos subsidios tienen implicaciones fiscales, distributivas y ambientales. Este ensayo analiza el impacto de la reducción de los subsidios a la energía y la introducción de mecanismos de compensación que se podrían aplicar en México mediante un modelo de equilibrio general computable, que permite determinar los impactos sobre distintos grupos de ingresos posiblemente afectados por la reducción de los subsidios. A manera de ejemplo, simulamos el efecto de usar estos recursos para expandir el sistema de salud pública que actualmente no cubre a una parte importante de los mexicanos. Los resultados muestran un aumento en el PIB, en la producción y en el consumo generalizado, incluso cuando algunos sectores se ven afectados en el corto plazo. La expansión del servicio de salud promueve formalidad laboral y lleva a una economía más productiva, con una distribución más equitativa del ingreso. Los precios más altos de los combustibles promueven el ahorro y la eficiencia energética y emisiones más bajas con menores efectos locales y globales, contribuyendo a mejorar la calidad del aire, reducir costos de salud y a alcanzar el 80% de las metas de mitigación anuales de CO_2 de México.

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Introduction

This paper analyzes the economic, distributional, and environmental impact that energy subsidy reductions and compensating mechanisms might have in Mexico. To achieve that goal, we use a computable general equilibrium model of the Mexican economy (for a detailed description, see Ibarrarán and Boyd 2006). We make several important changes to the original model to build the energy subsidies (to gasoline, diesel, electricity and LPG) into the benchmark and then do an array of simulations to see the effects of removing such subsidies. We report results for 2012, which is the initial year; 2018, which would be the end of this administration; and 2024 and 2030, which represent the medium and long term, respectively.

There can be basically an infinite array of alternative ways to make changes to the energy pricing policy. When doing the simulations, we first look at the elimination of energy subsidies, and then at the use the saved funds to finance an expanded healthcare program. Several authors have proposed alternative packages (Antón, Hernández, and Levy 2012; Chávez Presa, Hernández Trillo, and López-Calva 2012, among others). Toward that end, we examine the dynamic implications of financing a healthcare system with a cost of approximately Mex$560 billion a year[1]. This helps illustrate how those resources could be spent. Other proposals that entail different aspects and/or coverage could well be simulated. Depending on the specifics of the proposal, this might entail some combination of healthcare coverage, life insurance, and/or pension systems. The more ample the package, the higher its cost, so ultimately it will be up to the social security reform experts to put together the best combination of policies they can finance. The exercise presented here does not advocate for any particular package; rather, it presents to what extent a package of certain cost can be financed with the savings from energy subsidies.

On the other hand, Mexico is a growing emitter of greenhouse gases. Even though it is ranked 13th worldwide, it contributes approximately 25% of the emissions of Latin America and the Caribbean, although its emissions are only about 1.6% of total global emissions (CICC 2009). This makes emission abatement policy relevant since Mexico is a high-income developing country that is interested in becoming a significant player in climate change policy worldwide. In 2006, 28% of greenhouse gas emissions came from energy generation and 33% from energy use. Energy subsidies play a large role in this. Of total emissions from energy use, 62% are emitted by the transport sector and 10% by the residential sector (CICC 2009). Both of these sectors are heavily subsidized. The Mexican government has put forth a plan to mitigate emissions, the Special Program on Climate Change (Programa Especial de Cambio Climático, PECC), running from 2009 to 2012. Overall, it estimates that 129.03 million tons of CO_2 equivalent (MtCO2e) would be eliminated during that four-year period, 50.65 MtCO2e alone in 2012. Subsidy elimination was not considered within the PECC. Results of the model presented

1. As an illustration, we assume that the current cost in health per worker is $10,118 pesos. Given a workforce of 39.03 million workers, the cost of health insurance would be Mex$394.9 billion. To this amount, Mex$136.3 billion are added to cover retirement pensions and Mex$28.1 billion for life and disability insurance. This gives a total cost of Mex$559.3 billion according to Anton et al (2012).

here show that roughly 80% of CO_2 mitigation target could be achieved only by the elimination of energy subsidies, significantly contributing to the mitigation goals stated under PECC. Other environmental goals can also be achieved such as pollution reduction and thus health costs, and reducing groundwater overexploitation.

This paper is organized as follows. Section 1 describes the model, section 2 describes the scenarios and results, section 3 discusses the environmental impacts of these policies, and section 4 analyzes the findings from a public policy perspective.

1. The Dynamic Computable General Equilibrium Model

In this paper we look at a national model that has 12 producing sectors.[2] The primary sector is disaggregated into agriculture, livestock, fisheries, and forestry (see table 2). This was done so that we can now explicitly deal with and quantify the interaction of sector-specific policies with other sectors when policies are initiated. It is particularly important to do this given that the simulations we run affect across-the-board energy subsidies and several taxes to finance expanded healthcare, for example. For a formal mathematical description of the model, see Appendix A and Ibarrarán and Boyd (2006, 114–26).

The model has four household (income) categories (listed in table 1) and nine consumption sectors (in table 2). There is also a foreign sector and a government in this model. This model uses the latest information from the input-output matrix produced by the Instituto Nacional de Estadística y Geografía (INEGI), which uses 2003 as the base year, and other data from both national and international sources.

Table 1
Household Categories Based on Income

Category	Income Group
Agent 1	Bottom 2 deciles: 1–2
Agent 2	Deciles 3–5
Agent 3	Deciles 6–8
Agent 4	Top 2 deciles: 9–10

Source: Authors.

Table 2
Producing Sectors and Consumption Goods

Producing Sectors	Consumption Goods
Agriculture	Food
Livestock	Household and other goods
Fisheries	Consumption services
Forestry	Energy (electricity and LPG)
Manufacturing	Autos
Chemicals & plastics	Gasoline
Mining	Public transport
Oil and gas	Housing
Transport	Water
Electricity	n.a.
Services	n.a.
Refining	n.a.

Source: Authors.
Note: n.a. = Not applicable.

The economic variables determined by the model are investment, capital accumulation, production by each sector, household consumption by sector, imports and exports, relative prices, wages and interest rates, government budget expenditures and revenues, and total wage income. The level of depreciation and the initial return to capital are taken as exogenous, as is the rate of labor force growth.

Production

In each time period producers maximize profits in a competitive environment. Profit maximization, based on the described production technology, yields output supply and factor demands for each production sector and factor market in the model[3]. Output and input prices are treated as variables. Taxes are also included, with producers facing tax-exclusive prices and consumers (and input-consuming firms) facing tax-inclusive prices.

As a word of caution, the goods produced in the model's production sectors are not the same final goods consumed by consumers. Agricultural products, for example, must be combined with transportation services, manufacturing, and chemicals before individuals can consume them as food. Hence, in our model we use a matrix to map from the vector of production goods to the vector of consumption goods. We do this through

2. Data restrictions prevent us from constructing a regional model. Furthermore, a regional model is impractical given that the capital in any given region is owned by individuals and corporations throughout the country. Lack of regionalization is not a major drawback, however.

3. Appendix B lists the different elasticities of substitution across inputs used in the model.

the use of nested functions to the production side of the economy and to the production of final consumption goods and services. This allows for different degrees of substitution for the inputs considered, particularly between labor, capital, energy, and non-energy inputs. Technologies are represented by production functions that exhibit constant elasticities of substitution. Technical progress is taken as exogenous to the model.

Consumption and Income Distribution

On the demand side, the model reflects both the behavior of domestic consumers and foreigners (who can also invest through their savings) and that of the government. Domestic consumers are assigned to four groups (agents) according to income, and a demand equation is specified for each group, which has a different consumption bundle depending on its income. All four groups are endowed with labor. Since only the wealthy actually have (formal) savings in Mexico, we assume here (in accordance with the latest data from INEGI) that only the top two groups (agents 3 and 4) own capital.[4] The gross income of each group rises by the rate of population growth plus the rate of technological change, which is taken as capital augmenting. These resources are rented out to firms in order to finance the purchase of domestic or foreign goods and services, to save, or to pay taxes to the government. The membership of each group is fixed, and although group income increases (or decreases) with GDP, individuals do not "migrate," as such, from group to group.[5]

Government

The government agent is modeled with an expenditure function similar to the household expenditure functions (that is, based on a constant elasticity of substitution [CES] utility function). Revenues derived from all taxes and tariffs are spent according to an expenditure function. Within this expenditure function the government spends its revenues on goods and services from the various private production sectors discussed above. Consistent with the treatment of Ballard et al. (1985) and others, we posit an elasticity of substitution between inputs to the government's utility function. This allows for price responsiveness in the provision of government-purchased goods. The government also spends its revenues on labor. Together, these arguments represent the government purchases and payment of government employees necessary for it to carry on its work. The government also separately redistributes income through exogenously set subsidies and transfer payments, and the government budget is assumed to be balanced.

Taxes in the model are expressed ad valorem and include personal income taxes, labor taxes, capital taxes, property taxes, revenue taxes (such as payments from oil and gas activities), value-added taxes, sales taxes, and import tariffs. The taxes on final goods such as gasoline differ from other consumer goods because of special taxes levied on them by the government, that is, the Impuesto Especial sobre Produccion y Servicios (excise tax, IEPS). By the same token, final goods such as electricity differ in treatment due to existing government subsidies. Income taxes are based on marginal tax rates. Subsidies to industries are essentially treated as negative taxes, and in these cases the government transfers funds back to a sector in proportion to that sector's output. Thus, if these subsidies are abolished, the government has more revenue.

Trade

International trade within the model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. The model allows for a considerable amount of flexibility with respect to Mexico's international trade and balance flows. Initially imports and exports in each of the model's tradable production sectors are set at their benchmark year values. In subsequent years, however, these totals can vary endogenously both in terms of trade and the relative prices of each import and export in response to the tax, subsidy, tariff, or other exogenous changes made in the model.

Additionally, rather than requiring aggregate levels of imports and exports to match each other, our model allows for surpluses and deficits in the annual balance of trade. This is done by equating total injections (i.e. domestic investment plus exports). Hence, for example, a deficit in the current account is covered by an influx of investment currency from abroad.

4. Household savings here have a certain degree of endogeneity. The level of savings for each income group (that is, Agents 3 and 4) are set at the levels that actually occurred in the base year of the dataset (that is, 2004). After that time, however, they are allowed to vary in response to changes in the relative prices of consumption and savings.

5. Such migration, though a concept to explore, is computationally beyond the scope of this model. Furthermore, our chief concern with income distribution is how different income groups with varying consumption bundles and income streams are differentially impacted by the effects of policies.

The exchange rate is determined then by the interaction of capital made available for external uses, goods supplied for export, and the exogenous level of imports.[6] Price-dependent import supply schedules are derived from elasticity estimates found in the literature.[7] In specifying the level of substitutability between goods, we rely on the Armington (1969) assumptions, which allow for imperfect substitutability between foreign and domestically produced goods.

In this model, we assume that Mexico has no market power in the world petroleum market. Hence, we treat the international price of oil as a given, and Mexican oil producers as price takers in the market. Consequently, when the Mexican government institutes investment policies to increase aggregate oil output, the domestic price drops as output increases and more is exported as the international price increases relative to the domestic price.[8] Oil depletion, however, represents a curbing investment.

Labor Growth and Capital Formation

Growth within our Dynamic Computable General Equilibrium (CGE) model is brought about by the changes over time in both the labor force and the capital stock. In keeping with the theoretical underpinning of the Ramsey model (1928), we take the changes in the population as exogenous and constant over the time period considered. In the absence of any perturbation, Ramsey predicts that the economy will grow at the labor supply growth rate in the steady state.

Capital in the model is generally free to move among sectors both at a national and an international level. There are, however, three important ways in which the flow of capital is constrained. First of all, although capital is not initially sector specific as such, each production sector has a given elasticity of substitution between labor and capital. This elasticity is determined by prior estimates and the lower its value the more difficult it is for labor or capital to move to or from a sector in reaction to relative price changes. Second, although capital may move internationally (Mexico's payments are balanced for each year that the model is run), capital flows only in response to a trade balance. Thus if there is no change in the trade balance from one year to the next there is no net flow either inward or outward in the international capital account.

Finally, over time capital is modeled to become less mobile and more sector specific.[9]To add realism, we assume that the capital that goes into a sector works like putty and clay. More specifically, we assume that capital that is new can be readily combined with other inputs to produce outputs. Over time, this capital becomes locked into an older technology (that is, clay) and has a harder time combining with other inputs. In the growth literature, this is also known as "vintage capital." This is plausible as illustrated by sectors such as electricity production, which has been subject to a great deal of technological change over the years. The capital growth rate is modeled in accordance with neoclassical capital theory assumptions. More specifically, the growth of capital is modeled as investment net of economic depreciation.

The initial level of investment for each sector in the model is taken from the existing historical level of investment for the base year as given in INEGI's input output tables[10]. In the benchmark case it is assumed that capital formation and depreciation proceed according to their historic norms. Furthermore, all economic actors are assumed to have rational (rather than myopic) expectations and the model is solved for all years simultaneously rather than year by year in a recursive manner. As a practical matter then, this means that investment grows at a steady rate in the absence of any external shocks.

Benefits of a computable general equilibrium model

Some sectors are crucial to the way an economy works. Energy is one of such sectors, so any changes to pricing policies such as subsidy reductions will have effects over the entire economy. The use of a computable general equilibrium model, that is, a framework where all the sectors in the economy are seen as one linked system

6. As a side note, closure in our model is determined by the equality of domestic and foreign leakages and domestic and foreign injections. More formally, we have $(S + M) = (I + X)$ where S is domestic savings, M is imports (current account), X is exports (current account), and I is the total amount of investment made available from foreign and domestic agents.

7. See, for example, Fernandez (1997); Romero (1994); Serra-Puche (1984); and and Wylie (1995).

8. The domestic and international prices of oil may differ due to quality and transportation costs.

9. This is referred to as a "putty-clay" assumption in the literature and can be easily modeled using the GAMS-MPSGE program code which we use to construct the model.

10. Since the present model utilized real rather than nominal values in its calculations there is no clear relationship between aggregate government revenue and economic growth. As a practical matter then, any increase in government revenues will slow down growth relatively more in those sectors which are most highly taxed and increase growth in those sectors from which the government sector demands the most goods and services.

in which a change in any part affects prices and output economy-wide, is highly recommended, as opposed to a simplified framework of just one sector (i.e. partial analysis) that can have important limitations since no interaction effects may be captured. Economy-wide effects are appropriately dealt with a computable general equilibrium model specially designed for Mexico that is able to capture al the interrelations across the different sectors and on the different consumer groups. Additionally this is a dynamic model, so there is growth and capital accumulation along the period of analysis. This allows to a better understanding of how different variables adjust through time and reflects the way the economy works. It enables making complex simulations on different policies that may alter the long-term situation of the economy.

Caveats

Even though these models are very powerful, the usefulness of the results depends basically on the quality of the information that is fed, such as data from the input-output matrix and technical parameters of substitution, price and income elasticities, and other national data. On the other hand, even though this information is accurate, there is uncertainty among the exact value of the parameters, and of certain assumptions such as long term growth and population dynamics, for example, among other key variables. Therefore, the results should be interpreted with caution. For example, the basic take-home points should be the sign, the trend of the different variables, and the relative magnitude of the resulting numbers more than the values themselves. These results then show if the policy has positive effects, if they grow in time and what sectors are affected relatively more.

On the other hand, this is a national level model that has no regional interpretation. To have a regional model we would need regional input-output data and social accounting matrices. This, however, is not a drawback in this particular exercise given that the energy sector, and labor for that matter, across all sectors.

Our model takes technological change as given (exogenous). Therefore, it does not capture the full potential of alternative technologies, or the boost in technological change derived from the correction of relative prices of energy. It does, however, consider some substitution in the capital to labor ratio, given the elasticities observed.

2. Scenarios and Results

This section describes the various scenarios we ran and their comparison. We start by building the subsidies into the benchmark and then adding selected stylized facts of the Mexican economy, such as oil depletion and unemployment. We then simulate elimination of energy subsidies. One option among many is an expanded healthcare policy to cover employees in the formal and informal sectors under equivalent healthcare programs. To achieve this, we model a partial removal (about two-thirds) of social security employee-employer contributions, and the expansion of the VAT to food, medicines, and medical services[11], combining the elimination of energy subsidies with the expanded healthcare program, supported by some tax changes.

Scenario 1
Business as Usual

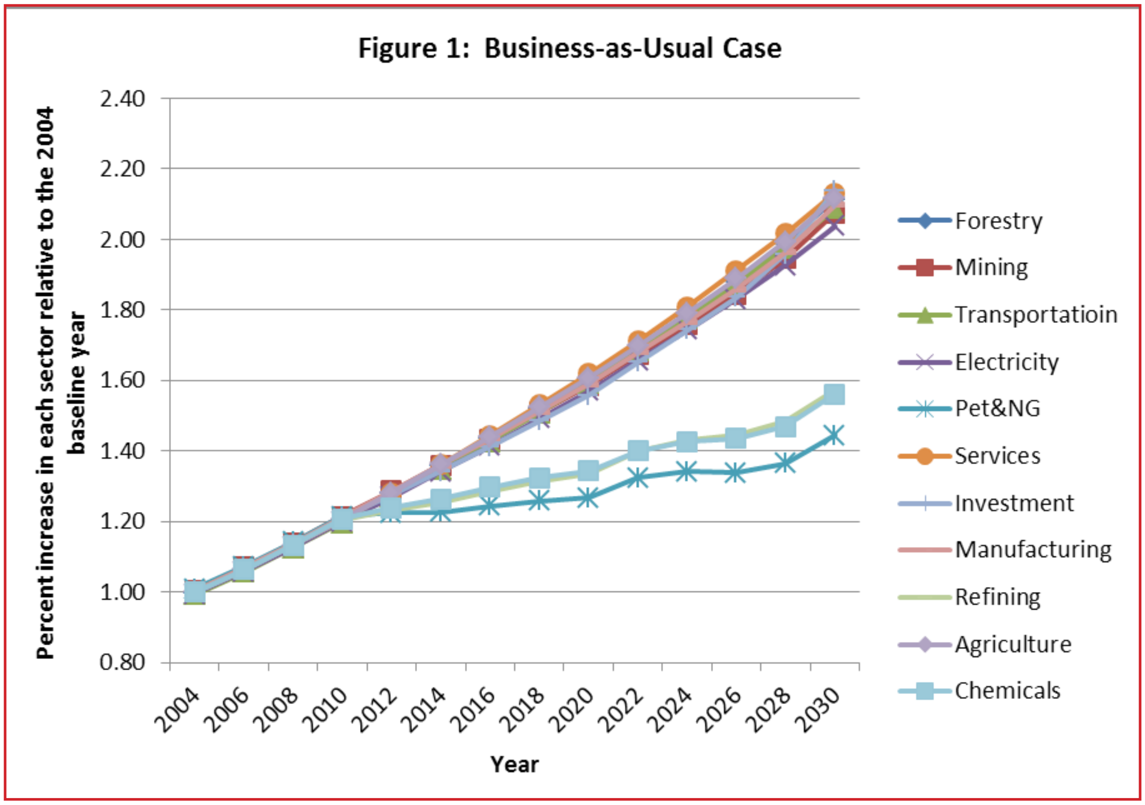
Before going into the business as usual case, we want to make sure that our CGE model is balanced both in terms of the social transactions matrix (SAM) constructed and in terms of its dynamic capital and labor components. To do this we run the model without any policy changes or dynamic constraints whatsoever. If the model is properly constructed, this should result in an algebraically consistent replication of the 2004 economy growing at the pre-specified rate of economic growth of 3.2%.

This balanced "steady state" run, though computationally important to our analysis, is unrealistic and of little use to the policy questions we are trying to answer. It assumes that the rate of growth is constant in all sectors including nonrenewable extraction of oil and natural gas. It also assumes no unemployment.

Thus, to begin our formal analysis, we assume that the level of oil extraction is initially approximately 2.6 million barrels per day and follows Secretaría de Energía de México (Ministry of Energy) estimates (SENER 2012), flattening out at approximately to 3.3 million barrels per day. Natural gas goes from 6.2 million cubic feet to 8.7 million cubic feet.

Unemployment is set at the 3.5% level, which held during the five year time period leading up to the benchmark year. Most of this is frictional though sticky

11. These are currently not covered under VAT, but there has been an ongoing discussion in Mexico on the option of expanding such coverage to these categories within some future fiscal reform.



Source: Authors.

wages are assumed to hold in some markets[12]. Hence, unemployment here is programmed by means of a side constraint in our dynamic Computable General Equilibrium (CGE) model.

Figure 1 shows some of the results comparing the business as usual case with the benchmark, in particular how investment and selected sectors grow relative to each other under this scenario. The driving force behind lower growth in some sectors is oil depletion.

Looking at our results for production and consumption, we find that there is a general lower growth in activities in all sectors. Growth is evenlower in production sectors such as electricity and refining, which are closely related to the burning of fossil fuels. Growth is also lower in consumer sectors such as energy and gasoline.

As for the foreign sector, oil and natural gas and refining sector imports grow to compensate for the domestic exhaustion of oil. The rest of the sectors are not significantly affected in terms of imports and exports.

12. It is possible that subsidy elimination could drive up nominal wages which, in the presence of inflexible wages, could trigger higher unemployment. At the same time, however, resources will be released to unsubsidized markets, stimulating supply and ameliorating this effect. The final impact of subsidy reduction on the unemployment rate then remains an empirical question.

In all cases, the business-as-usual case is crucial since all of the following scenarios will be compared against it.

Scenario 2
Gradual Removal of Energy Subsidies

In Scenario 2, we look at the effect on the Mexican economy of gradually removing energy subsidies. The amount of subsidies was provided by the Secretaría de Hacienda y Crédito Público (Ministry of Finance). The subsidies (expressed as a share of price) to electricity and gasoline are shown in tables 3 and 4, respectively. The electricity consumption of the residential sector is divided into a highly subsidized category (T1 and TF1 may have subsidies above 200%), and a high-consumption tariff (DAC) that is much less subsidized or even taxed, depending on the year analyzed. However, the DAC is less than 5% of residential power consumption[13].

13. Subsidies to electricity were provided by SHCP and they are subsidy/price. In the case of electricity, the size of a subsidy is not easy to determine as it implies dealing basically with a non-tradable good. The subsidy estimate is based on a calculation of the longer-term marginal cost of production with an administratively determined rate of return on assets. Inefficiencies in the production, transmission and distribution are part of the subsidy estimate and the latter is largely implicit as the government usually does not transfer a subsidy to the electricity company but largely foregoes a return on the assets it has historically invested. However, final price increases to consumer would have the effects described in this section.

Table 3
Subsidies to Electricity (% of price), 2005–10

	Electricity Subsidy (% of price)					
Sector	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential	157.8	145.3	132.6	177.8	179.4	149.4
T1–T1F	190.2	182.9	183.7	245.2	214.6	182.7
DAC	2.6	-1.0	2.0	9.6	8.5	-16.7
Commercial	14.1	6.7	-2.9	13.6	19.0	-4.5
Services	30.4	28.8	25.0	44.9	40.8	14.4
Street lighting	26.4	25.8	24.2	42.2	25.4	3.1
Water pumping	40.4	36.6	38.1	66.6	48.9	41.5
Agriculture	251.1	227.0	213.5	258.4	244.8	242.8
9–9M[a]	163.5	96.5	65.4	67.8	60.0	61.4
Incentive rate	282.1	297.3	290.4	357.2	291.7	314.2
Industrial	14.9	9.9	8.7	8.7	31.6	4.2
Medium voltage	16.2	14.3	15.1	13.6	35.1	3.1
High voltage	11.0	1.1	1.8	-2.0	23.5	1.5

Source: Informe de Gobierno and Comisión Federal de Electricidad.
Note: a. 9 and 9M are particular tariffs that apply to electricity for water pumping. Water pumping rates are set according to the consumption level. A basic rate is charged up to a threshold (incentive rate). Once consumption exceeds that threshold, the rate changes depending on the voltage (9 and 9M).

Gasoline prices are fixed by the government but with no transparent rule. This leads to some years in which it is highly subsidized and other periods when it is taxed[14]. We use 2010 as the reference year to determine subsidies that again are expressed as a share of the price. The subsidies that we eliminate in the next simulations are listed in table 4[15].

Thus, in this simulation, we calculate the impact of removing the existing gasoline, diesel, and electricity subsidies on consumers, public transportation, agriculture, fisheries, public lighting, and various manufacturing industries. In our simulation, the subsidy removal begins in 2012 and is completed in 2018 to avoid any sudden shock to the economy. In addition, to concentrate solely on the substitution effects of the subsidy removal, the policy is done in a non-revenue-neutral manner, with all funds from subsidy removal being collected by the government and then invested according to its own welfare goals. To give us a frame of reference, we run the model as described with subsidy removal taking place along with fossil fuel depletion, and compare our results with those of the business-as-usual case described in Scenario 1, above.

Looking first at the aggregate numbers in table 5, we see that removing energy subsidies increases the

Table 4
Subsidies to Gasoline (% of price), in 2010

Sector	**Gasoline Subsidy, 2010 (% of price)**
Agricultural sector diesel	13.55
Marine diesel	10.68
Auto vehicles diesel	13.55
Auto vehicles gasoline	18.69
Agricultural sector gasoline	18.76

Source: Secretaría de Hacienda y Crédito Público, Subsecretaría de Ingresos – Unidad de Política de Ingresos.

14. For fuels, subsidies in all of the simulations are estimated by SHCP and they reflect the subsidy as a share of domestic price. Given that fuel prices in Mexico are fixed by the government, volatility in international prices (that are taken into account when estimating costs) some years lead to negative subsidies and some to positive subsidies. In 2010 we observed a positive subsidy and that is the level of subsidies we work on eliminating in this document,

15. Even though there may be price volatility in gasoline and oil prices, we take the subsidies in 2010 as a possible example. Other options could have been used such as having the average subsidy over some time period, for example. A fact is that price volatility affects the size of subsidies. In any case, lower subsidies will most likely have an impact on energy efficiency as is shown in the paper, when particularly electricity and gasoline consumption falls as prices rise.

aggregate level of welfare by 0.84%[16]. Aggregate GDP declines slightly initially (that is, in 2012) due to adjustment processes, but rebounds quickly and increases by 0.34% in 2018 and 1.54% by the final period of the analysis. Aggregate investment increases significantly in the latter part of the analysis, and the final level of the capital stock goes up by 7.13% as a result of new investment. The aggregate level of government welfare goes up by 3.5 % and the welfare levels of the poorest agents go up by 1.10% and 1.01%, respectively, in spite of rising expenses as the gross domestic product (GDP) rises. Agent 3 sees a smaller increase of only 0.43%, and Agent 4 sees a slight decline of 0.18%. Thus, economic growth declines only in the very earliest part of the analysis and then speeds up in the later periods. A total removal of energy subsidies, it would seem at first glance, is beneficial to the level of economic welfare in Mexico over the 2004 to 2030 period studied. Welfare gains are larger for lower income agents because they consume proportionally less energy than the rich and therefore they lose less of their purchasing power once subsidies to energy are removed.

Several other things are worth noting here. First, the total level of government income plus consumer welfare rises because a subsidy removal increases net welfare by eliminating the welfare loss. Because the elasticities of demand for gasoline and energy goods are relatively inelastic (that is, ranging from -0.28 for gasoline to -0.32 for residential electricity[18]), the revenue gains by the government are fairly substantial even though the aggregate welfare gains are quite modest. This is consistent with partial equilibrium theory, since taxing (subsidizing) a good with an inelastic demand generates (expends) a large amount of revenue while leading to a small deadweight welfare loss (see, for example, Atkinson and Stiglitz [1980] for an extensive review of this theory[19]).

Turning next to the individual sectors, we find that, with the exception of the initial period (when capital and labor are adjusting to the subsidy removal), some or most production sectors see increases throughout the analysis. As would be expected, declines occur in the fossil fuel and electricity sectors that are most negatively impacted by the subsidy removal. Indeed, our model projects that, in 2030, electricity production will decline by approximately 25.3% compared to the business-as-usual case. Even though this number is high, it is explained by the extent of the subsidy removed. Significant losses are also experienced by the petroleum, natural gas, chemical (which includes petrochemicals), and refinery sectors. Increases are generally seen in all other sectors. Because of the large increases in investment, manufacturing (the largest supplier of investment goods) goes up by almost 14% by 2030. Fairly substantial increases are also experienced in the massive services

Table 5
Change in Aggregate Results, Gradual Energy Subsidy Phaseout vs. Business as Usual

Category	2012 (%)	2018 (%)	2024 (%)	2030 (%)
GDP	-0.9359	0.3358	0.6884	1.5397
Investment	-2.8067	-0.0347	3.3236	16.1049
Government [17]	6.2460	6.4166	5.8566	5.0945
Capital Stock	—	—	—	7.1322
Aggregate welfare (ΣAgent 1–4)	—	—	—	0.2920
Agent 1	—	—	—	1.0967
Agent 2	—	—	—	1.0063
Agent 3	—	—	—	0.4340
Agent 4	—	—	—	-0.1820
Government welfare	—	—	—	3.5042
Aggregate welfare	—	—	—	0.8403

Source: Authors.
Note: — = results not reported.

16. The results of each variable under each scenario are compared with the value obtained in the same year but under the business-as-usual case, for example, GDP for 2012 under the scenario of elimination of subsidies is compared with the value of GDP in 2012 under business-as-usual scenario. The variations that are reported in the text correspond to the percentage changes between these two scenarios.

17 Government refers to the total expenditure that, under a balanced budget, we assume here it is equal to total income from tax revenue and sales of publically provided goods and services. Since the idea here is to see how this concept changes when different policies are simulated, it out of the scope of this paper to include how the overall deficit will behave once policies are enacted in terms of its long terms sustainability. What we want to show here is how this balance in government revenues (or expenditure) changes under different policies.

18. Our gasoline elasticity is taken from Reyes Martínez, Escalante, and Matas (2010), and our residential electricity demand is taken from Bernstein and Griffin (2006) (this study is for the United States). All estimates of elasticities for energy demand, however, are inelastic in nature. Commercial demand for electricity was assumed to be about 1 (which is consistent with estimates by Bernstein and Griffin [2006] and Berndt and Samaniego [1983] for Mexico).

19. While, strictly speaking, welfare generation in CGE models is measured by equivalent variation (see Ballard et al. 1985), the partial equilibrium results follow their general equilibrium counterparts here fairly closely.

Table 6
Change in Production, Gradual Energy Subsidy Phaseout vs. Business as Usual

Sector	2012 (%)	2018 (%)	2024 (%)	2030 (%)
Agriculture	-2.1029	-1.4120	1.3247	8.9637
Livestock	-1.6484	-0.4198	2.5197	10.1736
Forestry	-0.8658	0.3597	3.2738	10.6729
Fisheries	-2.0134	-2.2727	-0.9524	2.3622
Oil	-5.5083	-8.4084	-6.5328	0.2007
Natural gas	-5.4565	-8.3945	-6.4797	0.2523
Mining	-3.6179	-2.3143	1.9057	12.7644
Refining	-9.1142	-14.9005	-12.2972	-3.9018
Transport	-1.2193	-1.0664	0.4664	4.1557
Electricity	-24.5343	-35.6061	-32.7927	-25.3132
Chemicals & plastics	-5.5546	-5.7596	-0.5537	14.0324
Services	-0.2402	0.2896	1.7343	5.2546
Manufacturing	-1.8774	0.0973	4.0762	13.9500

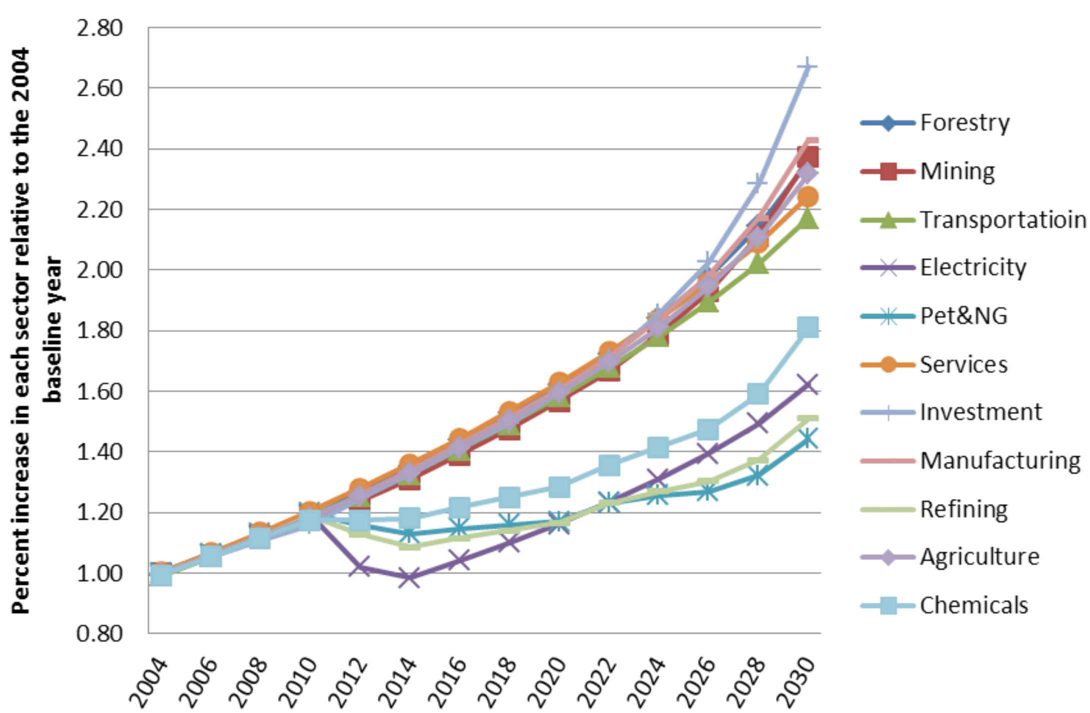
Source: Authors.

sector for most of the analysis (table 6). Here is important to note that even though sectoral growth lags with respect to aggregate GDP growth, services and manufacturing have positive growth even in 2018. This pulls aggregate growth even though individual smaller sectors linger behind. Figure 2 shows how particular sectors and investment behave once energy subsidies are gradually eliminated during the first years of the analysis.

Consumption goes up in all sectors with the exception of energy and gasoline (because of the large subsidies that both commodities receive in the business-as-usual case and that are eliminated in this scenario). Finally, except for petroleum, chemicals, and refinery products, trade in most commodities is largely unaffected by the elimination of energy subsidies. This is explained by the fact that eliminating subsidies has a local effect, bringing local prices closer to international prices.

As noted, the aggregate effect of subsidy elimination would seem to be highly positive, and this is fully in accord with economic theory since resources are directed to more productive areas of the economy. Initially, however, growth goes down slightly for several years.

Figure 2: Gradual Subsidy Removal: Non-Revenue Neutral



Source: Authors.

This is due to the fact that there is unemployment in the model, and both labor and capital need a short time to adjust as the initial effects of an energy subsidy removal provide a shock to the economy. Hence, we should not be surprised to see this result, especially since both capital and labor participation grow rapidly throughout the rest of the analysis. Not only does the directly measured level of welfare increase here, but a welfare gain also comes from considerations external to our analysis in the model, such as lower emissions and more sustainable groundwater sources that will be discussed later on.

First, and most important, the results in tables 6 and 7 show that sectors that consume fossil fuels decline substantially from the business-as-usual case. This, in turn, means that the emissions of pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrous oxides, carbon monoxide (CO), and particulates will also decline, resulting in a large unambiguous increase in welfare through better air quality and, therefore, health.

Second, if the elimination of subsidies were to be accompanied by a transfer to the poorer agents, there will be larger equity gains. These environmental co-benefits will be discussed later in the report.

One more point that is worth mentioning is the relevance of technological change. Even though we do not explicitly model it in any of the simulations, substitution elasticities across fuels are built into the model, so when relative prices of different energy sources change, adjustments in the fuel matrix takes place. Technological change could also be modeled explicitly when energy efficiency is modeled as a scenario rather than as a result. Alternatively, some models take technological change as an endogenous variable, reacting to any changes in energy prices. Again, trade in most commodities is largely unaffected by the elimination of energy subsidies, but results are not included in the interest of space.

Table 7
Change in Consumption, Gradual Energy Subsidy Phaseout vs. Business as Usual

Category	2012 (%)	2018 (%)	2024 (%)	2030 (%)
Food	-0.3580	-0.2945	0.6063	2.1070
Household goods	-0.5087	-0.4493	0.5024	2.0484
Consumer services	-0.5929	-0.4951	0.4027	1.9066
Autos	-0.7860	-0.6573	0.3002	1.8484
Electricity and LPG	-8.4621	-12.9987	-11.9806	-10.3041
Public transport	-0.6107	-0.7806	0.1122	1.5883
Gasoline	-1.8651	-2.8691	-2.1657	-0.4723
Water	-0.4622	-0.2571	0.6452	2.1641
Housing	-0.5644	-0.4711	0.4300	1.9231

Source: Authors.

Caveats

Some caveats have to be made with regard to the definition of energy subsidies and the way subsidies are modeled in this exercise. Most of these issues are explained in the footnotes above but it is important to discuss them overall. Subsidies are defined comparing final sales prices with production costs for electricity or considering international prices for other fuels. Occasionally, high subsidies reflect high inefficiencies in production. Subsidies could be reduced significantly by reducing production costs. If subsidies are cut back this way, then there will be effect on welfare if the costs are reduced inexpensively, otherwise they may be need to factor them into the calculations.

We are taking subsidies for 2010 and assuming they remain at the same rate in the business-as usual-scenario. This may be misleading since energy prices, particularly those of oil and gasoline vary in time, and therefore so do subsidies and final prices that may respond to volatility in world markets. This may affect the size of the subsidy since these international prices may be determining the final sales price. In any case we take the subsidies in 2010 as an example, but other exercises could have been made using an average over some period or some other projection for subsidies based on expected changes in production costs and international prices.

Sensitivity Analysis – Single-Year Option

We did sensitivity analysis to this scenario by simulating a sudden elimination of energy subsidies. The results are very similar to the previous scenarios but with greatest adjustment costs in the initial years. In this case, instead of gradually removing the energy subsidies between 2012 and 2018, we complete the entire policy in a single year. This has the advantage of avoiding delays. It does, however, have the disadvantage of causing a sudden disruption to the economy when it is first done. As before, to concentrate solely on the substitution effects of the subsidy removal, the policy is done in a revenue-neutral manner with the excess government funds being distributed to the lowest two income groups. We compare our results here with those of the business-as-usual case.

We see that a sudden removal of energy subsidies increases aggregate welfare slightly. This is a change in the same direction, albeit a bit less than when the subsidies were removed gradually. It would seem, then, that a sudden removal of subsidies is a little more disruptive than removing them gradually. The change, however, is not large. As in Scenario 2 GDP declines slightly in the first year but increases strongly in all subsequent years. Investment again increases throughout the analysis, and the final level of the capital stock goes up. The welfare level of the poorest agents rises as the added government funds are siphoned off to Agents 1 and 2. Agents 3 and 4, again experience more modest percentage gains but definitely gain welfare over the period of the analysis. Economic growth declines in the first year of the analysis but then turns around immediately and then speeds up in the later periods, as before. As with welfare and the level of the capital stock, all of the other aggregate variables show growth relative to business as usual, but the improvement is not quite as pronounced as when subsidies were removed gradually.

When we examine the individual sectors, we find that, as in Scenario 2 sectors increase from the business-as-usual case for the entire period of the analysis. We see that electricity production now goes down compared to the business-as-usual case, almost the same as before. Again, there is a large decline in the petroleum, natural gas, and refinery sectors, while the levels in all other sectors rise.

Consumption again goes up in all sectors except in energy and gasoline (again because of the large subsidies that both commodities now receive that are eliminated in this run). Most other sectors see gains, but transportation (another recipient of energy subsidies) sees those gains only in the very last part of the analysis. Food and water experience the largest percentage gains due to the government's lump-sum adjustments to the poorer agents.

Scenario 3
Using energy subsidies (and taxes) to finance an expanded healthcare system

In this final scenario, we quantify the economy-wide and sector-specific impacts of an expanded healthcare system financed by a VAT expansion and coupled with energy subsidy removal and a reduction in some of the private contributions to social security. We call this the joint policies case. We list the percentage changes of this scenario from the business-as-usual case.

Based on several authors, we model a fundamental change in the Mexican health policy accompanied by a radical overhaul of the present tax system and changes to the private contributions to social security. The main modification to the tax system that we include deals with having food and medicines pay the same 16% rate of the VAT that all other goods pay. This is an ongoing discussion taking place in Mexico that at this stage could be promoted given that it may generate additional resources to pay for the expansion of the healthcare system[20]. This would have the effect of moving labor from the informal sector (which does not formally and consistently contribute to social security) to the more efficient formal sector (which is currently taxed to provide security and health benefits).

To make up for the loss in revenue from these contributions, we recommend extending the current VAT (which is 16%) to food, medicines, and medical goods

Table 8
Change in Aggregate Results, Joint Policies vs. Business as Usual

Category	2012 (%)	2018 (%)	2024 (%)	2030 (%)
GDP	0.7517	1.9120	2.8208	3.0290
Investment	6.0117	4.6914	4.4717	4.4506
Government	-0.2063	2.4550	3.1721	3.4827
Capital Stock	—	—	—	7.5246
Aggregate welfare (ΣAgent 1–4)	—	—	—	3.6562
Agent 1	—	—	—	3.8493
Agent 2	—	—	—	3.7452
Agent 3	—	—	—	3.5033
Agent 4	—	—	—	3.6871
Government welfare	—	—	—	-0.0736
Aggregate welfare	—	—	—	4.2177

Source: Authors.
Note: — = results not reported.

20. Obviously there are other loopholes that would have to be closed to make the tax system more efficient, but at this point this is out of the scope of this paper.

and services that are currently exempt. In addition, a certain amount of all VAT revenues would be earmarked to cover the new national healthcare and social security system, and the government would subsidize the remainder from energy subsidies.

The increase in the level of the aggregate variables brought about by this joint policy implementation is both substantial and persistent. As we can see, total welfare in this case rises by 4.2% over the business-as-usual case. Significantly, the government deficit (relative to the business-as-usual case) is only about 0.07% over the entire period. This, in turn, suggests that the expanded healthcare policy could be almost totally financed with the help of revenues gained from subsidy removal and expansion of the VAT. Both GDP and investment go up in all periods from 2012 on, and by 2030 the level of GDP has risen by about 3% over the business-as-usual case. The increases in investment lead to a 7.5% increase in the capital stock, and the subsidy removal combined with a growth in income leads to a growth in government revenue by the latter part of the analysis (table 8).

Turning now to the results in the consumption sectors, we see that the aggregate impact of this joint policy implementation is quite encouraging. All sectors with the exception of energy see gains. The loss in energy consumption occurs as a consequence of subsidy removal, and is a good thing from a policy standpoint, since a cleaner environment is a goal of this particular simulation exercise. Overall gasoline consumption goes up by about 4.6% by 2030, since the marginal effect of subsidy removal is more than offset by the effects of the VAT tax reform (table 9).

Table 9
Change in Consumption, Joint Policies vs. Business as Usual

Category	2012 (%)	2018 (%)	2024 (%)	2030 (%)
Food	0.0167	2.7290	5.0913	7.5731
Household goods	1.4182	4.0003	6.3043	8.7493
Consumer services	1.3101	4.0216	6.3465	8.7971
Autos	1.6045	4.2354	6.5432	9.0148
Electricity and LPG	-6.7343	-8.2614	-5.6517	-2.8354
Public transport	0.9153	3.3576	5.7203	8.1597
Gasoline	-0.0564	1.6643	4.0685	4.5864
Water	1.2121	3.9409	6.2880	8.7468
Housing	1.2594	3.9705	6.3048	8.7503

Source: Authors.

Table 10
Change in Production, Joint Policies vs. Business as Usual

Sector	2012 (%)	2018 (%)	2024 (%)	2030 (%)
Agriculture	-1.4931	2.4744	6.0584	8.2192
Livestock	1.3333	4.6394	7.5844	9.2414
Forestry	1.2712	5.4608	8.7079	10.6729
Fisheries	0.0000	1.6393	4.0724	6.4151
Oil	-3.0570	-0.5104	3.3912	6.3818
Natural gas	-3.0769	-0.4864	3.4211	6.3931
Mining	1.9178	5.7239	9.2764	11.2903
Refining	-5.0018	-5.9706	-2.2452	0.3924
Transport	0.5081	3.1979	5.7540	7.9797
Electricity	-19.6943	-26.9004	-23.5970	-20.5423
Chemicals & plastics	0.9265	4.6952	9.5167	12.4518
Services	0.1908	3.2893	5.7892	8.0312
Manufacturing	3.4971	7.1829	10.4092	12.0129

Source: Authors.

The results in the production sectors are similar to those in the consumption sectors in that they show the overwhelming impact of tax reform of increasing production and consumption almost everywhere. Table 10 shows that all sectors experience gains except the electricity sector. Electricity is a big recipient of the current subsidies, and the marginal impact of subsidy removal is most severely felt in that sector. Subsidy removal cuts back on the growth of refining, natural gas, and petroleum. Nonetheless, with the exception of refining, all are positive for most of the period of the analysis.

Figure 3 shows how different sectors grow after both policies have been implemented. Compared to figure 2, which shows the non-revenue-neutral gradual elimination of energy subsidies, the trends of growth across sectors are fairly similar now under the joint policy. Investment does not grow as much as in figure 2 since it has now been used to finance expanded healthcare. The energy-related sectors behave quite similarly under the two scenarios.

Finally, since all policy changes considered here are concerned with domestic policy, there is little to report with respect to the foreign sector. With that said, how-

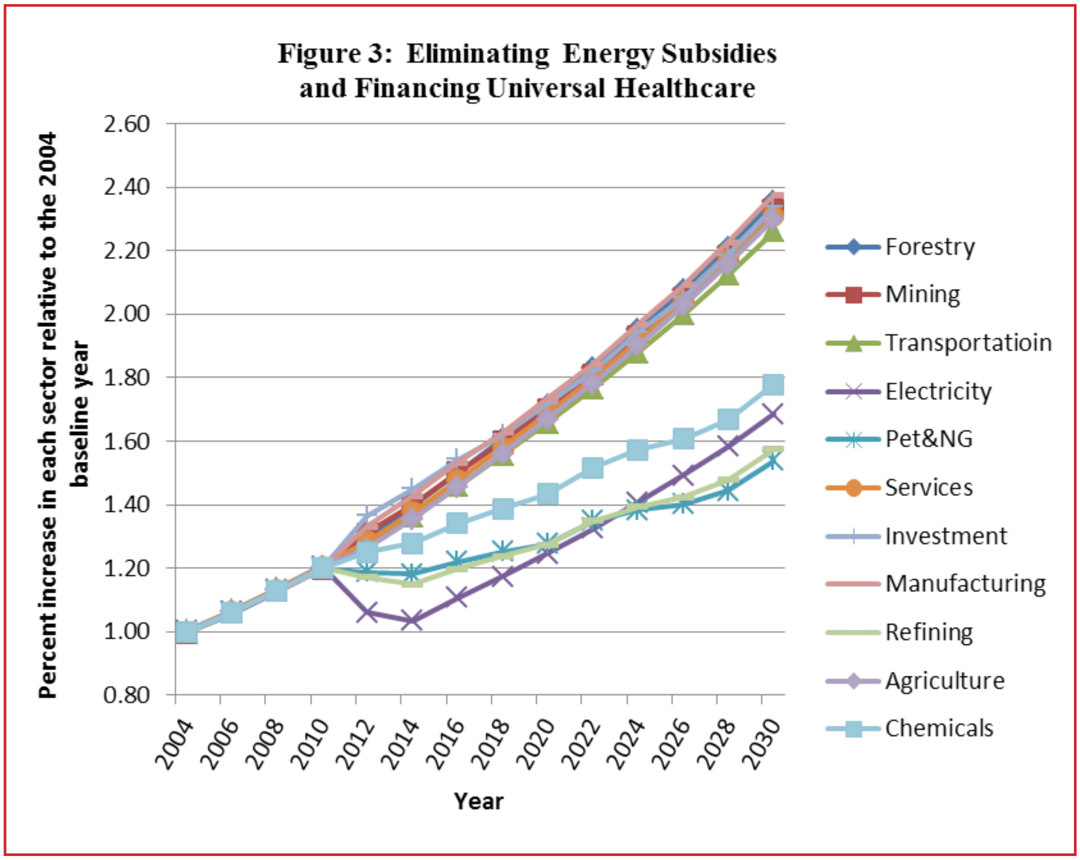


Figure 3: Eliminating Energy Subsidies and Financing Universal Healthcare

Source: Authors.

ever, we should note that there is an overall increase in both imports and exports. More domestic production and higher consumption spawns foreign trade activity and increases trade links with foreign trade partners.

3. Environmental Impacts of Reforms

One of the goals of this paper is to address the environmental effects of eliminating energy subsidies. Lower emissions are a goal in itself for the Mexican economy, which is now looking at low emission development strategies that focus significantly on mitigation. In addition, it has implemented the Special Program on Climate Change (Programa Especial de Cambio Climático, PECC) to achieve this. Eliminating subsidies to energy use may contribute significantly toward a low-carbon economy, as can be seen from this exercise.

Eliminating subsides to energy use across the board leads to lower use of fossil fuels and thus to a reduction in emissions. In this analysis, we look at only CO_2 emissions from the burning of fossil fuels. We do not consider any other greenhouse gas emissions or any CO_2 emissions from land use change.

Looking at energy use, we estimate that 41.7 million tons of CO_2 are abated every year during the period of analysis. PECC has an abatement goal of 51 million tons per year for 2012. This implies that only by eliminating energy subsidies are we able to meet roughly 80% of Mexico's annual emission abatement goals. As mentioned above, this does not include other greenhouse gases that could add to even more CO_2e abatement. These results are encouraging since they highlight the environmental benefit of these types of policies. In addition, they uphold the argument that elimination of energy subsidies is not regressive in terms of income distribution.

Lower CO_2 emissions also imply lower local emissions, leading to improved environmental quality across the board. This is relevant since a rough but educated guess shows that air pollution imposes a yearly cost of 1.5% of GDP on Mexico. This only measures the urban impacts on health in Ciudad Juárez, Guadalajara, León, Mexicali,

Table 11: Burden of Health Impacts of Urban Air Pollution

Health Impact	Cases	Million US$
Premature mortality	12,220	123.94
Premature mortality, children	1,934	19.62
Chronic bronchitis	19,648	1.79
Hospital admissions	56,760	2.81
Emergency room visits	1,113,442	4.78
Restricted activity days	187,662,750	54.19
Lower respiratory illness in children	2,478,047	4.82
Respiratory symptoms	597,257,100	3.66
Total		**216 (1.5% GDP)**

Source: Authors.

Mexico City, Monterrey, Puebla, Tijuana, and Toluca, as estimated by the World Bank for 2012 (table 11).

Finally, these types of policies are bound to have an impact on other natural resources[21]. For example, currently there is a subsidy to electricity used in water pumping for agriculture. This has led to a significant overexploitation of groundwater resources. Policies such as these that increase the effective cost of water extraction will lead to a more rational use of water and therefore less overexploitation of the resource (Ávila et al 2005).

4. Policy Implications and Future Work

The use of a computable general equilibrium model of the Mexican economy allowed us to analyze the economic, distributional, and environmental impact of energy subsidy reductions. When subsidies to energy use are eliminated, either gradually throughout 2012 to 2018 or suddenly in 2012, distortions are reduced and government resources are liberated, but short-run negative welfare effects take place.

The energy-intensive sectors are significantly affected because they do not now receive the subsidy. However, since subsidies cause distortions, when they are eliminated there are positive and progressive welfare gains for most income groups, with higher gains to lower-income agents.

Finally, when energy subsidies are eliminated and other important reforms such as an expanded healthcare program covering all workers are combined, the results are highly desirable. This leads to the conclusion that these reforms help reduce distortions to the economy; increase its productivity and have positive effects on growth, investment, and capital accumulation; they promote a more equitable income distribution and reduce emissions.

In terms of the environmental effects, eliminating subsidies to energy in itself achieves several goals. It cuts back on the use of a non-renewable resource that is currently facing depletion and the extraction costs of which are rising, and it promotes energy savings and efficiency. This, in turn, reduces emissions that have both global and local effects, contributing to improved air quality and reduced health costs. In addition, this contributes to mitigating climate change, since subsidy cutbacks alone get 80% of Mexico's yearly abatement goals for CO_2 emissions, as set by the 2008–2012 Special Program on Climate Change. Finally, since a significant part of energy subsidies goes to pumping water for agriculture, eliminating them may also help reduce groundwater extraction and therefore the replenishment of such sources.

As explained above, energy subsidies impose high fiscal costs and distortions to the Mexican economy. Healthcare is not readily available to all workers, and those that are not covered by any of the existing health systems face catastrophic expenditures and expensive private services if they happen to need medical attention. This exercise demonstrates that there may be other productive uses for those energy subsidies that may be welfare enhancing, promote overall economic growth, and that may certainly increase the quality of health of many more Mexicans, both directly and indirectly through a cleaner and more sustainable environment.

Finally, this paper was done while gasoline subsidies were in place with a substantial share of total energy subsidies. Since then, economic policy has evolved to practically eliminate gasoline subsidies, and policy makers even managed to set a surcharge in relation to international prices. However, gasoline prices are still set by the government and thus known as managed prices. Other energy subsidies are still present in the Mexican economy so this exercise is a good example of such price interferences.

21. This does not stem from the analysis but is it worth discussing as an effect of elimination of electricity subsidies.

Future Work

As usual, the scope of this paper is limited and throughout the analysis and discussion with colleagues an important set of possible extensions came up. Some recommendations are regarding what could be built into the baseline, what those resources saved from energy subsidies could be used for, and finally other interesting simulations that could provide resources.

In terms of the baseline, for example, if Mexico decides to exploit its natural gas reserves of tight gas, the baseline would change and this in turn could change relative prices of fuels. Assumptions on a slower or faster rate of oil exhaustion could also be built into the baseline and that would lead to a different set of possible simulations.

As for the type of programs that could be financed with resources from energy subsidies, the conditional cash transfer program Prospera could be expanded, investment in energy efficiency equipment that in the long run will translate into energy savings, generation of clean energy, and to the provision of cleaner and more efficient public transport. These exercises could definitely be done with the model in the future (and some have previously been done).

It would also be of interest to estimate external effects. For example, estimating co-benefits from health and productivity from the implementation of programs such as the one analyzed in this paper (expanding health care coverage), or effects associated to energy subsidies and the resulting pollution. These effects must be calculated separately and included as part of the effects of these policies.

To gain further insight of the energy sector, simulations to address the marginal effect of eliminating subsidies to each energy source could be done separately. This would provide a better understanding on the impact economic and distributional effects of different subsidies. Conversely, a set of simulations could be done to see the effects of imposing carbon taxes. This could provide arguments for international negotiations, as well as fund some of the other projects such as clean energy, energy efficiency, and clean transport discussed above.

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Appendix A. The model

Production

Production in each sector for every time period is represented as a constant elasticity of substitution (CES) value added function of capital, labor, energy and material inputs, where the elasticity of substitution can vary between zero and infinity. Hence,

$$(1)\quad V_t = \phi_t [\, \delta_L L_t^{(\sigma-1)/\sigma} + \delta_K K_t^{(\sigma-1)/\sigma} + \delta_E E_t^{(\sigma-1)/\sigma} + \delta_M M_t^{(\sigma-1)/\sigma} \,]^{(\sigma/\sigma-1)}$$

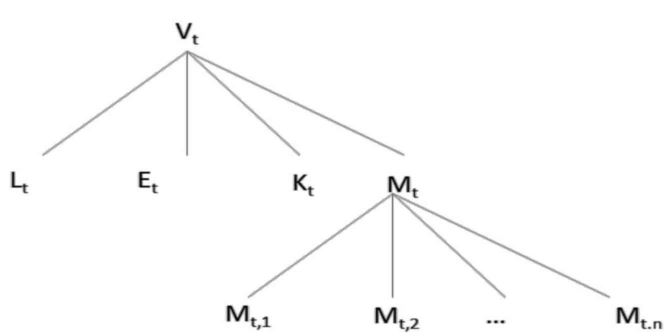
where V_t is the value added at time t, σ is the elasticity of substitution between inputs, ϕ_t is an efficiency parameter that shifts the whole production function, L_t is labor at time t, K_t is capital at time t, E_t is energy at time t, M_t are material inputs at time t, δ are share parameters defined so that

$$\delta_L,\ \delta_K,\ \delta_M,\ \delta_E > 0 \quad y$$

$$\delta_L + \delta_K + \delta_M + \delta_E = 1$$

Prices of all goods and services are equal to one, so that V_t refers to quantity as well as value of production. Material inputs are all inputs from the sectors of production, and M_t refers to a composite good based on a nested CES production function, where inputs from all sectors are included (See Figure A.1). These nested functions are used for production and consumption, permitting different levels of substitution between inputs or goods and services. For the production function, substitution is allowed between labor, capital, and energy as well as between energy inputs and non-energy inputs.

Figure A.1 Nested production function



Consumption

Total utility for each household c is modeled by

$$(2)\quad U_c = \Sigma_t\, U_{c,t}\,(X_{c,t}, R_{c,t}) * (1+\rho)^{-t} \qquad t = 1, \ldots, n$$

where U_c is household utility over all n time periods, $U_{c,t}$ is the utility derived from the present period consumption of goods and services, $X_{c,t}$ (a 7-dimensional vector) and leisure $R_{c,t}$, and where ρ is the rate of time preference. Each U_c is taken to be a nested CES utility function defined for all consumer goods as well as all time periods. The value of household utility is given by the addition of the value of consumption plus the value of leisure, which is equal to the number of hours devoted to leisure times the net wage per hour worked (Ballard et al., 1985).

Each consumer's expenditure constraint can be written as:

$$(3)\quad \sum_{t=1}^{n} (TG_{c,t} + TF_{c,t} + (P_{L,t} * L_{c,t}) + (r * K_t * S_{c,t})) =$$

$$\sum_{t=1}^{n} ((INV_t * S_{c,t}) + (P_{I,t} * X_{c,t}) + (P_{L,t} * R_{c,t}))$$

Where endowments are given on the left-hand side of the equation and expenditures are placed on the right hand side. $TG_{c,t}$ and $TF_{c,t}$ represent the transfer to the consumer from the government and the foreign agents; $P_{L,t}$ is the price of labor y r is the rental of capital. K_t is the level of stock capital in period t; $S_{c,t}$ is the share of total capital owned by consumer c, INV_t is the total investment in time period t; and $P_{I,t}$ is the vector of prices for consumer goods

Maximizing the nested utility function (2) with respect to the expenditure constraint (3), simultaneously determines the consumption level of the consumer goods and services, the amount of labor supply, and the consumers level of saving and investment in each of the periods.

Government

The government sector is treated as a separate agent (Ballard et al 1985). The government agent is modeled with an expenditure function similar to the household expenditure functions (based on a CES utility function). The equations that describe the behavior of the government are:

$$(4)\qquad G_u = x_1^{\alpha_1} x_2^{\alpha_2} x_i^{\alpha_i} x_n^{\alpha_n}$$

$$\sum_i \alpha_i = 1$$

$$E = \prod_{i=1}^{n} P_i^{\alpha_i}$$

where G_u is the utility function of the government and α_i represents the share of the sectors, and x_i are the units that the government consumes. E is total expenditure by the government; and P_i are the market prices of the goods and services.

Trade

International trade within the model is handled by means of a foreing agent. The balance of trade relationship is given by

(5) $\Sigma(P_{m,t} * IM_{j,t}) = \Sigma(P_{j,t} * EX_{j,t}) + \Sigma TF_{c,t} \qquad t = 1, \ldots, n$

where $IM_{j,t}$ is a vector representing the quantity of each to the producer goods imported; $P_{m,t}$ is the vector of imported goods prices, $EX_{j,t}$ is the vector of producer goods exported, $P_{j,t}$ is the vector of producer goods prices, including tariffs, and $TF_{c,t}$ is the level of transfers.

Labor growth and capital formation

The growth of labor over time is given by

(6) $L_{t+1} = L_t(1+\gamma)$

where γ is the labor growth rate over time. In absence of any perturbation the Ramsey model predicts that the economy will grow at the labor growth rate in the steady state. Capital growth rate is represented by a system of three equations:

(7) $P_{A,t} = P_{k,t+1} \qquad t = 1, \ldots, T$

where $P_{A,t}$ is the weighted price of consumption and $P_{k,t+1}$ is next year's price of capital. We also have

(8) $P_{k,t} = (1+r_t)\, P_{k,t+1} \qquad t = 1, \ldots, T$

meaning that the price of capital in this period $P_{k,t}$ must be equal to the present period's rental value of capital plus next period's price of capital $P_{k,t+1}$. Finally we have

(9) $K_{t+1} = K_t(1-\Delta) + INV_t \qquad t = 1, \ldots, T$

where Δ stands for the rate of depreciation and INV stands for gross investment. This states that the capital stock in the next period must be equal to this year's capital stock plus net investment. Taken together, eqs. 7-9 insure that economic growth will be consistent with profit maximization behavior on the part of investors.

Terminal conditions

A few adjustments are necessary to design a model which when solved over a finite horizon approximates infinite horizon choices (Lau, Puhlke, and Rutherford, 1997). We divide the problem into two distinct sub-problems, one defined over the finite period from t = 0 to t = T, and the second the infinite period from t = T+1 to T = ∞. Hence, the first problem is

(10) $$Max \sum_{t=0}^{T} \left(\frac{1}{1+\rho}\right)^t U_{c,t}(X_{c,t}, R_{c,t})$$

subject to

(11) $$\sum_{t=0}^{T} P_{A,t} X_{c,t} = \sum_{t=0}^{T} P_{L,t} \bar{L}_{c,t} + P_{k,0} K_{c,0} S_{C,t} - P_{k,T+1} \bar{K}_{c,T+1} S_{C,T+1}$$

and

(11a) $\bar{L}_{c,t} = L_{c,t} + R_{c,t}$ for all $t = 0, 1, \ldots T$

And the second problem is

(12) $$Max \sum_{t=T+1}^{\infty} \left(\frac{1}{1+\rho}\right)^t U_{ct}(X_{c,t}, R_{c,t})$$

subject to

(13) $$\sum_{t=T+1}^{\infty} P_{I,,t} \cdot X_{c,t} = \sum_{t=T+1}^{\infty} P_{L,t} L_{c,t} + P_{K,T+1} \bar{K}_{c,T+1} S_{c,t+1}$$

(13a) $\bar{L}_{c,t} = L_{c,t} + R_{c,t}$ for all $t=T+1, \ldots\infty$

where ρ is the rate or time preferences, r_o and $K_{c,o}$ refer to the rental value of capital and quantity of capital before the terminal period, r_{T+1} and $\bar{K}_{c,T+1}$ refer to these variables after the terminal period, and $\bar{L}_{c,t}$ is total labor plus leisure for each agent in the t time period. $P_{K,t}$ is the price of capital, and $P_{I,t}$ and $P_{L,t}$ are the prices of the consumption goods and the price of labor, both net of taxes.

We include the level of post-terminal capital as a variable and add a constraint on investment growth in the final period

(14) $INV_T/INV_{T-1} = Y_T/Y_{T-1}$

where Y_T gives the GDP at time T.

Appendix B. Elasticities

Table B1
Substitution elasticities between capital and labor

Sector	Σ	Source	Country
Agriculture	0.83	Hueter 1997	Mexico
Livestock	0.83	Hueter 1997	Mexico
Forestry	0.83	Hueter 1997	Mexico
Fishing	0.83	Hueter 1997	Mexico
Mining	0.8	Balistreti, 2002	United States
Electricity	0.85	Fu, 2010	United States
Chemicals	0.80	Claro, 2003	Average for several countries
Refining	0.94	Claro, 2003	Average for several countries
Transport	0.98	Balistreti, 2002	United States
Services	0.99	Balistreti, 2002	United States
Manufactures	0.93	Salgado and Bernal, 2007	Mexico

Source: Own based on references.