Energy, Economic Growth, Inequality, and Poverty in Iran[1]

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Abstract

This paper examines the relationships among energy consumption, economic growth, inequality, and poverty in Iran. We estimate these relationships at both the aggregate and sectoral level using instrumental variables to address endogeneity and simultaneous equation models to enhance efficiency. Results show that decreasing inequality will be beneficial for economic growth, poverty alleviation, and energy access. Inequality can negatively affect GDP directly, as well as indirectly through its negative effect on energy consumption. Similarly, inequality can increase poverty both directly as well as indirectly through its negative effect on energy consumption. We also find that increasing energy consumption has multiple benefits: it increases GDP, tends to decrease inequality, and decreases poverty. Energy consumption decreases poverty both directly as well as indirectly via its effect on decreasing inequality. Our results therefore suggest that policies to improve energy access are important, and will have the benefits of increasing GDP, decreasing inequality, and decreasing poverty.

Keywords: energy consumption, poverty and inequality, economic growth, simultaneous equation system

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1. Introduction

Energy is an important resource needed to fuel modern industrialized society and economic development. Economists have long been interested in understanding the nature of energy demand and the impact of energy consumption on different aspects of the economy, and research on this subject increased in the early 1970s following the oil crisis (Pindyck, 1979). Energy is essential to productivity and the delivery of health care, education, and employment; and energy and energy prices have been associated with poverty, income, and household welfare (Bridge, Adhikari and Fontenla, 2016; Krauss, 2016; Churchill, Smith and Farrell, 2020). Previous studies have shown that energy is one of the determinants of economic growth in different countries (Frank, 1959; Nordhaus, 1974; Stiglitz, 1974; Jorgenson, 1998; Weitzman, 1999; Corderi and Lin, 2011; Zhang and Lin Lawell, 2017; Jorgenson, 2018; Kerestes, Corderi Novoa and Lin Lawell, 2020; Tan, Chau and Lin Lawell, 2020), and that energy can affect other macroeconomic variables such as poverty and inequality (Gunder, 1959; Struckmeyer, 1986; Ngepah, 2011).

Access to energy services is critical for the reduction of poverty and inequality, and is thus an indispensable component of the economic and human development process (Brook and Smith, 2000). Households depend on energy in various forms to ensure adequate living conditions (Churchill, Smith and Farrell, 2020). Residential consumption of energy contributes to household living standards through lighting, cooking, heating, and cooling (Welsch and Biermann, 2017). Energy services, especially services of modern and clean energy such as electricity and natural gas, in combination with capital equipment, enable the production of goods and services in industries and households, which has a major impact on labor productivity, industrial productivity, and production efficiency, and thus contributes to economic growth. Increases in economic growth in turn lead to increases in household income and can lead to poverty reduction.

Access to modern and clean forms of energy is necessary for socio-economic development. A country's energy mix can play a non-negligible role in economic growth and poverty alleviation (World Bank, 2001). For example, electrical lighting will increase daylight during the day and hence provides extra hours for reading and other productive activities. Modern cook-stoves save wood collecting time for women, allowing them to reallocate time for human capital development and more productive activities, while also saving women and children from noxious fumes. Refrigeration can allow local clinics to keep vital medication at hand for prompt response to health needs. Since most economic activity is impossible without adequate and reliable modern energy, access to energy is important in the fight against poverty (Indrawati, 2015).

Although energy is important for economic, human, and social development, the impact of energy consumption on poverty and inequality reduction has not well established nor adequately addressed in the economic literature. For example, the microeconomic literature examining the impacts of electrifying households on economic development has produced a set of conflicting results (Lee, Miguel and Wolfram, 2020). Moreover, studies of the effect of energy consumption on inequality and poverty, particularly for oil-rich developing countries such as Iran, are scarce in literature despite their importance. Indeed, there is very little, if any, literature about the impact of energy on poverty and inequality reduction in Iran.

In this paper we analyze the relationships among energy consumption, economic growth, inequality, and poverty in Iran. We estimate these relationships at both the aggregate and sectoral level using instrumental variables to address endogeneity and simultaneous equation models to enhance efficiency. The relationships among energy consumption, economic growth, inequality, and poverty have important implications for policy. Our results suggest that policies to improve energy access are important, and will have the benefits of increasing GDP, decreasing inequality, and decreasing poverty.

2. Literature Review

Our paper builds on multiple strands of literature. One strand of literature upon which we build is the literature on energy and development. The previous literature on energy and development has heretofore focused primarily on the relationship between economic growth and energy. Energy can affect economic growth and income through multiple channels. First, energy is an input into production (Nordhaus, 1974; Stiglitz, 1974; Jorgenson, 1998; Corderi and Lin, 2011; Zhang and Lin Lawell, 2017; Jorgenson, 2018; Kerestes, Corderi Novoa and Lin Lawell, 2020; Tan, Chau and Lin Lawell, 2020). Second, increases in the production of energy requires labor, resulting in increases in labor demand, wages, and household income. Third, the use of energy, especially modern energy such as electricity and natural gas, will affect education and health, and will thus increase incomes (World Bank, 2008; Ngepah, 2011).

We also build on the literature on inequality and poverty. Most of the studies on poverty and the causes of poverty focus on financing, asset accumulation, health, nutrition, and the education system as important factors in the poverty reduction process (Honohan, 2004; Barrett, Garg and McBride, 2016; Barrett, Carter and Chavas, 2019). We build on these studies by analyzing the role of energy in poverty reduction, economic growth, and sustainable development.

According to the previous literature, there are several main ways through which inequality can affect economic growth (Bourguignon, 2004; Shin, 2012; Muinelo-Gallo and Roca-Sagalés, 2013; Chan, Zhou and Pan, 2014; Li et al., 2016; Yang and Greaney, 2017) and enter into the production function. The first is through credit constraints, investment, and borrowing and lending in the capital market. As more capital is accumulated in the economy, more funds may become available to the poor for investment purposes, which in turn enables them to grow richer. The redistribution of wealth from rich lenders to poor and middle-class borrowers improves the production efficiency of the economy both because it brings about greater equality of opportunity and also because it accelerates the trickle-down process (Banerjee and Newman, 1993; Galor and Zeira, 1993; Aghion and Bolton, 1997).

A second channel through which inequality may affect economic growth is through human capital accumulation. The distribution of income can affect whether the talents of all individuals in the economy can flourish, thereby affecting human capital accumulation, the factor productivity of labor and capital, and therefore economic growth on a large scale (Hassler and Rodríguez Mora, 2000; Voitchovsky, 2005; Schwabish, Smeeding and Osberg, 2006).

A third channel through which inequality can affect economic growth is political economy. An unequal distribution of income in the society may lead to an increase in social tension in the community and therefore affect economic activity, consumer demand, capital accumulation, and therefore economic growth (Rodrik, 1996; Deininger and Squire, 1998; Ngepah, 2011).

There is an emerging literature on energy and development that recognizes the role of energy on poverty and inequality reduction (see e.g., ESMAP, 2002; Karekezi, 2002; Heltberg, 2004; Nkomo, 2007; World Bank, 2008; Ngepah, 2011; Khandker, Barnes and Samad, 2012; Malla, 2013; Zulu and Richardson, 2013). According to the literature, energy can affect poverty both through economic growth and through inequality reduction. Giving poor people access to energy and its services leads to improving their standard of living, reducing their living costs and increasing their revenues, thus reducing inequality and poverty.

One of the most comprehensive models of the impact of energy on poverty and growth is the energy ladder model, which defines three different phases in fuel switching. The first phase is biomass. In the second phase, there is a transition to kerosene, coal, and charcoal in response to higher incomes, urbanization, and biomass scarcity. In final stage, the fuel changes to liquid petroleum gas (LPG), natural gas, or electricity for cooking (Leach, 1992; Hosier and Kipondya, 1993; Barnes and Floor, 1996; Ngepah, 2011). Households progress through the three phases in fuel switching as their incomes increase (Barnes and Floor, 1996; IEA, 2002; Heltberg, 2004). As they move up the energy ladder, households benefit from modern energy services, increased productivity, business development, poverty and inequality reduction, and community development (DME and ERC, 2002; ESMAP, 2002; Barnes, Peskin and Fitzgerald, 2003; DME, 2005; Prasad, 2006).

The importance of energy, coupled with rising energy prices, has spurred an interest in household fuel poverty, defined as the difficulty that households face in maintaining adequate temperature at home, as well as enjoying other essential residential energy services (Boardman, 1991). While a relatively new body of literature examines the impact of fuel poverty, energy prices and affordability on wellbeing, this literature is largely focused on European countries (see, e.g., Biermann, 2016; Thomson, Snell and Bouzarovski, 2017; Welsch and Biermann, 2017; Rodriguez-Alvarez, Orea and Jamasb, 2019). Churchill, Smith and Farrell (2020) find that fuel poverty lowers subjective wellbeing in Australia.

Although energy is important for socio-economic development, the impact of energy consumption on poverty and inequality reduction has not been well established nor adequately addressed in the economic literature. For example, the microeconomic literature examining the impacts of electrifying households on economic development has produced a set of conflicting results (Lee, Miguel and Wolfram, 2020). Moreover, studies of the effect of energy consumption on inequality and poverty, particularly for oil-rich developing countries such as Iran, are scarce in literature despite their importance. Indeed, there is very little, if any, literature about the impact of energy on poverty and inequality reduction in Iran.

In this paper we build on the previous literature by analyzing the relationships among energy consumption, economic growth, inequality, and poverty in Iran.

3. Econometric Model

We now develop an econometric model to empirically evaluate the relationships among energy consumption, economic growth, inequality, and poverty in Iran.

Based on the previous literature, we hypothesize that energy consumption affects poverty both directly and indirectly through its impact on economic growth and inequality. If increasing energy consumption promotes economic growth, and if the poor can take advantage of the benefits of growth so that the economic growth created by poverty can alleviate poverty, then poverty reduction occurs in society. Energy consumption can also affect poverty through its impact on income inequality. If energy is available to all segments of society, and if the benefits of energy consumption reduce inequality, the energy can also reduce poverty by reducing inequality. Moreover, energy consumption can also affect poverty reduction by increasing economic growth if economic growth can result in reducing inequality.

3.1. Production function

As commonly assumed, we model output as a function of capital, labor, and energy (Nordhaus, 1974; Stiglitz, 1974; Jorgenson, 1998; Corderi and Lin, 2011; Zhang and Lin Lawell, 2017; Jorgenson, 2018; Kerestes, Corderi Novoa and Lin Lawell, 2020; Tan, Chau and Lin Lawell, 2020). Following the convention in macroeconomic models of growth, we divide output and inputs by labor and express everything in per capita terms so that labor no longer appears as a separate input (Acemoglu, 2009). We also include inequality in the production function; inequality can affect economic growth and enter into the production function through the credit constraints, investment, and borrowing and lending in the capital market (Banerjee and Newman, 1993; Galor and Zeira, 1993; Aghion and Bolton, 1997); through human capital accumulation (Hassler and Rodríguez Mora, 2000; Voitchovsky, 2005; Schwabish, Smeeding and Osberg, 2006); and through political economy (Rodrik, 1996; Deininger and Squire, 1998; Ngepah, 2011).

To analyze the effects of inequality, energy consumption, capital, and energy prices on output and income, we estimate the following production function:

$$\ln y_t = \alpha_0 + \alpha_1 \ln \theta_t + \alpha_2 \ln e_{jt} + \alpha_3 \ln k_t + \varepsilon_{yt}, \tag{1}$$

where y_t is real GDP per capita, θ_t is the inequality index, e_{jt} is per capita consumption of energy type j, and k_t is capital per capita. For the inequality index, we use either the Thiel index, the Gini coefficient, or the Atkinson index in different specifications. For the different types j of energy consumption e_{jt}, we use either total energy, gasoil, kerosene, fuel oil, gasoline, electricity, or natural gas in different specifications.

3.2. Energy demand equation

As commonly assumed, we model energy demand is function of real income and real energy prices (Ramanathan, 1999; Alves and De Losso da Silveira Bueno, 2003; Polemis, 2006; Akinboade, Ziramba and Zumo, 2008; Lin and Prince, 2009; Lin, 2011; Lin and Zeng, 2013; Lin and Prince, 2013; Kheiravar, Lin Lawell and Jaffe, 2020). In addition, based on the energy ladder model, as a household's income increases, the demand for various types of energy, especially modern energy, will increase; as a consequence, the distribution of income as measured by inequality will affect energy demand as well.

We estimate the following energy demand equation:

$$\ln e_{jt} = \beta_0 + \beta_1 \ln \theta_t + \beta_2 \ln y_t + \beta_3 \ln price_{jt} + \varepsilon_{et}, \qquad (2)$$

where $price_{jt}$ is the real price of energy type *j*. The different types *j* of energy we use in different specifications are total energy, gasoil, kerosene, fuel oil, gasoline, electricity, and natural gas. Because we have a limited number of observations and therefore have limited degrees of freedom, we do not include the prices of other energy types in the demand for energy type *j*. For the inequality index, we use either the Thiel index, the Gini coefficient, or the Atkinson index in different specifications.

3.3. Inequality equation

We estimate the following inequality equation:

$$\ln \theta_t = \lambda_0 + \lambda_1 \ln y_t + \lambda_2 (\ln y_t)^2 + \lambda_3 \ln g_t + \lambda_4 \ln s_t + \lambda_5 \ln e_{jt} + \varepsilon_{\theta t}, \qquad (3)$$

where g_t is the ratio of government spending to GDP and s_t is the energy subsidy per capita. For the inequality index, we use either the Thiel index, the Gini coefficient, or the Atkinson index in different specifications.

According to Kuznets (1955), and as documented empirically by previous studies (Ahluwalia, 1976; Anand and Kanbur, 1993a; Anand and Kanbur, 1993b; Ngepah, 2011; Kanbur, 2019), there is a nonlinear and possibly inverted U-shaped relationship between inequality and per capita income. We therefore include both GDP and GDP squared. We also include government spending as a ratio of GDP, as a proxy for government redistribution policies which can affect inequality.

Owing to the importance of energy in the Iranian economy and its high energy subsidies (Ross, Hazlett and Mahdavi, 2017; Lin Lawell, 2017; Kheiarvar and Lin Lawell 2020; Kheiravar, Lin Lawell and Jaffe, 2020), we also include energy subsidy as an additional regressor in the inequality equation. Redistributing wealth and helping the poor are among the primary reasons for Iran's energy subsidies (Kheiravar and Lin Lawell, 2020). We also include per capita energy consumption in the inequality equation. For the different types *j* of energy consumption e_{jt}, we use either total energy, gasoil, kerosene, fuel oil, gasoline, electricity, or natural gas in different specifications.

3.4. Poverty equation

Building on the pro-poor growth framework of Son and Kakwani (2008), we model poverty as a function of inequality and of the determinants of per capita GDP. We estimate the following inequality equation:

$$\ln P_t = \gamma_0 + \gamma_1 \ln \theta_t + \gamma_2 \ln e_{jt} + \gamma_3 \ln k_t + \gamma_4 s_t + \varepsilon_{pt}, \tag{4}$$

where P_t is the poverty index and is captured by the Foster-Greer-Thorbecke (FGT) family of poverty indices. For the inequality index, we use either the Thiel index, the Gini coefficient, or the Atkinson index in different specifications. For the different types *j* of energy consumption e_{jt}, we use either total energy, gasoil, kerosene, fuel oil, gasoline, electricity, or natural gas in different specifications.

Owing to the importance of energy in the Iranian economy and its high energy subsidies (Ross, Hazlett and Mahdavi, 2017; Lin Lawell, 2017; Kheiarvar and Lin Lawell 2020; Kheiravar, Lin Lawell and Jaffe, 2020), we also include energy subsidy as an additional regressor in the poverty equation. Redistributing wealth and helping the poor are among the primary reasons for Iran's energy subsidies (Kheiravar and Lin Lawell, 2020).

3.5. System of equations

We estimate the following system of equations governing production, energy demand, inequality, and poverty:

$$\begin{pmatrix} \ln y_t = \alpha_0 + \alpha_1 \ln \theta_t + \alpha_2 \ln e_{jt} + \alpha_3 \ln k_t + \varepsilon_{yt} \\ \ln e_{jt} = \beta_0 + \beta_1 \ln \theta_t + \beta_2 \ln y_t + \beta_3 \ln price_{jt} + \varepsilon_{et} \\ \ln \theta_t = \lambda_0 + \lambda_1 \ln y_t + \lambda_2 (\ln y_t)^2 + \lambda_3 \ln g_t + \lambda_4 \ln s_t + \lambda_5 \ln e_{jt} + \varepsilon_{\theta t} \\ \ln P_t = \gamma_0 + \gamma_1 \ln \theta_t + \gamma_2 \ln e_{jt} + \gamma_3 \ln k_t + \gamma_4 s_t + \varepsilon_{pt} \end{pmatrix}_i \quad (5)$$

We estimate the system given by (5) for the whole economy and for three important sectors of Iran's economy: the agricultural sector, industrial sector, and service sector.

3.6. Methods

We use instrumental variables to address the endogeneity of many of the variables in the system given by (5). We estimate two types of instrumental variables models. The first instrumental variables model we use is equation-by-equation two-stage least squares (2SLS). In equation-by-equation 2SLS, we separately estimate the production function (1), energy demand equation (2), the inequality equation (3), and the poverty equation (4) using instruments. The estimates obtained via 2SLS are consistent (Lin, 2011).

Although the estimates yielded by 2SLS are identified, they are not efficient, however. This is because, in estimating each equation individually, 2SLS does not make use of all the available information. Estimating equations in the system of simultaneous equations (5) jointly can enhance efficiency since it incorporates all the available information at one time (Judge et al., 1985; Judge et al., 1988; Lin, 2011; Kahouli, 2011; Shehata, 2013). Thus, in order to address both the identification and the efficiency issues, the second instrumental variables model we estimate is three-stage least squares (3SLS). In 3SLS, not only are instruments used to help identify the structural parameters, but the equations (1)-(4) also are estimated jointly as the system of simultaneous equations (5) via generalized method of moments (GMM) to improve efficiency. 3SLS is more efficient than its equation-by-equation analog, 2SLS, because 3SLS incorporates all the available information at one time. Thus, 3SLS estimates are both consistent and efficient (Lin, 2011).

In the production function (1), y_t is real GDP per capita in the aggregate model and value added in each sector in the models by sector. For inequality, we try different specifications using the Theil index, the Atkinson index, or the Gini coefficient, respectively. In both the aggregate and sector-wise models, the endogenous variables are GDP, energy consumption, and inequality. Capital is an exogenous variable. For total energy consumption in the aggregate model for Iran's entire economy, we use energy use in countries in Middle East and North Africa; and energy use in Turkey, a country that is similar to Iran, as instruments for total energy consumption. For energy consumption of different types of energy, we use total energy consumption per capita and lagged energy consumption per capita as instruments for the consumption of different types of energy in each sector. We use lagged government expenditure on social welfare or lagged government expenditure on public services as instruments for inequality. In the aggregate model, we use GNP, GDP without oil, and oil revenue as instruments for GDP. When we estimate the production function by sector, we use GDP as an instrument for sector value added.

In the energy demand equation (2), energy consumption, inequality, GDP, and energy prices are endogenous. We use international energy prices as instruments for domestic energy prices in Iran. We use lagged government expenditure on social welfare and lagged government expenditure on public services as instruments for inequality. In the aggregate model, we use GNP, GDP without oil, and oil revenue as instruments for GDP. When we estimate the production function by sector, we use GDP as an instrument for sector value added.

In the inequality equation (3), we use the Theil index, the Atkinson index, or the Gini coefficient for inequality in different specifications. The ratio of government spending to GDP is exogenous. Inequality, GDP, and energy consumption are endogenous. In the aggregate model, we use GNP, GDP without oil, and oil revenue as instruments for GDP. When we estimate the inequality equation by sector, we use GDP as an instrument for sector value added. For total energy consumption in the aggregate model for Iran's entire economy, we use energy use in countries in Middle East and North Africa; and energy use in Turkey, a country that is similar to Iran, as instruments for total energy consumption. For energy consumption of different types of energy, we use total energy consumption per capita and lagged energy consumption per capita as instruments for the consumption of different types of energy in each sector.

In poverty equation (4), the poverty index is captured by the Foster-Greer-Thorbecke family of poverty indices. This is an endogenous variable. We use poverty indices for poverty incidence, intensity, and severity across different specifications. We use other poverty indices such as the headcount ratio as instruments for the poverty index.

To estimate the impact of energy subsidies on poverty and inequality in Iran, we include per capita energy subsidy in the inequality and poverty equations, because it has possible effect poverty and inequality. This variable is endogenous and we use the lagged of value of this variable as its instrument.

We conduct several tests of our instrumental variables models, including the Angrist and Pischke test (Angrist and Pischke, 2009), the Kleibergen-Paap test (Kleibergen and Paap, 2006), the Cragg-Donald test, the Anderson-Rubin test, the Stock-Wright test, and the Hansen test.

4. Data

We use annual data from 1989 to 2018 for the entire Iranian economy and for the agricultural, industrial, and service sectors of Iran.

Our data on gross domestic product (GDP) in 2000 constant prices is from the Central Bank of Iran. The value added of the agricultural sector, the industrial sector, and the service sector are from the Central Bank of Iran, and are converted to per capita values by dividing by the labor force, also from the Central Bank of Iran.

Capital per worker is the ratio of capital stock to labor force. This data is from the Central Bank of Iran.

Government expenses are measured by total government expenses as a ratio of GDP; this data is from the Central Bank of Iran.

Energy demand for each energy resource (total energy, electricity, fuel oil, gasoline, gasoil, natural gas, and kerosene) is from Iran's Annual Energy Balance.

Aggregate energy price is measured by weighted average of the prices of all types of energy, and is from Iran's Annual Energy Balance. Electricity prices and gas prices are different in different sectors; the energy prices of other types of energy are the same in different sectors. All energy data are from Iran's Annual Energy Balance.

The Theil index, Atkinson index, and Gini coefficient are inequality indices and are calculated from the annual household expenditure-income project in the Statistical Center of Iran.

The poverty variable is captured by the Foster-Greer-Thorbecke (1984) family of poverty indices. The poverty indices for poverty incidence, intensity, and severity are calculated based on the annual household expenditure-income project in Statistical Center of Iran. Per capita energy subsidy data is from Iran's Annual Energy Balance.

Summary statistics for the poverty and inequality indices are in Table 1. Summary statistics for the whole economy, agricultural sector, industrial sector, and the service sector are in Tables 2-5, respectively.

5. Results

5.1. Economy-wide results

Table 6 summarizes the 2SLS and 3SLS results for the economy-wide regressions. We run multiple specifications of each regression using different inequality indices and different poverty indices. For inequality, we try different specifications using the Theil index, the Atkinson index, or the Gini coefficient, respectively. For poverty, we use poverty indices for poverty incidence, intensity, and severity across different specifications. The different types j of energy we use in different specifications are total energy, gasoil, kerosene, fuel oil, gasoline, electricity, and natural gas. In the table, a "+" indicates that most of the coefficients on that regressor are significant at a 5% level and positive when using different inequality indices and different poverty indices; a "-" indicates that most of the coefficients are significant at a 5% level and negative; and a blank cell indicates that most or all of the coefficients are not significant at a 5% level.

5.1.1. Aggregate production function

For the production function (1) with GDP as a dependent variable, we find that inequality does not have a robust significant effect on GDP. Total energy, gasoil consumption, kerosene consumption, electricity consumption, and natural gas consumption have positive effects on per capita GDP. Gasoline consumption does not have a robust significant effect on GDP.

Capital stock has a positive effect on GDP in the regressions using total energy, in the regressions using gasoil, and in the regressions using kerosene. Capital does not have a robust significant effect in the regressions using fuel oil, gasoline, natural gas, or electricity.

5.1.2. Aggregate energy demand

For the energy demand function (2) with energy consumption as a dependent variable, we find that inequality does not have a robust significant effect on any form of energy consumption except gasoline consumption, on which it has a positive effect.

Per capita GDP has a positive effect on energy consumption, gasoil consumption, kerosene consumption, gasoline consumption, electricity consumption, and natural gas consumption. Per capita GDP does not have robust significant effect on fuel oil consumption.

Energy price has a negative effect on energy demand for total energy, gasoil, kerosene, fuel oil, gasoline, and natural gas; but not for electricity.

5.1.3. Aggregate inequality equation

For the inequality equation (3), we do not find evidence to support an inverted-U Kuznets curve in Iran because we do not find a robust significant coefficient on either GDP per capita or GDP per capita squared. Government spending does not have a robust significant effect on inequality.

The per capita energy subsidy has a negative effect on inequality in regressions where total energy is used. In the regressions where different types of energy are used in place of total energy, the per capita energy subsidy does not have a robust significant effect on inequality.

Gasoil consumption, electricity consumption, and natural gas consumption have robust and significant negative effects on inequality. Total energy consumption, kerosene consumption, fuel oil consumption, and gasoline consumption do not have any robust significant effect on inequality.

5.1.4. Aggregate poverty equation

For the poverty equation (4), we find that inequality increases poverty. Total energy consumption, kerosene consumption, gasoline consumption, and electricity consumption decrease poverty. Neither fuel oil consumption nor gasoil has a robust significant effect on poverty.

Per capita capital stock decreases poverty in the regressions using total energy, the regressions using gasoil, the regressions using kerosene, the regressions using fuel oil, and the regressions using gasoline. Per capita capital stock does not have a robust significant effect on poverty in the regressions using electricity or natural gas.

The per capita energy subsidy does not have a robust significant effect on poverty. The per capita gasoline subsidy increases poverty.

5.2. Results by sector

Table 7 summarizes the results of the 2SLS and 3SLS regressions by sector. We run multiple specifications of each regression using different inequality indices and different poverty indices. For inequality, we try different specifications using the Theil index, the Atkinson index, or the Gini coefficient, respectively. For poverty, we use poverty indices for poverty incidence, intensity, and severity across different specifications. For each sector, we use value added in that sector as our measure of GDP in that sector. In the table, a "+" indicates that most of the coefficients on that regressor are significant at a 5% level and positive when using different inequality indices and different poverty indices; a "-" indicates that most of the coefficients are significant at a 5% level and negative; and a blank cell indicates that most or all of the coefficients are not significant at a 5% level.

5.2.1. Production function by sector

For the production function (1) with value added as a dependent variable in the sector-wise estimation, we find that inequality does not have a robust significant effect on value added in agricultural and service sector but does have a significant negative effect on per capita value added in the industrial sector.

Energy has a positive effect on per capita value added in three sectors: energy consumption leads to an increase in per capita agricultural value added, in per capita industrial value added, and in per capita service value added.

Capital stock has a positive effect on per capita value added in the agricultural and industrial sector. Capital stock does not have a robust significant effect on per capita value-added in-service sector.

5.2.2. Energy demand by sector

For the energy demand function (2) with energy consumption as a dependent variable, inequality has a negative effect on energy demand in the agricultural sector, but does not have a robust significant effect on energy demand in either the industrial or service sectors.

Per capita value added has a positive effect on energy demand in three sectors: per capita agricultural value added, per capita industrial value-added, and per capita service value added all have positive effects on energy demand.

Energy prices have a negative effect on energy demand in the service sector, but do not a have robust significant effect on energy demand in either the agricultural or industrial sectors.

5.2.3. Inequality equation by sector

For the inequality equation (3), we do not find evidence to support an inverted-U Kuznets curve in any of the three sectors because we do not find a robust significant coefficient on either GDP per capita or GDP per capita squared in any of the three sectors.

Neither government spending nor the energy subsidy has a robust significant effect on inequality in any of the sectors. Per capita energy consumption decreases inequality in the agriculture and service sectors. Per capita industrial energy consumption does not have a robust significant effect on inequality.

5.2.4. Poverty equation by sector

For the poverty equation (4), inequality increases poverty in the industrial and service sectors. Inequality does not have a robust significant effect on poverty in the agricultural sector.

Energy consumption decreases poverty in the service sector. Energy consumption does not have a robust significant effect on poverty in either the agricultural sector or the industrial sector.

Per capita capital stock has a negative effect on the poverty index in all three sectors: per capita agricultural capital stock, per capita industrial capital stock, and per capita service capital stock have negative effects on the poverty index.

The per capita energy subsidy in the agriculture sector decreases poverty. The per capita energy subsidies in the industrial and service sectors do not have robust significant effects on poverty.

6. Conclusion

In this study, we investigate the impact of energy on economic growth, inequality, and poverty in Iran for the entire economy and by sector. We use instrumental variables to address endogeneity and simultaneous equation models to enhance efficiency.

Results of our aggregate and sector-wise production function regressions show that inequality has a negative effect on GDP while energy consumption has a positive effect on GDP.

Our result that inequality has a negative effect on GDP is consistent with the previous literature that finds that inequality can affect economic growth and enter into the production function through the credit constraints, investment, and borrowing and lending in the capital market (Banerjee and Newman, 1993; Galor and Zeira, 1993; Aghion and Bolton, 1997); through human capital accumulation (Hassler and Rodríguez Mora, 2000; Voitchovsky, 2005; Schwabish, Smeeding and Osberg, 2006); and through political economy (Rodrik, 1996; Deininger and Squire, 1998; Ngepah, 2011).

Our result that energy has a positive effect on GDP is consistent with previous models of energy as an input to production and a driver of economic growth (Nordhaus, 1974; Stiglitz, 1974; Jorgenson, 1998; Corderi and Lin, 2011; Zhang and Lin Lawell, 2017; Jorgenson, 2018; Kerestes, Corderi Novoa and Lin Lawell, 2020; Tan, Chau and Lin Lawell, 2020).

Results of our energy demand regressions show that inequality has a negative effect on energy consumption. This result suggests that inequality decreases the access of some people to energy. Moreover, when combined with our result from our production function, we find that inequality can negatively affect GDP both directly as well as indirectly through its negative effect on energy consumption.

Results of our inequality equation regressions show that GDP does not have a significant effect on inequality. We therefore do not find evidence in support of an inverted-U Kuznets curve in Iran. Moreover, this suggests that economic growth does not benefit poor people. In contrast, energy consumption tends to decrease inequality. Thus, while energy consumption may directly decrease inequality, contrary to the previous literature and the hypothesis we developed based on the previous literature, energy consumption does not also indirectly decrease inequality through its effect on GDP, since GDP does not have a significant effect on inequality.

Our result that GDP does not have a significant effect on inequality is in contrast to the previous literature that has posited a possibly inverted-U Kuznets curve relationship between GDP per capita and inequality (Kuznets, 1955; Ahluwalia, 1976; Anand and Kanbur, 1993a; Anand and Kanbur, 1993b; Ngepah, 2011; Kanbur, 2019).

Results of our poverty equation estimation shows that inequality increases poverty while energy consumption decreases poverty. Thus, when combined with our result from our energy demand estimation, we find that inequality can increase poverty both directly as well as indirectly through its negative effect on energy consumption. In addition, when combined with our result from our inequality equation estimation, we find that energy consumption decreases poverty both directly and as well as indirectly via its effect on decreasing inequality.

While the previous literature on poverty has focused primarily on financing, asset accumulation, health, nutrition, and the education system as important factors in the poverty reduction process (Barrett, Garg and McBride, 2016; Barrett, Carter and Chavas, 2019), our results show that energy and access to energy may be important for decreasing poverty as well.

Although redistributing wealth and helping the poor are among the primary reasons for Iran's energy subsidies (Kheiravar and Lin Lawell, 2020), our results also show that Iran's energy subsidies have mixed effects on inequality and poverty. Energy subsidies therefore do not lead to the intended wealth redistribution, and the benefits may instead to go mainly to the wealthy.

Thus, we find several key results. First, inequality has several adverse consequences. Inequality can negatively affect GDP both directly as well as indirectly through its negative effect on energy consumption. In addition, inequality can increase poverty both directly as well as indirectly through its negative effect on energy consumption. Thus, decreasing inequality will be beneficial for economic growth, poverty alleviation, and energy access.

Second, increasing energy consumption has multiple benefits: it increases GDP, tends to decrease inequality, and decreases poverty. Energy increases GDP because different economic sectors of the country require increasing energy consumption in order to increase production. Energy consumption directly decreases inequality, but, contrary to the previous literature and our hypothesis, energy consumption does not also indirectly decrease inequality through its effect on

GDP, since GDP does not have a significant effect on inequality. Increasing energy consumption can decrease poverty both directly as well as indirectly via its effect on decreasing inequality.

Our results have important implications for policy both in Iran and worldwide. First, given that energy consumption is one of the factors needed to increase economic growth, reduce poverty, and reduce inequality in the country, it is important to improving access to energy at the microeconomic level through policies for increasing households' access to energy, especially in areas where do not have access to different forms of energy. Second, at the macroeconomic level, policies such as investing in different sectors of the country in the field of renewable energy and in appropriate infrastructure to generate renewable energy will be important as well.

A third policy implication is that, given the positive impact of energy consumption on poverty alleviation in the service sector, our results suggest that energy policies in this sector should not reduce the energy consumption of households through preventing the consumption of energy, but should instead provide the necessary background and investment for households to access the necessary equipment and facilities for the optimal use of energy. Thus, countries should consider policies that increase energy access and facilitate the efficient and optimal use of energy while preventing the harmful effects of inefficient and dirty sources energy. These policies may include, for example, instituting standards for energy consumption labels; conducting building energy audits; establishing and developing a National Energy Saving Laboratory; optimizing energy and load management in industries; and providing optimal consulting software as well as training and information.

Our research points to several potential avenues for future research. First, the framework and empirical model we have developed for analyzing the relationships among energy consumption, economic growth, inequality, and poverty can be applied to other countries, including other oil-rich developing countries in the Middle East, as well as more resource-scarce developing countries, to examine whether the patterns we have found for Iran apply to other oil-rich developing countries, and whether they apply to developing countries more generally, even those that are not oil-rich.

Given our result that energy consumption increases GDP, tends to decrease inequality, and decreases poverty, a second potential avenue for future research is to compare the effectiveness, efficiency, and cost-effectiveness of policies aimed to decrease inequality and poverty directly compared to policies that aim to increase energy access. A third potential avenue for future research is to examine the design of policies for increasing energy access to the poor in Iran and elsewhere.

Our results regarding the relationships among energy consumption, economic growth, inequality, and poverty have important implications for policy both in Iran and worldwide.

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Table 1: Summary statistics for poverty and inequality indexes, 1989-2018

Variable name	# Observations	Mean	Std. Dev.	Maximum	Minimum
Gini coefficient	30	0.463	0.017	0.49	0.428
Atkinson 1	30	0.313	0.02	0.348	0.271
Atkinson 2	30	0.535	0.083	0.52	0.461
Atkinson 0.5	30	0.176	0.013	0.197	0.15
Poverty incidence	30	0.257	0.154	0.52	0.127
Poverty intensity	30	0.096	0.077	0.36	0.036
Poverty severity	30	0.049	0.047	0.222	0.015
Theil index	30	0.402	0.037	0.475	0.33

Data Source: Statistical Center of Iran

Table 2: Summary statistics for whole economy, 1989-2018

Variable name	# Observations	Mean	Std. Dev	Maximum	Minimum
GDP (Billion Rial)	30	288474.7	18580.1	539219.3	170281.2
Total Energy consumption (MBOE)	30	50716.39	19570.67	85624.64	16719.63
Gasoil consumption (MBOE)	30	18243.57	7252.535	29454.39	4707.243
Kerosene consumption (MBOE)	30	7750.138	1884.226	10880	3787
Fuel oil consumption (MBOE)	30	7381.165	1903.839	10937.74	2967.47
Gasoline consumption (MBOE)	30	11860.2	7300.63	26866.97	2346.23
Electricity consumption (MBOE)	30	66845.84	51105.42	184179.4	9152
Natural gas consumption (MBOE)	30	24.44375	26.19945	88.52592	0.993712
GDP per capita (Billion Rial)	30	0.020432	0.002741	0.027539	0.015564
Capital stock per capita (Billion Rial)	30	0.078133	0.008289	0.092346	0.048936
Per capita energy subsidy (Billion $)	30	1.17E-06	1.01E-06	3.11E-07	4.75E-06
Ratio of government spending to GDP	30	0.166665	0.052139	0.268645	0.094987

Notes: Energy consumption is in units of Million Barrel of Oil Equivalent (MBOE). GDP and value added for all sectors are in billions of constant 2000 Iran Rial.

Data Sources: Iran's Annual Energy Balance; Central Bank of Iran

Table 3: Summary statistics for agriculture sector, 1989-2018

Variable name	# Observations	Mean	Std. Dev	Maximum	Minimum
Total Energy consumption (MBOE)	30	3843.005	865.656	5135.121	1630.819
Gasoil consumption (MBOE)	30	3139.463	1061.684	4491.322	891.2373
Kerosene consumption (MBOE)	30	185.8317	3.639411	343.4873	19.257
Fuel oil consumption (MBOE)	30	0.817108	7.320953	21.546	0
Gasoline consumption (MBOE)	30	11.98028	7003.156	36.575	2.87576
Electricity consumption (MBOE)	30	6884.197	7003.156	24188.8	267
Natural gas consumption (MBOE)	30	34.84949	103.317	422.59	0
Per capita value added (Billion Rial)	30	0.011308	0.004420	0.023218	0.004684
Capital stock (Billion Rial)	30	36969.36	18241.51	85593.41	17207.1
Per capita Capital stock (Billion Rial)	30	0.011166	0.005225	0.028044	0.005478

Notes: Energy consumption is in units of Million Barrel of Oil Equivalent (MBOE). GDP and value added for all sectors are in billions of constant 2000 Iran Rial.

Data Sources: Iran’s Annual Energy Balance; Central Bank of Iran

Table 4: Summary statistics for industrial sector, 1989-2018

Variable name	# Observations	Mean	Std. Dev	Maximum	Minimum
Total Energy consumption (MBOE)	30	7277.11	2035.046	11601.42	3273.327
Gasoil consumption (MBOE)	30	1829.466	823.2865	3322.169	444.5588
Kerosene consumption (MBOE)	30	84.73245	37.81522	147.5636	20.306
Fuel oil consumption (MBOE)	30	4967.07	1366.157	7259.408	1906.93
Gasoline consumption (MBOE)	30	39.16453	16.7868	83.767	10.26033
Electricity consumption (MBOE)	30	20990.75	16784.52	61186	5001
Natural gas consumption (MBOE)	30	6460.797	5023.03	19928.43	869.2193
Value added (Billion Rial)	30	58918.43	36970.66	149187.7	21366.31
Per capita value added (Billion Rial)	30	0.023852	0.007388	0.045803	0.014114
Capital stock (Billion Rial)	30	136454.5	78437.93	345910.8	45945
Per capita Capital Stock (Billion Rial)	30	0.057017	0.016012	0.106199	0.030350

Notes: Energy consumption is in units of Million Barrel of Oil Equivalent (MBOE). GDP and value added for all sectors are in billions of constant 2000 Iran Rial.

Data Sources: Iran's Annual Energy Balance; Central Bank of Iran

Table 5: Summary statistics for service sector, 1989-2018

Variable name	# Observations	Mean	Std. Dev	Maximum	Minimum
Total Energy consumption (MBOE)	30	13652.29	3598.398	19622.31	5847.405
Gasoil consumption (MBOE)	30	2395.468	837.0874	3483.58	692.4171
Kerosene consumption (MBOE)	30	7456.757	1833.697	10388.99	3616.081
Fuel oil consumption (MBOE)	30	2022.279	625.0633	3191.643	1000.222
Gasoline consumption (MBOE)	30	83.44525	32.3602	135.122	22.06855
Electricity consumption (MBOE)	30	38933.48	27529.9	98505.1	3884
Natural gas consumption (MBOE)	30	14222.84	16081.02	47072.77	124.4924
Value added (Billion Rial)	30	154022.4	54565.08	281201.5	86641.69
Per capita value added (Billion Rial)	30	0.026599	0.006785	0.043398	0.019046
Capital stock (Billion Rial)	30	454442	180942.6	763964.7	147277.9
Per capita Capital Stock (Billion Rial)	30	0.073909	0.009466	0.092352	0.054135

Notes: Energy consumption is in units of Million Barrel of Oil Equivalent (MBOE). GDP and value added for all sectors are in billions of constant 2000 Iran Rial.

Data Sources: Iran's Annual Energy Balance; Central Bank of Iran

Table 6: Economy-wide 2SLS and 3SLS estimation results

Type of energy	Total Energy		Gasoil		Kerosene		Fuel oil		Gasoline		Electricity		Natural gas	
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS	2SLS-	3SLS	2SLS	3SLS
Production function *Dependent variable is GDP*														
Log inequality index		-		-										-
Log energy	+	+	+	+	+	+	+	+		+	+	+	+	+
Log per capita capital stock	+	+	+	+	+	+	+		+					
Energy demand *Dependent variable is Energy consumption*														
Log inequality index		-							+	+				-
Log per capita GDP	+	+	+	+	+	+			+	+	+	+	+	+
Log price	-	-	-	-	-	-	-	-	-	-			-	-
Inequality equation *Dependent variable is Inequality index*														
Log per capita GDP		+												+
(Log per capita GDP)^2														
Log ratio of government spending to GDP														
Log per capita energy subsidy	-	-		-		-		-	+	-		-		-
Log per capita energy		-	-	-	-		-		-	+	-	-	-	-
Poverty equation *Dependent variable is Poverty index*														
Log inequality index	+	+	+	+	+	+	+	+			+	+	+	+
Log energy	-	-		-	-	-			-	-	-	-	-	-
Log per capita capital stock	-	-	-	-	-	-	-	-	-	-				-
Log per capita energy subsidy	+								+	+		-		

Notes: This table summarizes the results of our economy-wide 2SLS and 3SLS regressions. A "+" indicates that most of the coefficients on that regressor are significant at a 5% level and positive when using different inequality indices and different poverty indices; a "-" indicates that most of the coefficients are significant at a 5% level and negative; and a blank cell indicates that most or all of the coefficients are not significant at a 5% level.

Table 7: Sector-wise 2SLS and 3SLS estimation results

	Agricultural sector		Industrial sector		Service sector	
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Production function *Dependent variable is Value added*						
Log inequality index		-	-	-		-
Log energy	+	+	+	+	+	+
Log per capita capital stock	+	+	+	+		+
Energy demand *Dependent variable is Energy consumption*						
Log inequality index	-	-				-
Log per capita GDP	+	+	+	+	+	+
Log energy price			-		-	-
Inequality equation *Dependent variable is Inequality index*						
Log per capita GDP						
$(\text{Log per capita GDP})^2$	-					
Log ratio of government spending to GDP						
Log per capita energy subsidy		-				-
Log per capita energy	-	-			-	-
Poverty equation *Dependent variable is Poverty index*						
Log inequality index			+	+	+	+
Log energy						-
Log per capita capital stock	-	-	-	-	-	-
Log per capita energy subsidy	-	-				-

Notes: This table summarizes the results of our 2SLS and 3SLS regressions by sector. A "+" indicates that most of the coefficients on that regressor are significant at a 5% level and positive when using different inequality indices and different poverty indices; a "-" indicates that most of the coefficients are significant at a 5% level and negative; and a blank cell indicates that most or all of the coefficients are not significant at a 5% level. For each sector, we use value added in that sector as our measure of GDP.