# Distributive Impacts from a Kyoto Policy

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## 1. Introduction

Energy plays a substantial role in present-day society. It improves the quality of life by providing physical comforts like heating, cooling, cooking and light to name a few. Energy also plays an integral role in supporting income-generating and livelihood activities. For example, electricity is essential for running irrigation pumps which are critical for many small farms in developing countries. Electricity is also an essential input for increasing the productivity of many industries, especially in the informal sectors. Processes that depended on human or draught power in the past, but that have been substituted with modern forms of energy, have seen dramatic increases in productivity—subsequently improving the welfare levels of many of the impoverished.

Many developing country governments have responded to increasing energy demands based on the understanding of the close dependency between energy and economic growth. In some countries, these energy plans have included the poor but in many countries the main focus has been on providing energy to large industrial sectors with the hope that the "trickle down theory" of economic growth will provide the benefits to the poor through increased wages and employment. No doubt, some of this has happened. However, the extent and depth of the trickle down effect is questionable and there is a real concern if energy becomes an essential service that would be available to all individuals like health and education.

This asymmetric treatment of the relationship between energy, economic growth and human well-being has translated into national governments paying undue attention to the provision of energy for the formal industrial sectors in the economy—the traditional engines for economic growth—while the informal and residential sectors have been given secondary priority **(**TNI 2003**).**

The growing energy divide among the various sectors in many developing countries was further exacerbated by the structural adjustment programs which emphasized the process of liberalization and privatization of the energy market. It forced many poor households to lose access to many of the basic amenities provided by energy supplies **(**Boardman 1995). In a similar vein, many small industries were forced to close down or experienced economic losses due to higher energy costs (TNI 2003). Both factors caused many of the lower-income households to suffer a loss in access to many of the basic amenities provided by energy and subsequently have experienced a real decline in their quality of life**.**

In this paper, we develop a welfare model based on consumer surplus and run a number of simulations looking at the welfare losses accruing from energy price increases caused by a shift to reduce carbon emissions by six per cent of 1990 levels. The price increases we use for this paper are derived from the MARKAL-EQUITY model (Guertin 2002). The energy demand function and the respective price elasticities used in this model are similar to the functions used in the MARKAL-EQUITY model.

The results from the various simulations run in this exercise show that the lower-income groups suffer larger welfare losses than the higher-income groups. An interesting result that emerged from the experiments is the "in-egalitarian" outcome from an egalitarian experiment. The low-income groups are unable to meet basic energy demands under a standard egalitarian simulation.

The paper is structured as follows. The following section includes a brief discussion of the various welfare standards that can be used and an explanation of why we chose consumer surplus. In section three, a literature review of existing studies looking at welfare impacts of energy price changes is presented. Section four has a description of the compensation model we use in this study. This is followed by a section describing the results from a number of experiments. In section six, we address the policy implications that arise from the results arising from the experiments. The paper ends with a synopsis of the main points highlighted in this study.

## 2. Welfare Measures

Households experience a change in well-being when they face an increase in energy prices, such as electricity, natural gas or oil. Households respond by either reducing their energy consumption; replacing inefficient technologies with more efficient appliances to reduce fuel/energy use; switch to cheaper fuels or energy sources; re-allocating their resources within their budget to maintain the present energy consumption; or any combination of the above options. Tienda and Aborampah (1981) found that in the five years following the 1973 oil embargo, several households reported switching to alternative fuels while many others experienced "decreased physical comfort" by reducing consumption. If energy prices were to continue to increase, most households favoured conservation strategies like turning off lights not in use, lowering indoor temperature a few degrees or limiting the hot water use for bathing and washing.

However, low-income households already use low levels of energy. Their ability to cope with increases in energy prices is limited. Their current low levels of energy consumption might not leave them with much margin or flexibility to substantially reduce their consumption. Furthermore, because of their low level of income, they might not be able to purchase more efficient appliances and furnaces, or weatherize their homes. The asymmetric impact of energy price increases across different income groups makes assessing the impact on the well-being of households a necessity.

Economic theory tells us that households maximize their utility within a budget constraint. The basket of goods finally purchased is dependent on the marginal utility the individual gets from the good and the marginal rate of substitution with other goods. A household demand function for each commodity can be derived from such a utility-maximizing household. Within the theoretical economic framework, one sees that any change in price will change a household's demand for goods and thus its level of welfare.

Changes in prices will have welfare impacts across individuals. These welfare impacts will be different across different income groups. Economists use three different measures to compute welfare changes caused by price changes. The first two, equivalent and compensation variation, are known as the exact measures while the third, consumer surplus, is termed as the approximate measure. The final choice over which measure to use is influenced by the magnitude of price change, the degree of price elasticity and the complexity of the demand function. The EV and CV are known to be exact measures of welfare change but are complex and difficult to compute. The CS on the other hand is a less exact measure of welfare change but is simple to compute. The CS is still the more popular measure used in empirical studies and has been proved to be a relatively close substitute for EV and CV when the price shifts are small and income elasticities are low (Bacon 1995, Dumagan and Mount 1982).

## 3. Brief Overview of Existing Studies

In the economic literature, two separate streams of work assess and investigate distributional impacts of energy prices increase, depending on the cause of the increase in price. The first stream of work relates to the introduction of an energy or carbon tax while the second to utility price increase due to economic reform programs. However, irrespective of the reason for the price increase, the welfare impacts can be assumed to be the same across the various income groups.

A majority of recent studies have focused their attention on carbon and energy taxation as a result of the climate change issue. Energy taxation is often investigated using an I/O model coupled with a demand model. The I/O model relates energy usage and $CO_2$ emissions for industries and final consumers, and can determine the increase in prices caused by a carbon or energy tax. The basic assumption of I/O models is that increase in prices is pushed to the final consumer.

This increase in prices of goods is the entry point for demand models that determine the distributional impacts of these price increases on household categories. This approach, using an I/O model coupled with a household demand model, has been applied for Australia (Cornwell and Creedy 1997), Canada (Hamilton and Cameron 1994), Spain (Labandeira and Labeaga 1999), the U.K. (Symons et al. 1994) and the U.S.A. (Casler and Rafiqui 1993, Herendeen and Fazel 1984).

The level of taxation used in these studies is exogenous. They are either taken from other studies (Cornwell and Creedy 1997, Labandeira and Labeaga 1999), fixed at some level (Casler and Rafiqui 1993, Herendeen and Fazel 1984). However, Hamilton and Cameron (1994) as well as Symons et al. (1994), who used an I/O model coupled with a demand model, computed the tax endogenously by specifying a $CO_2$ emission constraint.

Only two studies assessed the distributional impacts of a carbon tax on different household categories using an integrated general equilibrium framework. Aasness et al. (1996) used an integrated energy-environment model (empirical general equilibrium model) to assess distributional impacts following the introduction of a carbon tax in Norway, while Yang (2001) used a computable general equilibrium for Taiwanese households.

All studies, with the exception of the Norwegian study, showed that low-income groups are more likely to feel the adverse impacts of energy taxes than high-income groups. In the case of Norway, positive trade effects caused by an increase in energy prices caused household utility prices to increase but not as much for the lower-income households (Aasness et al. 1996). Results for Spain show an ambiguous distributional variation in welfare losses (Labandeira and Labeaga 1999). Hope and Sing (1995), stress that distributional impacts of an increase in energy prices depend on the structure of the energy demand coupled with the mitigation assistance programs implemented.

The advantage of the general equilibrium framework over a partial equilibrium framework is the inclusion of many sectors of the economy which takes into account not only the direct impacts of carbon taxation on energy usage, but also indirect impacts. Indirect energy use consists of energy that is used as input to produce other energy products (e.g., electricity from fossil fuel products) and non-energy products. Casler and Rafiqui (1993) show that when indirect effects of an energy tax are taken into account, the fuel tax is less regressive for the low-income groups. It leads them to propose to exempt from taxation all direct energy purchases by consumers (Casler and Rafiqui 1993).

The second stream of work looks at distributional effects of utility price increases due to economic reform programs in the energy sector. We focus here on increases of energy prices, particularly electricity. Lampietti et al. (2001), analyzed the price increase of electricity in Armenia on January 1, 1999. They showed that the lower-income groups were hit hardest by the 47 per cent price increase of electricity. The lower-income groups experienced a much larger drop in energy consumption even in the presence of family assistance programs.

Freund and Wallich (1996, 1997) investigated welfare losses on quintiles following a hypothetical 80 per cent energy price increase in Poland. They showed that welfare losses are smallest for the lowest quintiles. Higher-income households are relatively worse off. These results contrast with studies of energy price increases in the North. This is explained by the fact that, in Poland, the structure of energy demand is the opposite of the structure in developed countries: higher-income groups spend a larger amount of their budget on (conventional) energy expenditures, both in absolute and relative terms (ibid). When looking specifically at electricity, their results are comparable to the ones obtained in developed countries, i.e, poorer households spend a bigger share of their budget on electricity than other income groups and, as a result, experience a bigger welfare loss when the price of electricity increases.

Waddams, Price and Hancock (1998) investigated the welfare impacts caused by a decrease in utility prices following privatizations in Great Britain. Their study shows that the lowest quintile benefited most from the decrease in gas and electricity prices.

However, after removing the effects of privatization and only leaving the effects of structural price changes (due to the removal of cross subsidies), the authors show that the gains are small and ambiguous when looking across income groups. However, more structural price adjustments are likely to follow in the coming years, and the authors expect that the lowest-income group will be hit the hardest.

The literature review shows that the income group whose energy consumption share is the greatest will experience the greatest impact following a rapid increase in energy prices. In almost all cases we reviewed, low-income groups are hit the hardest as they have the greatest energy budget in relative terms. It is not always the case in developing countries, where higher-income groups have sometime the greatest ("modern") energy budget. Modern energies, as opposed to traditional energies, include electricity, gas and LPG, and they are usually cleaner. There is a strong correlation between the income and the energy carrier used: the greater the household income, the cleaner the fuel used. This is referred to as the "energy ladder." This might also explain variations observed within the lower-income groups with respect to impacts of energy price increases.

## 4. The Canadian Residential Sector Model

The Canadian residential sector is "driven" by the vector of demands for energy services (space heat, water heat, lighting, appliances). Generally, lower-income households in Canada allocate a greater share of their budget to energy expenses than higher-income groups (See Table 1). It can therefore be anticipated that increases in energy prices caused by climate change energy policies will be borne disproportionately by lower-income groups. However, the magnitude of these impacts on these groups has yet to be determined within an energy demand modelling framework.

*Table 1: Canadian Income Groups and their Energy Expenditures in 2000*

| Group | Income Range | Electricity Expenditures | Fuel Expenditures | Total Expenditures | Ratio of Total Energy Expenditures to Total Expenditure |
|---|---|---|---|---|---|
| Low | < $30,180 | 900 | 851 | 21,564 | 8% |
| Medium | $30,180 – $61,849 | 964 | 1,089 | 47,166 | 4% |
| High | > $61,849 | 1,061 | 1,301 | 95,753 | 2% |

Source: Compiled from Statistics Canada (2001, 2002)

The residential sector was divided into three income groups. The income groups were determined using the 2000 household spending survey (Statistics Canada 2001). This survey is processed in two separate datasets, one on household expenditures and the other on equipment. Statistics Canada (2001) performed the categorization of income groups based on the household equipment dataset whose reference period is December 31, 2000, while the household expenditure reference period is January 1 to December 31, 2000. It results in a slightly different number of reporting households, but the difference is considered marginal.

Table 2: Database Parameters by Income Group

| Parameter | Income Group | | |
|---|---|---|---|
| | Low | Middle | High |
| Number of households* | 150 | 200 | 90 |
| Household size | 2.5 | 3.3 | 3.5 |
| Income | $19,000 | $44,000 | $82,000 |
| Number of electricity-heated houses* | 94 | 111 | 47 |
| Number of gas-heated houses* | 56 | 89 | 43 |
| Percentage of gas-heated houses* | 37% | 45% | 48% |
| *Energy Consumption* | | | |
| Appliances and lighting | 24 GJ | 31 GJ | 37 GJ |
| Water heating | 25 GJ | 30 GJ | 33 GJ |
| Space heating | 70 GJ | 72 GJ | 79 GJ |
| Total | 119 GJ | 133 GJ | 149 GJ |
| Percentage of appliance and lighting* | 20% | 23% | 25% |
| Percentage of water heating* | 21% | 23% | 22% |
| Percentage of space heating* | 59% | 54% | 53% |
| *Characteristics related to location of house* | | | |
| Percentage of houses in eastern provinces (Ontario and Maritimes) | 55% | 44% | 35% |
| Percentage of houses in the prairies | 44% | 52% | 57% |
| Percentage of houses in British Columbia | 1% | 4% | 8% |
| Energy price in 1993 (SH and HW) | 11.5 | 10.6 | 10.2 |
| Electricity price in 1993 (AL) | 15.7 | 15.4 | 15.1 |
| Heating degree days | 5283 HDD | 5374 HDD | 5573 HDD |
| Ground temperature ($^0$C) | 6.7 | 6.6 | 6.4 |
| *Characteristics of house* | | | |
| Floor area of house | 100 | 117 | 134 |
| Number of storeys | 1.2 | 1.3 | 1.3 |
| Area of heated basement | 38 | 50 | 60 |
| Number of doors | 2.4 | 2.7 | 2.9 |
| Number of windows | 9.9 | 10.5 | 12.8 |
| Number of sky windows | 0 | 0.1 | 0.1 |
| Size of hot water tank | 182 | 186 | 201 |
| Index for hot water tank insulation | 0.19 | 0.10 | 0.08 |
| *Characteristics of appliances* | | | |
| Number of frost-free refrigerators | 0.8 | 1.1 | 1.1 |
| Number of non-frost-free refrigerators | 0.4 | 0.2 | 0.2 |
| Index for freezer | 0.8 | 0.9 | 0.8 |
| Age of range | 10.2 | 9.5 | 8.6 |
| Index for cooktop | 0.06 | 0.11 | 0.11 |
| Index for air conditioning | 0.1 | 0.2 | 0.3 |
| Number of lights | 26 | 38 | 48 |
| Index for furnace fan | 0.9 | 0.9 | 1.0 |
| *Household behaviour* | | | |
| Annual average of indoor temperature (Celsius) | 19.7 | 19.4 | 18.9 |
| Number of washer loads per year | 279 | 353 | 387 |
| Number of dryer loads per year | 209 | 274 | 339 |
| Number of dishwasher loads per year | 64 | 152 | 229 |

Source: CREEDAC (2001)  Note: All values are average values unless specified by*.

Table 2 presents an energy profile for the three income groups used in this study. The profile was developed using the expenditure and equipment data statistics from Statistics Canada. We note that the lower-income group uses the least energy overall (20 per cent less than the higher-income group. And if we look at the corresponding energy expenditure from Table 1, we observe that the low-income group spends about 35 per cent less than the high-income group. However, if we shift our attention to the ratio of energy expenditure to total expenditure, it was the largest for the low-income group—a staggering 300 per cent higher than the high-income group.

Another interesting observation from Table 2 is the proportionally larger amount of energy used for space heating by the low-income group *vis-à-vis* the high-income group even if they have smaller houses with the least-heated basement area and fewer doors and windows. This may be explained by the higher annual average indoor temperatures in low-income homes. Why do these homes have a higher indoor temperature than the higher-income homes? Schwarz and Taylor (1995) also observed this relationship in their study but were not able to explain it. Possible explanations range from older houses with more draft to demographic factors like age and culture. It is an observation worth exploring in future studies.

## 5. A Compensation Model

The majority of studies looking at welfare impacts caused by price changes in the energy sector have focused on analyzing the changes in welfare and the corresponding adjustments that need to be made in order to compensate the groups that witness a drop in welfare. The resources required for compensating the groups, however, either come from other sectors (cross-subsidies) or from general government revenues. One of the major weaknesses of these studies is the treatment of the residential sector as a homogenous group. This is definitely not the case as the willingness and the ability to pay higher energy prices vary across income groups. Therefore, any compensating policy that does not make this differentiation will in essence be unjust to the poor.

The approach we take in this study is slightly different. We take advantage of the willingness to pay concept underlying demand functions. A demand function essentially demonstrates or captures the willingness to pay by the respective individual or group for a particular economic commodity across a range of prices. In this study, we propose to estimate the demand function for energy services—in particular space heating service—for the low-income, middle-income and high-income groups. This way, we are able to capture the higher willingness to pay for energy services by the higher-income groups for energy services and use this as potential policy leverage for a differentiated energy pricing system.

In Figure 1 below, we illustrate the simple logic underlying the approach used in this study. The areas ZP0A and YP0B illustrates the consumer surplus experienced by the high- and low-income group respectively when price of energy service is $P_0$. Now if there is a price increase to $P_1$, the consumer surplus for the high and low-income falls to ZP1C and YP1D. Both groups experience a drop in consumer surplus. Both groups also see a drop in the quantity of energy service consumed—ΔQH and ΔQL. The percentage drop across the two groups is determined by the slope of the graphs and the intercepts. And if the demand function is expressed in logs, then the slope is also the price elasticity.

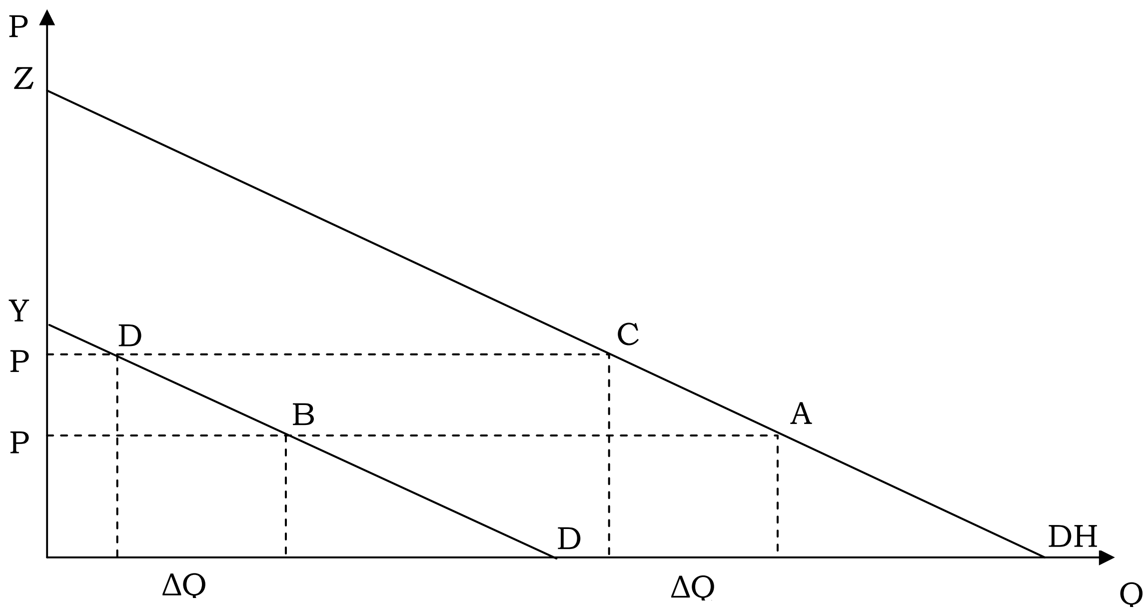

Figure 1. Demand functions and consumer surplus.

The question that arises relates to the fairness of the price increase. To answer this question, we will first need to estimate the demand functions for the respective income groups. Once we have the demand functions, we will want to develop a model that is able to compute the ex-ante and post-ante consumer surplus for price changes. The model should also be formulated such that consumer surplus transfers among income groups can take place in order to satisfy fairness criteria. The description of the model is presented next.

### 5.1 The Mathematical Model

In the compensation model we developed for this study, we maximize the sum of consumer surplus of the three income groups. We do not assign any weights to the respective consumer surplus of each group and we assume that they are treated equally. We bring in the issue of fairness through the use of constraints and rules which are imposed directly within the model structure.

Maximize Joint final consumer surplus CS where:

$$FCS = \sum_{i \in I} z_i$$

s.t

$$\Delta x_i = A_i \int_{p_{ipost}}^{p_i^0} p^{b_i}\, dp$$ change in consumer surplus for consumer i

$$y_i = \frac{\Delta x_i}{\left[ A_i p_i^{b_i+1} \big/ b_i + 1 \right]_{p_i = p_i^0}} X100$$ Percentage change in consumer surplus

$$z_i = y_i + \sum_{\substack{j \in J \\ j \neq i}} v_j^t$$ Consumer surplus after transfer

$$\sum_{j \in J} v_j^t = 0$$ Net transfer of consumer surplus

$$z_i = \left[ \frac{A_i p_{ipost}^{b_i+1}}{b_i + 1} \right]$$ New price after consumer surplus transfer

$$e_i = A_i p_{ipost}^{b_i}$$ New level of energy service used after transfer

## 6. Experiments and Results

In the model described above, all prices are exogenous except for the new price that is computed after a consumer surplus transfer is done. The exogenous prices we use are derived from the MARKAL-EQUITY (ME) model (Guertin et Al. 2003). The ME is regionally disaggregated and we use the prices for Alberta in the three experiments we ran below. The prices we get from the ME model reflect a Kyoto Protocol scenario—in this case, a six per cent reduction in carbon dioxide emissions from 1990 levels which is to start in the year 2010. The prices used were as follows: (1) 2000 – \$12.27; (2) 2005 – \$13.92; (3) 2010 – \$17.71; (4) 2015 – \$15.94; and (5) 2020 – \$17.64. All prices are in Canadian dollars and are for a GJ of energy service.

We then ran three experiments under the price regime for the Kyoto Protocol. The first experiment is called the Pareto Efficient Simulation (PES). In this simulation, we maximized joint sum of consumer surplus of all three groups but without allowing the transfer of consumer surplus among the various income groups. No emphasis was put on any particular income group. This simulation produces a Pareto efficient solution.

In the second experiment, we imposed a rule within the model framework that made sure that the percentage changes in consumer surplus across the three income groups were equal. This simulation is called the Egalitarian Simulation (ES).

In the third experiment, we shifted our focus away from the monetary dimension of utility and instead focused on meeting some minimum level of energy which all income groups will need for domestic comfort. The third experiment is called the Basic Need Simulation (BNS).

### 6.1 Experiment One: Pareto Efficiency

In this experiment, we ran a relatively straightforward simulation whereby the joint consumer surplus of all three income groups was maximized. No transfer among income groups is allowed to take place. In other words, $v_j^t = 0 \quad \forall j$ was imposed in the model structure.

Figure 2 shows the drop in energy use by the various income groups when a six per cent reduction of 1990 levels is implemented. The high-income group experiences the biggest drop in energy consumption followed by the middle- and low-income groups respectively.

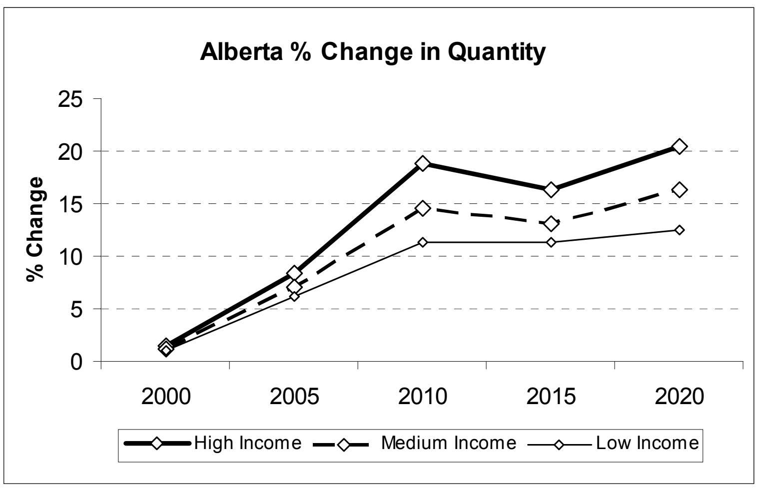


Figure 2. Percentage change in quantity of every service caused by price increase due to a carbon constraint.

However, we get a slightly different picture if we turn our attention to welfare impacts caused by the carbon constraint policy. Figure 2 shows that the low-income group suffers the biggest drop in welfare (as measured by consumer surplus) followed by the middle- and high-income groups respectively.

It would seem that from a welfare perspective the low-income suffers the most from a Kyoto Protocol. Although they see the smallest drop in the quantity used, the fact of the matter is that because they are already using a low level of energy in the first instance and have limited scope to reduce energy use further—they need the basic level to keep warm. Therefore, the marginal drop in welfare for a unit less of energy used is much larger for the low-income group *vis-à-vis* the other two income groups. Needless to say, the high-income group experiences the smallest drop in welfare.

The above results highlight the importance of using the right informative space when evaluating the impacts of the Kyoto Protocol across different segments of society. If quantity of energy is used as the informative space for welfare impacts, then we come to a conclusion that the high-income groups are the hardest hit by the measure while leaving the poor marginally affected. However, if we use change in consumer surplus as the informative space to evaluate welfare impacts, we then conclude that the low-income group suffers the largest drop in welfare while the high-income group experiences a marginal change in welfare. It is therefore critical that we use the right informative space when analyzing the impacts of the Kyoto Protocol in order to design appropriate policies to dampen the impacts across vulnerable segments of society like the low-income groups.

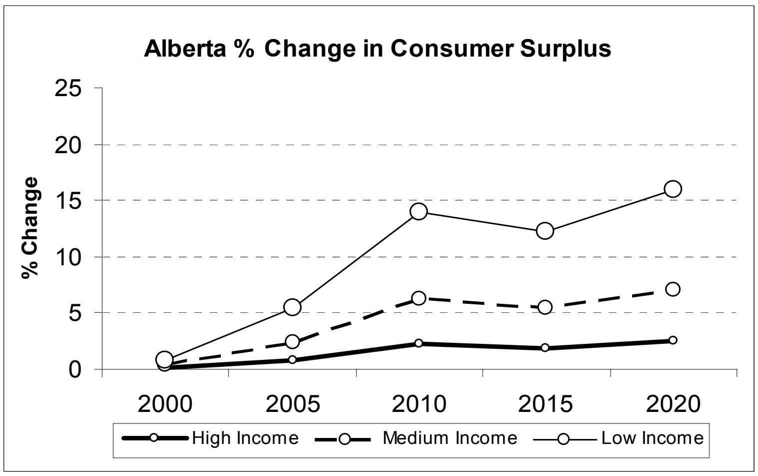


Figure 3. Percentage change in consumer surplus caused by price increase due to a carbon constraint.

## 6.2 Experiment Two: An Egalitarian Simulation

In this experiment, the percentage change in consumer surplus, $Y_{i,}$ caused by a price change is equalized across the three income groups. In order to achieve this, we allow the transfer of consumer surplus among the three income groups. Once the new consumer surplus has been computed after the transfer, the new price and quantity of energy service used is found.

If we compare the quantity change under the egalitarian scenario (Figure 4) with the utilitarian simulation (Figure 2), we find that the middle and low-income groups experience a smaller drop in quantity purchased *vis-à-vis* the higher-income group. This is primarily caused by the transfer of consumer surplus from the high-income to the other two incomes in order to satisfy the equity rule.

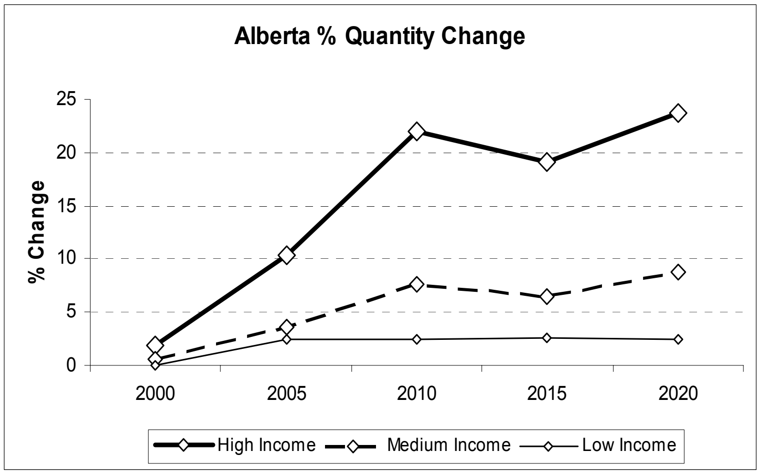


Figure 4. Percentage change in quantity of every service after price increase under an egalitarian region.

The transfer of consumer surplus from the high-income group to the other two groups allows the latter two to cushion the impact of the price increase and experience drops in welfare that are comparable to the high-income group. Figure 5 shows the change in consumer surplus experienced by all three groups. In comparison to the Pareto Efficient Solution (see Figure 3), the high-income group experiences a slightly higher drop in welfare *vis-à-vis* the other two income groups.

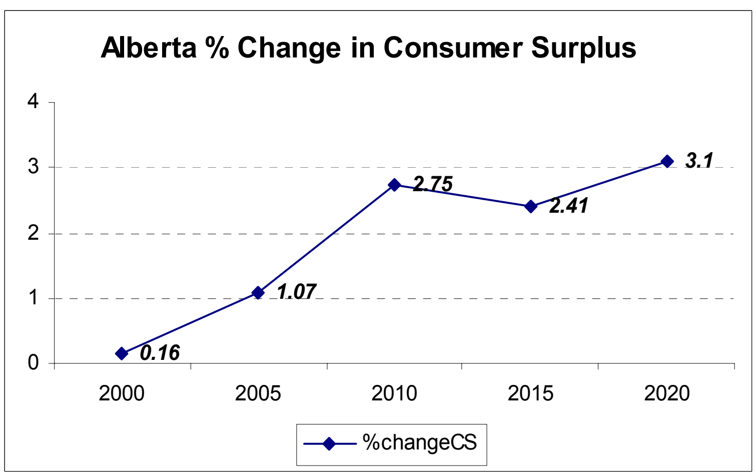


Figure 5. Percentage drop in consumer surplus experienced by all three groups under an egalitarian regime.

However, the higher drop in consumer surplus experienced by the high-income group allows a much smaller drop in consumer surplus experienced by the middle and lower-income groups. In marginal terms, the marginal benefit accrued to both the middle- and low-income groups from a percentage drop in consumer surplus of the high-income group is approximately 28 per cent. In other words, for every additional percentage drop in the consumer surplus of the high-income group allows us to reduce the loss in consumer surplus of both the middle and low-incomes groups by 28 per cent.

In order to provide the consumer surplus transfer, it was necessary to have an energy price differentiated system. The high-income group is charged a higher price than the other two income groups in order to facilitate the transfer of consumer surplus.

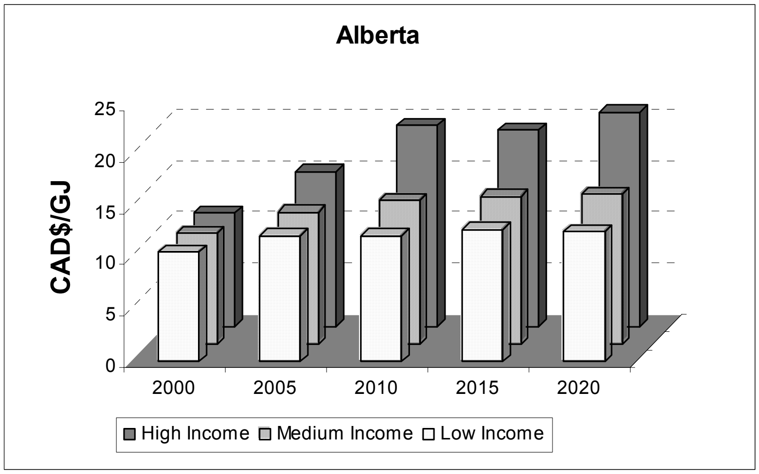


Figure 7. Price regime under an egalitarian system.

This means that, in actuality, if policy-makers want to provide an equitable energy policy under the Kyoto Protocol, they will need to introduce an energy price differentiated system whereby the high-income group pays a higher price than the price increase suggested by MARKAL-EQUITY or any of the other energy models used to predict the energy pricing strategy under the Kyoto Protocol. Figure 7 shows the new prices the three income groups are charged under an egalitarian system.

It can be seen that there is quite a bit of price difference between the high-income group *vis-à-vis* the other two income groups. Is this a viable option? The demand functions of the group suggest that the high-income group will pay this price based on their revealed willingness to pay. We should, however, understand that the demand functions were estimated without taking into assumption that the high-income group will not behave differently in the presence of a differentiated price system. It may turn out to be the case whereby this group actually changes its energy demand behaviour primarily because of the use of a differentiated price system which they think is unjust. This is an extension worth pursuing in the future.

### 6.3 Experiment Three: The Basic Need Simulation

In this simulation we impose a social condition which stipulates explicitly that the low-income group should not experience a drop in energy use lower than the level experienced prior to the implementation of the Kyoto Protocol through a price hike. Figure 8 shows that the low- and middle-income groups do not experience a fall in their energy consumption. However, in order to accommodate this, the high-income group sees a higher drop in energy consumed caused by a transfer of consumer surplus to the other two income groups.

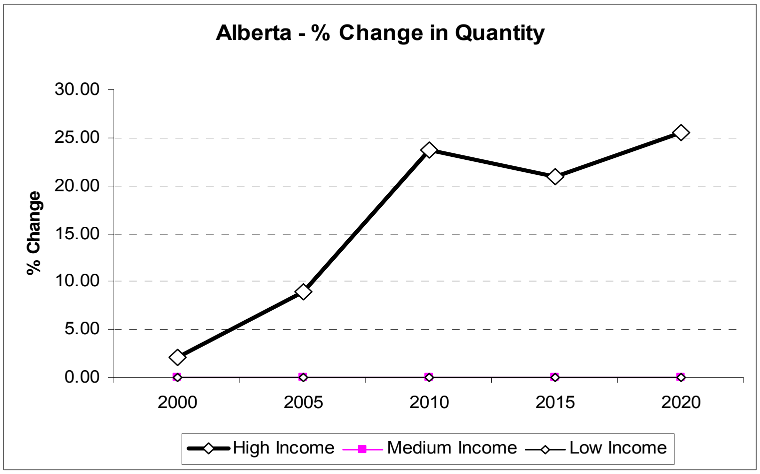


Figure 8. Percentage change in quantity under a SMS scenario.

The pricing structure used to achieve this result is shown in Figure 9. It is interesting to note that the differential cost incurred by the higher-income group (in terms of loss in consumer surplus) for allowing the other two groups to see a negligible decrease in their energy use is lower than the cost incurred under the egalitarian scenario. For example, under the BNS scenario, a 1.93 per cent decrease in energy use by the high-income group in 2020, induced through an increase in price could be used to make sure that the middle- and low-income groups do not see a drop in energy demand. In the case of the egalitarian scenario, the high-income group sees a drop in quantity of 23.66 per cent in order to mitigate the drop in quantity experienced by the low and middle income groups of 8.72 and 2.5 per cent respectively. In other words, for a further decrease in energy use by the high-income group of 1.93 per cent, we can mitigate completely the 8.72 and 2.5 per cent reductions in energy use by the other two income groups. The price differential we need to implement in order to achieve this result is a $1.10/GJ.

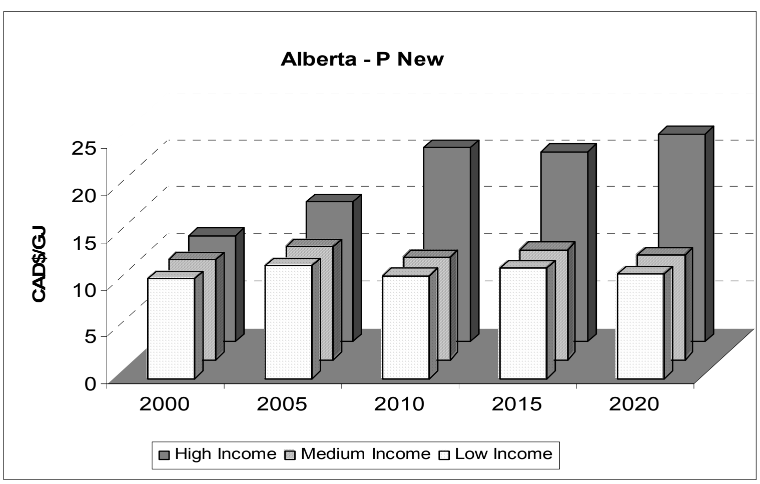


Figure 9. Price regime under a BN scenario.

## 6.4 Spatial Implications

In the previous sections, we had discussed the results for the Canadian province of Alberta. In many studies, the impacts on welfare are usually aggregated at the national level and in many instances regional disparities are ignored. How big are regional disparities and are they worth considering?

MARKAL-EQUITY (ME) is able to provide prices for energy at a provincial level. In this section, we take advantage of this additional information and investigate the spatial implications of the Kyoto Protocol and especially the distributive impacts. Our main aim is to study the differences in energy consumption as well as changes in consumer surplus income groups experience in different provinces.

The demand functions we use in the analysis are not different for the various provinces. Therefore, the willingness to pay for energy by the three income groups is assumed to be the same across the various provinces in Canada. This may not turn out to be true, but due to the complexity of estimating such a demand function and the limited scope of data available, we felt that this was an appropriate assumption to make in this study. It is definitely worth exploring the differences in energy use and demand behavior across the provinces in a follow up study.

We ran the model using the prices derived for Ontario from ME. The results in Figure 2 show the consumer surplus drop among the three income groups in Alberta under a utilitarian regime. Figure 9 below shows the change in consumer surplus incurred by the three income groups in Ontario, again under a utilitarian regime. Observation of the two graphs shows that residents in Ontario face smaller drops in amount of energy used as well as consumer surplus lost as compared with residents in Alberta if a carbon constraint is imposed.

The main group at a disadvantage is the low-income group in Alberta who face a drop of approximately 16 per cent versus the 11 per cent drop experienced by the low-income group in Ontario. Interestingly, (see Figure 9) the difference between the middle- and high-income groups across the two regions is much smaller than that observed among the low-income group.

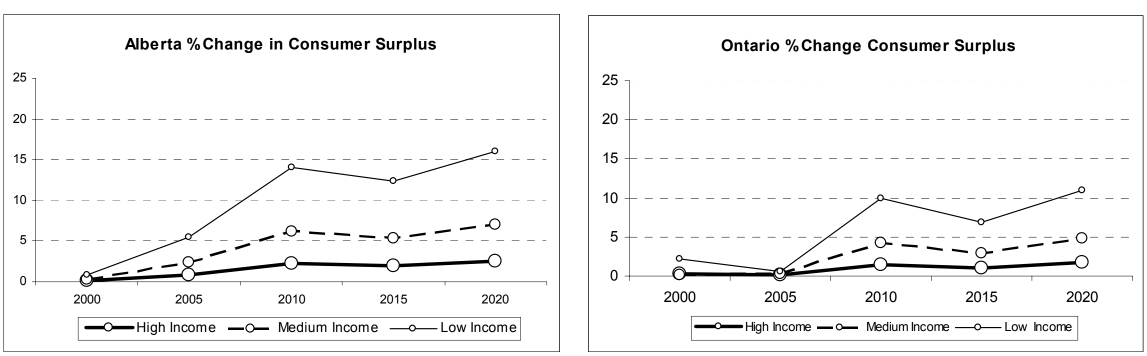


Fig 9. Percentage change in consumer surplus in Alberta.

The general trend among the two provinces is observed to be the same. In the egalitarian scenario, a transfer of consumer surplus is needed from the high-income to the middle- and low-income groups. However, because of the smaller change in consumer surplus experienced among the low- and middle-income groups, the transfer from the high-income group is not as large as that experienced by the high-income group in Alberta. This implies that the final prices implemented in Ontario will be higher for the low and middle income group and lower for the high-income group *vis-à-vis* the same income groups in Alberta.

## 7. Policy Implications

The results from the three experiments demonstrate that Kyoto Protocol climate change policies will inadvertently imply an increase in prices of energy utilities leading in turn to higher energy service prices experienced by the residential sector. The results also demonstrate quite clearly that the price increases will have a more detrimental impact on the welfare level of low-income households if we assume that welfare changes are captured by changes in consumer surplus and not by changes in level of energy service used or consumed.

The next question that needs to be addressed is what can be done about it. The current energy utility sector is characterized by a multitude of pricing schemes. Can we use one of these two pricing schemes (see Box 1) in a manner that will allow the poor to have access to energy services in order to meet their basic needs as well as produce a fair

Box 1. Electric Pricing Schemes

distribution of the loss in welfare computed in this study as changes in consumer surplus?

Box 1.

1) Flat rate tariff. A single rate is applied to all levels of electricity consumption.

2) Two-part tariff. It consists of two flat rates. The first part of the tariff is a fixed periodical fee that can be associated to an access fee to the network while the second part is a flat rate tariff.

3) Block structure tariff. The block structure tariff includes two levels of consumption or more. The price of electricity either increases or decreases with the level of electricity purchased, named increasing block tariff and decreasing block tariff, respectively. For example, in Armenia, the first 100 kWh of electricity purchased is charged at the rate of 15 ARD/kWh. The second block covers electricity purchased from 100 to 250 kWh and the rate increases to 20 ARD/kWh. Finally, the third block rate is 25 ARD/kWh for all electricity purchased exceeding 250 kWh (Lampietti et al. 2001).

4) Lifeline tariff. A lifeline tariff refers to a rate set below the costs of supplying the service. It can be viewed as a subsidy to the group who benefits from the lifeline tariff.

All four systems as presently structured will clearly not address distributive issues as they do not discriminate among income groups. The discrimination occurs at the level of energy utility used. However, all income groups face the same set of price discriminations. Therefore, a high-income household will pay the same rate as a low-income household. The only discrimination occurs because of the level of energy utility used by the various income groups.

For example, from Table 2, we know that the high-income group uses 149GJ of energy while the middle- and low-income groups use 133GJ and 119GJ respectively. However, we should be cautious in designing a two-part or block structure tariff rate that charges the first block of up to 119GJ at the low-income group price and the second block from 119GJ to 133GJ at the middle-income group price and any consumption above 133GJ at the high-income group price. This is because the high-income group will pay the same price as the low-income group for the first 119GJ of its energy use and only pay the higher prices for the remaining 30GJ. The consumer surplus transfer needed to allow the low- and middle-income group a lower price that the actual price will not materialize because the high-income group itself receives a subsidy by being charged a lower than actual price for the first 90 per cent of its energy use.

An income differentiated price system is required if policy-makers want to provide an equitable energy system under the Kyoto Protocol. One way of doing this is to design a price system based on income tax returns. Therefore, households will have energy utility prices based on the income of the household.

One way of dampening the tax burden of high-income groups in Canada is to provide tax rebates for the amount of carbon emissions that have been reduced because of the higher price they pay to offset the energy cost burden of middle- and low-income groups. There is a growing number of studies looking at the cost of a carbon emission and these can be used to compute the tax rebate high-income groups will be eligible for at the end of the tax year. In this way, the political feasibility of implementing a new tax in the form of higher energy prices can be increased by recycling the savings accrued by lower carbon emissions back to one segment of society which is subsidizing other segments of society by taking on the burden of higher energy prices.

However, we should caution the reader here that other variables influencing equity will need to be considered before the actual pricing bracket a household is slotted can be determined. For example, the number of members in a household is one criterion that should also be considered—a high-income household with six members is not the same as a high-income household with three members. Further studies on the demographics of the household may need to be considered before deciding the pricing structure to be imposed on a particular household.

## 8. Conclusion

This study identified the following critical points:

- The high-income group experiences the largest drop in the quantity of energy consumed followed by the middle- and low-income groups respectively when there is an energy price increase.

- The low-income group experiences the largest drop in welfare followed by the middle and high-income groups respectively when there is a hike in energy prices.

- The marginal benefit of minimizing the drop in welfare caused by an energy price increase for the low- and middle-income group by an increase in energy prices for the high-income group comes when a minimum level of energy use for the low-income group is ensured. This is the Basic Need scenario in this study. It allows the low- and middle-income groups to experience no drop in welfare.

- Low-income groups in Ontario fare better than the low-income groups in Alberta. The welfare impacts across the other two groups across the two provinces are not as pronounced as for the low-income groups.

- An income differentiated energy pricing system is needed if energy policies are to meet criteria of equity and fairness.

- A supporting policy to dampen the impacts of a higher energy price on the high-income groups is to provide a tax rebate based on the marginal reduction in carbon emissions they emit because of the higher price.

- An income determined energy pricing system can be highly useful in addressing carbon emissions and poverty reduction issues in developing countries. This is especially the case when the gap between the high- and low-income groups is substantial.

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## Appendix 1. The GAMS Program

```
* This is the egalatarian version of the compensation model
* Prices are in Cad$/GJ
* Quantities are in GJ
* Demand function used is for space heating

Set

i agents / HI High-income, MI middle income, LI low-income/ ;

Alias (i,j) ;

Parameter
PO  base price /12.47/
a(i) intercept of demand function / HI 131, MI 38, LI 15 /
b(i) slope of demand function /HI 0.43, MI 0.33, LI 0.26 /
p  equilibrium price / 17.64/  ;

Variables
z   total consumer surplus
csx(i) consumer surplus exante
CSR(I) consumer surplus reference
csp(i) consumer surplus post ante
cst(i) consumer surplus transfer
dcs(i) percentage change in consumer surplus
qo(i) base quantities purchased
q(i)  quantity purchased
qn(i)  new quantity
pn(i)  new price ;

positive variables  csx,csr, dcs,q,qn,pn,qo ;

equations

obj      objective
baseq(i)   base quantity
CONSUMREF(I) CONSUMER SURPLUS REFERENCE
consumex (i) consumer surplus exante
consumpost(i) consumer surplus post
delta (i)   percentage change in consumer surplus
rule(i)    consumer surplus transfer rule
dem(i)    demand function
balance    balancing equation
quantynew(i) new quantity after consumer surplus transfer
```

```
pricenew(i)  new price to effect consumer surplus transfer  ;


obj..  z =e= sum(i, csp(i)) ;

baseq(i)..  qo(i) =e= a(i)*po** (-b(i)) ;

dem(i)..  q(i) =e= a(i)*p**(-b(i));

consumref(i)..  csr(i) =e= 0.5*(a(i)/b(i)-po)*(b(i)*log(po)+a(i)) ;

consumex(i)..  csx(i) =e= 0.5*(a(i)/b(i)- p)*(b(i)*log(p)+a(i));

consumpost(i)..  csp(i) =e= csx(i) + sum(j $(ord (j) ne ord (i) ),cst(j));

delta(i)..  dcs(i) =e= ((CSR(i) - csp(i))/ csr(i))* 100 ;

rule(i) ..  sum(j, dcs(j))/ card (i) =e= dcs(i) ;

balance..   sum(i, cst(i)) =e= 0  ;

quantynew(i)..  qn(i) =e= a(i)*pn(i)**(-b(i));

pricenew(i)..  csp(i) =e= 0.5*(a(i)/b(i)-pn(i))*(b(i)*log(pn(i))+a(i));

q.lo(i) = 0.0001 ;
csr.lo(i) = 0.01 ;
pn.lo(i) = 1 ;
qn.lo(i) = 1 ;
*csx.l("Poor") = 130.2;
*csx.l("rich") = 348.6 ;

Model sample / balance, rule, delta, consumpost,consumex,consumref,obj / ;
Solve sample using nlp maximizing z ;

Model sample1/ balance, rule, delta, consumpost,consumex,consumref,obj,
 pricenew/ ;
Solve sample1 using nlp maximizing z ;

Model sample2/ all / ;
Solve sample2 using nlp maximizing z ;

Display qo.l,q.l, csx.l,csr.l,dcs.l,qn.l,pn.l,cst.l ;
```