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The electric shock: Causes and consequences of electricity prices in the United Kingdom

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ABSTRACT

This study explores the primary causes of wholesale electricity price fluctuations in the United Kingdom (UK). Using the structural vector autoregression (SVAR) model that identifies both supply-side and demand-side shocks, and monthly data for the period from January 1996 to May 2022, the findings show that the impact of electricity price increases on the real electricity price is dependent on the underlying cause of the price increase. Electricity price movements in the most recent period of global hardships from 2020 to 2022, including the Covid-19 pandemic and the Russian invasion of Ukraine, are further examined, which were widely discussed to have affected the global energy segment. The findings show that although shocks to natural gas had a part to play in the recent price increase of electricity, some major contributing factors remain unique to the UK. Finally, the findings put into perspective and question the effectiveness of the energy cap considering the large contribution of renewable power generation.

1. Introduction

The conversation on commodity prices has once again become the centre of attention among policymakers, regulators and academics following the Russia-Ukraine conflict. Previous discussions on commodity markets concentrate primarily around the 2000–2008 period when prices in general had a substantial bearish trend followed by a notable drop following the Global Financial Crisis.[1] In light of recent events, the price of energy commodities in general and natural gas in particular reached a 10-year high in May 2022. According to Wang et al. (2022), spillover effects of the Russia-Ukraine war have passed on to most energy commodities including crude oil and natural gas markets. According to the Department for Business, Energy and Industrial Strategy (DBEIS), natural gas was the primary non-renewable energy source for nearly 30%–48% of electricity production in the UK as of 1996. Therefore, it is highly likely that the price of electricity in the UK is highly affected by the changes in the global price of natural gas. Moreover, there have been numerous claims in media in the recent past that the Russia-Ukraine conflict has played a significant role in deciding the electricity price in the UK.

This paper explores causes of the producer (wholesale) price of electricity in the UK. To the best of our knowledge, this is the first study conducted into electricity markets. In addition to the above discussed global price of natural gas, several other supply-side and demand-side factors are identified that could potentially have an impact on the electricity price. Shortfalls in the current supply of natural gas used in the production of electricity could prompt producers to either source natural gas from elsewhere or to use an alternative energy source to match the demand for electricity, as natural gas power generations amount to 40% of the UK's electricity supply (Stern, 2004). Assuming that the current supply is the cheapest available, an alternative natural gas supply and/or an alternative energy source would increase the cost of production and therefore the price of electricity (Kirschen, 2003). Further, higher consumer demand could potentially right-shift the demand. This would mean that producers will have to use more expensive alternatives to meet the demand, which could potentially drive up the price of electricity.

The UK's electricity industry was restructured in 1990 and initial

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[1] Masters (2008) attributes the energy commodity price increase from 2000 to 2008 to excessive speculation in financial futures. However, this claim is widely rejected by academics (Fattouh et al. (2013), Alquist and Gervais (2013) and Alquist and Kilian (2010) among others) in the context of crude oil and natural gas, which are two of the largest commodity markets in the energy segment. Kilian (2009) shows that global aggregate demand had a substantial role in driving oil prices while Nguyen and Okimoto (2019) conclude that natural gas prices are mainly driven by the oil prices.

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steps for privatisation were taken in 1991. The electricity market in the UK is currently made up of three parties, in which there are power producers – who generate electricity; power suppliers – who purchase power from producers and supply consumers; and consumers – who purchase power from suppliers. The Office of Electricity Regulation (Offer) was established to regulate the suppliers and establish fairness in the retail electricity market, which was later merged with the Office of Gas Supply (OFGAS) to form the Office of Gas and Electricity Markets (Ofgem) in 2000. In the history of interventions, Ofgem had a number of price control reviews to amend distribution and transmission charges from 1998 to 2013 (Domah and Pollitt, 2001), while they later introduced the energy cap to prevent suppliers from charging consumers above a certain threshold. Such interventions, which are unique to electricity markets, should potentially influence the electricity price in the UK. In this study a structural vector autoregression (SVAR) model is used to capture the response of electricity prices in the UK to unexpected changes in supply-side factors, such as natural gas price and supply, and demand-side factors, such as consumer demand and electricity-market-specific factors. This is mainly to identify whether the real price of electricity responds differently depending on the underlying cause. The findings show that shocks to the real price of natural gas and shocks to electricity-market-specific factors (electricity-specific shocks for short) increase the real price of electricity, while shocks to consumer demand reduce the real price of electricity. Further, any unexpected shortages have no statistically significant effect on the real price of electricity.

The effects of energy price shocks on macroeconomic variables are widely assessed. However, a significant majority of these energy price shocks relates to other energy commodities such as crude oil (Kilian, 2009; Peersman and Van Robays, 2012; Farzanegan and Markwardt, 2009, for example). In this study, however, the macroeconomic implications of different electricity price shocks for the UK economy are examined. On the one hand, the results indicate that real natural gas price shocks and electricity-specific shocks increase the Consumer Price Index (CPI) inflation in the UK. The inflation pass-through of electricity-specific shocks is much greater than other electricity price shocks. On the other hand, electricity-specific shocks have a marginal negative impact on the real industrial production. However, these effects are short term and the real industrial production growth returns to its normal levels within two months from the shock.

The findings provide valuable insights to regulators, policymakers and academics on the contributing factors to this recent significant increase in electricity prices between February 2020 to May 2022, a period in which the UK economy underwent two full lockdowns due to the Covid-19 pandemic, followed by all-time high electricity prices in a span of two years. It is reported that there is a substantial contribution from natural gas price shocks, domestic supply shocks and electricity-specific shocks towards the price of electricity in the UK during this period and, interestingly, evidence is found that the increase in the energy cap had a significant impact on the wholesale price of electricity in the UK. It is also argued that power producers could be gaining an undue advantage during this period, as almost 40% of the power supply is generated through renewable sources, which would not have been affected by the war between Russia and Ukraine.

The remainder of the paper is organised as follows: Section 2 reviews the relevant literature; Section 3 describes the data and methodology used in the analysis; Section 4 presents the results, followed by a discussion on policy implications in Section 5; robustness tests are explained in Section 6; Section 7 concludes the paper.

2. Literature review

Over the years, an extensive array of empirical and theoretical studies has been conducted on the macroeconomic impact of energy price shocks or uncertainty (see Bashir, 2022 and Hamilton, 2008 for discussions). The majority have concentrated on crude oil due to its global significance in production and its widespread consequences on economic and/or financial activities (see e.g., Demirer et al., 2020; Herrera et al., 2019; Yang, 2019; Nasir et al., 2018; Kilian, 2014). Furthermore, most are focused on the United States (US) and other industrialised nations. Cho et al. (2007) find that an increase in electricity prices negatively influences several industrial sectors in South Korea. According to Jamil and Ahmad (2010), a bi-directional short-run causality exists between electricity prices and the output of manufacturing and agricultural sectors of Pakistan.

While it is generally agreed that energy price shocks result in a negative impact on economies, these studies rarely differentiate between the effects of energy demand and supply shocks (Gong et al., 2021). In studies that focus on the different pathways of energy shocks, it has been concluded that supply-side energy shocks have a lesser impact (negative) than demand-side shocks which appear to have both positive short- and long-run effects.

For instance, Kilian and Park (2009) were the first to suggest that negative responses from economic variables are triggered by oil-specific demand, while a positive effect is exerted only by aggregate demand. In a later study, Kilian (2009), using SVAR, concluded that aggregate demand and oil-market-specific demand shocks account for the majority of the unexpected variations in oil prices in the US. At the same time, the author showed that the effects of supply shocks have no significant effect on prices and are short-lived; aggregate demand shocks are inflationary over time and may lead to lower future output; and oil-market-specific demand shocks increase prices and are recessionary by nature.

Similarly, Hamilton (2008) identified high global demand and stagnant global oil output as the cause of the price run-up in 2007–2008, contrary to supply interruptions as the historical trigger. Cashin et al. (2014) further stated that the economic consequences from oil-supply-side and demand shocks are very different, and dependent on whether the country is an importer or exporter.

More recently, Kim and Vera (2019) came to a similar conclusion after expanding the data from Kilian (2009) to encompass the post-financial-crisis period (1974–2015). The authors specifically identified aggregate demand and oil-market-specific demand shocks as the driving factors in the 2008 oil price run-up, and that these factors have the most substantial effect on US pricing and output. On the contrary, Caldara et al. (2019), also applying the SVAR, found that supply-side shocks better explain oil price fluctuations than global demand shocks; supply-side-driven oil price drops having a positive economic effect in advance economies as opposed to emerging economies; and that it is essential to understand the sources of price movements and the oil price multiplier measurements.

Crude oil, however, is not the only source of energy used by consumers and enterprises. Furthermore, alternate metrics of energy price shocks other than crude oil can produce different modelling results (Melichar, 2016; Kilian, 2008), indicating that there is no primary energy market, as stated by Bachmeier and Griffin (2006).

Natural gas is a key input for electricity generation, especially in the UK where it is the main source of power generation, supplemented by nuclear and renewables. Nonetheless, both electricity and natural gas substitute as heating energy sources. Electricity generation costs increase with high natural gas prices, but at the same time, natural gas prices increase with higher electricity demand (Uribe et al., 2018). Moving forward, with the shift from crude oil and coal, the cost of natural gas will be a key determinant for electricity prices (Alexopoulos, 2017). Although the electricity and gas markets are linked, studies on the subtleties of the natural gas and electricity markets are still limited but growing (Uribe et al., 2022), with most agreeing that the natural gas market has a considerable influence on the electricity market (Xia et al., 2020), but is less understood and often overlooked for electricity to natural gas (Uribe et al., 2018).

Most studies have looked at how natural gas prices affect price formation and market clearing in the electricity markets, identifying three key channels (Alexopoulos, 2017; Xia et al., 2020; Diagoupis et al., 2016; Ding et al., 2020 among others). The first effect arises from the energy producer which determined wholesale electricity rates, which in turn affects the retail energy rates. Second, the retail energy provider may also be the wholesale energy producer and as such may be able to directly pass on the unexpected fuel costs to the consumers. Third, according to Woo et al. (2006), the demand-pull effect arises from greater disparity in electricity price and natural gas cost when electricity is expensive, i.e. demand for natural gas increases which results in greater bilateral trading bids for spot gas and higher natural gas prices. If these dynamics persist, the feedback effects between natural gas and electricity prices may generate conditions that make the system more vulnerable to energy crises and shortages. More recently, Mills et al. (2021) identified that the wholesale price of electricity reduced concurrently with gas price during 2008–2017.

The demand curve for electricity markets is found to be either perfectly price inelastic (Hirth, 2018) or relatively price inelastic in comparison to other commodities (Kirschen, 2003). Therefore, the shape of the supply curve matter towards determining the equilibrium price in the electricity market. According to Kirschen (2003), the slope of the supply curve of electricity markets increases rapidly beyond a certain volume of electricity. Even though the price change between base load and peak load is relatively smaller, any additional unexpected demand could drive the price significantly higher. Paraschiv et al. (2014) state that electricity price sensitivity to supply- and demand-side factors could change due to announcements by the energy policy regulators. Moreover, Frondel et al. (2010) show that policy interventions, such as the introduction of the feed-in tariffs scheme in Germany, increase the costs to the final electricity consumers, changing demand-side dynamics of electricity markets.

In this paper the impact of energy price shocks are considered, specifically gas on the UK economy, especially since the UK gas market had become more vulnerable to crises and shocks. Previous studies which have considered the UK had also focused on oil price (e.g. Aminu, 2019; Millard and Shakir, 2013; Peersman and Van Robays, 2012; Harrison et al., 2011).

3. Data and methodology

3.1. Data

Monthly data from January 1996 to May 2022 is used to generate structural electricity price shocks in the UK. Although there are arguments suggesting that only the supply-side matters in pricing electricity (Boogert and Dupont, 2005), both supply-side and demand-side effects are considered to examine the unexpected movements of electricity prices. Two supply-side variables are considered: that is, the real price of natural gas, which is the main source of power generation in the UK across the sample period, and the change in the domestic supply of natural gas to the UK. The dollar price of natural gas is from the Energy Information Administration (EIA). Following Abeysinghe (2001), the US Dollar to British Pound exchange rate from Bloomberg and the CPI of the UK published by the Office of National Statistics (ONS) is used to construct the real price of natural gas (RNG). The log difference of the monthly domestic supply of natural gas (ΔSUP) obtained from the DBEIS in the UK is taken.

The monthly consumer confidence index of the UK (CCIUK), compiled by the Organisation for Economic Co-operation and Development (OECD), is used to represent the consumer demand. Daily wholesale electricity spot prices published by the Amsterdam Power Exchange (APX) were obtained to calculate the average price for each month. However, the APX prices are available only from the year 2000 and, therefore, this timeseries for the 1996–1999 period is extrapolated using the electricity price index published by the ONS. This timeseries is then deflated by the CPI to obtain the real price of electricity (*ELEC*).

The industrial production (IP) of the UK in the OECD database and the real industrial production (ΔIP) is estimated as the log difference of the IP deflated by the CPI inflation.

3.2. Methodology

The SVAR model below is used to construct electricity price shocks.

$$B_0 Y_t = c + B(L) Y_{t-1} + \omega_t \tag{1}$$

where, L is the lag operator with 24 lags[2] and ω_t the mutually uncorrelated structural innovations. Following Kilian (2009), a recursive structure for ${B_0}^{-1}$ is assumed and hence the reduced form errors ε_t can be decomposed as $\varepsilon_t = {B_0}^{-1}\omega_t$. Therefore,

$$\begin{bmatrix} {\varepsilon_t}^{RNG} \\ {\varepsilon_t}^{\Delta SUP} \\ {\varepsilon_t}^{CCIUK} \\ {\varepsilon_t}^{ELEC} \end{bmatrix} = \begin{bmatrix} b_{1,1} & 0 & 0 & 0 \\ b_{2,1} & b_{2,2} & 0 & 0 \\ b_{3,1} & b_{3,2} & b_{3,3} & 0 \\ b_{4,1} & b_{4,2} & b_{4,3} & b_{4,4} \end{bmatrix} \begin{bmatrix} {\omega_t}^{NG\ price\ shock} \\ {\omega_t}^{NG\ supply\ shock} \\ {\omega_t}^{Consumer\ demand\ shock} \\ {\omega_t}^{Electricity-specific\ shock} \end{bmatrix} \tag{2}$$

Natural gas price shocks (NG price shocks) express the unexpected movements to the real cost of electricity generation while NG supply shocks capture the unexpected changes to the domestic supply of natural gas. These two variables are considered exogenous in comparison to the other two variables in the SVAR as it is unlikely to be affected by innovations to consumer demand and UK electricity price during the same month. According to the SVAR model above, it is assumed that global natural gas prices are exogeneous in comparison to the change in domestic natural gas supply. On the one hand, this allows the authors to capture instances in which the power producers change their supply contemporaneously based on the unexpected movement of natural gas price. On the other hand, it implies that innovations to the change in domestic supply will not affect the global market price of natural gas over the same month. Consumer demand shocks represent the movements of consumer demand that cannot be explained by the consumer confidence as well as the production cost of electricity.

Although a similar identification technique to Kilian (2009) was followed, the authors' interpretation of electricity-specific shock is in fact different to oil-specific demand shocks in the context of crude oil markets. According to Kilian (2009), oil-specific demand shocks represent unexpected price movement of oil prices due to uncertainties in the future supply of oil. In other terms, it is the price movements caused by the demand to accumulate crude oil inventories. Electricity, on the other hand, is not storable. Therefore, the electricity-specific price shock represents the unexpected movement of electricity prices that cannot be explained by production costs, production shortfalls and consumer demand shocks. For example, this shock captures the unexpected changes to the distribution and transmission tariff and/or changes made to the energy cap by the regulator (Ofgem). The model imposes the following restrictions: 1) the real electricity price driven by consumer demand shocks and electricity-specific shocks will not reduce the domestic supply of natural gas contemporaneously, and 2) changes in the real price of electricity due to electricity-specific shocks will not affect domestic demand within the same month.

Subsequent to the estimation of these monthly structural innovations, the following regressions are estimated in order to determine the effects of each electricity price shock on inflation and industrial production of the UK. These are:

[2] The choice of 24 as the lag length is consistent with research that favours longer lag lengths since it provides for a potentially long delay in the transmission of electricity price shocks, as well as a sufficient number of lags to address dynamic misspecification/serial correlation (see Kilian, 2009; Kilian and Park, 2009; Kilian and Murphy, 2014; Kang et al., 2015; Ahmadi et al., 2016; Hailemariam and Smyth, 2019; Shang and Hamori, 2020; Dagher and Hasanov, 2023, among others). Additionally, in modelling business cycles in commodities markets, a lag duration of 24 months is sufficient to reflect the trends in the data (Hamilton and Herrera, 2004). In addition to the above evidence, the Ljung-Box Q-test was conducted to examine residual autocorrelation. However, no evidence was found to confirm that there is any residual autocorrelation.

$$\Delta CPI_t = \alpha_k + \sum_{i=0}^{12} \theta_{k,i}\omega_{k,t-i} + m_{k,t} \quad (3)$$

$$\Delta IP_t = \vartheta_k + \sum_{i=0}^{12} \gamma_{k,i}\omega_{k,t-i} + n_{k,t} \quad (4)$$

where ΔCPI is the log monthly change of the CPI and ΔIP is the log change in monthly real industrial production. ω_k is the residual of the kth structural shock where k = 1, 2, 3 or 4. The impulse responses of ΔCPI and ΔIP are estimated over a horizon of 12 months which is also the number of lags used in the above regressions (3) and (4). The possible serial correlation in each error term is dealt with a block bootstrap following Kilian (2009).

4. Results

4.1. Electricity generation in the UK and the price movement of natural gas

Fig. 1 shows the contribution of each energy source towards electricity generation. According to this figure, the contribution of natural gas towards power generation in the UK since 1996 is 30%–40% of the total supply. Coal power generation has reduced significantly from 40% in 2013 to 2% in 2022. This was mainly caused by the gradual closure of coal power plants mainly due to environmental concerns. The shortfall of electricity supply is fulfilled by the environmentally friendly and renewable energy sources such as wind, solar and hydro power. These sources of power would not incur a cost for the source of energy that is being converted to electricity. Owen (2006) suggests that the cost of electricity generation using non-renewable sources of energy, such as coal and gas, is on average lower and stable in comparison to electricity generated using renewable energy sources. However, the cost of renewable energy is on a declining trend as a result of constant research and development to enhance the efficiency of the process and it may be lower in the future.

The behaviour of real natural gas prices and the real wholesale price of electricity are examined in Fig. 2. In addition to the price movement of both natural gas and electricity, the times when price caps were introduced by the UK government with the intention of preventing suppliers from overcharging consumers are indicated. Time (1) marks the introduction to the price cap on prepayment meter energy tariffs, while time (2) indicates the introduction to the price cap on default energy tariffs.

According to the figure, the real prices of electricity in early 2007 and early 2020 are almost similar. However, a contrasting difference can be seen between the natural gas price then and in 2020. Natural gas price reads £10 in early 2007, while it was approximately £2 in early 2020. The real price of natural gas was at its highest in late 2007, which was approximately twice the real price in May 2022. The real electricity price on the other hand records approximately £45 in late 2007 while it surpassed £130 in May 2022. Therefore, the electricity price increased by approximately 100% in 2007 in line with an almost 125% increase in natural gas prices. In contrast, the electricity price increase is approximately 500% in response to the abnormally high natural gas price increase (approximately 500%) during the Russia-Ukraine tensions. This suggests that wholesale prices have become more sensitive to the increase in the natural gas price over time. A possible reason for this behaviour could be the introduction of the prepayment and default energy caps.

4.2. The evolution of electricity price shocks

The four electricity price shocks are estimated according to the SVAR model in (2) and take the semi-annual average to improve the visibility of each shock over the years (Fig. 3). According to the plot, natural gas price was instrumental in the movement of real price of electricity in the early 2000s as well as after 2015. These shocks prior to 2008 are consistent with findings of Brown and Yücel (2008), who state that natural gas prices moved abnormally upwards in 2000, 2002, 2003, 2004 and 2005, and downwards in 2006 and 2007. Shocks to natural gas price have been persistent during the Russia-Ukraine tensions from 2020 to 2022.

Substantial supply disruptions of natural gas to the UK in 2009, 2015 and 2017 are observed. Further supply disruptions can be observed during the Covid-19 pandemic and Russia-Ukraine conflict from 2020 to 2022. The UK unexpectedly increased its supply of natural gas in line

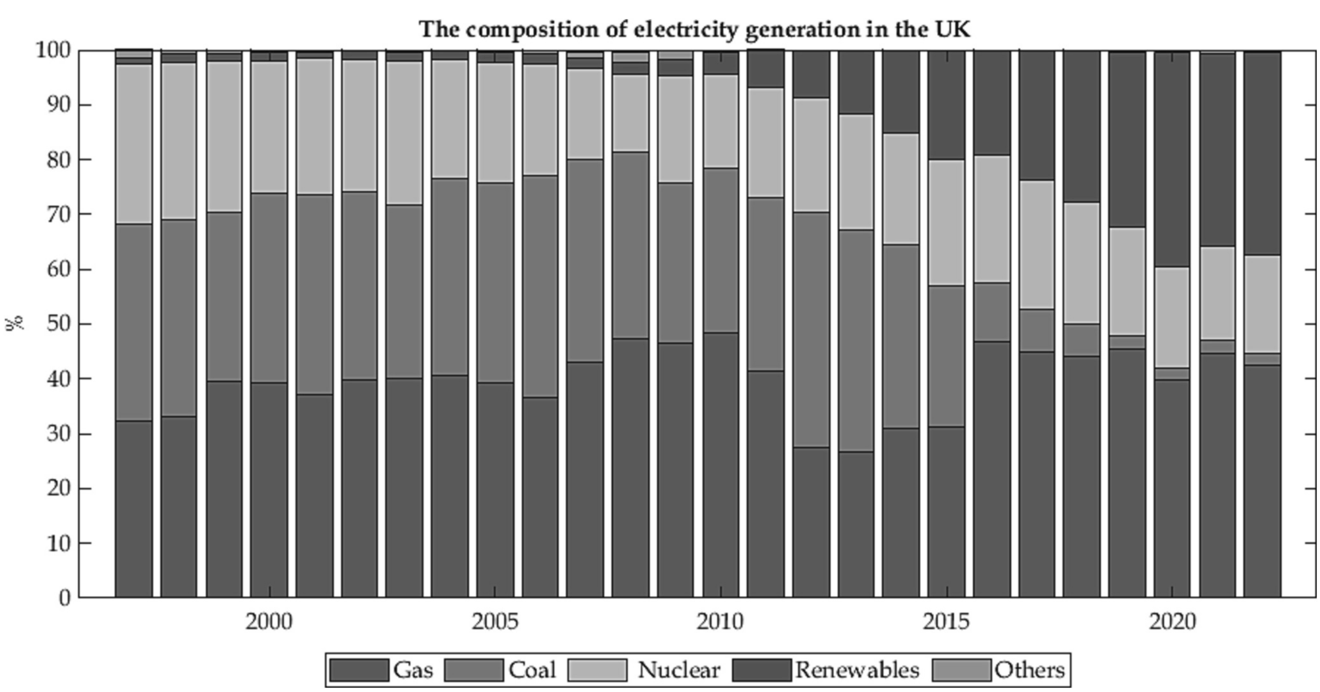

Fig. 1. This represents the relative share of fuels used in electricity generation in the UK from 1997 to 2022 as a percentage of the total electricity generation.

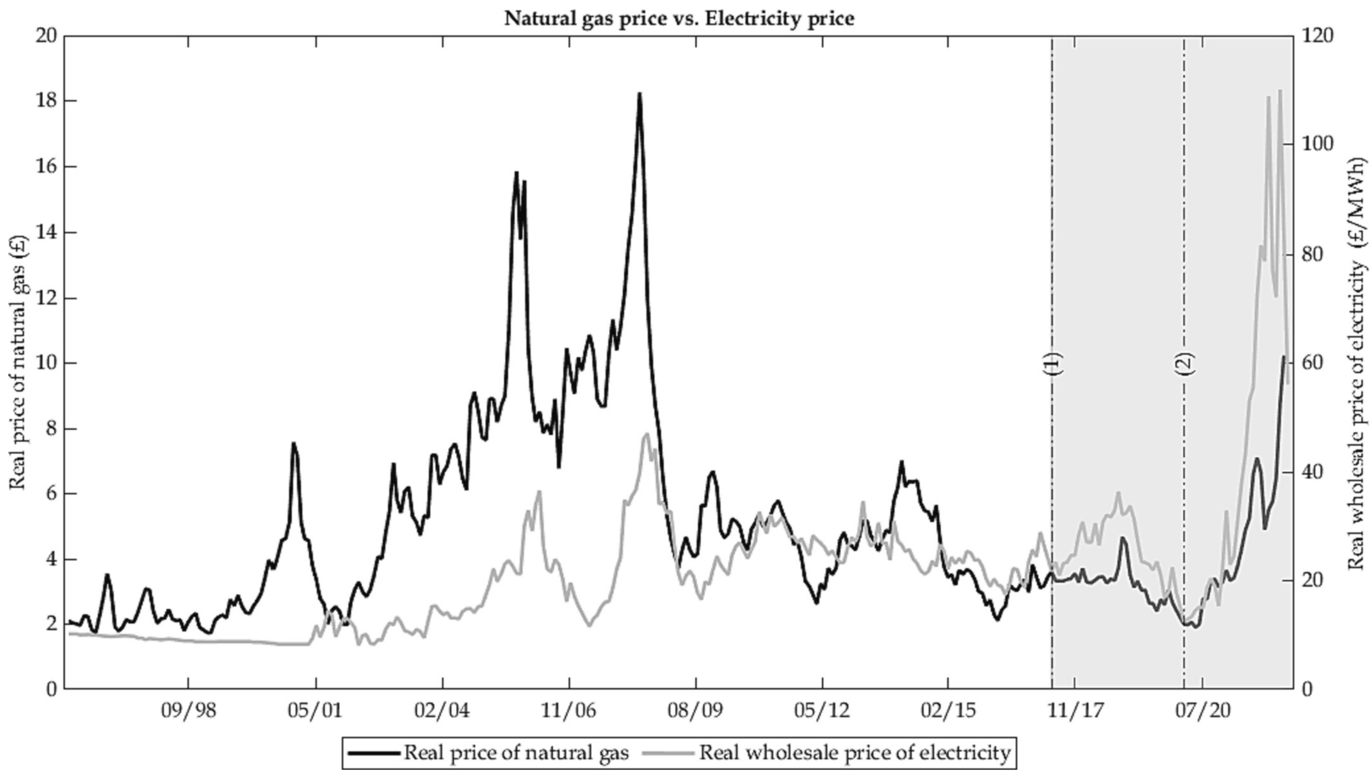

Fig. 2. This graph represents the movement of real natural gas price (£/MMbtu) and the real wholesale price of electricity (£/MWh) in the UK. Highlighted regions (1) and (2) reflect the introduction of price cap on prepayment meter energy tariffs and the price cap on default energy tariffs, respectively.

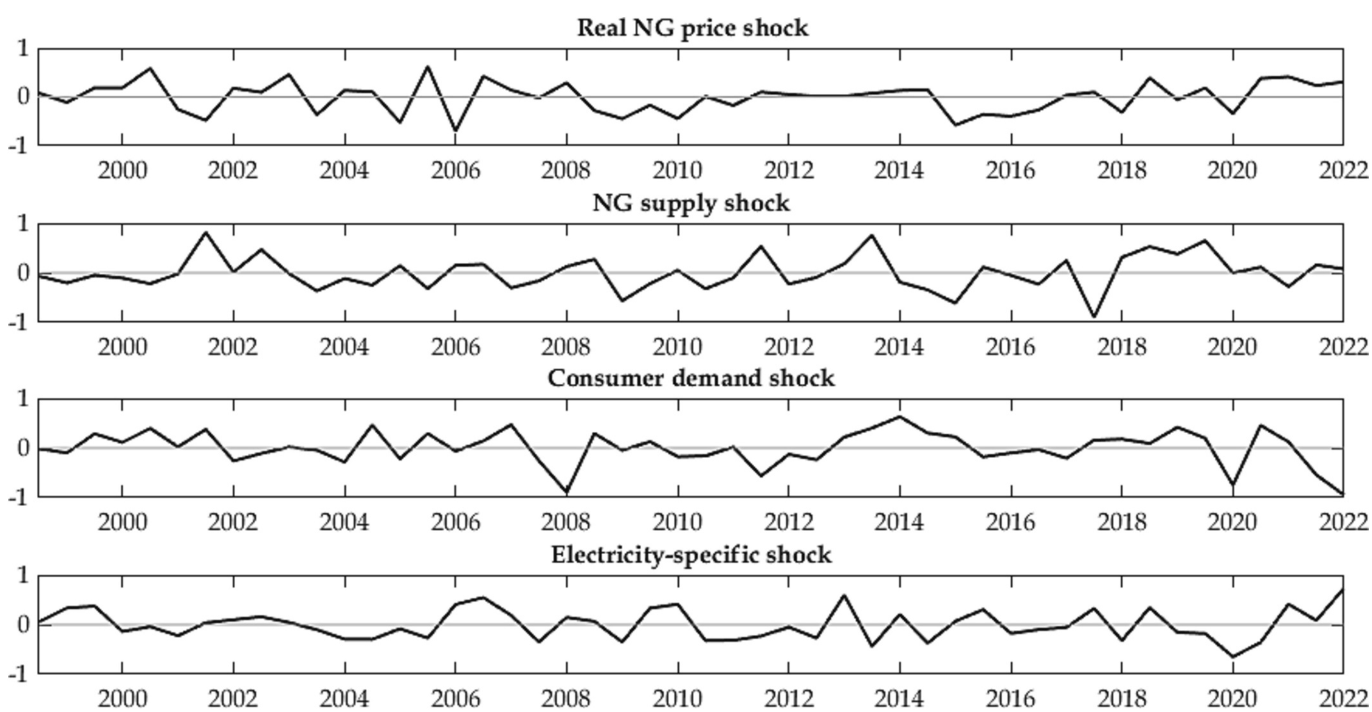

Fig. 3. This graph represents the evolution of electricity price shocks from 1998 to 2022. These shocks are estimated using estimated using the Structural VAR model (1).

with low market prices in 2001, 2012 and between 2018 and 2019.

Consumer demand does not appear to have been affected to a larger extent during the crisis that followed the 'DotCom' bubble. However, three large swings of consumer demand are observed during the period under consideration. These are: 1) the decrease in consumer demand over the Global Financial Crisis, 2) the slow economic growth during the Covid-19 pandemic (Monetary Policy Committee, 2022), and 3) the high inflationary period that followed Covid-19 restrictions that may have further reduced consumer demand.

Electricity-specific shocks capture any electricity price movement that cannot be explained by a majority of its supply-side and demand-side factors. These may include changes to taxes associated with tariffs and price changes due to regulator interference (i.e., implementation and changes to energy caps by Ofgem). According to Domah and Pollitt (2001), regulatory measures were taken by Ofgem as well as Offer (prior to 1999), following privatisation of the electricity supply industry in 1990. Although there were several regularity measures since privatisation, Domah and Pollitt (2001) conclude that consumers started receiving the benefits of regulation after 2000. In line with these findings, Jamasb and Pollitt (2007) show that during the third price control review after privatisation electricity rates were reduced by introducing cuts to distribution charges from 2000/2001 to 2004/2005. Further distribution price control reviews took place in the 2005–2010 and 2010–2015 periods, while transmission price control reviews took place in the 2007–2013 and 2013–2021 periods (see appendix A of Ajayi et al., 2022). Some of the negative electricity-specific shocks could be related to the first year of each price control review where the prices are expected to see an immediate reduction (Ajayi et al., 2022). Negative electricity-specific shocks represented in 2020 reflect the reduction in energy cap by 1% in April 2020 and 10% in October 2020. Subsequent positive shocks reflect increases to the energy cap by Ofgem on three different occasions in April 2021, October 2021 and April 2022 by 9%, 9% and 54% respectively.

4.3. The response of real NG price, domestic supply of natural gas, consumer demand and the real electricity price to electricity price shocks

Fig. 4 shows the impulse responses of real NG price, domestic natural gas supply, consumer demand and the real price of electricity to each electricity price shock as per our identification above.

A shock to the real price of natural gas increases the price of natural gas by almost 10% and this stimulus wears out in 15 months from the shock. Shocks to natural gas price have a negative effect on the domestic supply of natural gas with a lag of 10 months, although these effects are short-lived. This could be a result of reduced production of electricity due to the expensive natural gas prices. The consumer demand decreases following shocks to the real price of natural gas. This could be due to the increase in price of natural gas as well as other products that use natural gas as a source of energy. The real price of electricity has a positive and persistent response to real natural gas price shocks which could be the impact of natural gas being used as the source for almost 40% of the UK's electricity generation. This result is consistent with Brown et al. (2021) in relation to the Canadian energy market.

Domestic oil supply shocks reduce the real price of natural gas temporarily, five months after the shock. Following Gundersen (2020), this could be a result of foregoing high-priced imports of natural gas and utilising domestically produced natural gas in the short term. An unexpected disruption to the domestic natural gas supply decreases the supply of natural gas. These effects will remain persistent over the first 12 months from the shock and gradually decrease thereafter. The findings suggest that domestic natural gas supply shocks have a negative and short-lived impact on the UK's consumer demand. This result falls in line with the findings of Kilian (2009) and Gundersen (2020), among others, who show that global oil supply shocks have a negative effect on the global aggregate demand, and Nguyen and Okimoto (2019), who conclude that unexpected natural gas supply shortages could reduce the real economic activity in the US.

The impact of consumer demand shocks on real natural gas is statistically insignificant during the first few months from the shock. However, the effects of the shock lead to an increase in real price 10 months after the shock. Shocks to consumer demand increase the supply of natural gas to the UK. Consumer demand increases following a positive shock to itself, and the stimulus wears out within the first two years. Interestingly, the real electricity price decreases following a positive shock to consumer demand.

The SVAR model here defines positive electricity-specific shocks as unexpected increases to the price of electricity that cannot be explained by the real natural gas prices, change in supply of natural gas or

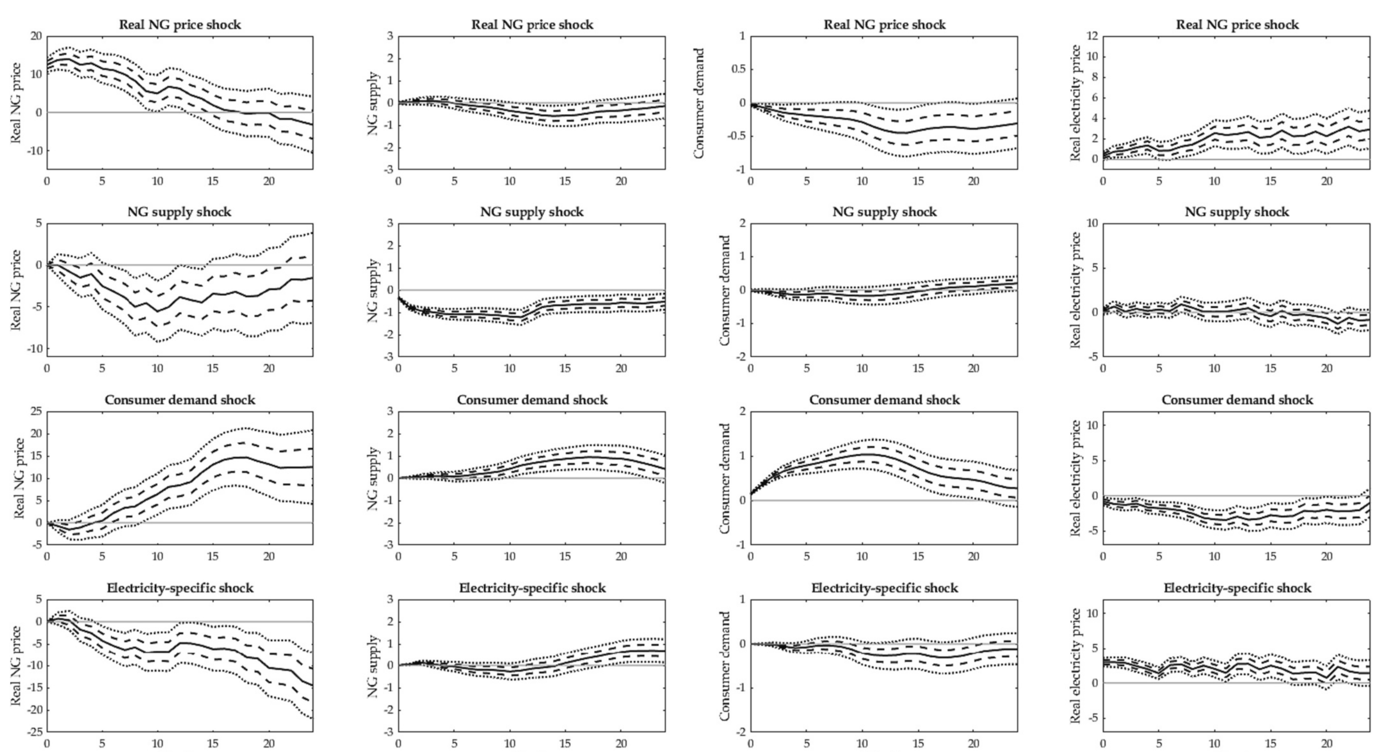

Fig. 4. This represents impulse responses of the real natural gas price, domestic natural gas supply, consumer demand and the real electricity price to each one-standard deviation structural electricity price shock. Solid lines represent point estimates while dashed and dotted lines represent 68% and 95% standard error bands, respectively.

consumer demand. Findings show that the real price of natural gas decreases with a delay of three months following an electricity-specific shock. Although it appears strange at first sight, this behaviour is attributed to increasing price levels that have forced the real price of natural gas to decrease.[3] The supply to natural gas in the UK marginally increases after the first year from the electricity-specific price shock. Finally, the results show that electricity-specific shocks have a positive and persistent effect on the real price of electricity over the first 12 months from the shock.

Fig. 5 shows the cumulative contribution of each electricity price shock based on the real price of electricity based on a historical decomposition of data. The first panel shows that the price of natural gas has contributed to the real price of electricity, especially prior to the Covid-19 pandemic when the real price of natural gas was below £4 per MMBtu[4] and during the Russia-Ukraine war when it was close to £8 per MMBtu. The contribution of natural gas supply shocks on the real price of electricity is not as severe in comparison to natural gas price shocks (panel 2). Aggregate demand shocks contributed positively to the increase in real electricity prices during the period that followed the global financial crisis. However, its subsequent contribution has been either low or negative. The most significant contribution to the real price of electricity is from electricity-specific shocks that capture regulatory measures on the electricity market. Large swings in positive contributions could be noted during the economic boom prior to the global financial crisis and the Russia-Ukraine war. Further, it appears that the volatility of this contribution has increased over time as UK electricity distribution and transmission is liberalised and energy caps are introduced.

4.4. *The impact of electricity price shocks on inflation and industrial production*

The impulse responses estimated using regressions (3) and (4) are reported in Fig. 6. The first column represents the response of CPI inflation (ΔCPI), and the second column represents the response of the change in real industrial production in the UK (ΔIP), to electricity price shocks.

Inflation responds positively to real natural gas price shocks almost immediately. However, this effect fades away within the first two months. An unexpected disruption to domestic natural gas supply causes a short-lived and partially significant drop in inflation. This behaviour is partly consistent with Kilian (2009) in relation to crude oil supply shocks. A positive, partially significant response from the CPI inflation could be observed towards the lower half of the impulse response horizon. A unit positive shock to consumer demand decreases the inflation during the first year of the shock. Electricity-specific shocks are inflationary immediately after the shock and will remain persistent over the first year.

The response of real industrial production to real natural gas price shocks and consumer demand shocks are statistically insignificant over the first 10 months from the shock. Industrial production increases towards the latter part of the impulse response horizon. Only a marginal and partially significant positive response could be observed from real industrial production following a shock to the natural gas supply in the UK. Electricity-specific shocks reduce the real industrial production although it recovers from the shock within two months.

4.5. *Electricity price shocks during Covid-19 and the Russia-Ukraine conflict*

Fig. 7 represents the movement of global natural gas prices, alongside a timeline of the events leading to the most recent Russia-Ukraine conflict. Natural gas prices started gaining momentum following the Ukrainian president's approval for Ukraine to partner with the North Atlantic Treaty Organisation (NATO) on 14 September 2020 indicated by vertical line [1]. Vertical line [2] represents the starting point of large-scale Russian military exercises near the Ukrainian border. President Joe Biden's statement on imposing “strong economic and other measures” if Russia attacked Ukraine (vertical line [3]) further accelerated the price increase. Vertical line [4] indicates the day that Russia started their invasion and hence the rapid increase in natural gas prices. In April (vertical line [5]), the Russian president declared victory in the Mariupol region, leading to further increases.

Given the rapid increase in the global natural gas price within a period of two years, and the significance of each electricity price shock as discussed above, it is essential to understand to what extent each shock contributed to the real price of electricity during the Covid-19 pandemic and the Russia-Ukraine conflict. The cumulative contribution of each electricity price shock as identified above is estimated based on historical decomposition of data from February 2020 to May 2022.

The first panel of Fig. 8 represents the cumulative contribution of natural gas price shocks to the real price of electricity in the UK. The contribution of natural gas price shocks to the real price of electricity is minimal prior to the Russian invasion of Ukraine. However, the contribution from these shocks towards the real price of electricity gradually increased with the events leading to the invasion represented by events [3], [4] and [5]. The contribution of natural gas price shocks to real electricity prices reached its highest in May 2022.

According to Fig. 8 (panel 2), the cumulative effects of natural gas supply shocks remain between -4% and $+4\%$ during the period under observation. Although the contribution from this shock is in an increasing trend, it changes rapidly within short time intervals prior to the full-scale Russian invasion. This suggests that the effect of supply disruptions in the UK caused by the Russia-Ukraine conflict seems to be short-lived to some extent and lower in magnitude, which could be a benefit of having its own production and other natural gas exporters such as Norway. This behaviour is consistent with findings from Kilian (2009) on supply shocks in crude oil markets.

The cumulative contribution of consumer demand shocks (Fig. 8, panel 3) is positive and an increasing trend, on average. However, certain phases are observed where the effects of consumer demand shocks on the real price of electricity have reduced. This could be due to the reduced economic activity and therefore the lower demand for power during the lockdown imposed by the UK government following the Covid-19 pandemic, as indicated by the shaded areas of the graph. The importance of cumulative effects of consumer demand shocks on the real electricity price has kept increasing at a rapid pace since the final stages of Covid-19 restrictions were lifted in the later part of Q2–2021.

According to panel 4 of Fig. 8, the contribution of electricity price shocks on the real price has been negative and in a decreasing trend from February 2020 to March 2021. Spikes are observed in its cumulative effects in April 2021, October 2021 and April 2022. In fact, the cumulative contribution significantly increases by almost 40% in April 2022. According to the figure, these changes could be attributed to the change in energy price cap by Ofgem, where they raised the energy caps by approximately 9%, 9% and 54% (Ofgem, 2022) respectively from November 2021, allowing producers to earn more from power distributors.

Interestingly, the use of renewable energy sources for power generation in the UK accounts for 35%–40% of the total power generation since 2020 (Fig. 1). However, as clearly argued in Section 4.1, the sensitivity of electricity price to natural gas has increased over time. Ideally, this sensitivity should decrease with the introduction of

[3] In order to confirm this, the real price of natural gas is replaced with nominal prices and the impulse responses re-estimated. Results show that the response of natural gas prices are statistically insignificant soon after the shock and mildly positive after the first year. These findings are consistent with Mohammadi (2009) and Uribe et al. (2018) in the context of the United States.

[4] Metric Million British Thermal Unit

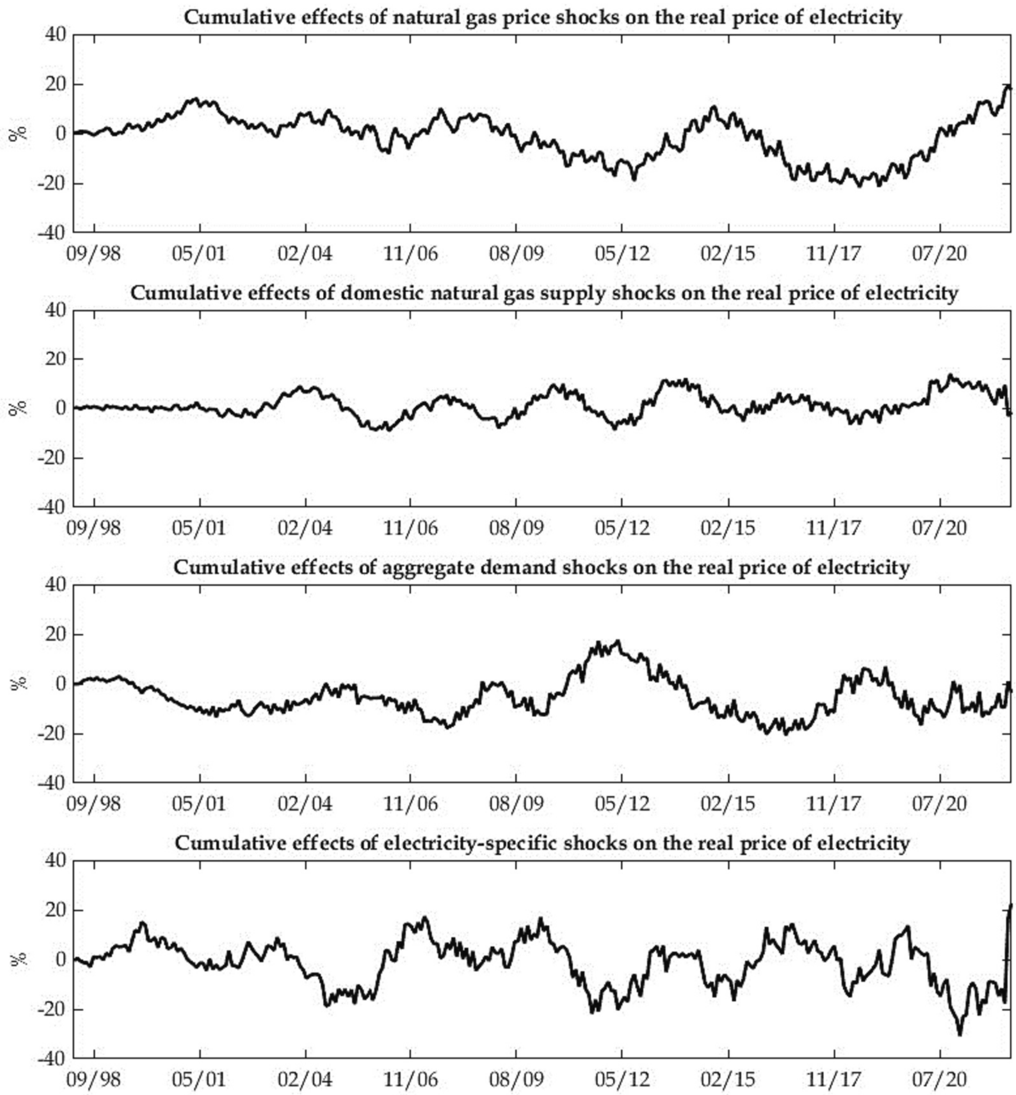

Fig. 5. This figure represents the historical decomposition of real electricity prices from 1998/01–2022/05 estimated using the Structural VAR model (1).

additional renewable power generators (Paraschiv et al., 2014; Fischer, 2010). Further, this implies that an increase in the energy cap allows producers and power suppliers to charge a higher premium on the significant proportion of electricity generated by renewable energy sources that should not have seen an effect from the Russia-Ukraine turmoil.

The analysis is further extended by examining the impact of electricity price shocks during this period on inflation and growth of the real industrial production in the UK. Regressions (3) and (4) are modified to accommodate a dummy variable to identify whether a given month falls in the period of the Covid-19 pandemic or the Russia-Ukraine war. Modified regressions are as follows:

$$\Delta CPI_t = \theta_k^{'}.D + \sum_{i=0}^{12} \theta^{'}_{k,i}\omega_{k,t-i} + \sum_{i=0}^{12} \theta^{''}_{k,i}D.\omega_{k,t-i} + m_{k,t} \quad (5)$$

$$\Delta IP_t = \gamma^{'}_{k.}.D + \sum_{i=0}^{12} \gamma^{'}_{k,i}\omega_{k,t-i} + \sum_{i=0}^{12} \gamma^{''}_{k,i}D.\omega_{k,t-i} + n_{k,t} \quad (6)$$

The dummy variable $D = 1$ if a given month falls within the Covid-19 pandemic (2020/03–2021/07) or the war between Russia and Ukraine (2021/03–2022/05), and $D = 0$ otherwise. Results of regressions (5) and (6) are reported in Tables 1 and 2, respectively.

According to Table 1, there is no evidence to conclude that either the Covid-19 pandemic or the war had any significant impact on inflation in the UK. Electricity-specific shocks have a positive and immediate impact on inflation, while real natural gas price shocks drive inflation with a five-month lag. Table 2 shows that the time of Covid-19 and the Russia-Ukraine war has a statistically significant impact on industrial production when it comes to natural gas price shocks. In fact, it can be found that shocks to natural gas prices during this period have a negative impact on real industrial production with a delay of 8 to 12 months. Consumer demand shocks usually affect real industrial production with a delay of 10 to 12 months. However, the impact is contemporaneous during the period of Covid-19 and war, and it could last up to two months. The real industrial production responds negatively to electricity-specific shocks during this period. The response of real industrial production to domestic natural gas supply shocks is statistically insignificant. This could be related to Kilian (2009), where he claims that an oil supply disruption in one region is immediately fulfilled by increase in production in another region. Therefore, it could be argued that although a disruption in domestic natural gas supply reduces the electricity production, the demand of electricity could still be catered for using alternative energy sources such as coal and nuclear power. Therefore, domestic shortages of natural gas may not have a significant impact on electricity prices, inflation and real industrial production.

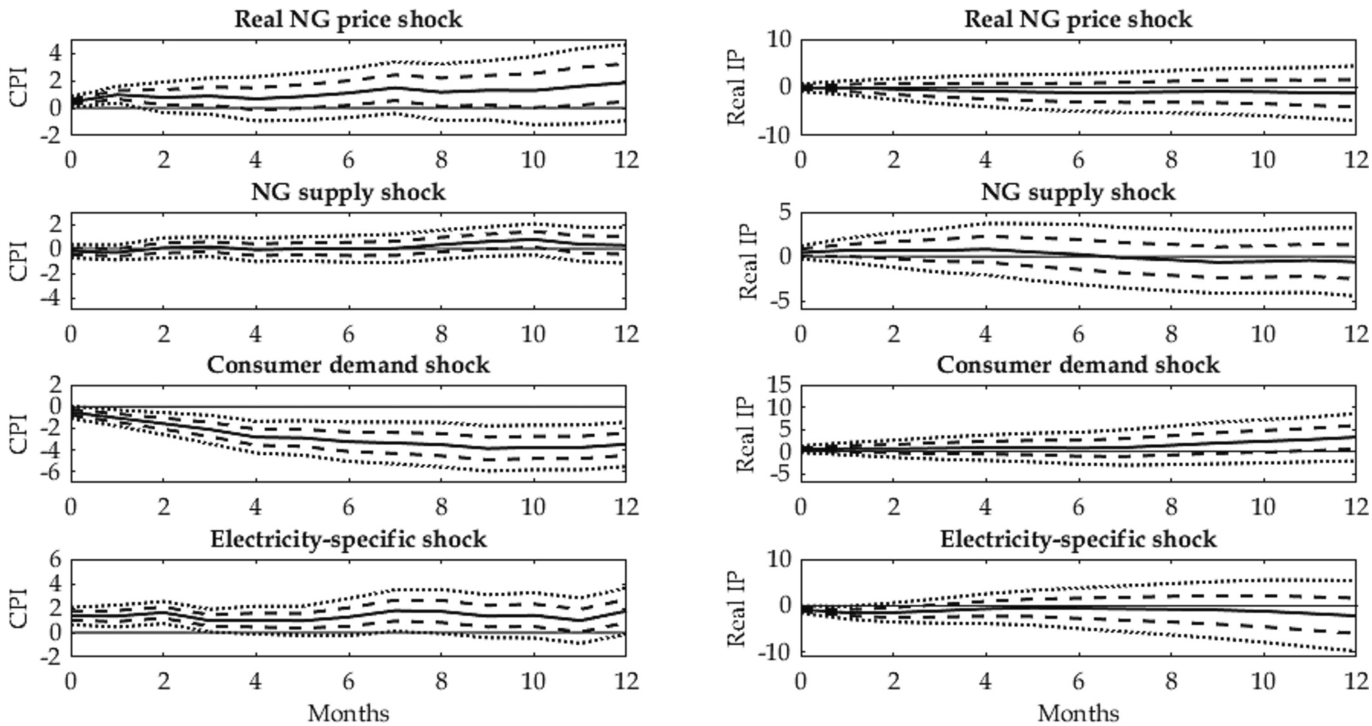

Fig. 6. This represents impulse responses of the CPI inflation (left column) and the real industrial production of the UK (right column) to each one-standard deviation structural electricity price shock. Solid lines represent point estimates while dashed and dotted lines represent 68% and 95% standard error band.

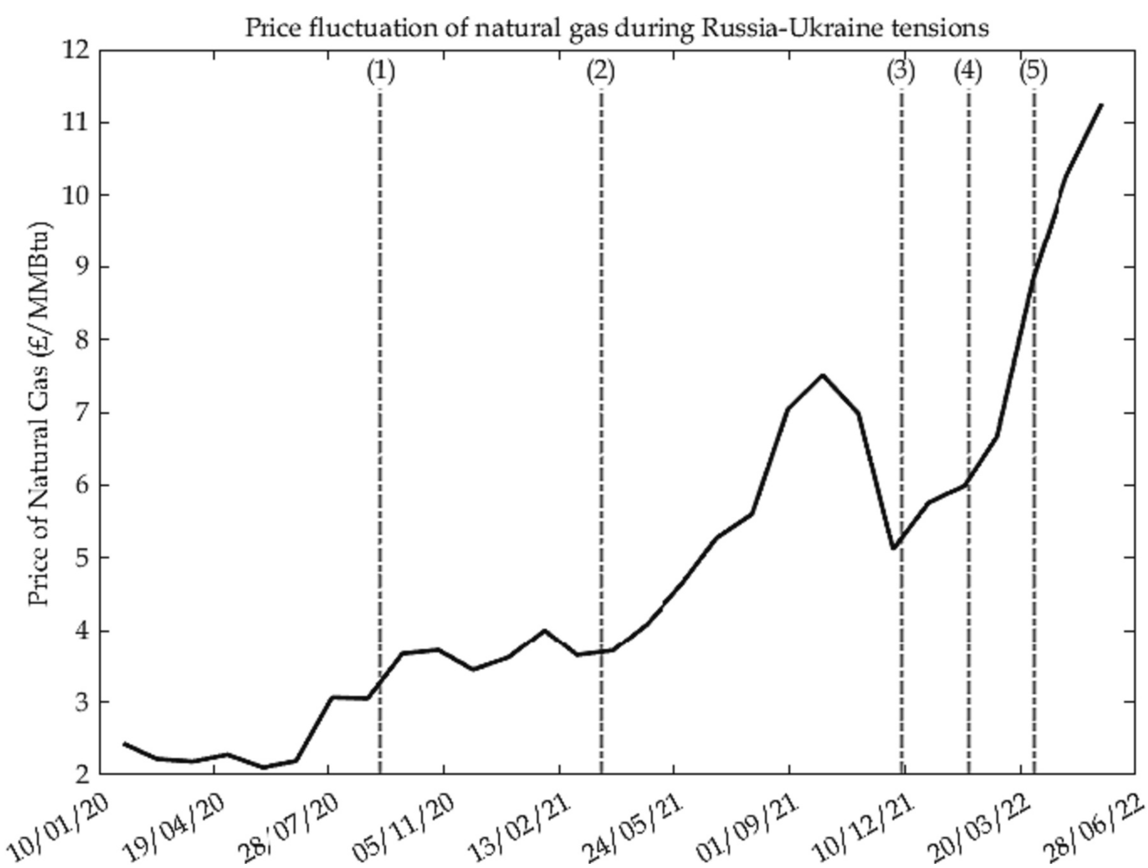

Fig. 7. Price of natural gas during Russia-Ukraine tensions. Notations (1)–(5) correspond to the following events. (1) Ukrainian president's approval for Ukraine to partner with the North Atlantic Treaty Organisation (NATO) on 14 September 2020. (2) The starting point of large-scale Russian military exercises near the Ukrainian border in March 2021. (3) President Joe Biden's statement on imposing "strong economic and other measures" if Russia attacked Ukraine – 3 December 2021. (4) Russia started their invasion of Ukraine on 24 February 2022. (5) The Russian president declared victory in the Mariupol region on 21 April 2022.

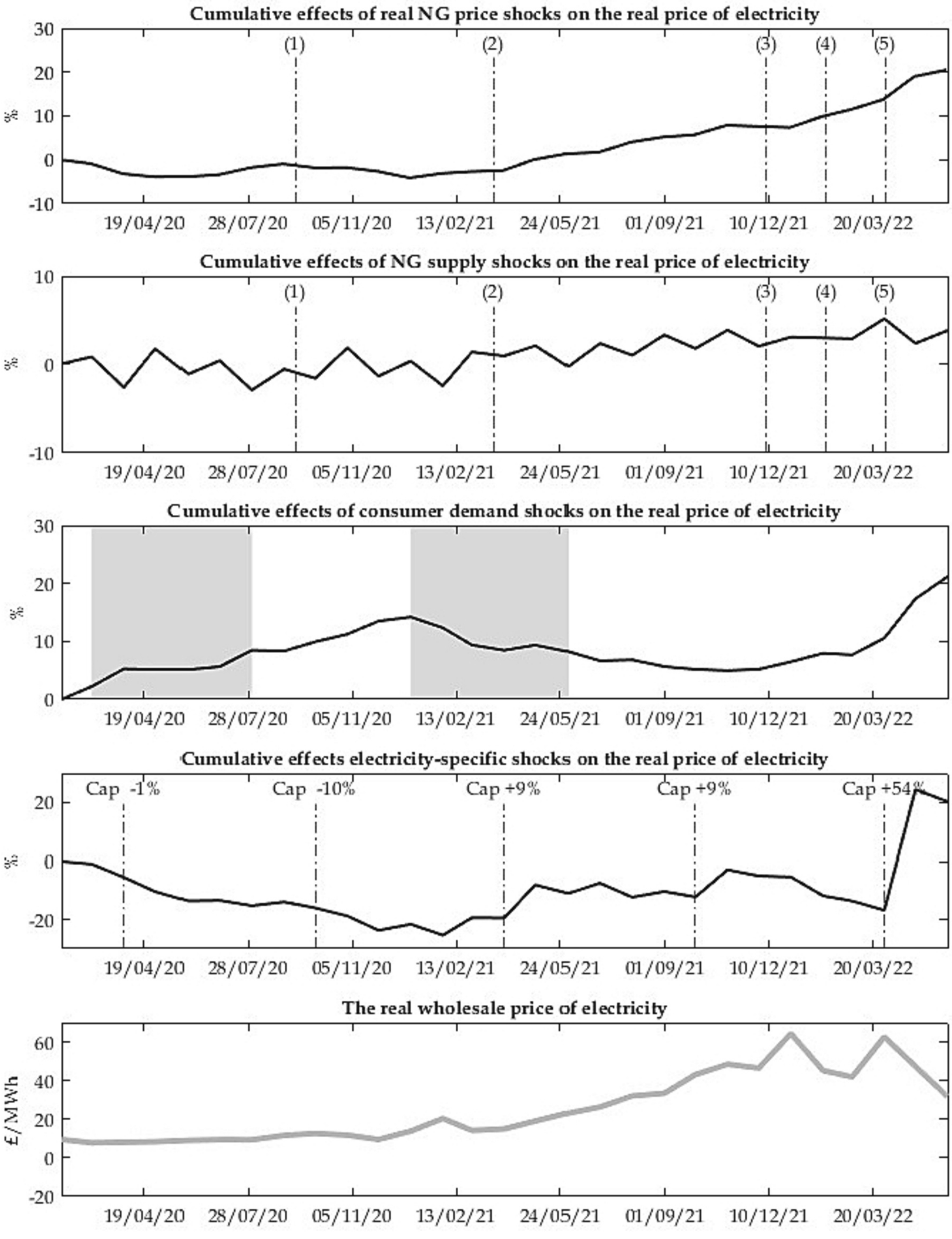

Fig. 8. Historical decomposition of real electricity prices during the Covid-19 pandemic and Russia-Ukraine conflict. Notations (1)–(5) correspond to the following events. (1) Ukrainian president's approval for Ukraine to partner with the North Atlantic Treaty Organisation (NATO) on 14 September 2020. (2) The starting point of large-scale Russian military exercises near the Ukrainian border in March 2021. (3) President Joe Biden's statement on imposing "strong economic and other measures" if Russia attacked Ukraine – 3 December 2021. (4) Russia started their invasion of Ukraine on 24 February 2022. (5) The Russian president declared victory in the Mariupol region on 21 April 2022. Shaded areas in panel 3 represent the timeframe of the first and second full lockdown in the UK due to the Covid-19 pandemic. Panel 4 reports the sign and percentage semi-annual revision of the energy cap.

5. Policy implications

Hamilton (2008) highlights two channels through which energy increases may affect production. First, the marginal cost of production may increase with the energy price. Second, the demand for production may decrease due to the reduction in the consumer expenditure due to a larger allocation for energy bills. However, studies that followed (Kilian, 2009; Peersman and Van Robays, 2012, among others) show that the

Table 1
Results of regression (5) given, dummy variable D = 1 during either COVID-19 pandemic or the war between Russia-Ukraine and D = 0 otherwise. ***, ** and * denote significance of coefficients at the 1%, 5% and 10% levels respectively.

Real NG price shock (k = 1)			NG supply shock (k = 1)			Consumer demand shock (k = 1)			Electricity-specific shock (k = 1)		
Variable	θ_1	*S.E.*	Variable	θ_2	*S.E.*	Variable	θ_3	*S.E.*	Variable	θ_4	*S.E.*
D	−0.65	(0.47)	D	−0.74	(0.48)	D	−0.65	(0.47)	D	−0.65	(0.48)
$\omega_{1,t}$	−0.40	(0.29)	$\omega_{2,t}$	−0.07	(0.36)	$\omega_{3,t}$	−0.22	(0.32)	$\omega_{4,t}$	0.68*	(0.37)
$\omega_{1,t-1}$	−0.17	(0.29)	$\omega_{2,t-1}$	0.64*	(0.36)	$\omega_{3,t-1}$	0.11	(0.32)	$\omega_{4,t-1}$	0.13	(0.37)
$\omega_{1,t-2}$	−0.33	(0.29)	$\omega_{2,t-2}$	−0.18	(0.36)	$\omega_{3,t-2}$	0.20	(0.32)	$\omega_{4,t-2}$	0.33	(0.37)
$\omega_{1,t-3}$	0.32	(0.29)	$\omega_{2,t-3}$	−0.16	(0.35)	$\omega_{3,t-3}$	−0.14	(0.32)	$\omega_{4,t-3}$	−0.11	(0.37)
$\omega_{1,t-4}$	0.19	(0.29)	$\omega_{2,t-4}$	−0.27	(0.36)	$\omega_{3,t-4}$	−0.27	(0.32)	$\omega_{4,t-4}$	−0.08	(0.37)
$\omega_{1,t-5}$	0.51*	(0.29)	$\omega_{2,t-5}$	0.17	(0.36)	$\omega_{3,t-5}$	−0.18	(0.31)	$\omega_{4,t-5}$	0.06	(0.36)
$\omega_{1,t-6}$	−0.32	(0.29)	$\omega_{2,t-6}$	0.02	(0.36)	$\omega_{3,t-6}$	−0.09	(0.31)	$\omega_{4,t-6}$	0.27	(0.36)
$\omega_{1,t-7}$	−0.08	(0.29)	$\omega_{2,t-7}$	0.15	(0.36)	$\omega_{3,t-7}$	−0.18	(0.31)	$\omega_{4,t-7}$	−0.16	(0.36)
$\omega_{1,t-8}$	−0.01	(0.29)	$\omega_{2,t-8}$	−0.35	(0.35)	$\omega_{3,t-8}$	0.16	(0.31)	$\omega_{4,t-8}$	−0.04	(0.36)
$\omega_{1,t-9}$	−0.19	(0.29)	$\omega_{2,t-9}$	−0.10	(0.35)	$\omega_{3,t-9}$	0.31	(0.31)	$\omega_{4,t-9}$	−0.33	(0.36)
$\omega_{1,t-10}$	0.40	(0.29)	$\omega_{2,t-10}$	0.57	(0.35)	$\omega_{3,t-10}$	0.03	(0.31)	$\omega_{4,t-10}$	0.17	(0.36)
$\omega_{1,t-11}$	−0.06	(0.29)	$\omega_{2,t-11}$	−0.01	(0.35)	$\omega_{3,t-11}$	−0.39	(0.31)	$\omega_{4,t-11}$	−0.14	(0.36)
$\omega_{1,t-12}$	−0.27	(0.29)	$\omega_{2,t-12}$	−0.13	(0.35)	$\omega_{3,t-12}$	−0.08	(0.31)	$\omega_{4,t-12}$	0.38	(0.36)
$D\times\omega_{1,t}$	0.70	(0.65)	$D\times\omega_{2,t}$	0.11	(0.54)	$D\times\omega_{3,t}$	−0.02	(0.56)	$D\times\omega_{4,t}$	−0.67	(0.53)
$D\times\omega_{1,t-1}$	−0.47	(0.65)	$D\times\omega_{2,t-1}$	−0.83	(0.54)	$D\times\omega_{3,t-1}$	−0.32	(0.56)	$D\times\omega_{4,t-1}$	−0.32	(0.52)
$D\times\omega_{1,t-2}$	0.29	(0.64)	$D\times\omega_{2,t-2}$	−0.16	(0.54)	$D\times\omega_{3,t-2}$	0.13	(0.57)	$D\times\omega_{4,t-2}$	−0.10	(0.61)
$D\times\omega_{1,t-3}$	−0.06	(0.64)	$D\times\omega_{2,t-3}$	0.03	(0.54)	$D\times\omega_{3,t-3}$	0.07	(0.57)	$D\times\omega_{4,t-3}$	0.02	(0.61)
$D\times\omega_{1,t-4}$	−0.18	(0.64)	$D\times\omega_{2,t-4}$	0.02	(0.55)	$D\times\omega_{3,t-4}$	0.40	(0.57)	$D\times\omega_{4,t-4}$	−0.15	(0.62)
$D\times\omega_{1,t-5}$	−0.18	(0.65)	$D\times\omega_{2,t-5}$	−0.69	(0.55)	$D\times\omega_{3,t-5}$	0.12	(0.57)	$D\times\omega_{4,t-5}$	−0.23	(0.62)
$D\times\omega_{1,t-6}$	0.04	(0.65)	$D\times\omega_{2,t-6}$	−0.07	(0.56)	$D\times\omega_{3,t-6}$	0.36	(0.58)	$D\times\omega_{4,t-6}$	−0.18	(0.62)
$D\times\omega_{1,t-7}$	0.21	(0.67)	$D\times\omega_{2,t-7}$	−0.25	(0.56)	$D\times\omega_{3,t-7}$	0.07	(0.58)	$D\times\omega_{4,t-7}$	0.08	(0.62)
$D\times\omega_{1,t-8}$	0.17	(0.67)	$D\times\omega_{2,t-8}$	0.06	(0.56)	$D\times\omega_{3,t-8}$	0.50	(0.57)	$D\times\omega_{4,t-8}$	−0.32	(0.63)
$D\times\omega_{1,t-9}$	0.81	(0.68)	$D\times\omega_{2,t-9}$	0.39	(0.56)	$D\times\omega_{3,t-9}$	−0.04	(0.58)	$D\times\omega_{4,t-9}$	0.41	(0.63)
$D\times\omega_{1,t-10}$	0.06	(0.68)	$D\times\omega_{2,t-10}$	−0.97*	(0.56)	$D\times\omega_{3,t-10}$	0.05	(0.58)	$D\times\omega_{4,t-10}$	0.49	(0.63)
$D\times\omega_{1,t-11}$	0.27	(0.69)	$D\times\omega_{2,t-11}$	0.15	(0.57)	$D\times\omega_{3,t-11}$	0.79	(0.59)	$D\times\omega_{4,t-11}$	−0.40	(0.62)
$D\times\omega_{1,t-12}$	0.58	(0.70)	$D\times\omega_{2,t-12}$	0.04	(0.57)	$D\times\omega_{3,t-12}$	−0.45	(0.60)	$D\times\omega_{4,t-12}$	−0.46	(0.62)

Table 2
Results of regression (6) given, dummy variable D = 1 during either COVID-19 pandemic or the war between Russia-Ukraine and D = 0 otherwise. ***, ** and * denote significance of coefficients at the 1%, 5% and 10% levels respectively.

Real NG price shock (k = 1)			NG supply shock (k = 1)			Consumer demand shock (k = 1)			Electricity-specific shock (k = 1)		
Variable	γ_1	*S.E.*	Variable	γ_2	*S.E.*	Variable	γ_3	*S.E.*	Variable	γ_4	*S.E.*
D	1.06*	(0.63)	D	0.52	(0.66)	D	1.04	(0.60)	D	−0.10	(0.61)
$\omega_{1,t}$	0.22	(0.39)	$\omega_{2,t}$	0.32	(0.50)	$\omega_{3,t}$	−0.54	(0.40)	$\omega_{4,t}$	−0.39	(0.47)
$\omega_{1,t-1}$	0.07	(0.39)	$\omega_{2,t-1}$	0.09	(0.50)	$\omega_{3,t-1}$	−0.53	(0.40)	$\omega_{4,t-1}$	0.07	(0.46)
$\omega_{1,t-2}$	0.03	(0.39)	$\omega_{2,t-2}$	0.10	(0.50)	$\omega_{3,t-2}$	−0.34	(0.40)	$\omega_{4,t-2}$	0.67	(0.46)
$\omega_{1,t-3}$	−0.20	(0.39)	$\omega_{2,t-3}$	0.05	(0.49)	$\omega_{3,t-3}$	−0.17	(0.40)	$\omega_{4,t-3}$	0.83*	(0.46)
$\omega_{1,t-4}$	−0.37	(0.39)	$\omega_{2,t-4}$	−0.29	(0.50)	$\omega_{3,t-4}$	−0.15	(0.40)	$\omega_{4,t-4}$	0.69	(0.46)
$\omega_{1,t-5}$	−0.19	(0.39)	$\omega_{2,t-5}$	−0.57	(0.50)	$\omega_{3,t-5}$	−0.34	(0.40)	$\omega_{4,t-5}$	0.45	(0.46)
$\omega_{1,t-6}$	0.10	(0.39)	$\omega_{2,t-6}$	−0.38	(0.50)	$\omega_{3,t-6}$	−0.31	(0.40)	$\omega_{4,t-6}$	0.37	(0.46)
$\omega_{1,t-7}$	0.25	(0.39)	$\omega_{2,t-7}$	−0.22	(0.50)	$\omega_{3,t-7}$	0.00	(0.40)	$\omega_{4,t-7}$	0.38	(0.46)
$\omega_{1,t-8}$	0.37	(0.39)	$\omega_{2,t-8}$	−0.22	(0.49)	$\omega_{3,t-8}$	0.22	(0.39)	$\omega_{4,t-8}$	0.43	(0.46)
$\omega_{1,t-9}$	0.22	(0.39)	$\omega_{2,t-9}$	0.09	(0.49)	$\omega_{3,t-9}$	0.49	(0.39)	$\omega_{4,t-9}$	0.47	(0.46)
$\omega_{1,t-10}$	0.10	(0.39)	$\omega_{2,t-10}$	0.24	(0.49)	$\omega_{3,t-10}$	0.86**	(0.39)	$\omega_{4,t-10}$	0.24	(0.46)
$\omega_{1,t-11}$	0.33	(0.39)	$\omega_{2,t-11}$	0.12	(0.49)	$\omega_{3,t-11}$	1.15***	(0.40)	$\omega_{4,t-11}$	0.19	(0.46)
$\omega_{1,t-12}$	0.53	(0.39)	$\omega_{2,t-12}$	0.12	(0.49)	$\omega_{3,t-12}$	1.25***	(0.39)	$\omega_{4,t-12}$	0.02	(0.46)
$D\times\omega_{1,t}$	−0.25	(0.88)	$D\times\omega_{2,t}$	0.04	(0.75)	$D\times\omega_{3,t}$	2.06***	(0.71)	$D\times\omega_{4,t}$	−0.56	(0.67)
$D\times\omega_{1,t-1}$	−1.03	(0.87)	$D\times\omega_{2,t-1}$	0.08	(0.75)	$D\times\omega_{3,t-1}$	1.34*	(0.71)	$D\times\omega_{4,t-1}$	−0.81	(0.66)
$D\times\omega_{1,t-2}$	−0.71	(0.86)	$D\times\omega_{2,t-2}$	−0.11	(0.75)	$D\times\omega_{3,t-2}$	1.35*	(0.72)	$D\times\omega_{4,t-2}$	−0.76	(0.78)
$D\times\omega_{1,t-3}$	0.61	(0.86)	$D\times\omega_{2,t-3}$	−0.27	(0.75)	$D\times\omega_{3,t-3}$	0.91	(0.73)	$D\times\omega_{4,t-3}$	−0.82	(0.78)
$D\times\omega_{1,t-4}$	0.77	(0.86)	$D\times\omega_{2,t-4}$	−0.04	(0.77)	$D\times\omega_{3,t-4}$	0.64	(0.73)	$D\times\omega_{4,t-4}$	−1.39*	(0.78)
$D\times\omega_{1,t-5}$	0.54	(0.88)	$D\times\omega_{2,t-5}$	0.54	(0.77)	$D\times\omega_{3,t-5}$	1.14	(0.73)	$D\times\omega_{4,t-5}$	−1.27	(0.78)
$D\times\omega_{1,t-6}$	−0.04	(0.88)	$D\times\omega_{2,t-6}$	0.23	(0.77)	$D\times\omega_{3,t-6}$	1.37*	(0.73)	$D\times\omega_{4,t-6}$	−1.18	(0.79)
$D\times\omega_{1,t-7}$	−0.66	(0.90)	$D\times\omega_{2,t-7}$	−0.11	(0.77)	$D\times\omega_{3,t-7}$	1.26*	(0.74)	$D\times\omega_{4,t-7}$	−1.59**	(0.78)
$D\times\omega_{1,t-8}$	−1.56*	(0.90)	$D\times\omega_{2,t-8}$	0.32	(0.78)	$D\times\omega_{3,t-8}$	0.86	(0.73)	$D\times\omega_{4,t-8}$	−1.68**	(0.80)
$D\times\omega_{1,t-9}$	−1.87**	(0.91)	$D\times\omega_{2,t-9}$	0.03	(0.79)	$D\times\omega_{3,t-9}$	−0.07	(0.73)	$D\times\omega_{4,t-9}$	−1.81**	(0.80)
$D\times\omega_{1,t-10}$	−1.73*	(0.92)	$D\times\omega_{2,t-10}$	−0.25	(0.79)	$D\times\omega_{3,t-10}$	−1.20	(0.74)	$D\times\omega_{4,t-10}$	−2.32***	(0.79)
$D\times\omega_{1,t-11}$	−2.44***	(0.93)	$D\times\omega_{2,t-11}$	−0.81	(0.79)	$D\times\omega_{3,t-11}$	−1.13	(0.75)	$D\times\omega_{4,t-11}$	−2.30***	(0.78)
$D\times\omega_{1,t-12}$	−1.88**	(0.94)	$D\times\omega_{2,t-12}$	−1.19	(0.79)	$D\times\omega_{3,t-12}$	−1.73**	(0.76)	$D\times\omega_{4,t-12}$	−0.88	(0.79)

effect of each oil price shock on the economy depends on its source of origin. In this paper, it is shown that this argument holds even in electricity markets. Moreover, these shocks could cause severe repercussions during times of uncertainty and increased geo-political risks. Therefore, it is essential that governments/policy makers accurately identify the source of electricity price increases instead of following a general procedure to address such situations.

Hardy et al. (2019) highlight several weaknesses in the price cap introduced by Ofgem in order to regulate the retail price of electricity in the UK. This discussion is continued further by highlighting potential failures of the energy cap in relation to wholesale markets. The purpose of the energy cap is to regulate the suppliers from charging unfair tariffs from the consumers. Suppliers prefer to buy electricity at the lowest cost in the wholesale market and sell at the highest allowed price in the retail market. An initial increase in production cost could increase the producer price, which affects the supplier's bottom line. In order to maintain fairness to the suppliers and more importantly keep them in business, Ofgem could announce an increase in the energy cap. This would mean that suppliers could charge more for the same amount of electricity in the retail market. Therefore, it would be rational to make an early entry to the wholesale market to secure electricity for the future at the lowest possible price. Hence, suppliers could take long positions in electricity futures contracts. Many suppliers competing for the lowest possible price at the same time could create a sudden upward pressure in prices in both futures and the spot market (Stoft et al., 1998). This could reduce the profit margins of suppliers once again, putting more pressure on Ofgem to increase the energy cap further. Therefore, it is essential that Ofgem identifies the cause of the electricity price increase and whether it is going to affect electricity markets in the long term.

As per the discussion in Section 4.1, renewable power generation contributes to approximately 40% of the total power requirement in the UK. In the meantime, it is observed that the sensitivity of electricity price to natural gas has increased over time, especially during the 2020–2022 period. Ideally, this sensitivity should decrease as newer renewable power generators are introduced (Paraschiv et al., 2014; Huisman et al., 2013). Given the fact that the production costs of renewable power generation remain unaffected by political events such as the Russia-Ukraine war, it is argued that power producers and/or power suppliers may be exploiting this opportunity by not letting consumers enjoy the benefit of cheaper sources of power. This underlines the importance of more measured policy decisions on energy price management that consider the contribution of renewable energy to the energy mix of each supplier.

6. Robustness test

The prime focus of this study is the 1996–2022 period. However, APX price data is only available from 2000. It is understood that this is a limitation of this study. Since a larger sample to estimate structural shocks was needed, wholesale electricity price data from 1996 to 1999 had to be estimated as APX data was unavailable prior to 2000.

It could be argued that the findings may be distorted by the estimated APX data, therefore, the SVAR model (1), and regression (3) and (4) for the 2000–2022 period, were re-estimated, which only includes actual APX data. The response of real natural gas price, change to natural gas supply, consumer demand and real price of electricity, to electricity price shocks are reported in Fig. 9, while Fig. 10 represents the response of inflation and the change in real industrial production to electricity price shocks. Possible differences were examined between Fig. 4 and Fig. 9, and Fig. 6 and Fig. 10, however, no significant difference between results generated using the 2000–2022 subsample and the full sample were observed. This implies that using extrapolated APX data does not affect the findings.

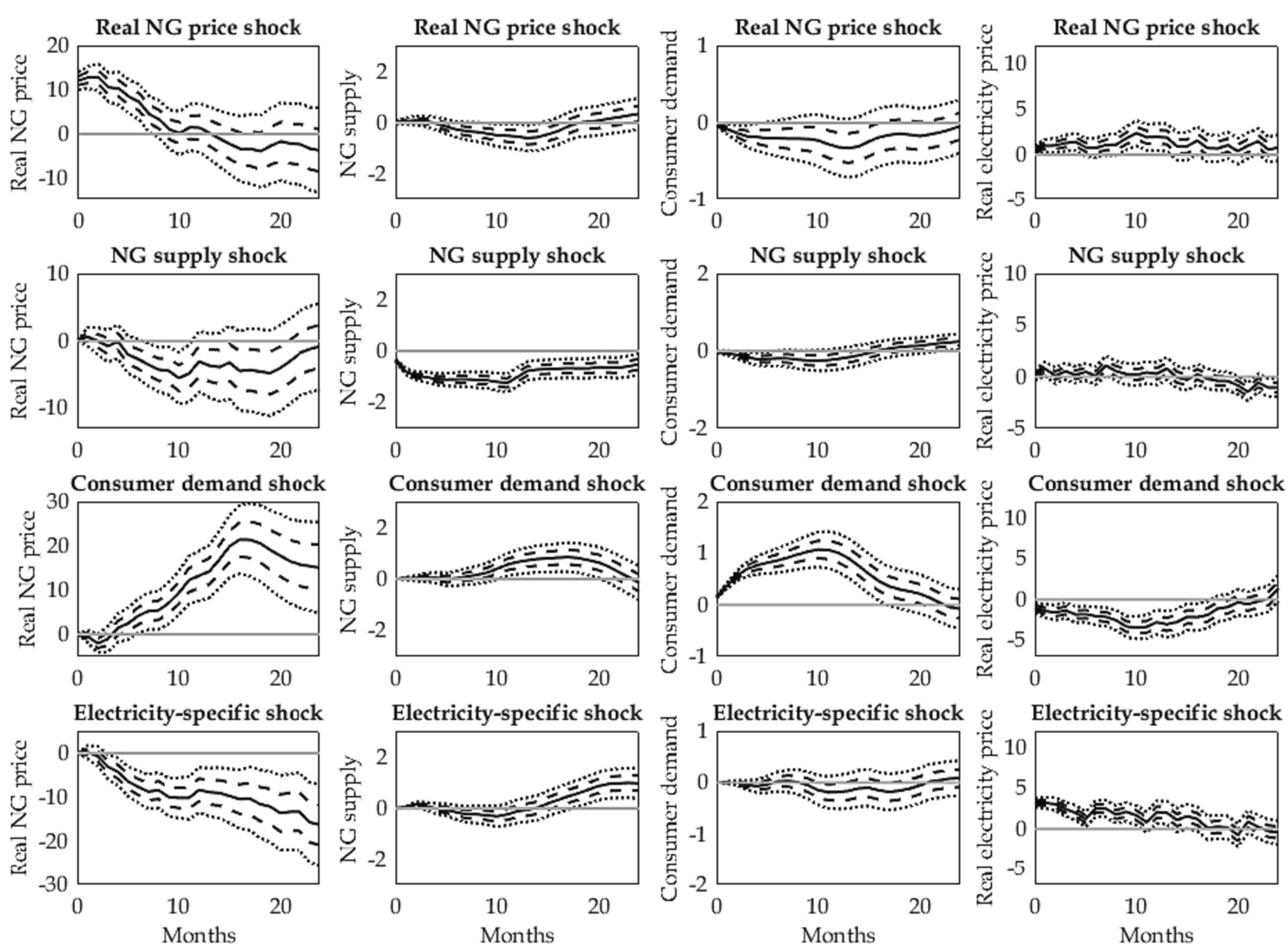

Fig. 9. This represents impulse responses of the real natural gas price, domestic natural gas supply, consumer demand and the real electricity price to each one-standard deviation structural electricity price shock across the sample period 2020–2022. Solid lines represent point estimates while dashed and dotted lines represent 68% and 95% standard error bands, respectively.

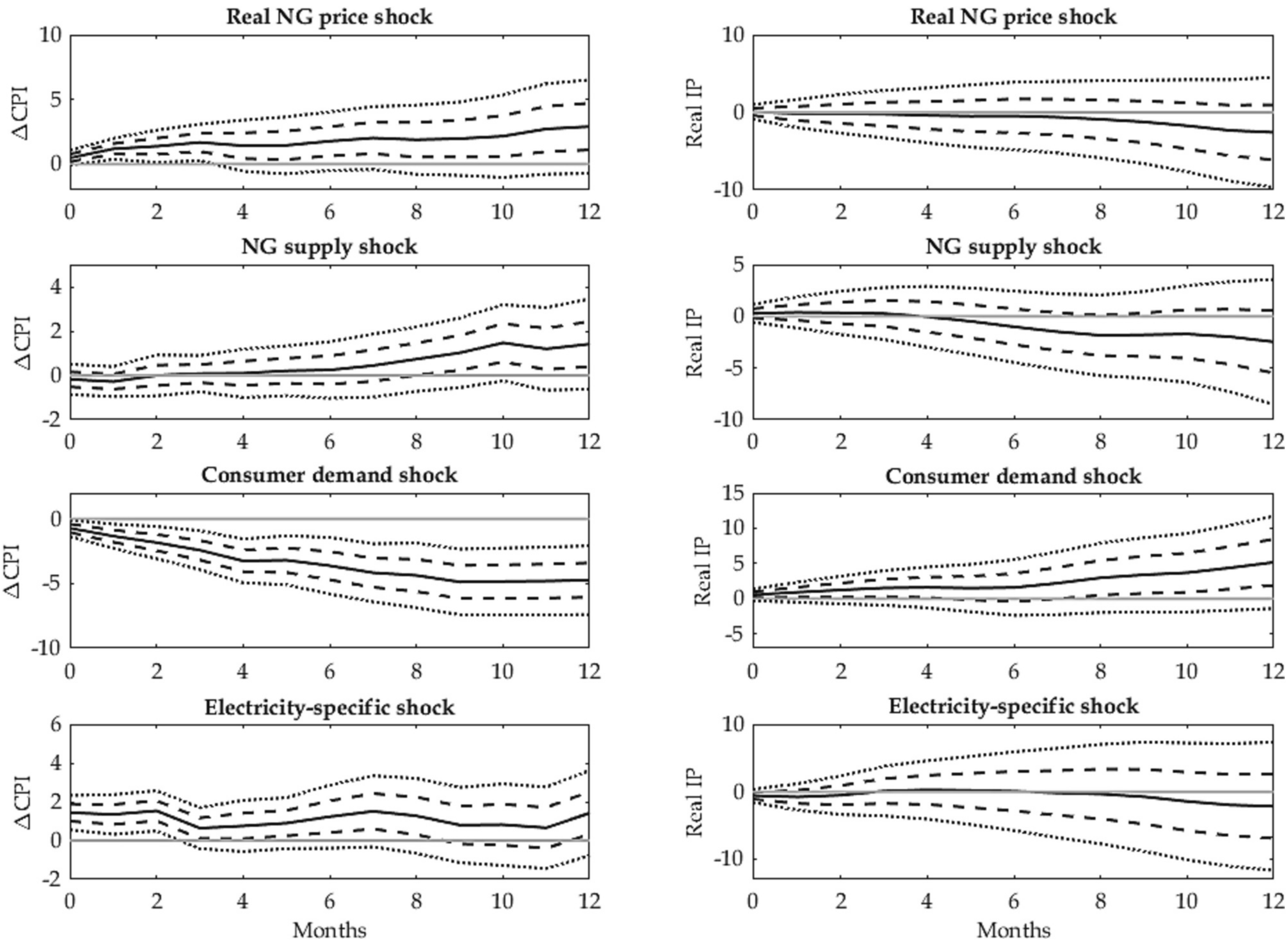

Fig. 10. This represents impulse responses of the CPI inflation (left column) and the real industrial production of the UK (right column) to each one-standard deviation structural electricity price shock over 2020–2022 period. Solid lines represent point estimates while dashed and dotted lines represent 68% and 95% standard error band.

7. Conclusion

In this paper, the causes and consequences of real wholesale electricity prices in the UK during the 1996–2022 period are examined. Four possible causes of electricity prices are identified. These are: 1) price changes due to unexpected changes in global natural gas price, 2) price changes due to unexpected shortages of domestic natural gas supply, 3) price changes due to unexpected changes in consumer demand, and 4) price changes due to electricity-specific factors. The findings show that shocks to natural gas and electricity-specific factors increase the real price of electricity, while shocks to consumer demand reduce. Unexpected shortages to the domestic supply of natural gas have no statistically significant effect on the real price of electricity.

Equipped with these findings, the impact of each structural shock on the CPI inflation and the real industrial production of the UK are assessed. Real natural gas price shocks and electricity-specific shocks are inflationary. In comparison, the inflationary effects of electricity-specific shocks dominate those of all other electricity price shocks. Electricity-specific shocks have a mild negative impact on the real industrial production. However, these effects are short term and the real industrial production growth returns to its normal levels within two months from the shock. The remaining three electricity price shocks do not have any statistically significant effect on real industrial production. To the authors' best knowledge, this is the first time causes and consequences of electricity prices are explored.

The impact of each shock on the electricity price during 2020–2022 are further assessed, in which the UK was under two full lockdowns due to the Covid-19 pandemic and the war between Russia and Ukraine which is widely claimed to have increased energy prices around the world. The findings show that shocks to natural gas price have contributed to the increase in the real electricity price. Consumer demand shocks, on the other hand, contributed to the increase in the real price of electricity, mainly during the time when Covid-19 restrictions were relaxed in the UK. It is found that the largest contributor to the real electricity price increase is electricity-specific shocks. There is also strong evidence to suggest that the real industrial production during this time was negatively affected by natural gas price shocks, consumer demand shocks and electricity specific shocks.

Further research is proposed to be conducted in electricity markets in the UK to assess the effectiveness of the energy cap considering the large contribution of renewable power generation and the household energy bill subsidy granted by the UK government starting from October 2022. If one believes that the increase in natural gas price is the primary reason behind the electricity price increase, it could be interesting to explore whether the alternative of subsidising the producers' natural gas supply is more economical in comparison to increasing the energy cap and/or subsidising household energy bills. Furthermore, the study may be expanded to incorporate the dynamics of high and low electricity price regimes using a structural threshold vector autoregressive (TVAR) model (Balke, 2000; Candelon and Lieb, 2013; Afonso et al., 2018; Donayre and Wilmot, 2016; Evgenidis, 2018).

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

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