Oil and US stock market shocks: implications for Canadian equities

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Abstract. Oil and US stock market shocks are relevant to Canadian equities because Canada is an oil exporter exposed to market developments in the wider continent. We evaluate how the relationship between Canadian stock market indices and such external shocks change under extraordinary events. To do this, we subject statistically identified oil and S&P 500 market shocks to a surprise filter, which detects shocks with the greatest magnitude occurring over a given lookback period, and an outlier filter, which detects extrema shocks that exceed a normal range. Then, we examine how the dependence structure between shocks and Canadian equities change under the extreme surprise and outlier episodes through various co-moment spillover tests. Our results show co-moments beyond correlation are important in reflecting the changes occurring in the relationships between external shocks and Canadian equities in extreme events. Additionally, the differences in findings under extreme positive and negative shocks provide evidence for asymmetric spillover effects from the oil and US stock markets to Canadian equities. Moreover, the observed heterogeneity in the relationships between disaggregated Canadian equities and shocks in the crude oil and S&P 500 markets are useful to policy-makers for revealing sector-specific vulnerabilities and provide portfolio diversification opportunities for investors to exploit.

Résumé. *Chocs sur les marchés boursiers pétroliers et américains : répercussions pour les actions canadiennes*. Les chocs sur les marchés boursiers pétroliers et américains sont pertinents pour les actions canadiennes, car le Canada est un exportateur de pétrole exposé aux aléas des marchés à l'échelon du continent. Nous évaluons comment la relation entre les indices boursiers canadiens et de tels changements engendrés par des chocs externes lors d'événements extraordinaires. Pour ce faire, nous appliquons un filtre de surprise, qui détecte les chocs avec la plus grande magnitude produite lors d'une période antérieure donnée, à des chocs sur le marché pétrolier et de l'indice S&P 500 déterminés statistiquement; et un filtre des observations aberrantes, qui détecte les chocs extrêmes dépassant une fourchette normale. Nous examinons ensuite comment la structure de dépendance entre les chocs et les actions canadiennes change lors des épisodes de surprise et d'observation aberrante extrêmes par divers tests de réaction en chaîne de co-moment. Nos résultats montrent que les co-moments au-delà de la corrélation sont importants pour tenir compte des changements survenant dans les relations entre les chocs externes et les actions canadiennes lors d'événements extrêmes. De plus, les différences dans les constatations lors de chocs extrêmes positifs et négatifs fournissent des données probantes sur les réactions en chaîne asymétriques des marchés pétroliers et boursiers américains pour les actions canadiennes. En outre, l'hétérogénéité observée dans les relations entre les actions canadiennes désagrégées et les chocs sur les marchés pétroliers et de l'indice S&P 500 est utile pour les décideurs politiques afin de révéler les

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We are grateful to Dan Bernhardt and two anonymous referees for their helpful feedback. We thank the audiences at the 7th time series workshop of the Rimini Centre for Economic Analysis, and at the International Association for Applied Econometrics in 2022, as well as the participants of an economics and finance research seminar at the University of Portsmouth, where earlier versions of this paper were presented.

Canadian Journal of Economics / *Revue canadienne d'économique* 2023 56(1)
February 2023. / *Février 2023.*

22 / pp. 247–287 / DOI: 10.1111/caje.12641

vulnérabilités propres à un secteur et de fournir des occasions de diversification du portefeuille que les investisseurs peuvent exploiter.

JEL classification: C32, G15, Q43

1. Introduction

THE EVOLUTION OF the international crude oil market and US stock market clearly matter for the Canadian stock market. Canada is one of the top five energy producers in the world in the past 40 years.[1] Accordingly, it is reasonable to expect a net oil exporter receiving positive (negative) oil price shocks to experience positive (negative) effects (Bashar et al. 2013). To understand the impacts of such shocks on Canada, one should also incorporate the tight interrelationship with US markets. The vast majority of Canadian petroleum and natural gas exports are to the US (EIA 2019) and, more generally, developments in the wider North American market affect Canadian asset prices (Karolyi 1995). Our paper investigates these relationships. Specifically, our contribution is to analyze the spillover effects of extraordinary shocks from these two source markets—oil and US stock markets—to Canadian equities.

There are studies that separately evaluate how the crude oil and US stock markets affect Canada. Such works either exclusively focus on Canada or include Canada as a country within the analysis. For instance, some employ the use of structural vector autoregressive (SVAR) models to estimate how shocks from the crude oil market impact either the Canadian macroeconomy (see, e.g., Elder and Serletis 2009, Bashar et al. 2013) or stock market (see, e.g., Kang and Ratti 2013, Kang et al. 2015b) through impulse response analysis. Other studies focus on the relationship suggested by second moments between the crude oil market and Canadian macroeconomic variables (see, e.g., Rahman and Serletis 2012) or Canadian stock market returns (see, e.g., Filis et al. 2011, Boldanov et al. 2016, Antonakakis et al. 2017). Similarly, the research on the US/Canada stock market relationship uses a wide range of approaches to examine the second-order moments between the asset returns of these two financial markets (see, e.g., Karolyi 1995, Racine and Ackert 2000, Wang et al. 2018).

Given the importance of the international crude oil and US stock markets to Canada, one of our contributions to the aforementioned rich body of literature is that our analysis incorporates shocks from both markets. In doing so, we can compare how the disturbances originating from both source markets affect the Canadian stock market. In this paper, we apply the strategy of Herwartz and Plödt (2016) and Herwartz (2018) to statistically identify international crude oil market supply and demand shocks proposed in the theory driven identified model of Kilian (2009) and shocks to the US stock market following Bjørnland and Leitemo (2009). The advantages of using this statistical identification strategy is that the structural shocks are orthogonal and the higher-order moment dependencies between shocks are also minimized. These structural shocks identified through independent components are consistent with those derived from zero restrictions implied by the SVAR models specified in Kilian (2009) and Bjørnland and Leitemo (2009), and from the impulse response analysis, we document additional evidence that the two estimation approaches closely align.

An interesting empirical issue, common to both the oil economics and financial contagion literatures, surrounds the dating of extraordinary shock events (Fry-McKibbin et al. 2014a). From studies on oil and the macroeconomy, Hamilton (1996) argues that it is the *surprise*

1 Data accessed from `https://www.eia.gov/international/rankings`.

increases in oil prices over the preceding year that are of consequence to the economy, while Akram (2004) suggests that it is *outlier* oil prices exceeding a normal range that matters most. Such premises sit well with the finance literature, which posits that unprecedented events arising from a stable environment is a hallmark of the contagion phenomenon (Kaminsky et al. 2003). Within this context, another contribution our paper makes is that we synthesize the discourse in the empirical oil economics and financial contagion analysis literatures surrounding extraordinary events, to be able to determine the possible repercussions such conditions imply for markets. As such, we propose filtering the statistically identified shocks into relatively quiet and extreme episodes to inform our understanding of how market relationships change in extraordinary times. We build on Mahadeo et al. (2022a), who augment such established non-linear oil price measures for sorting oil market shocks into quiet and extreme episodes. We are, therefore, able to empirically timestamp extraordinary *surprise* and *outlier* scenarios in both the international crude oil and US stock markets.

Using the quiet and extreme episodes derived from the surprise and outlier filters to develop discrete subsamples, the principal research question of this paper is: do the co-moments between Canadian equities and identified oil and US stock market shocks change under extreme shocks? While we align with the wider literature on the oil/Canada and US/Canada stock market relationships, by analyzing more conventional co-moments such as correlation and co-volatility, we also go further to include higher joint moments of the shocks and Canadian asset returns with co-skewness and co-kurtosis tests. Co-volatility conveys whether the volatility of a source market shock (from the crude oil or US stock market) changes the volatility in the recipient market (Canadian equities). On the other hand, the co-skewness has two variants: one evaluates whether the mean values of source market shocks affect the recipient market volatility, while the other evaluates whether the volatility from source market shocks affect the recipient market mean returns. Similarly, the co-kurtosis test also has two variants: one evaluates whether the mean values of source market shocks affect the skewness in the recipient market returns, while the other evaluates whether the skewness arising from the source market shocks affect the recipient market mean returns. In the analysis of financial markets, these additional co-moment tests have been able to detect important relationships not revealed by the linear correlation channel (see, e.g., Fry et al. 2010, Fry-McKibbin et al. 2014a, Fry-McKibbin et al. 2018). Therefore, to answer our research question, we consolidate the work of Mahadeo et al. (2019, 2022b),[2] who use recently introduced co-moment contagion tests in Fry et al. (2010) and Fry-McKibbin et al. (2014a) to analyze how the relationships between external source markets, such as oil and the US stock markets, affect small open economies under relatively stable and stressful source market scenarios.

Our analysis provides empirical support for contagion[3] effects to Canadian equities from both extraordinary S&P 500 shocks and demand forces in the crude oil market. For instance, we document strong evidence of asymmetric spillovers from extreme shocks originating in

2 Our work differs from these two related contagion studies, not only in our application to Canadian composite and disaggregated equities but also because we include an additional co-moment contagion channel (i.e, co-kurtosis) introduced in Fry-McKibbin and Hsiao (2018) and for the source market variables we use oil and S&P 500 market shocks instead of their returns. Hence, we also extend the idea of Broadstock and Filis (2014), who explicitly model the correlations between crude oil market shocks and stock returns, to also estimate the relationship between US stock market shocks and Canadian equities.

3 We define contagion as an increase in cross market linkages, net of market fundamentals, in the wake of an adverse shock to a source market (see, e.g., Forbes and Rigobon 2002).

both the S&P 500 market as well as the demand side factors affecting the international crude oil market, to the real returns of the headline index of the Toronto Stock Exchange (i.e., the TSX Composite), net of market fundamentals. Such inferences are based on the findings from multiple co-moment tests, which detect that changes in the relationship between source shocks and the recipient market occur primarily under extraordinary negative surprise and outlier disturbances, in comparison to extreme positive episodes when spillovers are much more subdued. In particular, this implies that extraordinary downturns in global demand, reductions in the specific demand for crude oil and adverse episodes in the S&P 500 market all spillover into the Canadian equity market; while, at the same time, this recipient market is comparatively less sensitive to extraordinary positive events from these external sources. Because stock market activity is a leading indicator of business cycles, and particularly so in the trough (Bosworth et al. 1975), such findings can be useful for policymakers to understand the impending real sector ramifications of exogenous developments on a recipient country through the performance of the stock market when unexpected events occur. Overall, similar results are achieved between the subsamples derived using the surprise and outlier filters. While our findings are robust to alternative specifications in our filters, to the inclusion of an extended set of market fundamentals for adjusting the Canadian equity returns and to variations in lag lengths, we, however, observe differences in spillover effects between contemporaneous and lagged-dynamic relationships. Consequentially, to develop a more comprehensive appreciation of market risks, we encourage stakeholders to be mindful of both.

In addition to assessing the spillover effects from shocks in these relevant external markets on Canada's headline equity index, we also consider the relationship between such shocks and the sector equities of the TSX index. In so doing, we can determine the winners and losers when extreme shocks occur and gain further insights into market resilience and vulnerabilities. From our analysis, we find that the sectors most vulnerable to spillover shocks from the crude oil and S&P 500 shocks are the TSX Energy and Real Estate sectors, whereas the TSX Consumer Staples, Telecommunication Services and Utilities sectors are comparatively less sensitive. We also document that certain sectors are more connected to certain extreme negative shocks. For instance, TSX Energy and Real Estate are more correlated with negative oil-specific demand shocks; the TSX Financials, Industrial, IT and Telecommunication sectors with extreme negative S&P 500 shocks; and the TSX Materials sector with extreme negative global aggregate demand shocks. In general, the main sources of spillovers are due to extreme negative oil-specific demand and S&P 500 market shocks. Indeed, the performance of the various sector equities in the wake of a given extreme shock, originating from either the crude oil or S&P 500 market, is of interest to Canadian investors for rebalancing their portfolio of assets in such times.

The rest of the paper is organized as follows. In section 2, we provide coverage of the literature on the effects of the US stock market on Canadian equities as well as the effects of the crude oil market on stock markets. Subsequently, we explain our empirical steps and describe the data used in section 3. We then present, analyze and discuss our findings in section 4, including those obtained from robustness analyses and extensions. Finally, section 5 concludes the paper.

2. Literature review

In this section, we consolidate some of the salient literature covering the influence of the US stock market on Canadian equities as well as the impact of the international crude oil market on stock markets, with particular reference to oil exporters, Canada and disaggregated stock returns.

2.1. The effects of the US stock market on Canadian equities

Many researchers have highlighted the impact of US developments on the Canadian real and financial sectors. Canadian and US economies are highly integrated, and the structure and regulation of stock markets in the two countries are similar. The stock markets share the same trading hours and some companies listed on Canadian stock markets are inter-listed on US markets. A strand of literature has studied the extent to which these two markets are financially integrated (see, e.g., Jorion and Schwartz 1986 and Mittoo 1992). Such studies employ capital asset pricing models (CAPM) and arbitrage pricing theory (APT) frameworks, whereby findings suggest a move from segmentation to integration of markets over time.

In Karolyi (1995), bi-variate generalized autoregressive conditional heteroskedastic (GARCH) models are used to study the dynamics of returns and volatility of the S&P 500 and the TSE 300[4] markets. In their Baba, Engle, Kraft and Kroner (BEKK) specification of the model no statistically significant spillovers from lagged TSE 300 returns to future S&P 500 returns cannot be rejected, while lagged S&P 500 returns are relevant for future TSE 300 returns. In all model specifications, the authors find a strong response of Canadian equity returns to S&P 500 shocks.

A further study applying multivariate GARCH models in the context of US/Canadian stock markets is Racine and Ackert (2000). They find significant cross-market volatility dependencies, with a correlation in volatility for the S&P 500 and Toronto 35 stock index of 0.679. Interestingly, when they split their sample, January 1988 to March 1993, in half, the second part of the sample shows a lower correlation between markets compared with the first part. They state a declining correlation in their conclusion, although the total sample considered is short.

From a forecasting perspective, Rapach et al. (2013) show that lagged US stock returns help to predict returns of major international markets. Working with monthly data from 1980:02 to 2010:12 and Granger causality tests, they give in-sample and out-of-sample evidence of the predictive power of lagged US returns on Canadian returns, among other markets. In addition, Wang et al. (2018) show that US stock volatility can predict volatility of other markets. Their proposed model is superior in forecasting 1-day ahead of the Canadian S&P TSX Composite index volatility compared with benchmark models.

2.2. The effects of the crude oil market on stock markets

We turn the emphasis now from the relationship between US and Canadian equities towards the relationship between the crude oil and stock markets. There are various mechanisms about how oil price shocks are theorized to impact stock markets, such as the cost channel, and income and wealth effects (see Basher et al. 2018). In the cost channel, given that cost is a determinant of stock returns, an oil price increase implies a rise in the cost of production for firms using oil either directly as an input or indirectly (e.g., through increases in electric bills and transportation expenses). Conversely, for oil companies listed on the stock market, their cash flows and returns are expected to be positive in such circumstances. For oil-exporting countries, in particular, the rise in oil prices suggest an increase in aggregate demand within the economy through the income effect. Various expansionary stimuli include the local spending of oil companies, which increases private sector consumption and investment, or government spending of the royalties derived from oil activity through public sector investment and transfer payments to households. The stock market, being a high frequency

4 The TSE 300 has been replaced by the S&P TSX Composite Index on May 1, 2002.

barometer for macroeconomic performance, may further benefit in these countries via a wealth effect from the optimism associated with the multiplier effects that rising oil prices bring.

Additionally, the co-movement of oil and the stock market is important to investors in deciding their optimal portfolio choice. There is a wide and growing body of literature that provides evidence that stock market risks related to price uncertainty can be appropriately hedged by holding commodities (Batten et al. 2021), including oil (see, e.g., Basher and Sadorsky 2016). Yet, the diversification benefits of oil in an investor's asset basket has its limits. In times of crisis, crude oil has been shown to not be a safe haven asset for offsetting negative stock market returns (Filis et al. 2011).

Unsurprisingly, the empirical literature has produced mixed results about how oil prices affect the stock market because the relationship between the two depends on many country-specific characteristics. For instance, the relative importance of oil to the macroeconomy plays a role: the larger the contribution of oil to national output, the more significant the impact of oil price shocks to the stock market (see, e.g., Wang et al. 2013). Also, the evidence suggest that the oil importing/exporting status of a country matters: oil importers gain when the price of oil falls, while oil exporters tend to lose (see Mohaddes and Pesaran 2017, and references therein). Furthermore, the size of the economy is relevant: large economies appear more resilient to oil price changes compared with small open economies (Abeysinghe 2001). Moreover, even when an oil-exporting country has a large macroeconomic exposure to the oil sector, oil price increases will be unable to materialise into equity market gains if too few oil companies are listed on the domestic stock exchange (see, e.g., Basher et al. 2018, Mahadeo et al. 2019). Indeed, these complexities illustrated in the empirical research on the oil/stock market relationship is an important reason why this line of work continues to be at the forefront of the applied macro-finance literature.

2.2.1. Evidence from the Canadian economy and equities

We particularly highlight the previous studies on oil and the Canadian economy and stock market for the remainder of the literature review. Elder and Serletis (2009), Rahman and Serletis (2012) and Bashar et al. (2013) all examine oil price uncertainty in Canada. The first study employs a SVAR with multivariate GARCH-in-Mean, while the second uses a vector autoregressive moving average (VARMA), GARCH-in-Mean, asymmetric BEKK model and the third uses alternative SVAR models. Across all studies, it is consistently illustrated that rising oil price uncertainty leads to a reduction in Canadian economic activity.

Another strand of literature has exploited big data approaches to evaluate the impact of international shocks on the Canadian economy. For instance, Vasishtha and Maier (2013) employ a factor-augmented VAR model, using monthly data from January 1985 to May 2008 and across 261 series, to examine how the sources of global shocks influence Canada. Their results show that Canada is vulnerable to foreign economic activity and commodity prices but is comparatively more isolated to global inflation and interest rates. In another example, using a combination of structural dynamic factor and VAR models, Charnavoki and Dolado (2014) estimate the dynamic responses of Canadian macroeconomic indicators to global commodity market shocks. Their analysis uses a quarterly data set that spans 1975 to 2010 and makes use of 281 variables. They show that positive global demand and negative commodity supply shocks lead to commodity price increases and generate favourable external balances and commodity currency effects. These authors also find a Dutch disease effect[5] in response to commodity price increases resulting from negative commodity supply shocks.

There are also insightful papers on the relationship between oil and the stock market that cover multiple countries, which includes Canada. In the remainder of this section, we place the spotlight on the results relating to Canada from such studies. One such study by Jones and Kaul (1996) find that the Canadian stock market reaction to oil price shocks, which is similar to the US but dissimilar to Japan and the UK, is rational—oil price shocks influence on the stock market is entirely explained through current and expected future real cash flows. In another study, Kang and Ratti (2013) use an extension of the SVAR model introduced by Kilian (2009) to disentangle the international crude oil market disturbances into supply and demand shocks. They do so by appending two additional variables to the bottom of the recursive identification structure in the contemporaneous matrix of the SVAR, i.e., economic policy uncertainty and stock returns. Their results show that oil price shocks and economic policy uncertainty are interrelated and that a rise in economic policy uncertainty leads to a significant reduction in real Canadian stock returns. Their results for Canada are in line with the US, but are much less pronounced than their findings for Europe. In yet another study, Kang et al. (2015b) use a mixture innovation time-varying parameter VAR model to examine structural oil market shocks on stock returns. Their results demonstrate that in Canada (and Europe), oil supply and oil-specific demand shocks are a greater source of volatility than in the US. However, global aggregate demand shocks are the main source of stock market volatility in Canada, and this finding is consistent for the US and Europe as well.

Filis et al. (2011), Boldanov et al. (2016) and Antonakakis et al. (2017) all investigate the relationship between oil and stock markets of multiple oil-exporting and oil-importing countries using different approaches, and all include Canada in their analyses. In the first study, a dynamic conditional correlations (DCC) model is used to examine the changes in the oil and stock market relationship during key events in the international crude oil market. They document that correlations do not differ between oil exporters and importers. A BEKK model is used in the second study, which contrastingly finds heterogeneity in correlations between oil exporters and oil importers. Their specific results for Canada (and Norway) suggests that time varying correlations between the volatilities of oil prices and the stock market are negatively correlated, which is a contrast to the positive correlations reported in the case of oil importers. The third study uses an extension of the Diebold and Yilmaz (2014) dynamic connectedness measure based on structural forecast error variance decompositions and reports both between and within country differences in both the strength and direction of the relationship between oil and stock markets for oil exporters and oil importers. Their specific analysis for Canada implies that in turbulent conditions, the transmission of shocks to the stock market are primarily driven by global aggregate demand shocks, but this source of transmission becomes much less pertinent in tranquil conditions.

In a recent study, Heinlein et al. (2021) assess the relationship between oil and stock markets for a heterogeneous selection of oil exporters and importers in the onset of the COVID-19 pandemic. They use local Gaussian correlations with high frequency

5 The Dutch disease characterizes the adverse effects a booming tradeable resource sector has on the non-booming tradeable sector (e.g., falling employment, output and exports), particularly through the appreciation of the real exchange rate. See, inter alia, Corden (1984, 2012) for further context.

intraday data to determine whether market connections increase between crude oil and stock returns in the wake of the crisis. Their results show that, even with such high frequency data, oil-exporting countries experience comparatively stronger oil and stock market correlations compared with importers in both pre-crisis and crisis periods. Similar to the other oil exporters in their analysis (i.e., Norway and Russia), the relationship between oil and stock returns for Canada is relatively stronger in the wake of the global pandemic.

2.2.2. Evidence from specific economic sectors and disaggregated equities

Instead of a focus of the relationship between crude oil market shocks and the headline stock market index in multiple countries (see, inter alia, Jones and Kaul 1996, Filis et al. 2011, Kang and Ratti 2013, Kang et al. 2015b, Boldanov et al. 2016, Antonakakis et al. 2017, Heinlein et al. 2021), another strand of the literature examines the impact of oil price shocks on sector equities and certain sectors of the economy. With specific reference to the Canadian housing market, Kilian and Zhou (2021) demonstrate that oil price shocks raise real estate demand and real house prices not only in oil-rich provinces but in oil-poor regions as well.

Some recent studies on the impact of structural crude oil market shocks on disaggregated stock returns include Sakaki (2019) for the US and Mishra and Mishra (2020) for India. The former study modifies the Kilian and Park (2009) SVAR model for identifying shocks from the crude oil market and other shocks to the US stock market, by substituting the returns of the composite US stock index with the returns of US sectoral stock indices. Their impulse response analyzes illustrate that oil supply and aggregate demand shocks have a positive effect on sector level stock returns, while oil-specific demand shocks adversely affects stock returns for all sector equities except energy and utilities. On the other hand, the latter study uses an alternative SVAR model to Kilian and Park (2009) suggested by Ready (2018) and estimates the time varying relationship between these shocks and sector equities in India. The results show oil demand shocks have positive effects on all sector equities.

3. Methods and data

Our empirical procedure consists of four steps. The first step documents how we disentangle structural shocks in the international crude oil and US stock markets. In the second step, we outline two approaches for filtering these shocks into discrete quiet and extreme episodes. For the third step, we explain the regressions used to adjust the returns of the Canadian equity indices for market fundamentals and describe the resulting data series. Finally, the fourth step illustrates various co-moment tests for evaluating whether the relationship between the identified shocks and the various returns of Canadian equity indices change during extreme episodes compared with relatively quiet conditions.

Monthly data are used for all empirical steps because this is the highest frequency at which the identifying assumptions made about demand and supply shocks in the crude oil market are valid (see Kilian 2009). Our period of investigation is January 1988 to June 2021, which is dictated by the availability of the Canadian equity indices for the third step of our analysis. Combined, the first and second steps of identifying oil and US stock market shocks as well as filtering the data into quiet and extreme episodes require approximately five preceding years of data to prime these procedures. We further describe the data attributes below.

3.1. Identifying structural oil and S&P 500 market shocks through independent components

We estimate two structural vector autoregression models (SVAR) based on monthly data, from 1983:1 to 2021:6, for the global oil market following Kilian (2009) and for the US economy following Bjørnland and Leitemo (2009), which are represented in equation (1):

$$\boldsymbol{y}_t = \boldsymbol{\nu} + \sum_{i=1}^{p} \boldsymbol{A}_i \boldsymbol{y}_{t-i} + \boldsymbol{B}\boldsymbol{\varepsilon}_t, \qquad t = 1, \ldots, T. \tag{1}$$

To identify oil market shocks, the vector $\boldsymbol{y}_t = (\Delta q_t, x_t, \Delta p_t)'$ includes the change in global crude oil production,[6] Δq_t, a detrended[7] world industrial production index, x_t, suggested in Baumeister and Hamilton (2019)[8] and the change of the real price of oil, Δp_t, for which we use the US crude oil imported acquisition cost by refiners, expressed in constant 2015 prices.[9]

To identify US stock market shocks, we follow Bjørnland and Leitemo (2009). The vector $\boldsymbol{y}_t = (ip_t, \pi_t, \Delta c_t, r_t, i_t)'$ includes the detrended[10] industrial production index times 100 (ip_t), the annual change in the log of consumer prices times 100 (π_t), the annual change in the log of the commodity price index times 100 (c_t), the real stock returns of the US stock market (r_t) for which we use the log of the S&P 500 market index deflated with 2015 prices, first differenced and multiplied by 100 to have monthly percentage returns, and finally, the federal funds rate (i_t).[11]

Figure A1 and figure A2 show the raw data for these series. With respect to the model of the international crude oil market, it is worth mentioning that, although Canada is a major global producer of petroleum, other related downstream liquids and natural gas (EIA 2019), the international crude oil market activity is considered sufficient to capture the information content across these hydrocarbon commodity markets. This is because natural gas prices and contracts are commonly indexed to crude oil prices (Zhang and Broadstock 2020). Considering the model of the US economy, the S&P 500 market index is considered to

6 World crude oil production in thousands of barrels per day is obtained from the US Energy Information Administration (EIA), available at https://www.eia.gov/opendata/qb.php?sdid=INTL.57-1-WORL-TBPD.M.

7 Hamilton detrending is employed, which applies a two-year (24 month) seasonal difference to the series (see Hamilton 2018, 2021).

8 The world industrial production index is available at Christiane Baumeister's website: https://sites.google.com/site/cjsbaumeister/research.

9 Refiners acquisitions cost per barrel of imported crude oil, accessed in October 2021, is also obtained from the US EIA at www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=r1300___3&f=m. The oil price data are expressed in constant 2015 prices using the US CPI obtained from https://fred.stlouisfed.org/series/CPIAUCSL and converted into percent changes.

10 We again use Hamilton's two-year seasonal difference detrending method. A linear detrending for industrial production employed in Bjørnland and Leitemo (2009) yields a non-stationary output gap for this particular sample, according to ADF test results.

11 The commodity price index is downloaded from the World Bank, the S&P 500 market index is from Yahoo Finance, while the other series are extracted from the Federal Reserve Bank of St. Louis database FRED. These data were accessed in October 2021.

be the most appropriate indicator for assessing the influence of the US stock market on Canadian equities, due to its size and prominence on global financial markets (see, e.g., Phillips and Shi 2020).

In the SVAR models, the structural shocks, $\boldsymbol{\varepsilon}_t$, in equation (1) are uncorrelated across equations and over time with mean zero and unit covariance matrix, $\boldsymbol{\Sigma}_\varepsilon$. The reduced form residuals, $\boldsymbol{u}_t = \boldsymbol{B}\boldsymbol{\varepsilon}_t$, are linear functions of the structural innovations and $Cov(\boldsymbol{u}_t) = \boldsymbol{\Sigma}_u = \boldsymbol{B}\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t'\boldsymbol{B}' = \boldsymbol{B}\boldsymbol{\Sigma}_\varepsilon\boldsymbol{B}' = \boldsymbol{B}\boldsymbol{B}'$. Up to 24 lags are included in the estimation of equation 1 for the oil market, as is conventional with the specification of SVAR models for capturing the dynamics in the international crude oil market (see Kilian 2009, Kilian and Park 2009, Kilian and Murphy 2014, Kang et al. 2015a, Baumeister and Kilian 2016a,b).

The model of the global crude oil market comprises three types of structural shocks, which are labelled as oil supply shock (ε_s), aggregate demand shock (ε_{ad}) and oil-specific demand shock (ε_{osd}). To identify the impact of the structural shocks on the variables in the system, Kilian (2009) applies economic theory to justify the use of a recursive form in the $\boldsymbol{B}$ matrix. One of the main premises of this SVAR model is a vertical short-run oil supply curve, whereby demand-side shocks do not contemporaneously affect the global oil supply because it is generally costly for oil producers to respond to high frequency demand innovations, and because of the sluggishness in global real economic activity, this variable does not respond to oil-specific demand shocks in the same month. In recent times, the financialization process in which commodity prices are not determined entirely on supply and demand but also by several financial factors and investors' behaviour in derivative markets (see Creti et al. 2013, Zhang and Broadstock 2020). Consequentially, it becomes important to carefully scrutinize the validity and relevance of an identification strategy implied by economic theory. Hence, in this paper, we follow the statistical identification strategy of Herwartz and Plödt (2016) and Herwartz (2018).

Under normality, the decomposition of the reduced form covariance matrix $\boldsymbol{\Sigma}_u = \boldsymbol{B}\boldsymbol{B}'$ is not unique such that the space spanned by $\boldsymbol{B}$ and its rotations can be considered as observationally equivalent. Comon (1994) shows that if the components of $\boldsymbol{\varepsilon}_t$ are non-Gaussian (i.e., not more than one marginal structural shock process is Gaussian), the independence of the ε_{it} can be used to identify the matrix $\boldsymbol{B}$. Lanne et al. (2017) prove uniqueness of $\boldsymbol{B}$ for non-Gaussian models, except for the ordering and sign of its columns. Herwartz (2018) introduces identification via least dependent structural innovations, using the copula-based Cramér-von Mises (CVM) statistics as a nonparametric independence test to measure the degree of dependence.[12] The matrix $\hat{\boldsymbol{B}}$ is chosen as such that the CVM dependence criterion for the structural shocks is minimized (for details, see Herwartz 2018).

The lower triangular Choleski factor $\boldsymbol{D}$ is a possible solution to the decomposition of $\boldsymbol{\Sigma}_u = \boldsymbol{D}\boldsymbol{D}'$, hence linking the structural errors to the reduced-form errors, $\boldsymbol{\varepsilon}_t = \boldsymbol{D}^{-1}\boldsymbol{u}_t$. More candidate structural shocks can be computed $\tilde{\varepsilon}_t = \boldsymbol{Q}\boldsymbol{\varepsilon}_t = \boldsymbol{Q}\boldsymbol{D}^{-1}\boldsymbol{u}_t$, when multiplying with a rotation matrix $\boldsymbol{Q}$ with $\boldsymbol{Q} \neq \boldsymbol{I}_3$ and $\boldsymbol{Q}\boldsymbol{Q}' = \boldsymbol{I}_3$. Because we are working with a $K = 3$ dimensional system, the rotation matrix can be parameterized as the product of three orthogonal Givens rotation matrices, $K(K-1)/2$, leading to the optimization of a three-dimensional vector of rotation angles. This identification via least dependent innovations is capable of identifying the link matrix $\boldsymbol{B}$ except for column permutations and column signs. If needed, we switch the columns of the matrix $\boldsymbol{B}$ by implementing the following procedure.

12 A parametric non-Gaussian structural error approach is suggested by Lanne et al. (2017), based on maximum likelihood estimation.

Lütkepohl and Netšunajev (2017) propose using column permutations and column signs in the $\boldsymbol{B}$ matrix to achieve positive diagonal entries and the largest diagonal sum because structural shocks should elicit the greatest effect on the variable to which they are primarily associated. Therefore, the impact effect on other variables is expected to be smaller than the effect on the originating variable. This procedure in Lütkepohl and Netšunajev (2017) has been implemented in recent studies such as Herwartz and Xu (2021) and Bernoth and Herwartz (2021).[13] Hence, we achieve an economic meaningful labelling of the structural shocks in a statistical identification procedure.

Our second SVAR model follows the model composition in Bjørnland and Leitemo (2009), but applies the empirical identification strategy introduced above. The model is a five-dimensional system, from which we extract the US stock market shock. The identification strategy in Bjørnland and Leitemo (2009) is a combination of short and long-run restrictions. Because the contemporaneous effects between policy rates and stock market returns are controversial to be restricted with a short-run zero restriction, the authors have introduced the long-run restriction that a monetary policy shock has no long-run effects on the level of real stock prices. Lütkepohl and Netšunajev (2017) have revisited the identification problem by applying identification with the use of heteroskedasticity, modelling a smooth change in variance. They reject the identification restrictions of Bjørnland and Leitemo (2009) when those are tested as over-identifying restrictions. We apply the identification strategy of non-normality outlined above on the 5D system. The lag lengths is decided on by the Akaike information criterion (AIC), which suggests 13 lags.[14]

3.2. Filtering shocks into discrete quiet and extreme episodes

We adopt two alternative measures to sort the statistically identified shocks into discrete outcomes of extreme and quiet episodes. One measure is based on the idea suggested by Hamilton (1996), who argues that it is actually surprise oil price increases over the preceding year that are of consequence to the economy rather than increases that are simply corrections for previous price declines. It becomes straightforward to use this measure to also obtain surprise oil price decreases, especially in analyses involving oil exporters such as Canada. Furthermore, capturing unexpected events arising from a stable oil market environment integrates comfortably with the literature on the causes of spillovers. For instance, Kaminsky et al. (2003) characterize surprise shocks in a source market as one of the unholy trinities of a contagion phenomenon. Therefore, it is also simple to extend the filter posited by Hamilton (1996) to acquire relatively quiet and extreme surprise shock episodes, across all

13 An alternative strategy would be to decide on the ordering of columns by comparing impulse responses with theory expectations, as suggested in Lanne et al. (2017). However, this strategy is at times difficult in practice because economic theory is contestable.

14 Because some of the variables are constructed as annual changes in monthly data, a somewhat larger lag length is expected, especially because we are using 24 lags in our SVAR for the oil market. Our optimal lag length is larger than the four lags of Bjørnland and Leitemo (2009) for a different sample but by differencing inflation due to issues of non-stationarity, the authors remove some of the persistence in their series and limit their lag order.

four identified shocks ($\varepsilon_s, \varepsilon_{ad}, \varepsilon_{osd}$ and ε_r), such that:

$$surprise^{+}_{i,t} = \begin{cases} 1, & \text{if } \varepsilon_{i,t} > \max\left(0, \varepsilon_{i,t-1}, \varepsilon_{i,t-2}, \ldots, \varepsilon_{i,t-12}\right) \\ 0, & \text{if } 0 \leq \varepsilon_{i,t} \leq \max\left(0, \varepsilon_{i,t-1}, \varepsilon_{i,t-2}, \ldots, \varepsilon_{i,t-12}\right), \end{cases}$$
$$i = s, ad, osd, r, \tag{2}$$

$$surprise^{-}_{i,t} = \begin{cases} 1, & \text{if } \varepsilon_{i,t} < \min\left(0, \varepsilon_{i,t-1}, \varepsilon_{i,t-2}, \ldots, \varepsilon_{i,t-12}\right) \\ 0, & \text{if } 0 \geq \varepsilon_{i,t} \geq \min\left(0, \varepsilon_{i,t-1}, \varepsilon_{i,t-2}, \ldots, \varepsilon_{i,t-12}\right), \end{cases}$$
$$i = s, ad, osd, r, \tag{3}$$

where $surprise^{+}_{i,t}$ and $surprise^{-}_{i,t}$ are indicator variables, with 0 representing the relatively quiet and 1 representing the relatively extreme positive (equation (2)) and negative (equation (3)) surprise shock episodes. The periods that are found to be consistently quiet (0) across all the four structural shocks, such that there exists no extreme positive or negative outlier shock episodes, forms a *mutually quiet sample*. This mutually quiet sample will provide the basis of how we will evaluate whether market relationships change in the presence of extreme shocks. In particular, we test whether various co-moments between external shocks and Canadian equity returns differ under shock episodes classified as extreme positive (negative) surprises compared with all other relatively quieter positive (negative) shock periods.

The second measure we use to sort the identified shocks into categories of extreme and quiet episodes is motivated by Akram (2004), that it is the extreme oil prices outside a normal range that are of consequence to the economy. It is also straightforward to apply this idea to the four identified structural shocks to obtain extreme outlier episodes in the oil and US financial markets. However, the band of stable oil prices, of USD 14 to USD 20, used in Akram (2004) is a feature of oil markets prior to the 21st century. Hence, we use the standard deviation (σ_i) of the structural shocks (ε_i) to provide context of what is considered quiet and extreme. Using σ is appealing because it does not require imposing priors about the typical range of values of the different structural shocks, which can be difficult to establish. Because testing for asymmetric responses to positive and negative shocks is a cornerstone of applied macroeconomics, especially oil empirics, we can further disaggregate extreme outlier shocks to also evaluate these cases. Given that $\sigma_i = 1$ for all ε_i, the filters in equations (4) and (5) are applied to each of the four identified shocks to sort values into relatively quiet and extreme outlier episodes:

$$outlier^{+}_{i,t} = \begin{cases} 1, & \text{if } \varepsilon_{i,t} > 1 \\ 0, & 0 \leq \varepsilon_{i,t} \leq 1 \end{cases}, \qquad i = s, ad, osd, r, \tag{4}$$

$$outlier^{-}_{i,t} = \begin{cases} 1, & \text{if } \varepsilon_{i,t} < -1 \\ 0, & 0 \geq \varepsilon_{i,t} \geq -1 \end{cases}, \qquad i = s, ad, osd, r, \tag{5}$$

where $outlier^{+}_{i,t}$ ($outlier^{-}_{i,t}$) takes the form of an indicator variable with 0 and 1 in equation (4) (equation (5)) representing the relatively quiet and extreme positive (negative) outlier shock episodes, respectively. Once again, values that are found to be consistently 0 for all four shocks will form a mutually quiet sample to determine if linkages vary under extreme scenarios. In this instance, we test whether co-moments between external shocks and Canadian equity returns change under shock episodes classified as extreme positive (negative) outliers compared with all other relatively quieter positive (negative) periods.

3.3. Estimating returns net of market fundamentals for Canadian equity indices

We work with the residuals, $\eta_{k,t}$, from the generic regression in equation (6) to represent the returns of the real Canadian equity indices adjusted for the macroeconomic environment:

$$r^{CAN}_{k,t} = \alpha_k + \Sigma^n_{j=1}\beta_{k,j} r^{CAN}_{k,t-j} + \Sigma^n_{j=1}\gamma_j i^{CAN}_{t-j} + \Sigma^n_{j=1}\delta_j i^{US}_{t-j} + \eta_{k,t} \tag{6}$$

where k denotes a given real Canadian equity index so that the returns, $r^{CAN}_{k,t}$, are the logarithmic difference of a particular index times 100. The regressors used to control for lead−lag effects follow the contagion literature, which include lags of the returns of a given real Canadian equity index, $r^{CAN}_{k,t-j}$; Canadian short term interest rates, i^{CAN}_{t-j}, for which we use Canada's interbank rate;[15] and US interest rates, i^{US}_{t-j}, for which we use the US effective federal funds rate.[16] Interest rates are commonly used to account for market fundamentals because they reflect information about both macroeconomic developments and the policy environment (Forbes and Rigobon 2002). We include lags of both Canadian and US interest rates, to respectively control for domestic and foreign activity. An optimal lag length, n, for these single equation regression models are selected by AIC.

We estimate the returns net of market fundamentals as described in equation (6) for 12 Canadian equity market indices. These include the S&P Toronto Stock Exchange (TSX) Composite, the headline Canadian equity market index, as well as the 11 sector indices. The sector equities are defined along the Global Industrial Classification Standard (GICS) Level 1 taxonomy, which is a subset of the constituents comprised in the parent S&P TSX Composite and consists of equities on the Consumer Discretionary, Consumer Staples, Energy, Financials, Health Care, Industrials, Information Technology, Materials, Real Estate, Telecommunication and Utilities sectors. AIC suggests an optimal lag length of two months for the real estate sector and one month across all other eleven regressions for adjusting the Canadian equity returns.

Canadian equity indices data are obtained from the Bloomberg terminal and deflated using Canada's CPI.[17] As previously discussed, our period of analysis is 1988:1 to 2021:6, determined by the Canadian equity indices data availability. This therefore implies that data for priming the surprise shock filters in the second step are needed 12 months in advance, i.e., January 1987. As a consequence, the first step of statistically identifying structural shocks requires data from January 1983, i.e., 48 months, which include 24 months for the detrending of the world industrial production index as well as a lag length of 24 months in estimating oil market shocks.

Figure A3 illustrates the returns, net of market fundamentals, for the real S&P TSX Composite and its 11 GICS Level 1 real S&P TSX sector equities. Firstly, the returns of the real TSX Composite is punctuated with spikes during the key contemporary global financial crises such as the Asian financial crisis (late 1990s), the dotcom crash (early 2000s), the 2008 Global Financial Crisis (GFC) and the COVID-19 pandemic (2020). Secondly, the returns of the real TSX Consumer Discretionary index shows relatively higher volatility in the wake of global financial crises when compared with the real TSX Consumer Staples

15 Canadian 3-month rates and yields are obtained from the FRED database, available at https://fred.stlouisfed.org/series/IR3TIB01CAM156N.

16 The US federal funds rate data are also obtained from the FRED database, available at https://fred.stlouisfed.org/series/FEDFUNDS.

17 Canadian stock market data are expressed in constant 2015 prices obtained from https://fred.stlouisfed.org/series/CPALCY01CAM661N.

returns, where the latter appears more stable as might be expected. The real equity returns of the TSX Energy, Finance, Materials, Real Estate and Utilities sectors all convey larger fluctuations for international events like the Asian financial crisis, the GFC and COVID-19. However, as anticipated, the real equity returns of the IT and Telecommunications sectors were particularly hard hit when the dotcom bubble burst but perhaps more resilient in the COVID-19 pandemic in comparison to spikes observed in other sectors, due to working from home and lock-down polices that rely on such technologies. The salient features of the real returns of the TSX Industrial sector index resembles that of the Composite Index, while the real Health sector equity returns experienced larger swings in the latter half of the 2010s.

3.4. Spillover channels from oil and the S&P 500 market shocks to Canadian equities

To analyze whether the relationship between Canadian equities and oil and S&P 500 market shocks change under extreme episodes, we adopt linear, asymmetric and extremal dependence tests employed in Fry-McKibbin and Hsiao (2018).[18] Fry-McKibbin et al. (2018) discuss that such dependence techniques are appealing over other approaches in the literature that focus only on expected returns (see, e.g., Bekaert and Harvey 1995) as well as other spillover measures that are based on second-order moments (see, inter alia, Diebold and Yilmaz 2009, 2012, 2014) because higher-order co-moments (such as co-skewness and co-kurtosis) are also considered. There are sufficient empirical studies that suggest that higher co-moment contagion tests detect increased market connectivity in the wake of a shock (see, e.g., Fry-McKibbin et al. 2014b, Fry-McKibbin and Hsiao 2018), even when correlation tests based solely on second moments convey none (see Fry et al. 2010). Fry-McKibbin et al. (2018) further explain that a principal advantage of the various co-moment tests we employ is that they do not involve the specification of complex economic models, requiring large data sets on trade and economic fundamentals, in order to gain valuable insights into the linkages between a source and recipient market in the wake of a shock.

The following notations are used in the specification of the dependence tests: z_i is the standardized scaling of ε_i, which are the statistically identified structural residuals and where i denotes the various source of the shocks (i.e., oil supply, global aggregate demand, oil-specific demand or the S&P 500 market shocks). z_k is the standardized scaling of η_k, which are the residuals of equation (6) representing the returns adjusted for market fundamentals, where k is a given real Canadian equity index. T_x and T_y are the sample sizes, such that x_t are the time periods of quiet shocks that come from the aforementioned mutually quiet sample (0) defined by either the surprise filters (i.e., equations (2) and (3)) or the outlier filters (i.e., equations (4) and (5)), and y_t are the time periods of surprise or outlier shock episodes, which can be positive or negative. $\hat{\mu}_{ix}$ ($\hat{\mu}_{kx}$) and $\hat{\mu}_{iy}$ ($\hat{\mu}_{ky}$) are the sample means of ε_{i,x_t} (η_{k,x_t}) and ε_{i,y_t} (η_{k,y_t}), respectively, and $\hat{\sigma}_{ix}$ ($\hat{\sigma}_{kx}$) and $\hat{\sigma}_{iy}$ ($\hat{\sigma}_{ky}$) are the corresponding sample standard deviations. Finally, as correlation coefficients are widely known to become spuriously over-inflated in the presence of heteroskedasticity, a correction is used in all dependence tests to scale the volatility in extreme shock episodes conditional on the volatility

18 Fry-McKibbin and Hsiao (2018) put forward the co-kurtosis channels of extremal dependence and also consolidates the linear and asymmetric dependence contagion tests introduced in Fry et al. (2010) into their analyses as well as the co-volatility channel of extremal dependence proposed in Fry-McKibbin et al. (2014a).

experienced in quiet shocks given by:

$$\hat{\rho}_{y|x_i} = \frac{\hat{\rho}_y}{\sqrt{1 + ((\sigma^2_{i,y} - \sigma^2_{i,x})/\sigma^2_{i,x})(1 - \hat{\rho}^2_y)}}, \tag{7}$$

where $\sigma^2_{i,x}$ ($\sigma^2_{i,y}$) is the variance of a given shock in quiet (extreme) episodes and $\hat{\rho}_y$ is the Pearson correlation coefficient between a given shock and the returns of a Canadian equity index in extreme shock episodes.

3.4.1. Linear dependence

To evaluate whether there is a change in correlation between a given external shock and a Canadian equity index, during quiet and extreme shock episodes, we employ a two-sided version of the Forbes and Rigobon (2002) significance test suggested in Fry et al. (2010):

$$CR_{11}(i \to k) = \left(\frac{\hat{\rho}_{y|x_i} - \hat{\rho}_x}{\sqrt{Var(\hat{\rho}_{y|x_i} - \hat{\rho}_x)}} \right)^2, \tag{8}$$

where $\hat{\rho}_{y|x_i}$ is the heteroskedasticity corrected correlation coefficient between an external shock and Canadian equities during extreme episodes and $\hat{\rho}_x$ is the Pearson correlation in the quiet sample.

3.4.2. Asymmetric dependence

We employ the co-skewness contagion tests introduced in Fry et al. (2010), to analyze whether there is a statistically significant difference between quiet and extreme shock episodes about: (i) how the mean of extreme shocks (denoted as z_i^1) affects the volatility of real Canadian equity returns (denoted as z_k^2), as specified in equation (9), and (ii) how the volatility of extreme shocks (denoted as z_i^2) affect the mean of real Canadian equity returns (denoted as z_k^1), as specified in equation (10):

$$CS_{12}(i \to k; z_i^1, z_k^2) = \left(\frac{\hat{\psi}_y(z_i^1, z_k^2) - \hat{\psi}_x(z_i^1, z_k^2)}{\sqrt{(4\hat{\rho}^2_{y|x_i} + 2)/T_y + (4\hat{\rho}^2_x + 2)/T_x}} \right)^2, \tag{9}$$

$$CS_{21}(i \to k; z_i^2, z_k^1) = \left(\frac{\hat{\psi}_y(z_i^2, z_k^1) - \hat{\psi}_x(z_i^2, z_k^1)}{\sqrt{(4\hat{\rho}^2_{y|x_i} + 2)/T_y + (4\hat{\rho}^2_x + 2)/T_x}} \right)^2, \tag{10}$$

where the parameters $\hat{\psi}_x(z_i^m, z_k^n)$ and $\hat{\psi}_y(z_i^m, z_k^n)$ are defined as:

$$\hat{\psi}_x(z_i^m, z_k^n) = \frac{1}{T_x} \sum_{t=1}^{T_x} \left(\frac{\varepsilon_{i,x_t} - \hat{\mu}_{ix}}{\hat{\sigma}_{ix}} \right)^m \left(\frac{\eta_{k,x_t} - \hat{\mu}_{kx}}{\hat{\sigma}_{kx}} \right)^n, \tag{11}$$

$$\hat{\psi}_y(z_i^m, z_k^n) = \frac{1}{T_y} \sum_{t=1}^{T_y} \left(\frac{\varepsilon_{i,y_t} - \hat{\mu}_{iy}}{\hat{\sigma}_{iy}} \right)^m \left(\frac{\eta_{k,y_t} - \hat{\mu}_{ky}}{\hat{\sigma}_{ky}} \right)^n, \tag{12}$$

where z^m (z^n) is the standardized returns for market $i(k)$ in the CS_{12} (CS_{21}) test version and squared standardized returns in the CS_{21} (CS_{12}) test version.

3.4.3. Extremal dependence

In order to examine whether the volatility of external market shocks (denoted as z_i^2) affect the volatility of real Canadian equity returns (denoted as z_k^2) differently during episodes of quiet and extreme shocks, we make use of the co-volatility contagion test suggested in Fry-McKibbin et al. (2014a), as described in equation (13):

$$CV_{22}(i \to k; z_i^2, z_k^2) = \left(\frac{\hat{\xi}_y(z_i^2, z_k^2) - \hat{\xi}_x(z_i^2, z_k^2)}{\sqrt{(4\hat{\rho}^4_{y|x_i} + 16\hat{\rho}^2_{y|x_i} + 4)/T_y + (4\hat{\rho}_x^4 + 16\hat{\rho}_x^2 + 4)/T_x}} \right)^2, \quad (13)$$

where the standardization parameters $\hat{\xi}_x(z_i^2, z_k^2)$ and $\hat{\xi}_y(z_i^2, z_k^2)$ are respectively defined in equations (14) and (15):

$$\hat{\xi}_x(z_i^2, z_k^2) = \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{\varepsilon_{i,x_t} - \hat{\mu}_{ix}}{\hat{\sigma}_{ix}}\right)^2 \left(\frac{\eta_{k,x_t} - \hat{\mu}_{kx}}{\hat{\sigma}_{kx}}\right)^2 - (1 + 2\hat{\rho}_x^2), \quad (14)$$

$$\hat{\xi}_y(z_i^2, z_k^2) = \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{\varepsilon_{i,y_t} - \hat{\mu}_{iy}}{\hat{\sigma}_{iy}}\right)^2 \left(\frac{\eta_{k,y_t} - \hat{\mu}_{ky}}{\hat{\sigma}_{ky}}\right)^2 - (1 + 2\hat{\rho}_{y|x_i}^2). \quad (15)$$

We use the co-kurtosis contagion tests, introduced in Fry-McKibbin and Hsiao (2018), to analyze whether there is a statistically significant difference between quiet and extreme shock episodes about: (i) how the mean of extreme shocks (denoted as z_i^1) affect the cubed returns of real Canadian equities (denoted as z_k^3), as specified in equation (16), and (ii) how the cubed values of extreme shocks (denoted as z_i^3) affect the mean of real Canadian equity returns (denoted as z_k^1), as specified in equation (17):

$$CK_{13}(i \to k; z_i^1, z_k^3) = \left(\frac{\hat{\zeta}_y(z_i^1, z_k^3) - \hat{\zeta}_x(z_i^1, z_k^3)}{\sqrt{(18\hat{\rho}^2_{y|x_i} + 6)/T_y + (18\hat{\rho}_x^2 + 6)/T_x}} \right)^2, \quad (16)$$

$$CK_{31}(i \to k; z_i^3, z_k^1) = \left(\frac{\hat{\zeta}_y(z_i^3, z_k^1) - \hat{\zeta}_x(z_i^3, z_k^1)}{\sqrt{(18\hat{\rho}^2_{y|x_i} + 6)/T_y + (18\hat{\rho}_x^2 + 6)/T_x}} \right)^2, \quad (17)$$

where cubed returns are a proxy for skewness, and the parameters $\hat{\zeta}_x(z_i^m, z_k^n)$ and $\hat{\zeta}_y(z_i^m, z_k^n)$ are defined as:

$$\hat{\zeta}_x(z_i^m, z_k^n) = \frac{1}{T_x}\sum_{t=1}^{T_x}\left(\frac{\varepsilon_{i,x_t} - \hat{\mu}_{ix}}{\hat{\sigma}_{ix}}\right)^m \left(\frac{\eta_{k,x_t} - \hat{\mu}_{kx}}{\hat{\sigma}_{kx}}\right)^n - (3\hat{\rho}_x), \quad (18)$$

$$\hat{\zeta}_y(z_i^m, z_k^n) = \frac{1}{T_y}\sum_{t=1}^{T_y}\left(\frac{\varepsilon_{i,y_t} - \hat{\mu}_{iy}}{\hat{\sigma}_{iy}}\right)^m \left(\frac{\eta_{k,y_t} - \hat{\mu}_{ky}}{\hat{\sigma}_{ky}}\right)^n - (3\hat{\rho}_{y|x_i}), \quad (19)$$

where z^m (z^n) is the standardized returns for market i (k) in the CK_{13} (CK_{31}) test version and cubed standardized returns in the CK_{31} (CK_{13}) test version.

3.4.4. Evaluating the null hypothesis of the dependence tests

The linear, asymmetric and extremal dependence tests, under their respective null hypotheses of no changes in the correlation, co-skewness, co-volatility and co-kurtosis during quiet and extreme shock episodes, are asymptotically distributed as:

$$CR_{11}, CS_{12}, CS_{21}, CV_{22}, CK_{13}, CK_{31}(i \to k) \xrightarrow{d} \chi^2_1.$$

As our sample sizes in the dependence tests are relatively small and the splits between extreme and quiet periods are unequal, the asymptotic critical values are suboptimal. In the case of short crisis periods, the linear test, CR_{11}, tends to be oversized while the higher moment tests, CS_{12}, CV_{22} and CK_{13}, tend to be undersized (see Fry-McKibbin et al. 2019). On these grounds we simulate critical values. When conducting simulation exercises, under the null hypothesis, we use sample sizes for the extreme and quiet shock periods identical to our applications, as implied by the surprise and outlier filters. The results of the critical values obtained from the simulation exercises, based on 50,000 replications, are presented in table A1 for the conventional levels of statistical significance (i.e., 1%, 5% and 10% levels).

4. Results and discussion

4.1. Empirical identification of the oil and S&P 500 market shocks

Jarque–Bera tests for normality on the reduced-form residuals of the VARs show that there is strong evidence against the null hypothesis of normality for all components of both models, see table A2. Hence, identification through independent components is an adequate identification technique.[19]

The estimated impact matrices of the recursive-Cholesky approach $\hat{\boldsymbol{D}}^K$ according to Kilian (2009) and of the identification-through-independent-components approach $\hat{\boldsymbol{B}}^K_{cvm}$ read as:

$$\hat{\boldsymbol{D}}^K = \begin{bmatrix} 0.974 & 0 & 0 \\ -0.035 & 0.842 & 0 \\ -1.959 & 1.399 & 6.950 \end{bmatrix},$$

$$\hat{\boldsymbol{B}}^K_{cvm} = \begin{bmatrix} 0.942 & 0.168 & 0.177 \\ -0.127 & 0.790 & -0.267 \\ -3.618 & 2.924 & 5.697 \end{bmatrix}.$$

While, the estimated impact matrices of the identification approach $\hat{\boldsymbol{B}}^{*BL}$ according to Bjørnland and Leitemo (2009) and of the identification-through-independent-components approach $\hat{\boldsymbol{B}}^{BL}_{cvm}$ are:

$$\hat{\boldsymbol{B}}^{*BL} = \begin{bmatrix} 1.035 & 0 & 0 & 0 & 0 \\ 0.012 & 0.238 & 0 & 0 & 0 \\ 0.044 & 0.626 & 2.416 & 0 & 0 \\ -0.025 & -0.145 & 0.300 & 3.918 & 0.669 \\ 0.015 & 0.016 & 0.013 & -0.029 & 0.144 \end{bmatrix},$$

19 We use the R package "svars" of Lange et al. (2019).

$$\hat{\boldsymbol{B}}_{cvm}^{BL} = \begin{bmatrix} 0.997 & -0.097 & -0.261 & 0.000 & -0.000 \\ 0.061 & 0.202 & 0.108 & 0.023 & -0.002 \\ 0.568 & -0.476 & 2.170 & -0.985 & -0.014 \\ 0.219 & -1.388 & 1.457 & 3.356 & 0.743 \\ 0.018 & 0.017 & 0.004 & -0.032 & 0.143 \end{bmatrix}.$$

To confirm the choice of our column permutation, we compare the structural shocks obtained from the statistical identification strategy with the theoretical approach suggested in Kilian (2009) and Bjørnland and Leitemo (2009), in figure A4 and figure A5, and note that the results are qualitatively consistent. We further investigate the impulse response functions of the identification strategies, in figure A6 and figure A7, and observe a close alignment in the dynamics between the approaches across a forecast horizon of 15 months and 70 months, respectively. The similarities in dynamics imply that the correct column permutations have been chosen in the statistical approach.

We prefer using the statistical identification strategy, because it does not rely on strict zero restrictions derived from economic theory. Further, under the statistical identification strategy the structural shocks are not just orthogonal but the higher-order moment dependencies between shocks are also minimized.

4.2. Evidence of spillover effects from oil and S&P 500 market shocks to Canadian equities

We return to our main research question of this paper: do various co-moments between real Canadian equity returns and shocks from the crude oil and US stock markets differ under extraordinary episodes compared with quiet periods? Due to the variations in quiet and extreme sample sizes produced by the positive and negative surprise and outlier shock filters in equations (2), (3), (4) and (5), we use simulated critical values to evaluate the null hypothesis of "no contagion" across the various co-moment channels.

For both the surprise and outlier shock filters, T_x and T_y in table 1 show the sample sizes of the amount of months distributed between quiet and extreme shocks, respectively. Out of the overall sample of 399 months (i.e., 1988:4−2021:6), the sum of positive and negative T_x samples in the case of each of the four shocks are equal to 199 (121) mutually quiet months under the surprise (outlier) filter. The remainder 200 (278) extreme episodes are distributed across positive and negative oil supply (os), global aggregate demand (gd), oil-specific demand (od) and S&P 500 market (sp) shocks, denoted in months by T_y, with the possibility of overlaps where some months experience multiple types of extreme shocks.

4.2.1. Implications for the S&P TSX Composite Index

Table 1 shows that, over all periods of time, the highest positive (lowest negative) returns in the real S&P TSX Composite are experienced when the S&P 500 market exhibits extreme positive (negative) shocks. These findings are similar for both the surprise and outlier shock filters and illustrate the synchronization between the financial markets of Canada and the US. Additionally, the return volatility of the real TSX Composite Index is typically higher under extreme shock episodes in the crude oil and S&P 500 markets relative to quiet shock episodes.[20] Furthermore, for each of the four identified shocks, the returns volatility of the TSX Composite is higher under negative episodes compared with positive episodes. An

20 The one exception where return volatility in the real TSX Composite is higher in the quiet episodes is observed under positive oil-specific demand shocks using the surprise filter.

TABLE 1

Spillover tests from shocks in the crude oil and S&P 500 markets to the adjusted returns of real S&P TSX Composite Index based on the surprise and outlier shock filters

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
Surprise shock filter								
T_x	103	96	98	101	109	90	107	92
T_y	32	26	36	34	31	32	30	33
$\hat{\mu}_x$	0.220	0.005	0.543	−0.298	0.329	−0.142	1.125	−1.058
$\hat{\mu}_y$	−1.308	0.334	−0.012	0.504	1.037	−1.028	2.078	−4.367
$\hat{\sigma}_x$	3.453	3.867	3.527	3.738	3.406	3.931	3.386	3.614
$\hat{\sigma}_y$	4.796	5.808	3.711	4.009	3.625	5.482	2.004	4.845
$\hat{\rho}_x$	0.035	−0.035	−0.021	0.108	0.011	0.028	0.307	0.395
$\hat{\rho}_y$	−0.029	−0.036	0.054	−0.376	−0.005	0.432	0.361	0.640
$\hat{\rho}_{y\|x_i}$	−0.023	−0.009	0.030	−0.127	−0.003	0.274	0.260	0.485
CR_{11}	0.115	0.053	0.140	4.280*	0.008	2.851	0.103	0.530
CS_{12}	4.150**	3.191**	0.603	5.428**	0.043	13.109***	0.337	6.319***
CS_{21}	0.373	0.103	0.047	38.979***	0.277	31.875***	0.960	0.485
CV_{22}	0.396	3.567**	0.049	79.059***	0.072	124.908***	0.719	4.445**
CK_{13}	2.632**	11.062***	0.027	56.355***	0.234	40.050***	1.583	19.308***
CK_{31}	0.126	2.639**	0.853	213.001***	1.182	159.674***	2.876**	0.359
Outlier shock filter								
T_x	58	63	56	65	76	45	68	53
T_y	44	47	47	43	57	64	54	60
$\hat{\mu}_x$	0.024	0.822	0.324	0.539	0.490	0.355	1.236	−0.583
$\hat{\mu}_y$	−0.928	0.747	−0.007	−0.904	0.792	−0.954	3.261	−4.218
$\hat{\sigma}_x$	2.909	2.765	2.556	3.099	2.952	2.703	2.450	3.022
$\hat{\sigma}_y$	4.984	3.736	4.367	5.061	3.694	5.966	3.105	4.754
$\hat{\rho}_x$	−0.057	−0.230	0.208	−0.209	0.020	−0.081	−0.082	−0.047
$\hat{\rho}_y$	−0.026	0.048	0.011	−0.348	0.247	0.303	−0.044	0.417
$\hat{\rho}_{y\|x_i}$	−0.013	0.011	0.006	−0.089	0.178	0.111	−0.029	0.214
CR_{11}	0.080	3.765*	1.856	0.952	1.166	1.520	0.120	2.968*
CS_{12}	0.379	0.220	0.013	5.630**	0.405	3.294*	3.186*	9.888***
CS_{21}	1.524	0.417	0.391	20.174***	3.000*	25.216***	0.015	14.293***
CV_{22}	1.270	0.000	0.405	45.992***	2.024	105.397***	2.072*	28.194***
CK_{13}	1.806	0.028	0.026	13.938***	4.582**	25.127***	1.256	44.279***
CK_{31}	0.080	0.303	3.376**	195.667***	0.815	252.281***	3.500**	25.490***

NOTES: * significant at 10% level, ** significant at 5% level, *** significant at 1% level. We apply simulated critical values, see table A1. Row headings T, $\hat{\mu}$, $\hat{\sigma}$ and $\hat{\rho}$ are the sample sizes, mean, standard deviation and correlation, respectively. The associated subscript x denote the quiet shock months, while y denotes the extreme shock months. $\hat{\rho}_{y|x_i}$ is the correlation coefficient under extreme shocks that is conditioned on the volatility in the quiet period to control for heteroskedasticity bias. CR, CS, CV and CK refer to the correlation, co-skewness, co-volatility and co-kurtosis contagion tests, respectively. Column headings *os*, *gd*, *od* and *sp* are the oil supply, global demand, oil demand and S&P 500 shocks, respectively. The associated subscripts *pos* and *neg* correspond to the positive and negative shock episodes. For further explanations, see the main text.

exception here is that return volatility in the real TSX Composite is higher under extreme positive, compared with negative, oil supply shocks using the outlier filter and this is associated with negative real TSX Composite returns. These are reasonable findings for a major oil producing economy when the international crude oil market experiences a production glut.[21] As stock return volatility is a proxy for market uncertainty (see, e.g., Bloom et al. 2007),

21 Although the surprise filter conveys lower volatility in the extreme positive, in comparison to negative, oil supply shocks; we observe that the returns are still lower under extreme positive oil supply shocks, which is consistent with the outlier filter.

higher volatility in extreme shock episodes reflect the fear associated with such events in the TSX market. The largest return volatility values in the real TSX Composite occur under negative oil supply and demand shocks. These aforementioned findings, regarding the return volatility of the real TSX Composite, are the same across both surprise and outlier filters.

From the spillover test results produced with the surprise and outlier filters, a general consistency is also observed in table 1. The results are also in line with the contagion literature that co-moments beyond the correlation channel are important in reflecting the changes occurring between market relationships in times of extreme events (see, e.g., Fry et al. 2010, Fry-McKibbin and Hsiao 2018). There is also strong evidence to support contagion effects based on asymmetric spillover effects from demand side shocks in the international crude oil market and the S&P 500 market shocks to Canadian equities. This is evidenced by the differences in findings under extreme positive shocks where spillovers are more subdued compared to extreme negative shocks where multiple co-moment tests are statistically significant.

We find a weak correlation between oil supply shocks and the TSX composite under quiet/extreme, positive/negative and surprise/outlier oil supply shock episodes. Although oil supply shocks are thought to become increasingly irrelevant in the recent literature (see, inter alia, Broadstock and Filis 2014), asymmetric and extremal dependence channels detect changes in the relationship between oil supply shocks and the TSX Composite in surprise episodes. This result for Canada resonates with empirical findings of Basher et al. (2018) that oil supply shocks do in fact matter for major oil exporters such as Kuwait and the United Arab Emirates.

Concerning the relationship between global aggregate demand side shocks and the TSX Composite, contagion effects are noted under extreme negative episodes, while extreme positive global aggregate demand side shocks appear comparatively inconsequential. This is evidenced by a generally weak correlation between global aggregate demand shocks and the TSX Composite, which becomes stronger and positive under extreme negative episodes, in both surprise and outlier shocks. Our results align with Antonakakis et al. (2017), who also document that global aggregate demand shocks only matter in Canada during turbulent periods, but the effects of such shocks are muted in tranquil conditions. However, the correlation coefficient corrected for heteroskedasticity underscores the upward bias in the linear correlation coefficient during the high volatility associated with extreme episodes. Nevertheless, even after correcting for this over-inflation, all co-moment spillover channels (with the sole exception of the linear correlation channel during outlier shocks) indicate that the dependence structure between the source shock and the recipient market change.

The relationship between oil demand shocks and the TSX Composite, is similar to the global aggregate demand shocks. Compared with positive shocks, it is extreme negative oil demand surprise and outlier shocks that appear to matter for the real TSX Composite returns through co-skewness, co-volatility and co-kurtosis dependence tests. Once again, it is the co-moments beyond the linear correlation test that detects changes between quiet and extreme episodes. The results from demand side shocks (both global aggregate demand and oil demand) are in line with the findings of Kilian and Park (2009) on the impact of oil price shocks on the US stock market, which suggests that it is demand side shocks that have a greater consequence for markets compared with supply side shocks.

With regards to the relationship between the S&P 500 shocks and the TSX Composite market, a relatively moderate and positive interdependence in quiet months become stronger in months characterized by extreme negative surprise shocks in the S&P 500 market. The outlier filter also reveals a marked increase in correlations between the two markets under such conditions. In fact, in comparison to all shocks, during extreme negative episodes the market correlations are highest in the relationship between the S&P 500 shocks and the real TSX Composite adjusted returns. This result is consistent across both filtering approaches and robust to the linear correlation coefficient corrected for heteroskedasticity bias (i.e., $\hat{\rho}_{y|x_i}$). From the various co-moment dependence test results, the outlier shock filter provide stronger evidence of spillover effects from S&P 500 shocks to the TSX market than the surprise shock filter. Our findings conform with the study of Karolyi (1995), who establish strong and robust spillovers from S&P 500 shocks to the TSE 300 market (i.e., the predecessor index of the TSX Composite), as well as earlier works of Jorion and Schwartz (1986) and Mittoo (1992) that provide evidence of financial integration between the US and Canadian equity markets.

4.2.2. Implications for the sector equities of the S&P TSX Composite Index

An understanding of the relative performance and spillover effects, which different Canadian equity sectors experience in the wake of shocks from the crude oil and S&P 500 markets, can be helpful to investors for developing hedging strategies to diversify their portfolio of assets on the TSX market. The findings can also inform Canadian policymakers interested in both systemic and sector vulnerabilities and resilience to external shocks. For these reasons, we subsequently highlight the main results obtained from the sectoral analysis using the surprise and outlier shock filters, respectively presented in tables A3 and A4.

Of all extreme episodes and across both shock filter approaches, 10 of the 11 real TSX Composite GISC Level 1 sectors all experience the lowest returns during the negative S&P 500 market shocks. Real TSX Energy sector returns is the one exception, which reasonably record the lowest values under extreme negative surprises in oil-specific demand shocks. In contrast, periods of the highest return volatility vary by both sector and shock filter. While correlation coefficients between sectors and shocks also differ by surprise and outlier shock filters, there are some consistencies between the results produced by the two approaches. Out of the four main types of shocks, we document that the strongest positive correlations for specific sectors, which are consistent across the two filters, are noted between:

- the returns of the real TSX Financial, Industrial, IT and Telecommunication sectors and S&P 500 shocks under extreme negative episodes,
- the returns of the real TSX Energy and Real Estate sectors and oil-specific demand shocks under extreme negative episodes, and
- the real TSX Materials sector returns and global aggregate demand shocks under extreme negative episodes.

Similar to the results of the parent composite index, the findings from the co-moment tests for the sector equities obtained using the surprise and outlier shocks are generally consistent. However, there is a tendency of the former to be the more conservative of the two filtering approaches in the detection of spillover effects from external shocks to Canadian equities. From the subsamples obtained using the surprise filter, extreme negative oil-specific demand shocks are the most common source of spillovers to TSX sector equities. For the subsamples acquired with the outlier filter, both extreme negative oil-specific demand shocks and S&P 500 market shocks are the most pertinent sources of spillovers. Overall, based on both the surprise and outlier shock filters, the co-moment tests show that the indices that experience the most spillovers from the international crude oil and S&P 500 markets are the TSX Energy and Real Estate sectors. In contrast, again based on both shock filters, the indices indicating minimal spillover effects from the co-moment tests are TSX Consumer Staples, Telecommunication Services, and Utilities sectors. Such heterogeneity in the results across the TSX sectors can be informative for policy-makers and investors with interests in monitoring and mitigating financial risk in a net oil exporter such as Canada.

From combining our findings for the TSX Energy sector and negative oil-specific demand shocks, we note that: (i) this sector revealed the lowest returns under this shock based on the surprise filter, while all other sectors experienced lowest returns under negative S&P 500 shocks, (ii) this sector has the highest correlation with this shock, when compared with all other shocks and (iii) all co-moment contagion tests beyond the linear correlation channel suggest that the TSX Energy sector is affected by spillovers from negative oil-specific demand. Such findings resonate with the assertions of Baumeister and Kilian (2016b) that oil price declines imply pronounced implications for oil producers of Western Canada, where unconventional crude oil is produced from oil sands at a relatively high cost, which consequently erodes the profit margins of these firms. They explain that the experience of such oil producers in Canada is in contrast to US oil producers, where the marginal cost of producing shale oil has fallen in recent years due to technological progress in the sector, making the US oil producers comparatively more resilient to oil price declines.

Summarising our results for the TSX Real Estate sector and the crude oil market, we document: (i) low returns to the TSX Real Estate sector during episodes of extreme negative oil-specific demand shocks, (ii) a strong positive correlation between this sector and this particular shock, especially compared with all other shocks, and (iii) in comparison to most other sectors, the TSX Real Estate is one that experiences some of the most spillover effects from the international crude oil market. Taken together, such findings complement the inferences of Kilian and Zhou (2021), who illustrate the counterpart result that positive oil price shocks increase real estate demand and real house prices across the Canadian housing market.

In addition, a focus of the two equities representing the consumer sector show more spillover effects for the TSX Consumer Discretionary sector in comparison to the TSX Consumer Staples sector, particularly from the outlier shock filter. Such results are theoretically consistent with the idea that the Consumer Discretionary sector is relatively more sensitive to extreme market conditions, whereas the Consumer Staples sector is more stable (unchanged) in the wake of an extreme shock compared with quiet periods.

4.2.3. Robustness analyses and extensions

We test the sensitivity of the results from the various dependence tests to alternative specifications in the filters for identifying discrete quiet and extreme shocks. For instance, in the case of the definition of surprise shocks corresponding to major increases or decreases in a shock over the preceding 12 months, we also consider the cases of 9 months and 15 months. With respect to the outlier shocks for classifying extreme episodes as values exceeding 1 SD band, we also vary the SD bandwidth to consider the cases of 1.2 and 1.5 SD bands. The overall results from both filters for identifying surprise and outlier shocks are robust to such alternative specifications in these rules.[22]

We provide a further robustness analysis, where we use an extended set of fundamentals to filter the returns, as described in equation (20):

$$
\begin{aligned}
r_t^{CAN} = \alpha &+ \Sigma_{j=1}^{n}\beta_j r_{t-j}^{CAN} + \Sigma_{j=1}^{n}\gamma_j i_{t-j}^{CAN} + \Sigma_{j=1}^{n}\delta_j i_{t-j}^{US} + \Sigma_{j=1}^{n}\zeta_j \pi_{t-j}^{CAN} \\
&+ \Sigma_{j=1}^{n}\eta_j \pi_{t-j}^{US} + \Sigma_{j=1}^{n}\theta_j ip_{t-j}^{CAN} + \Sigma_{j=1}^{n}\lambda_j ip_{t-j}^{US} + \eta_t. \qquad (20)
\end{aligned}
$$

In addition to short term interest rates, inflation rates (π_{t-j}^{CAN} and π_{t-j}^{US}) and detrended industrial production (ip_{t-j}^{CAN} and ip_{t-j}^{US}) are used to filter Canadian returns to account

22 The results on the robustness analysis can be made available upon request to the authors.

for domestic (Canadian) and foreign (US) price and output changes. A lag length of one is appropriate according to AIC. By comparing the main results in table 1 (which uses adjusted TSX returns based on equation 6) to the results in table A5, we document that our findings are robust to the inclusion of the additional market fundamentals suggested in equation (20). Moreover, we also experimented with different lag lengths in the original filtering equation (i.e., equation 6) and find that the results remain stable.

As stock markets are known to quickly react to all available information, inclusive of developments in the international crude oil market (Bjørnland 2009), our paper primarily focuses on contemporaneous relationships and contagion spillovers between external shocks and Canadian equities. However, to accommodate for some short-run dynamics, we pursue a further experiment where we study how the one-period lagged relationships between the shocks and the Canadian returns, net of macroeconomic fundamentals, are affected in extreme periods compared with quiet periods. Previous studies find that lagged US stock market returns (see, e.g., Rapach et al. 2013) and volatility (see, e.g., Wang et al. 2018) help to forecast movements in the returns for major international capital markets, including that of Canada. Our approach to use one-period lagged dynamics is also in line with Filis et al. (2011), who focus primarily on the contemporaneous correlations between oil and stock market returns but also include a sensitivity analysis to correlate the previous period oil returns with current period stock returns. Thus, we study the correlation and contagion between shocks at time period t with Canadian returns at time period $t + 1$.

From comparing the contemporaneous results in table 1 with those obtained using the one-period lagged dynamics in table A6, we document marked changes in the relationships between the shocks from the crude oil and S&P 500 markets and Canadian equities. For instance, a relatively strong and positive contemporaneous relationship between the negative S&P 500 shocks and the real TSX Composite returns become weak and negative in the one-period lagged dynamics. In addition, negative oil demand shocks go from a relatively moderate and positive relationship (contemporaneously) to relatively moderate and negative (one-period lagged dynamics). Furthermore, the spillover to Canadian equities arising during extreme negative global aggregate demand and S&P 500 shocks matter contemporaneously but the significance of these relationships mostly vanish in the one-period lagged dynamics. Important differences between contemporaneous findings and those of the lagged dynamics in the oil/stock market relationship is also noted in Filis et al. (2011). As such, we recommend the careful consideration of timing for traders to effectively exploit opportunities and mitigate spillover risks arising from the contemporaneous and lagged dynamic relationships between shocks and the TSX market.

5. Conclusion

Our paper contributes to the literature by consolidating various empirical procedures into an original approach to investigate the channels through which Canadian equities are affected by extreme spillover shocks, arising from two of the most important external markets of this country—the international crude oil and S&P 500 markets. To do this, we first disentangle structural shocks from these external markets through independent components. Comparisons of the shocks and impulse response functions implied by the statistically identified strategy and theoretical SVARs are found to closely align, yet pursuing the former strategy has advantages of orthogonality and a minimization of higher-order moment dependencies between the estimated shocks.

Subsequently, we filter the statistically identified oil and S&P 500 market shocks into discrete quiet and extreme episodes. This is achieved using two different approaches: (i) a surprise filter, which detects major shocks occurring over the preceding year, and

(ii) an outlier filter, to detect extreme shocks outside a normal range of values. These discrete filters fit well with the contagion literature, which advocates that it is the unprecedented shocks from a stable environment that gives rise to an increase in cross-market linkages. We then use the periods of quiet and extreme shocks to compose the sub-samples for constructing spillover tests through multiple co-moment channels. These tests evaluate whether correlation, co-skewness, co-volatility and co-kurtosis between Canadian equity returns and shocks from the crude oil and S&P 500 markets change during quiet and extreme shock episodes.

To directly address the main research question of this paper, we do in fact find that many co-moments between Canadian equities and various identified oil and US stock market shocks change under extreme events. Indeed, our analysis provides ample support for contagion effects to Canadian equities, from both extraordinary S&P 500 market shocks and demand forces in the crude oil market. This is based on the strong evidence of asymmetric spillover effects from oil and US financial market shocks to Canadian equities, as noted by difference in findings under extreme positive and negative shocks. More precisely, we observe that extraordinary downturns in global demand, reductions in the specific demand for crude oil and adverse episodes in the S&P 500 market all spillover into the Canadian equity market; yet, the TSX Composite market is relatively insensitive to extraordinary positive events from these external shocks. Additionally, our results show that although oil supply shocks are weakly correlated with the TSX Composite, the former can influence the latter through higher co-moment when extraordinary oil supply surprises occur.

In general, there is a consistency between our results obtained from the sub-samples using the surprise and outlier filtering specifications. Furthermore, our findings suggest that co-moments beyond the linear correlation test are significant in illustrating the changes that occur between markets during extreme shock episodes. Our results are robust to alternative specifications in both the outlier and surprise shock filters, as well as to the inclusion of an extended set of market fundamentals and lag lengths. However, we observe differences in the results of contemporaneous and lagged dynamic relationships between the TSX market and the shocks from the international crude oil and S&P 500 markets. We, therefore, recommend that both types of temporal relationships are important factors for stakeholders to consider in the assessment of risks on the TSX market.

In addition, from the relationship between oil and S&P 500 market shocks and disaggregated Canadian equities, our results suggest heterogeneity across various sectors. For instance, our findings suggest that the TSX Energy and Real Estate sectors experience the most spillover effects from crude oil and S&P 500 shocks detected through co-moment channels compared with all other sectors, whereas the TSX Consumer Staples, Telecommunication Services and Utilities sectors are relatively less affected by spillovers from these source markets. Moreover, certain sectors are more correlated with specific negative extreme shocks, i.e., the Financials, Industrial, IT and Telecommunication sectors with S&P 500 shocks; the Energy and Real Estate sectors and oil-specific demand shocks; and the Materials sector and global aggregate demand shocks. Further to this, our surprise filter shows that the shocks that are the most common source of spillovers to sector equities are extreme negative oil-specific demand shocks, whereas our outlier filter suggests that both extreme negative oil-specific demand and S&P 500 market shocks are most pertinent. These methods and findings can benefit Canadian policymakers interested in the assessment of vulnerabilities and resilience to external shocks, at both the systemic and sector levels. They are also useful to stock market participants with interests in the US, Canadian and international commodity markets seeking to develop diversification strategies for optimizing their portfolio choice.

Appendix: Additional tables and figures

TABLE A1
Simulated critical values, 50,000 repetitions

T_x		103	96	98	101	109	90	107	92
T_y		32	26	36	34	31	32	30	33
CR_{11}	10%	3.243	3.418	3.163	3.189	3.280	3.227	3.321	3.191
	5%	4.806	5.075	4.602	4.703	4.882	4.751	4.909	4.761
	1%	9.163	10.134	8.609	9.091	9.428	8.883	9.607	8.717
CS_{12}	10%	2.243	2.145	2.296	2.271	2.214	2.267	2.206	2.264
	5%	3.210	3.083	3.242	3.255	3.168	3.233	3.161	3.242
	1%	5.632	5.427	5.731	5.686	5.640	5.760	5.574	5.755
CV_{22}	10%	1.842	1.740	1.923	1.870	1.825	1.867	1.810	1.883
	5%	2.693	2.502	2.794	2.755	2.637	2.697	2.621	2.746
	1%	5.216	4.828	5.385	5.337	5.071	5.362	4.979	5.448
CK_{13}	10%	1.760	1.664	1.860	1.810	1.751	1.791	1.715	1.831
	5%	2.622	2.507	2.771	2.716	2.635	2.710	2.570	2.726
	1%	5.424	5.038	5.693	5.526	5.472	5.596	5.365	5.531
T_x		58	63	56	65	76	45	68	53
T_y		44	47	47	43	57	64	54	60
CR_{11}	10%	3.018	2.984	2.987	2.999	2.898	2.944	2.935	2.914
	5%	4.387	4.284	4.329	4.374	4.175	4.230	4.187	4.185
	1%	7.707	7.628	7.644	7.840	7.409	7.547	7.559	7.382
CS_{12}	10%	2.349	2.374	2.343	2.351	2.419	2.370	2.424	2.372
	5%	3.350	3.407	3.354	3.363	3.449	3.338	3.402	3.383
	1%	5.879	5.853	5.880	5.887	5.972	5.913	5.959	5.966
CV_{22}	10%	1.959	1.982	1.969	1.952	2.063	1.985	2.050	2.027
	5%	2.952	2.976	2.944	2.901	3.100	2.973	3.027	3.020
	1%	5.914	6.055	5.861	5.996	6.290	5.973	6.150	6.034
CK_{13}	10%	1.903	1.950	1.931	1.922	2.033	1.935	2.003	1.963
	5%	2.835	2.912	2.870	2.887	3.070	2.864	3.010	2.944
	1%	5.839	6.029	5.875	5.884	6.235	5.861	6.194	6.077

NOTES: We simulated critical values 10% (weak), 5% (moderate) and 1% (strong) levels of statistical significance, respectively, which corresponds to asymptotic χ^2_1 critical values of 2.706, 3.841 and 6.635. The top panel replicates the sample sizes for the Surprise shock filter and the bottom panel the sample sizes for the Outlier shock filter. CR, CS, CV and CK refer to the correlation, co-skewness, co-volatility and co-kurtosis contagion tests, respectively.

TABLE A2

Jarque–Bera normality tests

Component	Skewness	Kurtosis	JB statistic	p-value
Oil market SVAR				
u_{1t}	−1.525	14.212	2329	0.000
u_{2t}	−1.120	12.165	1535	0.000
u_{3t}	−0.122	5.439	103.7	0.000
US economy SVAR				
u_{1t}	−3.440	41.370	26909	0.000
u_{2t}	−0.058	4.316	30.91	0.000
u_{3t}	0.025	3.804	11.48	0.003
u_{4t}	−0.678	4.254	60.42	0.000
u_{5t}	−0.420	8.256	501.6	0.000

TABLE A3

Spillover tests from shocks in the crude oil and S&P 500 markets to the adjusted returns of real S&P TSX GICS sector indices based on the surprise shock filters

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Consumer Discretionary sector index								
$\hat{\mu}_x$	0.065	0.083	0.188	−0.037	−0.067	0.244	1.223	−1.263
$\hat{\mu}_y$	−0.471	1.318	−0.242	0.508	0.320	0.393	1.235	−4.424
$\hat{\sigma}_x$	4.017	3.555	3.652	3.938	3.537	4.093	3.539	3.652
$\hat{\sigma}_y$	5.377	5.557	4.562	5.286	4.622	6.952	3.152	5.389
$\hat{\rho}_x$	−0.036	−0.081	0.122	0.018	−0.065	0.012	0.242	0.548
$\hat{\rho}_y$	0.099	−0.100	−0.055	−0.320	−0.205	0.602	0.238	0.398
$\hat{\rho}_{y\|x_i}$	0.080	−0.026	−0.031	−0.106	−0.154	0.408	0.168	0.278
CR_{11}	0.448	0.241	1.251	1.176	0.300	7.912**	0.238	4.491*
CS_{12}	2.059	0.227	4.706**	23.379***	1.182	50.795***	0.172	0.135
CS_{21}	0.095	1.320	0.795	35.644***	0.243	47.333***	0.885	0.085
CV_{22}	0.417	0.293	0.126	252.000***	4.894**	341.867***	0.255	0.000
CK_{13}	0.700	1.501	0.741	133.935***	0.555	268.296***	2.245*	1.783
CK_{31}	0.436	13.885***	0.073	202.007***	0.031	225.331***	0.001	0.602
S&P TSX Consumer Staples sector index								
$\hat{\mu}_x$	−0.006	−0.120	0.112	−0.228	−0.375	0.320	0.598	−0.827
$\hat{\mu}_y$	0.102	0.122	0.363	0.484	0.251	1.018	−0.081	−2.915
$\hat{\sigma}_x$	3.475	3.063	3.238	3.318	3.358	3.149	2.965	3.463
$\hat{\sigma}_y$	3.826	4.393	3.265	4.469	3.585	4.346	3.283	4.076
$\hat{\rho}_x$	0.091	0.012	−0.069	−0.124	0.000	−0.197	0.183	0.108
$\hat{\rho}_y$	0.107	−0.138	−0.060	−0.187	−0.131	0.208	0.095	0.338
$\hat{\rho}_{y\|x_i}$	0.087	−0.036	−0.033	−0.060	−0.097	0.125	0.066	0.233
CR_{11}	0.001	0.175	0.068	0.326	0.357	4.844**	0.555	0.693
CS_{12}	6.235***	0.004	2.594*	2.080	1.096	2.173	0.052	1.270
CS_{21}	0.406	1.243	0.890	0.009	0.285	22.898***	0.493	1.173
CV_{22}	2.414*	0.258	1.323	12.403***	1.641	28.927***	0.143	1.110
CK_{13}	2.447*	5.890***	1.616	0.001	0.252	3.032**	0.041	0.121
CK_{31}	0.929	8.264***	1.083	10.568***	0.456	96.344***	0.682	4.085**
S&P TSX Energy sector index								
$\hat{\mu}_x$	−0.253	0.093	0.664	−0.814	0.895	−1.275	0.768	−1.080
$\hat{\mu}_y$	−1.066	2.112	0.858	0.678	4.057	−3.875	1.363	−3.314
$\hat{\sigma}_x$	5.188	5.553	5.528	5.107	4.995	5.563	5.136	5.463
$\hat{\sigma}_y$	6.189	8.359	4.788	6.449	5.611	8.918	5.417	6.045
$\hat{\rho}_x$	0.044	0.013	−0.113	0.240	−0.011	0.244	0.058	0.126
$\hat{\rho}_y$	0.039	−0.083	−0.105	−0.236	0.218	0.404	0.079	0.396
$\hat{\rho}_{y\|x_i}$	0.031	−0.021	−0.059	−0.076	0.164	0.253	0.055	0.277
CR_{11}	0.005	0.092	0.157	8.369**	1.169	0.004	0.000	1.024
CS_{12}	1.315	4.914**	5.378**	0.322	0.060	39.683***	4.554**	11.534***
CS_{21}	0.021	0.214	0.084	30.556***	1.694	35.959***	2.982*	1.565
CV_{22}	0.002	6.065***	1.521	1.774	0.365	252.447***	1.033	12.079***
CK_{13}	0.825	3.999**	0.030	8.776***	0.245	105.859***	1.552	21.430***
CK_{31}	0.092	0.842	1.413	182.582***	5.644***	230.035***	4.586**	3.491**

continued

TABLE A3
Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Financial sector index								
$\hat{\mu}_x$	0.312	0.089	0.361	0.053	0.375	−0.002	1.340	−1.117
$\hat{\mu}_y$	−2.342	−0.532	0.007	0.538	0.789	−0.252	2.010	−5.331
$\hat{\sigma}_x$	3.958	3.566	3.746	3.799	3.534	4.041	3.547	3.595
$\hat{\sigma}_y$	4.704	7.236	4.473	4.466	4.488	6.435	3.516	5.722
$\hat{\rho}_x$	−0.045	0.022	−0.063	0.234	−0.085	0.129	0.268	0.435
$\hat{\rho}_y$	−0.138	−0.014	0.129	−0.015	−0.043	0.487	0.249	0.588
$\hat{\rho}_{y\|x_i}$	−0.112	−0.004	0.072	−0.005	−0.032	0.314	0.176	0.436
CR_{11}	0.149	0.049	0.980	4.847**	0.108	1.699	0.376	0.000
CS_{12}	1.956	0.705	0.004	0.411	1.529	19.402***	0.169	11.001***
CS_{21}	0.160	0.002	0.024	14.840***	0.239	22.677***	0.741	0.861
CV_{22}	0.420	0.457	1.852	14.030***	0.270	91.926***	0.097	24.374***
CK_{13}	3.333**	8.114***	0.001	0.322	0.646	22.886***	2.929**	94.827***
CK_{31}	0.007	0.177	0.046	119.713***	1.887*	122.227***	0.017	2.440*
S&P TSX Health sector index								
$\hat{\mu}_x$	0.909	0.752	0.780	0.884	0.746	0.939	1.528	0.025
$\hat{\mu}_y$	−1.021	−1.639	−1.986	0.195	2.356	0.237	0.526	−5.507
$\hat{\sigma}_x$	8.648	7.385	8.093	8.036	8.151	7.955	7.186	8.910
$\hat{\sigma}_y$	7.408	19.376	8.797	8.612	10.925	8.656	14.228	11.121
$\hat{\rho}_x$	0.052	0.108	0.014	0.108	0.023	0.084	0.157	0.324
$\hat{\rho}_y$	0.183	−0.138	−0.067	−0.072	0.206	0.307	−0.012	0.361
$\hat{\rho}_{y\|x_i}$	0.148	−0.036	−0.037	−0.023	0.155	0.188	−0.008	0.250
CR_{11}	0.316	1.612	0.138	1.357	0.664	0.504	1.093	0.269
CS_{12}	0.304	2.424*	0.000	0.187	9.151***	12.869***	1.684	0.141
CS_{21}	1.617	0.366	0.412	7.893***	5.264**	17.673***	0.000	0.024
CV_{22}	0.091	0.859	0.093	0.918	11.270***	60.672***	2.766**	0.167
CK_{13}	0.261	16.454***	5.332**	0.079	28.576***	4.841**	1.725*	0.103
CK_{31}	6.176***	2.363*	1.069	51.453***	6.361***	117.730***	0.407	0.244
S&P TSX Industrial sector index								
$\hat{\mu}_x$	0.028	−0.376	0.033	−0.361	0.086	−0.473	0.999	−1.523
$\hat{\mu}_y$	−0.778	0.194	−0.150	0.681	0.321	0.501	2.931	−4.415
$\hat{\sigma}_x$	4.689	5.257	4.417	5.455	4.292	5.681	5.235	4.267
$\hat{\sigma}_y$	4.883	6.049	4.969	5.052	5.588	5.093	3.238	4.746
$\hat{\rho}_x$	0.047	−0.018	0.059	−0.005	−0.010	0.005	0.215	0.382
$\hat{\rho}_y$	0.090	0.003	0.072	−0.097	−0.222	0.387	0.372	0.617
$\hat{\rho}_{y\|x_i}$	0.073	0.001	0.040	−0.031	−0.167	0.242	0.268	0.463
CR_{11}	0.022	0.026	0.018	0.050	0.946	2.618	0.130	0.418
CS_{12}	0.020	0.019	0.134	0.316	0.102	5.483**	6.612***	4.222**
CS_{21}	1.575	0.004	0.000	4.845**	0.207	29.155***	1.968	2.304*
CV_{22}	0.128	0.149	1.380	7.014***	0.592	82.443***	6.029***	4.092**
CK_{13}	2.743**	0.924	0.001	1.493	0.028	12.558***	1.712	4.770**
CK_{31}	2.536*	0.322	0.141	16.338***	0.067	134.842***	5.614***	3.161**

continued

TABLE A3
Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Information Technology sector index								
$\hat{\mu}_x$	0.731	0.069	0.560	0.268	0.285	0.566	2.604	−2.138
$\hat{\mu}_y$	−1.697	0.674	−0.648	1.519	−0.757	−0.167	5.519	−9.005
$\hat{\sigma}_x$	9.145	10.129	8.427	10.680	9.728	9.525	9.595	9.034
$\hat{\sigma}_y$	11.463	10.100	9.418	11.741	11.160	7.821	8.479	14.482
$\hat{\rho}_x$	−0.072	0.034	0.064	0.170	−0.004	−0.022	0.216	0.312
$\hat{\rho}_y$	0.185	0.033	−0.096	−0.306	0.208	0.142	0.072	0.399
$\hat{\rho}_{y\|x_i}$	0.150	0.008	−0.054	−0.101	0.156	0.085	0.050	0.279
CR_{11}	1.689	0.049	0.739	5.857**	0.979	0.521	1.121	0.056
CS_{12}	0.092	0.211	0.678	0.107	3.408**	0.753	1.614	1.399
CS_{21}	0.576	3.116**	1.033	33.651***	6.874***	6.663***	0.048	0.167
CV_{22}	0.372	0.276	0.001	12.093***	4.061**	1.492	0.353	0.186
CK_{13}	2.214*	0.087	0.054	29.827***	3.044**	5.483**	1.791*	3.245**
CK_{31}	0.783	20.747***	1.522	165.940***	3.480**	28.028***	0.029	0.001
S&P TSX Materials sector index								
$\hat{\mu}_x$	−0.015	−0.438	0.603	−1.017	0.152	−0.669	0.197	−0.703
$\hat{\mu}_y$	−1.249	0.901	0.492	0.296	1.812	−1.379	1.054	−1.796
$\hat{\sigma}_x$	6.318	6.330	5.951	6.573	6.167	6.488	6.003	6.652
$\hat{\sigma}_y$	10.242	8.126	5.957	8.591	5.518	9.015	4.106	7.846
$\hat{\rho}_x$	0.149	0.017	−0.005	−0.122	−0.033	−0.090	0.102	0.061
$\hat{\rho}_y$	−0.091	−0.061	0.239	−0.494	−0.049	0.001	−0.005	0.449
$\hat{\rho}_{y\|x_i}$	−0.073	−0.016	0.136	−0.176	−0.036	0.000	−0.003	0.318
CR_{11}	1.678	0.085	1.064	0.235	0.000	0.373	0.442	2.994
CS_{12}	3.793**	2.338*	0.019	5.860***	5.819***	0.010	0.449	1.698
CS_{21}	1.651	1.401	0.794	10.335***	0.129	5.468**	0.348	3.309**
CV_{22}	0.529	3.612**	1.742	50.596***	3.080**	0.000	0.069	2.654
CK_{13}	8.958***	4.905**	0.108	57.690***	4.164**	0.583	0.000	5.317**
CK_{31}	0.427	4.429**	0.806	22.101***	1.062	28.201***	0.282	4.874
S&P TSX Real Estate sector index								
$\hat{\mu}_x$	0.018	0.215	0.250	−0.019	0.043	0.198	0.471	−0.303
$\hat{\mu}_y$	−2.096	−0.011	−0.590	−0.184	−0.315	−0.362	2.702	−3.333
$\hat{\sigma}_x$	4.264	4.533	4.745	4.026	4.228	4.592	4.740	3.919
$\hat{\sigma}_y$	6.155	5.852	5.070	4.599	5.952	8.942	4.270	5.052
$\hat{\rho}_x$	0.043	−0.015	−0.039	0.205	0.001	0.103	0.242	0.180
$\hat{\rho}_y$	−0.195	0.011	0.250	−0.352	−0.037	0.556	0.032	0.381
$\hat{\rho}_{y\|x_i}$	−0.159	0.003	0.142	−0.118	−0.027	0.369	0.022	0.265
CR_{11}	1.395	0.024	1.765	8.392**	0.030	3.570*	1.987	0.330
CS_{12}	18.872***	0.143	0.978	3.393**	0.259	42.125***	0.263	0.095
CS_{21}	0.762	1.465	1.308	38.683***	0.728	36.436***	1.617	0.003
CV_{22}	9.005***	0.045	0.129	52.736***	0.698	241.351***	1.392	3.403**
CK_{13}	18.778***	0.266	0.538	13.650***	4.090**	128.072***	0.197	9.139***
CK_{31}	0.252	4.629**	2.266*	182.078***	0.068	200.393***	0.687	0.623

continued

TABLE A3
Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Telecommunication Services sector index								
$\hat{\mu}_x$	0.302	−0.040	0.545	−0.259	−0.019	0.325	0.836	−0.676
$\hat{\mu}_y$	−1.663	0.285	−1.111	0.169	−1.180	1.513	1.893	−2.492
$\hat{\sigma}_x$	3.817	4.884	4.591	4.101	3.383	5.317	4.619	3.899
$\hat{\sigma}_y$	3.949	4.996	4.384	5.156	5.086	5.101	3.510	5.601
$\hat{\rho}_x$	−0.008	−0.128	−0.093	−0.013	0.055	0.041	0.380	0.333
$\hat{\rho}_y$	−0.045	0.027	−0.291	0.030	−0.098	0.047	0.161	0.421
$\hat{\rho}_{y\|x_i}$	−0.036	0.007	−0.167	0.009	−0.073	0.028	0.112	0.296
CR_{11}	0.027	1.435	0.303	0.040	0.614	0.008	3.225	0.071
CS_{12}	0.881	5.070**	5.695**	0.041	1.501	0.512	1.755	0.416
CS_{21}	0.007	0.040	2.200	0.239	0.859	5.707**	0.000	0.023
CV_{22}	0.454	3.716**	2.867**	0.575	0.371	0.033	1.752	0.012
CK_{13}	1.650	0.054	12.466***	2.329*	2.031*	0.245	7.474***	0.691
CK_{31}	1.070	1.934*	1.457	3.691**	0.043	23.808***	0.130	0.339
S&P TSX Utilities sector index								
$\hat{\mu}_x$	−0.187	−0.257	0.068	−0.502	−0.384	−0.024	−0.088	−0.376
$\hat{\mu}_y$	−0.237	−0.420	0.122	1.004	0.700	0.950	−0.095	−1.933
$\hat{\sigma}_x$	2.935	4.163	3.665	3.472	3.340	3.843	3.416	3.756
$\hat{\sigma}_y$	2.830	4.735	3.274	3.936	3.754	4.264	3.351	3.915
$\hat{\rho}_x$	0.103	0.051	−0.126	0.038	−0.056	−0.165	0.049	0.068
$\hat{\rho}_y$	−0.146	−0.101	0.099	−0.067	0.067	0.303	0.088	0.222
$\hat{\rho}_{y\|x_i}$	−0.118	−0.026	0.056	−0.021	0.050	0.186	0.061	0.150
CR_{11}	1.654	0.462	1.773	0.268	0.419	5.747**	0.006	0.285
CS_{12}	0.101	3.665**	0.067	1.254	0.384	8.359***	4.260**	1.479
CS_{21}	0.712	0.281	0.001	1.338	0.097	28.643***	0.574	0.188
CV_{22}	0.000	1.236	0.210	0.381	0.422	60.980***	0.141	4.747**
CK_{13}	0.056	1.689*	1.348	14.754***	0.003	4.379**	0.023	1.473
CK_{31}	0.182	0.056	0.269	0.264	1.068	138.512***	0.153	1.811

NOTES: * significant at 10% level, ** significant at 5% level, *** significant at 1% level. We apply simulated critical values, see table A1. For all other explantation, see table 1.

TABLE A4

Spillover tests from shocks in the crude oil and S&P 500 markets to the adjusted returns of real S&P TSX GICS sector indices based on the outlier shock filters

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Consumer Discretionary sector index								
$\hat{\mu}_x$	0.079	1.048	0.156	0.952	0.431	0.842	1.377	−0.434
$\hat{\mu}_y$	−0.684	0.644	0.269	−0.684	−0.396	−0.131	3.299	−4.982
$\hat{\sigma}_x$	3.083	2.719	2.569	3.178	3.052	2.719	2.584	3.048
$\hat{\sigma}_y$	6.410	4.301	4.600	5.659	4.347	6.534	4.236	5.647
$\hat{\rho}_x$	−0.278	−0.111	0.226	−0.101	0.120	−0.143	−0.173	−0.027
$\hat{\rho}_y$	0.121	−0.134	−0.075	−0.359	0.076	0.437	−0.195	0.260
$\hat{\rho}_{y\|x_i}$	0.062	−0.030	−0.039	−0.092	0.054	0.169	−0.133	0.127
CR_{11}	5.529**	0.393	3.176*	0.005	0.206	4.032*	0.071	1.044
CS_{12}	5.280**	0.064	2.247	12.291***	0.564	40.742***	0.056	1.110
CS_{21}	0.005	7.367***	0.152	43.702***	0.101	67.886***	2.314	3.892**
CV_{22}	0.515	4.934**	1.256	206.172***	10.266***	593.754***	0.373	0.976
CK_{13}	37.456***	0.058	2.674*	126.553***	1.005	274.359***	2.948*	0.277
CK_{31}	0.276	92.177***	0.548	357.011***	0.419	591.028***	1.816	10.822***
S&P TSX Consumer Staples sector index								
$\hat{\mu}_x$	0.074	0.617	0.329	0.380	−0.019	0.991	0.931	−0.380
$\hat{\mu}_y$	0.291	−0.138	0.361	−0.158	−0.181	0.755	1.130	−2.410
$\hat{\sigma}_x$	3.241	2.711	2.867	3.091	2.931	2.979	2.713	3.160
$\hat{\sigma}_y$	4.078	3.713	3.050	4.134	3.792	4.438	3.459	4.083
$\hat{\rho}_x$	−0.133	−0.053	0.137	−0.173	0.040	−0.108	−0.029	−0.050
$\hat{\rho}_y$	0.056	−0.156	−0.039	−0.320	0.061	0.112	−0.088	0.197
$\hat{\rho}_{y\|x_i}$	0.029	−0.035	−0.020	−0.081	0.043	0.040	−0.060	0.096
CR_{11}	1.153	0.019	1.073	0.545	0.001	0.914	0.040	0.932
CS_{12}	2.037	1.695	1.347	0.655	1.673	1.056	0.005	2.689*
CS_{21}	0.003	4.651**	2.176	13.443***	0.076	14.017***	3.796**	2.825*
CV_{22}	5.462**	1.848	1.144	3.477**	1.076	32.941***	0.848	5.001**
CK_{13}	0.188	1.617	2.235*	2.111*	0.344	1.365	0.285	2.826*
CK_{31}	0.563	61.801***	0.083	94.856***	0.062	145.228***	0.491	8.383***
S&P TSX Energy sector index								
$\hat{\mu}_x$	0.185	1.519	1.383	0.446	0.976	0.718	1.921	−0.456
$\hat{\mu}_y$	−1.682	1.587	0.783	−0.852	2.982	−3.383	2.076	−3.771
$\hat{\sigma}_x$	5.203	3.822	4.669	4.467	4.546	4.649	4.054	4.870
$\hat{\sigma}_y$	7.942	6.259	4.852	7.815	5.716	8.221	5.902	7.362
$\hat{\rho}_x$	0.129	−0.303	0.199	−0.024	−0.138	0.105	0.032	0.041
$\hat{\rho}_y$	0.127	−0.063	−0.041	−0.187	0.308	0.325	0.021	0.075
$\hat{\rho}_{y\|x_i}$	0.066	−0.014	−0.022	−0.046	0.224	0.120	0.014	0.036
CR_{11}	0.181	5.915**	2.180	0.027	6.165**	0.010	0.013	0.001
CS_{12}	2.645*	0.131	4.405**	0.151	0.754	34.823***	0.378	4.078**
CS_{21}	0.248	0.001	0.323	14.073***	0.613	41.046***	2.552*	1.310
CV_{22}	1.548	2.855*	0.229	2.941**	0.952	438.092***	0.826	3.654**
CK_{13}	24.717***	0.294	0.180	0.136	0.415	160.793***	3.711**	5.398**
CK_{31}	0.223	1.399	3.201**	92.380***	1.783	512.348***	12.378***	5.685**

continued

TABLE A4
Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Financial sector index								
$\hat{\mu}_x$	0.232	0.942	0.161	0.982	0.628	0.558	1.359	−0.369
$\hat{\mu}_y$	−1.732	0.267	0.167	−1.121	0.548	−1.013	3.362	−4.680
$\hat{\sigma}_x$	3.353	3.028	2.899	3.405	3.067	3.434	3.313	2.775
$\hat{\sigma}_y$	5.290	3.713	4.474	5.314	4.539	6.590	3.886	5.384
$\hat{\rho}_x$	−0.246	−0.092	0.024	0.091	0.051	−0.121	−0.057	0.121
$\hat{\rho}_y$	−0.161	0.120	0.079	−0.076	0.210	0.323	−0.121	0.468
$\hat{\rho}_{y\|x_i}$	−0.084	0.027	0.042	−0.018	0.150	0.119	−0.082	0.245
CR_{11}	1.265	0.848	0.013	0.719	0.457	2.408	0.027	0.694
CS_{12}	0.074	0.516	1.808	1.151	5.561**	4.492**	5.884**	11.793***
CS_{21}	0.271	1.479	0.038	2.421*	1.888	23.867***	1.524	16.495***
CV_{22}	1.931	1.034	1.299	0.175	3.184**	82.334***	0.358	75.455***
CK_{13}	3.365**	5.966**	2.977**	0.380	1.653	18.451***	6.421***	180.432***
CK_{31}	0.395	4.077**	0.893	21.280***	0.071	230.337***	1.211	36.744***
S&P TSX Health sector index								
$\hat{\mu}_x$	1.260	2.024	1.750	1.578	1.584	1.783	1.999	1.220
$\hat{\mu}_y$	0.454	0.116	−0.382	−0.596	0.179	−0.775	2.717	−5.504
$\hat{\sigma}_x$	9.052	7.588	9.162	7.542	8.110	8.692	6.560	10.150
$\hat{\sigma}_y$	7.516	8.997	9.475	8.944	14.357	9.005	12.871	9.418
$\hat{\rho}_x$	−0.149	−0.165	−0.096	−0.015	−0.020	−0.268	0.011	0.238
$\hat{\rho}_y$	0.165	0.017	0.014	−0.113	0.138	0.208	−0.137	0.240
$\hat{\rho}_{y\|x_i}$	0.086	0.004	0.008	−0.027	0.098	0.075	−0.093	0.117
CR_{11}	2.420	1.778	0.454	0.009	0.641	5.438**	0.470	0.727
CS_{12}	2.994*	1.624	1.168	0.429	3.132*	5.615**	0.131	2.011
CS_{21}	0.116	0.243	0.904	5.167**	5.649**	12.591***	1.236	3.987**
CV_{22}	0.004	0.622	0.031	0.017	1.252	45.572***	0.107	2.253*
CK_{13}	1.345	0.029	2.854*	0.001	27.735***	5.273**	3.343**	0.009
CK_{31}	0.649	13.110***	0.984	47.126***	20.464***	141.977***	3.235**	18.237***
S&P TSX Industrial sector index								
$\hat{\mu}_x$	0.232	0.795	−0.267	1.207	0.573	0.444	1.590	−0.841
$\hat{\mu}_y$	−0.169	0.179	0.195	−0.892	0.142	−0.329	3.197	−4.783
$\hat{\sigma}_x$	4.155	4.181	3.424	4.621	3.970	4.509	4.172	3.759
$\hat{\sigma}_y$	4.766	4.373	4.976	5.830	4.839	6.778	3.976	4.856
$\hat{\rho}_x$	−0.180	−0.037	−0.007	−0.139	0.094	−0.062	0.011	0.074
$\hat{\rho}_y$	0.032	0.033	0.045	−0.257	−0.001	0.188	0.187	0.396
$\hat{\rho}_{y\|x_i}$	0.016	0.007	0.024	−0.064	−0.001	0.067	0.128	0.202
CR_{11}	1.732	0.118	0.041	0.350	0.408	0.696	0.591	0.725
CS_{12}	0.613	0.341	0.000	0.419	0.441	0.023	0.265	2.865*
CS_{21}	0.635	0.213	0.023	9.047***	0.044	12.999***	4.214**	20.507***
CV_{22}	0.020	0.031	0.365	9.904***	2.800*	20.118***	1.648	27.913***
CK_{13}	0.418	5.904**	0.645	0.516	2.510*	3.070**	6.063**	18.284***
CK_{31}	0.759	0.029	0.735	102.665***	0.052	135.555***	25.024***	47.746***

continued

TABLE A4

Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Information Technology sector index								
$\hat{\mu}_x$	0.763	0.912	−0.197	1.734	1.201	0.232	2.870	−1.763
$\hat{\mu}_y$	−0.616	0.613	−0.983	−1.071	−0.564	−0.475	6.752	−6.983
$\hat{\sigma}_x$	9.910	7.703	9.138	8.453	9.497	7.519	7.543	9.634
$\hat{\sigma}_y$	9.121	9.783	13.120	14.227	10.583	11.257	9.168	13.327
$\hat{\rho}_x$	−0.175	−0.169	0.211	−0.059	0.080	−0.068	0.140	0.140
$\hat{\rho}_y$	−0.054	0.001	−0.070	−0.277	0.280	0.057	−0.076	0.368
$\hat{\rho}_{y\|x_i}$	−0.028	0.000	−0.037	−0.069	0.203	0.020	−0.052	0.185
CR_{11}	0.986	1.782	2.767	0.006	0.710	0.322	1.619	0.094
CS_{12}	2.605*	1.060	0.339	3.600**	3.878**	6.681***	0.349	6.078***
CS_{21}	1.010	3.385*	0.046	13.293***	11.023***	2.552*	0.726	9.686***
CV_{22}	0.668	0.148	0.785	10.989***	6.108**	0.012	0.117	8.256***
CK_{13}	0.169	2.018*	1.418	10.897***	3.802**	19.754***	0.875	11.095***
CK_{31}	0.039	49.053***	0.068	123.761***	19.172***	19.543***	0.384	20.236***
S&P TSX Materials sector index								
$\hat{\mu}_x$	−0.701	0.769	0.584	−0.384	0.345	−0.410	−0.139	0.326
$\hat{\mu}_y$	−0.539	1.008	0.871	−0.356	0.446	−1.046	1.717	−2.284
$\hat{\sigma}_x$	6.218	5.661	5.512	6.321	5.842	6.180	5.847	6.138
$\hat{\sigma}_y$	9.435	6.200	6.246	10.954	5.871	8.682	5.572	7.407
$\hat{\rho}_x$	0.236	−0.053	0.170	−0.135	0.057	−0.004	−0.126	−0.172
$\hat{\rho}_y$	−0.033	−0.034	0.096	−0.386	0.256	0.003	0.046	0.160
$\hat{\rho}_{y\|x_i}$	−0.017	−0.007	0.051	−0.100	0.184	0.001	0.031	0.077
CR_{11}	2.975	0.122	0.632	0.075	0.761	0.001	1.089	2.845
CS_{12}	0.669	0.310	0.152	3.592**	0.104	1.616	0.089	0.771
CS_{21}	1.899	0.134	1.431	27.736***	2.960*	2.806*	0.018	8.861***
CV_{22}	0.228	1.838	2.672*	44.767***	0.711	0.386	0.621	7.460***
CK_{13}	4.201**	0.271	0.887	21.984***	0.004	0.848	8.539***	12.364***
CK_{31}	0.033	2.790*	3.327**	200.184***	1.709	37.491***	1.269	15.214***
S&P TSX Real Estate sector index								
$\hat{\mu}_x$	0.033	0.912	−0.454	1.305	−0.122	1.525	0.554	0.410
$\hat{\mu}_y$	−2.449	0.323	−0.029	−1.622	0.409	−1.054	3.124	−3.122
$\hat{\sigma}_x$	4.306	4.913	4.777	4.381	4.743	4.297	5.201	3.832
$\hat{\sigma}_y$	7.848	3.997	4.752	6.098	4.869	7.410	4.922	6.070
$\hat{\rho}_x$	0.031	−0.184	0.108	−0.097	−0.007	0.010	−0.064	−0.165
$\hat{\rho}_y$	−0.045	0.083	0.169	−0.309	−0.003	0.387	0.083	0.202
$\hat{\rho}_{y\|x_i}$	−0.023	0.019	0.090	−0.078	−0.002	0.146	0.056	0.098
CR_{11}	0.126	2.576	0.014	0.024	0.001	0.763	0.631	3.126*
CS_{12}	0.007	2.464*	0.009	0.014	0.146	46.810***	0.937	3.323*
CS_{21}	1.795	5.312**	0.705	20.120***	1.356	61.909***	1.039	4.630**
CV_{22}	12.366***	0.207	0.616	16.818***	0.006	652.386***	1.901	0.024
CK_{13}	3.659**	0.248	2.506*	0.022	2.654*	285.708***	2.007*	0.610
CK_{31}	0.291	37.829***	5.046**	160.665***	3.112**	658.561***	2.430*	2.710*

continued

TABLE A4
Continued

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
S&P TSX Telecommunication Services sector index								
$\hat{\mu}_x$	0.280	0.457	0.396	0.351	0.226	0.618	0.795	−0.171
$\hat{\mu}_y$	−0.937	0.490	−1.002	−0.294	−0.628	0.818	3.509	−2.769
$\hat{\sigma}_x$	2.780	3.508	3.238	3.131	2.705	3.848	3.231	3.029
$\hat{\sigma}_y$	3.482	4.818	4.730	4.826	4.345	6.460	5.231	5.339
$\hat{\rho}_x$	−0.067	−0.155	−0.125	−0.182	0.080	0.114	−0.043	−0.099
$\hat{\rho}_y$	0.005	0.047	−0.188	−0.046	0.038	0.042	−0.085	0.320
$\hat{\rho}_{y\|x_i}$	0.003	0.010	−0.100	−0.011	0.027	0.015	−0.058	0.159
CR_{11}	0.211	1.692	0.027	1.849	0.130	0.416	0.010	2.922*
CS_{12}	0.139	1.275	7.865***	0.976	0.698	1.837	1.672	7.096***
CS_{21}	0.100	0.096	1.238	0.031	0.015	1.584	0.258	3.225*
CV_{22}	0.217	4.469**	2.085*	1.112	0.391	2.164*	2.468*	12.757***
CK_{13}	1.469	6.539***	2.138*	0.096	0.061	0.005	0.059	6.901***
CK_{31}	0.281	3.280**	1.484	1.906	1.266	22.119***	0.387	6.982***
S&P TSX Utilities sector index								
$\hat{\mu}_x$	−0.074	0.637	0.096	0.469	−0.179	1.098	0.532	−0.007
$\hat{\mu}_y$	−0.512	−0.259	0.762	−0.163	0.366	0.313	0.417	−2.061
$\hat{\sigma}_x$	2.807	3.304	3.092	3.090	2.990	3.105	2.871	3.340
$\hat{\sigma}_y$	3.327	4.234	3.458	4.345	4.197	4.660	3.762	3.731
$\hat{\rho}_x$	0.256	−0.135	−0.066	−0.079	−0.217	−0.103	−0.109	−0.069
$\hat{\rho}_y$	0.033	−0.040	0.010	−0.190	0.079	0.070	0.024	0.040
$\hat{\rho}_{y\|x_i}$	0.017	−0.009	0.005	−0.046	0.056	0.025	0.016	0.019
CR_{11}	2.723	0.972	0.217	0.065	3.576*	0.681	0.684	0.341
CS_{12}	1.033	3.470**	0.053	0.013	0.045	2.053	0.168	0.420
CS_{21}	1.684	0.359	0.062	5.807**	0.532	12.893***	0.069	3.526**
CV_{22}	0.031	4.334**	0.338	0.003	0.169	45.046***	0.409	11.074***
CK_{13}	0.289	0.072	0.675	14.062***	0.003	1.757	0.839	1.323
CK_{31}	0.195	1.120	0.162	33.541***	0.006	158.238***	0.870	4.619**

NOTES: * significant at 10% level, ** significant at 5% level, *** significant at 1% level.
We apply simulated critical values, see table A1. For all other explantation, see table 1.

TABLE A5

Robustness – Spillover tests from shocks in the crude oil and S&P 500 markets to the adjusted returns of real S&P TSX Composite Index based on the surprise and outlier shock filters

Surprise shock filter								
	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
T_x	103	96	98	101	109	90	107	92
T_y	32	26	36	34	31	32	30	33
$\hat{\mu}_x$	0.133	0.053	0.458	−0.258	0.340	−0.203	1.124	−1.104
$\hat{\mu}_y$	−1.244	0.236	−0.111	0.485	1.019	−0.802	2.098	−4.395
$\hat{\sigma}_x$	3.451	3.745	3.447	3.700	3.374	3.827	3.293	3.558
$\hat{\sigma}_y$	4.693	5.925	3.653	4.067	3.629	5.235	2.111	4.893
$\hat{\rho}_x$	0.021	−0.064	−0.039	0.106	−0.009	0.049	0.297	0.387
$\hat{\rho}_y$	−0.041	−0.032	0.041	−0.371	0.015	0.461	0.355	0.638
$\hat{\rho}_{y\|x_i}$	−0.033	−0.008	0.023	−0.125	0.011	0.295	0.255	0.484
CR_{11}	0.100	0.240	0.203	4.124*	0.015	2.913	0.081	0.609
CS_{12}	3.697**	2.928*	0.343	3.850**	0.228	17.405***	1.016	8.471***
CS_{21}	0.169	0.005	0.048	37.185***	0.363	34.035***	2.166	0.874
CV_{22}	0.255	2.830**	0.050	57.164***	0.351	150.468***	3.220**	7.588***
CK_{13}	1.068	10.109***	0.002	34.817***	0.200	61.772***	0.149	29.599***
CK_{31}	0.076	1.787*	0.492	209.137***	1.433	170.478***	4.400**	0.828
Outlier shock filter								
T_x	58	63	56	65	76	45	68	53
T_y	44	47	47	43	57	64	54	60
$\hat{\mu}_x$	0.064	0.870	0.364	0.586	0.541	0.386	1.262	−0.514
$\hat{\mu}_y$	−1.043	0.881	−0.144	−0.904	0.727	−0.893	3.163	−4.166
$\hat{\sigma}_x$	2.842	2.725	2.378	3.132	2.902	2.646	2.490	2.879
$\hat{\sigma}_y$	4.900	3.625	4.284	4.902	3.754	5.856	3.044	4.773
$\hat{\rho}_x$	−0.041	−0.250	0.174	−0.214	0.035	−0.016	−0.110	−0.023
$\hat{\rho}_y$	−0.033	0.082	0.008	−0.356	0.227	0.309	0.006	0.433
$\hat{\rho}_{y\|x_i}$	−0.017	0.018	0.004	−0.091	0.163	0.114	0.004	0.223
CR_{11}	0.025	4.764**	1.264	0.993	0.756	0.691	0.573	2.646
CS_{12}	0.409	0.056	0.011	4.435**	0.569	2.471*	2.108	12.915***
CS_{21}	1.208	1.195	0.310	19.676***	2.573*	24.222***	0.723	14.815***
CV_{22}	1.380	0.009	0.509	43.299***	2.503*	102.734***	0.346	41.264***
CK_{13}	3.137**	0.050	0.002	12.101***	2.612*	25.544***	0.358	61.486***
CK_{31}	0.025	0.191	2.634*	190.172***	0.346	267.834***	8.135***	28.989***

NOTES: The adjusted returns have been filtered with an extended set of fundamentals. * significant at 10% level, ** significant at 5% level, *** significant at 1% level. We apply simulated critical values; see table A1. For all other explantation, see table 1.

TABLE A6

Evaluating the impact of turbulent times on the one-period dynamics

	os_{pos}	os_{neg}	gd_{pos}	gd_{neg}	od_{pos}	od_{neg}	sp_{pos}	sp_{neg}
Surprise shock filter								
T_x	103	96	98	101	109	90	107	92
T_y	32	26	36	34	31	32	29	33
$\hat{\mu}_x$	0.024	−0.337	0.296	−0.584	0.042	−0.383	−0.319	0.045
$\hat{\mu}_y$	0.093	−0.995	0.660	−0.293	−0.366	0.267	0.569	−0.171
$\hat{\sigma}_x$	3.410	4.855	4.213	4.088	3.829	4.545	3.899	4.464
$\hat{\sigma}_y$	3.646	4.404	3.931	4.525	4.133	5.056	2.424	4.835
$\hat{\rho}_x$	−0.039	−0.061	−0.050	0.110	−0.122	−0.035	0.076	−0.070
$\hat{\rho}_y$	−0.135	0.123	−0.051	0.192	−0.117	−0.345	−0.155	−0.029
$\hat{\rho}_{y\|x_i}$	−0.109	0.032	−0.029	0.062	−0.087	−0.213	−0.108	−0.020
CR_{11}	0.166	0.673	0.024	0.190	0.045	1.473	1.359	0.104
CS_{12}	0.000	0.255	0.458	0.192	0.996	9.145***	0.325	0.155
CS_{21}	0.384	0.456	0.021	1.189	2.210	19.744***	0.880	0.111
CV_{22}	0.025	2.567**	1.372	0.566	0.399	23.850***	0.218	0.235
CK_{13}	0.158	1.992*	0.230	0.646	0.533	0.176	0.066	0.948
CK_{31}	0.686	1.955*	0.004	10.446***	1.650	80.324***	0.307	0.516
Outlier shock filter								
T_x	58	63	56	65	76	45	68	53
T_y	44	47	46	43	57	64	53	60
$\hat{\mu}_x$	−0.228	−0.495	0.030	−0.708	−0.192	−0.661	−0.627	−0.033
$\hat{\mu}_y$	0.589	−0.173	0.573	−1.273	0.109	0.068	0.379	−0.183
$\hat{\sigma}_x$	3.630	3.351	3.233	3.661	3.387	3.640	3.458	3.502
$\hat{\sigma}_y$	3.785	4.306	4.069	4.672	4.290	5.264	3.402	5.725
$\hat{\rho}_x$	−0.138	0.051	−0.099	0.091	−0.267	0.205	0.241	−0.227
$\hat{\rho}_y$	−0.313	0.119	0.000	0.070	−0.096	−0.258	−0.005	−0.013
$\hat{\rho}_{y\|x_i}$	−0.167	0.027	0.000	0.017	−0.068	−0.094	−0.004	−0.006
CR_{11}	0.037	0.037	0.422	0.338	1.982	3.901*	2.772	2.354
CS_{12}	0.293	0.304	0.043	0.039	0.051	2.245	1.494	0.107
CS_{21}	0.571	0.483	0.216	0.413	2.887*	21.414***	0.622	0.051
CV_{22}	0.001	2.841*	1.522	1.876	2.168*	27.004***	0.218	0.070
CK_{13}	0.199	0.021	0.350	1.267	2.991*	3.826**	10.598***	0.046
CK_{31}	1.074	0.425	0.037	6.128***	9.299***	140.225***	0.161	3.616**

NOTES: Spillover tests from shocks in the crude oil and S&P 500 markets to the adjusted returns of real S&P TSX Composite Index one period delayed. * significant at 10% level, ** significant at 5% level, *** significant at 1% level. We apply simulated critical values, see table A1. For all other explantation, see table 1.

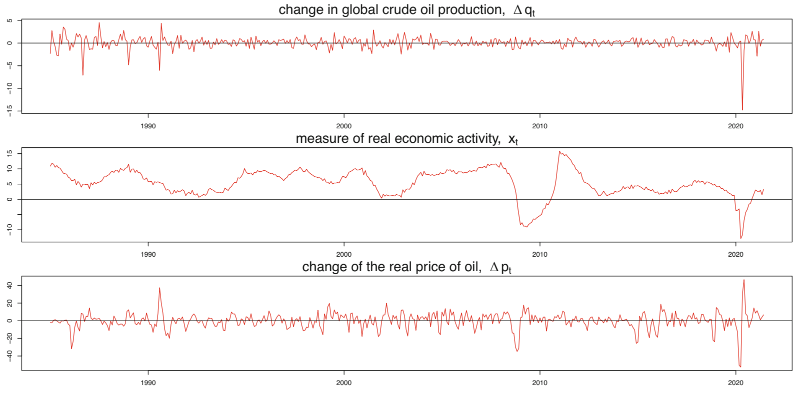

FIGURE A1 The three time series of the oil market SVAR model: the change in global crude oil production, Δq_t, a measure of real economic activity, x_t, and the change of the real price of oil, Δp_t

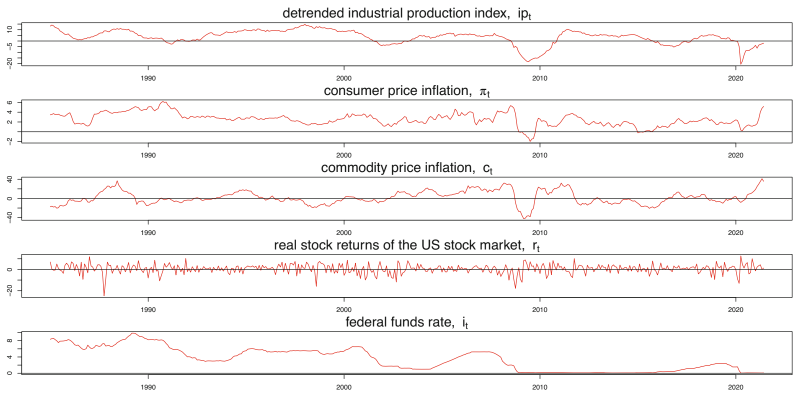

FIGURE A2 The five time series of the US economy SVAR model: Detrended industrial production, ip_t, consumer price inflation, π_t, commodity price inflation, c_t, real stock returns of the US stock market, r_t, and the federal funds rate, i_t

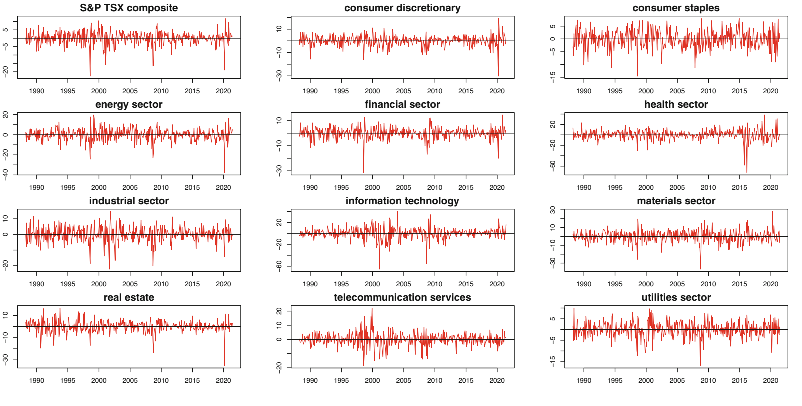

FIGURE A3 Returns net of market fundamentals for the real S&P TSX Composite and the corresponding real Level 1 GICS sector equities

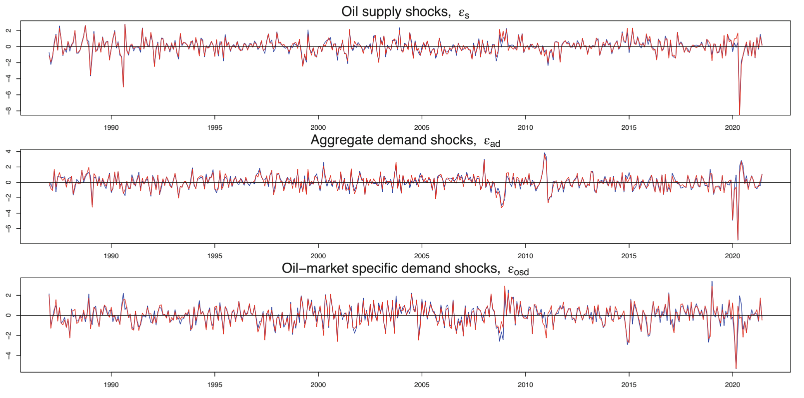

FIGURE A4 Structural shocks comparison of different identification approaches for the oil market model
NOTES: Blue line: shocks of a model identified as a recursive structure. Red line: shocks computed from a model that has been identified through independent components.

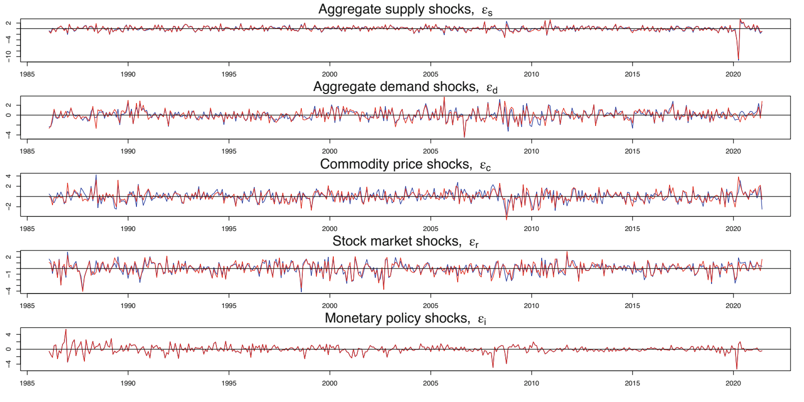

FIGURE A5 Structural shocks comparison of different identification approaches for the US economy model
NOTES: Blue line: shocks of a model identified as Bjørnland and Leitemo (2009). Red line: shocks computed from a model that has been identified through independent components.

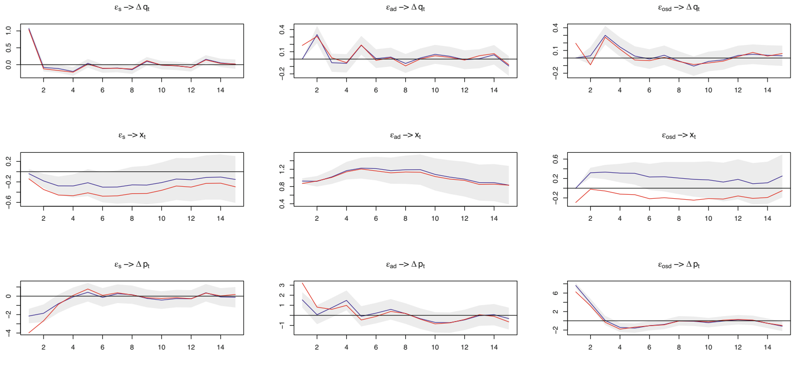

FIGURE A6 Impulse response comparison of different identification approaches
NOTES: Blue line: responses of a model identified as a recursive structure. Red line: responses computed from a model that has been identified through independent components. 95% confidence intervals.

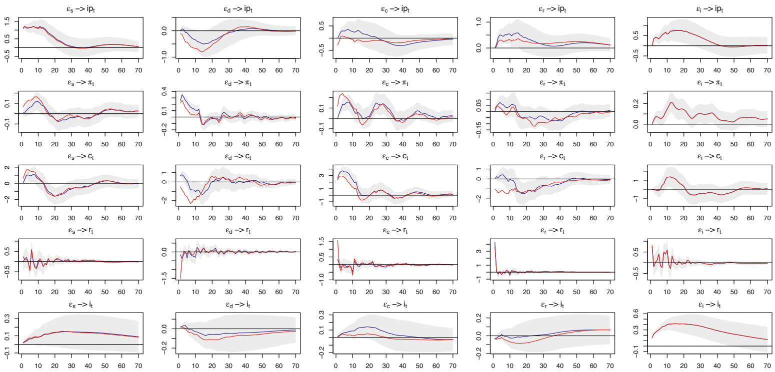

FIGURE A7 Impulse response comparison of different identification approaches
NOTES: Blue line: responses of a model identified as in Bjørnland and Leitemo (2009). Red line: responses computed from a model that has been identified through independent components. 95% confidence intervals.

Supporting information

The data and code that support the findings of this study are available in the Canadian Journal of Economics Dataverse at https://doi.org/10.5683/SP3/FGABHG.

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