WORKING PAPER

How should governments respond to energy shocks? A horse-race approach.

Geoffroy Duparc-Portier, University of Strathclyde

May 12, 2023

Abstract

This paper compares the economic impacts of five fiscal policies used during energy crises financed with debt or a combination of debt and windfall taxes. Aggregate and distributional impacts are evaluated using a computable general equilibrium model. The results suggest that production tax reductions and general energy price subsidies are preferable for addressing the aggregate impacts of energy shocks. Tax reductions boost aggregate output at very low inflation costs whilst general price subsidies boost aggregate output most of all the policies at a relatively low inflation cost compared to the other policies. The results also suggest that targeted income subsidies and targeted energy price subsidies are more effective at increasing welfare and reversing the regressive effects of the energy shock. Finally, the results motivate the use of windfall taxation if governments face high-interest rates on debt financing and/ or if households care sufficiently about the provision of public goods. Thus, the optimal policy is likely a mix of supply-side measures (production tax reductions, general price subsidies) and either targeted energy price subsidies or targeted income subsidies financed partially through windfall taxation.

Contents

1 Introduction

Stable energy markets are fundamental for macroeconomic stability. The 2022-2023 cost-of-living crisis has reminded economists of this fact with world consumer prices increasing from 3.1% in 2021 to 7.3% in 2022 whilst world output growth decreased from 6.2% to 3.4% (IMF 2023). Russia's invasion of Ukraine has been one of the main drivers of the inflationary pressure and output slowdown. This conflict has led to supply disruptions, political sanctions, and trade restrictions, which have reduced trade - especially between Russia and the EU. This is since Russia was the main exporter of crude oil, gas, and solid fossil fuels to the EU before 2022. To replace the energy supplied by Russia, EU countries had to find new, more expensive suppliers and had to compete with other countries affected by the energy crisis. These supply disruptions have led to substantial increases in energy prices. The consequences of this shock have not been felt evenly. Indeed, the energy shock had geographically and distributionally asymmetric impacts. On a geographical level, some countries such as Germany and Italy, are much more dependent on Russian energy imports in comparison to other EU countries and have been more affected. Distributionally, lower-income households have been more adversely affected as they typically consume a larger proportion of their income on energy goods compared with higher-income households.

Following the energy price shock, governments across the EU have been implementing a litany of different fiscal policies. These are designed to address aggregate and distributional consequences of the shock. The main measures taken by governments to address the energy shocks are price subsidies, income subsidies, and tax reductions on energy. Price subsidies have come in three broad forms: general (to firms and households), untargeted (to all households), and targeted (to lower-income households). Income subsidies have been typically targeted towards lower-income households, whilst production tax reductions have typically been associated to firms' energy use. Governments across the EU have mainly used debt financing to finance these policies. Due to unprecedented increases in energy firm profits, some governments have also financed these policies through windfall taxation.

Broad empirical and theoretical literature exists, that quantifies the aggregate and distributional effects of energy shocks and the effects of price subsidies, income subsidies, and tax reductions. Literature comparing the impacts of these policies using a harmonized framework is however sparse. Thus, I aim to understand how governments should respond to energy shocks by investigating the short-run aggregate and distributional implications of the policies listed above as well as their long-run welfare outcomes. The policies are compared and ranked under two forms of financing: pure debt and a mixture of debt and windfall tax financing.

A discrete-time dynamic computable general equilibrium (CGE) model is developed for the analysis. The model contains two household income groups to investigate the distributional implications of the policies. To capture international interdependencies of energy markets, the model contains data for two endogenous regions; Germany and the rest of the EU (REU). An energy shock is then introduced to both regions. Following this, the German government introduces one of the five fiscal policies (general/ untargeted/ targeted price subsidies, income subsidies, production tax reductions) using either debt financing or a combination of debt and windfall tax financing.

Using the CGE model, a few stylised conclusions can be drawn. First, targeted income and price subsidies best counteract short-run regressive impacts on consumption and provide the best long-run welfare outcomes following the energy shock. Second, tax reductions are the most effective policy to address inflationary pressures. These help aggregate output recover by roughly the same amount as the targeted subsidies and have a neutral impact on inflation. Third, general price subsidies are the most effective policy to counteract downward pressure on aggregate output in the short run. In fact, the aggregate output recovery through the general price subsidy is almost twice as large as all the other policies as long as households care slightly about the provision of public goods or if the interest rate on debt financing is not risk-free. Fourth, introducing a windfall tax is welfare-enhancing for all policies. Fifth and last, income subsidies are only effective if the marginal propensity to consume the subsidy is very high.

The rest of this paper is structured as follows: §2 summarises the context and related literature on energy shocks and policies; §3 provides an overview of the CGE model used in this paper; §4 details the data used to calibrate the model and quantify the energy shock; §5 describes the fiscal policy scenarios; §6 summarises and interprets the key results; §7 concludes the paper.

2 Background and Literature

2.1 Energy shocks

2.1.1 Early evidence

Following the First World War, the world economy has become very dependent on energy. Indeed, prior to the Great War, only 15.9% of dwellings in the United States (US) had access to electricity (Woolf 1987). Today, 100% of dwellings have access to electricity in the US and 90.4% have access to electricity across the World (World Bank 2023*a*). This increase in electricity demand has been accompanied by increases in private and firm motor vehicle demand as well as production and the development of new fuel-intensive technologies. Over time, these developments have led to considerable expansions in energy markets with the production of oil and liquefied natural gas increasing by over 85% between 1971 and 2019 (IEA 2023).

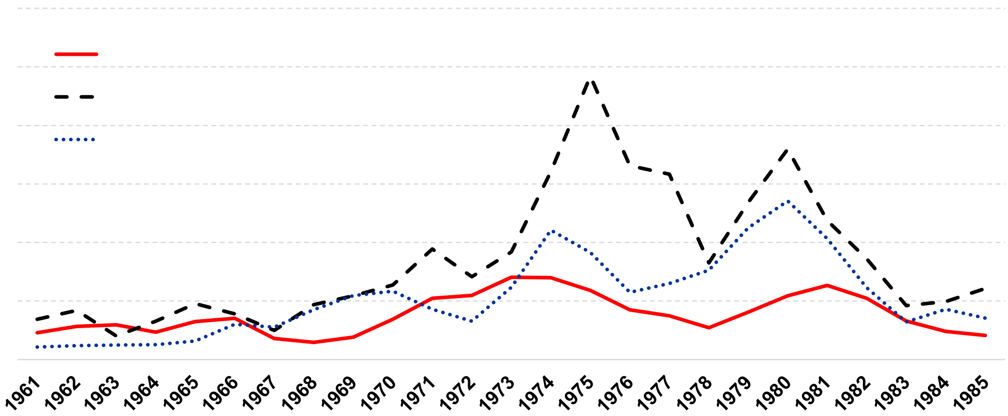

Figure 1: Consumer Price Inflation (annual %) (World Bank 2023*b*)

The growth of energy markets most notably the crude oil, and natural gas markets has led to economic development and welfare improvements, however, it has also made modern economies vulnerable to energy shocks. The importance of energy shocks to the world economy was made clear during the OPEC crisis of the 1970s. Between 1970 and 1980, crude oil prices increased twenty-fold (Ritchie et al. 2022, BP 2022). This substantial increase in the price of oil translated into stagflation for many Western economies such as Germany, the United Kingdom (UK), and the US amongst many others as is shown in figures 1 and 2.

Since the 1970s, economists have tried to gain a better understanding of the effects of energy shocks on the economy. Early research from Hamilton (1983) showed that “seven of the eight postwar recessions in the United States” were “preceded by a dramatic increase in the price of crude” oil. The early evidence of Hamilton (1983) is corroborated by other authors such as Gisser & Goodwin (1986) who find that crude oil price shocks have real effects on GDP and inflationary effects in the US. Gisser & Goodwin (1986) suggest that these effects are more significant than those of fiscal policies. More recently, Jiménez-Rodríguez & Sánchez (2005) find that oil price increases are associated with decreases in GDP growth in oil-importing countries. The size of the GDP growth decreases varies across countries (Jiménez-Rodríguez & Sánchez 2005). Importantly, Jiménez-Rodríguez (2008) finds that these impacts are heterogeneous both geographically and at an industrial level. As the input-output data used to build CGE models provide geographical and industrial-level detail, in this paper, a CGE modelling methodology is employed.

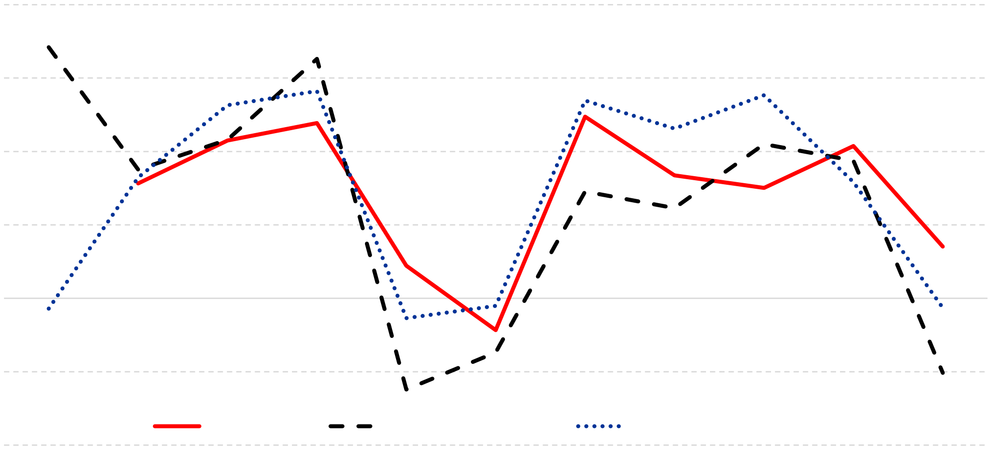

Figure 2: GDP growth (annual %) (World Bank 2023*c*)

2.1.2 Later evidence

Although early evidence suggests oil price shocks have adverse effects on GDP growth and heterogeneous effects across countries and industries, these often fail to address the complex relationship between oil prices and GDP growth (Barsky & Kilian 2004, Kilian 2009). Indeed, empiricists began to find a flattening relationship between oil prices and GDP growth in the 1980s and 1990s (Ven & Fouquet 2017). Kilian (2009) explained this flattening as a result of a failure in the methods adopted at the time. Kilian (2009) suggested that the failure was due to the exogenous treatment of oil prices in the Vector Autoregression (VAR) methods predominantly employed. They proposed a structural VAR method to capture both demand side and supply side factors driving oil markets and found that supply-driven oil price increases have the largest effect in the year proceeding the shock whilst this is two years for demand-driven oil price increases (Ven & Fouquet 2017, Kilian & Murphy 2012).

Although there is still a debate on the empirical methods which should be used to quantify energy shocks, the 2022-2023 cost-of-living crisis has certainly shown that their impacts are not negligible. The IMF (2023) estimates that world GDP growth slowed down by close to 3 percentage points (pps) between 2021 and 2022 whilst consumer prices surged by close to 4 pps. Part of this slowdown can be attributed to the abnormally high growth rate in 2021 due to the Covid-19 recovery however, the inflationary pressures were driven in big part by energy market frictions. Indeed, following the 2022 Russian invasion of Ukraine, the world's energy markets fundamentally changed. Due to political decisions and international sanctions, countries that had been highly dependent on Russian energy products such as crude oil, refined petroleum and natural gas drastically increased domestic energy production and altered their supply chains. Prior to the invasion, countries such as Germany and Italy imported most of their natural gas and crude oil from Russia. As the supply of Russian energy to the EU has decreased, energy prices in the EU have skyrocketed and EU countries such as Germany and Italy had to radically and swiftly switch their supply chains.

Due to gas market disruptions and supply chain changes, the price of gas has increased by over 80% in the EU between the first half of 2021 and the first half of 2022 (Eurostat 2023*d*). For energy consumers consuming more than 4 million Giga Joules, the gas price quadrupled. Comparable gas price increases were also observed in Germany (Eurostat 2023*c*). As the prices of gas and oil are closely connected to the price of electricity in the EU, electricity prices have also surged. According to Eurostat data, electricity prices increased by up to 50% in the EU and 36% in Germany (Eurostat 2023*e*).

Increases in the prices of gas, oil and electricity across Europe due to the current energy crisis have been investigated in recent papers by Celasun et al. (2022), Guan et al. (2023), Perdana et al. (2022) and Turner et al. (2022) amongst others. Celasun et al. (2022) suggest that in 2022, European households' cost-of-living will have increased by 7%. Guan et al. (2023) use an international input-output framework and estimate total household energy costs to increase by 62.6–112.9% across the world. These effects are found to be distributed unevenly both within and across countries supporting evidence from Celasun et al. (2022). Perdana et al. (2022) evaluate the consequences of the trade sanctions on Russia using a CGE methodology, mainly from an environmental perspective, but also find reductions in GDP and Welfare in the EU. Finally, Turner et al. (2022) evaluate the implications of the cost-of-living crisis using a CGE model of the UK. They focus on the distributional impacts of £400 Energy Payments in the UK.

2.1.3 Distributional impacts

Energy supply shocks have adverse effects on GDP growth and lead to increasing prices which have regressive impacts. These are driven by many factors including consumption basket composition. As low-income households consume a higher fraction of their income on necessary goods (and energy is a necessary good), we expect higher inflation for low-income groups. This expectation has been proven to be true by Michael (1979) and Hagemann (1982) for the 1970s energy shocks. Further evidence of differential inflationary impacts are also found by Pizer & Sexton (2019), Williams et al. (2015) and Metcalf et al. (2008) in the energy policy literature. These authors find that energy taxation has regressive impacts with low-income households being more adversely impacted by the tax than high-income households. Recently, Guan et al. (2023) and Celasun et al. (2022) find that the effects of the 2022-2023 energy shock are regressive in many high-income countries including Germany. Turner et al. (2022) also find regressive impacts of the energy shock in the UK and suggest that the £400 Energy Payment introduced by the UK government still leaves households on the lowest income £350 worse off than before the energy crisis. As distributional considerations are crucial to the determination of appropriate fiscal policy measures, this paper introduces two representative households. One for low-income households and one for high-income households.

Another reason for differential impacts across the income distribution is energy firm ownership. Through supply disruptions, domestic energy companies can benefit from decreases in international competition. In fact, many energy companies operating in the EU have recorded record profits during the 2022-2023 energy crisis. For instance, two of the largest oil and gas companies in the world, Shell and BP, saw record profits in 2022 (BP 2023, Shell 2023). Jolly & Elgot (2022) suggest that the profits of the 7 largest oil firms in the world exceeded £150bn in 2022. As a result, shareholders of these companies, who are typically high-income households, receive increased profits from domestic energy firms. Hence, in this paper, the profits of energy firms are modelled and redistributed to high-income households.

2.2 Fiscal policies

As a response to the energy shock, governments across Europe have introduced measures to support energy bills and protect households, reduce energy price inflation and support businesses. These measures have included production tax reductions (TR) to firms proportional to energy consumption, targeted and untargeted energy price subsidies to households (TPS and UPS), general energy price subsidies (GPS) and targeted income subsidies (TIS) (Sgaravatti et al. 2023). The size and precise form of these packages is well summarised in Sgaravatti et al. (2023) which provides detailed information on expenditure and revenue side fiscal policies across Europe.

Governments across Europe have also responded to increases in energy firm profits and the regressive impacts of the energy shock in Europe by introducing windfall taxation. These taxes on excess profits have been used to finance fiscal policies employed by governments as a response to surging energy prices and increasing inequality across the EU. Governments have also used debt financing to finance expenditure-side fiscal policies.

Based on the fiscal policies implemented across Europe, I choose to evaluate the implications of TRs, TPSs, UPSs, GPSs and TISs under pure debt and mixtures of debt and windfall tax financing in this paper. This will provide an overview of the strengths and weaknesses of each of the policies under a unified framework. Although the paper is inspired by the current measures implemented across Europe, it is designed as a theoretical contribution. Thus, the focus will be on comparing the policies rather than quantifying the effects of the energy crisis perfectly.

3 Model

In this paper, I use a multi-region discrete-time dynamic Computable General Equilibrium (CGE) model[1]. The equations of the model are described in detail in appendix A. The model consists of two endogenous regions, Germany and the rest of the EU, containing a set of representative agents and an external transactor group, the rest of the World (ROW). The representative agents are households in different income groups, firms in different sectors and a government. There are 22 sectors in the model. These are formally defined in section 4. The model is calibrated to a steady state where labour endowment and technology are assumed to be fixed. Capital follows a classical law of motion whereas labour supply decisions are defined using a wage curve. In the absence of shocks, the model replicates the baseline. This implies that the capital stock, labour stock and all decisions made by agents within the model will be constant as long as there is no change to the status quo.

3.1 Why CGE?

CGE models provide crucial information on financial flows between different sectors. This is particularly useful in the context of energy shocks compared to partial equilibrium and Dynamic Stochastic General Equilibrium (DSGE) models as it captures sector-specific shocks and their general impacts on other sectors and agents. In comparison, partial equilibrium models provide no insight into potentially large general equilibrium impacts and DSGE models provide no sector-level detail. Following the shock, the CGE model will provide detail on price effects on various sectors and as a result, demonstrate how trade and production may be affected in the endogenous regions. More, the CGE framework is a controlled environment and thus, provides a uniform foundation to compare the policies. For these reasons, a CGE model is employed to compare the policies.

3.2 Households and labour supply

There are two representative households in the endogenous regions of the model. German households are disaggregated into two net income groups[2]. One called "L" consists of all German households with net incomes below €5,000/ month. The other group called "H" consists of all German households with net incomes exceeding or equal to €5,000/ month[3]. Group "H" contains close to 25% and group "L" contains around 75% of German households. These groups are defined following the convention used in the

---

[1] The model includes 50 periods which can be interpreted as years as these are based on annual IO accounts.

[2] As the fiscal policies are only applied in Germany, the REU households are disaggregated into identical households.

[3] This data set does not include households earning over €18,000 nor self-employed households and homeless households.

"Continuous household budget surveys (LWR)" available on the Federal Statistical Office website; Germany's main statistic collection agency (FSO 2023*b*).

Households consume goods and services from the 22 industries both domestically and from other regions. A two-level consumption structure defines intratemporal consumption decisions. First, at the top level, households choose how much to consume from each sector. Second, at the bottom level households choose where to purchase goods from each sector. A Stone-Geary (Stone 1954, Geary 1950) function describes the top level of consumption. This function captures the fact that goods are consumed in different proportions depending on income levels. This is important in the context of energy shocks as energy is a necessary good and its consumption can't be reduced as easily as other types of goods. This is particularly pertinent for low-income households.

A constant elasticity of substitution (CES) function defines the bottom level of consumption. The CES function defines how much households purchase domestically and from other regions in each sector. The demand equation associated to the CES function is displayed in equation (3.1). This follows the Armington (1969) assumption where domestic and foreign goods are imperfect substitutes. The product of the CES function is called the Armington good and is the household's optimal combination of domestic and foreign goods in each sector given initial consumption shares, the budget and the economic constraints of the model.

$$CD^{H}_{h,r,i,t} = \left(\Psi^{C\ \rho^{V}_{i}}_{h,i} \cdot \alpha^{C}_{h,r,i} \cdot \frac{pc^{T}_{h,i,t}}{pd_{r,i,t}} \right)^{\frac{1}{1-\rho^{V}_{i}}} \cdot CT^{H}_{h,i,t}. \tag{3.1}$$

In equation (3.1), h, r, i and t are household, region, sector, and time subscripts respectively. $\Psi^{C}_{h,i}$ and $\alpha_{h,r,i}$ are CES push and share parameters respectively[4]. ρ^{V}_{i} is a substitution parameter linked to the Armington elasticity of substitution. $CD^{H}_{h,r,i,t}$ and $CT^{H}_{h,i,t}$ are household h's consumption of good i from region r and the Armington consumption good for household h sector i. $pc^{T}_{h,i,t}$ is the Armington price of commodity i for household h and $pd_{r,i,t}$ is sector i's sellers price in region r.

Intertemporally, each representative household maximizes the discounted value of time-separable utility functions. This follows the convention used by Devarajan & Go (1998), Lecca et al. (2014) and Duparc-Portier & Figus (2021). Using the Samuelson (1937) assumption (exponential discounting), an intertemporal household utility function

---

[4] The region subscript is dropped for simplicity.

is defined:

$$U_h = \sum_{t=0}^{\infty} \beta_h^t \cdot u_h(C_{h,t}^H). \tag{3.2}$$

In equation (3.2), $\beta \in (0,1)$ is the Samuelson (1937) discount factor. $U_h : \mathbb{R}^\infty \to \mathbb{R}$ is the intertemporal utility function. $u_h : \mathbb{R}_+ \to \mathbb{R}$ is the time-separable period household utility function. $C_{h,t}^H \in \mathbb{R}_+$ is household h's aggregate consumption in period t. The utility function has a Constant Relative Risk Aversion (CRRA) form as defined in Ljungqvist & Sargent (2004, p.451). Hence, letting $\epsilon_h \in \mathbb{R}_+^*$ be a constant elasticity of intertemporal substitution (EIS), utility is defined in equation (3.3).

$$u_h(C_{h,t}^H) = \begin{cases} \frac{{C_{h,t}^H}^{1-\epsilon_h}}{1-\epsilon_h} & \epsilon_h \neq 1 \\ \ln C_{h,t}^H & \epsilon_h = 1 \end{cases}. \tag{3.3}$$

Maximising equation (3.2) subject to the households' budget constraint and the structural equations in the CGE model, a Euler equation is derived defining the households' intertemporal consumption and savings decisions.

The households receive income ($II_{h,t}^H$) from capital, labour, energy firm profits, and government transfers. This is presented in equation (3.4).

$$II_{h,t}^H = \theta_h^K \cdot uck_t \cdot KS_t + \theta_h^L \cdot w_t \cdot LS_t + \theta_h^\Pi \cdot \sum_i \Pi_{i,t} + TR_{h,t} \tag{3.4}$$

Households receive a rental rate (uck_t) for each unit of capital rented to firms (KS_t). Similarly, households can supply their labour ($LS_{r,t}$) to firms each period to receive a wage (w_t). High-income households also hold shares in energy firms and therefore receive profits in the form of dividends from energy firms ($\Pi_{i,t}$). $\theta_h^K \in [0,1]$ is the capital share. $\theta_h^L \in [0,1]$ is the labour share. $\theta_h^\Pi \in [0,1]$ is the profit share of each household and is defined such that: $\theta_H^\Pi = 1$ and $\theta_L^\Pi = 0$. Both households receive transfers from the government ($TR_{h,t}$). Household gross income is taxed by the government at a constant rate.

Labour market dynamics are proxied by a wage curve in the medium to long run (Blanchflower & Oswald 1995). This assumes an inverse relationship between real wages and unemployment and is found to be a good estimate for labour market dynamics in regional contexts. This implies that workers have more bargaining power when unemployment is low as empirically estimated.

3.3 Production

Sectoral production in endogenous regions is defined through the activities of representative firms. There are two sets of equations used for representative firms; one for energy sectors (*ene*) and one for non-energy sectors (*nene*). Energy sectors are assumed to have an oligopoly structure with a small set of identical representative firms competing for the market (Hosoe et al. 2010). These firms produce the same good and have a degree of market power and therefore earn non-zero profits. The profit share depends on the number of firms in the market and the elasticity of demand. This is constant in the model and thus, the profit share is constant. Profits of the energy firms are sent to shareholders who may choose to save or consume these. Non-energy firms operate in perfectly competitive markets. Therefore, non-energy firms earn zero profits[5].

The remainder of the production structure follows Lecca et al. (2014) and Duparc-Portier & Figus (2021). A multi-level production structure is defined in which capital, labour and intermediate goods sourced domestically and abroad are used to produce output. Gross output is a Leontief composite of value added and the Armington goods. Value added is defined through a CES function in which capital and labour are imperfect substitutes. The degree of substitutability between the two factors of production is defined by the elasticity of substitution between capital and labour. The firms' Armington goods are defined through a CES function in which domestic and foreign intermediate inputs are imperfect substitutes (Armington 1969).

$$VR_{r,i,j,t} = \left({\Psi^{V}_{i,j}}^{\rho^{V}_{i}} \cdot \alpha^{ARM}_{r,i,j} \cdot \frac{pv_{i,t}}{pd_{r,i,t}} \right)^{\frac{1}{1-\rho^{V}_{i}}} \cdot V_{i,j,t}. \tag{3.5}$$

Equation (5.4) is the firms' Armington demand function. $\Psi^{V}_{i,j}$ and $\alpha^{ARM}_{r,i,j}$ are CES push and weight parameters respectively. $VR_{r,i,j,t}$ and $V_{i,j,t}$ are the demand for intermediate good i from region r by sector j and the Armington good for good i for sector j. $pv_{i,t}$ is the Armington price of good i.

The representative firms maximise profits subject to their budget constraints. Thus, the optimal combinations of capital, labour and intermediate goods are the solution to the firms' optimization problems.

3.4 Government

In the baseline, the government in each region is assumed to run a balanced budget. It receives income from households' income taxes (T_t) and firms' business (production) taxes

---

[5] Sensitivity checks are conducted where Krugman-style monopolistically competitive markets are assumed in the non-energy sectors.

$(T^F_{i,t})$.

$$G^Y_t = T_t + \sum_i T^F_{i,t}. \tag{3.6}$$

This income (G^Y_t) is then used for government expenditure domestically and abroad as well as government savings. Governments consume fixed shares in each sector (Leontief assumption) and view domestic and foreign goods as imperfect substitutes in their sectoral consumption decisions (Armington 1969). For simplicity, the government saves a fixed share of its income.

4 Data

4.1 SAMs

Thhe model is aggregated on three data sets. First, industry-by-industry input-output tables at basic prices are aggregated to create the base for the Social Accounting Matrices (SAMs) of the endogenous regions. For this, the 2020 wave of the Figaro dataset is used (Eurostat 2023*g*). The broad ISIC structure is applied as displayed in table 1. As the manufacturing sector includes the Manufacture of coke and refined petroleum products, this portion of Manufacturing is partialled out and defined as a separate sector (UN 2008). This is because the energy price shock will also influence manufactured energy sources such as the manufacture of coke and refined petroleum.

The Figaro data is supplemented by household saving rates and tax-to-GDP ratios for all EU countries to form the baseline SAMs. For the household savings rate, the 2020 “Gross household saving rate” for “Households; non-profit institutions” series is used (Eurostat 2023*b*). Finally, household tax rates are calculated using the “Total receipts from taxes and social contributions” data (Eurostat 2023*a*).

4.2 Household data

As Figaro data only provides data on a representative household, more data is used to disaggregate households into two net income groups. Shares of average gross income, net income, aggregate consumption, sectoral consumption, employment income, savings and taxes must be estimated. These shares are used to separate the broad categories (e.g. gross income) into household-specific categories (e.g. gross income for household “L”). Average gross income, net income, aggregate consumption, employment income, savings[6], and taxes are estimated using the 2021 “Continuous household budget survey (LWR)” (FSO 2023*c*). To estimate the “L” group shares, average values in each income group are

---

[6] Savings are defined as net income minus private consumption expenditure.

Label	Code
Agriculture, forestry and fishing	A
Mining and quarrying	B
Manufacturing	C
Electricity, gas, steam and air conditioning supply	D
Water supply; sewerage, waste management and remediation activities	E
Construction	F
Wholesale and retail trade; repair of motor vehicles and motorcycles	G
Transportation and storage	H
Accommodation and food service activities	I
Information and communication	J
Financial and insurance activities	K
Real estate activities	L
Professional, scientific and technical activities	M
Administrative and support service activities	N
Public administration and defence; compulsory social security	O
Education	P
Human health and social work activities	Q
Arts, entertainment and recreation	R
Other service activities	S
Activities of households as employers; undifferentiated goods- and services..	T
Activities of extraterritorial organizations and bodies	U

Table 1: Broad ISIC industry classification (UN 2008).

weighted by the extrapolated household weights provided in the "Continuous household budget surveys (LWR)" (FSO 2023*b*). As capital income is assumed to be proportional to savings in the model, the capital share equals the savings share. Assuming the profit rates and profits shares in energy firms, government transfers to households then act as a balancing element in the model. The key data used to define household shares is demonstrated in table 2.

Variable	**Average (EUR)**		**Share**	
Group	**L**	**H**	**L**	**H**
Gross household income	3,218	10,064	48.0%	52.0%
Gross employment income	1,747	7,147	41.4%	58.6%
Net household income	2,561	7,429	49.9%	50.1%
Private consumption expenditure	2,013	4,383	57.0%	43.0%
Taxes and expenses	669	2,783	41.0%	59.0%
Savings	547	3,046	34.2%	65.8%
Population weight	74.3%	25.7%	74.3%	25.7%

Table 2: FSO's 2021 LWR Survey and author's calculations (FSO 2023*c*).

The final information needed to disaggregate households is sectoral consumption. For sectoral consumption, the 2021 "Continuous household budget survey (LWR)" is used (FSO 2023*a*). The survey contains information on consumption on eleven broad categories. These categories are not all perfectly matched to the ISIC categories however, through a matching procedure, can provide some information on expected consumption by household and sector. For categories where no good proxy is found, shares are estimated by removing matched category quantities from aggregate private consumption expenditure. The resulting shares then ensure that private consumption per household group is the sum of sectoral consumption for each group. The matched shares are presented in table 3.

Figaro code	FSO Match
A, C	Food, beverages and tobacco, Clothing and footwear, Furnishings, equipment and household maintenance
B, C19, D	Housing, energy, maintenance of the dwelling
H	Transport
I	Restaurants and hotels
J	Postal and telecommunication services
P	Education
Q	Health
R	Recreation, entertainment and culture
N, O, S, T, U	Miscellaneous goods and services
E, F, G, K, L, M	*Aggregate minus matched weight*

Table 3: Author's matching of ISIC and FSO matching.

4.3 Energy shocks

An illustrative 200% increase in the price of imported energy is introduced. This captures the effects of the foreign energy supply contraction for Germany and REU markets. Hence, German and REU agents must compete with international agents for a restricted supply of energy.

Based on Eurostat data, we expect gas and electricity prices to increase in Germany and the EU (Eurostat 2023*c*,*d*,*e*,*f*). It is however difficult to estimate by how much the increase in foreign prices drives the domestic prices. It is also difficult to determine by how much we expect the price in the different energy sectors to increase. This is because some of the energy sectors include elements for which we expect the foreign price to increase and others that may not be very influenced by the foreign price increase. As the purpose of this paper is to compare fiscal policies when governments are faced with energy shocks, I do not take a firm stance on the size of the initial shock. Instead, a central scenario is assumed in which the price of the ROW mining and quarrying sector, electricity, gas, steam and air conditioning supply and the manufacture of refined petroleum sector all increase by 200%[7].

4.4 Profit shares

To calibrate the oligopoly model fully, a profit share is defined. This profit share is proportional to the product of the elasticity of demand and the number of firms in the industry (Hosoe et al. 2010). As precise data on the number of firms, the elasticity of demand for energy and the exact size of profit margins in the energy sectors is not available, I choose to assume a set of profit margins. These are chosen such that 30% of the capital and labour endowments of high-income households are converted to profit income. This implies that profit rates are roughly 5% in the Mining and Quarrying and Electricity, gas, steam and air conditioning supply sectors and 1% in the manufacture of refined petroleum sector. This is likely a lower-bound estimate of the profit margins in these sectors.

4.5 Parameters

To fully define the CGE model, four sets of behavioural parameters must be specified. These are the Armington elasticity of substitution between domestic and foreign goods (Armington 1969), the elasticity of substitution between capital and labour, the households' elasticity of intertemporal substitution (EIS) and the Stone-Geary sustenance parameters (Stone 1954, Geary 1950).

4.5.1 Armington elasticity

The EU and sector-specific estimates of Zofio et al. (2020) are used to define the Armington elasticities in Germany and the rest of the EU region[8]. Zofio et al. (2020) provide sector-specific estimates of the Armington elasticity of substitution for EU countries. These estimates will be used as a central case scenario as presented in the first column of table 4. As Zofio et al. (2020) measure Armington elasticities for the EU in general rather than Germany, two sensitivity checks are conducted using German-specific estimates from Bajzik et al. (2020). Bajzik et al. (2020) use 5324 reported estimates of the Armington elasticity, controlling for study quality and correcting the estimates for publication bias to provide a range of reasonable Armington elasticities. Using the approaches of Imbs & Mejean (2015) and Feenstra et al. (2018), Bajzik et al. (2020) suggest that the implied Armington elasticity of substitution between domestic and foreign goods in Germany is 2.9 or 3.5 with rather wide confidence intervals. Although these estimates are specific to

---

[7] To ensure that the results are not driven by this assumption, smaller and larger increases in the price of the two sectors are also tested. Asymmetric increases in the sector prices are also tested.

[8] The aggregate estimates of Bajzik et al. (2020) for Germany are used to test the sensitivity of the results

Sectors	Central	Sensitivity checks	
	Zofio et al. (2020)	Bajzik et al. (2020)	
Agriculture, forestry & fishing	2.7	2.9	3.4
Mining and quarrying	2.9	2.9	3.4
Manufacturing	1.7	2.9	3.4
All sectors	2.2	2.9	3.4

Table 4: Armington elasticities for simulations.

Germany, no sector-level detail is provided. More the size of these elasticities is rather large which contradicts evidence from short-run estimates of the Armington elasticity which is of more interest in this paper (Bajzik et al. 2020).

4.5.2 Elasticity of substitution between Capital and Labour and EIS

The elasticity of substitution between capital and labour is set at 0.3 in the baseline following Gechert et al. (2022). In their meta-analysis, Gechert et al. (2022) suggest that after controlling for publication bias, the best-guess estimate of the elasticity of substitution between capital and labour is around 0.3. As Mućk (2017, p.44) suggest that the country-specific elasticity of substitution between capital and labour is 0.4, a sensitivity check is conducted with this value. As Yogo (2004) finds that the EIS for developed countries including Germany is not statistically different from zero, the EIS is set to 0.1.

4.5.3 Stone-Geary sustenance parameter

In this paper, all Stone-Geary sustenance parameters are set to the initial consumption shares times 0.8 except those for low-income household energy consumption. The sustenance parameters are set to 0.97 times the initial energy consumption for low-income households. This captures the difference in the importance of energy consumption for lower-income households.

5 Fiscal Policy scenarios

In this section, I introduce the method used to capture the putative fiscal policy approaches the government can introduce to reduce the costs of the initial energy supply shock. The policies modelled are production tax reductions (5.1.1), untargeted household energy price subsidies (5.1.2), targeted household energy price subsidies (5.1.3), general energy price subsidies (5.1.4) and targeted income subsidies (5.1.5). The policies are financed using either pure debt financing (5.2.1) or a combination of debt and windfall tax financing (5.2.2). Finally, the aggregate welfare function is defined (5.3).

5.1 Fiscal policies - Expenditure side

5.1.1 Production tax reductions

In the first fiscal policy scenario, the government counteracts the effects of the energy shock by introducing tax reductions (TRs) proportional to domestic firms' energy consumption. This scenario, proxies for reductions in energy taxes.

$$\tau^P_{i,t} = \tau^P_{i,t=0} \cdot (1 - \tau_t \cdot \theta^{ENE}_i). \tag{5.1}$$

In equation (5.1), $\tau^P_{i,t} < 1$ is the production tax rate in sector i at time t[9]. $\tau^P_{i,t=0} < 1$ is the production tax rate in the baseline. $\theta^{ENE}_i \equiv \frac{\sum_{ene} V_{ene,i,t=0}}{X_{i,t=0}}$ is an index of the energy intermediate good cost $V_{ene,i,t=0}$ to total revenue $X_{i,t=0}$ for each sector. This ensures that the government targets tax rate reductions more toward energy-intensive sectors. In this scenario, τ_t is the endogenous tax rate reduction chosen based on the government's objective[10]. For all scenarios, $\tau_{t=1} \geq 0$ and $\tau_{t>1} = 0$. τ_t is the percentage reduction in the production tax rate.

5.1.2 Untargeted Household Price Subsidy

In the second fiscal policy scenario, the government introduces an untargeted energy price subsidy (UPS) to all households.

$$CD^H_{h,r,i,t} = \left({\Psi^C_{h,i}}^{\rho^V_i} \cdot \alpha^C_{h,r,i} \cdot \frac{pc^T_{h,i,t}}{pd_{r,i,t} \cdot (1 - \tau_t \cdot \theta^H_{h,i})} \right)^{\frac{1}{1-\rho^V_i}} \cdot CT^H_{h,i,t}. \tag{5.2}$$

Equation (5.2) is the household's Armington demand function (equation 3.1) extended to capture an energy consumption subsidy. The novel elements of the CES function are $\theta^H_{h,i} \in \mathbb{N} \leq 1$ which is a dummy that can only equal 0 or 1. It defines whether a household

---

[9] In cases where the government subsidizes sectors, $\tau^P_{i,t=0} < 0$. In those cases, the sign of θ^{ENE}_i is reversed such that the subsidy is increased and $\tau^P_{i,t} > \tau^P_{i,t=0}$.

[10] τ_t will be used as a generic policy rate for all policies.

is eligible for a subsidy and whether the sector is an energy sector. In the UPS scenario, all households receive the price subsidy hence, $\theta^{H}_{h,ene} = 1$. In this scenario, τ_t is the percentage reduction in the household energy price chosen based on the government's objective.

$$pc^{T}_{h,i,t} = \frac{\sum_r pd_{r,i,t} \cdot (1 - \tau_t \cdot \theta^{H}_{h,i}) \cdot CD^{H}_{h,r,i,t=0}}{\sum_{r'} pd_{r,i,t=0} \cdot CD^{H}_{h,r,i,t=0}} \tag{5.3}$$

As the price reduction affects the households' sectoral price index, we must adjust the price index to reflect the change. This weighted average of the Armington price by sector then defines the consumer price index by household.

5.1.3 Targeted Household price subsidy

The third fiscal policy targets the government's price subsidy toward lower-income households. This policy is named the TPS. Thus, the only difference between this scenario and the previous one is in the definition of $\theta^{H}_{h,i}$. In this case, $\theta^{H}_{H,ene} = 0$ and $\theta^{H}_{L,ene} = 1$.

5.1.4 General energy price subsidy

The fourth fiscal policy which will be evaluated is a general energy price subsidy (GPS) to both firms and households. This subsidy is a combination of policies UPS and a firm price subsidy. Equations (5.2) and (5.3) still hold. Analogous equations for firm consumption of energy must be added:

$$VR_{r,i,j,t} = \left({\Psi^{V}_{i,j}}^{\rho^{V}_{i}} \cdot \alpha^{ARM}_{r,i,j} \cdot \frac{pv_{i,t}}{pd_{r,i,t} \cdot (1 - \tau_t \cdot \theta^{GPS}_{i})} \right)^{\frac{1}{1-\rho^{V}_{i}}} \cdot V_{i,j,t}. \tag{5.4}$$

Equation (5.4) is the firms' Armington demand function (equation 3.5) extended to capture the energy price subsidy. The novel elements of the CES function are θ^{GPS}_{i} which is a dummy defining whether sector i is an energy sector. $\theta^{GPS}_{ene} = 1$ and $\theta^{GPS}_{nene} = 0$. In the GPS, τ_t is the percentage reduction in the price of energy households and firms pay.

$$pv_{i,t} = \frac{\sum_{r,j} pd_{r,i,t} \cdot VR_{r,i,j,t} \cdot (1 - \tau_t \cdot \theta^{GPS}_{i})}{\sum_j V_{i,j,t}}. \tag{5.5}$$

As $pv_{i,t}$ is influenced by the price subsidy, the intermediate good price index is modified to equation (5.5).

Additionally, we assume that τ_t is equal for both household and firm subsidies. This ensures that the per unit energy price subsidy is identical regardless of the energy consumer.

5.1.5 Targeted income subsidies

The final expenditure side fiscal policy evaluated is a targeted income subsidy (TIS) to low-income households. To account for the TIS, household income is supplemented by an additional transfer:

$$II^H_{h,t} = \theta^K_h \cdot uck_t \cdot KS_t + \theta^L_h \cdot w_t \cdot LS_t + \theta^\Pi_h \cdot \sum_i \Pi_{i,t} + TR_{h,t} + \theta^\Delta_h \cdot \Delta_t. \tag{5.6}$$

Equation (5.6), is an extension of equation (3.4) capturing the TIS. θ^Δ_h is a dummy capturing whether a household receives the income subsidy. $\theta^\Delta_H = 1$ and $\theta^\Delta_L = 0$. $\Delta_t \in \mathbb{R}_+$ is the lump sum transfer sent to low-income households in the period following the shock.

5.2 Fiscal policies - Revenue side

To gather revenue for the fiscal policies, I assume that the government has two options. First, it can obtain debt financing at an interest rate ir. This is the risk-free interest rate assumed in the baseline. It is equal to the user cost of capital minus the depreciation rate. The debt can then be used to finance any of the fiscal policies above. Alternatively, the government can use a combination of debt financing and a one-time windfall tax on excess profits of the energy companies following the shock to finance the expenditure side fiscal policies.

5.2.1 Debt financing

For the debt-financed revenue side fiscal policy, the government can borrow money at ir during the first year following the shock.

$$\begin{aligned}
G^Y_t &= T_t + \sum_i T^F_{i,t} - ir \cdot D^G_t - B_t \\
D^G_t &= D^G_{t-1} - B_t \\
B_t &= \frac{D^G_{t=1}}{dur}.
\end{aligned} \tag{5.7}$$

Equation (5.7), is equation (3.6) extended to capture interest payments and debt repayments. $D^G_t \in \mathbb{R}_+$ is the amount of additional debt accumulated by the government in period t. $B_t \in \mathbb{R}_+$ is the yearly debt payment. $dur \in \mathbb{N}_+$ is the number of periods the government will be repaying the debt. This is set to 25 years in the model.

5.2.2 Windfall tax financing

The government can choose to accompany the debt financing with a windfall tax on the excess profits of energy firms. Windfall tax revenue is added to equation (5.7).

$$G^Y_t = T_t + \sum_i T^F_{i,t} - ir \cdot D^G_t - B_t + T^w_{t=1}. \tag{5.8}$$

In equation (5.8), $T^w_{t=1} \in \mathbb{R}_+$ is the total amount of windfall tax revenue collected in period 1[11].

$$T^w_{t=1} = \sum_{ene} (RT_{ene,t=1} - RT_{ene,t=0}) \cdot \tau^{WT}_{t=1}. \tag{5.9}$$

Windfall tax revenue is defined in equation (5.9). $\tau^{WT}_{t=1} \in [0,1]$ is the windfall tax rate set by the government on energy firms. The windfall tax rate is set to 90% which is equal to the rate set in Germany for electricity. This revenue is collected from households that hold shares in energy companies. Thus, household income is affected by this policy as shown in equation (5.10).

$$II^{HWT}_{h,t=1} = II^H_{h,t=1} - \theta^\Pi_h \cdot T^w_{t=1}. \tag{5.10}$$

$II^{HWT}_{h,t=1}$ is gross household income following the windfall tax.

5.3 Welfare

Long-run welfare is defined as the discounted sum of intratemporal welfare. Intratemporal Welfare of the households in each group is defined using a welfarist approach (Sen 1970, Boadway & Keen 1999). Thus, intratemporal welfare is defined as the sum of the CRRA utility functions (equation 3.3) for private and public goods.

$$U_{T,t} = (1 - \gamma_g) \cdot \sum_h \gamma_h \cdot u_h(C^H_{h,t}) + \gamma_g \cdot v(G_t). \tag{5.11}$$

In equation (5.11), $\gamma_h \in (0,1]$ is a population weight for household group h defined such that $\sum_h \gamma_h = 1$. v_{G_t} is a CRRA utility function for the utility of public consumption for both households. As there is limited research on the EIS parameter for public good provision, the EIS for the government equals that set for the households. γ_g is the weight placed on public good utility relative to private good utility. It is set equal to 0.42 in the baseline following (Schram & van Winden 1989).

---

[11] For simplicity, a single period windfall tax is assumed.

6 Results and interpretation

6.1 Initial shock

Following the increase in foreign energy prices, the import price for both firms and households increases. As a result of the increase in the foreign price of energy relative to the domestic price of energy, firms and households decrease their purchases of foreign energy and increase their demand for domestic and REU energy. The increase in demand for domestic and REU energy drives prices up by 21.7% and 27.5% respectively in the energy sectors as displayed in table 5. Due to the relatively high increase in REU energy prices, demand for REU energy decreases relative to German energy.

Variable/ Region	Germany	Rest of the EU
Output	-1.3%	-2.7%
Energy output	-2.4%	-8.1%
Non-energy output	-1.3%	-2.5%
Consumer price index	0.6%	0.8%
Energy price index	21.7%	27.5%
Non-energy price index	-1.8%	-3.0%

Table 5: Output and price response to the energy supply shock.

Although domestic energy firms face a huge increase in demand, sectors such as the Manufacturing of refined petroleum are highly reliant on energy imports from the ROW in the baseline. As a result, energy prices in this sector increase by 58.4% whilst output decreases by 11%. On the other hand, the mining and quarrying sector sees a 70% increase in production and a 70.5% increase in prices. This is because this sector was less reliant on energy imports from the ROW and acts as a substitute to these imports in domestic demand[12].

Overall, German households increase their demand for domestic energy goods by 3.5% and decrease their demand for REU and ROW energy by 5.9% and 35.1% respectively. Average household energy consumption decreases by close to 3%. German firms increase their demand for domestic energy relative to ROW and REU energy. Overall, however, increased production costs decrease demand for intermediate inputs. Moreover, as the manufacturing of refined petroleum sector is highly reliant on foreign inputs, production in this sector is very constrained in the short run. As a result, aggregate intermediate demand for domestic energy decreases. Overall, German imports decrease by 4.3%; a result mainly driven by decreases in international energy trade.

With higher domestic production costs, firms in most non-energy sectors decrease their

---

[12] Coal mining and other energy production have increased in Germany since 2022 so this result could reflect increases in such production but the scale of the increase is likely exaggerated.

Variable	**Sector group**	**Source**	**DE**	**REU**
Import	Energy	REU/DE	-13.0%	11.2%
		ROW	-74.7%	-73.8%
	Non-energy	REU/DE	-1.9%	-2.5%
		ROW	-0.8%	-2.2%
Household consumption	Energy	Domestic	3.5%	8.1%
		REU/DE	-5.9%	46.2%
		ROW	-35.1%	-42.4%
	Non-energy	Domestic	-1.8%	-3.5%
		REU/DE	-3.1%	-3.1%
		ROW	-2.3%	-2.9%
Intermediate	Energy	Domestic	-5.6%	-11.3%
		REU/DE	-14.0%	1.8%
		ROW	-75.0%	-75.0%
	Non-energy	Domestic	-0.7%	-2.0%
		REU/DE	-1.3%	-1.7%
		ROW	-0.1%	-1.4%

Table 6: Changes in imports, household consumption and intermediate demand by sector group, source and destination.

demand for capital and labour. Hence, on aggregate output falls by 1.3%. Simultaneously, the consumer price index increases by 0.58% overall. This result is driven by energy price inflation.

The adverse aggregate consequences are not distributed evenly across the household groups as has also been found by Celasun et al. (2022), Guan et al. (2023), Perdana et al. (2022) and Turner et al. (2022) amongst others. This is because high-income households reap the benefits of a 15% increase in real energy firm profits. As a result, energy firm dividends to high-income households increase and the gross income of high-income households falls by 1.21% compared with the average household income fall of 1.35%. This is since the increased profit income partially offsets the reductions in income due to reductions in labour and capital demand and reductions in real factor prices. Low-income households do not own shares in the energy companies and thus receive no benefits from the increasing profits. Hence, low-income household income falls by 1.51%.

Variable/ Household group	**High-income**	**Low-income**
Real income	-1.2%	-1.5%
Consumption	-2.0%	-1.9%
Energy consumption	-5.9%	-0.8%
Non-Energy consumption	-1.7%	-1.9%
Household savings	0.4%	0.6%

Table 7: Key household group indicators.

The energy shock leads to increasing income inequality but also affects low-income households disproportionately due to Engel curve effects. As low-income German households consume a larger proportion of energy in their consumption basket and are closer to their sustenance levels of energy consumption, energy consumption falls only by 0.9% for low-income households depleting low-income households' resources for non-energy consumption. In contrast, high-income households are much further from their sustenance levels and reduce energy consumption by 5.9%. This asymmetric response across household types means that low-income households have less disposable income for non-energy consumption than high-income households. Thus, low-income households are disproportionately affected by the energy shock[13].

Overall, absent of a fiscal policy intervention, Output in Germany falls whilst prices rise, a result consistent with other recent papers (Celasun et al. 2022, Guan et al. 2023, Perdana et al. 2022, Turner et al. 2022) and empirical observations (Eurostat 2023*f*,*d*). Trade intensity decreases as imports fall due to the increase in energy prices and exports fall due to the decrease in Germany's international competitiveness driven by inflation. Energy firms in Germany increase prices by 21.7% on average whilst profits increase by over 15%. As higher-income households own energy firms, increased profits partially protect these households leading to differential impacts on the two household groups. Lower-income households' incomes fall by a larger amount and disposable income for non-energy consumption drops due to Engel curve effects.

6.2 Debt financed policies

Following the energy shock, the German government may choose to implement one of the five expenditure-side fiscal policies. The TR is a supply-side policy as it only affects firms' effective taxes. The UPS, TPS and TIS are all demand-side policies as they affect household demand. The GPS is a mixture of a demand-side and supply-side policy as it affects household demand through reduced energy prices and reduces intermediate good prices for firms.

6.2.1 TR

The TR is a reduction of taxes on production proportional to intermediate energy use. Following the shock, sectors more reliant on energy use receive greater tax cuts thus reducing marginal costs of production. Unsurprisingly, the three sectors most reliant on foreign energy intermediates are Mining and Quarrying, Electricity, gas, steam and air conditioning supply, and manufacturing of coke and refined petroleum. In these

---

[13] Note that high-income households' marginal propensity to save is much higher and thus, a 0.4% increase in savings is much larger than the 0.6% increase in savings of the low-income household.

sectors, 14.5%, 25.1% and 48.7% of intermediates are energy[14]. The Manufacturing of refined petroleum sector is particularly exposed to foreign energy shocks as 34.1% of the energy purchases come from the ROW. Thus, following the tax cuts, marginal costs of production in the three sectors decrease by 0.4, 1.5 and 3.6 percentage points (pps) respectively. Following the reductions in marginal costs of production, firms increase output. The Mining and Quarrying and Electricity, gas, steam and air conditioning supply sectors increase output by 0.2 pps relative to the no fiscal policy scenario. The Manufacture of coke and refined petroleum, which was highly reliant on energy products increases output by 2.3 pps relative to the no fiscal policy scenario. As production costs drop and output increases in most sectors, aggregate output increases by 0.2 pps relative to the no fiscal policy scenario. This increase in aggregate output is mainly driven by increased production in the energy sectors as these benefit from the tax reductions most. The TR has an almost negligible effect on inflation as the CPI increases by 0.02 pps relative to the no fiscal policy scenario.

The TR is also beneficial to households as it reduces energy prices and increases capital, labour and dividend income compared with the no fiscal policy scenario. Real household income of low-income households increases by 0.047 pps. The corresponding figure for high-income households is 0.054 pps. Consumption in both groups also increases by 0.3 pps and 0.4 pps for low-income and high-income households. Although the increase in household income and consumption will lead to a Pareto improvement in the short run, it does not impact the household groups symmetrically. Indeed, due to the increase in dividend income, high-income households' income increases proportionally more. High-income households also increase their consumption proportionally more. Thus, this policy increases income and consumption inequality compared with the no fiscal policy scenario and accentuates the initial regressive impacts of the shock.

6.2.2 UPS & TPS

The UPS and TPS increase household demand for energy products by decreasing the effective price paid by household consumers. In the case of the UPS, both high-income and low-income households receive a reduction in effective energy prices. As the effective energy price paid by households decreases, household demand for energy increases. This counteracts the effects of the initial energy shock and low-income energy consumption only decreases by 0.4% instead of 0.8%. For high-income households, the decrease in energy consumption is 3.6% instead of 5.9% in the absence of government intervention. Non-energy consumption increases as well for both household groups relative to the no fiscal policy scenario as the reduction in energy prices allows households to consume

---

[14] Agriculture, Forestry and Fishing and Manufacturing sectors are also comparatively more exposed to energy shocks as 4.2% and 2.3% of intermediates used in these sectors are energy products.

more non-energy goods. Non-energy consumption of low-income households decreases by 0.2% instead of 0.8% and high-income energy consumption decreases by 0.5% instead of 1.7%. The UPS leads to a Pareto improvement as both household groups consume more energy and non-energy products.

In the case of the TPS, similar effects are observed but only for low-income households. Low-income household energy consumption increases by 0.27% and non-energy consumption increases by 3.3% relative to a no-shock baseline. This provides a better outcome for low-income consumers, however, high-income consumers do not reap any benefits from this policy. Indeed, high-income households' consumption is crowded out by the targeted price subsidy. As low-income households increase energy consumption, energy output and prices increase. Indeed, energy prices increase by 0.7 pps compared with the no fiscal policy scenario. Thus, high-income households are worse off in terms of energy consumption. Overall, high-income household consumption decreases relative to the no fiscal policy scenario. This is since the increased prices lead to an intertemporal substitution. High-income households increase their savings by close to 6% relative to the no shock baseline. Thus, although this policy benefits low-income households greatly, it does not provide a Pareto improvement in the short run as high-income households are adversely affected.

Although the UPS and TPS each increase aggregate consumption, these policies are inflationary. Indeed, the consumer price index increases by almost one percentage point in both policies compared to a no fiscal policy scenario. This further decreases Germany's international competitiveness for both energy and non-energy goods. As a result, aggregate exports decrease by over 1.4 pps for both the TPS and UPS. Moreover, increased energy prices crowd-out demand for domestic intermediate energy goods. As a result, German firms substitute domestic energy intermediate demand for imports from the REU and ROW. This further contracts the trade balance.

Overall, German firms' energy and non-energy output increase relative to the no fiscal policy scenario for the UPS. This leads to an expansion in aggregate output relative to the no fiscal policy scenario. Instead of decreasing by 1.3%, aggregate output decreases by 1.1%. The expansionary effects are relatively small due to the inflationary pressure created by the policies. This weakens the trade balance relative to the no fiscal policy scenario. The TPS has similar aggregate impacts although energy output decreases relative to the no fiscal policy scenario.

6.2.3 GPS

The GPS is a combination of the UPS and a firm energy price subsidy. As a result, it has both demand side impacts as described in section 6.2.2 and supply side ones.

Where the GPS impact differs from the UPS is in the fact that firm energy prices also fall. Through the GPS, the marginal cost of production of firms decreases. On average, the marginal cost of production in this scenario decreases by 1.05 pps. This reduction is almost as large as that observed in the TR scenario. As a result, price inflation caused by increased household demand is tampered by reductions in final good prices due to the reductions in production costs. Thus, the CPI only increases by under 0.3 pps relative to the no fiscal policy scenario.

In terms of output, the GPS is particularly effective as aggregate output increases by 0.35 pps relative to the no policy scenario. The combination of household and firm energy price subsidies is particularly beneficial for energy sectors which record an increase of 2.5 pps compared to no policy. This even leads to an expansion in energy output relative to the no-shock scenario. Non-energy output increases by a little under 0.3 pps.

The GPS has strong expansionary effects on aggregate output however, it does not provide as much income and consumption support to households as the demand side policies. Real household income increases by 0.18 and 0.10 pps for high-income and low-income households respectively. This regressive effect is partially driven by increasing profits as real profit income, which is only received by high-income households, increases by close to 2.6 pps. This is 1.4 pps more than the TR scenario. Low-income households decrease savings by 1.64 pps whilst high-income households only decrease savings by 0.26 pps. As a result, despite the increased income inequality, low-income households increase consumption by relatively more. Low-income households increase aggregate consumption by 0.69 pps whereas high-income households increase consumption by 0.64 pps. Low-income households' increase in consumption is mainly driven by non-energy consumption which increases by over 0.7 pps. High-income households increase energy consumption by 1 pp and non-energy consumption by 0.6 pps.

Overall, the GPS provides a strong aggregate output recovery and supports the energy sectors particularly well. The policy is also relatively effective at addressing inflationary pressures by subsidizing both intermediate and household energy prices. Although the policy has strong aggregate impacts, it is less effective at addressing distributional impacts. Indeed, it has regressive effects on real income. That said, the policy is a Pareto improvement in the short run compared witth the no fiscal policy scenario.

6.2.4 TIS

Whereas the TPS and UPS act through the final price of energy, the TIS influences household consumption by increasing the incomes of low-income households. Following the increase in income, low-income households can use these additional resources for consumption or savings. As low-income households are more likely to be liquidity constrained, one expects the marginal propensity to consume the income subsidy to be relatively high (Parker et al. 2013, Johnson et al. 2006, Agarwal et al. 2007). For simplicity, a marginal propensity to consume of one is assumed for the TIS[15].

The qualitative effects of the TIS are very similar to those of the TPS. Following the increase in income, low-income households increase energy and non-energy consumption. As low-income households can choose how to spend the government transfer, in the TIS, low-income households increase non-energy consumption more than in the TPS. Consequently, the main qualitative difference between the TIS and TPS is that in the prior, non-energy consumption increases by more and energy consumption increases by less relative to a no fiscal policy baseline. Overall, low-income household consumption increases by more than the TPS but only by a small margin.

The aggregate impacts of the TIS are very similar to the TPS as well. Aggregate output decreases by 0.2 pps less than in the no fiscal policy scenario. This is a relatively weak output recovery only marginally better than the TR. This result is a consequence of the inflationary pressure of the policy deteriorating the trade balance. The effects of inflationary pressure also lead to an intertemporal substitution effect for high-income households as was observed in the TPS.

Overall, the result of the TIS are very similar to those of the TPS. There is a small substitution effect towards non-energy goods, however, as low-income households are very close to their sustenance levels, the substitution effect is very small. The TIS is the most inflationary policy and provides a relatively weak aggregate output recovery. That said, the recovery is quantitatively very close to that observed in the TPS, UPS and TR.

6.3 Windfall taxation

In the windfall tax scenarios, between 18% and 20.5% of the funding of the five expenditure policies is financed by windfall taxes. The GPS reaps the largest rewards

---

[15] Sensitivity checks are conducted to address the importance of this assumption.

from windfall taxation as it generates the largest recovery in the energy sector. The TIS on the other hand generates the lowest energy sector recovery and records the lowest windfall tax revenue as a result.

Financing/ Policy	**TR**	**UPS**	**TPS**	**GPS**	**TIS**
Debt	81.3%	80.9%	81.7%	79.4%	81.8%
Windfall tax	18.7%	19.1%	18.3%	20.6%	18.2%

Table 8: Proportion of Debt and Windfall tax financing

From a qualitative standpoint, the aggregate results of the purely debt-financed and partially windfall tax financed policies are very similar. As windfall taxation is an intratemporal redistribution policy whereas pure debt financing is an intertemporal redistribution policy, the latter has slightly more expansionary contemporaneous effects. Surprisingly, the additional expansionary effects of the pure debt policies are very small. By financing around 20% of the policy with windfall taxes instead of debt, aggregate output only contracts by around 0.005 pps. This is a very small cost when compared to the intertemporal cost of debt.

Whereas aggregate results only change marginally when the policy is financed by both windfall taxes and debt, household outcomes change more noticeably. Real household income of high-income households decreases by between 0.08 and 0.09 pps compared with purely debt-financed policies whereas that of low-income households decreases by less than 0.01 pps. Consumption of high-income households also falls proportionally more than that of low-income households.

Although the windfall tax has slightly less expansionary effects for all policies and reduces high-income households' income and consumption disproportionality, this effect partially offsets the initial regressive consequences of the energy shock. Moreover, the key advantage of windfall taxation is intertemporal. By using windfall taxation, governments avoid costly debt financing which reduces public good provision in future periods and weakens the transition to the new steady state.

6.4 Discussion

6.4.1 Aggregate output and prices (Short run)

The results of the illustrative simulations presented in this paper suggest that GPSs generate the largest aggregate output recoveries. This result is robust under both debt and winfall tax financing as shown in figures 3 and 4. Aggregate output recoveries by 26.6% of the distance between the pre-shock equilibrium and the no fiscal policy scenario. The next closest aggregate output recovery is 16.1% for the UPS. The GPS is particularly effective as it reduces prices for both households and firms. As a result, energy products are more efficiently allocated than under household subsidies or tax reductions. More, as the GPS reduces firm prices, it partially offsets the price pressure due to increased household and firm demand. In terms of the other policies, all perform surprisingly similarly. The UPS, TPS and TIS have recoveries of 16.1%, 15.3% and 15.7% respectively whereas the TRs has a recovery of 14.1% under debt financing. The recoveries are marginally smaller under windfall taxation but have the exact same ranking. Thus, in terms of aggregate output recoveries, the GPS clearly dominates and is the preferable fiscal policy measure.

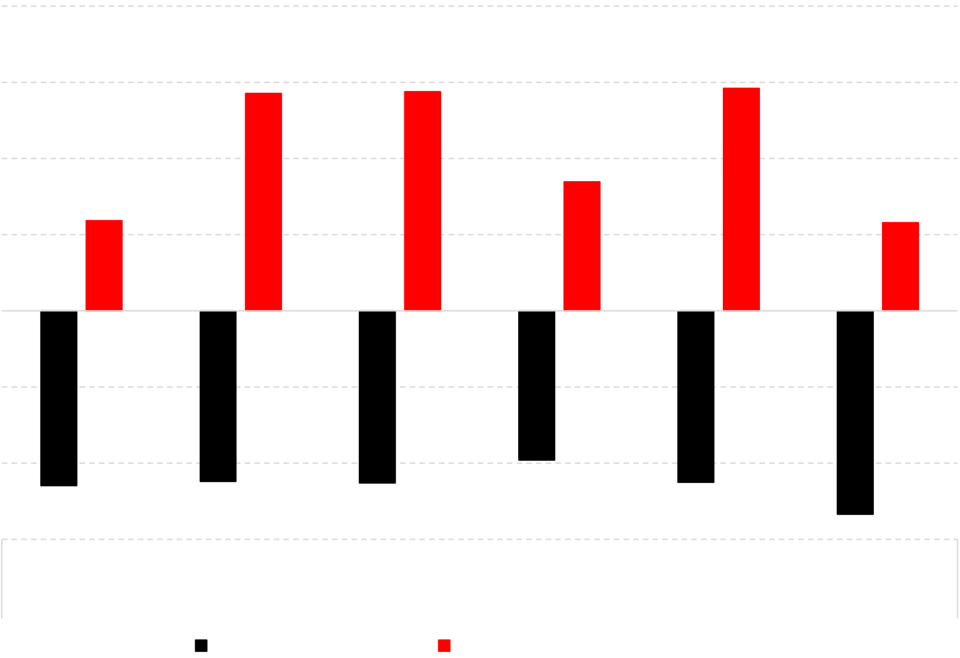

Figure 3: Aggregate output and CPI impacts of debt financed policies

Consumer price index (CPI) results are also summarised in figures 3 and 4. The TR provides the lowest inflationary pressure of the policies compared. As it is almost price neutral, the aggregate output recovery achieved is almost costless in terms of inflation. The CPI effect is even marginally negative for the TR under windfall tax financing. The GPS is also relatively effective at addressing price pressure as the CPI only increases by around 0.26 pps under debt and windfall tax financing. Clearly, the inflationary effects of the UPS, TPS and TIS are much greater than the ones under the TR and GPS. Under debt and windfall tax financing, the CPI increases by 0.84, 0.85 and 0.87 pps for the UPS, TPS and TIS. Thus, in terms of inflationary pressure, the TR is the preferred policy although the GPS may provide a better output recovery with relatively low inflationary effects.

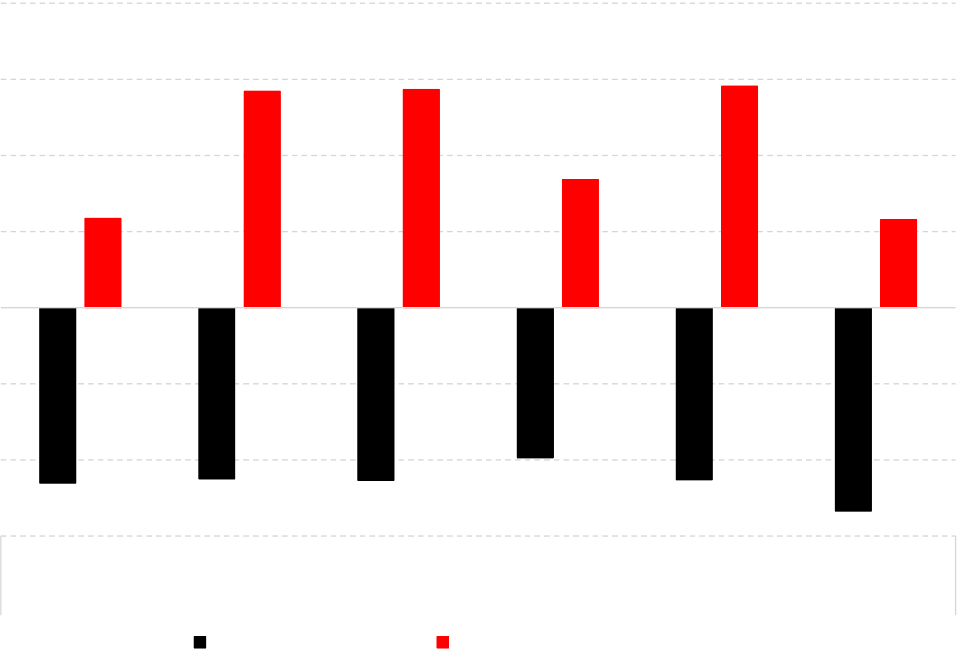

Figure 4: Aggregate output and CPI impacts of debt and windfall tax financed policies

If governments were not concerned about distributional considerations, the aggregate output and CPI results would suggest that the optimal policy is a mix of GPSs and TRs. This mix would be a function of the German government's optimal trade-off between inflation and output.

6.4.2 Distributional effects (Short run)

To understand the distributional implications of the policies short-run real income and energy and non-energy consumption are compared. Figures 5 and 6 present real income by household group in each of the policies under debt and windfall tax financing.

As can be seen in figures 5 and 6, only one policy fully reverses the regressive effects of the initial energy shock. This policy is the TIS. This is since, unlike the price subsidies, this policy acts through income rather than the price of energy. As a result, although its effects on consumption are comparable to the TPS, its implications for real household income are very different.

All policies except the TIS do little to address real income inequality. This is since none are designed to work through household incomes. Thus, the initial regressive effects on real household incomes of the energy price shock are sustained in the TR,

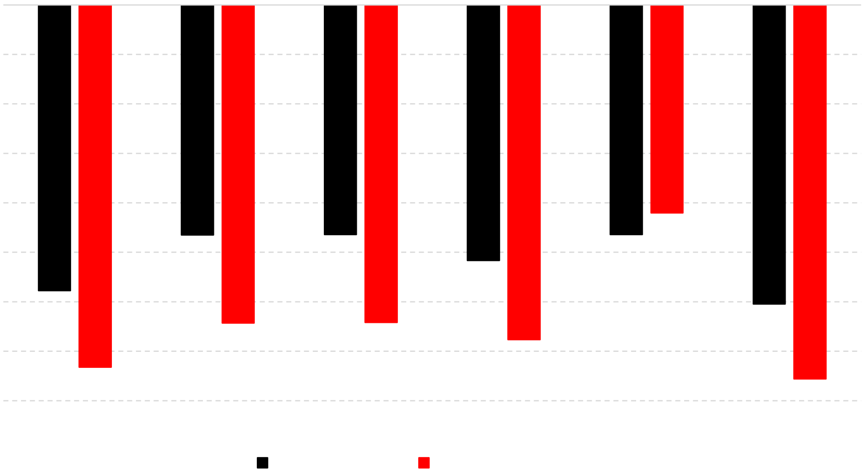

Figure 5: Real income by household group (Pure debt financing)

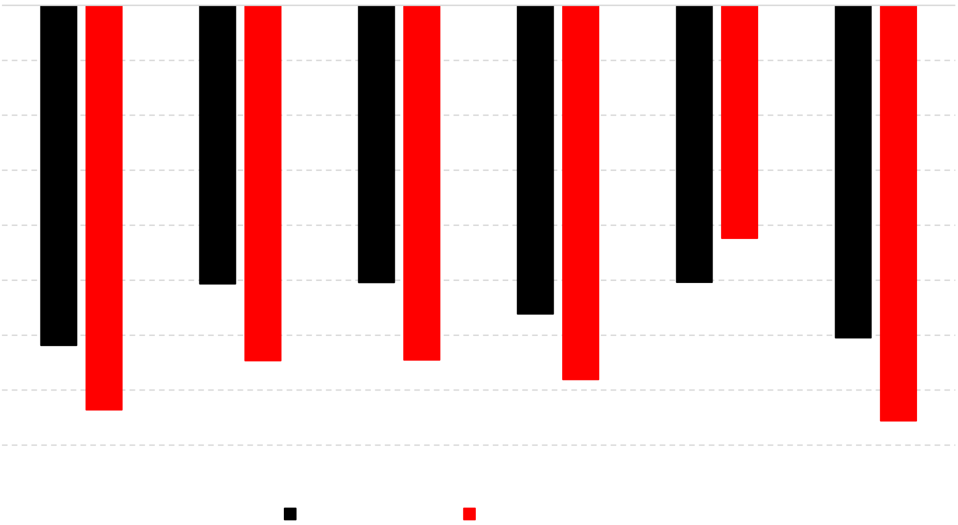

Figure 6: Real income by household group (Debt and Windfall tax financing)

UPS, TPS and GPS. Introducing a windfall tax slightly offsets the real income inequality driven by the energy shock for all policies. That said, the reduction in inequality is driven mainly by reductions in high-income households' real income. Although the introduction of windfall taxes reduced high-income households' real income, the income raised through windfall taxation is used to increase household consumption. Thus, it is important to evaluate household consumption by group to better understand the implications of the policies and windfall taxation.

Figure 7 summarises short-run aggregate consumption by household group under each of the policies. In the no fiscal policy scenario, high-income households decrease

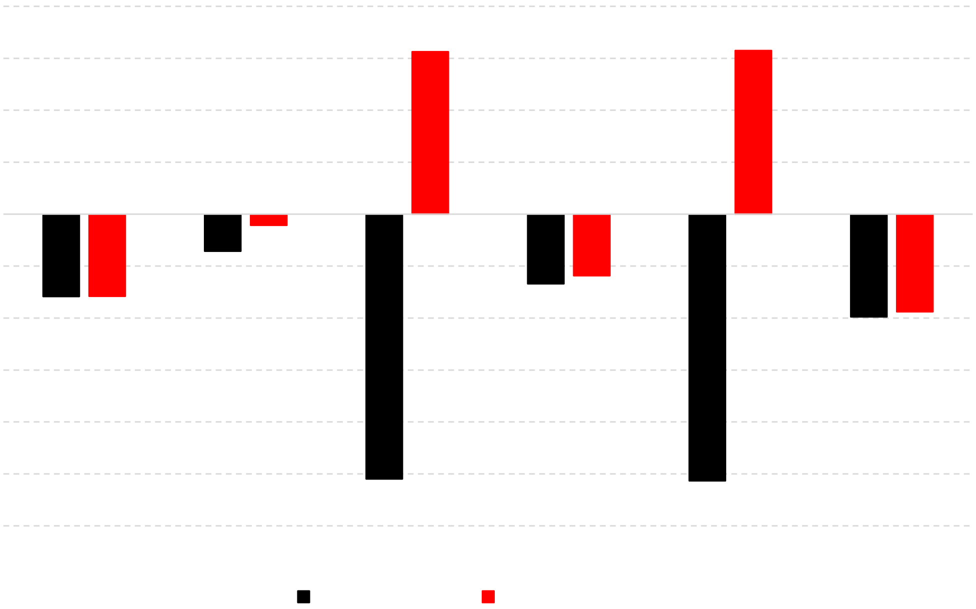

Figure 7: Aggregate consumption by household group (Debt financing)

consumption by roughly 2% whereas low-income households decrease it by 1.9% relative to a no shock baseline. The reason why high-income households decrease consumption by more is two-fold. First, high-income households are further from their consumption sustenance levels. Hence, following the shock, high-income households have less difficulty cutting consumption on both energy and non-energy goods. Second, high-income households increase savings to accumulate capital in the energy sector. This will increase future production and profits.

From figure 7, it is clear that all policies increase low-income households' consumption relative to the no fiscal policy scenario. Interestingly, the same conclusion is not drawn for high-income households under two of the policies. Indeed, under the TPS and TIS, high-income households decrease consumption by close to 3 pps relative to the no fiscal policy scenario. On the other hand, low-income households increase their consumption by close to 5 pps. The reason that high-income households decrease their consumption so drastically is that low-income households crowd-out their consumption. This is because low-income households drastically increase their consumption of both energy and non-energy goods following the targeted policies. This drives up the prices for all other consumers. High-income households are thus incentivised to save and increase their consumption in the periods following the policies.

The untargeted policies, namely the TR, UPS and GPS have positive short-run effects for all households. The TR has relatively weak effects only increasing consumption by 0.4 and 0.3 pps for high- and low-income households respectively. The GPS also has relatively weak but stronger overall effects with the matching numbers being 0.6 and 0.7 pps. The effects of the GPS are progressive whereas those of the TR are regressive. The UPS leads to much stronger consumption recoveries in both groups as consumption increases by 1.3 and 1.7 pps respectively in the high-income and low-income consumption groups. The UPS has broadly progressive effects on consumption and allows for an aggregate consumption recovery, almost as strong as that recorded for the TPS and TIS.

Interestingly, the source of financing for the policies has very little effect on the consumption results. The rankings of the policies are identical with TPS and TIS having the largest consumption recovery closely followed by the UPS. The TIS and TPS have the largest redistributive effects. The TR and GPS are relatively ineffective at stimulating household consumption recoveries. Even the quantitative effects are almost identical. Thus, in terms of consumption recoveries, governments should choose the targeted policies or the UPS. The prior will be much more effective at addressing distributional effects on consumption. This is because these hugely redistribute consumption from high-income groups to low-income groups. More they lead to the largest aggregate household consumption recoveries. The UPS is also relatively effective at helping aggregate household consumption recovery although it does not address distributional effects as efficiently.

6.4.3 Welfare effects

The Welfare measure captures both the short-run benefits of the policies and the intertemporal costs through debt repayments and the effects of the policies. Figure 8 presents the normalised Welfare figures for each of the policies under debt financing. Welfare is normalised such that no fiscal policy is equal to 0 and the best policy equals 1.

From the figures, it is clear that the TIS and TPS are the best policies given the Welfare definition. This is expected as these policies drive the largest consumption redistributions. Since the marginal utility of consumption of low-income households is higher than that of high-income households, the redistribution policies lead to large increases in Welfare. The UPS has a Welfare improvement of roughly 70% between the no fiscal policy scenario and the TIS under debt financing. This Welfare improvement is relatively strong given that the UPS has no direct redistributive effects. In comparison the GPS and TR lead to 28% and 0% increases in Welfare under debt financing. This result suggests that these policies are relatively ineffective at supporting households during energy shocks.

All results are qualitatively similar under debt and windfall tax financing. The ranking of the policies is identical, however, more importantly, Welfare is improved for all policies if windfall taxes are employed as long as the relative weight on the public

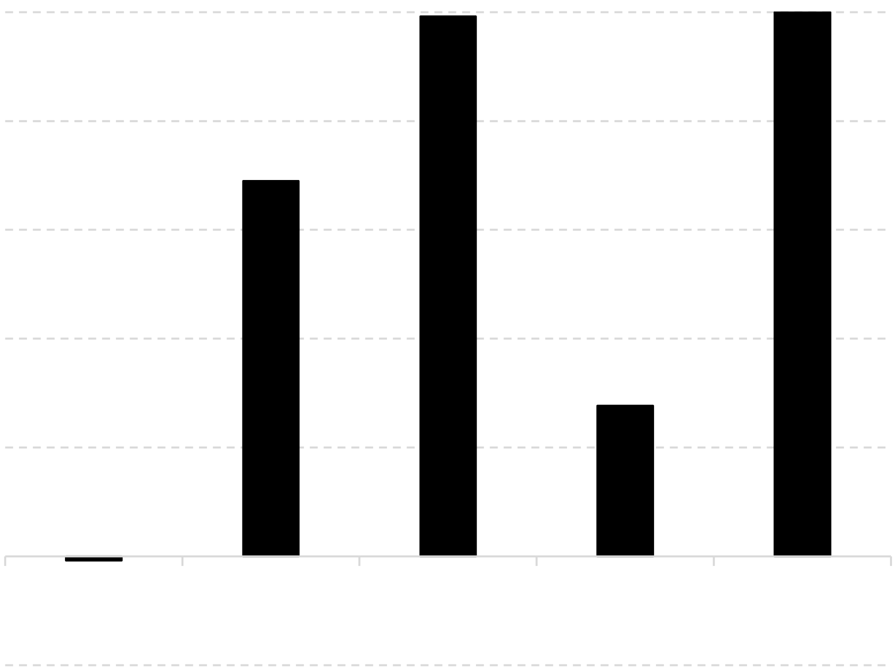

Figure 8: Welfare (Debt financing)

good $\gamma_G \geq 0.133$. The reasons for this are two-fold. First, windfall taxation leads to a direct redistribution of resources under all policies. As a result, regressive effects are counteracted under windfall taxation. Second, as the financing collected through windfall taxation has no intertemporal cost, less debt is used. Thus, the German government does not need to repay as much debt and has a higher public good provision in the following periods. This result is fascinating as the interest rate chosen for the policies is risk-free. This implies that, as long as households value the provision of public goods a bit and even when the interest rate on debt is low, windfall taxation is preferable to debt financing.

6.4.4 Summary

The results presented in this paper suggest that TRs and GPSs are preferable for addressing the aggregate impacts of energy shocks. TRs boost aggregate output at very low inflation costs whilst GPSs boost aggregate output most of all the policies at a relatively low inflation cost compared to the other policies. The results also suggest that TISs and TPSs are more effective at increasing Welfare and reversing the regressive effects of the energy shock. Finally, the results motivate the use of windfall taxation if governments face high interest rates on debt financing and/ or if households care sufficiently about the provision of public goods. Thus, the optimal policy is likely a mix of the supply-side measures (TR, GPS) and either TPSs or TISs financed partially through windfall taxation.

7 Conclusion

In this paper, I aim to understand the short-run aggregate and distributional implications as well as the long-run welfare effects of a set of fiscal policies typically used to respond to energy shocks. A 2-region discrete time dynamic CGE model is used to capture the policies in Germany and potential spillover effects from the rest of the EU. An energy price shock is introduced through the ROW price of energy and the German government is assumed to have an equal budget available for all policies. This budget could be financed through debt or a combination of debt and windfall taxation. Using this model, I find that targeted policies such as targeted income subsidies (TISs) and price subsidies (TPSs) best address distributional and long-run welfare outcomes. Indeed, TISs and TPSs entirely reversed the regressive effects of the initial energy shock and increased long-run welfare much more than the general price subsidy (GPS), untargeted price subsidy (UPS) and tax reduction (TR). Although the TIS and TPS counteract the regressive effects of the energy shock effectively, these have inflationary effects. Both the GPS and TR are much less inflationary and in fact, the TR is almost price neutral. This is the only price-neutral policy and achieves similar aggregate output rebounds to the TIS and TPS. Despite the desirability of price neutrality of the TR and the progressive effects of the targeted policies, the GPS is most favourable for aggregate output. Through the GPS, aggregate output rebounds twice as much as any of the other policies.

Importantly, all of the rankings are equivalent when windfall tax financing is introduced. The main differences with windfall tax financing are: (1) welfare is improved as long as households care sufficiently about the public good provision or interest rates on debt are not risk-free; (2) the aggregate output and inflationary impacts of the policies are slightly lower than under pure debt financing. The prior effect holds for very small public good provision weights under riskless interest rates. The second effect is expected as windfall taxation is an intratemporal redistribution. The fact that the aggregate output impacts and inflationary impacts are only slightly lower under windfall taxation implies that the redistribution has expansionary effects itself as lower-income households have a higher marginal propensity to consume than high-income households.

From a policy perspective, these results suggest that using a mixture of targeted subsidies, general price subsidies and tax reductions is likely optimal. Governments can implement targeted price subsidies for distributional effects and to reverse adverse long-run welfare effects. A mixture of general price subsidies and tax reductions can then be used to maximise aggregate output rebounds whilst managing inflationary pressures. If possible, governments should also use windfall tax financing to supplement their budgets as this is welfare-enhancing for all policies considered as long as households value public good provision a bit.

Future research should aim to test the results of this paper using alternative methodologies. One valuable extension would be to replicate this analysis using a different set of countries. Further research may also consider comparing the environmental implications of the policies.

References

Agarwal, S., Liu, C. & Souleles, N. (2007), 'The Reaction of Consumer Spending and Debt to Tax Rebates—Evidence from Consumer Credit Data', *Journal of Political Economy* **115**(6), 986–1019.

Armington, P. S. (1969), 'A Theory of Demand for Products Distinguished by Place of Production', *Staff Papers (International Monetary Fund)* **16**(1), 159–178.

Bajzik, J., Havranek, T., Irsova, Z. & Schwarz, J. (2020), 'Estimating the Armington elasticity: The importance of study design and publication bias', *Journal of International Economics* **127**, 103383.

Barsky, R. B. & Kilian, L. (2004), 'Oil and the Macroeconomy Since the 1970s', *Journal of Economic Perspectives* **18**(4), 115–134.

Blanchflower, D. G. & Oswald, A. J. (1995), 'An Introduction to the Wage Curve', *Journal of Economic Perspectives* **9**(3), 153–167.

Boadway, R. & Keen, M. (1999), Redistribution, Working Paper 983, Economics Department, Queen's University.

BP (2022), 'Statistical Review of World Energy: Energy Economics: Home'.

BP (2023), 'Fourth quarter and full year 2022 results'.

Celasun, O., Mineshima, A., Arregui, N., Mylonas, V., Ari, A., Teodoru, I., Black, S., Zhunussova, K., Iakova, D., Parry, I. & et al. (2022), 'Surging energy prices in Europe in the aftermath of the war: How to support the vulnerable and speed up the transition away from fossil fuels', *IMF Working Papers* **2022**(152), 1–40.

Devarajan, S. & Go, D. S. (1998), 'The Simplest Dynamic General-Equilibrium Model of an Open Economy', *Journal of Policy Modeling* **20**(6), 677–714.

Duparc-Portier, G. & Figus, G. (2021), 'The impact of the new Northern Ireland protocol: can Northern Ireland enjoy the best of both worlds?', *Regional Studies* **0**(0), 1–14.

Eurostat (2023*a*), 'Main national accounts tax aggregates'.

Eurostat (2023*b*), 'Key indicators - annual data'.

Eurostat (2023*c*), 'Gas prices for household consumers - bi-annual data (from 2007 onwards)'.

Eurostat (2023*d*), 'Gas prices for non-household consumers - bi-annual data (from 2007 onwards)'.

Eurostat (2023*e*), 'Electricity prices for household consumers - bi-annual data (from 2007 onwards)'.

Eurostat (2023*f*), 'Electricity prices for non-household consumers - bi-annual data (from 2007 onwards)'.

Eurostat (2023*g*), 'ESA supply, use and input-output tables - Data -FIGARO tables'.

Feenstra, R. C., Luck, P., Obstfeld, M. & Russ, K. N. (2018), 'In Search of the Armington Elasticity', *The Review of Economics and Statistics* **100**(1), 135–150.

FSO (2023*a*), 'Consumption expenditure'.

FSO (2023*b*), 'Continuous household budget surveys (LWR)'.

FSO (2023*c*), 'Income, receipts and expenditure of households: Net household income'.

Geary, R. C. (1950), 'A Note on "A Constant-Utility Index of the Cost of Living"', *The Review of Economic Studies* **18**(1), 65–66.

Gechert, S., Havranek, T., Irsova, Z. & Kolcunova, D. (2022), 'Measuring Capital-Labor Substitution: The Importance of Method Choices and Publication Bias', *Review of Economic Dynamics* **45**, 55–82.

Gisser, M. & Goodwin, T. H. (1986), 'Crude Oil and the Macroeconomy: Tests of Some Popular Notions: Note', *Journal of Money, Credit and Banking* **18**(1), 95–103.

Guan, Y., Yan, J., Shan, Y., Zhou, Y., Hang, Y., Li, R., Yu, L., Liu, B., Nie, Q., Feng, K. & Klaus, H. (2023), 'Burden of the global energy price crisis on households', *Nature Energy* **8**, 1–13.

Hagemann, R. P. (1982), 'The Variability of Inflation Rates Across Household Types', *Journal of Money, Credit and Banking* **14**(4), 494–510.

Hamilton, J. D. (1983), 'Oil and the Macroeconomy since World War II', *Journal of Political Economy* **91**(2), 228–248.

Hosoe, N., Gasawa, K. & Hashimoto, H. (2010), *"Model Extension"*, Palgrave Macmillan UK, London, pp. 158–190.

IEA (2023), 'World Oil Supply and demand, 1971-2020'.

Imbs, J. & Mejean, I. (2015), 'Elasticity Optimism', *American Economic Journal: Macroeconomics* **7**(3), 43–83.

IMF (2023), 'World Economic Outlook: Inflation Peaking amid Low Growth', *IMF* .

Jiménez-Rodríguez, R. (2008), 'The impact of oil price shocks: Evidence from the industries of six OECD countries', **30**(6), 3095–3108.

Jiménez-Rodríguez, R. & Sánchez, M. (2005), 'Oil price shocks and real GDP growth: empirical evidence for some OECD countries', **37**(2), 201–228. Publisher: Routledge.

Johnson, D. S., Parker, J. A. & Souleles, N. S. (2006), 'Household Expenditure and the Income Tax Rebates of 2001', *American Economic Review* **96**(5), 1589–1610.

Jolly, J. & Elgot, J. (2022), 'Profits at world's seven biggest oil firms soar to almost £150bn this year', *The Guardian* .

Kilian, L. (2009), 'Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market', *The American Economic Review* **99**(3), 1053–1069.

Kilian, L. & Murphy, D. P. (2012), 'Why Agnostic Sign Restrictions Are Not Enough: Understanding the Dynamics of Oil Market Var Models', *Journal of the European Economic Association* **10**(5), 1166–1188.

Lecca, P., McGregor, P. G., Swales, J. K. & Turner, K. (2014), 'The added value from a general equilibrium analysis of increased efficiency in household energy use', *Ecological Economics* **100**(C), 51–62.

Ljungqvist, L. & Sargent, T. J. (2004), *Recursive Macroeconomic Theory, 2nd Edition*, Vol. 1 of *MIT Press Books*, The MIT Press.

Metcalf, G. E., Paltsev, S., Reilly, J., Jacoby, H. & Holak, J. F. (2008), Analysis of U.S. Greenhouse Gas Tax Proposals, NBER Working Papers 13980, National Bureau of Economic Research, Inc.

Michael, R. T. (1979), 'Variation Across Households in the Rate of Inflation', *Journal of Money, Credit and Banking* **11**(1), 32–46.

Mućk, J. (2017), Elasticity of substitution between labor and capital: robust evidence from developed economies, Technical report.

Parker, J. A., Souleles, N. S., Johnson, D. S. & McClelland, R. (2013), 'Consumer Spending and the Economic Stimulus Payments of 2008', *The American Economic Review* **103**(6), 2530–2553.

Perdana, S., Vielle, M. & Schenckery, M. (2022), 'European Economic impacts of cutting energy imports from Russia: A computable general equilibrium analysis', *Energy Strategy Reviews* **44**, 101006.

Pizer, W. A. & Sexton, S. (2019), 'The Distributional Impacts of Energy Taxes', *Review of Environmental Economics and Policy* **13**(1), 104–123.

Ritchie, H., Roser, M. & Rosado, P. (2022), 'Energy', *Our World in Data* .

Samuelson, P. (1937), 'A Note on Measurement of Utility', *Review of Economic Studies* **4**(2), 155–161.

Schram, A. & van Winden, F. (1989), 'Revealed Preferences for Public Goods: Applying a Model of Voter Behavior', *Public Choice* **60**(3), 259–282.

Sen, A. (1970), *Collective Choice and Social Welfare*, Holden Day, San Francisco. Backup Publisher: Holden Day.

Sgaravatti, G., Tagliapietra, S., Trasi, C. & Zachmann, G. (2023), 'National fiscal policy responses to the energy crisis'.

Shell (2023), 'Fourth Quarter 2022 results – February 2, 2023'.

Stone, R. (1954), 'Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand', *The Economic Journal* **64**(255), 511–527.

Turner, K., Katris, A., Stewart, J. & Corbett, H. (2022), 'The impacts of the October 2022 gas and electricity price increase on the UK economy and the cost of living for different household income groups', *Policy Brief University of Strathclyde Centre for Energy Policy* p. 1–4.

UN (2008), 'Standard International Trade Classification Revision 4 - UNSD'.

Ven, D. J. v. d. & Fouquet, R. (2017), 'Historical energy price shocks and their changing effects on the economy', *Energy Economics* **62**, 204–216.

Williams, R., Gordon, H., Burtraw, D., Carbone, J. & Morgenstern, R. D. (2015), 'The Initial Incidence of a Carbon Tax Across Income Groups', *National Tax Journal* **68**(1), 195–214.

Woolf, A. G. (1987), 'The Residential Adoption of Electricity in Early Twentieth-Century America', *The Energy Journal* **8**(2), 19–30.

World Bank (2023*a*), 'Access to electricity (% of population)'.

World Bank (2023*b*), 'Inflation, consumer prices (annual %)'.

World Bank (2023*c*), 'GDP growth (annual %)'.

Yogo, M. (2004), 'Estimating the Elasticity of Intertemporal Substitution When Instruments Are Weak', *The Review of Economics and Statistics* **86**(3), 797–810.

Zofio, J. L., Diaz-Lanchas, J., Persyn, D. & Barbero, J. (2020), Estimating foreign and national trade elasticities in the EU internal market using Generalised Transport Costs, JRC Working Papers on Territorial Modelling and Analysis 2020-05, Joint Research Centre (Seville site).

A CGE Model

Prices:

$$cpi_{r,t} = \frac{\sum_h C^H_{h,r,t} \cdot cpi^H_{h,r,t}}{C_{r,t}} \tag{A.1}$$

$$cpi^H_{h,r,t} = \frac{\sum_i pc^T_{h,r,i,t} \cdot \mu^{HC}_{h,r,i}}{\sum_i pc^T_{h,r,i,t=0} \cdot \mu^{HC}_{h,r,i}} \tag{A.2}$$

$$pc^T_{h,r,i,t} = \frac{\sum_{r'} pd_{r',i,t} \cdot CD^H_{h,r',r,i,t=0}}{\sum_{r'} pd_{r',i,t=0} \cdot CD^H_{h,r',r,i,t=0}} \tag{A.3}$$

$$w_{r,t} = \begin{cases} \exp\left(\log cpi_{r,t} + \alpha^{WC}_r - \beta^{WC}_r \cdot \log UN_{r,t}\right) \text{ Regional Bargaining} \\ w_{r,t=0} \text{ Fixed nominal wage} \\ cpi_{r,t} \text{ Fixed real wage} \end{cases}$$

(A.4)

$$rk_{r,i,t} = py_{r,i,t} \cdot \alpha^K_{r,i} \cdot \Psi^{K\,\rho^H_i}_{r,i} \cdot \left(\frac{Y_{r,i,t}}{K_{r,i,t}}\right)^{1-\rho^H_i} \tag{A.5}$$

$$uck_{r,t} = ipi_{r,t} \cdot (ir_r + \delta_r) \tag{A.6}$$

$$pv_{r,i,t} = \frac{\sum_{r',j} pd_{r',i,t} \cdot VR_{r',i,r,j,t}}{\sum_j V_{r,i,j,t}} \tag{A.7}$$

$$pd_{r,j,t} \cdot (1 - \tau^p_{r,j,t}) = \sum_i \left(pv_{r,i,t} \cdot \mu^V_{r,i,j}\right) + py_{r,j,t} \cdot \mu^Y_{r,j} \tag{A.8}$$

$$gpi_{r,t} = \frac{\sum_{i,r'} G^C_{r',i,r,t=0} \cdot pd_{r',i,t}}{\sum_{i,r'} G^C_{r',i,r,t=0} \cdot pd_{r',i,t=0}} \tag{A.9}$$

$$ipi_{r,t} = \frac{\sum_{i,r'} pd_{r',i,t} \cdot \mu^I_{r',i,r}}{\sum_{i,r'}, pd_{r',i,t=0} \cdot \mu^I_{r',i,r}} \tag{A.10}$$

$$pd_{r,i,t} = \begin{cases} ps_{r,i,t} \text{ Perfect competition} \\ \frac{\epsilon^M_{r,i}}{\epsilon^M_{r,i}-1} \cdot ps_{r,i,t} \text{ Monopoly model} \\ NZ_{r,i,t}^{\frac{1}{1-\epsilon^D_{r,i}}} \cdot pd^Z_{r,i,t} \text{ Krugman model} \end{cases} \tag{A.11}$$

$$pd^Z_{r,i,t} = \frac{\epsilon^D_{r,i}}{\epsilon^D_{r,i} - 1} \cdot ps_{r,i,t} \tag{A.12}$$

(A.13)

Household aggregation:

$$II_{r,t} = \sum_h II^H_{h,r,t} \tag{A.14}$$

$$C_{r,t} = \sum_h C^H_{h,r,t} \tag{A.15}$$

$$CD_{r,i,t} = \sum_{h} CD^{H}_{h,r,r,i,t} \tag{A.16}$$

$$CI_{r,i,t} = \sum_{h,r' \neq r} CD^{H}_{h,r',r,i,t} \tag{A.17}$$

$$S_{r,t} = \sum_{h} S^{H}_{h,r,t} \tag{A.18}$$

$$T_{r,t} = \sum_{h} T^{H}_{h,r,t} \tag{A.19}$$

Household level equations:

$$C^{H}_{h,r,t} \cdot cpi^{H}_{h,r,t} = II^{H}_{h,r,t} - S^{H}_{h,r,t} - T^{H}_{h,r,t} \tag{A.20}$$

$$T^{H}_{h,r,t} = \tau^{H}_{h,r} \cdot II^{H}_{h,r,t} \tag{A.21}$$

$$CT^{H}_{h,r,i,t} = \begin{cases} \mu^{HC}_{h,r,i} \cdot C^{H}_{h,r,t}, \text{ Leontief} \\ \gamma^{SG}_{h,r,i} + \frac{\beta^{SG}_{h,r,i}}{pc^{T}_{h,r,i,t}} \cdot (C^{H}_{h,r,t} \cdot cpi^{H}_{h,r,t} - \sum_{j} \gamma^{SG}_{h,r,j} \cdot pc^{T}_{h,r,j,t}), \quad \text{Stone-Geary} \end{cases} \tag{A.22}$$

$$CD^{H}_{h,r',r,i,t} = \left({\Psi^{C}_{h,r,i}}^{\rho^{V}_{r,i}} \cdot \alpha^{C}_{h,r',r,i} \cdot \frac{pc^{T}_{h,r,i,t}}{pd_{r',i,t}} \right)^{\frac{1}{1-\rho^{V}_{r,i}}} \cdot CT^{H}_{h,r,i,t} \tag{A.23}$$

$$II^{H}_{h,r,t} = \theta^{K}_{h,r} \cdot \sum_{i} uck_{r,t} \cdot K_{r,i,t} + \theta^{L}_{h,r} \cdot w_{r,t} \cdot \sum_{i} L_{r,i,t} + \theta^{\Pi}_{h,r} \cdot \sum_{i} \Pi_{r,i,t} + TR_{h,r,t} \cdot cpi_{r,t} \tag{A.24}$$

Forward-Looking household:

$$\frac{C^{H}_{h,r,t}}{C^{H}_{h,r,t+1}} = \left[\beta_{h,r} \cdot \left(\frac{1 + \Delta ipi_{r,t+1}}{1 + \Delta cpi^{H}_{h,r,t+1}} \cdot \left((1-\delta_{r}) + (ir_{r} + \delta_{r}) \cdot \left(1 - \tau^{H}_{h,r}\right) \right) \right) \right]^{-\frac{1}{\epsilon_{h,r}}} \tag{A.25}$$

Myopic household:

$$S^{H}_{h,r,t} = \mu^{HS}_{h,r} \cdot II^{H}_{h,r,t}. \tag{A.26}$$

Production:

“Classical” production structure:

$$Y_{r,i,t} = \left(\alpha^{K}_{r,i} \cdot (\Psi^{K}_{r,i} \cdot K_{r,i,t})^{\rho^{H}_{i}} + \alpha^{L}_{r,i} \cdot (\Psi^{L}_{r,i} \cdot L_{r,i,t})^{\rho^{H}_{i}} \right)^{\frac{1}{\rho^{H}_{i}}} \tag{A.27}$$

$$KS^{T}_{r,i,t} = \left({\Psi^{K}_{r,i}}^{\rho^{H}_{i}} \cdot \alpha^{K}_{r,i} \cdot \frac{py_{r,i,t}}{uck_{r,t}} \right)^{\frac{1}{1-\rho^{H}_{i}}} \cdot Y_{r,i,t} \tag{A.28}$$

$$L_{r,i,t} = \left({\Psi^{L}_{r,i}}^{\rho^{H}_{i}} \cdot \alpha^{L}_{r,i} \cdot \frac{py_{r,i,t}}{w_{r,t}} \right)^{\frac{1}{1-\rho^{H}_{i}}} \cdot Y_{r,i,t} \tag{A.29}$$

$$VR_{r',i,r,j,t} = \left({\Psi^{V}_{r,i,j}}^{\rho^{V}_{r,i}} \cdot \alpha^{ARM}_{r',i,r,j} \cdot \frac{pv_{r,i,t}}{pd_{r',i,t}} \right)^{\frac{1}{1-\rho^{V}_{r,i}}} \cdot V_{r,i,j,t} \tag{A.30}$$

$$pv_{r,i,t} \cdot V_{r,i,j,t} = \mu^{V}_{r,i,j} \cdot O_{r,j,t} \cdot ps_{r,j,t} \tag{A.31}$$

$$py_{r,i,t} \cdot Y_{r,i,t} = \mu^{Y}_{r,i} \cdot O_{r,i,t} \cdot ps_{r,i,t} \tag{A.32}$$

Perfect competition:

$$NZ_{r,i,t} = NZ_{r,i,t=0} \tag{A.33}$$

"Monopoly" production structure:

$$\Pi_{r,i,t} = \frac{1}{\epsilon^{M}_{r,i}} \cdot O_{r,i,t} \cdot pd_{r,i,t} \cdot (1 - \tau^{p}_{r,i,t}) \tag{A.34}$$

$$NZ_{r,i,t} = NZ_{r,i,t=0} \tag{A.35}$$

"Oligopoly" production structure:

$$\Pi_{r,i,t} = \frac{1}{\epsilon^{O}_{r,i} \cdot NZ_{r,i,t}} \cdot O_{r,i,t} \cdot pd_{r,i,t} \cdot (1 - \tau^{p}_{r,i,t}) \tag{A.36}$$

$$NZ_{r,i,t} = NZ_{r,i,t=0} \tag{A.37}$$

"Krugman" extended production structure:

$$\Pi_{r,i,t} = NZ_{r,i,t} \cdot f^{Z}_{r,i} \cdot \frac{ps_{r,i,t}}{ps_{r,i,t=0}} \tag{A.38}$$

$$\begin{aligned} pd_{r,i,t} \cdot O_{r,i,t} \cdot (1 - \tau^{p}_{r,i,t}) &= w_{r,t} \cdot L_{r,i,t} + rk_{r,i,t} \cdot K_{r,i,t} \\ &\quad + \sum_{r',j} pd_{r',j,t} \cdot VR_{r',j,r,i,t} + f^{Z}_{r,i} \cdot NZ_{r,i,t} \cdot \frac{ps_{r,i,t}}{ps_{r,i,t=0}} \end{aligned} \tag{A.39}$$

$$VR^{Z}_{r',i,r,j,t} = \left({\Psi^{Z}_{r',i,r,j}}^{\rho^{SZ}_{r,j}} \cdot \left(\frac{pd_{r,i,t}}{pd^{Z}_{r,i,t} \cdot NZ_{r,j,t}} \right) \right)^{\frac{1}{1-\rho^{SZ}_{r,j}}} \cdot VR_{r',i,r,j,t} \tag{A.40}$$

Factor accumulation:

$$KS_{r,i,t} = \begin{cases} KS_{r,i,t=0} \text{ if t=1} \\ KS_{r,i,t-1} \cdot (1 - \delta_r) + I^{D}_{r,i,t-1} \text{ if } t \in (1, \infty) \\ \frac{I^{D}_{r,i,t}}{\delta_r} \text{ if t} \rightarrow \infty \end{cases} \tag{A.41}$$

$$\sum_{i} L_{r,i,t} = LS_{r,t=0} \cdot (1 - UN_{r,t}) \tag{A.42}$$

Market clearing conditions:

$$K_{r,i,t} = KS_{r,i,t} \tag{A.43}$$

$$X_{r,i,t} = \sum_{r'} X^R_{r',i,r,t} - X^R_{r,i,r,t} \tag{A.44}$$

$$X^R_{r,i,r',t} = M^R_{r',i,r,t} \tag{A.45}$$

$$M^R_{r',i,r,t} = \sum_j VR_{r',i,r,j,t} + \sum_h CD^H_{h,r',r,i,t} + G^C_{r',i,r,t} + I^O_{r',i,r,t} + STK_{r',i,r} \tag{A.46}$$

$$M_{r,i,t} = \sum_{r'} M^R_{r',i,r,t} - M^R_{r,i,r,t} \tag{A.47}$$

$$O_{r,i,t} = \sum_{r'} X^R_{r',i,r,t} \tag{A.48}$$

$$D_{r,i,t} = M^R_{r,i,r,t} \tag{A.49}$$

$$I^T_{r,t} \cdot ipi_{r,t} = S^G_{r,t} + S_{r,t} + S^F_{r,t} \tag{A.50}$$

$$\sum_i I^D_{r,i,t} = \sum_{i,r'} I^O_{r',i,r,t} + \sum_i STK_{r,i,r} + STK^F_r \tag{A.51}$$

Export demand:

$$X^R_{row,i,r,t} = X^R_{row,i,r,t=0} \cdot \frac{pd_{row,i,t}}{pd_{r,i,t}} \tag{A.52}$$

Government expenditure and income:

$$G^C_{r',i,r,t} = G_{r,t} \cdot \mu^{GC}_{r',i,r} \tag{A.53}$$

$$G_{r,t} \cdot gpi_{r,t} = G^Y_{r,t} - S^G_{r,t} - TR^T_{r,t} \tag{A.54}$$

$$G^Y_{r,t} = T_{r,t} + \sum_i T^F_{r,i,t} \tag{A.55}$$

$$S^G_{r,t} = \mu^{GS}_r \cdot G^Y_{r,t} \tag{A.56}$$

$$T^F_{r,i,t} = \tau^p_{r,i,t} \cdot O_{r,i,t} \cdot pd_{r,i,t} \tag{A.57}$$

Investment:

$$I^D_{r,i,t} = (KS_{r,i,t} \cdot \delta_r) + (KS^T_{r,i,t} - KS_{r,i,t}) \cdot \phi_r \tag{A.58}$$

$$I^O_{r',i,r,t} = I^T_{r,t} \cdot \mu^I_{r',i,r} \tag{A.59}$$

$$I^O_{row,i,r,t} = I^O_{row,i,r,t=0} \tag{A.60}$$

Sets:

r/r' := region subscript

h := household subscript

t := time subscript

i/j := industry subscript

Parameters:

$\alpha^{ARM}_{r',i,r,j}$:= Armington share parameter
α^{WC}_{r} := wage curve intercept
$\alpha^{C}_{h,r',r,i}$:= Armington share parameter
$\alpha^{K}_{r,i}$:= CES share parameter
$\alpha^{L}_{r,i}$:= CES share parameter
$\beta^{SG}_{h,r,i}$:= Stone-Geary weight parameter
β^{WC}_{r} := wage curve slope
$\beta_{h,r} \in (0,1)$:= Samuelson discount factor
$\delta_{r} \in (0,1)$:= depreciation rate
$\epsilon^{D}_{r,i}$:= Dixit-Stiglitz elasticity of demand
$\epsilon^{M}_{r,i}$:= monopoly elasticity of demand
$\epsilon^{O}_{r,i}$:= oligopoly elasticity of demand
$\epsilon_{h,r}$:= CRRA parameter
$\gamma^{SG}_{h,r,i}$:= Stone-Geary sustenance parameter
$\mu^{GC}_{r',i,r}$:= Leontief share parameter
$\mu^{GS}_{r} \in [0,1]$:= government marginal propensity to save
$\mu^{HC}_{h,r,i} \in [0,1]$:= Leontief consumption share parameter
$\mu^{HS}_{h,r} \in (0,1)$:= marginal propensity to save (myopic model)
$\mu^{I}_{r',i,r}$:= share of investment by sector
$\mu^{V}_{r,i,j}$:= Leontief share parameter
$\mu^{Y}_{r,i}$:= Leontief share parameter
$\phi_{r} \in (0,1)$:= capital adjustment speed
ρ^{H}_{i} := CES substitution parameter
$\rho^{SZ}_{r,j}$:= Dixit-Stiglitz substitution parameter
$\rho^{V}_{r,i}$:= Armington substitution parameter
$\tau^{p}_{r,j,t}$:= business tax rate
$\tau^{H}_{h,r}$:= tax rate for h
$\theta^{\Pi}_{h,r}$:= share of firm ownership
$\theta^{K}_{h,r}$:= share of capital endowment
$\theta^{L}_{h,r}$:= share of labour endowment
$\Psi^{C}_{h,r,i}$:= Armington push parameter
$\Psi^{K}_{r,i}$:= CES push parameter
$\Psi^{L}_{r,i}$:= CES push parameter
$\Psi^{Z}_{r',i,r,j}$:= Dixit-Stiglitz push parameter
$\Psi^{V}_{r,i,j}$:= Armington push parameter

Variables:
Prices:

$cpi^H_{h,r,t} \in \mathbb{R}^*_+ :=$ consumer price index for h
$cpi_{r,t} \in \mathbb{R}^*_+ :=$ consumer price index
$gpi_{r.t} \in \mathbb{R}^*_+ :=$ government price index
$ipi_{r,t} \in \mathbb{R}^*_+ :=$ investment price index
$ir_r \in \mathbb{R}_+ :=$ interest rate
$pc^T_{h,r,i,t} \in \mathbb{R}^*_+ :=$ price of Armington good for h
$pd^Z_{r,i,t} \in \mathbb{R}_+ :=$ firm level demand price
$pd_{r,i,t} \in \mathbb{R}^*_+ :=$ market price
$ps_{r,j,t} \in \mathbb{R}_+ :=$ supply price
$pv_{r,i,t} \in \mathbb{R}_+ :=$ price of Armington intermediate good
$py_{r,i,t} \in \mathbb{R}_+ :=$ price of value added
$rk_{r,i,t} \in \mathbb{R}^*_+ :=$ rental rate of capital
$uck_{r,t} \in \mathbb{R}^*_+ :=$ user cost of capital
$w_{r,t} \in \mathbb{R}^*_+ :=$ wage
Quantities:
$\Pi_{r,i,t} \in \mathbb{R}_+ :=$ profits
$C^H_{h,r,t} \in \mathbb{R}_+ :=$ aggregate household consumption for representative household h
$C_{r,t} \in \mathbb{R}_+ :=$ aggregate household consumption
$CD^H_{h,r',r,t} \in \mathbb{R}_+ :=$ region r household h's consumption of goods from region r'
$CD_{r,t} \in \mathbb{R}_+ :=$ domestic household consumption
$CI_{r,t} \in \mathbb{R}_+ :=$ foreign household consumption
$CT^H_{h,r,i,t} \in \mathbb{R}_+ :=$ Armington good for h
$D_{r,i,t} \in \mathbb{R}_+ :=$ domestic demand
$f^Z_{r,i} \in \mathbb{R}_+ :=$ fixed cost of entry
$G_{r,t} \in \mathbb{R}_+ :=$ aggregate government expenditure
$G^C_{r',i,r,t} \in \mathbb{R}_+ :=$ government expenditure of i from r'
$G^Y_{r,t} \in \mathbb{R}_+ :=$ government income
$I^D_{r,i,t} \in \mathbb{R}_+ :=$ investment by destination
$I^O_{r',i,r,t} \in \mathbb{R}_+ :=$ investment by origin in i from r'
$I^T_{r,t} \in \mathbb{R}_+ :=$ total investment
$II^H_{h,r,t} \in \mathbb{R}_+ :=$ gross household income for representative household h
$II_{r,t} \in \mathbb{R}_+ :=$ gross household income
$K_{r,i,t} \in \mathbb{R}_+ :=$ capital demand
$KS^T_{r,i,t} \in \mathbb{R}_+ :=$ desired capital
$KS_{r,i,t} \in \mathbb{R}_+ :=$ capital supply
$L_{r,i,t} \in \mathbb{R}_+ :=$ labour demand
$LS_{r,t} \in \mathbb{R}_+ :=$ aggregate labour supply
$M^R_{r',i,r,t} \in \mathbb{R}_+ :=$ purchases of i from r' to r
$M_{r,i,t} \in \mathbb{R}_+ :=$ imports from ROW

$NZ_{r,i,t} \in \mathbb{R}_+ :=$ number of firm index
$O_{r,j,t} \in \mathbb{R}_+ :=$ output
$S^F_{r,t} \in \mathbb{R}_+ :=$ FDI
$S^G_{r,t} \in \mathbb{R}_+ :=$ government savings
$S^H_{h,r,t} \in \mathbb{R}_+ :=$ household saving for h
$S_{r,t} \in \mathbb{R}_+ :=$ aggregate household saving
$STK^F_r \in \mathbb{R}_+ :=$ foreign change in inventories (balancing item)
$STK_{r',i,r} \in \mathbb{R}_+ :=$ change in inventories
$T^F_{r,i,t} \in \mathbb{R}_+ :=$ indirect business tax
$T^H_{h,r,t} \in \mathbb{R} :=$ household tax for h
$T_{r,t} \in \mathbb{R} :=$ aggregate household tax
$TR^T_{r,t} \in \mathbb{R}_+ :=$ total government transfers
$TR_{h,r,t} \in \mathbb{R}_+ :=$ government transfers
$UN_{r,t} \in (0,1) :=$ unemployment rate
$V_{r,i,j,t} \in \mathbb{R}_+ :=$ Armington intermediate good
$VR^Z_{r',i,r,j,t} \in \mathbb{R}_+ :=$ firm level intermediate good
$VR_{r',i,r,j,t} \in \mathbb{R}_+ :=$ intermediate good
$X^R_{r',i,r,t} \in \mathbb{R}_+ :=$ sales of i from r' to r
$X_{r,i,t} \in \mathbb{R}_+ :=$ exports to ROW
$Y_{r,i,t} \in \mathbb{R}_+ :=$ value added