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ABSTRACT

Energy Demand and Trade in General Equilibrium: An Eaton-Kortum-type Structural Model and Counterfactual Analysis*

This paper sheds light on the role of the impact of taxes on energy production versus tariffs on imported goods for trade, energy demand, and welfare. For this, we develop a structural Eaton-Kortum type general equilibrium model of international trade which includes an energy sector. We estimate the key parameters of that model and calibrate it to domestic prices and production using data for 34 OECD countries and the rest of the world in the average year between 2000 and 2005. The model helps understanding the interplay between country-specific energy productivity, energy demand, and trade. The energy sector turns out to be an important determinant of the size of welfare gains from trade liberalization. We find that general import tariffs can be an effective instrument to reduce energy demand. For small open economies, taxing imports as an indirect instrument may be even preferable to taxing energy as a direct instrument from a welfare perspective, if countries pursue the goal of reducing energy demand to a specific extent. This is not the case for large countries such as the United States.

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1 Introduction

The reduction of energy consumption is one of the central issues mankind struggles with in the wake of the 21st century. Energy consumption brings about negative externalities such emissions and pollution and their impact on the planet's climate. It is more or less uncontroversial that the world as a whole and some countries in specific have to lower their respective consumption levels. Already now, many countries provide incentives to reduce energy demand and/or encourage usage of more environmentally friendly technologies.[1] However, it is controversially debated *how*, *by how much*, and *where* cuts in energy consumption should be implemented in general.

Economists have for long analyzed problems associated with energy as a production factor at both the microeconomic and macroeconomic levels. For instance, earlier macroeconomic work points to the role of oil as one energy resource for the business cycle and suggests that almost all of the recessions since World War II were predated by energy price shocks (see Hamilton, 1983, 2005, 2009). In general, energy prices are viewed to affect economic output through five channels (see Kehoe and Serra-Puche, 1991; Rotemberg and Woodford, 1996; Bernanke, Gertler and Watson, 1997; Atkeson and Kehoe, 1999; and Barsky and Killan, 2004): final goods output prices through mark-up pricing over marginal costs which include energy costs, current account deficits through higher energy import bills, sectoral employment shifts, the timing of investments, and monetary response. Macroeconomic consequences besides the downturn in real output are reduced productivity growth and higher inflation.

With few exceptions, trade economists have paid little attention to the interplay between goods trade and energy demand.[2] Energy, however, should be relevant to many issues that

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[1]For instance, the *European Union Emission Trading Scheme* (EU ETS) places a green tax on the emitters of relatively high volumes of carbon dioxide within the member countries of the European Union. The United States discusses to launch a *Cap and Trade Program*, a similar program that entails placing an extra cost on producers with pollutant technologies. Another option to reduce carbon emissions would be through higher import tariffs on tradable resources such as crude oil or coal.

[2]In general, most of the work on the matter is concerned with the problem of carbon leakage rather than energy demand at large. The problem of carbon leakage implies that a reduction in carbon emissions in a country or group of countries will lead to an increase in emission in other countries. This problem has been extensively studied in various frameworks. For example, Babiker and Rutherford (2005) use a multi-country multi-commodity calibrated general equilibrium model to study different policy measures such as carbon import tariffs, voluntary export restraints, and carbon taxes on domestic exporters aimed at reduction of CO_2 and their implications for carbon leakage and welfare. The authors find that voluntary export restraints is an efficient measure of reducing carbon leakage but also the most costly in terms of welfare loss. Recently, Elliott, Foster, Kortum, Munson, Pérez, and Weisbach (2010) examine the effects of different tax policies on carbon emissions. The authors use a computable general equilibrium model to quantify the comparative effects of different forms of carbon taxes on emissions and conclude that border tax adjustment is preferable to a carbon tax on producers when aiming for lower global emissions without carbon leakage.

are at the heart of international trade. For instance, changes in energy prices should have an impact on the pattern of specialization (see Gelragh and Mathys, 2011).[3] This implies that tariffs on goods (not even directly on the embodied energy or carbon consumption) will affect energy demand to the extent that tradable and nontradable goods differ in their energy intensity. Moreover, changing energy prices should have an impact on the volume of trade. As countries differ starkly with regard to their productivity in energy production, and shocks to energy prices and local energy supply display a country-specific pattern, changes in the pattern of energy prices across countries affect the volume of trade.[4]

This paper's focus is on the role of the energy sector rather than emissions per se for large open economies in general equilibrium. In particular, we are interested in the consequences of instruments that affect energy demand directly (such as ad-valorem taxes on the price of energy) or indirectly (such as tariffs on imported inputs which are also or specifically used by the energy sector) for outcomes such as trade and welfare. We analyze these questions by means of a structural general equilibrium model in the vein of Eaton and Kortum (2002) which we estimate and calibrate to 34 OECD economies and a rest of the world in the average year between 2000 and 2005 to conduct comparative static effects consistent with general, multi-country, large-open-economy equilibrium. The model consists of three sectors, a final goods sector, an intermediate goods sector, and an energy sector. Energy production uses tradable intermediate goods and local labor. Final and intermediate goods production employ energy, tradable intermediates, and local labor. In this model, tariffs on tradable intermediates may be used as indirect instruments to reduce the demand for energy while ad-valorem taxes on the energy price are a direct instrument to achieve that goal.

Among a host of findings in the paper which we will explore in what follows, it is worth mentioning that a given goal of reducing energy demand may be met at lower total welfare costs when using tariffs on all imports rather than ad-valorem taxes on energy in small countries. This is not the case for large economies. The reason for that difference lies in the fact that tariff revenue gains in small economies may outweigh otherwise distorting effects of trade protection through tariffs. This renders tariffs preferable relative to energy taxation for

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[3]Steinbuks and Neuhoff (2010) suggest that one reason for specialization effects of energy demand and supply for trade is the variance of energy input coefficients across sectors. Sato, Grubb, Cust, Chan, Korppoo and Ceppiet (2007) study the possible effects of the EU's Emissions Trading System (ETS) on industry market shares and profitability. They conclude that, while most industries should benefit from the program, the tradable sector is expected to experience a reduction in market share relative to the nontradable sector.

[4]For instance, Graus and Worrell (2007) found significant differences in efficiencies in fossil power generating plants across countries. This suggests differences in comparative advantage due to differences in the efficiency of energy production and in energy prices. Finally, international goods transactions involve transport as an energy-intensive activity so that energy price shocks inter alia translate into higher non-tariff trade costs. Bridgman (2008) illustrates that this effect may explain a large part of the downturn in the growth of international trade in the 1970s, a time when tariffs were significantly liberalized.

small countries which rely more heavily on foreign inputs than large economies do. Hence, small countries will prefer to use tariffs rather than ad-valorem energy taxes to cut energy demand for a larger energy cap support region than larger countries. The welfare effects and preferable instruments vary qualitatively and quantitatively among the 35 economies considered in this study.

The remainder of the paper is organized as follows. Section 2 summarizes the model set-up. Section 3 is dedicated to the structural estimation of the model's key parameters and to the calibration. We conduct several counterfactual experiments using the calibrated model in Section 4 to shed light on how the energy sector alters the effects of trade liberalization on world general equilibrium and how import tariffs versus taxes on energy production affect welfare and energy demand differently in large as compared to small economies. We summarize the most important results and provide conclusions in the last section.

2   The model

The purpose of the model is to help us shed light on how the energy sector affects the gains from trade liberalization from the viewpoint of consumers and how a tax on energy versus imported goods affects welfare. For this, we model energy not as an endowment but as a secondary production factor which is produced locally in a country using labor and intermediate tradable goods. It is then employed in the production of both intermediate and final goods producers. We do so by following Eaton and Kortum (2002) and Alvarez and Lucas (2007) in broad terms in considering a multi-country Ricardian world. In our quantitative analysis, we calibrate the model so as to match empirical data for the OECD countries.

We formulate our model so as to fit bilateral and unilateral characteristics of the OECD. Altogether, there are $N = 35$ countries of which 34 are individual OECD members and one is a rest of the world. Each country i is endowed with L_i units of labor which is perfectly mobile between sectors but not across countries. The labor force is employed by three different types of firms: a final good producer, intermediate goods producers, and energy producers. This leads to identical wage costs across sectors but not countries. The final good and energy are non-tradable, whereas intermediate goods are tradable subject to trade costs.[5]

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[5]Assuming energy to be nontradable appears consistent with data. For instance, according to data from the US Energy Information Administration (www.eia.doe.gov), the difference between production and consumption of electricity in the OECD countries in 2005 was less than 5% which implies that export/import flows are negligible relative to total consumption. For the argument here, we have to distinguish between unrefined *energy products* (such as coal, oil etc.) and *energy itself* which is directly consumed by local producers. In the context of the model, energy products can be subsumed under the category of tradable intermediate goods. Energy itself is produced locally by, e.g., power plants, and assumed to be nontradable.

Trade costs at large encompass transaction costs and tariff barriers. We assume that trade is balanced multilaterally and, hence, there is no sector beyond the ones mentioned. Intermediate goods can be used locally only after aggregating them by using a Spence-Dixit-Stiglitz technology (SDS). The corresponding aggregate is referred to as the SDS aggregate for short hereafter. Households receive utility only from consuming the final good.[6]

2.1   Producers of intermediate goods

As in Eaton and Kortum (2002), producers of differentiated goods produce a unique product per firm j based on a Cobb Douglas technology with total factor productivity parameter $z_i(j)^{-\theta}$. The latter is drawn for each country from a distribution function. Following Alvarez and Lucas (2007), we assume that $z_i(j)$ has exponential distribution with country-specific parameter λ_i. Producers of differentiated goods use labor, the SDS bundle of intermediates, and energy as inputs, and they solve the following profit maximization problem:

$$\max_{l_i(j),q_i(j),e_i(j)} \left\{ p_i(j)z_i(j)^{-\theta}l_i(j)^{\epsilon}q_i(j)^{\nu}e_i(j)^{\mu} - p_{qi}q_i(j) - w_i l_i(j) - p_{ei}e_i(j) \right\}, \quad (2.1)$$

where ϵ, ν, and μ are the cost shares for labor, intermediates, and energy, respectively. Solving the problem yields the equilibrium price for an individual good j:

$$p_i(j) = A z_i(j)^{\theta} w_i^{\epsilon} p_{qi}^{\nu} p_{ei}^{\mu} \text{ where } A = \epsilon^{-\epsilon} \nu^{-\nu} \mu^{-\mu}. \quad (2.2)$$

2.2   Producers of the SDS aggregate of intermediates

Suppliers of the SDS aggregate of intermediates aggregate all individual varieties j of intermediate goods according to the SDS production function:

$$q_i = \left(\int_0^{\infty} j^{\frac{\sigma-1}{\sigma}} f_i(z_i(j)) dj \right)^{\frac{\sigma}{\sigma-1}}. \quad (2.3)$$

The solution to the cost minimization problem yields the price index for q in country i:

$$p_{qi} = \left(\int_0^{\infty} p_i(j)^{1-\sigma} f_i(z_i(j)) dj \right)^{\frac{1}{1-\sigma}}. \quad (2.4)$$

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[6]Hence, we should interpret utility losses from active energy policy as pure economic losses. It would be straightforward to account for energy savings (or a reduction in pollution) itself in the utility function. However, one would have to make assumptions about unobservable parameters for that. In the chosen framework, one could determine a monetary welfare equivalent to the utility gains from energy reduction which would balance the associated losses in welfare (which correspond to losses in real GDP in the adopted approach).

Following the literature, we assume that there is only one producer of the SDS aggregate in each country who does not use outside factors other than intermediates, and this producer does not exert market power.

2.3 Producers of energy

Energy producers face a country-specific total factor productivity parameter of T_i and use labor and the SDS aggregate with ζ and $1 - \zeta$ as the respective cost share parameters in a Cobb Douglas technology. Their optimization problem is as follows:

$$\max_{l_{ei}, q_{ei}} \left\{ p_{ei} T_i l_{ei}^{\zeta} q_{ei}^{1-\zeta} - w_i l_{ei} - p_{qi} q_{ei} \right\}, \tag{2.5}$$

which yields a price of

$$p_e = Z T_i^{-1} w_i^{\zeta} p_{qi}^{1-\zeta} \text{ ,where } Z = \zeta^{-\zeta} (1 - \zeta)^{\zeta - 1}, \tag{2.6}$$

per unit of energy.

2.4 Final good producers

Final good producers are perfectly competitive with identical constant returns to scale production functions. They employ l_{ci} units of labor at wage w_i each and use q_{ci} units of the SDS bundle of intermediates and e_{ci} units of energy at the respective prices of p_{qi} and p_{ei} to produce c_i units of the final consumption good. They sell their output at a price of p_{ci}. Without loss of generality and for simplicity, assume that there is only one final good producer in each country which solves the following maximization problem involving a Cobb Douglas technology:[7]

$$\max_{l_{ci}, q_{ci}, e_{ci}} \left\{ p_{ci} l_{ci}^{\alpha} q_{ci}^{\beta} e_{ci}^{\gamma} - w_i l_{ci} - p_{qi} q_{ci} - p_{ei} e_{ci} \right\}, \tag{2.7}$$

where α, β, and γ are Cobb Douglas cost share parameters for labor, intermediate input, and energy, respectively, as can be seen from the first-order conditions to this problem:

$$\alpha p_{ci} c_i = w_i l_{ci}; \ \beta p_{ci} c_i = p_{qi} q_{ci}; \ \text{and } \gamma p_{ci} c_i = p_{ei} e_{ci}. \tag{2.8}$$

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[7]Atkeson and Kehoe (1999) assume a constant-elasticity-of-substitution technology and abstract from material inputs to explain cross section versus time series patterns in the use of energy.

With perfect competition, the price of the final good is determined as:

$$p_{ci} = B w_i^\alpha p_{qi}^\beta p_{ei}^\gamma \text{ ,where } B = \alpha^{-\alpha} \beta^{-\beta} \gamma^{-\gamma}. \tag{2.9}$$

2.5 Endowment constraints

The endowment constraints are straightforward. They simply imply that firms in country i exactly employ all labor i is endowed with, that all of the SDS aggregate supplied is used in production, and that all the energy produced is used as well in each country. When expressing those constraints in per capita terms, we obtain

$$l_{ci} + l_{ei} + \int_0^\infty l_i(j) f(z_i(j)) dj \leq 1,$$

$$q_{ci} + q_{ei} + \int_0^\infty q_i(j) f(z_i(j)) dj \leq q_i,$$

$$e_{ci} + \int_0^\infty e_i(j) f(z_i(j)) dj \leq e_i. \tag{2.10}$$

3 Open-economy equilibrium

Each country's SDS producer may buy inputs around the world.[8] The autarky and trade equilibria differ with respect to the distribution of prices of tradable goods available to the SDS producer in each country. Parameter θ governs the variance of productivity and, hence, prices of tradables and plays a central role for the welfare effects of trade liberalization. The level of θ will inter alia affect the size of welfare gains in comparative static analysis.

To solve for the trade equilibrium, let us start with the distribution of $p_i(j)$ available to the SDS producer in each country at given trade costs. We distinguish between tariffs and other trade cost factors as follows. Denote $t_{in} \geq 0$ as the ad-valorem tariff that country i imposes on goods from n and assume that tariff revenues are rebated as a lump-sum transfer to the consumers in i[9]. Let d_{ni} represent iceberg trade costs expressed as the number of

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[8]In fact, if we ruled out trade in intermediate goods, we could even solve for the closed economy equilibrium price and quantity vectors analytically. However, the open-economy equilibrium requires numerical solutions under the adopted assumptions, because SDS producers in i will look around for the lowest available $p_i(j)$ for $i = 1, ..., N$ subject to trade costs.

[9]When considering an (ad-valorem) energy production tax, a tax on the SDS input for energy producers alone, and a value added tax in the counterfactual analysis, we will grant rebating the corresponding tax revenues to consumers, too.

units of a good that has to be shipped from n to deliver one unit of that good to i.[10] Given trade costs, i's SDS producer will buy input j at price

$$p_i(j) = \min_n \left\{ A z_n(j)^\theta w_n^\epsilon p_{qn}^\nu p_{en}^\mu d_{ni}(1 + t_{in}) : n = 1, ..., N \right\}. \tag{3.1}$$

Using the properties of the exponential distribution, we can derive the distribution of prices of intermediate goods:[11]

$$p(j)^{\frac{1}{\theta}} \sim exp \left(A^{-\frac{1}{\theta}} \sum_{n=1}^{N} \lambda_n \left(w_n^\epsilon p_{qn}^\nu p_{en}^\mu d_{ni}(1 + t_{in}) \right)^{-\frac{1}{\theta}} \right). \tag{3.2}$$

Let $y = p_i(j)^\theta$ and $h_i = \left(A^{-\frac{1}{\theta}} \sum_{n=1}^{N} \lambda_n \left(w_n^\epsilon p_{qn}^\nu p_{en}^\mu d_{ni}(1 + t_{in}) \right)^{-\frac{1}{\theta}} \right)$. Then, we can use (2.4) to derive

$$p_{qi}^{1-\sigma} = \int_0^\infty y^{(1-\sigma)\theta} h e^{-hy} dy. \tag{3.3}$$

Let $x = hdy$, then, by change of variables we may determine p_{qi}:

$$p_{qi} = h_i^{-\theta} \Gamma_k, \tag{3.4}$$

where $\Gamma_k = \Gamma(1 + \theta(1 - \sigma))$. In order for the integral to converge, $1 + \theta(1 - \sigma)$ must be positive. We assume that θ and σ adhere to this requirement. Now, use (2.6) to express h_i in terms of wages and the price of tradables. We then arrive at the system of N equations:

$$p_{qi} = \Gamma_k A \left(\sum_{n=1}^{N} \left[Z T_n^{-1} w_n^{\epsilon + \zeta\mu} p_{qn}^{\nu + (1 - \zeta\mu)} (t_{in} + 1) d_{ni} \right]^{-\frac{1}{\theta}} \lambda_n \right)^{-\theta}. \tag{3.5}$$

Solving this system for all p_{qi} and substituting the corresponding values into (2.6) determines the price of tradables and the price of energy in each country in terms of wages.

With all the factor prices expressed in terms of wages at hand, we specify excess demand for labor in order to solve for w_i. More specifically, we determine w_i by utilizing each country's multilateral trade balance condition. For stating the latter, let us derive the expressions for bilateral trade flows in the model. Since there is a mass of varieties of intermediate goods, the probability for country i to buy good j from country n equals the share of i's income spent on goods from n. This share π_{in} equals the probability that $p_n(j)$

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[10]We make the usual triangular inequality assumption that eliminates opportunities for arbitrage: $d_{ni} \leq d_{ki} d_{kn}$.

[11]For detailed derivation steps please refer to the Appendix.

is lowest among all n subject to trade costs $d_{ni}(1 + t_{in})$.

$$\pi_{in} = \Pr\left\{ z_n(j)^\theta \left(w_n^\epsilon p_{qn}^\nu p_{en}^\mu d_{ni}(1 + t_{in}) \right)^{\frac{1}{\theta}} \leq \min_{k \neq n}\left(z_k(j)^\theta \left(w_k^\epsilon p_{qk}^\nu p_{ek}^\mu d_{ki}(1 + t_{ik}) \right)^{\frac{1}{\theta}} \right) \right\}. \quad (3.6)$$

Using properties of the exponential distribution and (3.5), we obtain[12]

$$\pi_{in} = (A\Gamma_e)^{-\frac{1}{\theta}} \lambda_n \left(\frac{w_n^\epsilon p_{qn}^\nu p_{en}^\mu (t_{in} + 1) d_{ni}}{p_{qi}} \right)^{-\frac{1}{\theta}}. \quad (3.7)$$

Then, multilateral trade balance for country i may be stated as

$$L_i p_{qi} q_i \sum_{n=1}^{N} \pi_{in} \frac{1}{1 + t_{in}} = \sum_{n=1}^{N} L_n p_{qn} q_n \pi_{ni} \frac{1}{1 + t_{ni}}. \quad (3.8)$$

Of course, we have to account for tariff revenues in each country being redistributed as a lump-sum to households there. Total value added in the production of tradables in country i is $L_i w_i (1 - l_{ci} - l_{ei})$. We can express this also as returns to labor from sales of i-borne producers at home and abroad, $\epsilon L_i p_{qi} q_i R_i$, where $R_i = \sum_{n=1}^{N} \pi_{in} \frac{1}{1 + t_{in}}$. Expressing $L_i p_{qi} q_i$ in terms of the labor share and substituting the value into the multilateral trade balance equation yields Excess Demand for labor:

$$ED_i = \frac{1}{w_i} \left(\sum_{n=1}^{N} \frac{L_n w_n (1 - l_{cn} - l_{en})}{R_n} \frac{1}{1 + t_{ni}} \pi_{ni} - L_i w_i (1 - l_{ci} - l_{ei}) \right). \quad (3.9)$$

We will use equation to solve for the vector of wages. At this point, all the variables, except for the labor shares l_{ci} and l_{ei}, are functions of wage. We derive labor shares from:

$$L_i p_{qi}(q_i - q_{ci} - q_{ei}) = \nu L_i p_{qi} q_i R_i \quad (3.10)$$

$$L_i p_{ei}(e_i - e_{ci}) = \mu L_i p_{qi} q_i R_i \quad (3.11)$$

$$L_i w_i (1 - l_{ci} - l_{ei}) = \epsilon L_i p_{qi} q_i R_i \quad (3.12)$$

$$q_{ci} = l_{ci} \beta w_i (\alpha p_{qi})^{-1} \quad (3.13)$$

$$e_{ci} = l_{ci} \gamma w_i (\alpha p_{ei})^{-1} \quad (3.14)$$

$$(1 - \zeta) e_i p_{ei} = p_{qi} q_{ei} \quad (3.15)$$

$$\zeta e_i p_{ei} = w_i l_{ei} \quad (3.16)$$

Equations (3.10)-(3.12) represent returns to the factors used in the production of tradeable

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[12]See the Appendix for details on the derivation.

goods. Equations (3.13) and (3.14) are first-order conditions the final good producer faces. Finally, equations (3.15) and (3.16) represent the returns to factors used in the production of energy. This system of equations allows us to solve for l_{ei} and l_{ci} in terms of parameters of the model and R_i as a function of wages. Now, the excess demand equation system can be used to solve for w_i.

The multi-country equilibrium is a vector of positive wages w_i that satisfy (3.9), prices of intermediate goods p_{qi} that satisfy (3.5), prices of energy p_{ei} that satisfy (2.6), import shares π_{in} that satisfy (3.7), and labor shares l_{ci} and l_{ei} that satisfy (3.10)-(3.16).

4   Estimation

In the following, we directly estimate the elements of the vector of parameters

$$\{\alpha, \beta, \gamma, \epsilon, \nu, \mu, \zeta, \theta, \lambda_i\} \tag{4.1}$$

from data of 34 OECD countries and one rest-of-the-world (ROW) country as described below. Furthermore, we calibrate labor endowments L_i, country-specific productivity parameters λ_i and/or country-specific energy productivity parameters T_i so as to match data on GDP, relative prices and energy consumption. We conduct comparative static experiments regarding the consequences of taxes on imports (tariffs) versus energy on outcome of the countries in the sample.

4.1   Data

We use five major sources of data. First, estimation of the technology parameters $\{\alpha, \beta, \gamma, \epsilon, \nu, \mu, \zeta, \lambda_i\}$ requires data on prices for non-tradable final goods, tradable intermediates, and factors such as labor. In our regressions, we use two series from the Penn World Tables. In particular, we use the price level of consumption as a measure of p_{ci} and the price level of investments as a measure of p_{qi}. We are aware that the price of investment goods in Penn World Tables includes a non-tradabale component. Data on investment goods from that source, however, are the most accurate data that reflect prices of machinery and equipment with cross-country time-series variation.

In one version of the calibration of the model, we used prices of machinery and equipment from the International Comparison Program (ICP) benchmark study of 1996 as an alternative measure of the prices of tradables to the average price level of investment over the period 2000-2005 from Penn World Tables. Using this alternative measure did not result

in noticeable differences in the comparative static experiments.[13] The data on machinery and equipment from the benchmark study, however, do not cover all the countries in our sample. Hence, we replaced missing values by the corresponding value of the price of investments in the calibration section. In general, we opted for using data from Penn World Tables in the estimation section as these data provide relatively comprehensive information in all required aspects on an annual basis for the sample of countries we consider.

Furthermore, we use data on value added – which may be interpreted as being proportional to wages in the context of the model. The share of value added in total costs as a measure of parameters α,ϵ and ζ is taken from OECD's (*S*tructural *A*nalysis) STAN Database. For each country, we use the sector-level average share in total production over the period 2000-2005. Aggregate energy price indices were calculated by using data from the International Energy Agency Database. More detailed information on the calculation of aggregate energy prices can be found in the Appendix.

Ad-valorem tariffs are used to identify the parameter θ. Tariffs and other iceberg trade costs are estimated as a product of observable variables to yet unknown but estimable parameters as is common in the literature. Data on average (trade-weighted) ad-valorem tariff rates as well as variables related to non-tariff iceberg trade costs such as distance, common language, adjacency, and colonial relationship in the past are taken from databases provided by the Centre d'Études Prospectives et d'Informations Internationales. The data on bilateral trade flows are from the International Monetary Fund's Direction of Trade Statistics database.

- INSERT TABLE 1 HERE -

Data used in the calibration section only refer to GDP, relative prices and energy demands. We also check how well the calibrated model fits the data in predicting trade flows. Data for these variables are taken from the World Bank's World Development Indicators Database, Penn World Tables and the United States Energy Information Administration. Table 1 summarizes our data sources as well as the country and period coverage.

Estimating α, β, **and** γ:
We interpret L_i as an endowment of labor and capital together for the sake of matching features of the model with empirical data on economic activity as best as possible. Accordingly,

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[13]The correlation coefficient for the price of machinery and equipment from ICP and the price of investment goods from Penn World Tables amounts to 0.756. ICP allows for an alternative classification of prices of tradables and non-tradables altogether. However, it turns out that the price level of consumption from Penn World Tables and the average price of non-tradables from ICP in 1996 exhibit a correlation coefficient of 0.988. Moreover, the price of investment goods from Penn World Tables and the price of tradables from ICP in 1996 display a correlation coefficient of 0.921. Hence, the calibration and comparative static results may also be suspected to be largely invariant to those alternative measures for p_{ci} and p_{qi}.

w_i in the model corresponds to total valued added rather than wages in a narrow sense in a country. Hence, α can be estimated as the average ratio of total value added in total output according to equation (2.8). This ratio is directly observable across seven manufacturing sectors for 34 OECD countries during 1970-2009 in OECD's STAN database. We classify the sectors into tradables and non-tradables. Industries in the latter group along with the average value added to output ratio and its standard deviation within a sector are:

- Community, social, and personal services - 0.65(0.05)

- Construction - 0.39(0.06)

- Finance, insurance, real estate, and business services - 0.61(0.09)

- Transport, storage, and communications - 0.46(0.07)

- Wholesale and retail trade - restaurants and hotels - 0.54(0.07)

The values reported correspond to average shares and their standard deviations for the period 2000-2005. The average value of this ratio calculated across non-tradable sectors using employment shares is 0.55 with a standard deviation of 0.05. The weighted average using sector shares in total output amounts to 0.56 with a standard deviation of 0.04. Hence, we use $\alpha = 0.55$ both in estimation and model calibration. We obtain β and γ by estimating a stochastic version of the correspondingly modified equation (2.9). Using $\hat{\alpha} = 0.55$, we normalize the left-hand side of (2.9) by $w^{\hat{\alpha}}$ and restrict $\gamma + \beta = 0.45$. Specifically, we estimate the log-transformed model

$$\ln p_{it} - \hat{\alpha} \ln w_{it} = constant + \beta \ln p_{q,it} + \gamma \ln p_{e,it} + error_{it} \text{ s.t. } \beta + \gamma = 0.45. \qquad (4.2)$$

We allow the stochastic term $error_{it}$ in (4.2) to be heteroskedastic and autocorrelated of unknown form and to contain time-specific and country-specific components. To avoid an endogeneity bias, we therefore estimate all models by including time-specific and country-specific fixed effects. Notice, that price data from Penn World Tables only include prices relative to the US, thus all the values in (4.2) are normalized such that the US prices and wages equal 100. We then drop observations on the US for estimation.

- INSERT TABLE 2 HERE -

Table 2 summarizes estimates of parameters of the production function for non-tradable final goods. The left column includes unrestricted estimates of β and γ (Model A), whereas the right column includes the restricted estimates thereof (Model B). The specification works

quite well regarding the explanatory power of both models and there is only a minor quantitative difference between the two models. Since we impose constant returns to scale in the calibration, we consider Model B to be the preferred one.

Estimating the parameters ϵ, ν, and μ:
In order to identify ϵ we use equation (3.12). The strategy of identifying this parameter parallels our technique of estimating α. However, we can not directly use the share of value added in total output as a direct measure because of the extra term R_i in equation (3.12). Thus, we first deflate the share of value added by the term R_i which can be calculated using data on tariffs and trade flows. Specifically, we use data on average tariffs across countries for the period of 2000-2001 and average import shares for the same period to calculate R_i. We then deflate value added in the sectors which we define as tradable. Below we list simple averages of value added for each tradable industry for 2000-2005 along with standard deviations in parenthesis.

- Agriculture, Hunting, Forestry and Fishing - 0.48(0.08)

- Manufacturing - 0.30(0.04)

- Mining and Quarrying - 0.55(0.15)

As in the case of non-tradable sectors, we calculate the average share of value added in total output using production and employment shares. The average of these two measures suggests $\hat{\epsilon} = 0.35(0.06)$. We present shares of value added in total output for non-tradable and tradable sectors in Table 3.

- INSERT TABLE 3 HERE -

To estimate ν and μ, we use the system of equations (3.10)-(3.16). First, we divide (3.10) by (3.12). The right-hand side of that ratio corresponds to $\frac{\epsilon}{\nu}$. We then express q_{ci} and q_{ei} as a function of labor shares l_{ci} and l_{ei}, respectively, and substitute them into the right-hand side of that equation. This allows us to express $\frac{\epsilon}{\nu}$ in terms of the value added in non-tradable, tradable, and energy sectors and total output in the tradable sector as:

$$\frac{\nu}{\mu} = \frac{L_i p_{qi} - L_i w_i l_{ci} \frac{\beta}{\alpha} - L_i w_i l_{ei} \frac{1-\zeta}{\zeta}}{L_i w_i l_{qi}} \tag{4.3}$$

After eliminating outliers and missing observations,[14] the average value of the ratio is 1.49

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[14]We declare outliers as countries, where the corresponding ratio is negative. This is the case for Luxembourg, Greece, and the United Kingdom. Furthermore, data for at least one variable needed to calculate $\frac{\nu}{\mu}$ were missing for Ireland, Israel, New Zealand, Norway, and the United States.

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with a standard deviation 0.8. Hence, using $\hat{\epsilon} = 0.35$, we conclude that $\hat{\nu} = 0.52$ and $\hat{\mu} = 0.13$.

Notice that our approach to identify parameter μ is very different from the one to identify γ. Yet, the two estimates are very close to each other. This indicates that the estimated parameters are plausible.[15]

Estimating the parameter ζ:
Our strategy of obtaining $\hat{\zeta}$ is identical to the estimation of α. In particular, equation (3.16) implies that ζ is the share of value added in the total output of the energy sector. The data from STAN suggest that the share for energy producing activities was 0.38 with a standard deviation of 0.11 between 2000-2005. Hence, we conclude that $\hat{\zeta} = 0.38$.

Estimating the parameter θ and the determinants of d_{ni}:
We obtain θ and a measure of time-invariant barriers to trade, d_{ni}, by estimating an empirical counterpart to (3.7). Notice that a time-variant measure π_{int} can be obtained when normalizing imports gross of cost, insurance, and freight costs by country i's GDP of that year. In the stochastic counterpart to equation (3.7), we generally employ fixed exporter×time effects η_{nt} and fixed importer×time effects η_{it} to eliminate any bias from omitting wages and prices. Then, we may write the stochastic counterpart to (3.7) as

$$\pi_{int} = \exp\left(-\frac{1}{\theta}\ln(1 + \tau_{int}) - \frac{1}{\theta}\left(lnd_{ni} + \eta_{it} + \eta_{it}\right)\right)error_{int} \tag{4.4}$$

where $error_{int}$ may be heteroskedastic and autocorrelated of unknown form. Of course, $\ln d_{ni}$ is not directly observable but it is modeled in a log-linear fashion as is usual in the literature on estimating gravity models (see Eaton and Kortum, 2002). We propose the following version of $\ln d_{ni}$:

$$\ln d_{ni} = \delta_1 adjacency_{in} + \delta_2 language_{in} + \delta_3 colony_{in} + \iota \ln distance_{in}, \tag{4.5}$$

where $adjacency_{in}$, $language_{in}$, and $colony_{in}$ are binary variables indicating whether two countries share a common land border, a common language, or a historical colonial relationship, respectively, and $\ln distance_{in}$ measures the log of the great circle distance between countries i and n.

Estimating (4.4) in a nonlinear fashion is preferable over estimating it in a log-linear way for two reasons. First, zeros are not eliminated so that a sample selection from dropping observations is avoided. Second, using a Poisson pseudo-maximum-likelihood (PML) model

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[15]Alternatively, we estimated μ based on equation (3.7). From that, we obtained $\hat{\mu} \simeq 0.16$. The results in the calibration and counterfactual analysis sections are robust to using a value of 0.13 versus one of 0.16 for μ.

with robust standard errors one can avoid inconsistent marginal effects accruing to mis-specification of the stochastic process as log-additive versus level-additive (see Santos Silva and Tenreyro, 2006). We summarize Poisson PML model estimates of (4.4) in Table 4.

- INSERT TABLE 4 HERE -

Again, the estimated models have a high explanatory power, of which some part accrues to the fixed effects $\hat{\eta}_{it} + \hat{\eta}_{it}$. However, all the trade friction and facilitation variables enter highly significantly and in the expected way. Our estimates suggest that $\hat{\theta} \simeq -\frac{1}{-8.93} \simeq 0.11$ which is well in the range of estimates reported by Eaton and Kortum (2002) and the values used by Alvarez and Lucas (2007) or Mutreja, Ravikumar, and Sposi (2011).[16] $adjacency_{in}$, $language_{in}$, and $colony_{in}$ exert a positive impact on d_{in} and log distance displays a non-log-linear (hump-shaped) impact on d_{ni}.

Estimating country-specific technology parameters λ_i:

We use (3.7) to estimate λ_i in the following manner. We first normalize each observation π_{in} by $\pi_{i,USA}$ and then express country i's productivity relative to the one of the United States as follows:

$$\widetilde{\lambda}_i \equiv \left(\frac{\lambda_i}{\lambda_{USA}}\right)^{\theta} = \left(\frac{\pi_{in}}{\pi_{i,USA}}\right)^{\theta} \left(\frac{w_i^{\epsilon} p_{qi}^{\nu} p_{ei}^{\mu}}{w_{USA}^{\epsilon} p_{q,USA}^{\nu} p_{e,USA}^{\mu}}\right) \left(\frac{(t_{in}+1)d_{ni}}{(t_{i,USA}+1)d_{n,USA}}\right). \qquad (4.6)$$

We estimate the empirical counterpart to (4.6) using time-series data for 2000-2005. In particular, using data on bilateral trade flows[17] we are able to calculate (relative) productivity of country i, $\hat{\widetilde{\lambda}}_{i,t}$. We take the average of $\hat{\widetilde{\lambda}}_{i,t}$ across all partner countries n and years 2000-2005.[18] The values of $\hat{\widetilde{\lambda}}_i$ for the data at hand are summarized in Table 5.

Alvarez and Lucas (2007) note that the value of σ will not affect outcome of the model but only units of measurement. We employ a conventional value of 2 for this parameter.

4.2 Model calibration - benchmark features

Consistent with the sample the empirical estimates are based on, we calibrate the model for 34 OECD countries and one country taken as the rest of the world to average values of

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[16] An estimate of $\hat{\theta} \simeq 0.11$ is somewhat smaller than the one estimated by Simonovska and Waugh (2010) in a different country sample and a different method applied: lacking data on tariffs, they can not estimate θ directly but have to estimate it from price data by method of simulated moments.

[17] Notice that since we calculate relative productivities we do not have to worry about measuring *manufacturing absorption* as in Bernard, Eaton, Jenson and Kortum (2003) or in a broad sense home market size. This is possible because we can drop home market size from $\frac{\pi_{in}}{\pi_{i,USA}}$. Hence, it is no longer necessary to use manufacturing trade flows only. Indeed, the estimate $\hat{\widetilde{\lambda}}_i$ calculated using all goods trade flows versus manufacturing goods trade flows only are virtually the same with correlation coefficient of 0.99.

[18] When data for 2000-2005 were unavailable, we calculated $\hat{\widetilde{\lambda}}_{i,t}$ using pre-2000 data.

key variables between 2000 and 2005.[19] We use three different calibration techniques and calibrate the model to three different combinations of three out of four variables calculated from the data:

$$\left\{ GDP_i, \tilde{P}_i, \lambda_i, \hat{E}_i \right\},$$

where $\tilde{P}_i$ [20] refers to relative prices and $\hat{E}_i$ to total energy demand.

Benchmark Model:

In our benchmark calibration, we match data on GDP_i and relative energy prices p_{ei}/w_i for the year . The data used in the calibration are in Table 5.

- INSERT TABLE 5 HERE -

To calibrate the model we proceed as follows. First, GDP accounts for total value added plus revenues from collecting import tariffs. Note that we can express total tariff revenues of i by first expressing total spending on tradables using employment shares from (3.12) and then normalizing the value by weighted import tariffs. We therefore can express GDP as:

$$GDP_i = L_i w_i + \frac{L_i w_i l_{qi}(1 - R_i)}{\epsilon R_i}. \tag{4.7}$$

We use (3.7), (3.9), and (2.6) to express T_i as follows:

$$T_i = \left((L_i(\lambda_i \kappa_i)^{-1})^{\frac{\theta}{\mu}} \tilde{P}_i^{\omega} (Z w_i^{\zeta} p_{qi}^{(1-\zeta)})^{\omega} \right)^{\frac{1}{1+\omega}}, \tag{4.8}$$

and similarly for its counterpart based on estimated rather than true parameters. Equations (3.5), (3.9), (4.7) and (4.8), form a 4×35 system of equations that we solve for 4×35 unknowns: $\{L_i, T_i, w_i, p_{qi}\}$, given the data on GDP_i, λ_i, $\tilde{P}_i$, functional form of κ_i and parameters of the model.[21]

We exactly match the data with respect to GDP and relative price of energy p_{ei}/w_i. The correlation coefficients between the data and the model with respect to these two variables

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[19]To calculate GDP_{ROW} and the value of total imports of ROW we take the difference between world GDP and the sum of all OECD countries' GDPs on the one hand and between total world imports and all OECD imports, respectively. Data for ROW that could not be simply aggregated, such as trade costs and relative prices, were calculated as weighted averages of non-OECD countries. For instance, in order to calculate $\frac{p_{cROW}}{p_{qROW}}$, as required for calibration, we take the average of that ratio for all non-OECD countries where the data were available weighted by their share in GDP_{ROW}.

[20]$\tilde{P}_i$ equals p_{ei}/w_i in the benchmark model and p_{ci}/p_{qi}, p_{qi}/w_i, respectively, in two alternative calibration models. We used the data average of $\tilde{P}_i$ for some countries when country-specific data were not available.

[21]κ_i and a derivation of the equations used in the calibration can be found in the Appendix

equal unity. As is evident from Figure 1, the calibrated model almost perfectly predicts total energy demands.[22] The correlation coefficient between the model and the data in that dimension is 0.99. The correlation with other prices is also high and ranges between 0.34 and 0.77. The calibration results for this calibration, *Calibration 1*, are summarized in Table 6, and statistics about the goodness of fit of *Calibration 1* with the data along several dimensions are presented in Table 7.

<div align="center">- INSERT TABLE 6 HERE -</div>

Perhaps one of the most important variables for evaluating the fit of the calibration beyond GDP, relative prices, and energy demand are bilateral trade flows. For this, consider total imports relative to importer country GDP for each economy. Notice that our approach in using estimated trade costs is different from Alvarez and Lucas (2007). While they assumed trade costs to amount to an average of 1.33, we use estimated values consistent with the stochastic version of equation (4.1). Aggregating predicted and observed bilateral imports, we may plot the predicted versus observed import-to-GDP ratios against each other in Figure 2.

<div align="center">- INSERT FIGURES 1-2 HERE -</div>

It is obvious from Figure 2 that the model does well in predicting trade flows. Pearson's correlation coefficient for the data underlying the figure amounts to 0.8. When excluding clear outliers such as Luxembourg and ROW[23] the correlation coefficient even rises to 0.83. Notice that the respective correlation coefficient in Alvarez and Lucas (2007) was 0.62 with uniform tariffs and 0.69 when they used country-pair-specific tariffs.[24]

We have also calibrated the model to the alternative set of variables: $(GDP_i, E_i, p_{ci}/q_i)$ (*Calibration 2*) and $(GDP_i, \lambda_i, p_{qi}/q_i)$ (*Calibration 3*). The goodness of fit with the data of those two alternative calibrations along with the one of *Calibration 1* is reported in Table 7.

<div align="center">- INSERT TABLE 7 HERE -</div>

Subsequently, we use *Calibration 1* as the benchmark for counterfactual analysis because it fits the data better than the others across a number of dimensions, according to Table 7. We, however, should note that *Calibration 2* also fits the data quite well in multiple dimensions.[25]

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[22]We used data on energy consumption from the US Energy Information Administration website (*http://www.eia.doe.gov/*). For each country we calculated total energy demand using data on petroleum products, natural gas, and electricity in British Thermal Units (BTU).

[23]We consider these two *countries* as outliers because Luxembourg's import-to-GDP ratio exceeds unity and ROW is a country bloc which poses problems for aggregation of bilateral trade or trade cost data.

[24]Of course, we admit that the country sample used in Alvarez and Lucas was different from ours.

[25]Equations used in the *Calibrations 1-3* can be found in the Appendix.

5 Counterfactual analysis

In this section, we analyze the consequences of trade and energy policy and their interplay in determining outcome. In particular, we do so for small versus large economies, and it will turn out that those behave qualitatively differently. However, it seems useful to consider the consequences of trade policy alone on outcome as a benchmark. For this, let us first consider the welfare effects from completely abolishing existing tariffs by primarily focusing on energy demand and welfare as outcomes. Then, we shall examine the consequences of a liberalization of non-tariff trade costs – which may be interpreted as *search and transaction costs* – on the same outcome in comparison. Subsequent to that analysis, we determine to which extent existence of an energy sector alters the effects of trade liberalization. On the one hand, we do so in an unrealistically drastic experiment which compares equilibria in a world with versus without an energy sector. For the latter we shut down the energy sector completely and assume that production could be sustained by substituting energy inputs completely by labor and intermediate goods in the proportions dictated by an otherwise unchanged Cobb-Douglas technology. Such an experiment turns out illustrative for understanding the comparative static effects. On the other hand, we conduct less drastic experiments by considering the impact of a general import tariff on all tradable intermediates versus a tax on energy imports to see which policy provides for smaller welfare losses at a given goal of energy reduction. This will be informative about preferable policies for small versus large countries for the sake of reducing energy demand.

Trade liberalization

We measure the effects of trade liberalization on welfare as follows. Consumer utility is linear in consumption of the final good. Hence, the change in real consumption is a welfare measure in models such as the one employed here.[26] Let us use subscript b to denote variables measured <u>b</u>efore liberalization and subscript a to refer to values <u>a</u>fter liberalization. For instance, c_{bi} then refers to per-capita consumption before and c_{ai} to consumption after liberalization in country i. Real aggregate consumption corresponds to the ratio of GDP to the price of the final good. Then, we can express the comparative static effect of liberalization on the corresponding change in welfare as follows:

$$\frac{c_{ai}}{c_{bi}} = \frac{GDP_{ai}p_{cbi}}{GDP_{bi}p_{cai}}, \tag{5.1}$$

where GDP_i and p_{ci} are as in (4.7) and (2.9). Take logs on both sides of (5.1) and multiply

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[26] As said before, it would be straightforward to broaden the concept of utility to cover possible utility gains from reduced energy consumption per se. We refrain from this in the interest of avoiding arbitrariness in attributing weights to energy reduction versus economic welfare.

by 100 to express the percentage change in welfare as the difference between percentage change in GDP after and before liberalization and the corresponding value of the change in the price of consumption:

$$\%\Delta c_i = \%\Delta GDP_i - \%\Delta p_{ci}. \tag{5.2}$$

As is well known, OECD countries levy relatively low multilateral (most-favored nation) average tariffs on imports during the observation period at stake in this study (in the early 2000s). Even more so, they have low tariffs vis-à-vis each other due to preferential trade liberalization. Abolishing these tariffs completely would lead to comparably small economic effects. Indeed, for many countries the gain from eliminating status-quo tariffs is negligible in our model. Of course, with some non-tariff barriers to trade, smaller countries benefit relatively more from full trade liberalization, but even their gains are below 3.5% in welfare terms in our sample of countries.[27] Figure 3 illustrates the argument.

- INSERT FIGURES 3-5 HERE -

The gains from abolishing non-tariff trade costs[28] contained in d_{ni} – were this possible – would be much bigger than those from tariff liberalization. In our model, such gains would range from 1% for the United States to nearly 22% for Estonia. Most countries would reap welfare gains of $5-15\%$ if trade transaction costs were eliminated completely. These results are evident from Figure 4. A reduction of d_{ni} by 10% for all country pairs would raise welfare by $1-12\%$ depending on country size (see Figure 5). Such an experiment seems realistic in comparison to a complete abolishment of non-tariff trade costs to the extent that search and communication costs to trade could be reduced through activity of trade intermediaries, or education such as language training and the acquisition of knowledge about foreign markets.

Trade liberalization and the energy sector

In our model, energy is a produced factor of production. In order to study its role in the economy, let us compare equilibria and comparative static effects of a trade cost reduction at large – i.e., of both tariff and non-tariff trade costs – in a world with and without the energy sector. Hence final and intermediate goods producers, both of which use energy in the outset, would then be forced to produce without energy but using the other production factors under constant returns to scale as in equilibria with an energy sector. For this, we

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[27]Notice that this outcome is not inconsistent with findings suggesting that trade policy was one of the most important drivers of trade in the aftermath of World War II (see Bergoeing and Kehoe, 2003). It just means that trade was liberalized already to such an extent during our sample period that we should not expect further blunt tariff reductions to have large welfare effects anymore.

[28]We may refer to them as search and transaction costs in a broad sense associated with, e.g., greater geographical distance, the absence of a common language, or the absence of former colonial ties between two countries.

proportionately adjust $\hat{\alpha}$ and $\hat{\beta}$ so as to obtain $\hat{\alpha} = 0.65$ and $\hat{\beta} = 0.35$ and ϵ and ν so as to yield $\hat{\epsilon} = 0.40$ and $\hat{\nu} = 0.60$.[29]

In order to highlight the differences between the welfare effects in the model with energy from the one without energy we isolate the driving forces behind the total welfare effect in (5.2) and analyze them separately. In particular, GDP consists of total value added and tariff revenues. We use (4.7) to express per capita quasi-tariff revenue (QT) as:

$$QT_i = \left(1 + \frac{l_{qi}(1 - R_i)}{\epsilon R_i} \right). \tag{5.3}$$

The aggregate consumption price can be decomposed using wages and prices of tradables from (2.9). We can then express the change in welfare per capita of an economy without an energy sector as follows:

$$\frac{c_{ai}}{c_{bi}} = \left(\frac{w_{ai}}{w_{bi}} \right)^{-(\alpha-1)} \left(\frac{p_{qai}}{p_{qbi}} \right)^{(\alpha-1)} \left(\frac{QT_{ai}}{QT_{bi}} \right). \tag{5.4}$$

Equation (5.4) is quite intuitive. An increase in wages raises welfare, whereas an increase in prices of tradables reduces welfare. The effect of a change in tariff revenues will depend on the distribution of technologies. Taking logs on both sides of (5.4), multiplying by 100 to express changes in percent of real consumption per capita, and using Δ to denote such changes, we obtain:

$$\%\Delta c_i = (1 - \alpha)\%\Delta w_i + (\alpha - 1)\%\Delta p_{qi} + \%\Delta QT_i. \tag{5.5}$$

Similarly, we can decompose welfare gains in the model with an energy sector as follows:

$$\%\Delta c_i = (1 - \alpha)\%\Delta w_i - \beta\%\Delta p_{qi} - \gamma\%\Delta p_{ei} + \%\Delta QT_i. \tag{5.6}$$

Equations (5.5) and (5.6) are very intuitive. For example, in case of the (admittedly un-realistic) "no energy" model, an increase in wages leads raises welfare with a multiplier of $1 - \alpha$ whereas an increase in the price of the SDS aggregate reduces welfare with a multiplier of $\alpha - 1$. The trade liberalization experiment in Figures 3-5 suggests that relative welfare gains are relatively bigger in smaller countries. Countries with smaller labor endowments L_i

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[29]Of course, with a Cobb Douglas technology, we have to adopt such a strategy, since the technology displays a constant elasticity of substitution. However, shutting down the energy sector completely and readjusting Cobb Douglas coefficients for the other factors can still provide some qualitative insights. in the subsequent analysis we use policy instruments which reduce energy demand only gradually anyway so that the scenario of shutting down the energy sector completely does not surface there. To get stable solution we have to assume that γ and μ are larger than zero by some small ψ.

display a lower technology parameter λ_i as in Alvarez and Lucas (2007) and, hence, consume relatively more foreign tradables. Conversely, countries with high L_i and λ_i will consume mainly from local producers. This implies that a reduction in the price of tradables will benefit smaller countries more since the SDS aggregate in these countries has a relatively smaller home component. Since production inputs are substitutable, wages will adjust accordingly in case of trade liberalization. In particular, relatively big countries may suffer from the reduction in wages. The question of interest then is how the elements in (5.5) and (5.6) change and what their aggregate impact is on welfare (i.e., Δc_i). Since tariffs are quite low already, let us shed light on the consequences of trade liberalization in terms of non-tariff trade costs (d_{ni}) and their interplay with the importance of the energy sector. As in Figure 5, let us do so when considering welfare gains from a 10% reduction in such trade costs. Figure 6 contains two panels, where the one at the top allows for positive energy supply, while the one at the bottom shuts down the energy sector. In either panel, we rank countries in our sample by their size in terms of GDP_i as a fraction of world GDP, and we display the welfare change per capita analogous to (5.5) and (5.6), respectively, on the vertical axis.

- INSERT FIGURE 6 -

The results of this experiment can be summarized a follows. First, (non-tariff barrier) trade liberalization unambiguously raises wages in small countries and reduces the price of tradables gross of costs of insurance and freight in all countries. Either effect contributes positively to the welfare change. Of course, effects on wages ($\%\Delta w_i$) and on tradables ($\%\Delta p_{qi}$) are generally larger in small than in large countries due to their relatively greater dependence on trade. Trade is stimulated by the decline in the price of tradables so quasi-tariff revenues rise as well. For large countries, the wage effect induced by (non-tariff barrier) trade liberalization may be negative. The reason for the latter is that small countries gain in competitiveness by relying more on now cheaper foreign goods than large countries do. In other words, the home bias of large countries which supports higher wages at positive trade costs there diminishes as non-tariff barriers to trade decline.

Second, the welfare effects of trade liberalization are larger in economies with an energy sector than in ones without energy supply. This is evident from higher amplitudes of the total welfare change profile in the upper panel relative to the lower panel of Figure 6. The reason is that the energy sector itself is an employer of local workers. This contributes to higher wages. The importance of the price of tradables is, of course, bigger in the absence of an energy sector than with energy supply. The reason is simply that total costs of production are shared by two rather than three factors without any energy supply. Moreover, the relative importance of the interplay between the energy sector and trade liberalization on $\%\Delta w_i$ and

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on $\%\Delta p_{qi}$ is greater for small than for large economies. The reason is that the energy sector, as an employer of production factors, amplifies comparative static effects to a larger extent in more open economies than in more closed ones.

Third, while there are relatively larger positive trade liberalization-induced welfare gains associated with higher wages and lower prices of tradables in small versus large economies, there are larger gains from lower energy prices in large than in small countries. The reason behind this result is that the drop primarily in wages but also in tradables leads to lower energy costs in large relative to small economies. The latter partly – though for the largest countries in the sample not fully – cushions the negative direct effect of declining wages on welfare.[30]

Reducing energy demand by taxing energy vs. imported goods

Suppose a government's goal were to reduce energy production. We analyze the effect of different tax instruments available to assess their relative impact on energy demand and welfare at large. In particular, we consider four different policy instruments: higher import tariffs (general protection), an ad-valorem tax on energy prices, a tax on the SDS input of the energy producer only, and a value added tax on the energy producer only. Let us denote the four respective instruments as follows: t_{in}, $\tau_{e,n}$, $s_{e,i}$ and $v_{e,i}$. As is custom in public finance and international economics, we assume that the associated revenues are then rebated to all households in i in a lump-sum fashion.

In the context of our model, higher import tariffs vis-à-vis energy producers alone may be interpreted as taxing imports of energy sources such as oil.[31] Higher import tariffs at large affect (reduce) energy demand indirectly since they raise the price of tradables (but they do so for production in general rather than only energy production). The latter three instruments, namely $\tau_{e,n}$, $s_{e,i}$ and $v_{e,i}$ are more direct instruments that immediately affect price of energy either through a direct tax on production (in case of $\tau_{e,n}$) or through higher costs of inputs of the energy producer (in case of $s_{e,i}$ and $v_{e,i}$). We compare the consequences of these four instruments for both energy consumption and welfare. This analysis will reveal interesting features about *which instrument* is preferable for *which country* and *why* from the viewpoint of the (purely economic) welfare costs of reducing energy demand.

We have seen in the previous analysis that the presence of an energy sector may have qualitatively different effects on large versus small countries. Hence, it is elemental to study

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[30]The results suggest that for Australia the decline in wages would be more than compensated by the decline in energy prices in determining total welfare. For Japan, the United States, and ROW, wages decline with the introduction of an energy sector as for Australia. However, unlike there, the drop in energy prices due to (non-tariff barrier) trade liberalization can not outweigh the negative welfare effect from lower wages.

[31]A tariff on all imports should not be interpreted in this way but, as mentioned before, reflects a measure of protection at large.

the impact of (direct or indirect) policy instruments on energy demand and welfare for small versus large economies. As in the previous analysis, we will principally allow all countries to have some impact on the world economy so that inference about *small* and *large* countries is possible within the same calibrated multi-country framework as before.

Let us set out with analyzing the case of a small open economy first. A vivid example thereof is Estonia. It is the smallest economy in our sample, accounting for less than 0.05% in world GDP. Suppose that Estonia wished to reduce local energy demand. We let it choose between levying a local ad-valorem tax rate $\tau_{e,i}$ on energy, an import tariff rate $t_{i,n}$ on all goods imported, a tax $s_{e,i}$ on the SDS input of the energy producer, and a value added tax $v_{e,i}$ on the labor input of the energy producer. Certainly, either policy will lead the Estonian energy sector to contract. An introduction of a positive $\tau_{e,i}$ will have a first-order negative effect on energy demand. However, an increase in $t_{i,n}$ will raise the price of imported intermediates which are inter alia used by the energy sector, thereby inducing energy prices to increase indirectly. Introduction or an increase of $s_{e,i}$ will increase the price of energy and incentivize the energy producer to substitute away from the SDS input to labor. Conversely, introducing or raising a value added tax $v_{e,i}$ will lead energy producers to substitute away from labor.[32]

To analyze the effect of taxes we have to modify (5.3) to account for revenue flows from taxes $\tau_{e,i}$, $s_{e,i}$ and $v_{e,i}$. In particular, in case of $\tau_{e,i}$ we have to account for rebates of revenues from taxing energy $\tau_{e,i}p_{e,i}e_i$ and, in case of $s_{e,i}$ and $v_{e,i}$, for revenues from taxing SDS inputs of the energy producer $s_{e,i}p_{q,p}q_{ei}$ and, respectively, labor input $v_{e,i}w_il_{ei}$. This is accomplished as follows:[33]

$$QT_i = \left(1 + \frac{l_{qi}(1 - R_i)}{\epsilon R_i} + v_{e,i}l_{ei} + s_{e,i}\frac{(1 - \zeta)l_{ei}}{\zeta(1 + s_{e,i})}\right). \tag{5.7}$$

Now we can use (5.6) to analyze the effect of these policies on both energy consumption and welfare. The channels through which these policies affect energy demand are largely different and so are the associated effects on welfare. In Figure 8, we illustrate the percentage responses of energy demand ($\%\Delta e_i$) and welfare ($\%\Delta c_i$) for six economies: Estonia, Portugal, Australia, Great Britain, Germany, and the United States. Each panel contains four loci, one portraying the relationship between $\%\Delta e_i$ and $\%\Delta c_i$ for a set of energy tax rates $\tau_{e,i}$, one for a set of tariff rates t_{in}, one for a set of tax rates $s_{e,i}$ on SDS inputs of the energy

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[32]Note that, in contrast to $s_{e,i}$ and $v_{e,i}$, $\tau_{i,n}$ will have no effect on the relative shares of inputs in energy production. Consider the system (3.10)-(3.16). Introduction of $\tau_{e,i}$ such that the new price of energy is $(1 + \tau_{e,i})p_{e,i}$ will have no effect on the relative use of inputs by the energy producer, as can be seen from the ratio of (3.15) and (3.16). Placing $s_{e,i}$ such that the new price of the SDS aggregate for energy producers *only* is $(1 + s_{e,i}p_{q,i})$, however, will change the relative use of $l_{e,i}$ and $q_{e,i}$ as in (3.15)-(3.16). The same holds true in case of introducing a value added tax $v_{e,i}$.

[33]Notice that in case of $s_{e,i} = v_{e,i}$ the sum of tax revenues equals exactly the revenue from $\tau_{e,i}$ s.t. $\tau_{e,i} = s_{e,i} = v_{e,i}$.

producer, and one for a set of value added tax rates $v_{e,i}$ of the energy producer. In each of the panels $\tau_{e,i} \in [0; 2.3]$, $t_{in} \in [0; 2.3]$, $s_{e,i} \in [0; 2.3]$ and $v_{e,i} \in [0; 2.3]$. Of course, larger negative responses of energy demand are associated with bigger increases of $\tau_{e,i}$, t_{in}, $s_{e,i}$, and $v_{e,i}$. Since $\tau_{e,i}$, $s_{e,i}$, and $v_{e,i}$ are relatively more direct instruments for reducing energy demand, the corresponding loci are more linear within the support region than the one pertaining to t_{in} is.

- INSERT FIGURE 7 HERE -

Three findings stand out when considering Figure 8. First, as a tendency there is a bigger energy reduction support region for smaller and less remote countries where the indirect tariff instrument, t_{in}, dominates relatively more direct energy tax instruments in effectively reducing energy demand relative to the welfare costs associated with it. The upper left panel in Figure 8 suggests that Estonia would be better off in reducing energy demand by up to about 20% when using import tariffs on all tradables rather than any other form of taxation. By way of contrast, the United States should do so only up to the goal of an energy reduction of less than 1%.

Second, a tax on the SDS input of the energy producer dominates a direct tax on the output and a value added tax of the energy producer within the support region of import tariffs for small open economies. As mentioned earlier, a tax on the SDS input targets the use of imported energy sources more directly than the other considered instruments do. Figure 7 confirms the intuition. Since small countries rely heavily on imports, a tax $s_{e,i}$ on energy producers displays virtually no negative effect in terms of the price of tradables. There is, however, a positive effect of increased tariff revenues since under $s_{e,i}$ foreign tradable goods become relatively cheaper and thus substitute locally produced ones. It is not surprising that a value added tax $v_{e,i}$ exerts the biggest negative effect for small countries. This is due to the assumption of labor being immobile across national borders.

Third, big countries do not depend as heavily on imports as small ones. Thus, they should prefer other instruments than small countries to target energy demand. This is confirmed in the lower right panel in Figure 7. A value added tax is the least harmful instrument and dominates both a tax on the SDS input of energy producers and a tax on energy consumption when targeting a given level of reduction of energy consumption. This is due to the fact that the latter two measures entail a relatively bigger (positive) impact on the price of tradables.

Of course, we do not suggest countries to use protectionism to reduce energy demand as such. In our analysis, we assume that countries can use tariffs without any retaliatory consequences. In reality, most countries would be bound to apply most-favored nation tariffs to members and even non-members of the World Trade Organization. However, countries

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may use import tariffs for exceptional reasons specified in Article XX of the GATT, and our analysis suggests that small ones will likely be better off in doing so than large ones if their goal is to reduce energy consumption with an eye on overall (purely economic) welfare distortions.[34]

- INSERT FIGURES 8 AND 9 HERE -

Figures 8 and 9 shed light on the mechanisms at work behind the effects displayed in the panels for Estonia and the United States in Figure 7. The corresponding insights can be summarized as follows. First of all, smaller countries depend more largely on foreign production than large ones do. Hence, the imposition of tariffs generates larger quasi-tariff revenues in small than in large economies (compare the left panels of Figures 8 and 9). Positive tariff revenue effects will even outweigh detrimental protection-induced wage effects – which are relatively bigger in small than in large countries according to Figure 8 – in small countries and for low to medium-large levels of protection. Then, higher energy costs *and* detrimental wage effects may be smaller than positive tariff revenue effects on welfare. However, the relative magnitude of these effects declines with country size. Of course, with increasing tariffs domestic producers would even start substituting foreign inputs by domestic factors. Yet, this would only happen at levels of protection that would not be beneficial for a country as a whole (see the left panel of Figure 9). Workers would even benefit from protectionism in large countries such as the United States. However, those effects together with the tariff revenue effects would be relatively small in comparison to the direct and indirect effects through tariffs on foreign inputs. Hence, large countries will likely lose from tariff protectionism, and while the total welfare costs would be small in comparison to small economies, they would be positive at extremely low levels of protection.

Relatively more direct instruments induce starkly different effects on small versus large countries. That can be seen from a comparison of Estonia with the United States. For instance, Estonia is able to enjoy positive welfare gains in case of $s_{e,i}$ and $\tau_{e,i}$ in a large support region in Figure 8. The reason for that are relatively large positive quasi-tariff revenues along with a small negative effect induced by changing prices of tradables. Taxing value added in the energy sector, on the other hand, generates lower revenues and, hence, is dominated by other instruments. This effect is opposite for the United States in the same experiment. In particular, positive quasi-tariff revenues are outweighed by a negative impact induced by higher prices of intermediates, lower wages, and higher price of energy there. As

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[34]Beyond tariffs, countries have and actually use an array of protectionist policy instruments, especially, pertaining to non-tariff trade barriers. It is interesting to see that (tariff or non-tariff) barriers to trade as indirect instruments would be preferably used when small countries aim for reducing energy demand subject to keeping total welfare costs as low as possible.

evident from Figure 9, a value added tax on energy production or an ad-valorem tax on energy prices induces relatively lower negative effects on the prices of tradables and energy than the other considered instruments. Thus, they are preferable from an economic welfare perspective over tariffs either on SDS inputs in the energy sector or on all imported goods (protection at large).

Overall, taxing the energy sector directly induces almost linear effects on factor and goods prices as well as demand and welfare, according to the calibrated model. The relatively greater concavity of the tariff locus in $\%\Delta e_i$ and $\%\Delta c_i$ space and the relatively bigger incentive for protectionism in small as compared to large countries renders levying import tariffs rather than taxing energy demand or energy-sector value added a preferable strategy over a bigger support region in small countries such as Estonia than in large ones such as the United States. In general, while bigger countries would prefer a value added tax (hurting labor directly) or a direct tax on energy consumption as a more neutral policy, small countries may take advantage of generating positive tariff revenues by taxing only imports of inputs used in the energy sector or of all imports.

- INSERT FIGURE 10 HERE -

Certainly, the previous discussion focused on sovereign countries' welfare and energy demand response to their use of alternative (direct and indirect) policy instruments to target energy consumption. While such policies would induce negligible effects on other countries on average, the consequences for the world economy may be significant if such policies were imposed by large players such as the United States. Figure 10 sheds light on this matter by considering energy reduction by different instruments in the United States and its consequences on domestic versus foreign welfare. While the panel on the left-hand side of Figure 10 pertains to welfare effects in Estonia of policies adopted by the United States, the one on the right-hand side refers to aggregate welfare effects of countries other than the United States. The impact on third countries is negative throughout and mainly linear in $\%\Delta e_i$ and $\%\Delta c_i$ space. The detrimental spillover effects from an energy consumption tax levied by the United States on foreign economies has relatively bigger effects on small countries. In contrast to tariffs, taxing energy consumption in the United States as a direct instrument to achieve the goal of energy reduction has the most detrimental effects on the United States itself within the support region. As discussed above, the United States should prefer taxing imports in the interest of minimizing welfare losses only if the targeted level of reduction of energy consumption is small enough (see Figure 7). Such a policy, however, entails larger detrimental spillover effects on third countries as can be seen in Figure 10. It exerts direct negative effects on exports by other countries which are larger than the ones under taxing

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energy output prices. The rationale behind that effect is that tariffs on all traded goods affect foreign countries directly while the detrimental foreign economic welfare effects of a tax on energy output prices are cushioned in part by a burden on the taxing country's domestic factors. Moreover, a tax on energy output prices is less harmful than a tariff on imported energy inputs. The reason is that, through the induced factor bias, the associated detrimental welfare effects of an input tax on energy producers are not shared by labor to the extent as with an energy consumption tax so that negative third-country effects are relatively larger.

6   Conclusion

This paper assesses the role of energy as a locally produced factor of production for economic outcome such as trade, goods and factor prices, and welfare. We utilize a structural model in the spirit of Eaton and Kortum (2002) to assess this question. In particular, we estimate the parameters and calibrate the model so as to fit data of 34 OECD countries and one (rest of the world) outside economy. The model serves to conduct comparative static experiments with regard to, inter alia, the consequences of taxing energy versus goods imports for outcome.

By assumption and consistent with data, the energy sector itself employs intermediate inputs and labor and produces a (virtually) non-tradable good. A cap on the output of that sector has negative consequences for small and large countries. One of the main results of the paper flows from a comparison of an ad-valorem tax on energy and a tax on labor used in the production of energy as relatively more direct instruments and import tariffs and a tax on tradable input used in the production of energy as relatively more indirect instruments to reduce energy demand. It turns out that the same goal can be achieved at relatively lower total welfare costs when using tariffs rather than taxes in small and energy taxes rather than tariffs in large economies. The total welfare costs of protection or energy taxation with a moderate, given cap of energy demand in mind will induce smaller total welfare effects in small as compared to large countries.

Future work may consider two issues in particular. First, it would be fruitful to consider issues related to energy input and output such as the carbon content or emissions. Furthermore, it would be interesting to consider optimal instruments chosen noncooperatively by governments.

TABLES

Table 1: DATA SOURCES

Acronym	Variable description	Data source	Countries	Period
	Estimation section			
p_{ci}	Price Level of Consumption	Penn World Tables	34 OECD	1980-2007
w_i	Value Added	OECD STAN Database	34 OECD	1980-2007
		UNCTAD Database	34 OECD	1980-2007
p_{qi}	Price Level of Investment	Penn World Tables	34 OECD	1980-2007
p_{ei}	Price of Energy Aggregate	International Energy Agency	25 OECD	1980-2007
π_{in}	Ratio of export from n to i to $i's$ GDP	DOTS*,IMF	34 OECD	1980-2003
	Manufacturing trade flows	CEPII**	34 OECD	1980-2004
d_{ni}	Trade Costs Variables	CEPII	34 OECD	-
t_{in}	Average ad valorem tariff on manufactured goods	CEPII(WITS)	34 OECD	1980-2003
E_i	Total Energy Demand	USEIA***	35 OECD	2000-2005
	Calibration Section			
GDP	Share of World's GDP	World Bank WDI**** database	34 OECD	2000-2005
IMP/GDP	Ratio of Imports to GDP	World Bank WDI database	34 OECD	2000-2005

Notes:
* - Direction of Trade Statistics, International Monetary Fund.
** - Centre d'Etudes Prospectives et d'Informations Internationales Databases.
*** - US Energy Information Administration
**** - World Development Indicators Database.

Table 2: ESTIMATING PARAMETERS β AND γ

variable	parameter	Dependent variable is $\ln p_{it} - \hat{\alpha} \ln w_{it}$			
		Unconstr.		Constr.	
		Model A		Model B	
$ln(p_{qit})$	β	0.2019	***	0.2982	***
		0.0185		0.0114	
$ln(p_{eit})$	γ	0.1070	***	0.1517	***
		0.0136		0.0114	
R^2		0.93		0.93	
Root MSE		0.03		0.03	
Countries		27		27	
Years		23		23	
Years		OLS		CLS	

Notes: The constraint imposed in model B is that $\hat{\beta} + \hat{\gamma} = 0.45$. The regression includes fixed country and time effects. Standard errors are reported below coefficients and are robust to heteroskedasticity and autocorrelation of unknown form.

Table 3: VALUE ADDED SHARE IN TOTAL OUTPUT

| Country | Tradables | | Non-Tradables | |
| | Weighted by share in: | | | |
	Output	Employment	Output	Employment
Australia	-	-	-	-
Austria	0.35	0.39	0.58	0.60
Belgium	0.26	0.27	0.51	0.55
Canada	0.37	0.35	0.59	0.59
Czech Republic	0.26	0.27	0.46	0.48
Denmark	0.38	0.35	0.55	0.59
Estonia	0.27	0.28	0.49	0.51
Finland	0.33	0.36	0.55	0.56
France	0.29	0.31	0.60	0.62
Germany	0.34	0.35	0.61	0.62
Greece	0.37	0.49	0.63	0.64
Hungary	0.26	0.27	0.55	0.55
Iceland	0.39	0.40	0.51	0.52
Ireland	0.34	0.36	0.45	0.47
Israel	0.31	0.32	0.58	0.56
Italy	0.30	0.34	0.55	0.57
Japan	0.39	0.41	0.66	0.64
Korea	0.26	0.37	0.56	0.56
Luxembourg	0.32	0.33	0.39	0.48
Mexico	0.38	-	0.71	-
Netherlands	0.30	0.31	0.55	0.57
New Zealand	0.35	0.32	0.53	0.53
Norway	0.31	0.38	0.54	0.57
Poland	0.30	0.36	0.54	0.57
Portugal	0.29	0.37	0.55	0.55
Slovak Republic	0.25	0.28	0.50	0.53
Slovenia	0.33	0.35	0.54	0.55
Spain	0.30	0.36	0.56	0.58
Sweden	0.33	0.34	0.55	0.57
Switzerland	0.35	0.36	0.59	0.61
United Kingdom	0.37	0.37	0.53	0.54
United States	0.35	0.36	0.61	0.61
MEAN	0.32	0.35	0.55	0.56
STD.DEVIATION	0.04	0.05	0.06	0.04

Table 4: ESTIMATING PARAMETER θ AND TRADE COSTS FROM EQUATION (4.4)

Variable	Parameter	Dependent variable is π_{int}	
$\ln(1 + \tau_{int})$	$-\frac{1}{\theta}$	-8.9369	***
		0.8726	
$adjacency_{in}$	$-\frac{1}{\theta}\delta_1$	0.7371	***
		0.0477	
$language_{in}$	$-\frac{1}{\theta}\delta_2$	0.3148	***
		0.0565	
$colony_{in}$	$-\frac{1}{\theta}\delta_3$	0.2593	***
		0.0605	
$\ln distance_{in}$	$-\frac{1}{\theta}\iota$	-0.4980	***
		0.0218	
R^2		0.9119	
Importers		25	
Exporters		25	
Years		23	
Estimator		Poisson PML	

Notes: All regressions include fixed exporter×time an importer×time effects. Standard errors are reported below coefficients and are based on Eicker-White sandwich estimates. The reported R^2 corresponds to the correlation between observed and predicted values of the dependent variable.

Table 5: DATA FOR THE MODEL CALIBRATION*

Country	GDP_i/GDP_{world}	E_i/E_{world}	$\hat{\tilde{\lambda}}_i$	p_{ei}/w_i	p_{ci}/p_{qi}	p_{qi}/w_i
United States	0.3048	0.2535	1.0000	1.0000	1.0000	1.0000
Rest of the World	0.1987	0.3975	0.5737	1.9766	6.3347	0.5840
Japan	0.1398	0.0605	1.3854	1.9274	1.3995	1.2167
Germany	0.0565	0.0358	1.0000	2.0345	1.6310	1.0896
Great Britain	0.0460	0.0282	0.9875	1.7014	1.6102	0.9359
France	0.0404	0.0243	0.9227	1.9578	1.6206	1.1231
Italy	0.0329	0.0251	0.8518	2.9578	1.5241	0.9241
Canada	0.0225	0.0301	0.6994	1.3954	1.3506	0.9481
Spain	0.0184	0.0150	0.7145	2.7374	2.0474	0.9865
Mexico	0.0175	0.0207	0.5179	1.9766	1.6269	0.5290
Korea	0.0175	0.0210	0.6500	2.6518	1.4319	1.1967
Australia	0.0132	0.0111	0.8226	1.0929	1.2973	0.8295
Netherlands	0.0116	0.0125	0.8494	1.6596	1.5508	1.1061
Turkey	0.0083	0.0076	0.4281	1.9766	1.4624	0.4563
Sweden	0.0077	0.0042	0.9843	2.1787	1.7288	1.1774
Switzerland	0.0075	0.0029	1.3471	1.5570	1.1882	1.2373
Belgium	0.0070	0.0073	0.7895	1.6931	1.2124	1.1774
Austria	0.0058	0.0034	0.7287	1.6890	1.4879	1.1406
Poland	0.0053	0.0057	0.4816	6.7449	4.2365	0.4771
Norway	0.0052	0.0032	0.9129	1.9766	1.5003	1.2167
Denmark	0.0048	0.0026	1.0087	1.7742	1.8624	1.0896
Greece	0.0041	0.0037	0.9531	3.3964	1.7247	0.7935
Finland	0.0038	0.0029	0.8784	1.9202	1.2959	1.0139
Israel	0.0038	0.0023	0.6495	1.9766	1.7489	1.1967
Portugal	0.0035	0.0031	0.5992	5.0361	3.3143	0.7019
Ireland	0.0032	0.0020	0.8139	1.6223	0.8382	0.9481
Chile	0.0024	0.0028	0.2928	1.9766	0.8016	0.5984
Czech Republic	0.0018	0.0030	0.4255	7.0440	3.7459	0.3763
New Zealand	0.0017	0.0021	0.6155	1.9766	2.0104	0.9359
Hungary	0.0016	0.0028	0.4630	6.2533	3.9029	0.3822
Slovak Republic	0.0009	0.0016	0.3459	1.9766	4.3260	0.3174
Luxembourg	0.0006	0.0005	0.7895	1.2653	1.3580	1.0896
Slovenia	0.0006	0.0006	0.9189	1.9766	1.6386	1.0429
Iceland	0.0003	0.0002	0.6308	1.9766	1.8056	1.0896
Estonia	0.0002	0.0004	0.4081	1.9766	6.0695	0.8202

Notes: * The data were averaged across 2000-2005

Table 6: CALIBRATION RESULTS

Country	$Import_i/GDP_i$	L_i	T_i	l_{ci}	l_{qi}	l_{ei}
United States	0.0504	0.1758	0.0360	0.5977	0.2982	0.1040
Rest of the World	0.0321	0.4105	0.0414	0.5989	0.2971	0.1040
Japan	0.0381	0.0476	0.0136	0.5978	0.2982	0.1040
Germany	0.2603	0.0348	0.0187	0.5979	0.2980	0.1040
Great Britain	0.2169	0.0278	0.0221	0.5983	0.2977	0.1040
France	0.2947	0.0284	0.0211	0.5982	0.2978	0.1040
Italy	0.2223	0.0309	0.0168	0.5982	0.2978	0.1040
Canada	0.3570	0.0241	0.0390	0.5994	0.2966	0.1040
Spain	0.2779	0.0233	0.0220	0.5987	0.2972	0.1040
Mexico	0.1416	0.0371	0.0453	0.6069	0.2894	0.1037
Korea	0.1265	0.0269	0.0265	0.6030	0.2931	0.1039
Australia	0.1150	0.0099	0.0406	0.5999	0.2961	0.1040
Netherlands	0.4694	0.0081	0.0252	0.5985	0.2975	0.1040
Turkey	0.2859	0.0261	0.0558	0.6028	0.2933	0.1039
Sweden	0.3801	0.0043	0.0169	0.5995	0.2966	0.1040
Switzerland	0.5240	0.0019	0.0141	0.6026	0.2935	0.1039
Belgium	0.6399	0.0051	0.0250	0.5985	0.2975	0.1040
Austria	0.5422	0.0052	0.0288	0.5999	0.2961	0.1040
Poland	0.3189	0.0162	0.0175	0.6173	0.2793	0.1034
Norway	0.4030	0.0032	0.0197	0.6012	0.2948	0.1039
Denmark	0.4945	0.0023	0.0185	0.5994	0.2966	0.1040
Greece	0.4344	0.0026	0.0118	0.5999	0.2961	0.1040
Finland	0.4725	0.0024	0.0208	0.6000	0.2960	0.1040
Israel	0.4103	0.0045	0.0312	0.6030	0.2931	0.1039
Portugal	0.4658	0.0065	0.0153	0.5997	0.2964	0.1040
Ireland	0.6100	0.0021	0.0249	0.5998	0.2962	0.1040
Chile	0.2765	0.0152	0.0898	0.6082	0.2881	0.1037
Czech Republic	0.5613	0.0061	0.0177	0.6191	0.2775	0.1033
New Zealand	0.3141	0.0023	0.0327	0.6020	0.2941	0.1039
Hungary	0.5279	0.0045	0.0177	0.6155	0.2810	0.1035
Slovak Republic	0.6334	0.0032	0.0625	0.6213	0.2755	0.1033
Luxembourg	0.7671	0.0003	0.0267	0.6098	0.2866	0.1036
Slovenia	0.5898	0.0003	0.0188	0.6374	0.2598	0.1027
Iceland	0.7112	0.0003	0.0258	0.6072	0.2891	0.1037
Estonia	0.7860	0.0004	0.0397	0.6000	0.2960	0.1040

Table 7: FIT OF CALIBRATION

	Correlation coefficient: data versus model		
variable	*Calibration 1*	*Calibration 2*	*Calibration 3*
GDP_i/GDP_{world}	1.00	1.00	1.00
E_i/E_{world}	0.99	1.00	-0.05
p_{ci}/p_{qi}	0.73	0.98	0.73
p_{ci}/w_i	0.58	0.37	0.10
p_{qi}/w_i	0.33	0.36	0.97
p_{ei}/w_i	1.00	0.25	0.01
λ_i	1.00	0.77	1.00
π_{in}	0.80	0.80	0.80

FIGURE 1: Energy Demand; Model versus Data
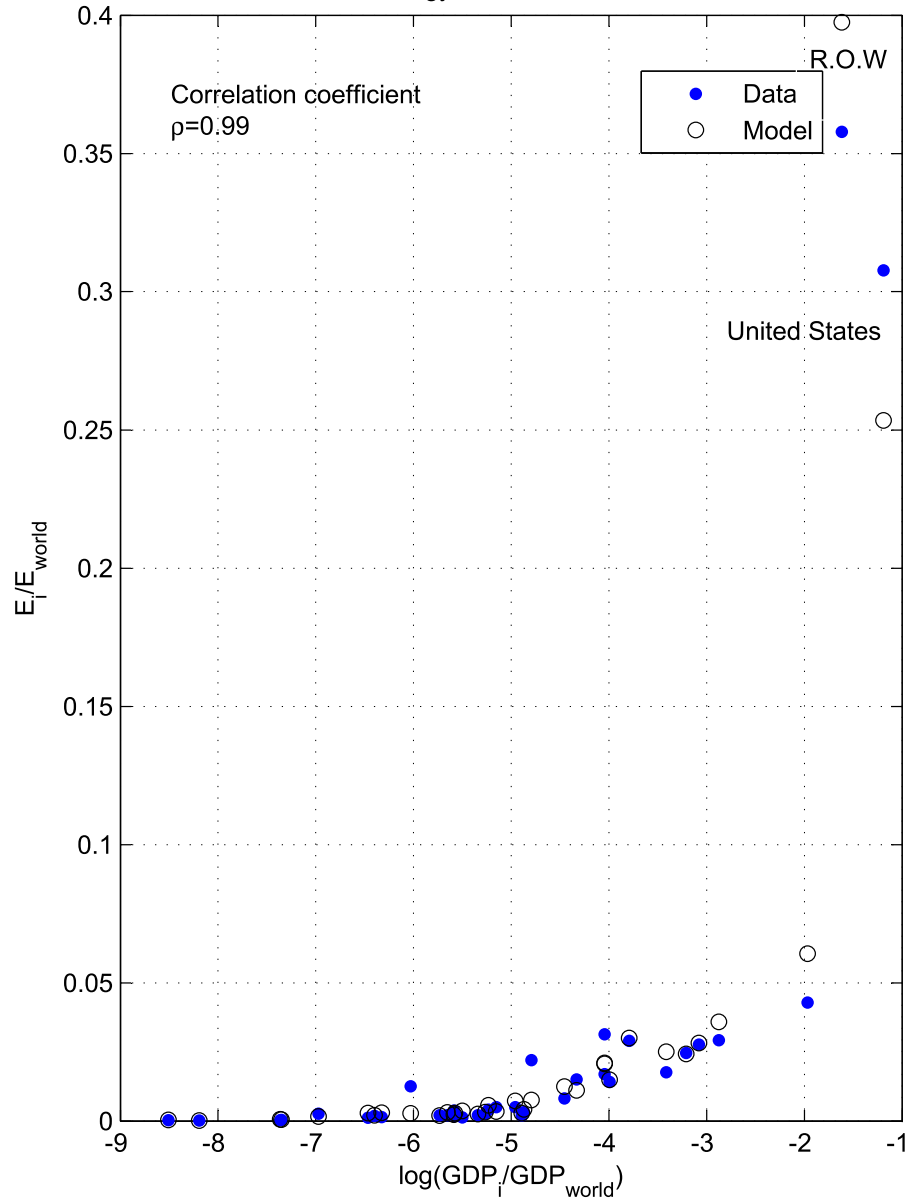
FIGURE 2: Ratio of Total Imports to GDP; Model versus Data
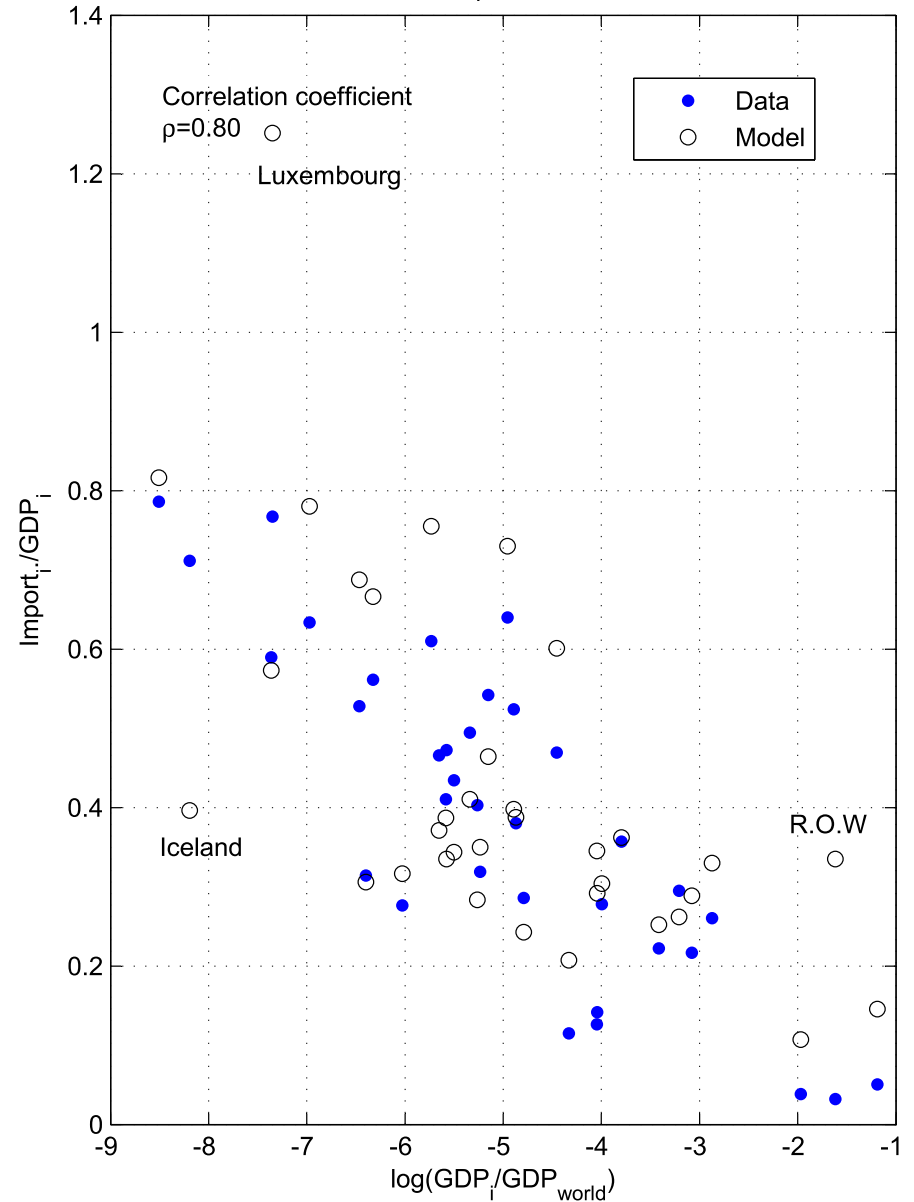
FIGURE 3: Welfare Gains from Abolishing Tariffs
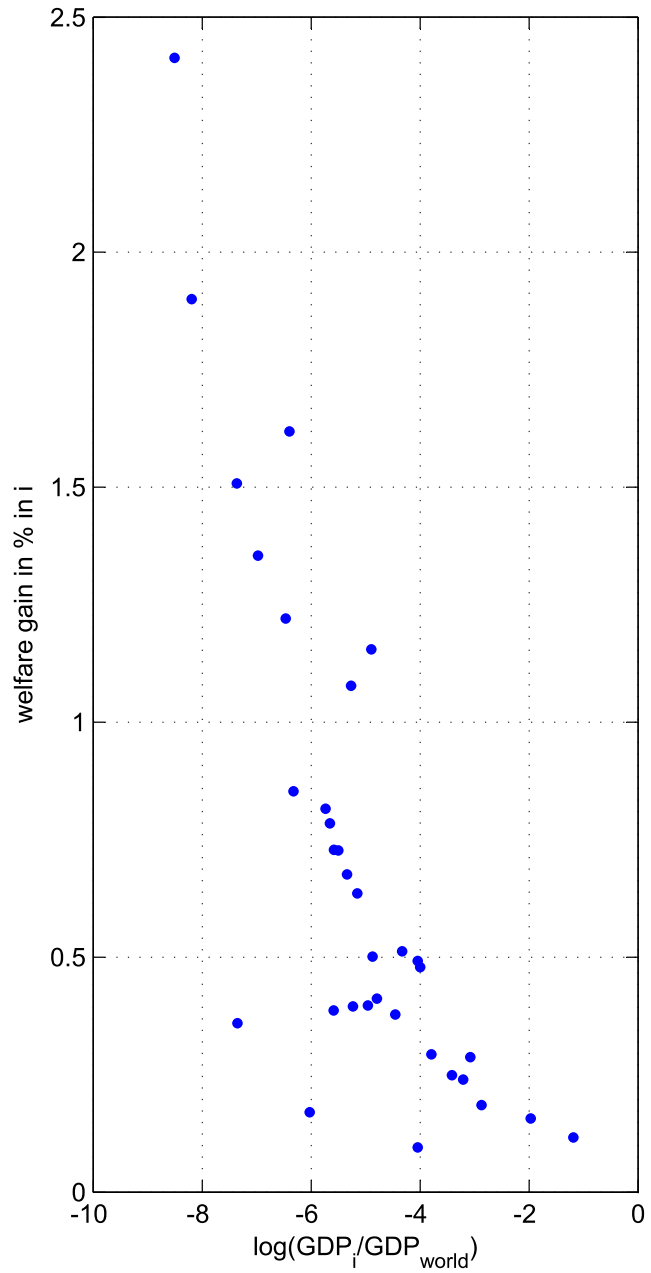
FIGURE 4: Welfare Gains from Abolishing Search and Transaction Costs
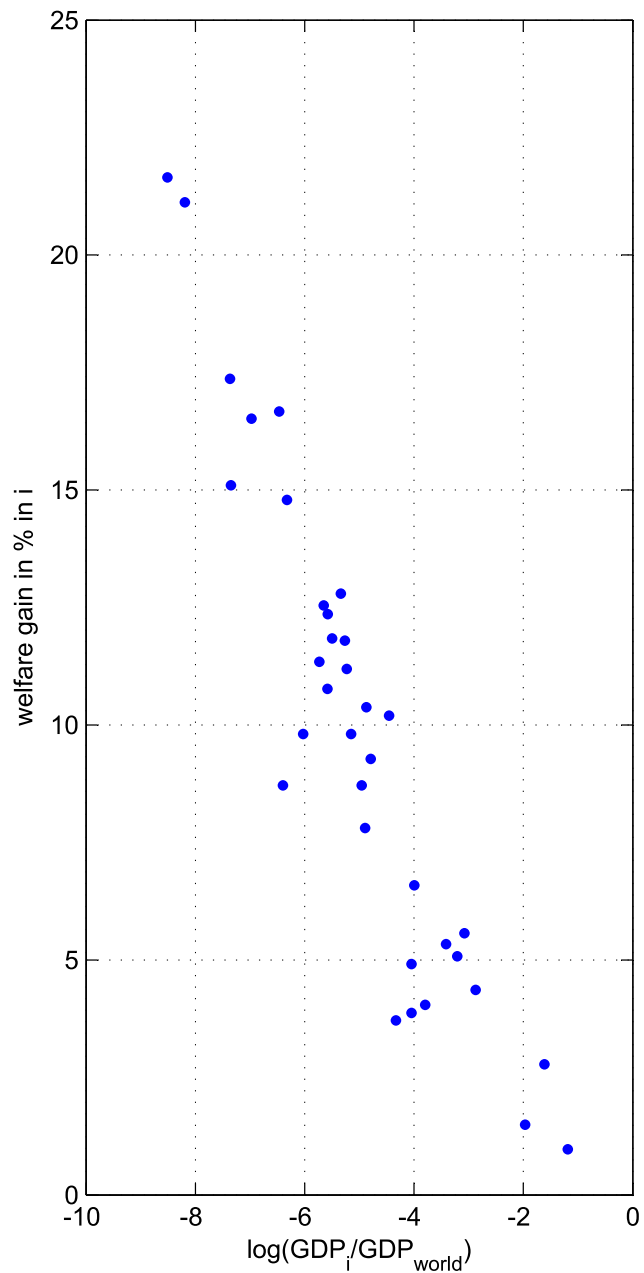
FIGURE 5: Welfare Gains from a 10% Reduction in Non-Tariff Trade Costs
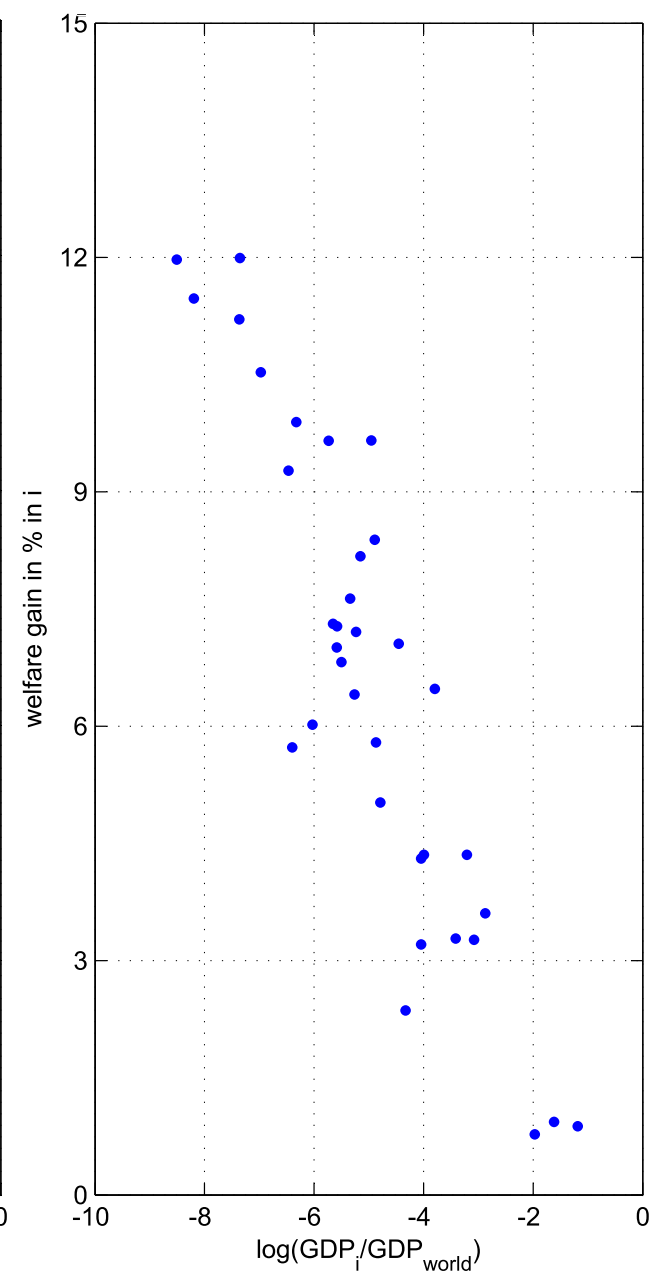
FIGURE 6: Trade Liberalization Effects from a 10% reduction in Non-Tariff Trade Costs
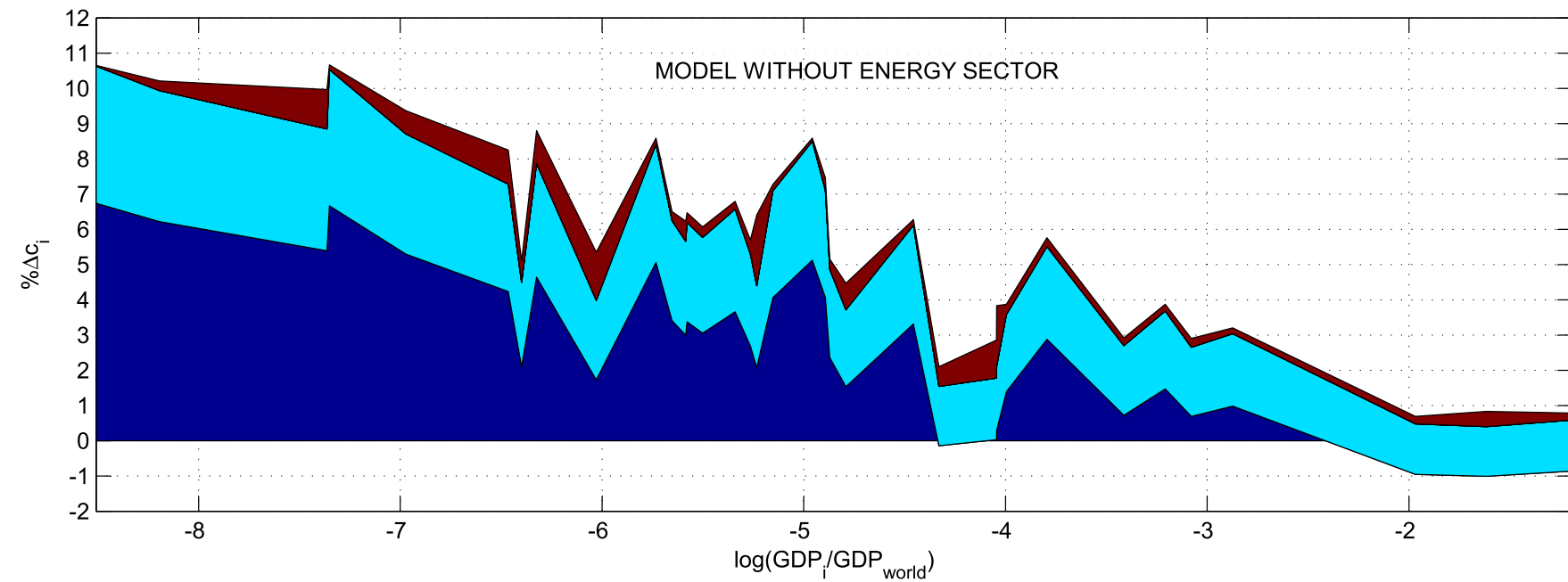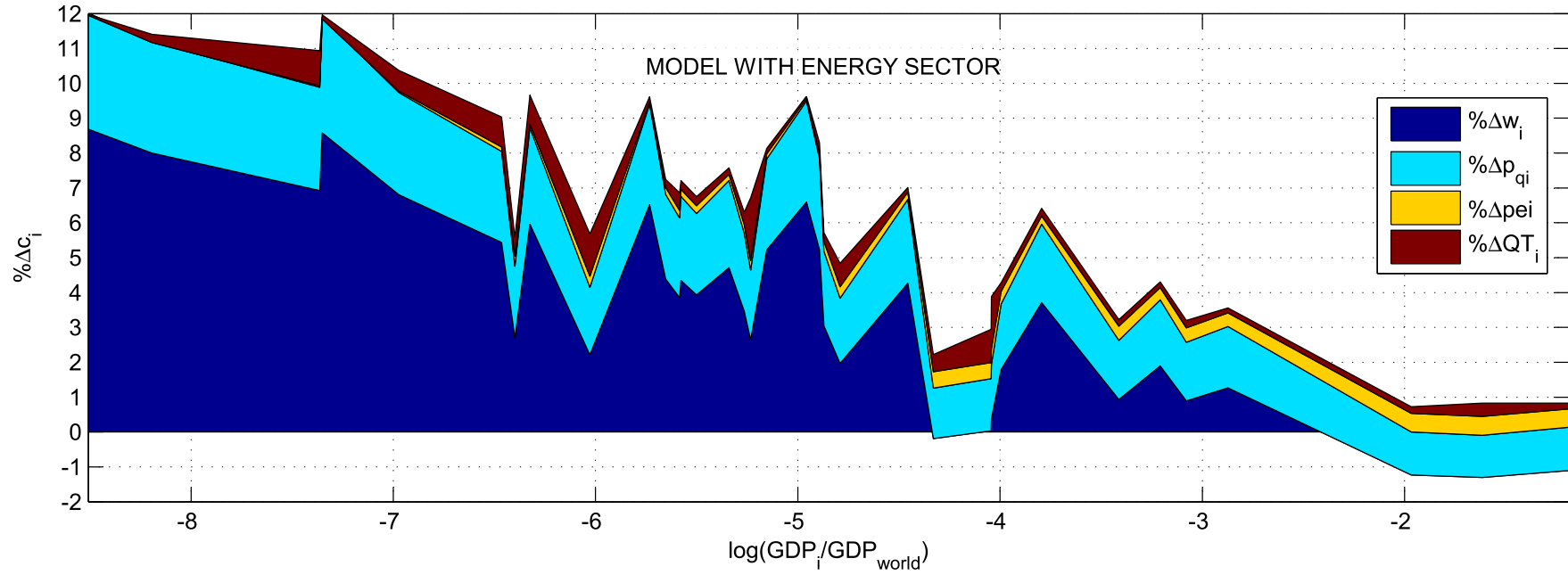
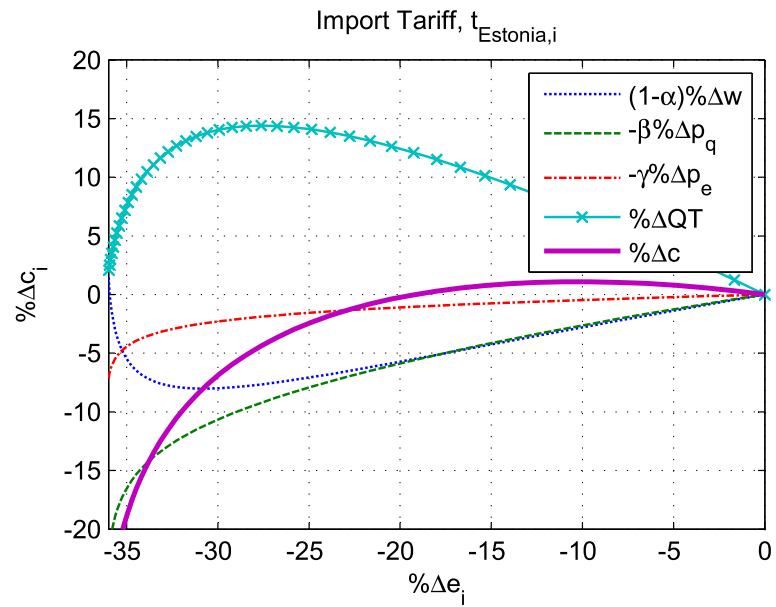FIGURE 7: Welfare Effect of Policy Instruments at Alternative Levels of Reduction in Energy Demand
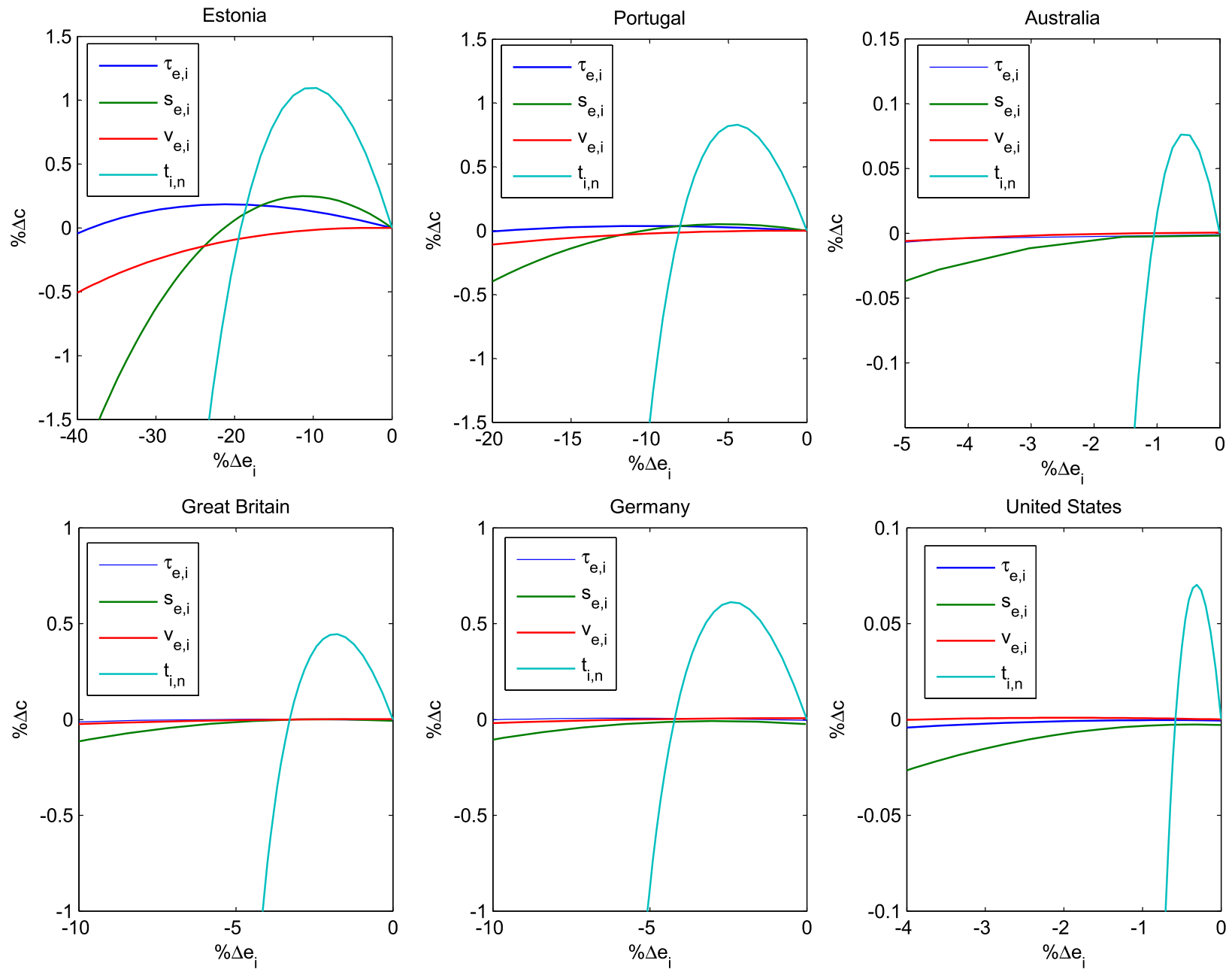
FIGURE 8: Decomposed Welfare Effects of Alternative Policy Instruments to Reduce Energy Demand in a S.O.E.
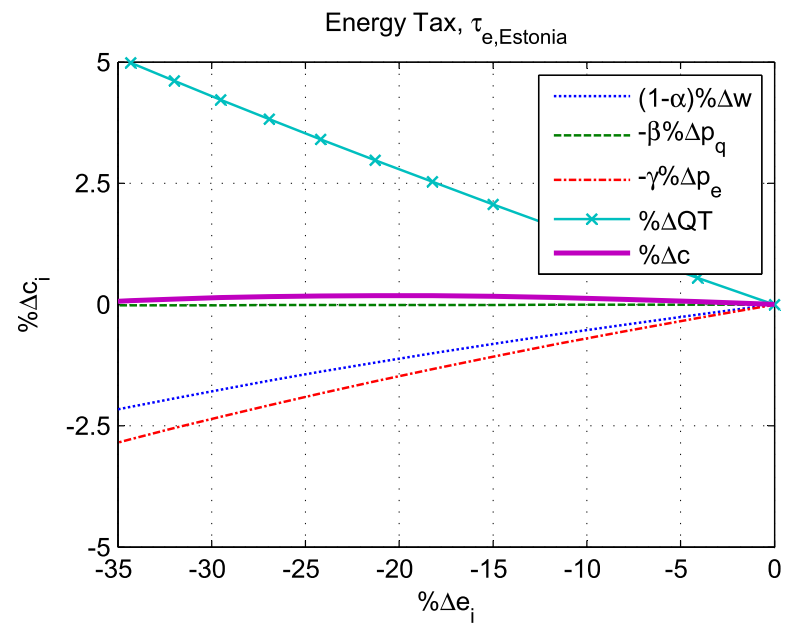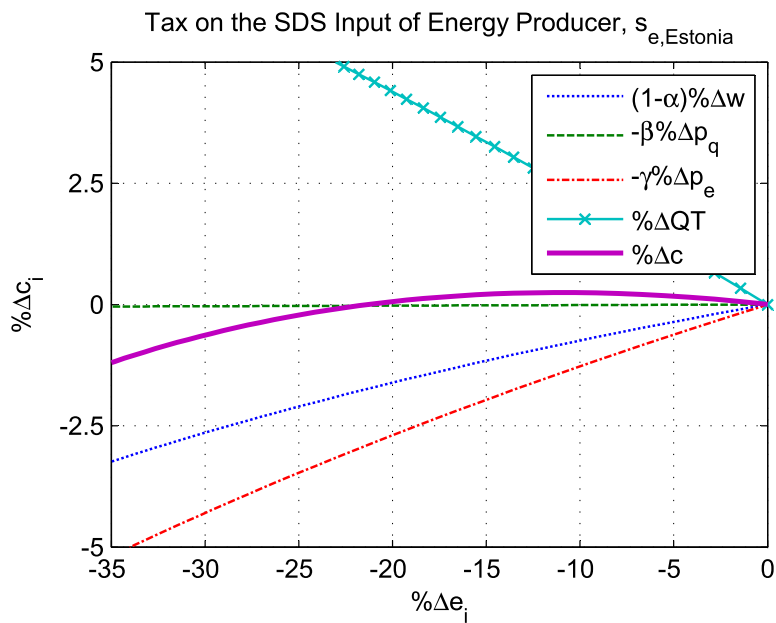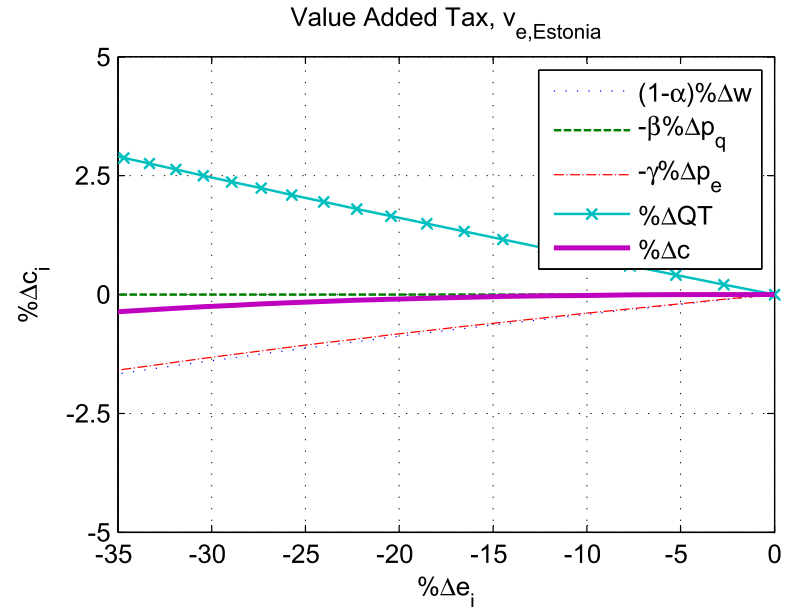
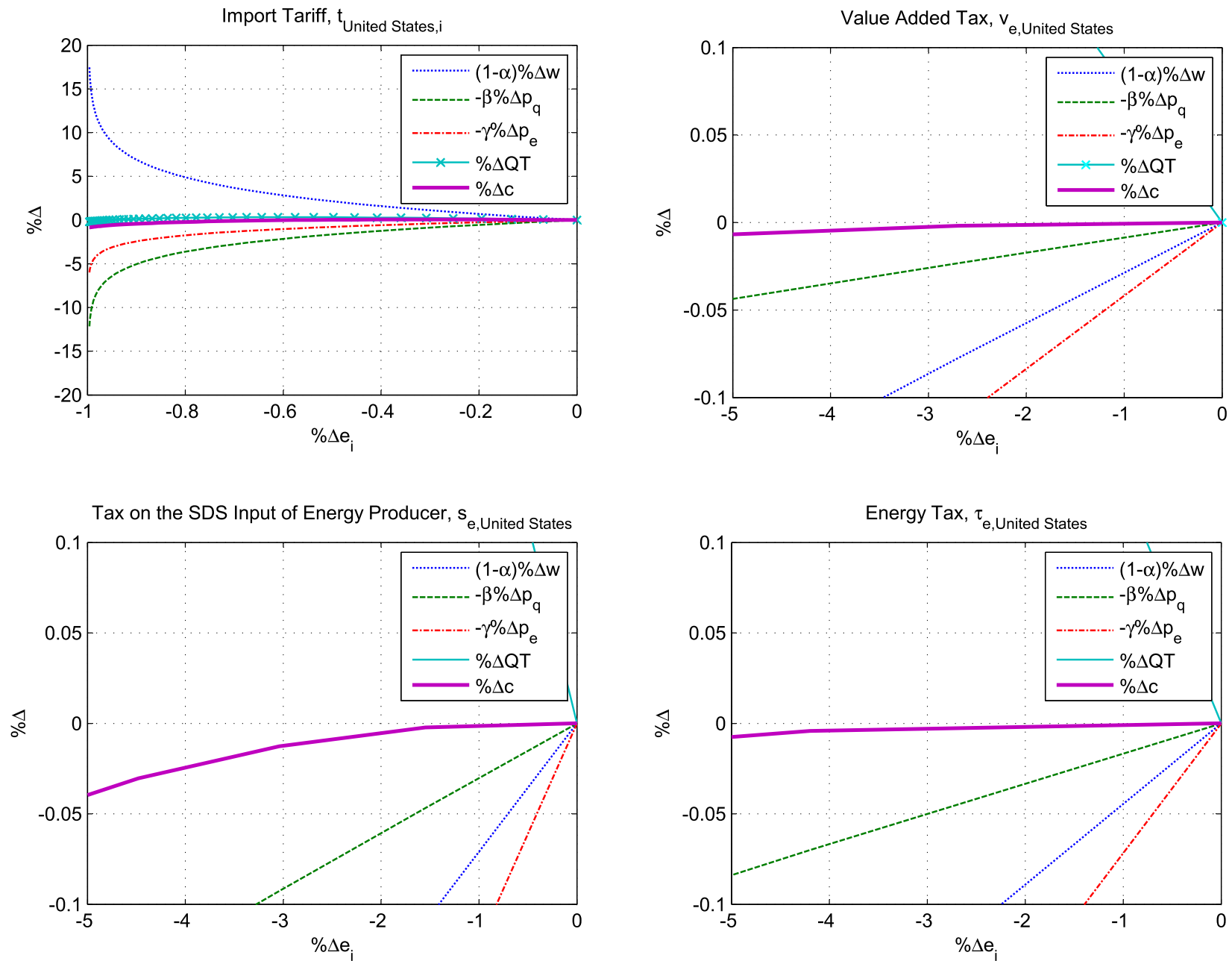FIGURE 9: Decomposed Welfare Effects of Alternative Policy Instruments to Reduce Energy Demand in a S.O.E.
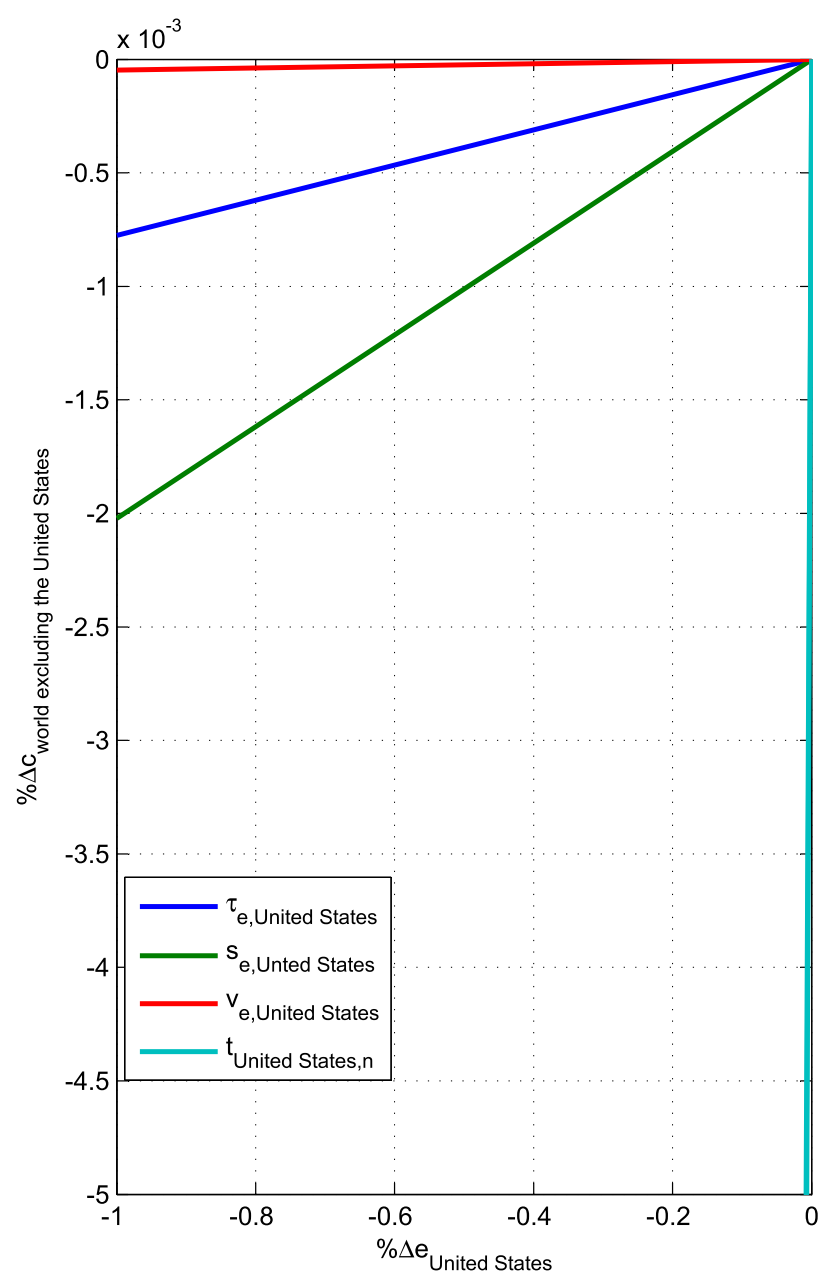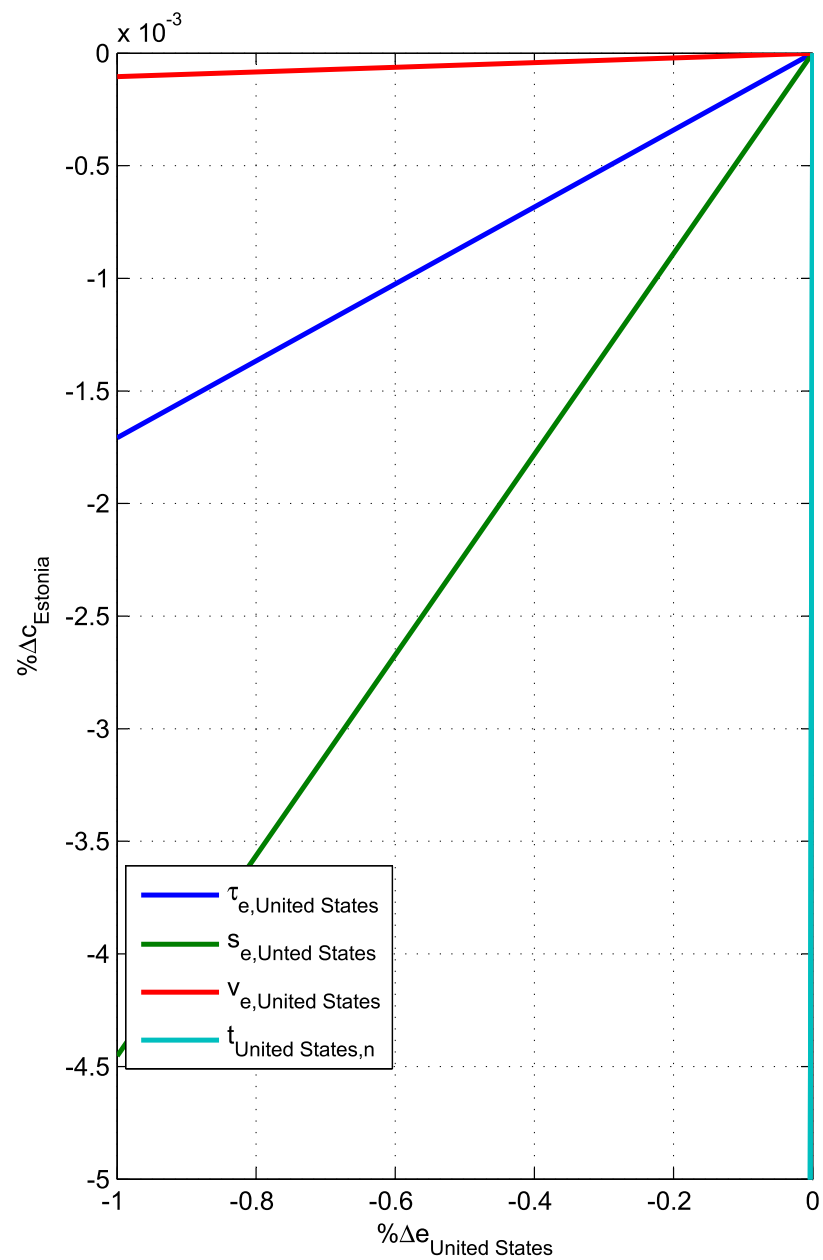
FIGURE 10: Welfare Effects of the United States' Alternative Policies to Reduce Energy Demand on Third Countries

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Appendix

Derivation details

We use three properties of the exponential distribution in our derivations:

(i) If $z(j) \sim exp(\lambda) \Rightarrow Kz(j) \sim exp(\frac{\lambda}{K})$.

(ii) If $x \sim exp(\lambda_x)$ and $y \sim (\lambda_y)$ are independent $\Rightarrow min(x, y) \sim exp(\lambda_x + \lambda_y)$.

(iii) If $x \sim exp(\lambda_x)$ and $y \sim (\lambda_y)$ are independent $\Rightarrow Pr(x \leq y) = \frac{\lambda_x}{\lambda_x + \lambda_y}$.

To derive (3.2) from (3.1) use property (ii). To derive (3.7) from (3.6), use properties (ii) and (iii) to obtain:

$$\pi_{in} = \frac{\lambda_n \left(w_n^\epsilon p_{qn}^\nu p_{en}^\mu d_{ni}(1 + t_{in}) \right)^{-\frac{1}{\theta}}}{\lambda_k \sum_{k=1}^N \left(w_k^\epsilon p_{qk}^\nu p_{ek}^\mu d_{ki}(1 + t_{ik}) \right)^{-\frac{1}{\theta}}}.$$

Then, by using (3.5) we can express π_{in} as:

$$\pi_{in} = (A\Gamma_e)^{-\frac{1}{\theta}} \lambda_n \left(\frac{w_n^\epsilon p_{qn}^\nu p_{en}^\mu (t_{in} + 1)d_{ni}}{p_{qi}} \right)^{-\frac{1}{\theta}}.$$

Calibration

Benchmark model

We calibrate the benchmark model to GDP_i, λ_i, $\tilde{P}_i$ as follows. First, substitute π_{in} from (3.7) into the *Excess Demand* equation to get the following:

$$\sum_{n=1}^N \frac{L_n w_n l_{qn}}{R_n(1 + t_{ni})} \lambda_i \left(\frac{(A\Gamma_e)w_i^\epsilon p_{qi}^\nu p_{ei}^\mu}{(t_{ni} + 1)d_{in}p_{qn}} \right)^{-\frac{1}{\theta}} = L_i w_i l_{qi}$$

Next, substitute p_{ei} from equation (2.6) and express T_i as:

$$T_i = \frac{L_i}{\lambda_i \kappa_i} w_i^\omega$$

$$\text{,where } \kappa_i = \sum_{n=1}^N \frac{L_n w_n l_{qn}}{R_n(1 + t_{ni})} \left(\frac{(A\Gamma_e)}{(t_{ni} + 1)d_{in}p_{qn}} \right)^{-\frac{1}{\theta}} p_{qi}^{-\frac{\nu + \mu(1-\zeta)}{\theta}}$$

$$\text{,and } \omega = (\epsilon + \theta + \zeta\mu)\mu^{-1}$$

$$\text{,or } T_i = \frac{L_i}{\lambda_i \kappa_i} \left(\frac{w_i}{p_{ei}} \right)^\omega p_{ei}^\omega$$

Finally, use (2.6) once again to arrive at (4.8).

Calibration 2

We calibrate this version so that the following variables match the data: $(GDP_i, E_i, \tilde{P}_i)$. The relative price $\tilde{P}_i$ in this version is a ratio of p_{ci} to p_{qi}. As in the benchmark model we use the following equation to pin down the relationship between λ_i and T_i:

$$\sum_{n=1}^{N} \frac{L_n w_n l_{qn}}{R_n(1+t_{ni})} \lambda_i \left(\frac{(A\Gamma_e)w_i^\epsilon p_{qi}^\nu p_{ei}^\mu}{(t_{ni}+1)d_{in}p_{qn}} \right)^{-\frac{1}{\theta}} = L_i w_i l_{qi}$$

We also use (2.7) and (3.16) to express T_i in terms of total energy demand. We then add the following two equation to (3.9),(4.7):

$$T_i = \zeta Z E_i w_i^{(\zeta-1)} \left(p_{qi}^{(\zeta-1)} l_{ei} L_i \right)^{-1}$$
$$\lambda_i = L_i \tilde{P}_i \hat{\kappa}_i(w_i, T_i)^{-1}.$$

Calibration 3

In this model we calibrate the variables to match the data on GDP_i, λ_i, $\tilde{P}_i$. This model is different from the benchmark model in terms of $\tilde{P}_i$. In this specification we match the ratio of price of tradables to wages. Otherwise, equations used in the calibration are identical to the benchmark model.

Assembling energy price data

One measure which is at the heart of our analysis, namely energy prices for country i and year t ($p_{e,it}$) that are comparable across countries are quite difficult to obtain. For construction of our measure, we identify three main sources of energy for industries and households: natural gas, petroleum products, and electricity.[1] For each country, we calculate the shares based on overall consumption of these three energy types. The energy price index is then a share weighted average of the price of gas, petroleum products, and electricity in U.S. dollars per BTU (British Thermal Unit).[2] Specifically, we applied the following rules in constructing $p_{e,it}$:

1. The data suggest that end−use energy prices differ between industry and households. Yet, the model assumes parity in energy prices that households and firms face. We use industry end−use prices to calculate the index.

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[1]We do not include coal in the index for two reasons. First, coal has been becoming less important for households and manufacturing industries in most of the OECD countries. For example, in the United States the share of coal in household consumption of energy was about 22 percent in 1940 but less than 0.01 percent in 2009. In general, during the period of 1980−2003 the average share of coal in residential energy consumption was much less than one percent (see the U.S. Energy Information Administration, http://www.eia.doe.gov/aer/consump.html, accessed on December, 2010. Second, the data on coal prices are not available for a number of OECD countries.

[2]Energy consumption in Germany up to 1990 was calculated as a sum of energy consumption in East and West Germany. Energy consumption in Czech Republic and Slovak Republic prior to 1993 was calculated using 1994 ratios and using data for former Czechoslovakia.

2. Data on the price of gas, petroleum products, and electricity are incomplete even for the 28 OECD countries in our sample. In fact, about 32% of of the data points are missing for the 28 economies over the period 1980−2003. The three time series are complete for only eight countries. We imputed missing observations using several methods. First, we used the nominal price index specific to a country and energy type where possible. Second, we assumed that the relationship between industry and residential end−use prices was fairly stable and used residential end−use prices dynamics to project industry end−use prices where possible. Third, if neither of the two previous techniques were applicable, we imputed missing data by using region and energy type specific nominal price indices to project the dynamics. Imputation based on the first two methods allowed us to increase the number of observations to 87%. The third method allowed us to close all remaining gaps.

The time series are most incomplete for natural gas consumption in Greece, Korea, Portugal, Sweden, and Turkey. These countries, however, exhibited very low natural gas consumption relative to two the other two sources of energy during the years with missing price data. In particular, the average share of gas consumption for the years with missing price data was around 1%. If we had assumed the share of gas to be zero for observations where it was lower than 1%, we would have had to impute only 4% of the observations by the third imputation algorithm. Thus, imputing observations on natural gas prices should not induce a significant bias in our framework.

After having imputed the data of the aforementioned 28 OECD countries we assume the average price of the 28 economies and the same parameters for the remaining six OECD countries and the rest of the world in our analysis so as to obtain complete price and consumption data for the 35 economies covered in this paper.