# A Computable General Equilibrium Model of International Sanctions

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**Abstract**

We detail recent international sanctions against the Iranian economy and its government imposed by a subset of developed countries. The effects of these sanctions on the Iranian economy in general and upon upper- and lower-income rural and urban Iranian households, as well as the Iranian government, are modelled using a Computable General Equilibrium (CGE) model which uses endogenous trade taxes to simulate the effects of sanctions on Iranian oil exports and Iranian imports of petroleum products. The model is calibrated to simulate the effects of international sanctions as closely as possible. Results suggest that sanctions on Iranian oil exports had a serious negative effect on the Iranian government budget but much more limited effects on the well-being of Iranian rural and urban households.

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# 1 Introduction

International sanctions have become an important tool of developed market economies for use against a target country to pursue various foreign policy goals. According to Hufbauer et al. (2007), economic sanctions "mean the deliberate, government-inspired withdrawal, or threat of withdrawal, of customary trade or financial relations". International economic sanctions are known as a less expensive alternative to military intervention (Kaempfer and Lowenberg, 2007). According to data from the Institute for International Economics (2002), there were only five countries affected by economic sanctions in 1950s. This number increased to 47 in 1990s. Advocates of sanctions believe that economic pressures can be effective in altering the target country's policies without military intervention (Baldwin, 1985). However, others argue that sanctions on a target country have not resulted in anticipated outcomes while imposing considerable costs on citizens who have little influence on the behaviour of their governments (Drezner, 1999; Elliott, 1998; Hufbauer et al., 1990; Pape, 1997).

While the main goal of economic sanctions is to interrupt a target country's economic and diplomatic relations in order to alter its political and military behaviour, these measures are increasingly being employed against weaker and more dependent nations without full consideration of their impact on the welfare of citizens in these countries, particularly vulnerable groups of households. In the literature of sanctions, the unintended economic impacts of sanctions on citizens of sanctioned countries have always been a major source of concern. Scholars argue that broad economic sanctions unintentionally damage the well-being of citizens in targeted countries, by deteriorating the quality and access to education and public health care services and worsening their economic conditions (Cortright et al., 2001; Drury and Li, 2006; Galtung, 1967; Lopez and Cortright, 1997; Weiss, 1999; Weiss et al., 1997). As a dramatic example, Pape (1998) argues that comprehensive UN sanctions imposed on Iraq in the 1990s had devastating humanitarian consequences, causing the deaths of over 560000 Iraqi children from hunger while significantly reducing Iraq's GDP.

There is considerable evidence that economic sanctions aimed at imposing hardships on the economy of a target country can severely disrupt economic activities in sanctioned sectors and consequently restrict economic growth in the sanctioned country (Andreas, 2005; Crawford and Klotz, 1999; Dizaji and van Bergeijk, 2013; Heine-Ellison, 2001; Hufbauer et al., 2007; Jacobson, 2008; Neumeier and Neuenkirch, 2014; Nossal, 1989). Kaempfer and Lowenberg (2007) note that there is "no doubt that embargoes or restrictions on flows of goods and capital impose welfare costs on the target economy". While there have been some studies which have estimated the aggregate effects of sanctions on target countries, few have employed economic models to estimate the welfare losses imposed by economic sanctions on different economic agents and households in sanctioned countries.

Over the past three decades, an enormous amount of effort has been expended by the United States (arguably the most prominent actor on the sanctions scene) to induce the international community to develop a sanctions policy against Iran due to concern over attempts by Iran to develop weapons of mass destruction and humanitarian concerns. In recent years, severe economic sanctions have been imposed by the US and the European Union (EU) on Iran's economy in an attempt to discourage the government of Iran from continuing to engage in the development of a nuclear weapons capability (Abrams et al., 2012; O'Sullivan, 2010; Schott, 2012). This article seeks to analyse the welfare impact of comprehensive economic sanctions on Iran's economy in general, on the government of Iran and on households of different socio-economic backgrounds, especially those from the lower and middle classes of society.

This study makes a number of contributions to the literature on models which evaluate the effects of international economic sanctions imposed by developed economies on an oil exporting country in general, and on welfare impacts of these sanctions on each economic agent and on different income groups of Iranian rural and urban households in particular. We use a Computable General Equilibrium (CGE) model with data on production, consumption and trade from the Global Trade Analysis Project (GTAP), a popular CGE model used extensively in such exercises. The model uses endogenous trade taxes to simulate the effects of sanctions on Iranian oil exports and Iranian imports of petroleum products. We augment the GTAP8 dataset with information from the Statistical Centre of Iran (SCI) to produce a microconsistent CGE model with 20 urban and rural households disaggregated by income level. This allows us to provide a more accurate representation of the ownership of factors of production by different households and the government of Iran. The model is calibrated to simulate the effects of international sanctions as closely as possible.

The paper proceeds as follows. Section 2 gives a summary of international sanctions against Iran, including a description of the sectors of the Iranian economy which have been most strongly affected. The dataset, production technology and utility functions which comprise the CGE model of Iran are described in Section 3. This includes a description of the aggregation of the GTAP8 data base, as well as detailed descriptions of the necessary modifications to the GTAP8 data base, including the disaggregation of private demand to ten urban and ten rural consumer groups, using information from the Statistical Centre of Iran. Section 4 reports and interprets quantitative estimates of the effects of economic sanctions on the Iranian government budget and the well-being of Iranian rural and urban households. Simulations demonstrating the sensitivity of results to exogenously specified parameters in the CGE model including domestic/import (Armington) substitution elasticities and the intersectoral mobility of capital used to produce oil in Iran are presented in Section 5, while Section 6 concludes.

# 2 International Sanctions and the Iranian Economy

The Iranian economy has been exposed to ongoing political and economic sanctions by the United States, including trade and financial sanctions since Iran's 1979 Islamic revolution. But the goals of U.S. sanctions policy against Iran have changed over time. According to Katzman (2013), U.S. economic sanctions in the mid-1980s were aimed at limiting Iran's strategic power in the Middle East in general, and forcing Iran to stop supporting terrorism in particular. Since the mid-1990s, U.S. sanctions have targeted Iran's petroleum sectors and nuclear program with the objective of weakening Iran's economy. In the meantime, European nations refused to follow U.S. policy to impose economic sanctions against Iran (Pollack and Takeyh, 2005). In 1996, the U.S. Senate approved the "Iran and Libya Sanctions Act" (ILSA), prohibiting foreign investment in any oil and gas development projects in Iran of over $40 million during any 12-month period (Hufbauer et al., 2012). In spite of ongoing sanctions imposed by the U.S. on economic sectors in Iran that contributed to the proliferation of sensitive nuclear and missile programs, and despite international opposition, Iran has nonetheless developed its missile and nuclear programs with major assistance from the Russian government (Ataev, 2013).

The ILSA ran for five years and was twice renewed by the U.S. Senate, in 2001 and 2006. Over those fifteen years, the ILSA combined with other problems in the Iranian economy including economic mismanagement to produce a considerable drop in the growth of Iranian oil production (Schott, 2012). The European Union (EU) joined the U.S. in imposing economic sanctions against Iran from 2006 as a result of Iran's contentious nuclear program. Since 2010, the EU sanctions have mainly targeted the oil and gas, transportation and financial and insurance sectors in the Iranian economy (Patterson, 2013). In 2010, the Iran Sanctions Act of 1996 was substantially amended and expanded into the Comprehensive Iran Sanctions Accountability and Divestment Act (CISADA), limiting the sale of gasoline, other petroleum products as well as refinery-related equipment to Iran (Hufbauer et al., 2012; Katzman, 2014). Many other countries including Australia, Canada, Japan, South Korea and Switzerland have adopted economic sanctions against Iran due to its nuclear ambitions from 2010.

The U.S. and the EU launched a new series of tough energy sanctions against Iran in late 2011 and early 2012. The main objective of these sanctions was to discourage Iran from developing its nuclear program by reducing Iran's oil-export revenues. Both politicians and oil-market experts initially believed that the new U.S. and EU sanctions which targeted Iranian exports of petroleum, natural gas, oil and chemicals would not force Iran to slow down the progress of its nuclear program since they would not significantly shrink Iran's oil exports (Van de Graaf, 2013). However, reports by the International Energy Agency in early 2013 (IEA, 2013) and Iran's oil minister revealed that Iran's oil exports fell by 40 percent from 2011 levels, and Iran's oil-export revenues dropped by over $40 billion in 2012 because of new sanctions. Table 1 highlights the effectiveness of these expanded international sanctions against the Iranian oil sector.

| | Oil exports by destination | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | World | Europe | Asia and Pacific | Africa | Oil Prod'n | Petrol Prod'n | Gas Prod'n |
| 2007 | 2639 | 847 | 1469 | 148 | 4030.7 | 1498.0 | 111900 |
| 2008 | 2574 | 749 | 1542 | 147 | 4055.7 | 1587.0 | 116300 |
| 2009 | 2406 | 568 | 1538 | 127 | 3557.1 | 1726.1 | 175742 |
| 2010 | 2583 | 878 | 1571 | 134 | 3544.0 | 1743.3 | 187357 |
| 2011 | 2537 | 741 | 1392 | 127 | 3576.0 | 1748.7 | 188753 |
| 2012 | 2102 | 162 | 1839 | 101 | 3739.8 | 1811.9 | 202431 |
| 2013 | 1215 | 128 | 1085 | 2 | 3575.3 | 1918.4 | 199293 |

Source: OPEC "Annual Statistical Bulletin", various years

Table 1: Iran – Oil Exports and Energy Production (1000b/d, except Gas, 1000000 cu m)

In early 2012, the U.S. enacted a new generation of financial sanctions against Iran's Central Bank, restricting Iran's ability to use the international financial system. The new financial sanctions produced a serious problem for the Iranian government for both non-oil transactions as well as oil-related transactions between the Central Bank of Iran and any foreign financial institutions (Farzanegan, 2011). These new financial sanctions successfully forced Iran to agree to receive payment for oil in either the national currencies of oil importing countries or gold (Katzman, 2012).

In July 2012, the EU imposed an embargo on the import, purchase and transport of Iranian crude oil (Katzman, 2013). As a result, EU oil imports from Iran which had accounted for more than a quarter of Iran's oil exports (see Table 1) fell dramatically. This EU ban started a new phase of sanctions against Iran. The EU also decided to ban European insurance companies for shipping oil and petrochemical products from Iran. The EU financial sanctions came into force in October 2012, banning the provision of financial communication services with the Central Bank of Iran, except for humanitarian transactions with Iranian banks (Farzanegan, 2011).

## 2.1 Impacts of International Sanctions on Iran's economy

Before describing the general equilibrium model used to study the effects of international sanctions on Iran's economy in general, and on the government budget and the welfare of different income groups of households in particular, it is important to evaluate Iran's economic structure and its development planning. Therefore, this Section provides a brief background on certain macro-economic variables and key economic sectors of Iran's economy, and the impacts of international sanctions on these sectors.

Iran has a population of more than 77 million (increased from 75 million in 2013), the second largest in the Middle East and North African region after Egypt (World Bank, 2014). Urban areas are heavily populated, accounting for 70 percent of the Iranian population (United Nations, 2013). Since 1979, Iran has endured almost two decades of revolution, war and reform as well as international pressures which brought about considerable socio-economic disruption, heavy military and civilian casualties, and a drop in the production and export of energy commodities. Over the past three decades, the burden of the eight-year war, a drop in domestic production in the 1980s and massive shortages in fuels, medicines and necessities, high inflation as well as increasing speculation and a growing black market all combined to produce strong grounds for direct government intervention in Iran's economy (Esfahani and Pesaran, 2009). Energy commodities and other sizable industries and enterprises are under the control of the state, while the private sector has a negligible authority to run small businesses (Esfahani et al., 2013).

From the beginning of 2002, the Iranian government committed itself to implementing trade reforms, exchange rate unification, ratification of the law on foreign investment, the licensing of three private banks and tax reform, intended to adjust distortions and structural imbalances. The government in Iran has since launched several market-oriented reforms aimed at reversing the recent downward economic spiral. However, international sanctions combined with years of government mismanagement and widespread corruption have left the economy vulnerable to very high inflation and negative growth rates (Hufbauer and Schott, 2006; Katzman, 2013; Plaut, 2013; IMF, 2014). For instance, the Statistical Centre of Iran (SCI) reported that the inflation rate in Iran reached 35 percent in December 2013, and the economy faced an unemployment rate of around 13 percent. Both international sanctions and the elimination of food and energy subsidies in recent years have been the likely cause of high inflation in Iran. Devarajan and Mottaghi (2014) note that the economy of Iran has experienced negative growth rates of -3.0 and -2.1 percent for 2012 and 2013 respectively. Since the tightening of energy and financial sanctions against Iran in 2012, the Iranian currency (Rial) lost more than 80% of its exchange value (Monshipouri and Dorraj, 2013).

## 2.2 Iran's Energy Sector under International Sanctions

According to CBI (2010), the oil and gas sector dominated the economy of Iran, accounting for an estimated 90 percent of foreign exchange revenues and providing 60 percent of government earnings in fiscal year 2008-2009. Iran possesses the world's second largest natural gas reserves and the fourth largest proven oil reserves (IEA, 2012). Even though Iran boasts vast gas resources, the country has been incapable of becoming a leading global gas exporter because natural gas produced by the underdeveloped sector is mostly used to meet domestic demand. In 2010, 59 percent of Iran's total domestic energy consumption came from natural gas (U.S. Energy Information Administration, 2013).

In recent years, the undermining of Iran's sources of government revenue has been the main goal of the international sanctions imposed on Iran's economy so as to discourage the development of its nuclear program. Iran's oil and gas sectors, which make up the major share of government revenue, have been a major target of the latest international economic sanctions against Iran. According to U.S. Energy Information Administration (2013), the toughening of sanctions against Iran in 2012 resulted in a 40 percent decrease in Iran's oil exports, though Iran was still producing 3.5 million bpd over the period of 2012-2013, with the unsold crude oil being stockpiled in onshore and floating storage (International Energy Agency, 2012, 2013). Prior to 2010, Iran had stockpiled crude oil in floating storage in order to increase profits from the world energy market. However, since 2010 there has been a correlation between Iran's floating oil storage and the toughening of sanctions against Iran's energy sector (Lee, 2004; Mann, 2013; EIA, 2011). According to IEA (2013), estimates of Iran's crude oil stockpile in floating storage in 2013 were around 20-25 million barrels. Estimates also show that Iran has a total onshore storage capacity of 25 million barrels, and that most of this capacity is filled (IEA, 2013).

According to Hufbauer et al. (2012), the average welfare loss caused by the U.S. sanctions on Iran was around \$80 million over the period 1984-2005, less than one percent of the Iranian GDP in the same period. Over the period of 2006-2012, the international sanctions against Iran produced an average welfare loss of \$5.7 billion, equivalent to about 1 to 3 percent of Iranian GDP (Hufbauer et al., 2012). While few studies have employed economic models to evaluate the socio-economic impacts of international sanctions on Iran, to our knowledge, no studies have analysed the economic impacts of these sanctions on separate economic agents in general, and on different income groups of rural and urban households in particular. To our knowledge no other studies have used a CGE model to take account of the general equilibrium effects of international sanctions on all inter-related sectors of the Iranian economy. Since the impact of the U.S., EU and UN trade and financial sanctions against Iran on needy and vulnerable households in Iran is a source of concern, this study specifically attempts to evaluate the welfare impacts of international sanctions on 20 Iranian household types in rural and urban areas, grouped according to income, along with their effect on the Iranian government.

# 3 Data and CGE Model

We begin with a brief description of the relevant data which characterize multilateral sanctions applied to trade with Iran, and detail how these sanctions are reflected in the general equilibirum dataset. We then describe the Computable General Equilibrium (CGE) model which is used to generate the counterfactual results for different levels of multilateral sanctions on trade with Iran.

## 3.1 Data

We begin with version 8 of the GTAP dataset which depicts a global general equilibrium of production, consumption, and trade for 129 countries/regions and 57 commodities produced using 5 primary factors of production and intermediate inputs for the year 2007, described in Narayanan *et al* (2012). We aggregate GTAP regions into three separate regions: Iran, a single aggregate of all countries/regions which apply sanctions on trade with Iran ('SAN'), and an aggregate rest-of-world ('ROW') of all remaining regions. Given the description of international sanctions on trade with Iran in Section 2, the aggregate region 'SAN' of countries applying sanctions on trade with Iran includes:

> Canada, the United States, Mexico, Central America, Australia, New Zealand, Japan, Republic of Korea, China, Hong Kong, Taiwan, Malaysia, Singapore, India, Sri Lanka, the 28 EU countries, South Africa

The commodity aggregation is presented in Table 2 and is constructed to allow us to reflect multilateral sanctions as accurately as possible, and to accommodate disaggregation of private consumption using information from the Urban and Rural Household Income and Expenditure Survey from the Statistical Center of Iran (SCI) (Statistical Centre of Iran, 2005). Commodities in Table 2 with an $^x$-superscript (oil, petroleum products, metals) are those where sanctions are applied on Iranian exports to 'SAN' countries, while commodities with an $^m$-superscript (petroleum products, metals, motor vehicles) are those where sanctions are applied on Iranian imports from 'SAN' countries.

To highlight how the economies of Iran and the two aggregated regions differ, Table 3 shows output value shares using the commodity aggregation detailed in Table 2. Economic activity in Iran has long been dominated by the oil sector, and before their recent reform in 2010, large state fuel subsidies resulted in a petrol sector which is considerably larger (as a share of the value of output) than that in other regions (see Gharibnavaz and Waschik (2014)). As a result, the share of output accounted for by the manufacturing and service sectors is notably smaller in Iran.

## 3.2 CGE Model

Since international sanctions on trade with Iran focus on oil and petrochemical products, we adopt a specification of the demand side of the CGE model which follows that in other studies which focus on energy markets like the GTAP-E model (see Burnieaux and Truong, (2002), Rutherford and Paltsev (2000) and Fischer and Fox (2007)). For each region private and public demand derives from the maximization of a CES function of an aggregate 'energy' good and an aggregate 'non-energy' good, with a CES substitution elasticity $\sigma = 0.5$. The 'energy' aggregate is a Cobb-Douglas function of energy goods (coal, oil, gas, petrol, electricity, gas distribution), while the 'non-energy' aggregate is a Cobb-Douglas function of the remaining commodities. For the aggregated regions of sanction countries 'SAN' and the rest of the world 'ROW', real aggregate public demand is fixed. A single representative agent owns all primary factors of production, and all tax revenue is assumed to be costlessly collected and redistributed to this representative

| | |
|---|---|
| Sector | GTAP8 Sectors (sector code) |
| Wheat | Wheat (wht), Cereal Grains (gro), Plant-based Fibers (pbf) |
| Milk | Milk (rmk) |
| Meat | Cattle, Sheep, Goats, Horses (ctl), Fishing (fsh), Cattle, Sheep, Goats, Horse (cmt), Meat Products (omt) |
| Vegetable oil | Oil Seed (osd), Vegetable Oils and Fats (vol) |
| Dairy products | Animal Products (oap), Dairy Products (mil) |
| Sugar | Sugar (sgr) |
| Primary agricultural products | Paddy Rice (pdr), Vegetables, Fruits and Nuts (v_f), Sugar cane and Sugar beet (c_b), Crops (ocr), Wool, Silk-worm Cocoons (wol) |
| Processed agricultural products | Processed Rice (pcr), Food Products (ofd), Beverages and Tobacco Products (b_t) |
| Coal | Coal (coa) |
| Oil$^{x}$ | Oil (oil) |
| Gas | Gas (gas), Gas manufacture, distribution (gdt) |
| Electricity | Electricity (ely) |
| Petroleum products$^{x,m}$ | Petroleum and Coal Products (p_c) |
| Metals$^{x,m}$ | Chemical, rubber, plastic prods (crp), Mineral products n.e.c. (nmm), Ferrous metals (i_s), Metals n.e.c. (nfm), Metal products (fmp) |
| Motor Vehicles$^{m}$ | Motor vehicles and parts (mvh) |
| Manufactures | Forestry (frs), Minerals n.e.c. (omn), Textiles (tex), Wearing apparel (wap), Leather products (lea), Wood products (lum), Paper products, Publishing (ppp), Transport equipment n.e.c. (otn), Electronic equipment (ele), Machinery and equipment n.e.c. (ome), Manufactures n.e.c. (omf) |
| Transport services | Transport n.e.c. (otp), Sea Transport (wtp), Air Transport (atp) |
| Services | Water (wtr), Construction (cns), Trade (trd), Communication (cmn), Financial services n.e.c. (ofi), Insurance (isr), Business services n.e.c. (obs), Recreation and other services (ros), PubAdmin/Defence/Health/Educat (osg), Dwellings (dwe) |

Table 2: Sectors in Aggregated GTAP8 Data Base

| Sector | Iran | Sanction Countries | Rest of World |
|---|---|---|---|
| Wheat and Cereal Grains | 1.5 | 0.3 | 0.9 |
| Raw Milk | 1.1 | 0.2 | 0.6 |
| Meat | 1.0 | 0.9 | 2.1 |
| Vegetable Oil | 0.4 | 0.3 | 0.8 |
| Dairy | 2.1 | 1.0 | 1.4 |
| Sugar | 0.1 | 0.1 | 0.3 |
| Other Primary Agriculture | 2.2 | 0.9 | 2.5 |
| Other Processed Agriculture | 2.7 | 2.7 | 3.7 |
| Coal | 0.0 | 0.2 | 0.3 |
| Oil | 21.1 | 0.4 | 6.5 |
| Gas | 2.7 | 0.3 | 1.7 |
| Electricity | 3.5 | 1.8 | 2.7 |
| Petrol | 9.3 | 2.5 | 3.6 |
| Metal Products | 6.5 | 10.1 | 9.2 |
| Motor Vehicles | 2.5 | 3.1 | 1.8 |
| Manufactures | 4.4 | 15.1 | 11.6 |
| Transport | 4.9 | 4.9 | 5.9 |
| Services | 34.0 | 55.3 | 44.5 |

Table 3: Output Value Shares from GTAP8 Dataset (2007)

consumer.

But many features of the international sanctions applied to trade with Iran and of the Iranian economy in general make it inappropriate to adopt such a structure for private and public demand in Iran. The stated objective of sanctions is to affect the behaviour of the government in Iran, so we cannot exogenize real aggregate public demand in Iran. We also need to model the distribution of the ownership of factors of production in Iran so that it reflects the reality of factor ownership in Iran. We assume that the government owns all Natural Resources, and earns all rents generated by capital employed in the energy sectors in Iran. Private consumers earn all income generated from the use of Land and Labour, and also earn all income from capital usage, except for capital used in the energy sectors. This reflects the reality in Iran where the government earns all income from value added except labour in energy sectors. In Iran, all tax revenue accrues to the government. Government revenue is used to fund (exogenous) investment and to purchase services, primarily education, health care and defense. Since the government in Iran earns such a large share of its revenue from rents accruing to the oil sector and since international sanctions have effectively targeted Iranian oil exports, government revenue (and hence government expenditure and 'welfare') will respond endogenously to the imposition of international sanctions.

We are also interested in the distributional consequences of the application of international sanctions in Iran, since it is often argued that sanctions impose a significant burden on private consumers and can disproportionately affect low-income or disadvantaged consumers. As such, it is necessary to disaggregate private consumption in Iran. To capture the disparate effects of international sanctions on low and high income consumers, and to reflect the fact that sanctions could have different effects on urban versus rural consumers, we disaggregate private consumption in Iran into ten rural and ten urban consumption groups. This requires us to disaggregate both private income and expenditure for Iran in the GTAP8 dataset. To disaggregate private expenditure, we use the Income and Expenditure Survey published by the Statistical Centre of Iran (SCI) (2005) to calculate expenditure shares $\theta_{i,h,n}$ at different income deciles $n \in (1, 2, \ldots, 10)$ of households $h \in (urban, rural)$ which are consistent with the 17 aggregated commodities $i$ in Table 2. These are reported in Tables A1 and A2 of Gharibnavaz and Waschik (2014). We also use the SCI Income and Expenditure Survey to disaggregate income by household. The Survey includes information on all wages and salaries obtained from self-employment in agricultural and non-agricultural activities, private and public sector employment, and other income during the reference period. In the GTAP8 dataset, income earned by factor of production $f$ is reported in vector $vfm(f, i)$, for factors of production $f \in \{labour, capital, land, natural\ resources\}$. As noted earlier, all natural resource rents accrue to the government in Iran, as does income earned by capital employed in energy sectors. Remaining income is allocated to disaggregated urban and rural households using shares reported in Table A3 of Gharibnavaz and Waschik (2014), where income categories in the SCI Income and Expenditure Survey are matched to GTAP8 factors as follows:

Land: includes household income as employer or own account worker in agricultural sector after deduction of job on-costs, where on-costs include paid wage and salary, primary material charges, non-durable appliances, amortization, other production charges and job taxes.

Labour: includes all wage and salary income earned in public, cooperative and private sectors after deduction of tax and retirement allowances.

Capital: includes household income other than employment income, including that derived from the sale of home-made manufactures, retirement pensions, rental of movable and immovable assets, dividends, and charity and social security organization aids.

After disaggregating household income by source and household expenditure by commodity, the income equals expenditure constraint for each household will no longer be satisfied, because the accounting disaggregation does not take account of savings. Data on savings by households is not available from the Iranian Statistical Centre. To rebalance household accounts, we assign that share of aggregate savings to each household so that their income equals expenditure constraint is satisfied. Since the initial dataset is balanced, assigning the remaining savings to the government will then balance the government account. Private and government savings is assumed to be exogenous throughout. Allocating savings between households and the government in this way leaves the government in Iran with an 80% share of aggregate savings in the benchmark equilibrium.

For each of the 17 production sectors, production technology is represented with a series of nested CES production functions, as shown in Figure 1. For example, beginning at the bottom-most nest of Figure 1, the input 'liquid fuels' for any industry $i$ is produced as a CES aggregate of 'petrol' and 'gas' according to the CES production function:

$$Q_{liquidfuel,i} = \gamma^{i}_{liquidfuel} \left[ \alpha_{petrol,i} \cdot Q_{petrol,i}^{\frac{\sigma_{lqd}-1}{\sigma_{lqd}}} + (1 - \alpha_{petrol,i}) \cdot Q_{gas,i}^{\frac{\sigma_{lqd}-1}{\sigma_{lqd}}} \right]^{\frac{\sigma_{lqd}}{\sigma_{lqd}-1}} \tag{1}$$

where $\alpha_{petrol,i}$ is the value share of 'petrol' used in production of 'liquid fuel' in sector $i$. As shown in Figure 1, the aggregate 'liquid fuel' is then combined with 'coal' to produce an aggregate which includes all non-electric energy inputs, with a CES substitution elasticity $\sigma_{nel} = 0.5$. This structure for production and the central case values for the substitution elasticities in Figure 1 are similar to those used in other CGE models with disaggregated energy sectors (for example, see Rutherford and Paltsev (2000) and Fischer and Fox (2007), among others). Note that oil enters into production under the top-most nest with a substitution elasticity of zero: Virtually all oil is used in fixed coefficients in production of petrol.

To give a more intuitive idea of the implications of this method of specifying and calibrating consumption and production, note that the CES substitution elasticities in Figure 1 and the share parameters implied by the GTAP8 equilibrium dataset will imply demand elasticities for all commodities. For example, industry $i$'s own-price elasticity of demand for 'petrol' $\eta^{i}_{petrol}$ will be given by:

$$\eta^{i}_{petrol} = -\sigma_{lqd} - (1 - \sigma_{lqd}) \cdot \alpha_{petrol,i} + \alpha_{petrol,i} \cdot (1 + \eta^{i}_{non-electric}) \tag{2}$$

where $\eta^{i}_{non-electric}$ is industry $i$'s demand elasticity for aggregate 'non-electric' energy inputs, itself a function of the 'non-electric' substitution elasticity $\sigma_{nel}$ and shares in the

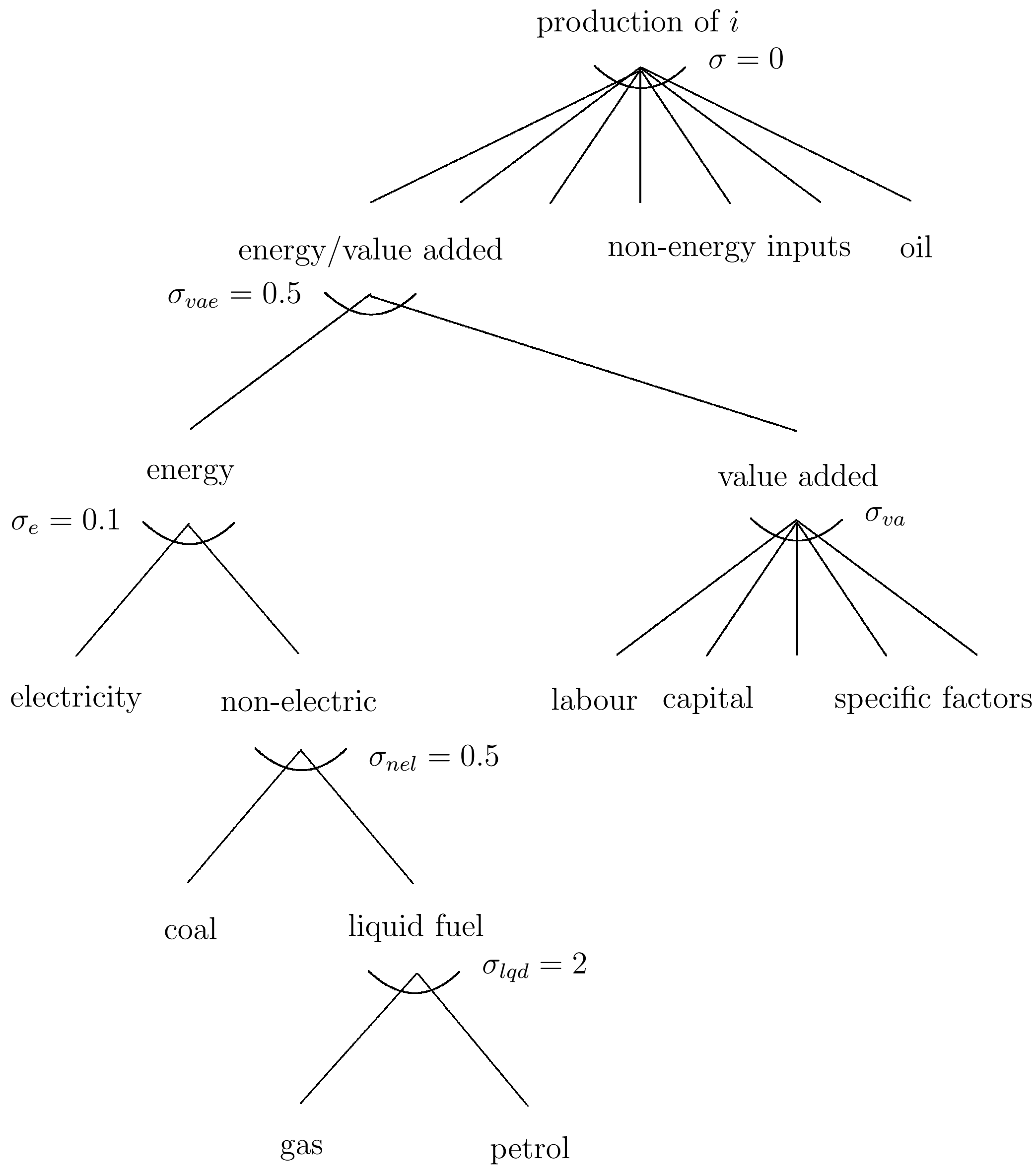


Figure 1: Structure of Production

nests above 'liquid fuel' in Figure 1. Similar expressions can be solved for the demand elasticities for all commodities in all nests in Figure 1 for all firms, and for public and private demand. The demand elasticities in each region will then be a share-weighted aggregate of these public, private and firm-level demand elasticities. Table 4 reports the demand elasticities for Iran and for the aggregate regions of sanction countries 'SAN' and the rest of the world 'ROW' for all aggregated commodities.[1]

In all regions, each agent's endowment of primary factors of production is assumed

[1]These demand elasticities are often approximated by the value of the substitution elasticity in the lowest nest (ie: $\eta_{petrol} \approx -\sigma_{lqd}$), a valid practice when shares like $\alpha_{petrol,i}$ are small and substitution elasticities in the higher nests like $\sigma_{nel}$ are close to Cobb-Douglas.

| Sector | Iran | Sanction Countries | Rest of World |
|---|---|---|---|
| Wheat and Cereal Grains | −0.567 | −0.155 | −0.335 |
| Raw Milk | −0.005 | −0.254 | −0.498 |
| Meat | −0.513 | −0.521 | −0.545 |
| Vegetable Oil | −0.525 | −0.264 | −0.398 |
| Dairy | −0.683 | −0.438 | −0.571 |
| Sugar | −0.292 | −0.482 | −0.568 |
| Other Primary Agriculture | −0.616 | −0.403 | −0.487 |
| Other Processed Agriculture | −0.691 | −0.583 | −0.606 |
| Coal | −0.494 | −0.431 | −0.482 |
| Oil | −0.001 | 0.000 | 0.000 |
| Gas | −1.191 | −1.281 | −1.123 |
| Electricity | −0.413 | −0.416 | −0.424 |
| Petrol | −0.522 | −0.457 | −0.649 |
| Metal Products | −0.088 | −0.087 | −0.136 |
| Motor Vehicles | −0.230 | −0.301 | −0.326 |
| Manufactures | −0.175 | −0.165 | −0.208 |
| Transport | −0.391 | −0.248 | −0.382 |
| Services | −0.181 | −0.123 | −0.174 |

Table 4: Demand Elasticities

to be fixed. These factors are ultimately all supplied to the production sectors in each region, and factors are assumed always to be fully employed. We adopt the GTAP primary factor substitution elasticities, available from Chapter 14 in Narayanan *et al* (2012), reflected on the right side of Figure 1 as $\sigma_{va}$. There are a number of distortions in the GTAP8 dataset reflected by *ad valorem* taxes on private and public consumption, usage of intermediate inputs by firms, production of outputs and trade.

Following Armington (1969), imports are incorporated into the model by treating domestic and imported varieties of the same good as differentiated products by domestic users of those goods. This is reflected by assuming that intermediate inputs in production and inputs into private and public consumption are CES aggregates of domestically produced goods and their imported counterparts, where the CES substitution elasticity $\sigma^i_{dm}$ reflects the extent to which imported goods are substitutable for the domestic variety. As $\sigma^i_{dm} \to \infty$, goods become homogeneous or perfect substitutes. We adopt the Armington substitution elasticities $\sigma^i_{dm}$ from the GTAP8 dataset, available from Narayanan *et al* (2012). So the price of one unit of the Armington aggregate of good $i$ in region $r$ will be given by equation (3):

$$PA_{i,r} = \left[\beta_{i,r} \cdot PD_{i,r}^{1-\sigma^i_{dm}} + (1-\beta_{i,r}) \cdot PM_{i,r}^{1-\sigma^i_{dm}}\right]^{\frac{1}{1-\sigma^i_{dm}}} \tag{3}$$

$$PM_{i,r} \quad = \quad \left[ \sum_s \delta_{i,s} \cdot [PD_{i,s} \cdot (1 + \tau_{i,s,r})]^{1-\sigma^i_{mm}} \right]^{\frac{1}{1-\sigma^i_{mm}}} \tag{4}$$

where $\beta_i$ is the share of domestically-produced $i$ in a country/region's use of $i$. The price of one unit of the aggregate import of good $i$ into region $r$ $PM_{i,r}$ will be given by equation (4), where $\tau_{i,s,r}$ reflects trade and transport margins associated with imports of good $i$ from region $s$ into region $r$, and $\sigma^i_{mm} = 2 \cdot \sigma^i_{dm}$ is the substitution elasticity between imports of good $i$ from different regions. The CGE model is solved using MPSGE in GAMS.

# 4 Counterfactual Results

The effects of international sanctions on trade with Iran are simulated using the CGE data and model described in Section 3 by generating a counterfactual general equilibrium in which trade between sanction countries in the aggregated region 'SAN' and Iran is reduced consistent with the description of international sanctions in Section 2. The desired reductions in sanction country imports from Iran are achieved by introducing an endogenous tax on sanction country imports of oil, petroleum products and metals from Iran. We also introduce an endogenous tax on 'SAN' exports to Iran of sanctioned commodities, to reflect sanctions on exports of petroleum products and metals from 'SAN' to Iran. These endogenous taxes adjust until 'SAN' trade with Iran of sanctioned commodities falls to $1-k$ of its level in the initial benchmark equilibrium. This allows us to model successive tightening of sanctions on 'SAN' exports to Iran and 'SAN' imports from Iran by increasing $k \in (0, 1)$.

The effects of sanctions imposed by 'SAN' on trade with Iran are reported in Table 5 for successive tightening of sanctions from $k = 0.25$ of benchmark trade in sanctioned commodities to $k = 0.75$. The data on Iranian oil exports reported in Table 1 suggest that sanctions resulted in a reduction in Iranian oil exports of 54.0% from 2007 to 2013. While most countries/regions in the aggregate 'SAN' region reduced oil imports from Iran dramatically by the end of 2013, this was not the case for China, which accounted for over 21% of benchmark Iranian oil exports.[2] Katzman (2014:38) suggests that from 2011-2013, Chinese oil imports from Iran fell by 20-25%. In the counterfactual equilibrium for $k = 0.75$ (so that 'SAN' exports to Iran and imports from Iran of sanctioned commodities fall by 75%), total Iranian oil exports by volume fall by 54.8%, so we choose $k = 0.75$

[2]Benchmark country/region trade shares for the disaggregated GTAP8 dataset for all sanctioned Iranian exports and imports are reported in the Appendix in Table A-1 for countries/regions with trade shares greater than 1.0%. Countries which are members of the 'SAN' region are preceded with an $^s$ superscript.

| Welfare | $k$=0.25 | $k$=0.50 | $k$=0.75 |
|---|---|---|---|
| urban1 | −2.47 | −4.00 | −5.34 |
| urban2 | −0.99 | −1.51 | −2.02 |
| urban3 | −0.71 | −1.04 | −1.39 |
| urban4 | −0.43 | −0.57 | −0.79 |
| urban5 | −0.13 | −0.06 | −0.11 |
| urban6 | −0.19 | −0.18 | −0.28 |
| urban7 | 0.12 | 0.34 | 0.41 |
| urban8 | −0.05 | 0.05 | 0.02 |
| urban9 | 0.07 | 0.24 | 0.25 |
| urban10 | −0.09 | −0.04 | −0.12 |
| rural1 | −4.42 | −7.21 | −9.63 |
| rural2 | −1.91 | −2.98 | −4.04 |
| rural3 | −0.86 | −1.25 | −1.76 |
| rural4 | −0.10 | 0.06 | −0.01 |
| rural5 | 0.25 | 0.65 | 0.78 |
| rural6 | 0.54 | 1.14 | 1.44 |
| rural7 | 1.13 | 2.13 | 2.74 |
| rural8 | 1.20 | 2.25 | 2.91 |
| rural9 | 1.38 | 2.53 | 3.27 |
| rural10 | 1.42 | 2.52 | 3.23 |
| govt | −21.93 | −34.11 | −41.85 |
| Iran | −4.39 | −6.71 | −8.27 |
| San | −0.01 | −0.06 | −0.15 |
| RoW | 0.15 | 0.31 | 0.49 |

Table 5: Welfare Effects of International Sanctions (%$\Delta$)

as representative of the level of sanctions that simulates changes in Iranian oil exports which are broadly consistent with those actually observed.[3]

Table 5 shows that the sanctions had only a very small negative effect on welfare in region 'SAN' which imposes sanctions. While 'SAN' welfare falls by 0.15%, the 'RoW' region which does not impose sanctions sees a welfare improvement of 0.49% of benchmark welfare, as they increase imports of sanctioned Iranian commodities, and increase exports of sanctioned commodities (especially metal products and motor vehicles) to Iran.[4] But aggregate welfare in Iran falls by over 8%. The largest share of this change

[3]The default GTAP8 Armington elasticity which governs the substitutability between domestic and imported oil is 5.2. When we adopt this value, the 'RoW' region responds to international sanctions of 75% of benchmark trade between Iran and 'SAN' with such a large increase in imports of Iranian oil that total Iranian oil exports fall by only 39.8%. This response in 'RoW' imports of Iranian oil seems inconsistent with that observed and reported in Table 1. To generate oil trade and production changes which are more consistent with those observed and reported in Table 1, we adopt an Armington elasticity for oil of 3.5. Specifically, we set $\sigma_{dm}^{oil} = 3.5$ and $\sigma_{mm}^{oil} = 7.0$.

[4]Welfare effects are the percentage change in Hicksian equivalent variations, except for the government sector in Iran where they are changes in real aggregate government spending, and for Iran where

in welfare is accounted for by changes in government activity in Iran, which sees real spending fall by almost 42%. This is due primarily to a decrease in rents earned from government-owned factors employed in oil production. For example, rents earned by natural resources in Iran (almost all of which are derived from ownership of natural resources specific to the oil sector) fall by just over 69%.

While the government in Iran bears the largest share of the effects of international sanctions, the lowest-income rural and urban households also fare poorly, with the lowest-income rural and urban households experiencing a 9.3% and 5.3% welfare loss, respectively. But sanctions cause resources to move out of oil production and into production of agricultural commodities, so the real return to land increases. Since land is mostly owned by rural households and since higher income rural households own more land, the higher income rural households actually see an increase in welfare after the imposition of international sanctions. Finally, international sanctions are focused on highly capital-intensive energy and metals sectors, so the real return to capital in Iran falls while the real return to labour rises, and the wage-rent ratio increases by almost 11%. Since rural households derive relatively more income from the ownership of labour than urban households who earn relatively more income from capital ownership, international sanctions cause larger welfare losses on urban households than rural households for all but the three lowest-income deciles.

In the counterfactual where the level of international sanctions is set at 75%, the trade results are roughly consistent with those reported in Table 1. But in this counterfactual, the production of oil in Iran falls by 19.5%, while the production data reported in Table 1 suggest that Iranian oil production fell by only 11.3% over the period 2007-2013. As noted in Section 2, there is evidence that the Iranian government purchased and stockpiled oil from Iranian production facilities in response to international sanctions on exports of Iranian oil. Results in Table 5 presume that no oil was stockpiled by the Iranian government. To show the effects of this stockpiling behaviour, we re-run the counterfactual simulations with the level of sanctions $k = 0.75$, assuming that the Iranian government stockpiles a share $s$ of the oil which would otherwise have been purchased by sanction countries. Since it is difficult to find evidence on the volume of oil stockpiled by the Iranian government, we run simulations for $s = 0$, 0.10, 0.20 and 0.30. That is, we assume that the Iranian government stockpiles $s \cdot k$ of the oil which was purchased by sanction countries in the initial benchmark equilibrium. We include an endogenous subsidy on government oil purchases which adjusts to the point

they are a weighted average of welfare changes for households and real aggregate government spending.

| | $s$=0.0 | $s$=0.10 | $s$=0.20 | $s$=0.30 |
|---|---|---|---|---|
| urban1 | −5.34 | −5.58 | −5.86 | −6.16 |
| urban2 | −2.02 | −2.28 | −2.57 | −2.88 |
| urban3 | −1.39 | −1.68 | −2.00 | −2.34 |
| urban4 | −0.79 | −1.12 | −1.47 | −1.85 |
| urban5 | −0.11 | −0.45 | −0.81 | −1.20 |
| urban6 | −0.28 | −0.61 | −0.96 | −1.34 |
| urban7 | 0.41 | 0.06 | −0.31 | −0.72 |
| urban8 | 0.02 | −0.31 | −0.67 | −1.05 |
| urban9 | 0.25 | −0.05 | −0.38 | −0.74 |
| urban10 | −0.12 | −0.37 | −0.65 | −0.95 |
| rural1 | −9.63 | −10.02 | −10.44 | −10.90 |
| rural2 | −4.04 | −4.59 | −5.17 | −5.80 |
| rural3 | −1.76 | −2.30 | −2.88 | −3.50 |
| rural4 | −0.01 | −0.61 | −1.25 | −1.93 |
| rural5 | 0.78 | 0.15 | −0.53 | −1.25 |
| rural6 | 1.44 | 0.81 | 0.14 | −0.58 |
| rural7 | 2.74 | 2.08 | 1.38 | 0.63 |
| rural8 | 2.91 | 2.26 | 1.59 | 0.86 |
| rural9 | 3.27 | 2.65 | 1.99 | 1.29 |
| rural10 | 3.23 | 2.75 | 2.25 | 1.70 |
| govt | −41.85 | −45.22 | −48.64 | −52.07 |
| Iran | −8.27 | −9.23 | −10.21 | −11.23 |
| San | −0.15 | −0.15 | −0.16 | −0.17 |
| RoW | 0.49 | 0.50 | 0.51 | 0.52 |

Table 6: Welfare Changes with Iranian Government Oil Stockpiling

where the government purchases $s \cdot k$ of the initial oil imports by 'SAN' countries. More stockpiling requires larger government purchases of oil, which require larger values for the endogenous subsidy. Since all tax revenue accrues to the government in Iran, this endogenous subsidy is a direct cost to the government for stockpiling oil.

The welfare effects of stockpiling of oil by the Iranian government are reported in Table 6, where the first column ($s = 0$) corresponds to the lats column in table 5. As we would expect, oil stockpiling by the Iranian government has only the smallest effect on regions 'SAN' and 'RoW'. But as oil stockpiling increases from 0-30% of benchmark oil imports by sanction countries, the decrease in aggregate welfare in Iran worsens from almost 8.3% to over 11.2%. All households in Iran see larger welfare losses or smaller welfare gains as the government stockpiles oil in response to international sanctions. But again, the largest share of Iran's welfare loss due to stockpiling is borne by the government in Iran, as the decrease in real government spending in Iran worsens from just under 42% with no stockpiling ($s = 0$) to over 52% with $s = 0.30$. Since the

Iranian government is effectively protecting its oil sector by subsidizing oil consumption to stockpile oil, the price of oil in Iran does not fall by as much as when there is no stockpiling, and real rents earned from natural resources in oil production do not fall as far as they do without stockpiling. But this gain to government revenue (relative to the counterfactual where there is no stockpiling) is much more than offset by the cost of the subsidy to pay for the stockpiling of oil. For example, with $s = 0.20$, real natural resource rents fall by \$US18.5 billion compared to their level in the benchmark, while they drop by almost \$US20.9 billion with no stockpiling. But the cost of the subsidy to stockpile oil is just over \$US7.4 billion when $s = 0.20$, so real government spending falls by considerably more when the Iranian government stockpiles oil.

# 5 Sensitivity Analysis

Since international sanctions are focussed directly on Iranian exports and imports, the effects of international sanctions will be strongly affected by the way the central case values for the Armington elasticity are set. To illustrate, we focus on the counterfactual where the level of international sanctions is set at $k = 0.75$ and the level of Iranian government stockpiling of oil is set at $s = 0.20$. We reset the value of the Armington elasticity to $0.75 \cdot \sigma_{dm}^{gtap8}$ and $1.5 \cdot \sigma_{dm}^{gtap8}$, where $\sigma_{dm}^{gtap8}$ is the central case value for the Armington elasticity adopted from the GTAP8 dataset. In each case, after resetting the Armington elasticity, we reset the substitution elasticity between imports from different regions to $\sigma_{mm} = 2 \cdot \sigma_{dm}$.

Table 7 shows that changes to the specification of the Armington elasticity have very little effect on welfare in the 'SAN' and 'RoW' regions. But increasing (decreasing) the Armington elasticity improves (worsens) the welfare for all economic agents in Iran. Changes in the Armington elasticity will have little effect on trade between Iran and 'SAN' countries since so much of this trade is controlled by sanctions. But *cet. par.*, higher Armington elasticities will increase trade flows between Iran and the 'RoW' region. As a result, damage to the Iranian economy due to the strong negative effect of international sanctions on Iran's trade balance will be mitigated when the Armington elasticity is increased.

The final example we use to illustrate sensitivity of welfare results considers the mobility of capital in oil production. Oil production costs in Iran are due almost entirely to capital costs and rents accruing to natural resources. Intermediate inputs and labour account for slightly less than 3% and 1%, respectively, of the cost of producing of oil in

$k = 0.75 \quad s = 0.20$

| | $0.75 \cdot \sigma_{dm}^{gtap8}$ | $\sigma_{dm}^{gtap8}$ | $1.5 \cdot \sigma_{dm}^{gtap8}$ |
|---|---|---|---|
| urban1 | −10.38 | −5.86 | −2.35 |
| urban2 | −5.51 | −2.57 | −0.37 |
| urban3 | −4.84 | −2.00 | 0.07 |
| urban4 | −4.29 | −1.47 | 0.55 |
| urban5 | −3.37 | −0.81 | 0.97 |
| urban6 | −3.57 | −0.96 | 0.88 |
| urban7 | −2.74 | −0.31 | 1.34 |
| urban8 | −3.18 | −0.67 | 1.08 |
| urban9 | −2.62 | −0.38 | 1.18 |
| urban10 | −2.71 | −0.65 | 0.82 |
| rural1 | −18.31 | −10.44 | −4.41 |
| rural2 | −11.48 | −5.17 | −0.60 |
| rural3 | −8.05 | −2.88 | 0.80 |
| rural4 | −5.95 | −1.25 | 1.98 |
| rural5 | −5.08 | −0.53 | 2.53 |
| rural6 | −4.05 | 0.14 | 2.91 |
| rural7 | −2.39 | 1.38 | 3.80 |
| rural8 | −1.94 | 1.59 | 3.82 |
| rural9 | −1.21 | 1.99 | 4.00 |
| rural10 | 0.02 | 2.25 | 3.66 |
| govt | −51.76 | −48.64 | −45.27 |
| Iran | −13.02 | −10.21 | −8.02 |
| San | −0.16 | −0.16 | −0.16 |
| RoW | 0.55 | 0.51 | 0.48 |

Table 7: Sensitivity of Welfare Changes to Armington Elasticity $\sigma_{dm}$

Iran in the benchmark. Capital costs account for just over two-thirds of oil production costs, while the remaining 28% of production costs accrue to natural resources. As noted earlier, capital and natural resources in oil production in Iran are all owned by the government, but while natural resources are modelled as a specific factor, capital is treated as perfectly mobile. As a result of international sanctions, there is a large drop in rents earned by natural resources. But since capital is modelled as being perfectly mobile, large amounts of capital leave the oil sector. As a result, the decrease in the real return to capital (-3.0% when $k = 0.75$ and $s = 0.20$) is much smaller than the decrease in the real return to natural resources (-61.7%).

But it is arguable that at least some of the capital used in oil production is more appropriately modelled as a specific factor, since it will have little or no productive value in other sectors. Since such a large share of value-added in oil production (and of government revenue in Iran) is accounted for by capital in oil production, it is important to illustrate how results depend upon the treatment of capital in the oil sector. For example, if we treat 20% of the capital which is initially used in oil production in Iran as a specific factor, then this capital will not be able to flee the oil sector when the introduction of international sanctions causes a large decrease in oil production in Iran. The ensuing drop in the real return to mobile capital should be much smaller, and more of the costs of the international sanctions will be borne by the immobile and specific capital in the oil sector. More importantly, since such a large share of government revenue depends upon rents from capital used in oil production, the share of the burden of international sanctions borne by the government in Iran will increase, and that borne by households in Iran will fall.

| | $s$=0.0 | | $s$=0.20 | |
|---|---|---|---|---|
| | all mobile capital | 20% specific capital | all mobile capital | 20% specific capital |
| urban1 | −5.34 | −2.16 | −5.86 | −3.22 |
| urban2 | −2.02 | 0.22 | −2.57 | −0.70 |
| urban3 | −1.39 | 0.72 | −2.00 | −0.22 |
| urban4 | −0.79 | 1.39 | −1.47 | 0.37 |
| urban5 | −0.11 | 1.87 | −0.81 | 0.86 |
| urban6 | −0.28 | 1.82 | −0.96 | 0.81 |
| urban7 | 0.41 | 2.38 | −0.31 | 1.36 |
| urban8 | 0.02 | 2.08 | −0.67 | 1.08 |
| urban9 | 0.25 | 2.28 | −0.38 | 1.33 |
| urban10 | −0.12 | 1.88 | −0.65 | 1.04 |
| rural1 | −9.63 | −5.38 | −10.44 | −6.90 |
| rural2 | −4.04 | −0.97 | −5.17 | −2.58 |
| rural3 | −1.76 | 0.94 | −2.88 | −0.59 |
| rural4 | −0.01 | 2.15 | −1.25 | 0.60 |
| rural5 | 0.78 | 2.80 | −0.53 | 1.22 |
| rural6 | 1.44 | 3.27 | 0.14 | 1.73 |
| rural7 | 2.74 | 4.31 | 1.38 | 2.76 |
| rural8 | 2.91 | 4.37 | 1.59 | 2.88 |
| rural9 | 3.27 | 4.76 | 1.99 | 3.31 |
| rural10 | 3.23 | 4.82 | 2.25 | 3.63 |
| govt | −41.85 | −48.09 | −48.64 | −53.78 |
| Iran | −8.27 | −7.88 | −10.21 | −9.86 |
| San | −0.15 | −0.14 | −0.16 | −0.15 |
| RoW | 0.49 | 0.47 | 0.51 | 0.50 |

Table 8: Welfare Changes with Specific Capital in Oil Production (%$\Delta$)

To demonstrate these concerns over the modelling of capital used in oil production in Iran, we re-run the counterfactual where sanctions are set at $k = 0.75$ for central case values of all other exogenously specified parameters (including Armington elasticities) after assuming that 20% of the capital used in oil production in Iran is a specific factor. Table 8 shows how welfare changes are affected by specification of capital mobility in the oil sector in Iran. When some capital in oil production is modelled as a specific factor, all households are better off, the government in Iran is worse off, and overall welfare in Iran improves, compared to the case where all capital is perfectly mobile. With less capital leaving the oil sector due to the imposition of international sanctions, the decrease in the real return to capital is smaller. For example, with $k = 0.75$ and $s = 0.20$, the real return to capital falls by only 0.5% when 20% of capital in oil production is specific, while it falls by 3.0% when all capital is perfectly mobile. While the increase in the real return to labour is also smaller when some capital in oil production is specific (5.0% with some specific capital versus 5.7% with all mobile capital), the gain in the real return to capital is much larger than the loss in the real return to labour, so households are all much better off when 20% of the capital initially used in oil production is modelled as being a specific factor.

With more specific factors in oil production, the elasticity of supply of oil is smaller, so for a given level of international sanctions and government stockpiling of oil, the drop in Iranian oil production is smaller. With $k = 0.75$ and $s = 0.20$, oil production and exports fall by 15.6% and 59.3%, respectively, when all capital is perfectly mobile, while they fall by 10.7% and 54.7% when some capital in oil production is specific. (The corresponding values for the drop in Iranian oil production from 2007-2013 in Table 1 are 11.3% and 54.0%, respectively). The real return to the factors which are specific to oil production (natural resources and 20% of the capital used to produce oil in the benchmark) falls by less (55.5% when $k = 0.75$ and $s = 0.20$) than when all capital is perfectly mobile (61.7% when $k = 0.75$ and $s = 0.20$). But total real government revenue from 20% of the capital used in oil production is so much lower when this capital is specific than when it is mobile that real government spending in Iran falls by much more when some capital used in oil production is modelled as a specific factor.

# 6 Conclusion

In recent years, severe economic sanctions have been imposed by the US, the European Union (EU) and other countries on Iran's economy in an attempt to discourage the government of Iran from continuing to engage in the development of a nuclear weapons capability. This article analysed the welfare impact of comprehensive economic sanctions on Iran's economy in general and upon upper- and lower-income rural and urban Iranian households, as well as the Iranian government. We used a Computable General Equilibrium (CGE) model with data on production, consumption and trade from the Global Trade Analysis Project (GTAP). The model used endogenous trade taxes to simulate the effects of sanctions on Iranian oil exports and Iranian imports of petroleum products. We augmented the GTAP8 dataset with information from the Statistical Centre of Iran (SCI) to produce a microconsistent CGE model with 20 urban and rural households disaggregated by income level.

Results suggest that the government in Iran bears the largest share of the effects of international sanctions due to a decrease in rents earned from government-owned factors employed in oil production. The lowest-income rural and urban households also fare poorly, while the sanctions had much more limited effects on the welfare of middle- and upper-income rural and urban households. Tighter sanctions have a progressively more negative effect on welfare in Iran, but particularly on the government. Results also suggest that as oil stockpiling by the Iranian government increases in response to international sanctions, the decrease in aggregate welfare in Iran worsens. However, the sanctions had only a very small negative effect on welfare in region imposing sanctions, while the remaining region which does not impose sanctions experiences a welfare improvement. Results also show that higher Armington elasticities make trade volumes more responsive to a given level of international sanctions, dampening the negative effect on Iran's trade balance. Furthermore, modelling some of the capital used in oil production in Iran as a specific factor increases the burden of international sanctions which is borne by the government in Iran, and improves the welfare of households and of the overall economy relative to the case where all capital is perfectly mobile.

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# Appendix

| | Iran Exports to | | | Iran Imports from | | |
|---|---|---|---|---|---|---|
| | oil | p_c | met | p_c | met | mvh |
| $^s$China | 21.33 | 41.14 | 9.94 | 4.71 | 16.80 | 22.45 |
| $^s$Japan | 25.99 | 9.77 | 2.18 | | 2.12 | 7.35 |
| $^s$Korea Republic of | | 9.06 | 2.49 | | 7.75 | 13.71 |
| $^s$Taiwan | 20.56 | 3.19 | 3.33 | | 1.63 | |
| $^s$Malaysia | | | | | 1.20 | |
| $^s$Singapore | 1.05 | 6.80 | | 2.71 | | |
| Thailand | | | 1.23 | | | |
| $^s$India | | 7.12 | 8.96 | 24.41 | 3.10 | 1.01 |
| Pakistan | | | 2.61 | | | |
| Rest of South Asia | | | 2.89 | | | |
| $^s$United States of America | | | | 1.02 | | |
| Argentina | | | | | | 1.13 |
| Brazil | | | | | | 1.57 |
| $^s$Belgium | | | 2.47 | | 1.43 | |
| $^s$France | 9.91 | 2.07 | | | 3.66 | 19.25 |
| $^s$Germany | | | 1.71 | | 8.50 | 8.82 |
| $^s$Italy | 12.12 | | 7.07 | | 3.54 | 3.23 |
| $^s$Netherlands | | | | 1.73 | | |
| $^s$Spain | | | 2.50 | | 1.29 | 2.99 |
| $^s$Sweden | | | | | | 1.12 |
| $^s$United Kingdom | | | | | 2.17 | 1.24 |
| $^s$Switzerland | | | | | 2.41 | |
| $^s$Romania | | | | | | 1.61 |
| Russian Federation | | | | | 12.65 | |
| Ukraine | | | | | 1.72 | |
| Kazakhstan | | | | 2.78 | 4.67 | |
| Rest of Former Soviet Union | | | 1.98 | 3.57 | | |
| Armenia | | 1.40 | 1.38 | | | |
| Azerbaijan | | | 1.34 | 12.42 | | |
| Kuwait | | | 3.47 | | | |
| Qatar | | | 1.24 | | | |
| Saudi Arabia | | | 6.29 | | 1.63 | |
| $^s$Turkey | | 1.33 | 5.49 | | 3.29 | 2.62 |
| United Arab Emirates | | 3.64 | 9.17 | 40.75 | 9.83 | 5.23 |
| Rest of Western Asia | | 1.44 | 9.47 | | | |
| Egypt | | | 1.16 | | | |
| Ethiopia | | 1.63 | | | | |
| $^s$South Africa | 5.19 | | | | | |

Table A-1: Benchmark GTAP8 Country/Region Trade Shares with Iran