Distributional Impacts of Energy-Heat Cross-Subsidization*

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Abstract

Energy and heat cross-subsidies are common in developing and transitioning countries, but the distributional and efficiency impacts of these policies (and reform) are largely unknown. In Post-Soviet countries such as Belarus, revenues from an industrial tariff on electricity are used to cross-subsidize heating for households. Input-Output (IO) data and a household consumption survey are used to analyze the distributional impacts of this cross-subsidization. We analyze distributional impacts of subsidy reform with a calibrated static computable general equilibrium (CGE) model with heterogeneous households. Sizable impacts to the aggregate economy are found, with GDP gains of roughly a quarter of a percent. Importantly, we find that policy reform is regressive when using a blunt instrument as poorer households are overly-burdened due to lost income from subsidized heat while richer households enjoy gains from cheaper market prices for goods. However, the GDP gains are even higher when the tax rates are structured to create a distributionally-neutral reform.

JEL Codes: D570, D580, H220, H230, Q430

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1 Introduction

Energy subsidies are often used by governments to achieve economic and social objectives, and these policies are widespread: the global bill of fossil fuel subsidies was around USD 260 billion in 2016. Many studies have analyzed the economic consequences of energy subsidies (IEA 2013; Vagliasindi 2012; IEA et al. 2010), and conclude that while poor people receive some of the benefits of fossil fuel subsidies, overall they are skewed to wealthier groups, crowd out priority public spending and encourage inefficient, carbon-intensive use of energy.

One type of subsidy that has received little attention in the literature is cross-subsidization between consumer groups, i.e. industrial customers paying a different price than households (for instance, see Faulhaber (1975)).[1] In addition to cross-subsidies between different customer groups, governments sometimes also impose cross-subsidies between different services. Such revenue redistribution schemes are common across Eastern Europe and Central Asia. For example, in Belarus, industrial customers pay roughly a 30 percent premium for electricity to keep heating prices low for residential customers (currently about 17 percent of the cost of the service).

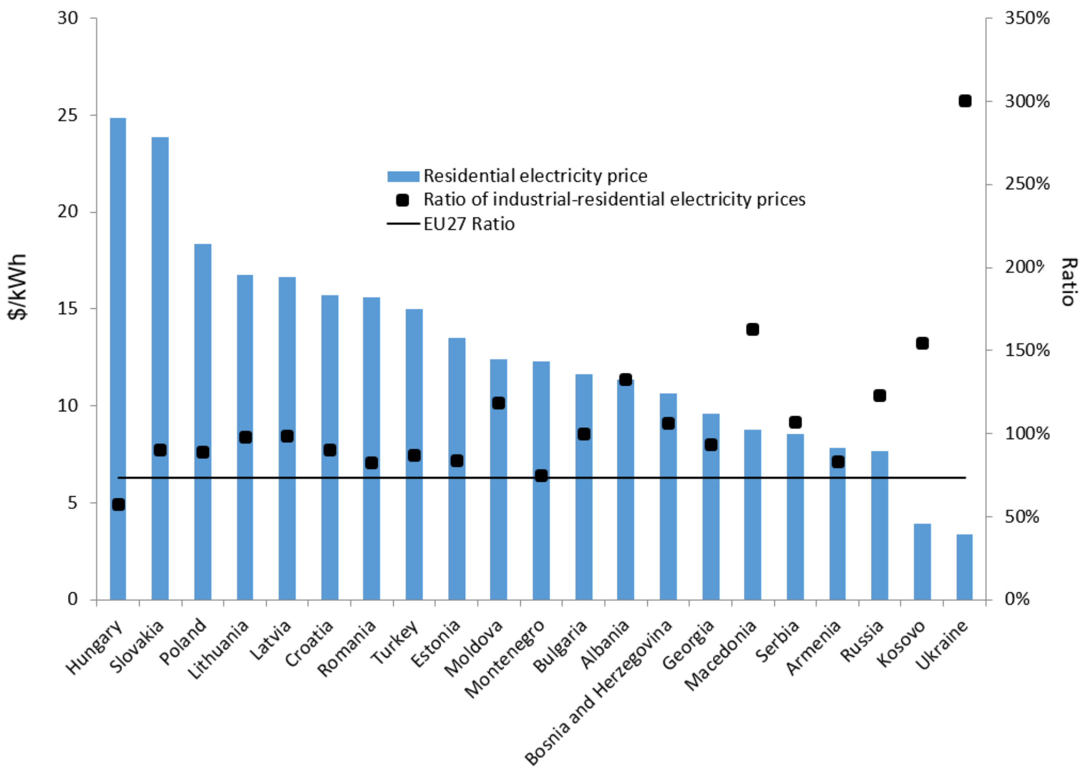
In many settings electricity is provided to residents well below the cost of production (Freund and Wallich 1997). In other settings, cross-subsidies are structured to favor certain sectors. In South Asia, many countries cross-subsidizes residential and agricultural consumers of electricity by overcharging industrial and commercial users. For instance, in India non-agricultural users of electricity pay roughly 15 times the electricity price of agricultural producers (Abeberese 2012; Lin and Jiang 2011). Since energy is required to produce and distribute goods from all sectors in an economy, by charging higher tariffs to nonresidential customers cross-subsidies impose an implicit tax on all goods and services produced. The purpose of this analysis is to understand the economic incidence and the distributional impact of the implicit energy tax, taking into account the inter-linkages across sectors. To achieve this, we use economic data and consumption expenditure surveys from Belarus to model the economy-wide implications of cross-subsidization schemes across producers and consumers. Though our study focuses on Belarus, our methodology and findings could inform policy debate in many other developing countries, such as in Eastern Europe and Central and South Asia, where such cross-subsidies are widespread.

To illustrate the scope of cross-subsidies, Figure 1 shows relative electricity prices for a selection

[1] Energy subsidies take many forms. They can be direct budget support to energy suppliers or consumers, under-collected/forgone revenues, or non-internalized externalities (Davis 2014).

of countries in Eastern Europe. Because it is typically less expensive to serve industrial customers than residential customers, industrial tariffs should be lower than residential tariffs. However, in roughly half of the countries, the ratios of industrial to household retail electricity prices are either at the 100% level (both consumers and firms face the same price) or above. Moreover, the price ratios in many Eastern European countries exceed the EU27 average. A more detailed discussion of cross-subsidies in Eastern Europe is available in Deichmann and Zhang (2013).

Figure 1: Nonresidential Electricity Tariff Ratios in Eastern Europe and Central Asia

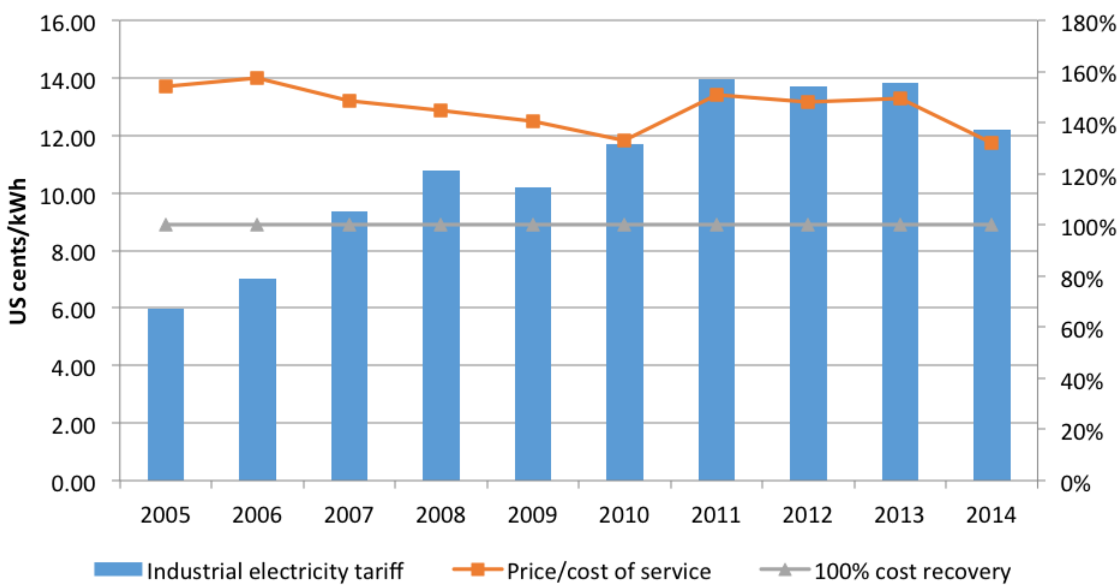


Source: Deichmann and Zhang (2013).

Many studies have examined the distributional impact of energy subsidy reform (see Mitra and Atoyan (2012), Zhang (2015), and Freund and Wallich (1997) for example), though few have looked at the general equilibrium impact of removing cross-subsidies. The cross-subsidization of heat from electricity in Belarus relies on a tariff on non-residential electricity use, which is meant to cover the cost of providing district (or communal) heating to residents through cogeneration. As a result, residential prices for district heating are well below the cost of service in Belarus. Since

2003, production costs have risen sharply while the cost-recovery levels of residential heat service have dropped by 50 percent due to inflation and depreciation of the Belarusian ruble to the US dollar. Belenergo, the state-owned district heating utility, on average achieves 17.2 percent cost recovery from residential heat consumers. Belenergo does not receive state subsidies and so must make up the entire shortfall by cross-subsidization. As a result, Belenergo's non-residential energy consumers pay tariffs that are substantially above cost (Figure 2).

Figure 2: Nonresidential Electricity Tariffs in Belarus



Source: Belarusian Ministry of Economy.

Electricity is consumed directly by households as a final product, but it also plays a critical role in production processes for intermediate and final goods. Because electricity is widely used as an input to other production processes, it is critical to understand how other prices would be affected by a change in non-residential electricity prices. A tax on electricity (as with the current cross-subsidization policy) will likely impact the price of nearly all goods and services. The economic incidence of a tax differs from its statutory incidence because a tax burden is passed on through product and factor markets (Fullerton and Metcalf 2002). The extent to which a tax burden is passed "forward" (to consumers) or "backward" (to factor owners) depends on behavioral and technological responses to the tax[2]. If consumers can easily substitute for a different product,

[2]Previous studies have looked at the distributional impacts of taxes on carbon or energy. For example, see Metcalf

or if prices for a good are effectively determined in international markets, firms will not be able to simply pass on the cost increase to its consumers (Coxhead and Grainger 2018). Similarly, the substitutability of production factors (such as labor for capital, which is generally a complementary input to electricity) will affect how a firm responds to a higher cost of electricity. In general, the tax burden is distributed according to relative magnitudes of relevant elasticities of demand or supply.

For necessity goods that are not easily substitutable, the effects of subsidies can be ambiguous. For instance, in the case of food subsidies, critics argue that richer households often receive a disproportionate share of the benefits from cheaper food while proponents contend that such subsidies provide an affordable supply of food for all constituents in the economy (Adams 2000). Similar cost and benefit calculus is necessary for cross-subsidization policies aimed at providing manageable access to heating at the cost of potentially driving up the price of other consumption goods.

The high tax rates on industrial uses of electricity raises the cost of a critical input to other production processes, services, and the distribution of final goods and services. When the costs of producing a good increase (such as due to an electricity tax), someone must bear the burden. The government's role, therefore, is critical in determining the overall distributional impacts of the system. Taxes on industrial uses of electricity generate government revenue. How the revenues are used will affect the net impact on different consumer groups. Under the current system, high electricity taxes cross-subsidize heating for consumers. While consumer prices for most goods are likely higher due to the electricity tariff, consumers are compensated by paying low communal heating prices. Under current prices, consumers spend a relatively small share of their overall income on district heating and fuels for heating. If the electricity tariff were reduced and the heating subsidy were reduced proportionately, lower prices for other consumer goods would come at an increased cost for heating. This analysis quantifies the net impact of decreasing the tax and subsidy for households of different incomes.

In this paper, we use both input-output and general equilibrium methods to estimate the heterogeneous impact of energy price reform across sectors and household income groups[3]. We find that production is expected to expand following the elimination of the implicit energy tax in most of the sectors, with transportation experiencing the largest gain. However, such price reform appears to be regressive, as poor households suffer more from heat price increases while wealthier

(1999) and Grainger and Kolstad (2010).

[3]Note that most general equilibrium studies consider the effects of energy taxation as a means of reducing emissions from fossil fuel based energy production and use (for instance, see Böhringer and Rutherford (2010)), rather than the effects of subsidies to achieve other social objectives.

households benefit from price reductions in the output market.

2 Data

Data used to study the implications of removing the cross-subsidization scheme in Belarus come from the national 2011 input output tables and the consumer expenditure survey provided by the National Statistical Committee of the Republic of Belarus. The input output table describes inter-sectoral relationships within an economy and the flow of commodities between producers and demanding agents. The household survey provides detailed information regarding each household's expenditures on final demand.

We use matrix balancing techniques outlined in Appendix B to enforce micro-consistency in the input output table. Sectors are aggregated to match the Belarusian consumer expenditure commodity demand indices. Linking the datasets allows us to characterize distributional household effects in our modeling frameworks. Table 1 denotes the aggregation scheme employed. Table 8 details the disaggregated list of input output indices in Appendix C. Because there is no direct bridge available between the IO sectors and consumption categories (such as the Personal Consumption Expenditure, or PCE, Bridge in the United States), we develop the mapping described in Table 9 in Appendix C. Due to differences in the level of aggregation between the consumer expenditure data and input output table, we aggregate rent payments with utilities (electricity, gas and water) into a single composite sector.

2.1 Input Output Descriptive Statistics

Table 2 provides descriptive statistics of the overall economy. The first column denotes the percentage share of GDP that is attributed to a given aggregate sector. The "other manufacturing" sector (includes wood, chemical, metal and machine manufacturing) is the largest composite sector in the economy, with goods and services (including retail and trade) following in second. The rent and utilities sector accounts for roughly 8% of total GDP which includes rent payments, utility and forestry expenditures.[4] Total GDP is calculated via the income approach and is given in the bottom part of the table.

The next two columns denote the effective tax rate and value of direct rent and utility use

[4]Note that forestry is included in our rent and utilities aggregate sector because firewood heating is included in the cross-subsidy policy. In the disaggregate data matrix, it represents a small fraction of total GDP.

Table 1: Aggregated Sectoring Scheme

Category	Description
Interindustry Transactions	Agriculture
	Food and beverage
	Rent and utilities
	Oil production
	Mining
	Clothing
	Other manufacturing
	Goods and services
	Transport
	Construction
	Education
	Health care
	Public administration
	Banking/finance
Value Added	
	Labor remuneration
	Gross profit
	Gross mixed income
	Other production duties
Margins and Input Taxes	
	Transportation margin on disposed products
	Trade margin on disposed products
	Net taxes on disposed products
Final Demand	
	Households
	Public institutions for individual goods and services
	Public institutions for collective services
	Noncommercial service providers for households
	Gross fixed capital formation
	Changes in inventory
	Exports of goods and services
	Imports of goods and services
	Indirectly measured financial intermediation services

This table provides the aggregated sectoring scheme used to map input output categories to consumer expenditure categories. Interindustry transactions categories are equivalent with consumer expenditure categories.

by each sector. The other manufacturing category spends the most on rent and utilities followed by rent and utilities and transport. Effective tax rates (given as a percentage) are largest in the education and health care sectors, however this group comprises a small fraction of utility use. Subsidies are to the rent and utilities sector is evident, as the effect tax rate is roughly 34%. Household rent and utility taxes are given in the bottom of the table. Due to the subsidized heat, effective tax rates are roughly -14%. The final column provides the amount of tax revenue that is received by the government directly from industrial use of rent and utilities. Summing across sectors shows that in total, the government accrues negative tax revenue from rent and utilities.

Table 2: Descriptive Statistics

Aggregate Sector	**GDP (%)**	**Rent/Utility Tax Rate (%)**	**Rent/Utility Use (Tr BYR)**	**Rent/Utility Tax Rev. (Tr BYR)**	**Rent/Utility Intensity**
Agriculture	6.23	-3.14	1.03	-0.03	0.05
Banking/finance	5.20	20.88	0.17	0.04	0.02
Clothing	2.27	8.65	0.70	0.06	0.06
Education	4.20	23.98	0.83	0.20	0.06
Food and beverage	4.80	0.90	1.36	0.01	0.06
Goods and services	17.34	3.53	5.79	0.20	0.10
Health care	2.73	23.23	0.38	0.09	0.05
Tranport	8.10	6.80	6.46	0.44	0.18
Oil production	4.26	7.05	1.71	0.12	0.03
Mining	0.25	4.98	0.13	0.01	0.11
Rent and utilities	8.06	-34.22	7.95	-2.72	0.17
Other manufacturing	23.69	8.29	11.33	0.94	0.09
Construction	7.64	5.87	1.55	0.09	0.05
Public administration	5.24	10.98	1.47	0.16	0.08
Total:			40.86	-0.39	
Total GDP (Tr BYR)	296.54				
HH Utility Tax Rate (%)	-13.62				

Total GDP and industrial use of rent and utilities is denoted in trillions of Belarusian rubles (BYR). Rent and utility intensity are calculated using the disaggregated Leontief Inverse. Intensity is measured in rubles and provides the indirect energy requirements for a ruble's worth of increased final consumption in the associated sector.

The government derives part of its income from indirect business taxes on output (duties, roughly 7% of government revenue), taxes on industrial intermediate demand (23% of government revenue) and taxes on household demand of goods (31% of government revenue). The percentage of total revenue does not add to 100 due to other income sources such as transfers. Because we use an input output table as opposed to a social accounting matrix, specific information on income taxes and other transfers between demanding agents are not provided. The rent and utilities sector generates 1.2 trillion BYR in subsidies to households, an aggregate of .4 trillion BYR in subsidies to industry and .7 trillion BYR in tax revenue from output duties. Overall subsidy payments on intermediate industrial use is due to subsidized rates for rent and utilities in agriculture and within rent and utilities production.

Indirect information on the underlying economic system can also be observed through features of the input-output modeling framework. The linkages in the dataset describe a snapshot of the connectedness of sectors both upstream and downstream of production. The input output formulation is well-known in the economics literature (Leontief 1936; Leontief 1986). While the restrictions and needed assumptions of this approach are also well-known, it can be seen as a tool for providing a compact illustration of inter-linkages reported in the data. In this framework, the economy is modeled at the sector level. There are J sectors, where each sector j produces x_j units of a homogeneous good. Technical coefficients, a_{ij} (j aliased with i) are used to describe the per ruble contribution of sector i's output used as an input for sector j. Each sector sells output both to other sectors in the form of intermediate inputs and demanding agents. The typical demand driven backward linked model can be formulated as in Appendix A.[5].

The input output table provides a convenient structure for writing down basic economic identities that must hold given the current accounting system. In order to measure the extent of inter-sectoral linkages, we compute the Leontief Inverse: $(I - A)^{-1}$. This calculation describes a distribution of domestic indirect effects of an additional ruble of final demand for a given sector. While solving for the Leontief Inverse is a simple task, it is worth noting that this matrix is actually the Jacobian of the output with respect to final demand in a system of linear equations. Using information embedded in the Leontief Inverse, we compute the indirect energy intensity in sector level production. This captures the level of utility use needed for sector level production across the entire supply chain. For off-diagonal elements, the row vector provides information on the indirect impacts a change in final demand will have (for diagonal elements, we need to subtract 1 for indirect effects). Indirect rent and utility intensity is reported in the final column of Table 2. The transport and rent and utilities sectors has a large indirect effect because a large amount of utilities is required in production of its own output. Mining, goods and services, other manufacturing and public administration also have large levels of indirect rent and utility needs relative to other sectors.

2.2 Household Data

Table 3 shows spatially averaged household incomes and sizes, by income decile.[6] Household incomes vary widely between the bottom and top deciles. A household at the 90^{th} percentile earns nearly five times that of a household at the bottom decile. Moreover, the average household size

[5]Backward and forward linkages are terms often used to describe the direction of causation with input output methods. For demand driven models like the one presented here, the change in final demand is interpreted as generating increased demand for inputs in the production process, backwards through the supply chain. For supply side methods, changes in value added components are interpreted being forward linked.

[6]Incomes also vary significantly by region, which suggests that a region-by-region analysis may be appropriate in subsequent studies. Most notably, incomes in Minsk are substantially higher than in other regions. However, our input output data is structured as a national table so therefore we restrict our attention to national level calculations.

varies systematically with income.

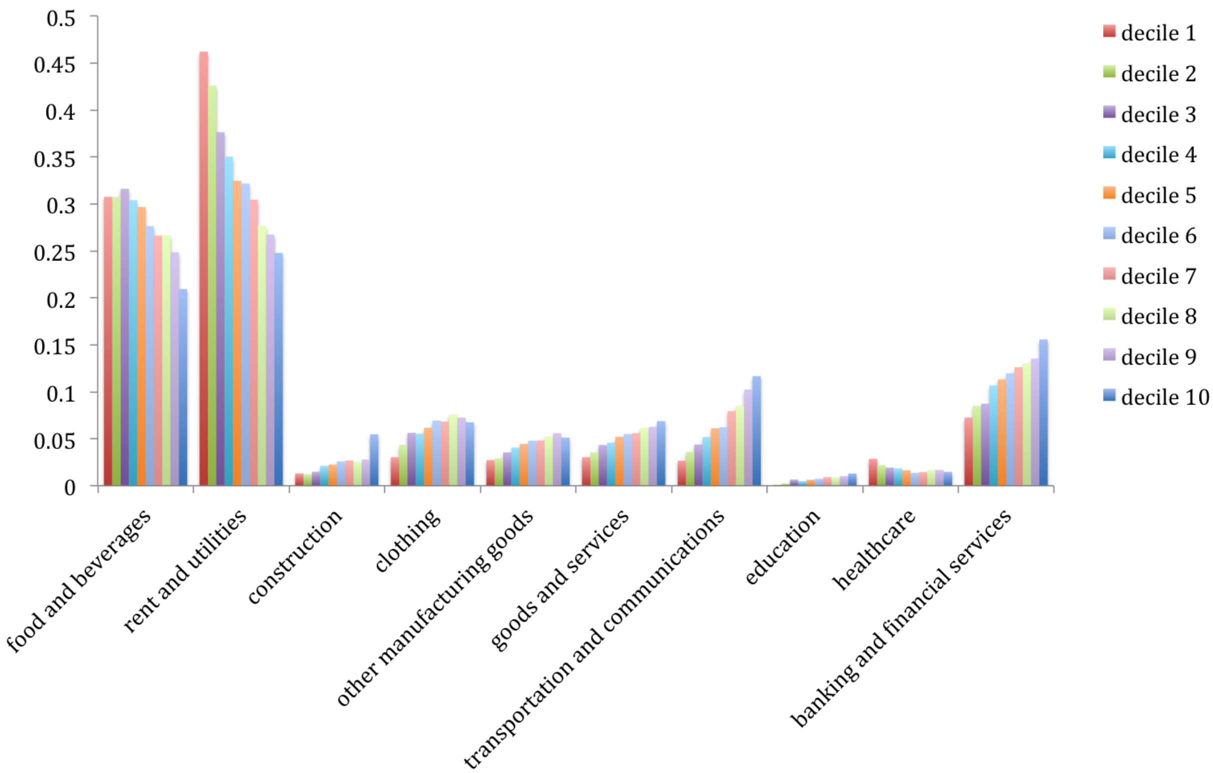
Table 3: Household Income and Size, by Income Decile

Income Percentile	**Average Income**	**Average Household Size**
10	809,575	1.10
20	1,163,036	1.40
30	1,582,812	2.02
40	1,919,941	2.35
50	2,237,421	2.58
60	2,562,030	2.85
70	2,924,984	2.90
80	3,360,679	3.12
90	3,959,351	3.30
100	5,541,067	3.52

Income levels are given in rubles.

The household survey provides detailed information regarding each household's expenditures on the goods categorized above. Though there are differences in consumption patterns between regions, we focus on the differences in expenditure shares between income deciles at the country level. Figure 3 summarizes expenditure shares by income group. The first two categories, food and rent and utilities, constitutes the largest expenditure shares on average for each income decile. The top income group spends less than a quarter of its income, on average, on food, while the average household in the bottom decile spends nearly a third of its income on food. Rent and utilities shows a similar pattern though with larger expenditure shares. Other good categories, such as clothing, transport, and banking/finance take up a larger share of income as household income grows.

Figure 3: Expenditure Shares by Consumption Category and Income Decile



Currently residents of large and small cities are served by district heating. They pay a relatively small share of the total cost of heating, though cost calculations vary (due to cogeneration, etc.). As a share of income, average urban households in the bottom and top deciles spend between 15% and 5.5%, respectively, of total income on rent and utilities. Firewood, peat and gas are also subsidized. Urban households in the bottom ten percent spend an average of 8% of their income, while the average urban household in the top decile spends about one-half of one percent on these fuels. The shares of income spent on firewood, peat and gas are similar for rural consumers, though not all rural households receive district heating. These additional fuel types are included in our aggregate rent and utilities sector.

3 Linear Price Model

Before proceeding to a general equilibrium analysis, we first characterize the implications of a change in taxes on firms using a linear price model. Notably, due to modeling restrictions in this framework, we can only characterize cross-subsidization at the rent and utility sectoral level.

However, because supply side models are interpreted as being forward linked, this change in utility subsidy can be translated to expected effects on households, assuming no price responsiveness. We impose tax reductions on other industries and reduce the subsidy received by the rent and utility sector. The input output price model can be thought of as the "dual" of the traditional input output model described up to this point. Whereas input output analysis often considers the impacts of final demand shocks, we can also consider the impact of "cost-push" forces, such as changes in tax rates (see Dietzenbacher (1997)).

When creating output multipliers in traditional input output analysis, formulation requires the use of the common row identity:

$$\sum_j z_{ij} + f_i = x_i, \quad \forall i$$

where z_{ij} denotes total interindustry transactions between sectors i and j. The price model, conversely, uses the column identity:

$$\sum_i z_{ij} + \sum_l v_{lj} = x_j, \quad \forall j$$

where v_{lj} denotes a matrix of value added components l for sector j. The identity states the sum of interindustry payments from j to i, plus value added paid by j equals the value of total output. Note that total inputs equal total outputs to enforce microconsistency; this is guaranteed because we are dealing with a balanced matrix. The standard demand driven model is written using the market clearance identity of the input output table while the price model relies on zero economic profits.

The input output matrices for Belarus are constructed in *value* terms. Therefore we can decompose value terms into (price×quantity) terms by writing the above column identity as (switching to matrix notation and following notation found in (Miller and Blair 2009)):

$$x' = i'_Z Z + i'_V v'$$

where $v' = [v_1, \ldots, v_n]$ is an $(L \times J)$ matrix of value added, i'_Z and i'_V denoting corresponding summation row vectors, x' the row vector of total outputs and Z a $(J \times J)$ matrix of interindustry transactions. By our typical construction, we can substitute $Z = Ax$ where $[a_{ij}] = z_{ij}/x_j$. Let $\hat{x}$ denote a $(J \times J)$ diagonal matrix with the diagonal being total output in each sector. Post multiplying the above by $\hat{x}^{-1}$, we have:

$$i'_Z = i'_Z A + i'_V v' \hat{x}^{-1}$$

Let $v_c = v\hat{x}^{-1}$ be the fraction of total input use attributed to value added purchases. In order to find relative price changes, simply assume a price index of $p = i$ such that all prices, in this benchmark equilibrium as represented by the input output table are set to unity.

$$p' = p'A + i_V' v_c' \tag{1}$$

which can be rewritten as the following:

$$p' = i_V' v_c' (I - A)^{-1} \quad \iff \quad p = (I - A')^{-1} v_c i_V \tag{2}$$

Note the relationship between this expression and our originally defined input output model in matrix notation. The Leontief inverse here is the transpose of the Leontief inverse as computed by the standard model.

Before we are able to introduce a price shock for the utility sector, we must calibrate the price model. In our initial benchmark equilibrium as represented by the data, computing the model above will result in a vector of prices solely consisting of one (consistency check). In order introduce a price shock, we modify the above. Let Q^j denote a separate $(L \times 1)$ vector for each j. The price model can then be written as:

$$p = (I - A')^{-1} v_c (i_V + Q^j) \tag{3}$$

Q^j allows for changes to the valuation of the value added components by scaling the summation vector differently for each sector j. The term, $(i_V + Q^j)$ acts as the new relative price of a value added component for a given sector. This allows us to characterize changes in sector level prices due to fluctuations in value added elements. In our case, we are interested in reducing the taxes paid on industrial rent and utility use, while also reducing the subsidy received by the utility sector by the total amount of reduced industrial taxes. The policy experiment seeks to understand how reducing the taxes paid on industrial use of rent and utilities by 40% and subsequent reductions in subsidies effects prices[7]. Because aggregate input taxes are included in the input output table as defined, we calculate Q^j for each sector based on taxes paid for utility use relative to total taxes paid.

Results are given in Table 4. The model predicts that the percentage change in the price of utilities increases by 2.1%. Given the intersectoral linkages in the data, other prices change, though at a much smaller magnitude. The second largest price change in absolute value occurs in the education sector with roughly half a percent.

[7] Notably, the agricultural sector receives large subsidies for utility use. We take this sector out of the industrial tax reduction.

Table 4: Price Experiment

Aggregate Sector	**Price (%)**	**Q**
Agriculture	0.05	
Food and beverage	0.05	-0.01
Rent and utilities	2.10	-0.50
Oil production	-0.02	-0.01
Mining	-0.03	-0.06
Clothing	-0.09	-0.06
Other manufacturing	-0.11	-0.06
Goods and services	0.02	-0.11
Transport	-0.19	-0.18
Construction	-0.05	-0.02
Education	-0.43	-0.17
Health care	-0.26	-0.09
Public administration	-0.19	-0.10
Banking/finance	-0.07	-0.05

Prices are measured in percentage change from the benchmark (unity). Q denotes the policy parameter which reduces input taxes by 40% proportioned to how much total tax is attributed to rent and utilities.

With these modeled reductions in output prices, we now turn to the household data to determine how reforming the current cross-subsidization would affect different income groups holding fixed expenditure patterns. We should quickly note that the price model is not a general equilibrium model in the sense that agents are not price responsive. Moreover, while we have considered cross subsidization at the utility level, we can also run simulations where we restrict transfers to households directly (via taxes) in our later general equilibrium model. This model exposes the sectoral linkages and determines, everything held equal (including fixed production and consumption functions), which sectors are likely to be most affected.

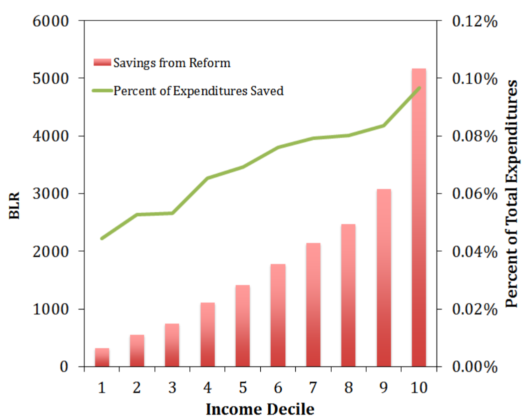
3.1 Calculating Distributional Impacts

Under the current tax-and-subsidy policy, high taxes on industrial electricity consumption are driving up consumer good prices for goods. In this section we calculate how much consumers of each income group could save on goods other than rent and utilities if the tax on industrial rent and utility use were eliminated (assuming expenditure shares remain constant) and a net effect including the reduced subsidy for the utilities sector. As evident in the linear price model, we only approximate subsequent reductions in household subsidies at the utility level. More precise treatment is provided in the general equilibrium section. There we explore the role that price responsiveness may play in distributional impacts of eliminating the current policy as well as relative tradeoffs between lower output prices but less available household income given revenue neutral simulations.

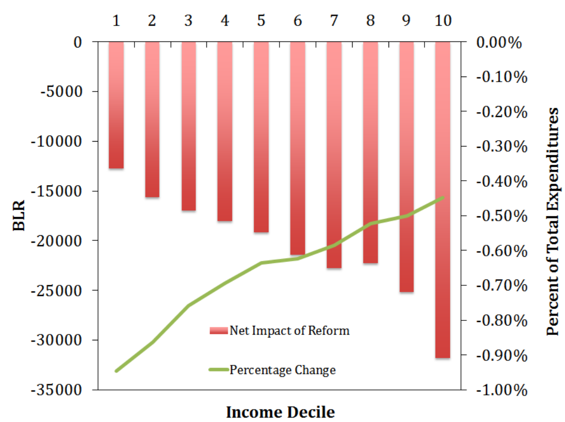
In a linear world, eliminating of the electricity tariff on firms would lead to an overall reduction in the price levels for consumers. The net effects of cross-subsidization for consumers are not so clear. Without the inclusion of price changes for rent and utilities, we calculate predicted savings by income group for each type of consumption good in Figure 4a. Every income group would see a cost decrease on key consumption goods such as clothing and household articles. The amount saved in absolute terms as well as a percent of total expenditures is highest for households in the top income decile, suggesting that this aspect of the policy reform may actually be regressive.

Figure 4: Distributional Impacts of Linear Price Model Results

(a) Savings from Policy Reform



(b) Net Effects of Policy Reform



When considering the net effects of reduced subsidies for heating as in Figure 4b, the story changes. Figure 4b considers the effect of reducing taxes on industry for rent and utilities by 40% while subsequently reducing subsidies for utilities by the same amount. The net effect of the policy in the linear model predicts large increases in the rent and utilities price, dominating any savings from reduced prices of other goods. Given fixed expenditure patterns, this leads to substantial losses in expenditures relative to the benchmark. The upper income groups see the largest losses, though as a percentage of total expenditures, the lower income groups are most affected.

These simulations have focused on a linearized model with fixed production/consumption coefficients, which represents a very stylized version of the economy. While useful in getting a first order approximation of the likely implications of policy reform, caution is warranted in the overall magnitude of results. Without embedding substitution possibilities and endogenous activity levels and prices, such estimated impacts are likely to be an over approximation. Moreover, this method crudely assess the reduction in taxes on sector level electricity and subsequent reductions in household subsidies. We construct a computable general equilibrium model in the next section which "closes the gap" on the application of modeled policy reform. Such framework allows for income and substitution effects, and in particular, study which dominants the other given policy reform. The multi-sectoral CGE model also provides the opportunity to explicitly model cross-subsidization in an optimization framework where optimal taxation can be simultaneously determined.

4 Computable General Equilibrium

Results thus far have considered mapping the input output calculations to the consumer expenditure survey data as a first order approximation of the effects of eliminating the cross-subsidization policy and have served to illuminate the interconnectedness between sectors. However, this assumes that households do not respond to price changes and will continue to buy the same bundle of goods.[8] In order to relax this assumption, we employ a static general equilibrium model calibrated to the national input output data. A CGE model allows for economically consistent functions to locally approximate induced changes from policy elimination. The model will help characterize a response on the consumer side of the economy and allow for more flexibility when computing relative price changes.

We assume initially that the input output table represents a benchmark equilibrium in a snapshot in time. In the current state, everyone (both agents and firms) is maximizing subject to feasibility restrictions and all markets clear to determine equilibrium price levels. Note that input output tables are compiled in value terms, so all initial prices can simply be set to unity as in our linear price model.

4.1 Heterogeneous Households

In order to understand the distributional impacts associated with eliminating cross-subsidies, we disaggregate the household category of the input output table based on the consumer expenditure data to allow for different representative households in the model. To do so, we share out both

[8] There is no behavioral response in such IO calculations, which may overstate the regressivity or progressivity of a tax (e.g. West and Williams III (2004)).

expenditures and endowment incomes for each income decile. We first constrain total expenditures to match the share of aggregate expenditures from the consumer expenditure data (shares computed based on Figure 3 and Table 3). Given this constraint, we partition household demand of each good based on each households use of such good in the expenditure data as closely as possible.[9] Endowment income was similarly treated. Shares used for household expenditures are summarized by Table 5. On average, the richer income deciles tend to account for larger proportions of demand for each good.

Table 5: Household Share of Total Good Expenditures (%)

Aggregate Sectors	**Households** *hh1*	*hh2*	*hh3*	*hh4*	*hh5*	*hh6*	*hh7*	*hh8*	*hh9*	*hh10*
Oil production	2.41	3.33	4.54	5.35	6.44	7.43	8.80	10.03	12.16	39.52
Agriculture	5.25	7.30	9.32	9.90	10.71	10.40	11.06	13.19	11.72	11.16
Food and beverages	4.11	5.49	6.87	8.18	9.48	10.27	11.70	12.76	14.78	16.36
Rent/utilities	5.84	7.30	7.96	8.56	9.17	10.31	11.09	11.05	12.62	16.10
Mining	2.60	3.61	4.93	5.77	6.93	7.97	9.36	10.67	12.81	35.36
Clothing	1.81	3.45	5.51	6.36	8.23	10.55	11.90	14.45	16.55	21.18
Other manufacturing	3.18	5.06	7.14	8.03	9.18	10.29	11.53	14.31	16.70	14.57
Goods and services	2.17	3.45	5.18	6.23	8.14	9.70	11.18	13.53	16.17	24.25
Transport	1.31	2.38	3.56	4.90	6.70	7.79	11.29	13.20	18.96	29.92
Construction	2.71	3.74	5.36	7.35	8.09	9.63	10.80	11.76	13.62	26.95
Education	0.27	1.49	5.03	4.33	6.54	8.68	12.15	12.92	17.44	31.16
Health care	6.62	6.85	7.42	8.22	8.55	8.06	9.72	12.15	14.48	17.94
Public administration	2.81	3.90	5.32	6.20	7.43	8.54	10.05	11.47	13.78	30.51
Banking/financing	2.46	3.98	4.99	6.79	8.14	9.61	11.38	12.97	15.62	24.05

Shares are given in percentages. Summing over columns results in 100% of total household demand for each good.

4.2 Model Setup

The model assumes a perfectly competitive environment; firms are price-taking profit maximizers, and consumers (both households and government) maximize utility subject to a budget constraint. We also assume a small open economy which asserts that foreign prices are unaffected following a domestic policy shock. Taxes enter the model through output taxes or taxes on intermediate demand (for both sectors and households). Taxes are collected by the federal government, which then are recycled back to the households via public spending and transfers. We assume an equal

[9] Shares were slightly perturbed in order to match expenditure totals based on a least squares optimization framework. Notably, expenditure data was not available for oil and mineral production or public administration. We assumed a distribution based on averages. The optimal percentage change in expenditure shares was 5.9%. Code is available upon request.

yield constraint on government purchases to investigate revenue neutral policy reductions.

The model describes a circular economy. Households supply firms with labor and capital, which in turn are used to produce output. Output is demanded by households, government and used as intermediate inputs to the production process of other firms domestically or exported out of the country. Goods are imported into the economy for immediate final demand, industrial intermediate demand or for transshipments. Intermediate demand is a composite of domestically produced goods, imports and trade and transport margins. Explicit taxes are paid to the government for output duties and intermediate demand by industry and households in the model, with additional aggregate transfer information in representative agent income constraints.

Table 6: Variables and Sets

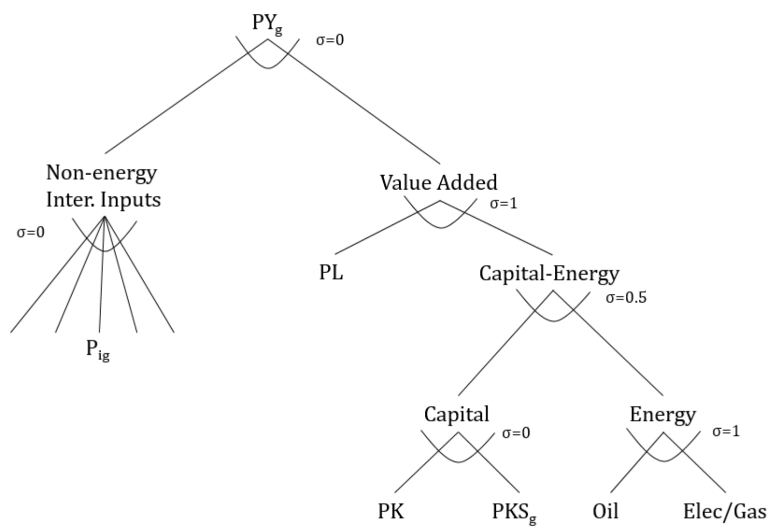
Type	**Item**	**Description**
Sets	g	Aggregate index for all sectors in IO table
	i	Commodity subset index
	h	Household index
	mrg	Margins subset index
	pub	Public institution index
Activity Levels		
	Y_g	Aggregate production
	ID_{ig}	Intermediate demand
	X_i	Exports
	TT_{mrg}	Transport/trade margin
	M_i	Imports
	C_h	Household consumption
Prices		
	PY_g	Production price
	PD_g	Domestic output price
	PM_i	Imported goods price
	PX_g	Export price
	PT_{mrg}	Price of margins
	P_{ig}	Price of intermediate demand
	PK	Mobile rental rate of capital
	PKS_g	Sector specific capital rental rate
	PL	Wage rate
	PFX	Price of foreign exchange
	PC_h	Household expenditure index
Multipliers		
	τ^{TAX}	Flat multiplier on household utility tax
	τ_h^{HH}	Welfare neutral tax multiplier
Agents		
	HH_h	Representative agent income level
	GOV	Government income level

Model notation. See Appendix D for model equations.

Table 6 lists sets and variable names used in the model. While conceptualizing the market flows in the modeled economy is useful, it does not characterize optimal choices by producing sectors and consumers. In order to understand the structure of our choice rules, a tree diagram is provided in Figure 5 to describe the assumed production and output structure in the model.

Figure 5: Model Structure: Supply side

(a) Production



(b) Output

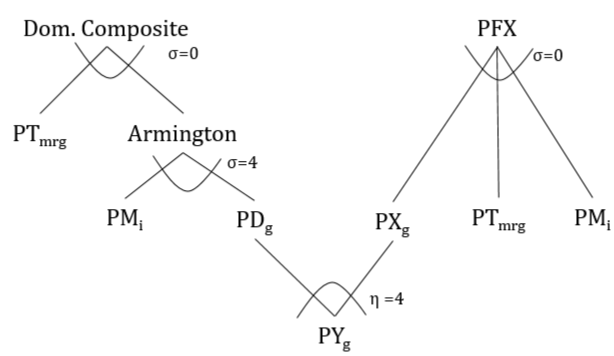


Figure 5a illustrates the assumed structure of production and output along with elasticity values in the model. We employ nested constant elasticity of substitution (CES) functional forms to capture various levels of trade-offs between inputs to activities. Similar to the GTAP-E structure (see Burniaux and Truong (2002), Rutherford and Paltsev (2000)), producers of PY_g must use a fixed proportion of value added inputs (capital, labor and energy) and intermediate inputs (non-energy commodities). We specify a value added sub-nest in the production function where labor (mobile across sectors), capital (both mobile and sector specific[10] and energy) are substitutes with elasticity of substitution equal to one (Cobb-Douglas). We form a capital-energy composite based on two subnests which detail our assumed capital composite and energy composite. We assumed mobile and sector specific capital must be used in fixed proportions while energy types are substitutable. Due to our necessitated level of aggregation, two types of energy form this composite nest: oil and electricity/gas. The capital-energy composite has an outer elasticity of 0.5. Figure 5b shows that output PY_g is allocated between the domestic market at price PD_g and the export market PX_g via an elasticity of transformation η. To form our domestic composite (for use as intermediate demand by both firms and households), we employ the Armington assumption in that locally produced goods are not perfect substitutes for imports (location of production matters in terms of substitutability) by specifying an elasticity of substitution $\sigma = 4$ between imports and domestic production (denoted as Armington in Figure 5). Such Armington composite commodity as well as trade and transport margins, priced at PT_{mrg} are combined to form the domestic composite for use as intermediate inputs at price P_{ig}. Finally, trade margins, transshipments and exports are combined to formulate the price of foreign exchange (PFX). We set PFX as the numeraire for the model in order to describe relative price changes in terms of foreign prices.

Households are assumed to have Cobb-Douglas preferences for the domestic composite. We assume the national government spends public funds in fixed proportions subject to a fixed budget. Investment and savings are treated as exogenous.

4.2.1 Model Equations

Equilibrium conditions are characterized as a mixed complementarity problem (MCP) (Rutherford 1995). Aside from auxiliary constraints, three separate conditions must be satisfied. (1) Zero-profit requires that unit revenues must not exceed unit costs for all activities. The complementarity condition requires that if costs exceed revenues, the associated activity level must be zero. Letting $\Pi_i(p)$ be the unit profit function, $C_i(p)$ denote the unit cost function in industry i, and $R_i(p)$ the unit revenue function, both in terms of prices, the zero profit conditions can be concisely written as:

$$-\Pi_i(p) = -R_i(p) + C_i(p) \geq 0 \quad \perp \quad Y_i \geq 0, \quad \forall\, i$$

[10] We assume a proportion of the capital is sector specific (fixed in the short run to a given sector). The default value used to calibrate the model is 0.5 though other assumed values are explored in sensitivity simulations.

where $\perp$ denotes the associated complementarity condition (production in i). (2) Market-clearance asserts that supply must be greater than or equal to demand for all prices. The complementarity condition requires that if supply exceeds demand, the associated price must be zero. The algebraic structure of these conditions relies heavily on Shepard's lemma. That is,

$$\sum_j Y_j \frac{\partial \Pi_j(p)}{\partial p_i} + \sum_h \omega_{ih} \geq \sum_h \delta_{ih} \quad \perp \quad p_i \geq 0 \quad \forall\, i$$

The generic market clearance equation above dictates that the sum over all net outputs (note we specify a unit profit function which implies supply coefficients rather than total supply) and household endowments, ω_{ih}, must be greater than or equal to the sum of household demands, δ_{ih}, where h denotes household type. (3) Incomes must balance. Consumers cannot spend more than their endowment income. The algebraic structure is that of a simple budget constraint:

$$I_h = \sum_i p_i \omega_{ih} \geq \sum_i p_i \delta_{ih} \quad \perp \quad I_h \geq 0 \quad \forall\, h$$

That is, total endowment income, I_h, for household type h must be greater than or equal to the amount spent. The complementarity condition here generally is not a problem because we deal with well behaved utility functions in which Walras' Law holds and consumers spend their total budget.

Model formulation is done in GAMS (General Algebraic Modeling System) and MPSGE (Mathematical Programming System for General Equilibrium analysis (Rutherford 1999)). We use calibrated share form equations to calibrate model assumptions to the benchmark equilibrium. A full algebraic description of the model can be found in Appendix D.

4.3 Policy Experiment

We begin by considering a series of policy experiments consisting of reductions in the benchmark taxes paid by each sector for rent and utility use while subsequently reducing the subsidy rate received by households for rent and utilities equally across income groups. This cross-subsidization reduction is characterized by an equal yield constraint on government expenditures which allows us to endogenize a tax multiplier (τ^{TAX}) on household use of rent and utilities. Notably, we exclude changes in industrial taxes paid for rent and utilities in the agriculture and rent and utilities sector because these sectors receive subsidized rates. The complementarity condition required for endogenizing tax rates is:

$$\tau^{TAX}(GOV - \sum_{pub} PD_{pub}\overline{d}_{pub}) = 0$$

The main simulation considers a 40% reduction in the taxes paid for rent and utilities. By all accounts, such reduction would likely eliminate the distortions due to cross-subsidization within the Belarusian economy. Sensitivity analysis is employed to compute results for a range of reductions around 40% (10-70 percent reductions) to explore the nonlinearities around our solution and explore fixed government budget implications on shifting tax losses from firms to households. Moreover, we include perturbations to our assumed elasticity structure (along with the sector specific capital proportion) to compute pseudo confidence intervals around our main policy scenarios[11].

4.4 Results

4.4.1 Aggregate Impacts

Confidence intervals are included in aggregate impact results, though will be dropped for disaggregate effects in subsequent sections. We denote the default elasticity and sector specific share values as the main policy simulation while our upper and lower bounds are denoted as maximum and minimum, respectively. Aggregate results are computed as percentage change from the benchmark and given in Figure 6. The figure describes gross domestic product (GDP) impacts and rent and utility use implications for firms and households. Cutback denotes the percentage decrease in taxes paid by firms on rent and utility use.

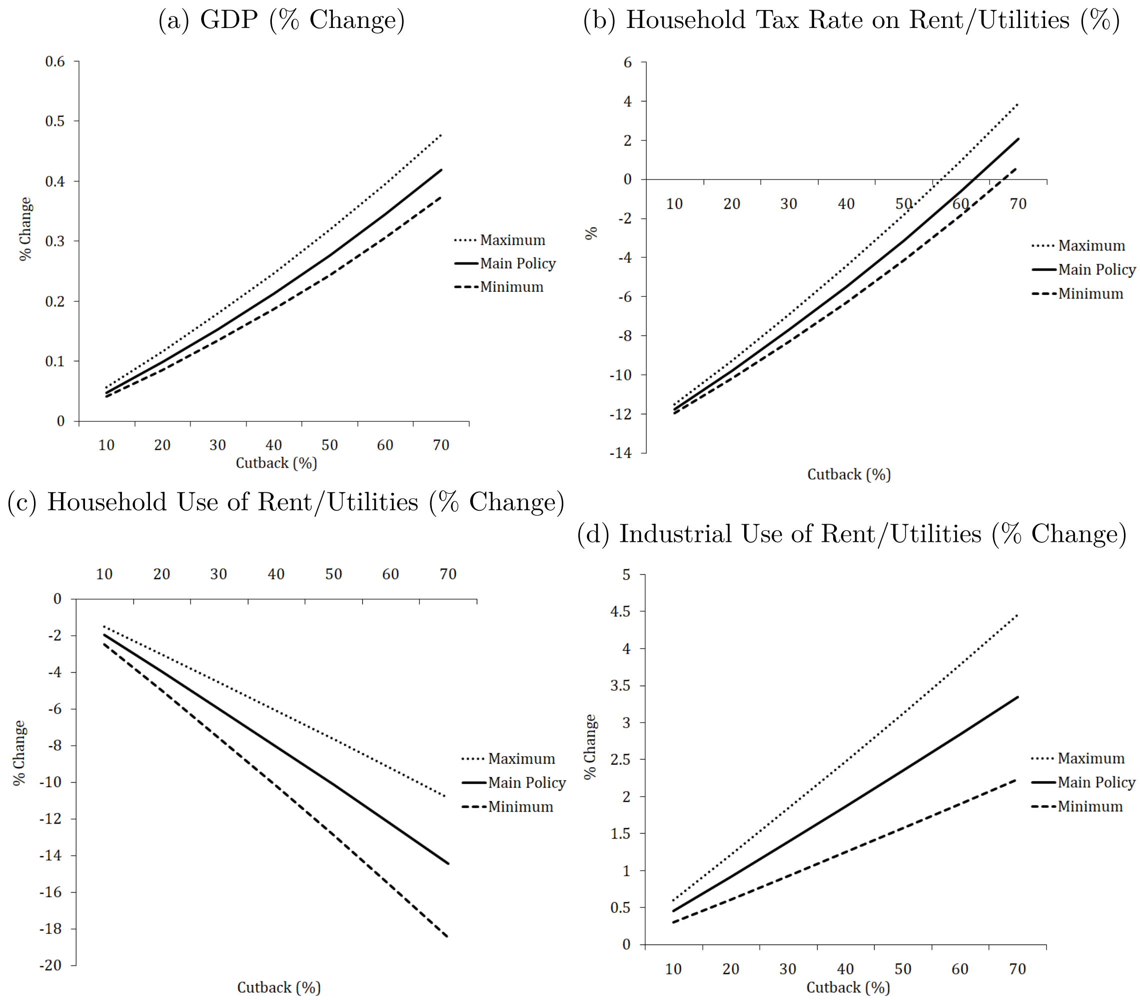
Figure 6a denotes the percentage change in total GDP from varying levels of percentage reductions in the taxes paid by industries on rent and utilities[12]. Relative prices are weighted by a consumer price index characterized by a weighted sum of the bundle of goods demanded by households. Results are fairly stable across magnitudes of reductions, though our psuedo confidence intervals widen as the policy becomes more restrictive. Our main policy simulations finds a point estimate of GDP increases of roughly 633 billion BYR due to a 40% reduction in the rent and utility tax paid by industries.

The benchmark subsidy rate on household use of rent and utilities is -13.62% (see Table 2). By imposing our budget balance constraint, the endogenous tax multiplier scales the benchmark tax rate to achieve a revenue neutral policy. The equilibrium household tax rates are given in Figure 6b

[11] We alter assumed parameters by ± 0.25 to compute our confidence intervals and characterize the upper bound as the maximum across all sensitivity simulations and the lower bound as the minimum.

[12] GDP is calculated based on the income approach.

Figure 6: Aggregate Impacts



All figures show varying levels of impacts for different tax rate reductions on industries. Cutback denotes the percentage reduction on taxes paid by industry for rent and utilities. 6a represents aggregate GDP impacts measured in percentage change. 6b denotes the resulting tax rate applied to households for rent and utilities following the reduction in cross-subsidized heat. 6c represents aggregate percentage change in household use for rent and utilities and 6d the industrial change.

for each level of cutback in the industrial tax rate on rent and utilities. Notably, a uniform tax rate is applied to each household group. The larger the cutback on firms, the more the government is forced to reduce the subsidy given to households for rent and utilities. A 60% reduction corresponds to roughly eliminating any subsidy provided for rent and utilities. Indeed, reductions in industry tax rates greater than this amount require a positive tax on consumers. Our sensitivity calculations show that this increase in tax rate is fairly robust across perturbations of our assumed elasticity structure.

Change in the aggregate use of rent and utilities for households and industry is given in Figure

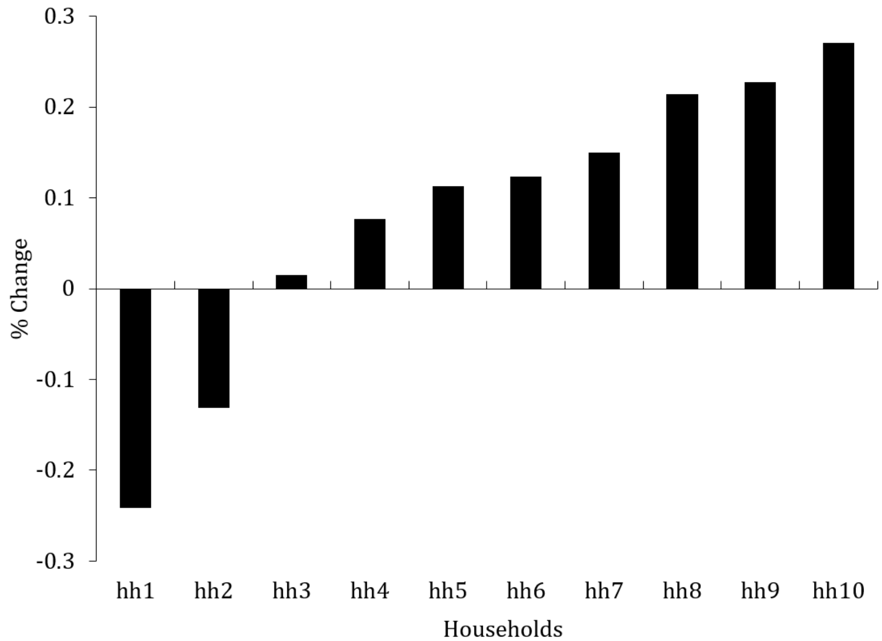
6c and Figure 6d. Given the resulting equilibrium household tax rates on rent and utility, in aggregate, the model prescribes reductions in rent and utility for consumers and increases in use by producers. Because we allow for energy substitution in the production nest, industries substitute for more utilities (gas and electric) relative to oil because of the effective price reduction. Conversely, reducing the degree of cross-subsidization leaves households with more expensive rent/utilities, leading substitution away from such goods.

4.4.2 Disaggregate Impacts

As modeled, the reduction in household subsidies for rent and utilities is the same for all income levels. Figure 7 describes the percent change in welfare levels for household types measured using equivalent variation. Our most significant finding is that policy reform is regressive using a blunt instrument, harming poorer households more so than richer households. The poorest two deciles are computed to have negative welfare effects due to the policy, while richer groups are computed to experience welfare improvements, of roughly a quarter of a percent for the richest decile. Due to income and substitution effects, lost income outweighs cheaper market prices for most goods for the bottom two deciles while cheaper prices outweigh reductions in subsidized heating for the richer households. Translating these equivalent variation changes into rubles, the lowest representative decile loses -0.01 tr BYR while the highest income decile gains 0.08 tr BYR in expenditures following the policy reform.

Domestic output price, production and import impacts are provided in Table 7. Though the magnitudes are different, the sign of domestic relative price changes follows the linear price model outputs. Notably, the price of food and beverages and goods and services, both large components of each household type's consumption bundle, increases following policy reform. The price for rent and utilities also increases, though to a much smaller degree than the linear price model due to income and substitution effects, which is common in comparing linear input output models with general equilibrium models. Production is expected to increase for all sectors except for food and beverages (though to a very small degree) up to half of a percent for the transport sector, due to a cheaper input bundle for firm level production. Imports are also computed as increasing. More electricity and gas is expected to be imported into the economy due to sufficient increases in industrial demand outweighing reductions in demand by households.

Figure 7: Household Welfare: Equivalent Variation (% Change)



Welfare calculations are reported in percentage change and computed using the equivalent variation measure.

Table 7: Sector Level Impacts (% Change)

Aggregate Sector	**Dom. Output Price**	**Production**	**Imports**
Agriculture	0.13	0.07	0.84
Banking/financing	0.10	0.08	0.85
Clothing	-0.04	0.18	0.45
Construction	-0.06	0.02	0.00
Education	-0.36	0.14	-0.14
Food and beverage	0.11	-0.03	0.79
Goods and services	0.26	0.25	1.33
Health care	-0.22	0.09	0.25
Mining	-0.08	0.27	0.19
Oil Production	-0.12	0.13	0.05
Other manufacturing	-0.13	0.32	0.16
Public administration	-0.20	0.17	0.17
Transport	-0.14	0.57	0.27
Rent/utilities	0.05	0.02	1.06

All prices are reported in percentage change weighted by a consumer price index. The consumer price index is computed as a weighted sum of the bundle of goods demanded by households.

4.5 Distributionally-Neutral Policy Reform

So far, we have assumed a blunt policy instrument for reducing the subsidy of household use of rent and utilities, finding that in doing so, the policy is regressive. A natural follow up question would be whether there exists a tax structure which achieves a similar reduction in industrial use of rent and utilities that also equalizes welfare outcomes across household groups. We investigate this question by introducing another endogenous multiplier (τ_h^{HH}) which characterizes the change in government subsidized rent and utilities by household type h. Additional constraints needed for implementation are:

$$\tau^{TAX}\tau_{i,hh}\sum_h \delta_{ih}(p) = \sum_h \tau_h^{HH}\tau_{i,hh}\delta_{ih}(p) \qquad \text{for} \quad i = \text{utility}$$

where $\delta_{util,h}(p)$ denotes the demand function for rent and utilities by household type h. This condition asserts that tax revenue across the sum of household types at different multipliers is the same as the flat tax case. τ_h^{HH} is determined by the complementarity condition:

$$\tau_h^{HH}(HH_h - PC_h\overline{hh}_h) = 0 \qquad \forall \quad h$$

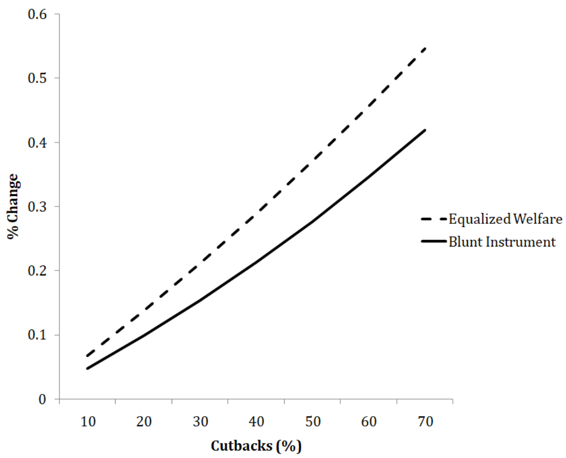
where $\overline{hh}_h$ are benchmark income levels. Here, we rely on equivalent variation as a metric for assessing welfare changes as in previous sections with reference levels set to unity.

Running equivalent simulations in this welfare neutral environment produces larger increases in changes to GDP. Figure 8a plots the GDP implications for the main policy parameter values for the blunt instrument relative to the differentiated tax reductions in the welfare neutral case. Minimal changes exist between the two.[13] The household level taxes associated with this equalized welfare framework are provided in Table 8b. Point estimates provided correspond to main policy simulations for a 40% reduction in the taxes paid on rent and utilities by sectors. Imposing an equalized welfare constraint produces a distribution of tax rates across income percentiles. Importantly, households included up to the 90th percentile still receive subsidized rates for rent/utilities. Only those within the top decile have a positive tax rate. The third column corresponds to a rough confidence interval which provide the range of point estimates across systematic sensitivity simulations.

[13]Sensitivity simulations show that the welfare neutral policy outcomes are virtually identical to the blunt instrument.

Figure 8: Equalized Welfare Impacts

(a) GDP (% Change): Welfare Neutral vs. Blunt Instrument



(b) New Household Tax Rates on Rent/Utilities: 40% Reduction

Income Pct.	Point Estimate	Sensitivity Intervals
10	-0.081	(-0.082,-0.078)
20	-0.071	(-0.072,-0.068)
30	-0.054	(-0.055,-0.051)
40	-0.044	(-0.045,-0.04)
50	-0.036	(-0.038,-0.033)
60	-0.034	(-0.036,-0.031)
70	-0.028	(-0.03,-0.024)
80	-0.009	(-0.013,-0.005)
90	-0.005	(-0.008,0)
100	0.011	(0.007,0.017)

5 Discussion

In order to examine the question of how the elimination of cross-subsidization between industrial electricity prices and residential heating affect different sectors and household groups, we use both input output and general equilibrium methods. Our analysis serves three important purposes. First, it serves as an interesting example of how input output results can overestimate more theoretically consistent general equilibrium results, but do offer intuition on the likely impacts of the policy in question. Secondly, we present a method for analyzing cross-subsidization in a general equilibrium model by endogenizing a tax multiplier on household subsidies in a revenue neutral setting. Finally, our analysis serves to fuse consumer expenditure data into a standard single consumer input output table to impose consumer heterogeneity in a general equilibrium model. Given that this type of cross-subsidy is common in developing countries, our study could help guide policymakers as energy subsidy reforms are proposed. We believe our methodology can be employed in other cases where cross-subsidies exist.

We have shown that given a uniform decrease in subsidized heating and rent across all household types lead to likely regressive reform. The reduction in electricity prices on the production side not only has the effect of making production relatively less costly, it also increases consumer welfare in a manner which benefits wealthier households, who spend a smaller fraction of their total income on rent and utilities relative to other consumption goods. This leads to additional questions as to the advantages and costs of more flexible policy reform. Reform improvements might be achieved if considering welfare neutral reductions in household subsidies by bracketing subsidy reductions by household income. We provide a case of differentiated subsidy schedules at the decile level which equalize welfare changes across household types that corresponds to improvements in national GDP. It should be noted, however, that such a system could be associated with significant administrative costs.

A few caveats should be noted to motivate further research. Our model explicitly assumes perfect competition in all sectors, which may not be the case in Belarus (or other transitional economies). Many sectors in the Belarusian economy are state-owned and likely do not follow such simplifying assumptions. Next, we should note that the analysis suffers from sector aggregation due to linking data sets. While the policy specifically treats industrial use of electricity and household heating, we were forced to combine the two to link input output data to consumer expenditure data. As such, our estimates should serve as approximations due to the lack of specificity in the data. Our analysis also would be improved with more explicit data on the tax markup experienced by industry for electricity input use. Such information is unavailable and therefore, our policy simulations treat the problem with a range of possible cutback percentages in the tax rate on industry. To the extent that this is representative, it serves as a benchmark for likely policy impacts.

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A Input Output Assumptions

The typical demand driven backward linked model can be formulated as follows. Denote f_i as the final demand for good i, where $i = 1, ..., J$. For each sector i we can write

$$x_i = a_{i1}x_1 + a_{i2}x_2 + ... + a_{iJ}x_J + f_i. \tag{4}$$

Let A be the matrix of coefficients a_{ij}, x be the vector of total output, and f be the vector of final demands, then we can simplify our expression for the economy as:

$$x = Ax + f \tag{5}$$

which can be rewritten $(I - A)x = f$, where I is the J-dimensional identity matrix. Rearranging (and assuming that the normal conditions for invertibility hold), we can rewrite as follows:

$$x = (I - A)^{-1}f. \tag{6}$$

The term $(I - A)^{-1}$ is the Leontief Inverse matrix. This matrix shows how an additional ruble of final demand in a given sector leads to direct and indirect effects across sectors. The fact that it is linear in nature is simply a byproduct of the linear identities embedded in the model. It is also worth emphasizing that this approach describes an equilibrium. Deviations from the observed data assume that changes will be linear and proportional, which may not be true, especially for "large" changes.

Input output tables provide the value and use of output in the economy. The value depends on the point of evaluation. If evaluated before taxes and transport costs, basic prices are given. If the value is net of taxes and transport margins, purchaser prices are described. This relationship between basic and purchaser prices can be written as:

$$\textit{Basic Prices} + \textit{Taxes (less subsidies)} + \textit{Trade/Transport Margins} = \textit{Purchaser Prices}$$

We calculate multipliers and distributional impacts from direct and indirect use of intermediate goods with concern for domestic use rather than total use of a good. The initial basic price table includes imports and domestic use in the interindustry matrix, which would obscure information concerning domestic production and retention of goods and services. We structure the total input output table to account only for domestic interindustry transactions with an additional row for total imports by each industry.

B Matrix Balancing

B.1 Least Square Matrix Balancing

The matrix balancing routine used is a nonlinear program formulated using least squares. The program can be summarized as follows. Let $\overline{a}_{ij}$ denote the inconsistent benchmark input output table (i.e. row sums not equal to column sums) and A_{ij} denote the variable to be solved for. The least squares routine seeks to minimize the percent difference between the benchmark data and variable subject to micro-consistency constraints. Also, let γ denote a zero penalty term used to induce sparsity,[14] Θ_{ij} be the set of (i, j) pairs such that $\overline{a}_{ij} \neq 0$ and Θ_{ij}^c be its compliment. The program is formulated as:

$$\begin{aligned} \min_{A_{ij}} \quad & \sum_{\Theta_{ij}} \left(\frac{A_{ij}}{\overline{a}_{ij}} - 1 \right)^2 + \gamma \sum_{\Theta_{ij}^c} A_{ij}^2 \\ \text{s.t.} \quad & \sum_i A_{ij} = \sum_i \overline{a}_{ij} \quad \forall j \\ & \sum_i A_{ij} = \sum_i A_{ji} \quad \forall j \end{aligned}$$

All primary findings in the paper correspond to this matrix balancing routine. Note that in the general equilibrium section, this quadratic program is solved with all benchmark parameters.

[14]In practice, this is simply a large constant such that entries that were initially zero remain zero; it imposes a large penalty in the optimization framework for large deviations from the initial values.

C Sectoring Schemes

The complete disaggregated sectoring scheme in the original input output data is provided in Table 8. The exact mapping scheme used to bridge the input output sectors to the consumer expenditure categories are provided in Table 9.

Table 8: Table of IO Indices

Category	Index	Description
Interindustry Transactions	01	Agriculture, hunting husbandry and related services
	02	Forestry and related services
	03	Fishery, fish husbandry and related services
	04	Extraction of fuels
	05	Extraction of natural resources, other than fuels
	06	Production of foods, including beverages and tobaccos
	07	Production of textiles and clothing
	08	Production of leather, articles of leather and production of footwear
	09	Wood processing and production of articles of wood
	10	Pulp and paper production. Publishing
	11	Production of coke, oil products and nuclear materials
	12	Production of chemicals
	13	Production of articles of rubber and plastics
	14	Production of other non-metal mineral products
	15	Metallurgic production and production of finished metal articles
	16	Production of machines and equipment
	17	Production of electrical equipment, electronic and optical equipment
	18	Production of transportation means and equipment
	19	Other industries
	20	Production and distribution of electricity, gas and water
	21	Construction
	22	Trade, repair of cars, household and personal articles
	23	Hotels and restaurants
	24	Transportation and communication
	25	Financial operations
	26	Real estate transactions, lease and consumer services
	27	Public administration
	28	Education
	29	Healthcare and social services
	30	Municipal, social and personal services
Value added		
	32	Labor remuneration
	33	Gross profit
	34	Gross mixed income
	35	Other production duties
Margins/taxes		
	36	Transportation margin on disposed products
	37	Trade margin on disposed products
	38	Net taxes on disposed products
Final Demand		
	31	Indirectly measured financial intermediation services
	39	Households
	40	Public institutions for individual goods and services
	41	Public institutions for collective services
	42	Noncommercial service providers for households
	43	Gross fixed capital formation
	44	Changes in inventory
	45	Exports of goods and services
	46	Imports of goods and services

Table 9: Mapping

Category	Index	Mapping
Agriculture	*agri*	01
Food and beverage	*food*	03,06
Rent and utilities	*util*	02,20,26
Oil production	*oil*	04,11
Mining	*mine*	05
Clothing	*cloth*	07,08
Other manufacturing	*oman*	09,10,12,13,14,15,16,17,18,19
Goods and services	*goods*	22,23
Transport	*trans*	24
Construction	*cons*	21
Education	*educ*	28
Health care	*health*	29
Public administration	*opubs*	27,30
Banking/finance	*bank*	25
Labor remuneration	*wages*	32
Gross profit	*profit*	33
Gross mixed income	*mixed*	34
Other production duties	*duties*	35
Transportation margin on disposed products	*transp*	36
Trade margin on disposed products	*trade*	37
Net taxes on disposed products	*taxes*	38
Households	*hh*	39
Public institutions for individual goods and services	*pubsgs*	40
Public institutions for collective services	*pubscoll*	41
Noncommercial service providers for households	*noncom*	42
Gross fixed capital formation	*capform*	43
Changes in inventory	*inven*	44
Exports of goods and services	*exp*	45
Imports of goods and services	*imp*	46
Indirectly measured financial intermediation services	*idir*	31

D Model Equations

Three sets of conditions characterize a competitive equilibrium in the general equilibrium model: firms make zero profits, markets must clear, and incomes must be balanced. For ease in notation, let Π denote the unit profit function. We denote our complementarity conditions using the $\perp$ symbol. By making extensive use of Shepard's Lemma, demand and supply coefficients can be computed by differentiating the unit profit function with respect to a given price. Refer to Table 3 for variable notation and Table 8 for data parameters used in model equations.

D.1 Zero Profit

This condition requires that firms make non-positive profits. There is a series of similar conditions for each activity level variable in the model. Let NE denote the set of i of non-energy commodities.

1. Sectoral production:

$$-\Pi_g^Y = -\left(1 - ty_g\right)\left[\theta_g^d PD_g^{1+\eta^Y} + (1-\theta_g^d)PX_g^{1+\eta^Y}\right]^{1/1+\eta^Y} +$$

$$\sum_{i \in NE} \theta_{ig}^{yd} \frac{P_{ig}(1+\phi_{ig}\tau_{ig})}{1+\tau_{ig}} + \theta_g^{va} PL^{\theta_g^l} KE_g^{1-\theta_g^l} \geq 0 \quad \perp \quad Y_g \geq 0$$

where:

$$KE_g = \left[\theta_g^{ke}(\theta_g^{km}PK + (1-\theta_g^{km})PKS_g)^{1-\sigma^{ke}} + (1-\theta_g^{ke})(P_{oil,g}^{\theta_g^{oil}} P_{util,g}^{1-\theta_g^{oil}})^{1-\sigma^{ke}}\right]^{1/1-\sigma^{ke}}$$

2. Intermediate demand:

$$-\Pi_{ig}^{ID} = -P_{ig} + \sum_{mrg} \theta_{mrg,ig}^{ig} PT_{mrg} + \theta_{ig}^{ig}\left(\theta_{ig}^{id} PD_i^{1-\sigma^{di}} + (1-\theta_{ig}^{id})PM_i^{1-\sigma^{di}}\right)^{1/1-\sigma^{di}} \geq 0 \quad \perp \quad ID_{ig} \geq 0$$

3. Imports:

$$-\Pi_i^M = -PM_i + PFX \geq 0 \quad \perp \quad M_i \geq 0$$

4. Margins:

$$-\Pi_{mrg}^{TT} = -PT_{mrg} + \theta_{mrg}^{tt} PD_{mrg} + (1-\theta_{mrg}^{tt})PM_{mrg} \geq 0 \quad \perp \quad TT_{mrg} \geq 0$$

5. Exports:

$$-\Pi_i^X = -PFX + \theta_i^{xx} PX_i + \theta_i^{xm} PM_i + \sum_{mrg} \theta_{mrg,i}^{xt} PT_{mrg} \geq 0 \quad \perp \quad X_i \geq 0$$

6. Consumption:

$$-\Pi_h^C = -PC_h + \prod_i \left(\frac{P_{i,hh}(1+\alpha_i \tau_{i,hh})}{(1+\tau_{i,hh})}\right)^{\theta_i^c} \geq 0 \quad \perp \quad C_h \geq 0$$

D.2 Market Clearance

This condition stipulates that supply must not exceed demand or the price for a good will be zero. There is a single equation for each price in the model.

7. Domestic goods:

   (a) Commodities:

$$Y_i \frac{\partial \Pi_i^Y}{\partial PD_i} + \overline{D}_i \geq \sum_g ID_{ig} \frac{\partial \Pi_{ig}^{ID}}{\partial PD_i} \quad \perp \quad PD_i \geq 0$$

(b) Margins:

$$Y_{mrg}\frac{\partial \Pi^Y_{mrg}}{\partial PD_{mrg}} + \overline{D}_{mrg} \geq TT_{mrg} \quad \perp \quad PD_{mrg} \geq 0$$

(c) Government demand (embedded in production structure):

$$Y_{pub}\frac{\partial \Pi^Y_{pub}}{\partial PD_{pub}} + \overline{D}_{pub} \geq \frac{\theta^G_{pub} GOVT}{PD_{pub}} \quad \perp \quad PD_{pub} \geq 0$$

8. Imported goods:

$$M_i + \overline{M}_i \geq \sum_g ID_{ig}\frac{\partial \Pi^{ID}_{ig}}{\partial PM_i} + \theta^{xm}_i X_i \quad \perp \quad PM_i \geq 0$$

9. Exported goods:

$$Y_i\frac{\partial \Pi^Y_i}{\partial PX_i} \geq \theta^{xx}_i X_i \quad \perp \quad PX_i \geq 0$$

10. Margins:

$$TT_{mrg} + \overline{TT}_{mrg} \geq \sum_{ig} \theta^{td}_{mrg,ig} ID_{ig} + \sum_i \theta^{tx}_{mrgi} X_i \quad \perp \quad PT_{mrg} \geq 0$$

11. Intermediate demand:

(a) Firm and government use:

$$ID_{ig} \geq Y_g\frac{\partial \Pi^Y_g}{\partial P_{ig}} \quad \perp \quad P_{ig} \geq 0$$

(b) Household use:

$$ID_{i,hh} \geq \sum_h C_h\frac{\partial \Pi^C_h}{\partial P_{i,hh}} \quad \perp \quad P_{i,hh} \geq 0$$

12. Aggregate consumption:

$$C_h\frac{\partial \Pi^c_h}{\partial PC_h} \geq \frac{HH_h}{PC_h} \quad \perp \quad PC_h \geq 0$$

13. Mobile capital:

$$\sum_g \theta^{km}_g \overline{K}_g \geq \sum_g Y_g\frac{\partial \Pi^Y_g}{\partial PK} \quad \perp \quad PK \geq 0$$

14. Sector specific capital:

$$(1-\theta^{km}_g)\overline{K}_g \geq Y_g\frac{\partial \Pi^Y_g}{\partial PKS_g} \quad \perp \quad PKS_g \geq 0$$

15. Labor:

$$\overline{L} \geq \sum_g Y_g\frac{\partial \Pi^Y_g}{\partial PL} \quad \perp \quad PL \geq 0$$

16. Foreign Exchange:

$$\sum_i X_i + \overline{FX} \geq \sum_i M_i \quad \perp \quad PFX \geq 0$$

D.3 Income Balance

This condition requires that incomes levels must be equal to the value of endowments. There is one condition for each agent in the model.

17. Government (including tax flows on production):

$$GOVT = \sum_h PC_h \overline{TH}_h + PFX\overline{BOP} + \sum_i (PD_i \overline{TD}_i + PM_i \overline{TM}_i) + \sum_{mrg} PT_{mrg} \overline{TT}_{mrg} +$$

$$\sum_g ty_g Y_g \left[\theta_g^d PD_g^{1+\eta^Y} + (1-\theta_g^d) PX_g^{1+\eta^Y} \right]^{1/1+\eta^Y} + \sum_{ig} \phi_{ig} \tau_{ig} ID_{ig} P_{ig} + \sum_{hi} \alpha_i \tau_{i,hh} ID_{i,hh} P_{i,hh}$$

18. Households:

$$HH_h = \sum_i (PD_i \overline{HD}_{hi} + PM_i \overline{HM}_{hi}) + \sum_{mrg} PT_{mrg} \overline{HT}_{h,mrg}$$

$$PL\overline{LS}_h + PK\overline{KSM}_h + \sum_i PKS_i \overline{KSF}_{hi}$$

Table 10: Data Parameters

Type	Symbol	Description
Cost Shares:		
	θ_g^d	Cost share of revenue function in production
	θ_{ig}^{yd}	Cost share of intermediate demand input to production
	θ_g^l	Cost share of labor as input to production
	θ_{mrgig}^{ig}	Cost share of transfers as input to intermediate goods
	θ_{ig}^{id}	Cost share of Armington input to intermediate goods
	θ_{mrg}^{tt}	Cost share of inputs to transfer demand
	θ_i^{xx}	Cost share of export input
	θ_i^{xm}	Cost share of imports input
	θ_{mrgi}^{xt}	Cost share of transfer input
	θ_{pub}^G	Cost share of government demand
	θ_h^c	Cost share of consumption
	θ_g^{km}	Cost share for mobile versus sector specific capital
	θ_g^{ke}	Cost share of capital versus energy demand
	θ_g^{va}	Cost share for value added
Elasticities:		
	σ^{di}	Armington substitution elasticity
	σ^{ke}	Capital-Energy substitution elasticity
	η^Y	Transformation elasticity domestic and exported goods
Data Parameters:		
	ty_g	Tax rate on output
	τ_{ig}	Tax rate on intermediate demand inputs
	ϕ_{ig}	Policy parameter
	α_i	Endogenous tax multiplier
	$\overline{D}_*$	Benchmark domestic good supply
	$\overline{M}_i$	Benchmark imported good supply
	$\overline{TT}_{mrg}$	Benchmark transfer supply
	$\overline{K}_g$	Benchmark total capital supply for good g
	$\overline{L}$	Benchmark total labor supply
	$\overline{FX}$	Benchmark foreign exchange supply
	$\overline{TH}_{hh}$	Benchmark transfers from households
	$\overline{BOP}$	Benchmark balance of payments
	$\overline{TD}_i$	Benchmark government domestic good endowment
	$\overline{TM}_i$	Benchmark government imported good endowment
	$\overline{HD}_{hi}$	Benchmark household domestic good endowment
	$\overline{HM}_{hi}$	Benchmark household imported good endowment
	$\overline{HT}_{hmrg}$	Benchmark household transfer endowment
	$\overline{LS}_h$	Benchmark household labor endowment
	$\overline{KS}_{hi}$	Benchmark household capital endowment