UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI "M.FANNO"

CORSO DI LAUREA MAGISTRALE IN
BUSINESS ADMINISTRATION

TESI DI LAUREA

**"THE EFFECTS OF GLOBAL DISASTER RISK:
AN EMPIRICAL ANALYSIS"**

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ANNO ACCADEMICO 2015 – 2016

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Firma dello studente

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ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to everyone who supported me throughout my University course.

I would first like to thank Professor Giovanni Caggiano for the time he has dedicated to me over these last few months, and for his precious comments and suggestions.

A special thanks to my parents, my family, and in particular to my grandmother, for all their unconditional love and encouragement: without them I would never have reached this point.

I would also like to thank my friends, who have made these years so much easier and more enjoyable, and last but not least Marco, who is close to me and "deflates" my worries in every moment necessary.

ABSTRACT

This empirical analysis investigates the effects of disaster risk shocks in open economies, and to which extent a heterogeneous exposure to disaster risk can be considered as an explanation for differences in their impact across countries.

Results appear in line with the main theoretical models proposed in the literature, since they suggest a recession following a disaster shock, and show an interest rate evolution consistent with the hypothesis of an increase in precautionary savings from risk-averse investors when disaster risk increases.

Attention is given to exchange rate dynamics, countries' relative riskiness and their relation with interest rates.

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1 Introduction

The aim of this thesis is to investigate the effects of disaster risk shocks in open economies, and to which extent a different level of exposure to disaster risk can be considered an explanation for differences in macroeconomic dynamics and asset pricing facts across countries.

Since Rietz (1988), who presented a model based on the possibility of rare disasters as determinant of asset prices, and Barro (2006), who measured the frequency and sizes of disasters during the twentieth century, finding them large enough to make Rietz's hypothesis plausible, many works have proposed disaster risk phenomenon to explain business cycles, investment dynamics and asset prices fluctuations. Some example are Gabaix (2011, 2012), Gourio (2008a, 2008b, 2012, 2013), Backus, Chernov and Martin (2011), Longstaff and Piazzesi (2004), Wachter (2013).

This thesis is closely related to the recent work of Gourio et al. (2013), since here attention is given not only to disaster risk effects, but also to country-specific riskiness and its possible determinants, in relation with interest rate levels.

Moreover, of enormous relevance for this work is the recent literature concerning the phenomenon of uncertainty and its effects on the economy, since the change in the probability of disaster can be considered "a particular shock to uncertainty" (Gourio, 2013), giving evidence to the fact that this two phenomena (even if distinct for the mechanism through which they affect macroeconomic dynamics and their implications) are closely related. Some examples can be found in Bloom (2009), Baker and Bloom (2013), Baker, Bloom and Davis (2013), Gourio et al. (2015), Orlik and Veldkamp (2014).

Through an empirical (VAR) analysis, with a methodology which follows Bloom (2009), we investigate the impact of time-varying risk on exchange rates, inflation, industrial production and interest rates in the G7 countries.

With disaster risk being a latent variable, the proxy we adopt for it is the volatility of the MSCI World Index, which appears aligned with indicators of uncertainty commonly-used in the literature, first of all the Chicago Board Options Exchange Volatility Index (VIX index, see CBOE, 2004) with a correlation of 0.87.

The results of our analysis are the following. At first, we find our empirical estimates in line with the main theoretical models, which suggest disaster risk as a determinant of macroeconomic dynamics and asset prices. VARs responses show a recessionary effect following volatility shocks in all the countries included in the analysis, with a drop in industrial production and consumer prices. The interest rates decrease, a fact that can be explained in the light of disaster risk theories as a shift of preference of risk-averse agents toward assets perceived safer (government bonds instead of corporate bonds). Also the evolution of industrial production, that after some periods shows a positive growth, is consistent with works speculating a recovery after disaster (as Gourinchas et al., 2010, or Gourio 2008b, 2008c).

The results related to countries' relative riskiness are also interesting. Following Gourio et al. (2013), the disaster risk is assumed to be global, and differences in its impact among countries can be explained as a consequence of heterogeneity in their exposure to such risk (perhaps due to different industry compositions or financial structure). In their model, countries with a lower interest rate level are the ones considered more exposed to risk, because of "higher demand for precautionary savings". These countries should present not only more pronounced negative effects in production and inflation, but also an exchange rate appreciation because "their marginal utility rise more".

Our estimates appear consistent with these assumptions, showing both stronger negative real effects in the economy, and an appreciation in exchange rates of the country with the lower interest rates (Japan in this case). Moreover, while in Gourio et al. (2013) a conflict emerges between their assumption of low interest rate countries as more risky and their observations in the data showing the lower volatile quantities and returns for them (while they should be expected to be the higher), our results suggest that a direct linear relation between low interest rates and riskiness can be found when relative riskiness remains constant. This happens in the case of Japan: it is the only country which has government bond yields below the benchmark -United States- for the entire sample period, so the only one which can be strictly considered a “low interest rates country”, showing marked appreciation and decrease in production. Furthermore, the higher volatility in interest rates of “safer” countries can be explained as flight to quality or flight to liquidity episodes. After an uncertainty shock, risk averse investors (also foreign investors) sell assets considered risky, and purchase safer and more liquid assets, as the government bonds of those countries are supposed to be (phenomena explained for example in Caballero and Kurlat, 2008, Caballero and Krishnamurthy, 2008, Longstaff, 2004).

The robustness of our results is confirmed by a series of checks, consisting in the change of sample periods and variables involved, the use of a different disaster risk indicator, the modification of variables ordering, and finally the exclusion of the Zero Lower Bound from the sample. Analysis without Zero Lower Bound results particularly informative, because it suggests an increase in riskiness determined by monetary policy which becomes unable to offset negative exogenous shocks (consistently with Basu and Bundick, 2015); this lead to exacerbated negative effects of a disaster risk shock and a higher appreciation in its currency.

The thesis is organized as follows. Section 2 provides an overall introduction to disaster risk phenomenon. Section 3 explains more in detail the effects, illustrated in the reference literature, of the disaster risk in the economy. Section 4 presents our empirical analysis (VAR) estimation and results, whose robustness is tested in section 5. Section 6 concludes.

2 An overview on disaster risk

2.1 Reference literature

One of the major puzzles in financial economics is constituted by the equity premium. Mehra and Prescott (1985) show an average equity return too high, and an average risk-free rate too low, determinants of an equity premium that far exceeds the one predicted by the fluctuations observed in the consumption growth rate over U.S. history.

In order to solve this equity premium puzzle, Rietz (1988) tried to capture in his model "the effects of possible, though unlikely, market crashes". In this way, he proposed an explanation based on the possibility of rare disasters as determinant of asset prices: the high return on equity compensates investors for disaster risk, and low risk-free returns are justified.

As an extension of Rietz's work, Barro (2006) measured the frequency and sizes of disasters during the twentieth century (especially War World I, the Great Depression, War World II, post-War World II depressions). It is worth noting that economic disaster risk is defined as an unlikely but severe market crash, or consumption disaster, and could reflect not only economic events, but also wartime destruction, natural disasters, and epidemics of disease: factors capable of both physical and intangible capital destruction. By calibrating the disaster probabilities (but also the sizes of contractions and default probabilities) while looking at these events, he showed that their frequency and magnitude are large enough to make the rare disaster framework, proposed by Rietz, plausible.

The Rietz-Barro hypothesis is formulated with constant intensity of disaster, but in more recent literature (Gabaix 2012) we find the incorporation in the hypothesis of an intensity of disasters that is time-varying. Here there is the attempt to provide a framework to solve some of the main puzzles in macro-finance (as the equity premium, the risk-free rate, the excess volatility puzzle) through the “variable rare disaster model”. This augmentation of the rare disaster hypothesis which considers downward jumps in output of an amount that can vary overtime, allows, as stated by Gabaix, to account for some key features of asset markets, such as volatile price-dividend ratios for stocks, volatile bond risk premia and return predictability, while investigating the impact of time-varying disaster intensity on them.

The concept of disaster risk (with disaster to be intended as “large catastrophic shock”) is also taken into account in the model proposed by Longstaff and Piazzesi (2004), with the aim to analyse the equity premium puzzle. In their model the equity premium is expressed as the sum of three risk components: the standard consumption-risk premium, a corporate-risk premium and an event-risk premium (that is disaster related). Although their model does not generate an equity premium as large as historical observations, it is larger than in the Mehra and Prescott (1985) framework; the event-risk premium results in being a relevant component for its determination, even under conservative assumptions on the disaster probability and the size of its impact on earnings and consumption.

In Longstaff and Piazzesi (2004), the probability of a downward jump is assumed as constant. Wachter (2013) also looks at Rietz (1988) and Barro (2006) to address the equity premium puzzle, but, as well as Gourio (2008a), a consumption disaster probability that is time-varying is considered. Moreover, this model allows to predict the fact that the volatility of stock market returns exceeds the volatility of dividends (volatility puzzle not addressed in Barro and Rietz models).

The relevance of disaster risk, and the way it can affect the economy, have widely been discussed also in Gourio’s works since 2008, as will be shown in the next paragraphs: time-varying disaster risk models allow to investigate (and to replicate) asset prices and macroeconomic quantities’ dynamics.

2.2 Disaster risk and uncertainty

Before starting to observe models which focus on disaster risk, it is worth noting the (close) relation between the phenomenon of disaster risk and uncertainty shocks. Briefly, an increase in the probability of disaster determines an increase in risk and so a greater uncertainty. The intuition is, as explained by Gourio (2012), that “a higher probability of disaster increases the uncertainty, because

(i) whether the disaster will hit is uncertain; (ii) conditional on the disaster occurring, its size is uncertain". However, even if closely related, these phenomena are distinct concepts, and they affect macroeconomic dynamics through very different mechanisms. It is interesting to see these main differences and similarities by looking at some works in which concept and effects of uncertainty are studied, to see that not only the two phenomena differ by definitions, but also because of their implications for the economy (that are not necessarily equal).

The connection between disaster risk and uncertainty is visible for example in Baker and Bloom (2013). In fact, to find the relationship between uncertainty and real GDP growth they use some types of disaster shocks, such as natural disasters, terrorist attacks and unexpected political shocks, as instruments for their stock market proxies of first and second moment (respectively stock market levels and volatility) shocks of business conditions (see figure 1, where their proxies for uncertainty and its counter-cyclicality with growth are reported). They found that these exogenous shocks generate a large increase in stock-market volatility, so in uncertainty; both the first and second moments result in being highly significant in explaining GDP growth, and the second moment shocks seem to account for at least one half of the variation in growth.

However, in the work of Baker and Bloom (2013), disaster risk affects uncertainty only when it is realized: the focus here is on variation of uncertainty following disaster realization, with uncertainty that dramatically increases after major economic and political shocks, and not because of changes in disaster probability. Furthermore, it appears evident that, while uncertainty refers to a second moment shock (as already specified by Bloom (2009), that studies second moment component of major macroeconomic shocks), disaster risk has to be associated with tail events and their probability of realization. We find it in Gourio (2013), where "tail risk", to which the economy is exposed and that can determine a very large downturn, is defined as "low probability events with disastrous consequences", or in Orlik and Veldkamp (2014) (for more details see paragraph 2.3), where the learning process that can generate beliefs about the probability of "extreme, negative outcomes" is described.

This also highlights the fact that an increase in risk probability implies not only more uncertainty about the future economic outlook, but more specifically that there is a higher possibility of future situations which are negative. On the contrary, in the case of uncertainty shocks, expectations about the future are uncertain, so not necessarily bad. Moreover in his work Bloom (2014) underlines the fact that increasing uncertainty can also lead to positive consequences: uncertainty varies because of exogenous shocks, and during recession it appears to endogenously rise further; in the short-run this uncertainty is damaging for investment and hiring, but in the long-

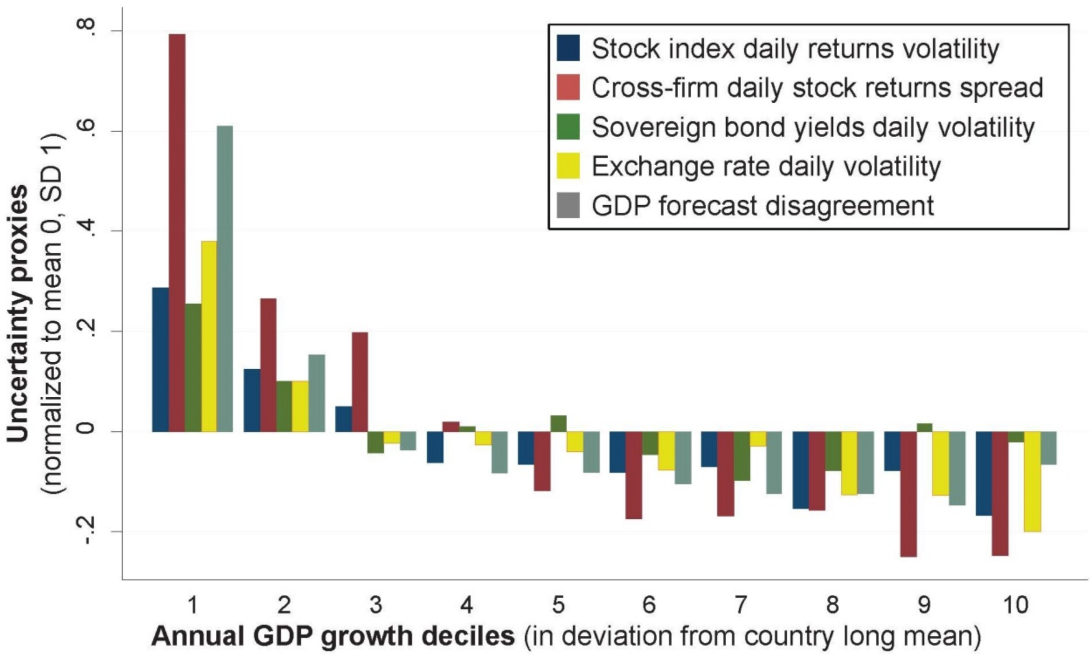

Figure 1 Uncertainty proxies (constructed from unbalanced panel of daily data from 1970 to 2012 from 60 countries) and GDP growth. (From Baker and Bloom, 2013)

run it seems that it can stimulate innovation (since some firms appear to be more willing to innovate if they face a more uncertain future) and so it can help in fostering a recovery.

As previously mentioned, Bloom (2009) studies the negative effect of second moment shocks on output. He provides a framework to analyse the impact of uncertainty shocks, with labour and capital adjustment costs that are jointly estimated, and emphasizes a "wait-and-see" attitude of firms when the uncertainty increases. More in detail, uncertainty shocks that are large and temporary generate short sharp recessions and recoveries: employment and output drop because "higher uncertainty increases the real-option value to waiting", and so causes firms to temporarily pause their investment and hiring. Firms become very cautious in responding to any stimulus because of uncertain business conditions: by not being sufficiently good to hire and invest or sufficiently bad to fire and disinvest, the inaction results in being the optimal behaviour to be adopted. This suggests the possibility of a trade-off between policy "correctness" and "decisiveness": it could be better "to act decisively (but occasionally incorrectly) than to deliberate on policy, generating policy-induced uncertainty". Moreover, as specified by Bloom et al. (2014), the increased uncertainty reduces aggregate productivity growth. This happens because the previously mentioned drop in investment and hiring reduces the rate of reallocation (which plays an important role as a driver of aggregate productivity, according to Foster, Haltiwanger, and Krizan, 2000), from low to high productivity firms: "productive plants pause expanding and unproductive plants pause contracting". Finally, the fact that firms tend to postpone action also determines the temporary lack of effectiveness of a possible expansionary policy (see Bloom et al., 2014). Since the uncertainty shock considered is temporary, it is interesting to observe what happens when uncertainty decreases: also the effects of shocks result to be temporary, and the recovery is fast, with employment and output bouncing back, as well as productivity growth, due to the increasing rate of reallocation.

In summary, as already referred to, the increase in disaster probability determines an increase in aggregate uncertainty regarding productivity and depreciation. However, as stated by Gourio (2013), by considering a model with the introduction of the variation in disaster probability as determinant of macroeconomic dynamics, the mechanism through which it affects the economy is very different (as will be shown later in paragraph 3.2). At first, briefly, the recession following a shock to uncertainty is not a consequence of a "wait-and-see" response by firms, but it is due to risk-averse consumers that are led to invest less in risky capital, because of lower risk-adjusted return on investment (the expected return on capital decreases, because of the future productivity that is expected to be lower, as well as a greater expectation of depreciation); also the volatility of real interest rate increases, and (for the increasing risk premium on capital) the overall response of the economy to a disaster probability shock closely depends on the investors' risk aversion. Furthermore, the focus is on aggregate uncertainty, so there is an high correlation of firm defaults while no consequences at idiosyncratic level (as in Fernandez-Villaverde et al., 2011, who propose a DSGE model to study the effects of uncertainty shocks, showing how the time-varying volatility of real interest rates is an important force behind the size and pattern of business cycle fluctuations of emerging economies). Last, in the model proposed by Gourio (2013), business cycle dynamics happen even without change in total factor productivity (while in Bloom's works, uncertainty shocks always cause the reduction in endogenous aggregate TFP), which results to be attractive since "some recessions, such as the recent financial crisis, occur without significant change in TFP".

It is also interesting to notice that Gourio et al. (2015) consider the impact of uncertainty not only on macroeconomic variables, but also on capital flows: they observe that the amount of uncertainty allows predict future capital inflows and net inflows, with results that are an extension to the ones presented by Gourio et al. (2013) in reference to the effect of variation in disaster risk in open economies (their work will be shown more in detail in paragraph 3.3).

Finally, disaster risk and uncertainty are both variables which are unobservable, and difficulties arise in regard to their measure, also because of their relation (which could cause confusion in the use of proxies for them, as explained in the next paragraph).

2.3 Disaster risk indicators

An extremely relevant issue related to disaster risk, and more specifically to disaster probability and its variations, is the fact that it is a latent variable, therefore impossible to be directly observed. An objective measure does not exist, and the use of proxies for it is necessary; this leads to problems (especially in models that consider a disaster probability which is time-varying) of correctness of model calibration and of proxy adopted.

The first issue in the models with disaster risk regards the size and the average probability of disaster; fundamental works which attempt to provide estimates of the value of these parameters are the ones by Barro (2006) and Barro et Ursua (2008).

More specifically, Barro (2006) calibrates his model using the observed probability distribution for economic disasters in the twentieth century, that reflects economic events, natural disasters, epidemics of disease (the more relevant ones considered are World War I, the Great Depression, and World War II). In particular, by using long-term international GDP data (from Maddison, 2003) for thirty-five countries, he applies a peak-to-trough method to isolate economic crises, defined as cumulative declines in GDP of at least 15 percent (in a range between 15 to 64 percent). He finds a frequency of disasters of 60 occurrences over 100 years, corresponding to a probability of disaster p = 1.7 percent a year (constant overtime and across countries), and an average b, the size of contraction in output, of 0.29 percent. However, the value of disaster parameters proposed by Barro and Ursua (2008) and Barro and Jin (2011) are different: with data starting at 1870 on real per capita personal consumer expenditure, C, of twenty-four countries and GDP of thirty-six countries, they find a disaster probability of 3.5 percent per year, and a mean size of 21-22 percent. These differences are due to the fact that in the latter work there is the inclusion of disaster sizes between 10 and 15 percent (so there are more occurrences, and with an average lower downward jump in output).

These papers have demonstrated the quantitative relevance of rare events, and the disaster probabilities, the sizes of contractions (fall in real per capita GDP), the recovery rate and the default probabilities which they have assessed are used as calibration parameters for the modelling of disasters in the main works proposing models with disaster risk. In fact we find this, for example, in Gourinchas (2010), Gabaix (2012), Gourio (2012, 2013), Gourio et al. (2013), where the disaster probability and the frequency distribution of disaster sizes follow Barro (2006) and Barro and Ursua (2008).

In models that focus on disaster risk which is time-varying, it is necessary to measure a disaster probability which is also time-varying; being it unobservable, an appropriate proxy is needed. Since also uncertainty is not directly observed, and it is shown to be connected to risk, it could be interesting to observe what the approach is to this issue in works related to uncertainty.

As already mentioned, Baker and Bloom (2013) (see figure 1) show the proxies they use for uncertainty. Their main uncertainty indicator is stock market volatility, but since its appropriateness is not ascertainable, they try to use also cross-firm stock-price returns dispersion, bond-price volatility, exchange rate volatility and forecaster disagreement measures (finding similar results). This paper also gives evidence to the importance of newspaper coverage for uncertainty measure. Here it is used to confirm the unpredictability of the events considered, but in Baker, Bloom and Davis (2013) (see later in the paragraph) also to create a proper policy uncertainty index. In Baker and Bloom (2013) analysis, the interest is on those that are external shocks, and not endogenous events; their identification strategy focuses on surprise events, and to highlight this they weight the events by looking at the average increase in newspaper coverage (Google News daily articles reporting the name of the impacted country) for fifteen days before and after the shocks. As clearly shown in figure 2, there is an upward jump on the day of the events, while no increase in newspaper mention of the countries of occurrence in the days immediately before, and an increase of 39% over the fifteen days after that. On the contrary, by considering predictable media-important events, as general elections, World Cup or Super Bowl, they find no jump in newspaper coverage around them.

In Gourio et al (2015) they measure uncertainty using the realized aggregate stock market volatility return in each country, which is “the canonical measure for uncertainty”, as in Bloom (2009). In this Bloom’s work we also find the Chicago Board of Options Exchange VXO index of percentage implied volatility, on a hypothetical at the money S&P100 option 30 days to expiration. More details on this proxy and Bloom’s (2009) analysis are provided in paragraph 5.2, where it is considered to check the robustness of the estimates from our analysis, presented in chapter 4. Moreover, Bloom, Bond, and Van Reenen (2007) showed volatility in stock to be significantly correlated with other alternative proxies proposed, as real sales growth and the cross-sectional dispersion across financial analysts’ forecasts.

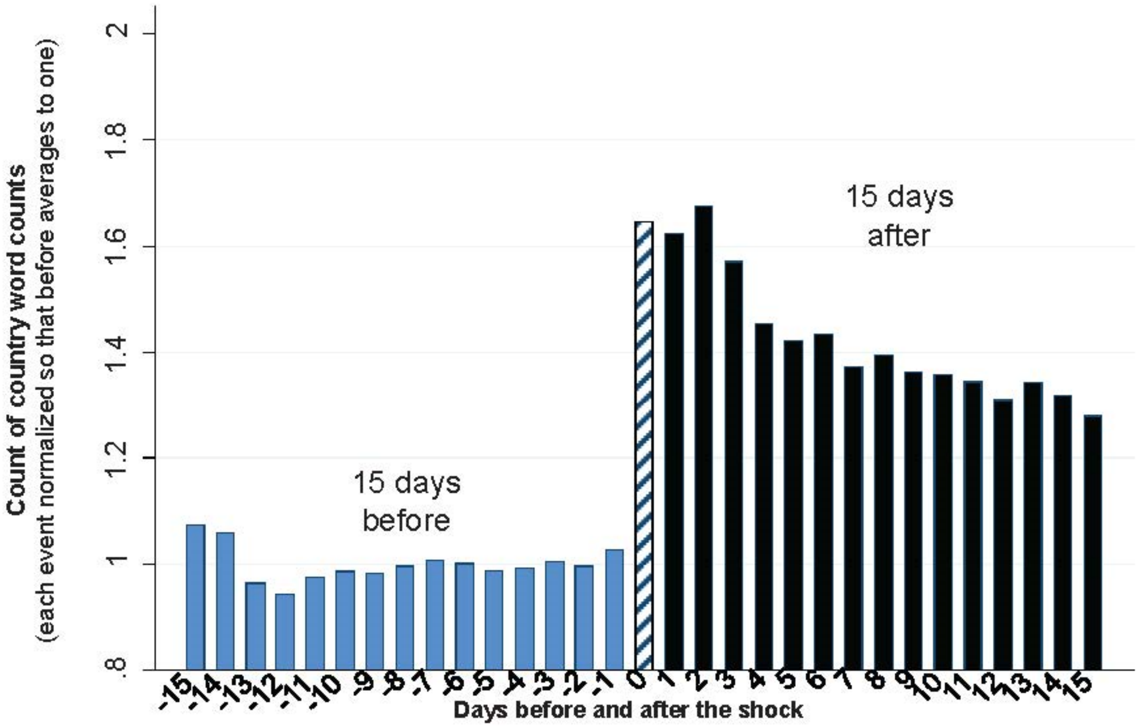

Figure 2 Newspaper daily word counts for the affected country (daily counts of the name of the impacted country) in the one month around the natural disaster, political or terrorist shock. (From Baker and Bloom, 2013)

Orlik and Veldkamp (2014) propose a different way for measuring uncertainty. In their model they describe how people form beliefs, since they argue that changes in people's beliefs, caused by the learning about the distribution of economic outcomes, are determinants of financial and business cycle fluctuations. They assume that "agents use everyday events to revise their beliefs about probabilities over the entire state space", and also their perception of tail risk (the probability of an extreme negative event, which they call "black swan risk") vary on a daily basis. This is the main source of uncertainty fluctuations, where uncertainty is defined as the square root of the conditional variance of economic outcomes distribution, about which agents form believes (and so forecasts on future outcomes, conditional on their information set).

The uncertainty indicators which result to be more correlated with Orlik and Veldkamp's measure are Jurado, Ludvigson, and Ng's (2015) macro uncertainty index (a stochastic volatility measure, which aggregates conditional volatilities of the unforeseeable component of the future value of a large set of time series) , Baker, Bloom, and Davis's (2013) policy uncertainty index and the market volatility index (VIX).

Baker, Bloom and Davis (2013) develop a new measure of economic policy uncertainty (EPU) from three underlying components (capturing "three aspects of economic uncertainty"): one reflect the number and revenue effects of federal tax provisions set to expire in future years, one is the disagreement among economic forecasters about policy relevant variables, and the main one is the newspaper coverage of policy-related economic uncertainty. To construct their news-based index, they rely on automated text-search results for nationals and local U.S. newspapers since 1985, to find articles related to economic policy uncertainty, and use their frequency "as an indicator for the intensity of concerns about economic policy uncertainty". To evaluate their automated news-based EPU index, they compared it to an index based on the human readings (human audit of 4,300 newspaper articles), and to discussions about uncertainty in the Beige Book (the Summary of Commentary on Current Economic Conditions by Federal Reserve District, prepared before every Federal Open Market Committee) finding close correspondence. Moreover, their news-based index of equity market uncertainty and the monthly average of the market-based VIX values are plotted in figure 3; their comparison shows an high correlation between the two series.

About the market volatility index (VIX), it measures the 30-day implied volatility on the S&P500 index, and it is provided by the Chicago Board of Options and Exchange (for more details about the index and its calculation, see CBOE, 2004). It is a widely used proxy of uncertainty, but we find it used also as a proxy for disaster probability (and this fact makes it extremely visible not

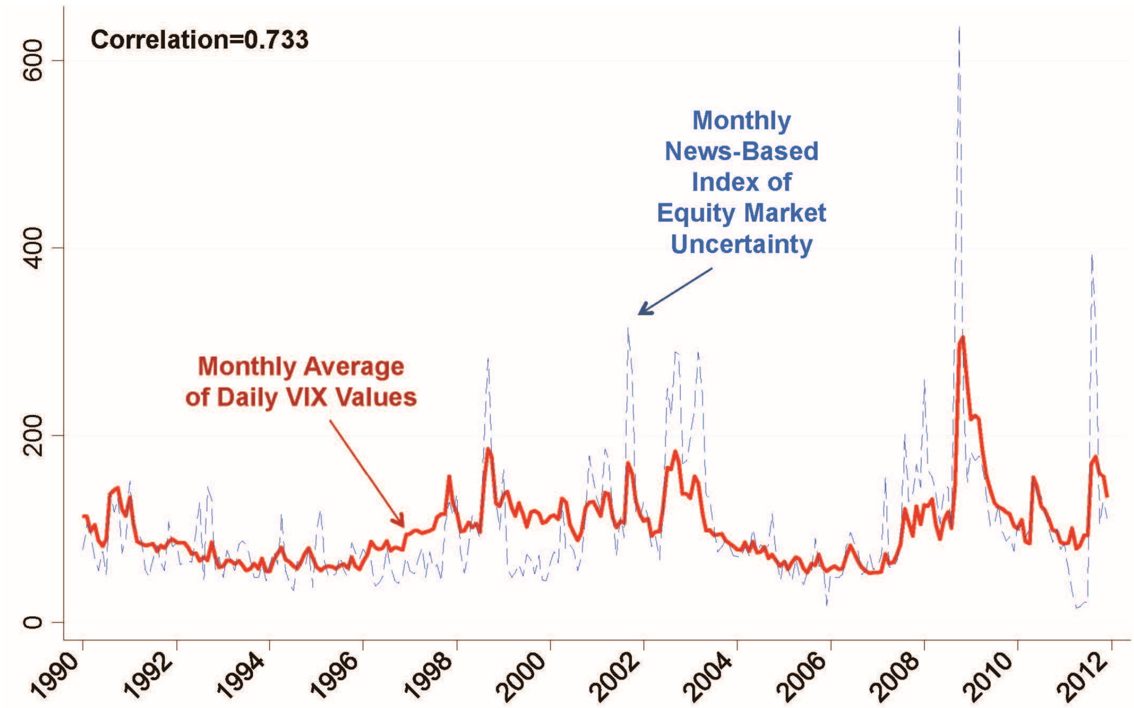

Figure 3 News-based index of equity market uncertainty compared to market-based VIX (both normalized to a mean of 100 over the period), from January 1990 to December 2012. (From Baker, Bloom and Davis, 2013)

only the connection between disaster risk and uncertainty, but, more importantly, the problem of the lack of a proper and objective measure for them).

Specifically, in the model proposed by Gourio (2012), to analyse the effects on output in response to a change in disaster risk, a one-standard deviation shock to VIX is used to represent the variation in disaster probability.

More generally, as in Gourio et al. (2013), disaster probabilities are approximated by equity market volatility. They compare the implied volatilities from put options, risk reversals, and the VIX Index (focusing on “implied volatilities measured out-of-the-money, i.e., for strikes that differ from the value of the S&P 500 index”), finding high correlation. They support their interpretation of shocks to equity volatility as shocks to disaster probabilities by showing that aggregate volatility shocks have a significant effect on macroeconomic aggregates; moreover this interpretation is consistent with their model since disaster probability is assumed common across countries and there is a substantial co-movement of volatility worldwide. In the data, increases in global volatility (they look at G7 countries simultaneously) are associated to falls in industrial production and rises in unemployment This is coherent with the assumptions of their model and supports the use of equity volatility as proxy for disaster probability.

3 Disaster risk effects in macroeconomic models

Having presented an overview of the disaster risk phenomenon and its relations with uncertainty (also pointing out differences and similarities between them), it would be interesting to observe how the possibility of disaster could be embedded in macroeconomic models (so under which assumptions, and the main issues to deal with in doing so), as well as what could be the effects, illustrated in the reference literature, of the disaster risk in an economy.

Since our empirical analysis, whose setting and results will be presented in the following chapter, has been performed with the aim to investigate macroeconomic, asset prices and exchange rate dynamics in the light of disaster risk and different countries' exposure to such risk, it is relevant to observe which estimates (and how they are identified) arise from the main model in the literature in this regard.

Therefore, after the presentation of some works showing examples of disaster risk introduction in macroeconomic models, the chapter illustrates the main models aimed at the study of disaster risk effects in closed economies (so, what happens generally because of a disaster risk shock, as variation in the disaster probability, without taking into account cross-country dynamics), and in open economies. This latter case is the more interesting for the aim of this thesis, because the hypothesis of heterogeneous exposure of countries to a global disaster risk is considered.

3.1 Introduction of disaster risk in macroeconomic models

In Gourio (2008a) the introduction of time-varying risk premia in consumption-based model is proposed. He specifies a model in which the probability of a disaster varies over time, as well as the size of disaster. This model is solved numerically, assuming recursive preferences, since with power utility the model is consistent only when the potential size of dividend disaster is time-varying, while the potential size of consumption disaster remains constant, and this assumption could result in not being empirically reasonable (see Longstaff and Piazzesi, 2004). The introduction of "some variation over time in the riskiness of the economy" seems reasonable, as the perceived risk of a rare, large downward jump strictly depends on the historical period and economical and political situations. In addition, he uses Epstein-Zin preferences (see Epstein and Zin, 1986): to allow for Epstein-Zin utility solves the difficulty for the disaster model to fit the facts on predictability of stock returns and excess stock returns. In case of a high disaster probability, the risk-free rate decreases, because it leads to a reduction in expected growth and an increase in risk, so agents tends to save more in less risky assets. In the model with power utility, the risk-free rate appears too volatile, with a reduction in risk-free rate being higher than the increase in equity premium, and a too low variance of P-D ratios. On the other hand, with Epstein-Zin utility the risk aversion is separate from IES (risk aversion is assumed to be higher than the inverse of the IES, so agents prefer an early resolution for uncertainty), and the IES parameter can be used to control the volatility of the risk-free rate.

Generally, even if it has to be assumed an IES above unity, which could determine an excessive reduction in equity premium if disasters are not fully permanent, as explained in Gourio (2008b) (more details are provided in paragraph 4.3), this model can qualitatively (and quantitatively if probability of disaster is assume to be highly persistent and volatile) replicate asset pricing dynamics, with results that are closely related to the ones presented by Wachter (2013). More interesting and noticeable, it proposes a simple way to extend the standard real business cycle framework through the introduction of disaster probability with persistent changes.

Also Gabaix (2011) proposed a model in which he includes the possibility of a disaster in a traditional economy without disaster (a process that he calls "disasterization"), with the aim to fix the asset pricing properties of traditional macroeconomic models. His approach consists in starting from a real business cycle model, that is quantitatively reasonably successful, and in the construction of a new economy including the disaster risk. In this way, he provides a general framework, a starting point that shows how to add disaster probability in an economy and that is capable of generating realistic macro dynamics. It also makes it possible to have an idea of what happens because of the inclusion of the risk, and so to see its effects on asset pricing by comparing the two economies (the original and the "disasterized" one). In the model, the economies maintain the same business cycle properties, and variables such as consumption, capital and investments do not change, but are subject to a rescaling after disasters (they are therefore multiplied by a factor D_t representative of the cumulative disaster). However, asset prices changes: disaster risk is a part of risk premia, and the possibility of disaster is revealed by a higher equity premium. Disaster here has to be intended as a shock both to productivity and capital, with the drop in productivity resulting from also political and institutional disruptions. The shock is supposed to hit equally productivity and capital, that fall by the same amount, while in Gourio (2012) the falls in capital and productivity are not equal (as will be shown in the next chapter). This assumption is taken by Gabaix mainly for convenience reason, to provide a clear benchmark, but it is consistent with the possibility of no recoveries after a disaster, as evidenced by Cerra and Saxena (2008) or by Barro, Nakamura, Steinsson, and Ursua (2013), that find output losses only partially reversed.

With Gabaix model it is possible to derive bond yield curve and stock prices, while keeping macroeconomic side constant and allowing to have both stable interest rate and a varying equity premium. Considering the bond pricing, it is assumed that inflation during a disaster jumps up, making nominal bonds riskier, that results in a positively sloped yield curve and a positive bond risk premia. The variations in this curve are not determined directly by the changes in disaster probability and intensity, but mainly by variation in inflation and inflation risk. There is the introduction in the model of an inflation disaster risk premium, to reflect the dimension of the jump in inflation in case of disaster, and the consequent increase in riskiness of long term bonds. Also, an extension to the model is proposed, consisting in the disasterization of other economies, such as monetary economies with sticky prices (where real wages and monetary stock are scaled from disaster) and economies with habits (where people downwardly revise their habits in the case of disaster).

Generally, this model can be considered a good starting point to study disaster risk in an economy, with disaster literature and RBC modelling of business cycle fitting together. Also Gourio (2012) draws on this model but, as already mentioned, he takes a different direction, by considering a case in which disasters cause a fall in capital and in productivity that are not equal.

3.2 Effects of disaster risk in closed economies

One of the most relevant model investigating disaster risk effects is proposed by Gourio (2012), which draws on recent research related to rare event risk, as Rietz (1988), Barro (2006), Gabaix (2011, 2012), Wachter (2013), Backus, Chernov and Martin (2011) (the latter uses equity index options to infer the distribution of asset returns, and includes extreme events, like the disasters apparent in macroeconomic data). Gourio (2012) considers time-varying disaster risk and recursive preferences (as previously in Gourio 2008a), and generates an “empirically reasonable connection between risk premia and output or investment”; he suggests that business cycle and asset prices are connected with changes in disaster risk, and this model matches the relations existing between macroeconomic quantities and asset prices well. Here disaster has to be intended as a large macroeconomic shock, which is modelled as a combination of a productivity shock and a depreciation shock to the capital stock (and looking at the work of Kehoe and Prescott (2007), it seems that during economic depressions the total factor productivity is an important contributor, while the capital factor seems to play a relatively minor role). The reduction in productivity can be due to an inefficient capital allocation because of poor government policies or disruption in financial intermediation. Regarding the capital that is destroyed, it is both tangible and intangible (such as human capital, or specialized capital goods becoming worthless). This definition of capital is necessary, since otherwise, by considering only the physical capital, a capital destruction following an economic depression would not be so realistic, as in the case of a war or some kind of natural disaster.

After modelling the disaster, it is possible to replicate the dynamics of consumption, output and other macroeconomic quantities during a disaster. Furthermore, and more interestingly, the model tries to investigate what the effects on the economy are, due not to a disaster realization, but to changes in disaster risk. An increase in the disaster probability p_t (that is the probability, in each period, of a switch of the economy from a normal state to a “disaster state”), is capable of affecting employment, output, investment, stock prices and interest rates by lowering them, and to determine an increase in the expected return on risky assets. Moreover, this higher risk leads not only to higher risk premia, but also to an increasing demand for precautionary savings from investors (which are supposed to be risk averse), and a consequent fall in the yield on less risky assets. This probability of disaster is assumed stochastic. If it were assumed as constant, the macroeconomic quantities would be the same as those implied by a model without disaster: the only difference would be the value of the discount factor β, that accounts for the lower risk-adjusted return on capital.

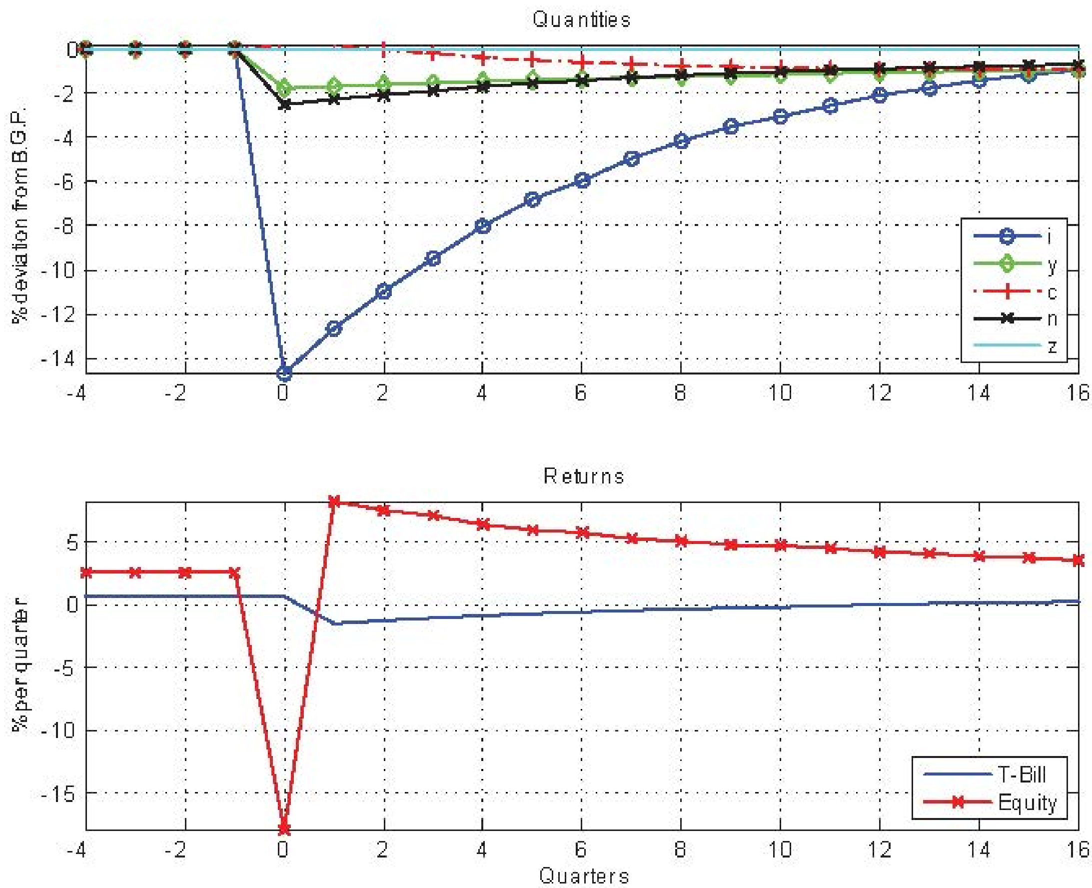

Figure 4 Impulse response function to a temporary increase in disaster probability from 0.72% to 2%, in the model extended to imply perfect co-movement of key macroeconomic aggregates. Top panel: macroeconomic quantities; bottom panel: asset returns. (From Gourio, 2012)

Another element to consider is the number of periods hit by the disaster, as well as the possibility of future recoveries. In the model is included a probability q, that represents the probability for an economy which has entered in disaster state to remain there the following period, since (as in Gourio, 2008b and Barro et al., 2013) data seems to suggest that disasters generally occur over several years, and there are at least partial recoveries (and we will see later in paragraph 4.3 that the implications for the economy could be different if models accounts for recoveries after disasters or not).

These dynamics are clearly illustrated in figure 4. Here it is possible to observe the effects of an increase in disaster probability, with a model extended to imply perfect co-movement of key macroeconomic aggregates. If the productivity shocks are not permanent, the macro quantities initially fall, then the model economy has a recovery to its initial steady-state; regarding asset pricing facts, the risk premium increase, due to both the lowering of risk-free rate and the increase in equity returns.

Gourio's model with disaster probability and shocks that are partly transitory, allows to replicate not only the level and the volatility, but also the counter-cyclicality of risk premia (for empirical evidence on counter-cyclicality of risk premia see Cochrane, 2007). The classic RBC model or the DSGE model fail to capture it, and are less effective also in accounting for macroeconomic quantities. As visible in figure 5, the model, in addition to showing the implications of variations in disaster risk for business cycle quantities and asset prices, matches well the relations between macroeconomic aggregates and asset prices. Here the covariance between GDP and excess stock returns is reported, and while the benchmark model (so after numerical calibration and numerical analysis, which has lead it to be capable of generating disasters coherent with the data) mimics the data, the RBC model fails to capture any variation in risk premia due to lowering output. It happens especially in the right-side of the graph, when the covariance is negative and low output is associated with high future return.

Another aspect of disaster risk that this model highlights is the fact that it can be interpreted as a rational expectation, but the results are also consistent with a "behavioural" interpretation of the model. In other words, the disaster mechanism can be viewed through this alternative perspective: disaster probability may vary overtime because it captures agents' beliefs, which are time-varying

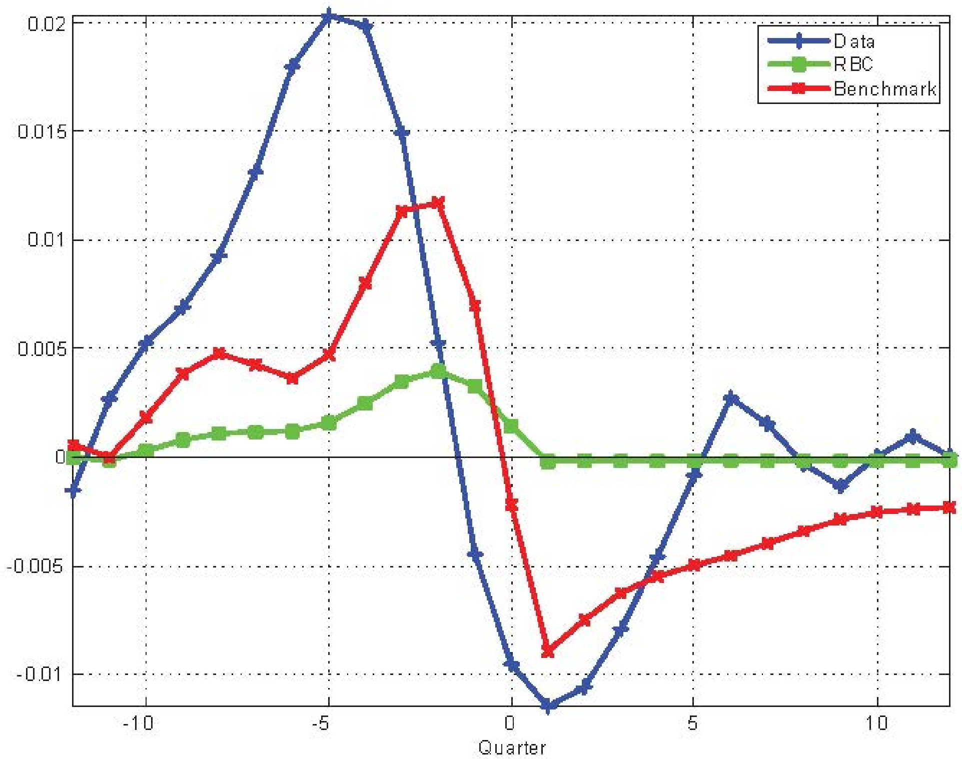

Figure 5 Cross-covariogram of detrended GDP and excess stock returns in the data, in the RBC model, and in the benchmark model. (Source Gourio, 2012)

and may be irrational and subjective (so biased or excessively volatile). The time-varying disaster risk is therefore representative of "the apparent oscillation between periods of optimism where expected growth is high and uncertainty is low (such as the Great Moderation) vs. periods of low expected growth and high uncertainty (such as 2008-IV)" (Gourio 2012), and this interpretation is very close to the agents' "time-varying perception of risk (rational or irrational) of disaster", mentioned by Gabaix (2012).

A direct (but significant) extension of this model is represented by Gourio (2013). The focus here is on the key features of credit spreads, and its implication for the business cycle (this paper is related with Philippon (2009), who demonstrates the link between bond prices and real investment, by adopting a market-based measure of value of capital relative to its replacement cost – Tobin's q, see Tobin (1969) - constructed from corporate bond prices). More in detail, Gourio in this work "embeds a trade-off theory of capital structure - in which the choice of defaultable debt depends on taxes and bankruptcy costs - into a real business cycle model", and adds the risk of economic disaster. Coherently with Gourio (2012), the risk is assumed to be exogenously time-varying, and captures the possibility of a very large recession. Moreover, in this case the model has to take into account not only the aggregate risk, so a common risk factor, but also an idiosyncratic component since it heavily affects the probability of default (especially in periods when the probability of aggregate disaster is low) and as a consequence the credit spread and leverage choices. Idiosyncratic and common risk factors are assumed independent.

This work is interesting since its approach to evaluate credit spread dynamics as influenced by disaster risk seems reasonable in the light of facts stressed in the recent financial literature. In particular, credit spreads appear to be larger than expected credit losses (which are the expected loss in case of default, weighted for default probability). This "credit spread puzzle" is emphasized for example in Huang and Huang (2003), which provide a framework for understanding the credit risk premium, and investigate on how much of the corporate-Treasury yield spread is actually attributable to credit risk. Moreover, the movements of credit spread, as well as the movement correlated with investments, appears to mainly depend on corporate bond risk premium. In particular, in Gilchrist and Zakrajsek (2012) the relationship between credit spreads and economic activity is examined, and it results that excess bond premium has substantial predictive content for the growth of investments (they are negatively correlated: positive shocks to the excess bond premium lead to economically and statistically significant declines in investment).

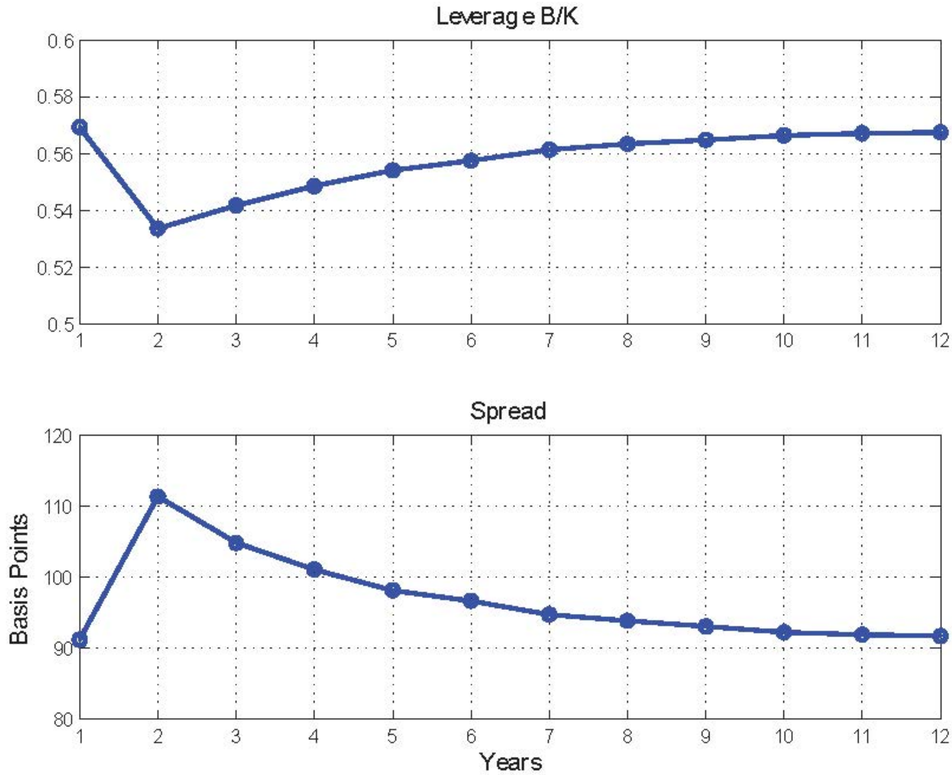

Figure 6 Impulse response of leverage and credit spreads to a one-standard deviation increase in the probability of disaster. (From Gourio, 2013)

So, to draw upon a disaster risk model seems a coherent choice, since changes in credit spreads are mostly driven by variation in the risk premium (rather than by variation in expected default losses): corporate bonds are safe in normal time, and risk premium is supposed to reflect compensation for bearing the risk of rare events which can determine a very large economic downturn. We find a similar approach also in Bhamra and Strebulaev (2012): in their paper they investigate how rare disasters affect endogenous default and capital structure decisions by firms and so, as a consequence, how these corporate financial decisions affect the way in which rare disasters impact credit spreads, leverage and the equity risk premium.

The above-mentioned facts regarding credit spread can be interpreted from a different point of view: the variations could reflect a time-varying intermediation wedge rather than an aggregate risk premium. We find this interpretation in Brunnermeier and Sannikov (2012) or in He and Krishnamurthy (2013), who model the dynamics of risk premia during crises in asset markets where the marginal investor is a financial intermediary, and underline the relevance of financial frictions. However, as argued by Gourio (2013), "corporate bonds are not exotic assets that *have* to be intermediated", so a risk premium explanation seems to result more attractive.

In Gourio (2013) rare disasters are modelled as instantaneous permanent jumps, that entails a total factor productivity and a capital shock; during disasters the realized return on capital is low, as well as the consumption and the marginal utility of consumption (the results regarding macroeconomic implication of variation in disaster probability p_t mirror Gourio, 2012). Since focus here is on credit spread, it is interesting to observe the related results: as in the data, credit spreads are large, volatile and countercyclical, and these features are determined mainly by risk premium than expected credit losses.

In figure 6 how credit spread and leverage react in response to an exogenous increase in disaster probability is represented; there is a substantial increase in credit spread, going with a deleveraging from firms: the model generates the “correct negative co-movement of investments and credit spreads”. With a higher disaster probability, the probability of default becomes higher too if leverage is kept constant, but with deleveraging this effect is counterbalanced. Nevertheless, the default now is expected to be mainly due to aggregate shock (not to idiosyncratic shock: as shown in figure 7, the expected default appears more correlated between firms as the disaster probability rises, and this increase in correlation is mitigated only when firms reduce leverage), so agents find corporate bond a less attractive investment, and a higher credit spread is required. The higher expected discounted bankruptcy cost therefore increases the cost of capital, and firms (which by substituting equity for debt lose the related tax shield, too) cut back on investments. This results are coherent with Bhamra and Strebulaev (2012), who find that the possibility of rare disasters makes firms more conservative in their financial policy, leading to lower leverage ratios, together with larger credit spreads and equity risk premia.

Before concluding, it has to be notice, as we have briefly mentioned above, that disaster risk effects are found to be dependent on the fact that they are considered permanent or not (the consequences for the economy tend to be of lower magnitude if the probability of a recovery is higher), but it will be explained more in detail in paragraph 4.3 while looking at results of our VAR.

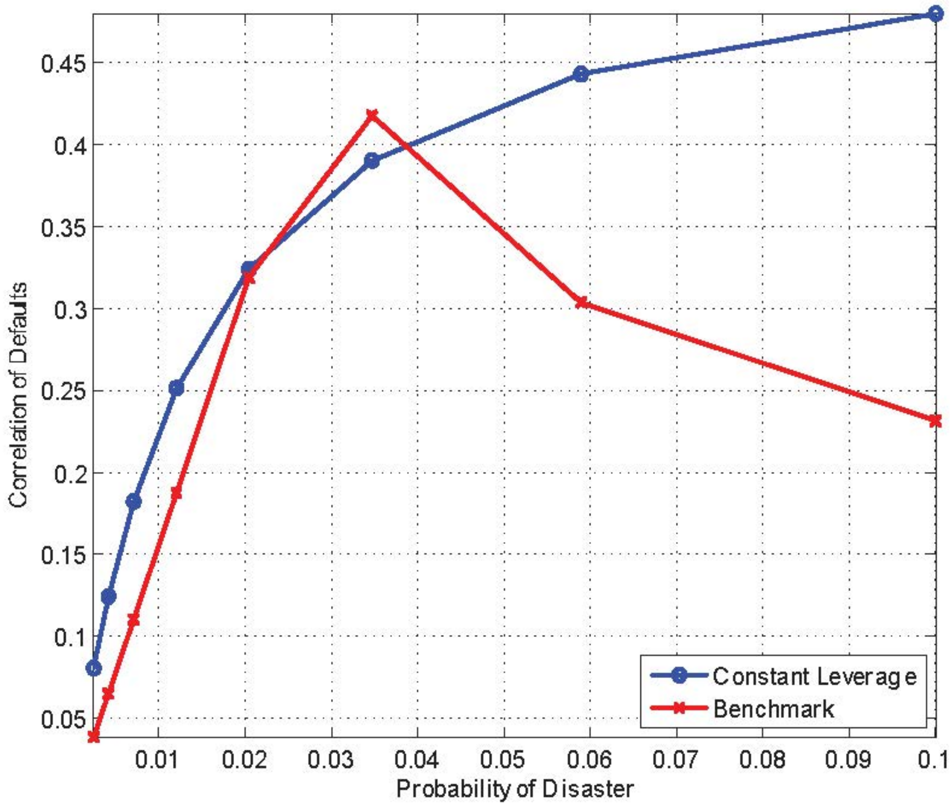

Figure 7 Time-varying systematic risk. Correlation of defaults across firms, as a function of the disaster probability, for the benchmark model and for the model with constant leverage. (From Gourio, 2013)

3.3 Effects of disaster risk in open economies

A model with the introduction of disaster risk could also account for exchange rate puzzle (exchange rates that present high volatility and correlation across countries and with interest rates, features that DSGE models are not able to reproduce). This is the purpose of the work of Gourio et al. (2013), with a two-country, one-good international RBC model, enriched with disaster probability.

This work is closely related to the studies by Farhi and Gabaix (2008) and Guo (2009): they try to explain classic exchange rate puzzle and the connection between exchange rates and stock market movement, with standard open-economy general equilibrium models in which disaster risk is introduced, with disaster probability that is time-varying and different riskiness across countries. It is closely related also to the model of Gourio (2012) presented above, in the sense that it introduces in the standard RBC model recursive preferences and time-varying disaster risk, as a "small, time-varying probability of a worldwide economic disaster" (insertions which are necessary to make the model effective in capturing exchange rate dynamics). Also the economic consequences due to a variation in disaster probability are in line with Gourio (2012). In fact the intuition is the same: when agents perceive a higher disaster probability, there is a decrease in macroeconomic quantities such as investment (risky assets are less attractive), output and employment, and positive variation in risk premia. Moreover, also this model does not generate any change in TFP (an attractive feature since some recessions, such as the recent financial crisis, occur without significant change in TFP), and to trigger business cycle dynamics a disaster realization is not needed: the variation in realization probability is sufficient.

As already referred to, these features are embedded in a standard two-country real business cycle (RBC) model, that is designed as in Backus et al. (1992). So, the production of a single homogeneous good is assumed, and there is complete market for state-contingent claims, with agents that participate in international capital markets. In Gourio et al. (2013) model, the difference between the countries ("home" and "foreign" country) is about their exposure to aggregate risk. They have the same preferences and technology, and the disaster, a "simultaneous large permanent decline in productivity and capital destruction", is perfectly correlated across them. So, the domestic and the foreign economy differ only because one of them (the home country in this case) is assumed to have a higher exposure to the world disaster. In fact, the indicator of disaster realization, the probability of disaster (indicated respectively as x_{t+1} and p_{t+1} in the model setup) and the innovation to the log probability of disaster $\varepsilon_{p,t+1}$ are the same, and the two economies differ in the riskiness parameters: the capital destruction (represented by the parameter b_k) and the reduction in TFP (b_{tfp}) if disaster is realized are not assumed to be the same, to capture the different exposures to world risk (that could be due to different industry composition or financial structure).

Therefore, it is no longer only about the introduction of disaster risk in an economy without disaster, to see if (and how) it affects macroeconomic dynamics and asset pricing, but the model allows to investigate what could be the effects in an open economy, so how the disaster probability interferes in the relations among countries, and which consequences it could lead to. In this regard, the work is related to Gourinchas et al. (2010), who provide a disaster risk model to account for asset pricing and excess return in open economy. They introduce a model of risk sharing with heterogeneity in risk aversion (which is supposed to be constant and permanent) and in countries' size, with the home country being larger and less risk averse. The home country explicitly provides insurance to the rest of the world in case of disasters (that are global and affect output in all countries and all sectors identically), since it is assumed to have a greater risk tolerance. This model can give an explanation for the large collapse in the net foreign asset position of the United States between the third quarter of 2007 and the first quarter of 2009, as well as the higher return on US external assets than on its external liabilities during normal times, that has to be considered as an insurance premium that the rest of the world has to pay.

Looking at Gourio et al. (2013) results, in case of disaster realization, the more risky country is subject to a higher destruction of capital and reduction in productivity, which lead in a stronger recession and resulting decline in stock prices. Interest rates fall more where the level of riskiness is higher, for the higher demand for precautionary savings (we will come back on the interest rates issue later in the paragraph), and spreads on risky securities increase. So, in the country that would be hit hardest by the disasters, these effects are qualitatively the same than in the other country, but quantitatively stronger. Moreover (more interestingly) the exchange rate of this country appreciates during disaster, because of the decreased supply of goods.

Given the difference in riskiness, it is worth noting what the dynamics occurring in case of variation in disaster probability are, so without disaster realized in sample: in figure 8, which also allows for comparison between the less and the more risky country, the impulse response functions to an increase in disaster probability is represented. The agents' expectations regarding GDP are influenced by the shock to disaster probability (that is equal in both countries), and it is clearly noticeable the decline in investment, employment and output, as well as in equity prices (because of the increase in discount rate), and the magnitude of the impact is larger in the more risky country: it mirrors the case of disaster realization. Similar results can be derived with stochastic volatility, as in Bansal and Yaron (2004), who rely on Epstein-Zin preferences too, but, instead on model time-varying aggregate risk using time-varying probability of worldwide economic disaster, decoupled consumption and dividend growth rates in "a small persistent expected growth rate component, and fluctuating volatility, which captures time-varying economic uncertainty" (another evidence about the close relation between literature on economic uncertainty and disaster risk, as highlighted above).

Coming back to Gourio et al. (2013) results, the dynamics of the exchange rates are interesting to observe. With the rise of disaster probability, the exchange rate of the more risky country appreciates, because its marginal utility rises more. So, the country that is most risky in terms of its stock market and quantities results to be the country whose currency is the safest in case of disaster. Looking at the variation in exchange rate in relation to the change in consumption, the model is not able to account for Backus-Smith puzzle (see Backus and Smith, 1993): even if with Epstein-Zin utility and heterogeneous exposure to shocks, the correlation between consumption

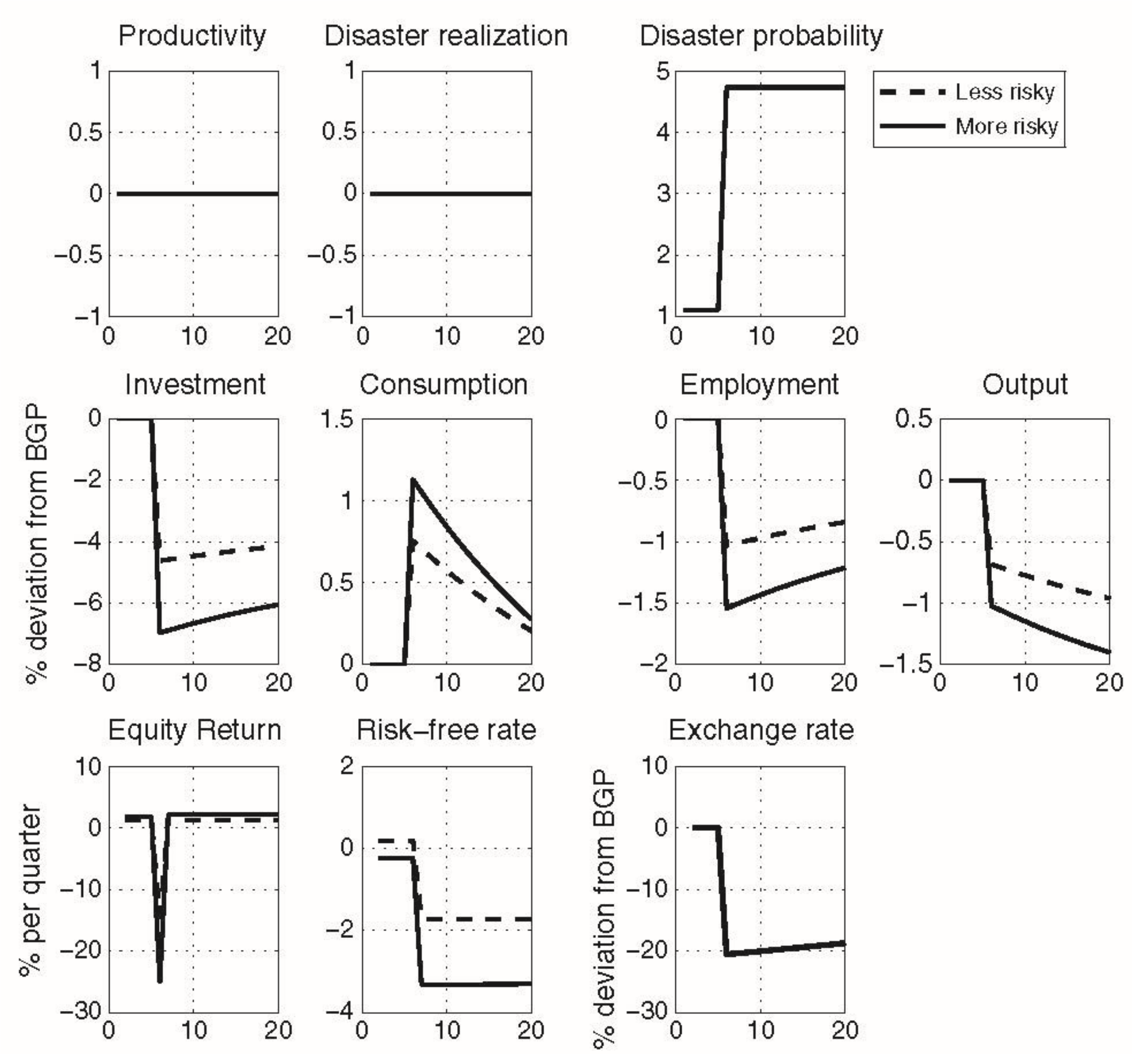

Figure 8 Impulse response functions of macroeconomic and financial variables to a disaster probability shock, i.e. an increase to the probability of disaster. Quantities are in percentage deviation from the balanced growth path (BGP). Asset returns are in percentage change per quarter. The disaster probability is in percentage, and the disaster realization is an indicator function. (From Gourio et al., 2013)

growth and exchange rates variations is not perfect (as it is in basic RBC models with power utility, indeed), it is still strong, while the data suggest it negligible. The model does not provide for perfect co-movement between consumption and investment, employment and output, as in Gourio (2012); the consumption increases at first (since IES is assumed greater than unity) then falls in following periods, and the future decline in consumption growth is expected to be larger in the more risky country, so with Epstein-Zin preferences there is an immediate appreciation of its currency.

Thanks to heterogeneous exposure to disaster risk, in the model a carry trade strategy can generate a significant excess return, coherently with the data, given the fact that the interest rates are correlated with countries riskiness (while in the standard RBC model it does not happen). A carry trade strategy is strictly dependent on disaster risk: a disaster realization, or just an increase in perception of disaster probability, can significantly influence its payoff. In fact, in case of rising disaster risk, the currency with lower interest rate tends to appreciates and, since in a carry trade strategy agents borrow in a low interest rate country (that in the model is the riskiest) and lend in a high interest rate county, a positive expected excess return is required on average, in order to compensate the risk of an appreciation in the first currency.

Since the measuring of time-varying disaster probability is challenging (disaster probability is not directly observable), there is the need to use a proxy for it. The proxy used in this case is the change in equity implied volatility: shocks to equity volatility can provide an approximate measure for shocks to disaster probability, and it seems consistent with the model for the effects that high equity return volatilities have on macroeconomic aggregates and asset prices, and for the fact that in the model are correlated with high probabilities of disaster, coherently with the data.

Coming back to interest rates, it has to be notice that the model calibration falters in an important way: the most risky countries in terms of fundamentals are the low interest rates one, and so they have the most volatile real quantities and returns. However in the data they have lower volatilities; we will come back to this fact in paragraph 4.3, by comparing it with the results of our analysis.

With this work, Gourio et al. (2013) provide a simple framework which, through the combination of time-varying risk and the heterogeneous exposures to that risk, helps to reconcile IRBC models with the data. This model replicates well the volatilities of consumption, investment, employment, and output for countries more exposed to aggregates risk. It is also consistent with asset pricing facts within each country ant their relations with macroeconomic aggregates, as well as with basic features of exchange rates (such as their volatility and correlation with interest rates).

Having presented the reference literature concerning disaster risk effects, in the next chapter our VAR analysis will be illustrated.

4 VAR analysis

4.1 VAR analysis and variables involved

In order to estimate the impact of a shock to disaster probability on the main macroeconomic variables, and to see to which extent these are influenced by different exposure of single countries to global risk, an empirical analysis (VAR) is performed. The measure used as proxy for disaster risk is the MSCI World Index volatility, as explained below, and the VAR analysis focus is on G7 countries: Canada, France, Germany, Italy, Japan, United Kingdom and United States.

4.1.1 Variables

The variables considered for the analysis are: MSCI World Index and its volatility, long-term government bond yields (10 years), consumer price indices, nominal exchange rates (expressed in U.S. dollars per unit of foreign currency, such that an increase in exchange rates has to be interpreted as a foreign currency appreciation; for the United States, a trade-weighted exchange rate is taken, such that an increase means a U.S. dollar appreciation), industrial production indices (production of total industry). MSCI World Index data are extracted from Datastream, long-term government bond yields from International Monetary Fund database. Consumer price indices and nominal exchange rates are retrieved from FRED, Federal Reserve Bank of St. Louis database (except for France, Germany and Italy, for which European Central Bank database - European Central Bank Statistical Data Warehouse - provided data regarding exchange rates on periods before 1999), and industrial production indices from Organisation for Economic Co-operation and Development database.

4.1.2 *MSCI World Index volatility*

In this empirical analysis, the proxy used for disaster risk probability is the volatility of the MSCI World Index.

The MSCI World Index represents large and mid-cap equity performance across 23 developed market countries (so without emerging markets exposure), covering approximately 85% of the free float-adjusted market capitalization in each (for more details about the index, see MSCI website).

MSCI World Index volatility can offer a good representation of variations in disaster risk which are global, and not country-specific; this is coherent with the assumptions of the analysis because, following Gourio (2013), every country is supposed to be subjected to the same disaster risk probability as the other countries, and differences between them depends only on their level of exposures to such risk.

Regarding the calculation of the MSCI World Index volatility, its measure (represented in figure 9a) corresponds to the standard deviations of its daily returns over calendar months. Daily performances of the index are available since January 1972, and the series here considered is up to July 2015. Peaks are consistently correspondent to the periods characterized by high uncertainty; more details about this correspondence will be provided in paragraph 5.2, looking also at Bloom's (2009) analysis for a comparison.

This proxy for disaster risk appears aligned with commonly-used indicators of uncertainty. In figure 9b, the MSCI World Index volatility, Chicago Board of Options and Exchange Volatility Index and Economic Policy Uncertainty Index are plotted. As already anticipated in paragraph 2.3, VIX is widely used in the literature as proxy for disaster risk (e.g. Gourio, 2012, or Gourio et al., 2013) and uncertainty (e.g. Bloom, 2009, or Gourio et al., 2015) and represents the 30-day implied volatility on the S&P500 index, while Economic Policy Uncertainty Index is the one created by Baker, Bloom and Davis (2013), based mainly on newspaper coverage frequency of information related to economic uncertainty. For comparison reasons, in the figure all series are presented from January 1990 to July 2015, as the Volatility Index is available since 1990; they are normalized to a mean of 100 over the period, and data are monthly.

It is interesting to observe that there is an overall co-movement of these indicators, and in particular that the Volatility Index and our proxy for disaster risk calculated from MSCI World Index daily returns are highly correlated (they have a correlation of 0.87). This is worth noting since our VAR analysis is performed by requiring MSCI World Index volatility a consistent indicator of disaster risk.

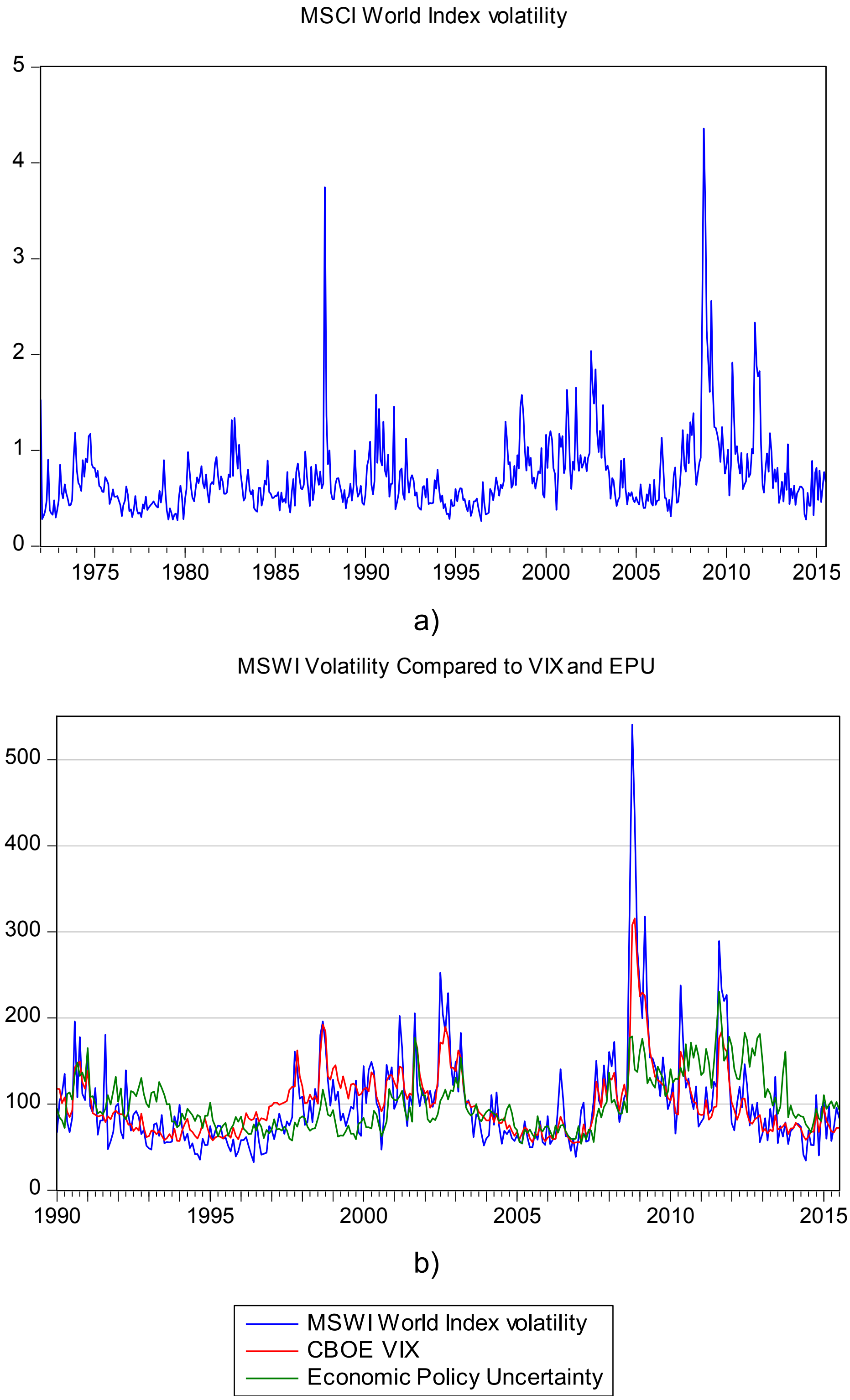

Figure 9 a) MSCI World Index volatility. Volatility measures correspond to the standard deviations of daily returns over calendar months. b) Comparison between MSCI World Index volatility and main disaster risk measures used in the literature (indexes are normalized to a mean of 100 over the period). CBOE VIX is the monthly average of daily values for the Chicago Board Options Exchange Volatility Index. Economic Policy Uncertainty is the uncertainty measure from Baker, Bloom, and Davis (2013). Data are monthly, sample is a) 1972M01-2015M07, b) 1990M01-2015M07.

4.2 Empirical analysis (VAR)

In this paragraph the main characteristics of the estimation of the VAR and its responses are presented. Since the aim of this analysis is to observe the effects of variation in disaster probability, the focus will be on responses arising from disaster risk indicator (MSCI World Index volatility) innovation.

4.2.1 VAR estimation

The time series included in the analysis are composed by monthly observations, and annual growth rates of variables are used, in order to obtain series which are stationary (except for long-term government bond yields, which are expressed in percentages).

About the sample period for which the VAR is estimated, data from January 1972 (time which, as already mentioned, corresponds to the first measure of MSCI World Index volatility computed) up to July 2015 for all the countries are considered. So, the number of observations included for each variable results to be 523 (before adjustments). Since nominal exchange rates for Euro are not available before January 1999, for France, Germany and Italy the exchange rates series between United States dollar and their old currencies are used, normalized to the same mean and variance as the Euro-Dollar exchange rates series when they overlap (from January 1999 to December 2001).

VARs order is selected following Akaike criterion (see Lütkepohl, 2005, chapter 4), and the resulting order is three for United Kingdom and United States, two for the other countries.

Regarding the adopted ordering of the variables (at first MSCI World Index and volatility, then long-term government bond yields, consumers price indices, nominal exchange rates and finally industrial production indices), it is chosen looking at Bloom (2009), whose assumption is that shocks "instantaneously influence the stock market (levels and volatility), then prices (wages, the consumer price index (CPI), and interest rates), and finally quantities (hours, employment, and output)". For a robustness check, variation of the analysis proposing different variables ordering has been performed, and will be presented in paragraph 5.3.

4.2.2 VAR responses

With the estimation of the impulse response functions, it is possible to trace the effect of a shock to MSCI World Index volatility on current and future values of the endogenous variables included in this exercise.

The above-mentioned ordering of the variables is extremely important, since Cholesky decomposition is applied to orthogonalize the impulses (so, the Cholesky factor of the residual covariance matrix is used, and VAR responses can change by changing the ordering of the variable: at first each variable can not affect the previous ones. See Stock and Watson, 2001).

Figures 10, 11, 12 and 13 report the impulse response to one standard deviation volatility shock of long-term government bond yields, consumer price indices, exchange rates and industrial production indices, respectively. The variables evolution appears coherent with the hypothesis of a recession following an increase in the probability of global disaster. Generally, a decrease in long-term government bond yields is observed in periods after shock (figure 10), with a magnitude that is statistically significant (dashed green lines in all the graphs represent 68% confidence bands, while dashed red lines 95% confidence bands, x-axes report months after the shock). This is true especially for United States, which experience the more pronounced drop of government bond yields (while Italy is the only country presenting not a reduction, but a statistically significant increase in the period immediately following the shock). These results are aligned with disaster risk theories, as well as the negative effect in consumer price indices (see figure 11, where it appears significant in all the countries) and industrial production indices. In this regard, it is interesting to observe that Japan is the country which sees the higher growth reduction in production, with a negative peak of -0.59 percentage points seven periods after shock, and -7.7 cumulatively (vs. Canada and United Stated with -3.6 and -4.8 percentage points, as plotted in figure 13). Regarding the exchange rates (figure 12), it is worth noting that there is no statistically significant change looking at France, Germany and Italy, while the currencies of remaining countries depreciate (in particular, Canada and United Kingdom experience a cumulative depreciation growth of 1.1 and 1.73 percentage points respectively), except for Japan, where there is an appreciation, with a cumulative increase in growth of 20.1 percentage points, and a peak of +1.28 five periods after shock.

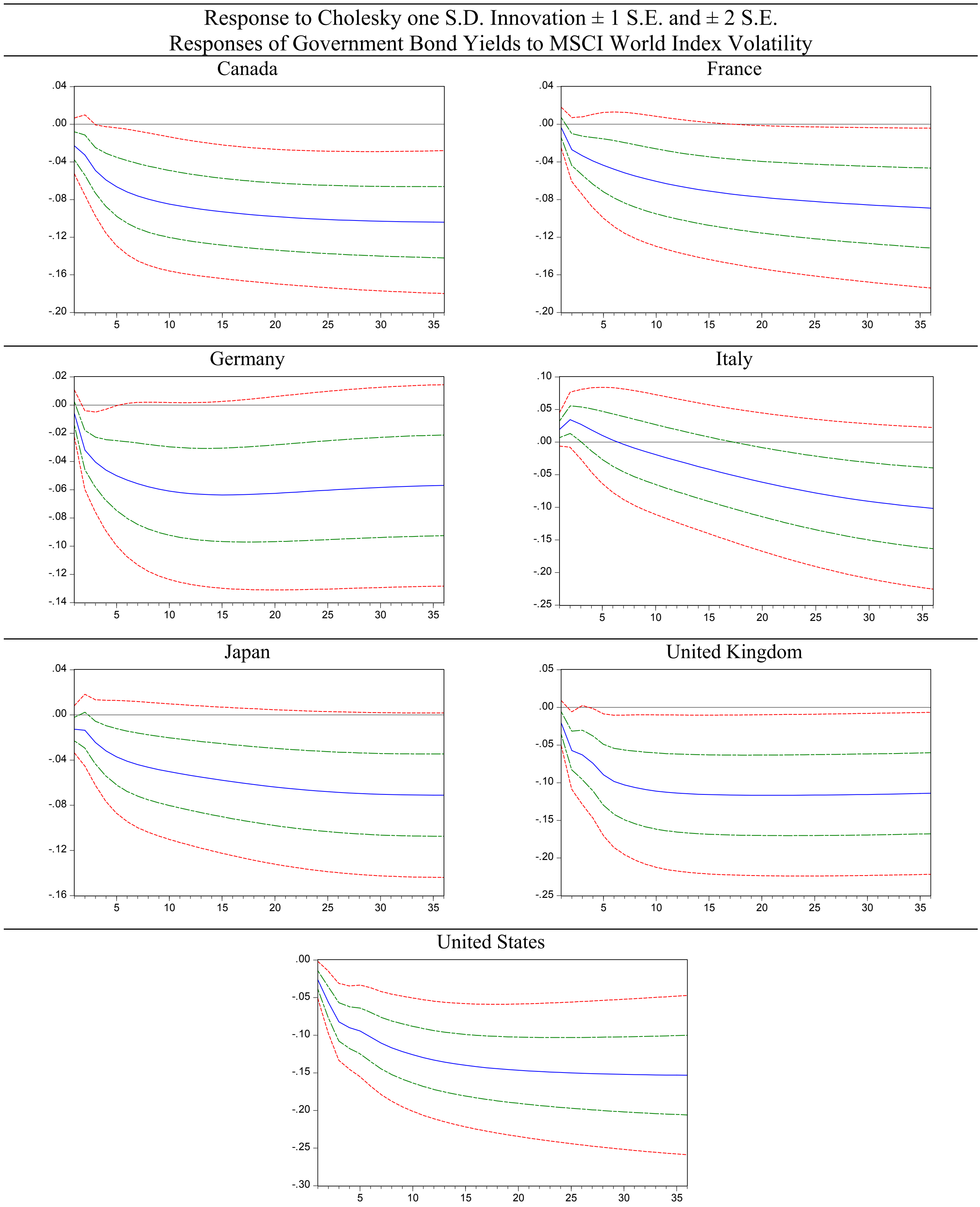

Figure 10 Impulse response functions of Government Bond Yields to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index. Dashed green lines are 1 standard-error bands around the responses to the volatility shock, dashed red lines are 2 standard-errors bands.

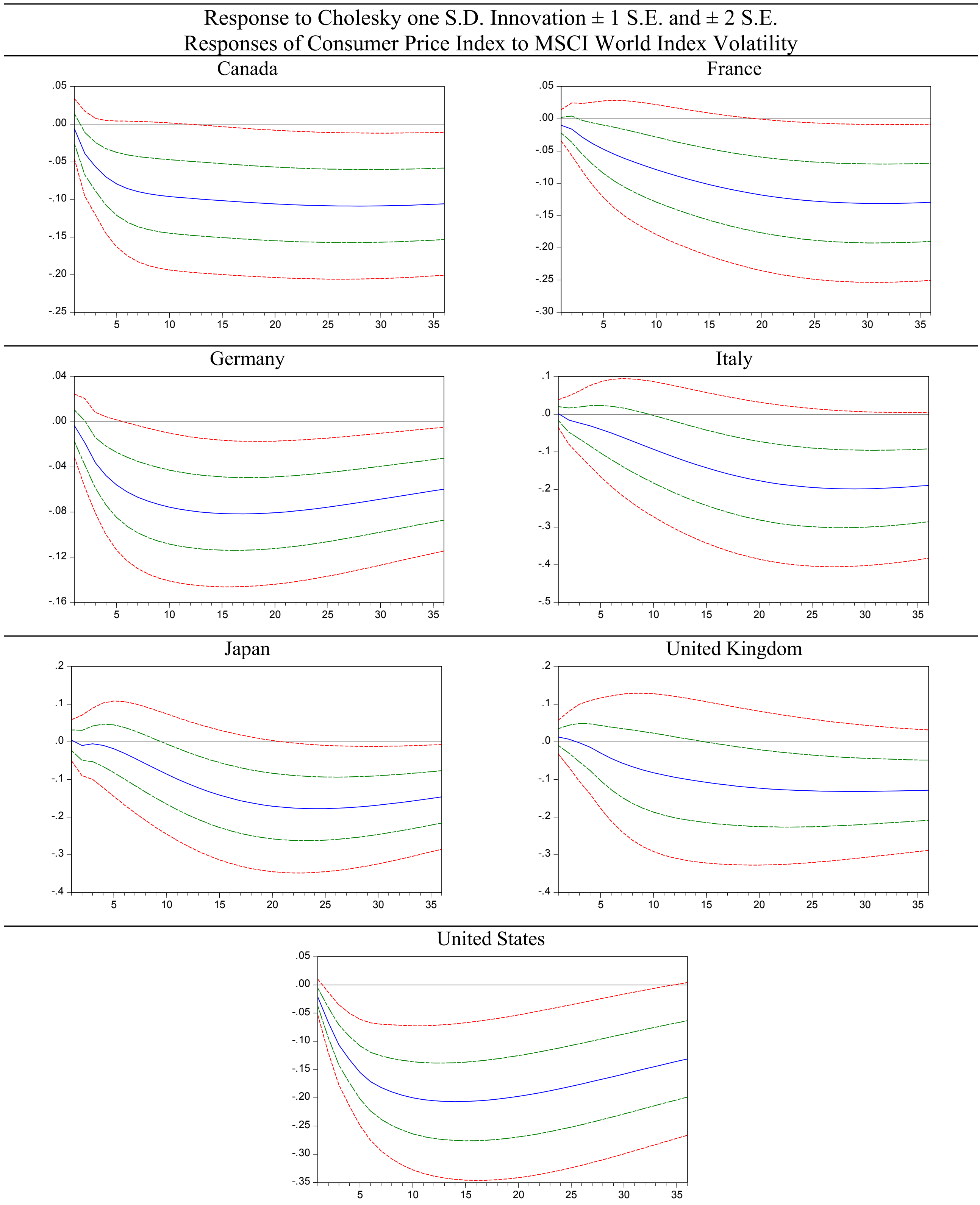

Figure 11 Impulse response functions of Consumer Price Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index. Dashed green lines are 1 standard-error bands around the responses to the volatility shock, dashed red lines are 2 standard-errors bands.

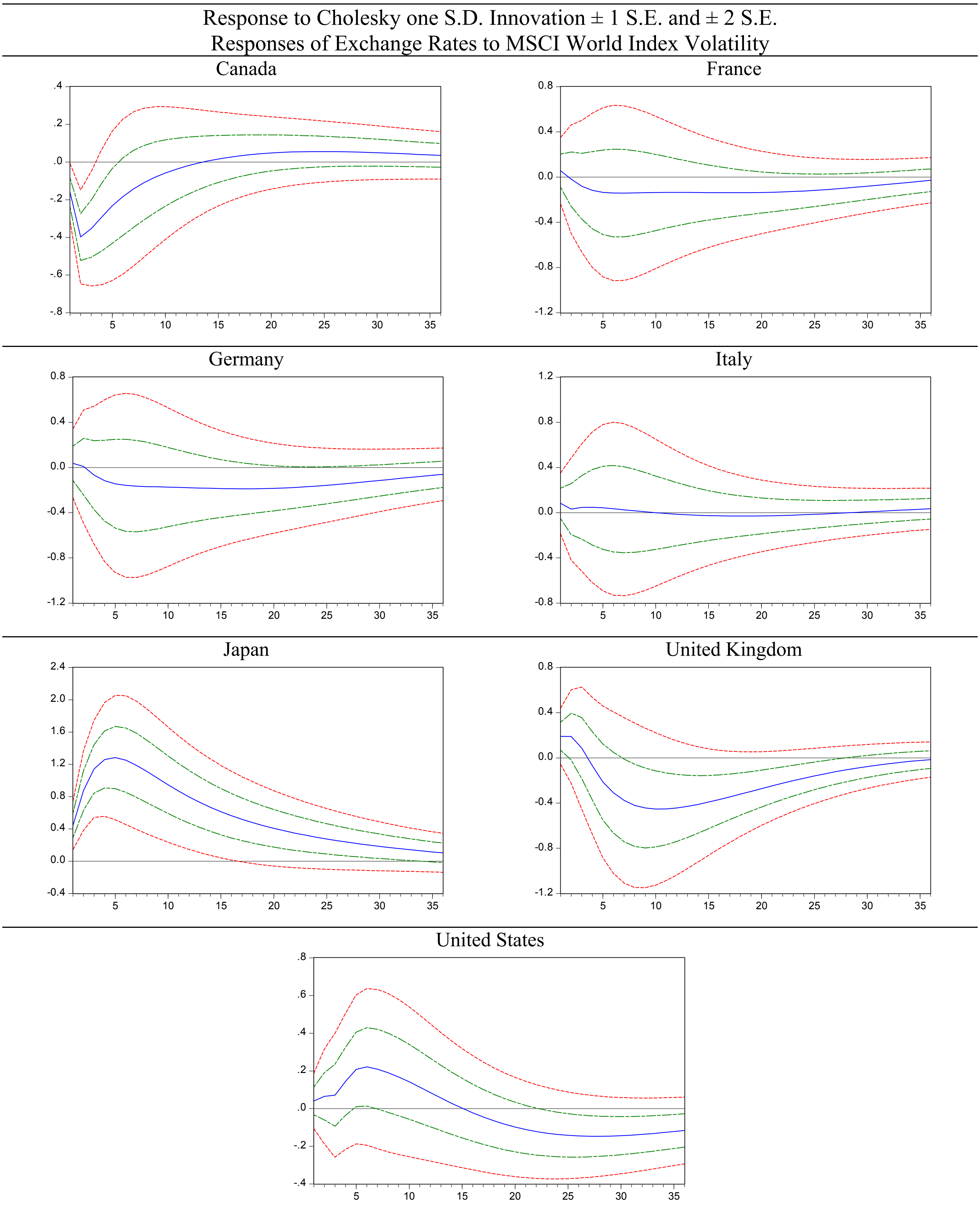

Figure 12 Impulse response functions of Exchange Rates to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index. Dashed green lines are 1 standard-error bands around the responses to the volatility shock, dashed red lines are 2 standard-errors bands.

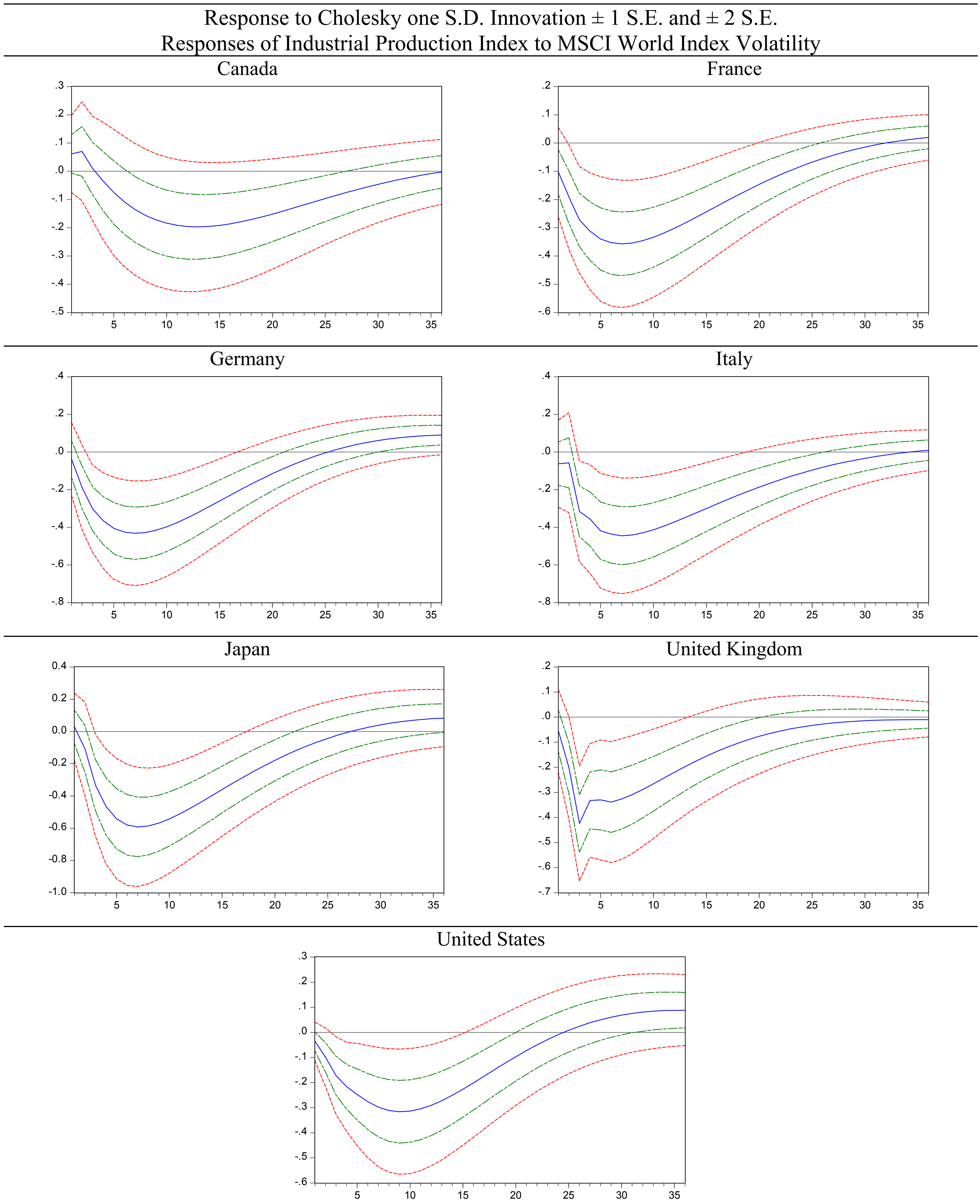

Figure 13 Impulse response functions of Industrial Production Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index. Dashed green lines are 1 standard-error bands around the responses to the volatility shock, dashed red lines are 2 standard-errors bands.

4.3 Results and riskiness evaluation

While the disaster risk is assumed to be global, countries can have an heterogeneous exposure to this risk. It implies that the effects of disaster risk could be different, depending on whether a country is more or less exposed. In Gourio et al. (2013), as already explained in paragraph 3.3, in more risky countries the impact of disaster in terms of output and consumption decline should be higher. Moreover, to assess the level of riskiness they take into account the interest rate levels: from the model, they assume a negative correlation between the interest rates and the exposure to disaster risk.

The aim of this paragraph is a possible interpretation of our VAR analysis results, considering the mechanism through which variations in disaster risk probability affect the economy. The results will be explained in the light of disaster risk exposure of each country, to try to find a criterion for determining such exposure, and ranking countries accordingly.

4.3.1 Results

From our analysis, it is possible to observe a general decrease in long-term government bond yields, which is consistent with disaster risk theories: as implication of disaster risk shock, investors run from risk and required assets which are perceived safer, as government bonds (in relation to this, see also flight-to-quality phenomenon, presented in the following paragraph). In figure 14a the impulse responses of long-term government bond yields are shown; the United States experience the more pronounce on-impact decline, a fact that confirms their image of “safe haven”, where sustained and stabilizing net capital (also from foreign investors) inflows toward its safest assets (as in Caballero and Kurlat, 2008). On the other side, Italy seems to be perceived as the more risky, (followed by Japan), in the sense that an increase, that is statistically significant, in its long-term government bond yields occurs immediately after disaster risk shock, and this can be interpreted as the consequence of a lower demand, from risk-averse investors, for Italian government bonds because now they are perceived more risky.

Overall, the recessionary effect is also visible in the growth decrease of industrial production and inflation. The higher riskiness prevents investment, despite the decreasing level of interest rates, and lowers consumer price indices (as can be seen in figure 14b) in all the countries under study. Looking more specifically at real variables, impulse responses point out a shock of demand that is not permanent. In fact after the first impact and the following negative periods, industrial production indices show a growth rate that is increasing. This is coherent with the assumption of a recovery in the economy after disaster shocks, which are not permanent but only transitory, with

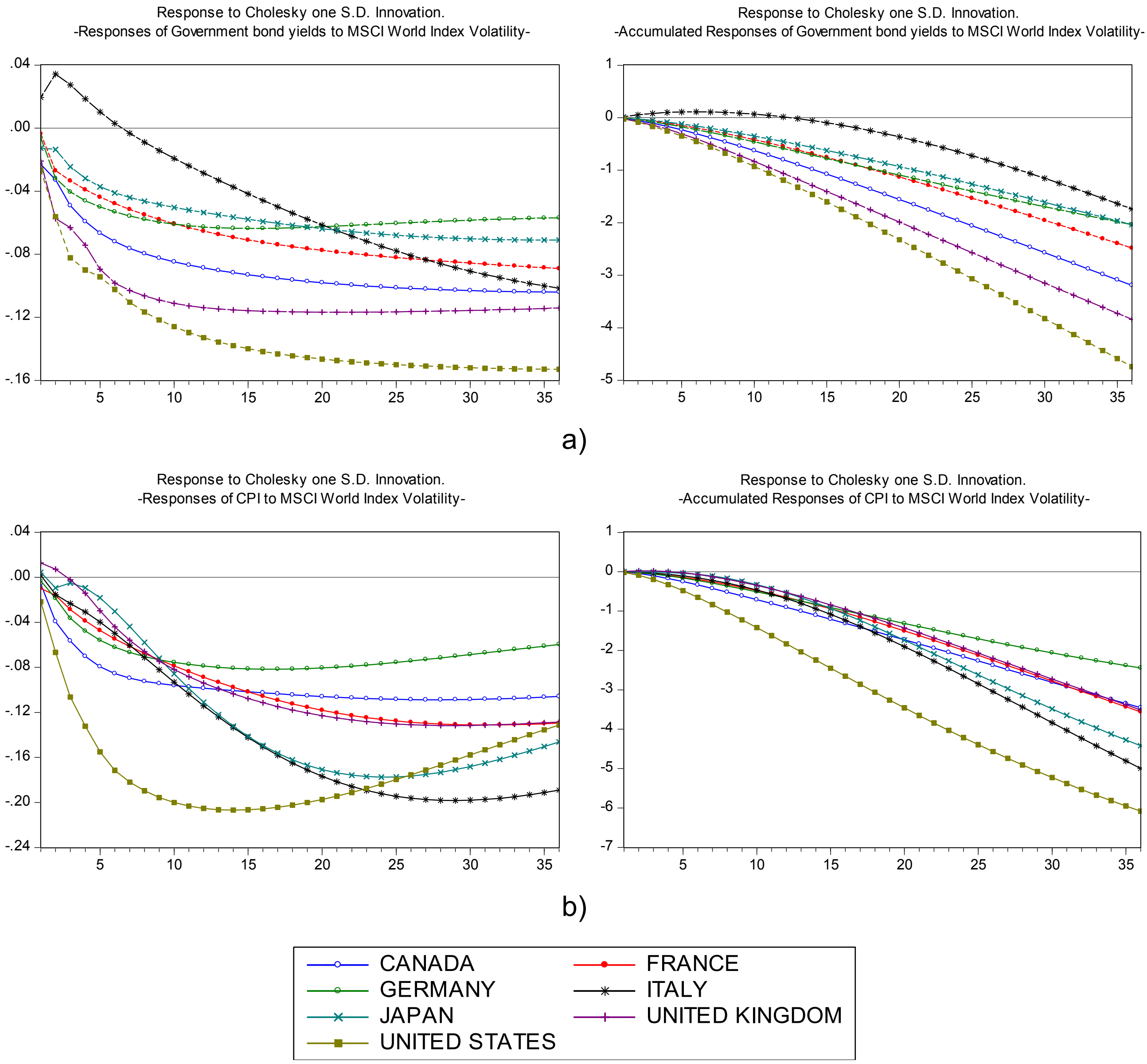

Figure 14 Impulse response functions (left) and accumulated responses (right) of a) Government Bond Yields and b) Consumer Price Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

production bouncing back at its previous level (as in Bloom, 2009, and in Gourio, 2008b, 2008c).

In the literature, generally, while in some works the possibility of a recovery after disaster is just not taken into account, in other works it is considered, bringing evidence to the fact that the variation in the probability of disaster could lead to different results (so it could have different effects in the economy) if there is the expectation of future recoveries or not. In many models, extended to incorporate the time-varying incidence of disasters, disasters are assumed, for parsimony and tractability, to be permanent. For instance, considering the more relevant papers related to this topic (whose results has already been presented in paragraph 3.3), in Gourio et al. (2013) and Gabaix (2012) the decline in productivity and capital destruction are permanent, and also in Gourio (2013) and Wachter (2013) rare disasters are modelled as instantaneous permanent jumps, and not as shocks that are followed by recoveries. In other models, however, the possibility of recoveries is embedded, such as in Gourinchas et al. (2010), (where p_d and p_n represent respectively the conditional probability of a disaster in good times, and the probability of a recovery from a disaster), or in Longstaff and Piazzesi (2004), where the effects of a jump downwards are not permanent.

In Gourio (2008b, 2008c), the possibility of a recovery is not only an assumption in the model, but he tries to investigate if this possibility influences the way in which the changes in disaster probability affect the economy. Here disasters are measured (as in Barro, 2006) as the total decline in GDP, greater than 15%, from peak to through, so the GDP goes up after disaster by definition. By measuring the recoveries after a disaster (data from Maddison, 2003), he finds that disasters are substantially reversed, and GDP growth is larger after a disaster than unconditionally. Then, he studies “how recoveries affect the predictions of the disaster model”, by extending the Barro-Rietz model and allowing for recoveries: in case of disaster realization, in the following period there is the probability of a recovery (π), which is the probability that consumption goes back up, by an amount that depends on the time-varying size of disaster (b). The main result is that, with an IES above unity, the possibility of a recovery reduces the equity premium. The intuition is that “the decrease in dividends is transitory and thus in disasters stock prices fall by a smaller amount than dividends do”, so equity is less risky than in the case without recoveries (results which are consistent with John Y. Campbell (1999), considering the behaviour of financial asset prices in relation to consumption).

Coming back to the results of our analysis, in regard to the exchange rates (figure 12) in France, Germany and Italy there is not statistically significant currency appreciation nor depreciation. Moreover, the fact that there is a depreciation of Canada, United Kingdom and United States currencies, while Japan currency appreciates, is a result in line both with actual episodes and disaster risk theories if we consider the country subject to appreciation (Japan in this case) as riskier compared to the others. An example of exchange rate appreciation following a disaster realization (but the effects should not change even by considering it an increase in disaster probability, not necessarily a realization) can be found in the nuclear facility accident in Japan when, as reported in Gourio et al. (2013), within the first five days of the earthquake on March 11, 2011, the Japanese yen appreciated by about 6% against the U.S. dollar.

4.3.2 Relative riskiness evaluation

After the presentation of our results, the focus now is on countries relative riskiness. Recalling Gourio et al. (2013), their assumption is that countries are exposed to a risk that is global, and the effects of a shock differ among them only because there is an heterogeneity in risk exposure. But which countries are the least exposed, and what are the most?

In this work, Gourio et al. (2013) state that the most risky countries are the ones with lower interest rates. Their explanation is that in a more exposed country (where in case of disaster realization the capital destruction and the reduction in TFP will be higher) there are more precautionary savings, hence the interest rates are low.

Under the assumption that times in which uncertainty is high have a high marginal utility of consumption, and that realized return on capital is low when disaster hits, the mechanism is that when probability of disaster increases, risk-averse consumers are led to invest less in risky capital (which now has a lower expected return), while they find safer assets (as government bonds, here assumed risk-free) more attractive, causing a drop in interest rates. In countries with a larger increase in their marginal utility in case of disaster shock (the riskier countries) this drop is more pronounced, and occurs together with an exchange rate appreciation and a stronger negative effect on employment and output.

So, to see if the results of our analysis are consistent with Gourio et al. (2013) theory, in the sense that they could suggest a correspondence between interest rates and the country-specific exposure to disaster risk, first of all G7 countries are ranked accordingly to their interest rate levels.

This ranking is presented in table 1: United States are taken as the benchmark, and other countries are ordered looking at the number of periods in which they present long-term government bond yields lower than the United States level. Japan is the country with the lower interest rates, since they are lower than the benchmark for all the sample period, while on the opposite side Canada has only 14.99% of observation below the United States level.

According to Gourio et al. (2013), a global shock to disaster probability should have different effects on each country because of their heterogeneous exposure, and in particular its impact should be of larger magnitude where the disaster risk is supposed to be larger: in countries with lower interest rates. So, coming back to the analysis, in countries which according to this criterion are more risky, higher negative effects should be expected. It will be shown whether the responses, especially regarding real variables - industrial production indices - and exchange rates, to a volatility shock are coherent with expectations, hence the extent at which the ranking based on low or high long-term government bond yields values is correlated with such responses.

Periods in which countries present Government Bond Yields lower than U.S.		
Countries	Periods (/367)	Percentage
Japan	**367**	**100 %**
Germany	266	72.48 %
France	167	45.50 %
Italy	85	23.16 %
United Kingdom	68	18.53 %
Canada	55	14.99 %

Table 1 Countries ranked according to the number of periods in which long-term government bond yields of the single country are lower than United States level. Data are monthly, sample is 1985M01 - 2015M07.

As already seen in figure 13, the responses of nominal exchange rates to disaster risk shock varies across countries not only in magnitude, but also in their evolution. In figure 15a the impulse responses and the accumulated responses to one standard deviation volatility shock are summarized, for all the countries included in the analysis. To recall Gourio et al. (2013), in case of disaster realization the exchange rate of the more risky countries appreciates, and this holds also in case of change in disaster probability; he explains this with Epstein–Zin preferences and decline in consumption growth, expected to be higher in countries with higher exposures.

Regarding industrial production indices, already presented in figure 14 and summarized in figure 15b, heterogeneous exposure should determine declines in the growth of this variable of different magnitude (which leads to a larger recession) depending on country-specificities.

In this analysis, the only country that experiences a statistically significant exchange-rate appreciation is Japan, while other currencies depreciate or have no significant changes. Moreover, as can easily be seen in figure 15a, where the accumulated responses to a volatility shock for all the countries included in the analysis are reported, even in this case the country subjected to the higher impact is Japan. On the opposite side, Canada and United Kingdom are the ones which suffer less reduction in industrial production growth, and a significant depreciation following the shock.

So, accordingly with these results, Japan seems to be the country more exposed to disaster risk shock, while Canada and United Kingdom seems to be less exposed. Looking at the ranking

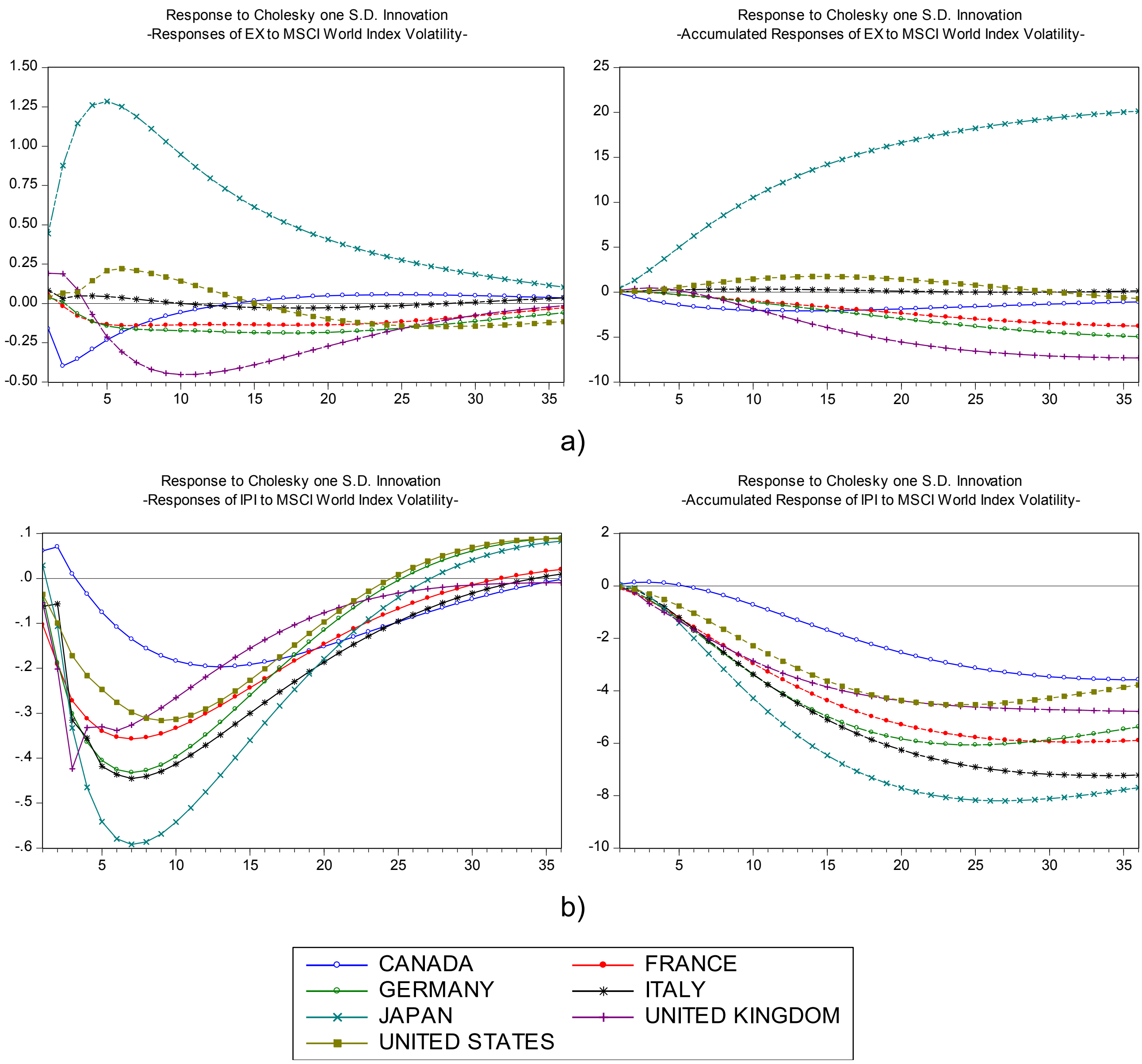

Figure 15 Impulse response functions (left) and accumulated responses (right) of a) Exchange Rates and b) Industrial Production Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

proposed in table 1, they have higher long-term government bond yields, while Japan results to be the only one whose values are lower than the United States for the entire sample.

It is worth noting also the level of exchange rate volatility in different countries from the data, since it appears coherent with the determination of countries risk exposure based on their government bond yields. Table 2 reports the standard deviations of exchange rates series

Nominal Exchange Rates Volatility	
Countries	Standard Deviation
Japan	**13.21**
Germany	12.55
France	11.82
Italy	11.79
United Kingdom	9.86
Canada	7.19

Table 2 Nominal exchange rates volatilities of G7 countries, calculated as standard deviations of annual growth rates. Actual monthly data, sample is 1985M01 - 2015M07.

used in the analysis (which are nominal, in annual growth rates and all expressed in terms of U.S. dollars per unit of foreign currency).

There is a correspondence between the riskiness assessed looking at long-term government bond yields and the level of volatility of exchange rates between benchmark -U.S.- and the other countries. Countries which are the most volatile in the data are also the ones with the lowest government bond yields, so the higher exposure to global disaster risk, and our VAR results are consistent with this fact.

Even if a match can be found between interest rate level and riskiness exposure (in the sense of higher impact in real variables and in exchange rates after disaster risk innovations), it is not possible to explain the correlation with a linear model. But even if a linear model is not effective, it has to be considered the fact that the number of countries in the sample is small, and (even more relevant) that there is only one country, Japan, which has the level of interest rates that is lower than the benchmark for the entire period.

To highlight the importance of this element, Gourio et al. (2013) have to be recalled, where the level of interest rates is stated as indicator of risk exposure. For their analysis they construct an artificial, composite “low interest rate” and a “high interest rate” country (gathering countries according to their interest rate level), and they find in data more volatile quantities and returns in high interest rate countries, while according to their assumptions they should be the less risky and so the less volatile. But from the data, the relative riskiness of every country, if intended as interest rate level, is not constant, and the classification of countries following this criterion not so straightforward (just think about the composition of groups they use for construction of “low” and “high” interest rate countries: it is time-varying, so a country can be in the low or high group in different periods).

So, in an empirical analysis, as our VAR, in which countries have government bond yields that fluctuate above and below the benchmark level, it is not surprising to not find a linear relation between this riskiness measure and macroeconomic quantities volatility.

And at the same time, coming back to the case of Japan, it is the only one that can be strictly considered “low interest rate country”, with a relative riskiness that is constant over the entire period, and so suitable for a linear analysis; it is the one for which high volatility in the results is associated with the lower government bond yields level, finding a correspondence in the data.

4.4 Flight to quality and Flight to liquidity

As anticipated in the previous paragraphs, in this analysis after a volatility shock the responses of long-term government bond yields present a decline in growth (this is true for every country except for Italy, which at first presents a statistically significant increase, and it is clearly visible in figure 14a).

These effects are consistent with Gourio et al. (2013) model on disaster risk: briefly, as already explained in the previous paragraph, the higher risk leads to an increasing demand for precautionary savings, and a consequent fall in the yield of less risky assets, as government bonds are supposed to be.

After trying to explain the fact that riskless interest rates are low, it is interesting to notice that, despite this, investments are low and do not respond to the decreased interest rates growth: it happens “precisely because of high disaster risk” (Gourio, 2012), naturally followed by the problem of not sufficient private risk taking.

This behaviour of (risk averse) investors can be considered as a “flight to quality”. This term is used to describe “episodes where investors seek to sell assets perceived as risky and purchase safe assets instead, leading to widening risk premia and severe disruptions in credit and other financial markets” (Caballero and Kurlat, 2008). So, the value of risky debt decreases, since perceived default probabilities are changed and higher premium is required for bearing credit risk.

Caballero and Krishnamurthy (2008) in their work present a model of optimal intervention in flight-to-quality situations, and they show that a lender of last resort pledging intervention in extreme events can unlock private capital markets. Moreover, they specify that most of flight-to-quality episodes are triggered by unanticipated or unexpected events, and when these events occur, economic agents act as they are uncertainty averse rather than simply risk averse, since “tail events and worst-case scenarios” play a fundamental role in their decision rules.

Agents seems to make decisions based on worst-case scenarios, and an increase in uncertainty leads them to a series of “protective actions” reflecting a flight-to quality (as decreasing risk exposures or hoarding liquidity). Hence, higher uncertainty (but also decrease in aggregate liquidity) results to be an important source of financial and macroeconomic instability since it causes agents to take these kinds of decisions, which are aimed to “guarantee safety for themselves”, but which leave the aggregate economy overexposed to negative shocks.

Caballero and Kurlat (2008), with their study focused on Financial Markets in the U.S., state that this strategic (or speculative) behaviour from the investors leads to an increase in credit spread on “all but the safest and most liquid assets”. So, aligned with flight to quality, also a distinct but related phenomenon has to be taken into account: the “flight to liquidity”. In periods of high uncertainty, investors prefer to hold not only safe assets, but also assets that are more liquid (such as US Treasury bonds).

Using data on the Euro-area government bond market, Beber, Brandt and Kavajecz (2009) try to understand in which times and for what reasons bond investors are interested more in credit quality or in credit liquidity: in times of economic distress, investors rebalance their portfolio toward less risky and more liquid assets, but they seem to chase liquidity even more than credit quality.

To observe the relation between preference for liquidity of investors (so assets liquidity premia) and uncertainty, Vayanos (2004) proposes an equilibrium model in which assets differ in their liquidity, and stochastic uncertainty is represented by the asset payoffs volatility. It is shown that during volatile times, investors become more risk averse: there is a preference for liquidity that results to be time-varying and increasing with volatility (thus, times of high volatility are associated with a flight-to-liquidity), when illiquid assets become riskier, in the sense that their market betas increase.

So the level of liquidity is priced, and evidence of this is provided by Longstaff (2004). In fact in this paper a work is proposed aimed at examining if there are flight-to-liquidity premia in U.S. Treasury bond prices. They do this by comparing them with prices of bonds bearing the same credit risk, but which are less liquid, finding evidence of significant liquidity premia in Treasury bond prices (and it is worth noting, since in standard asset pricing theory the value of a security "should equal the present value of its cash flows, and should not depend on how popular among the investors the security is as a trading vehicle").

Looking at the results of our analysis from a flight-to-quality or flight-to-liquidity perspective, the effects on the real economy, so the decrease in industrial production, can be explained, according to Caballero and Krishnamurthy (2008), as a consequence of excessive prudence that hinder private investments, while in Bernanke, Gertler and Gilchrist (1996) more specifically by focusing on the access to credit of the single firms, depending on the fact they are perceived as high or low quality. In particular, in their work it is stated that, after adverse macroeconomic shock, "banks deny loans to weaker borrowers, in favour of stronger borrowers". When prospective agency costs of lending (in the form of bankruptcy risks) increase, lenders reduce the amount of credit extended to firms that require monitoring So, borrowers who are subject to agency problems in credit markets experience a reduced access to credit, and, resulting more difficult and costly to obtain credit, they reduce spending ad production.

Also the overall decrease in long-term government bond yields can be interpreted in the light of both a flight-to-quality or flight-to-liquidity episode following an uncertainty shock. Government instruments see their value increase because of their popularity (Longstaff, 2004), since they are considered safer than corporate bonds, and at the same time there is a shift of capital from countries which are perceived more risky toward the less risky ones (in particular the U.S., as underlined in Caballero and Kurlat, 2008). This could be coherent with an increase in long-term government bond yields in Italy, resulting from our VAR analysis, in the months immediately after the disaster probability shock.

5 Robustness checks

The results of our VAR analysis suggest an impact of disaster risk which is relevant for macroeconomic dynamics. In this chapter, robustness checks are performed in order to test the reliability of this analysis and its results. At first, an analysis with short-term interest rates instead of long-term government bond yields is presented. Then another variation, consisting in the shifting of the starting time (from January 1972 to January 1985, to have the same sample period in all the VARs) is performed. The baseline case is also tested for a different disaster risk indicator (still from MSCI World Index volatility, but calculated following Bloom, 2009), and for a different variables ordering. Finally, the last paragraph presents the analysis performed excluding from the sample the years in which there is the presence of Zero Lower Bound in the United States (so, sample period becomes January 1972 - December 2007), and then the analysis which involves only the years of Great Moderation (January 1985 - December 2007).

5.1 Changes in variables and sample period

5.1.1 ***Estimation***

In the first variation of the VARs here presented, nominal long-term government bond yields are substituted with nominal short-term interest rates (policy rates). These series, that consist of monthly observations, are extracted from International Monetary Fund database. VAR estimation is as in paragraph 4.2.1: policy rates are expressed in percentages, as previously government bond yields, and the ordering of the variables is unchanged. However, in this case the sample period is different: as in the baseline analysis, data up to July 2015 are considered for all the countries, but the starting point varies across them. In fact, the maximum sample period is still from January 1972, (so, corresponding to 523 observations included for each variable, before adjustments), but for France, Italy and Japan the sample period starts in April 1984, January 1985 and January 1980 respectively, that means 376, 367 and 427 observations included for them before adjustments. Akaike criterion for VAR order selection suggests an order of two for Canada, Japan and United Kingdom, three for Italy, four for France, Germany and United States.

The second variation presented consists in keeping the baseline analysis (so with variables, data and estimation as in paragraphs 4.1 and 4.2), but modifying the time range. Sample period is smaller, and it comprises months from January 1985 to July 2015 for every country in every VARs, in order to have a homogeneous sample size. In this way, observations included are 367 (before adjustments), and following Akaike criterion the VAR order suggested results to be three for Italy and Japan, six for United States and two for the other countries.

5.1.2 ***Results***

Responses are shown in figures 16 - 18, which plot respectively the impulse responses of long-term government bond yields (or nominal short-term interest rates), exchange rates and industrial production indices to an innovation of MSCI World Index volatility. On the top of every figure there are the impulse responses and accumulated responses from the baseline analysis for every country included, then impulse responses and accumulated responses from the analysis in which policy rates are included in the place of government bond yields, finally on the bottom impulse responses and accumulated responses from the analysis with reduced sample period.

From this exercise, results appear to be not far from our baseline, with only small statistically significant exceptions.

At first, while the long-term interest rates of Japan are estimated to react (decrease) after disaster risk shock (so, both in the baseline VAR and in the sample from January 1985, as visible in figure 16), short-term interest rates are fund not affected by the shock (negative reaction is not statistically significant with a confidence interval of 68%). However this discrepancy can be explained considering the fact that in Japan policy rates (which are the lowest among the other countries) since 1999 are zero or nearly zero. The long-term government bond yields increase for Italy, in the period immediately subsequent to the shock, is still present. In both robustness exercises, the United Kingdom and United States show the higher decrease in interest rates after shock, and this result is coherent with a flight-to-quality episode, leading to interest rates of safer assets lowering (see paragraph 4.4).

Looking at the exchange rates (figure 17), impulses goes in the same directions. In particular, Japan appreciates with a peak after five periods from shock, and at cumulative level it is more accentuated in the case with policy rates (with a statistically significant difference in increase in growth of 4 percentage points: 24 instead of 20.1). Canada and the United Kingdom are still the only one to experience a statistically significant depreciation (confidence interval 68%), with negative peaks (two periods after shock for Canada and seven for the United Kingdom) of magnitude coherent with the baseline.

Regarding the industrial production index (figure 18), Japan presents also in this case the maximum negative reaction seven periods after shock, with value that is nearly -0.6 in all the analyses, even if, at a cumulative level, with short-term interest rates it is slightly higher (from -7.3 to -7.7 percentage points), but not significant. Japan is not the only one to present differences in accumulated responses in these estimations: the result for Italy, considering the accumulated results obtained from the smaller sample period, is -8.4, while in baseline -7.2. This could be interpreted as a possible coherence between the results and the assumptions underlying the baseline analysis: it could be seen as the consequence of an increase in perceived riskiness of the country, for the lowering of its interest rates (since by eliminating from the series data from 1972 to 1985, the level of interest rates decrease markedly). Looking at the United States, the recovery results faster, after nineteen instead of twenty-six periods.

Therefore, our baseline seems to be robust to a shift from long-term to short-term interest rates, and a sample reduction: its results and results from these two robustness exercises appear very similar, from a qualitative point of view, in responses’ overall behaviour, and the main differences could be still explained coherently in the light of disaster risk theory.

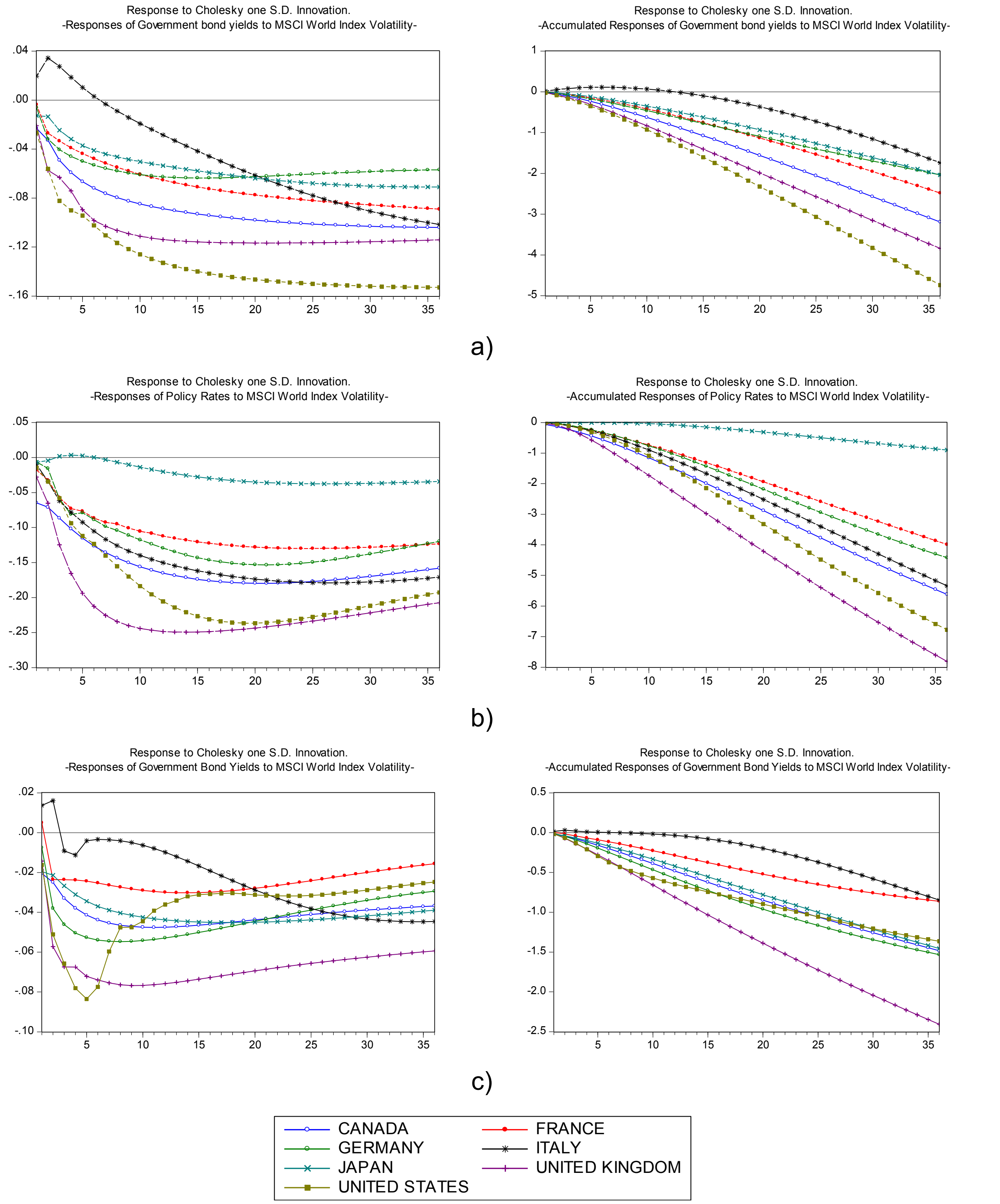

Figure 16 Impulse response functions (left) and accumulated responses (right) of Government Bond Yields to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline, b) VAR with policy rates, c) VAR with reduced sample period. Data are monthly, sample is 1972M01-2015M07 in a) and b), 1985M01-2015M07 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields (short-term interest rates in c)), consumer price index, exchange rates, industrial production index.

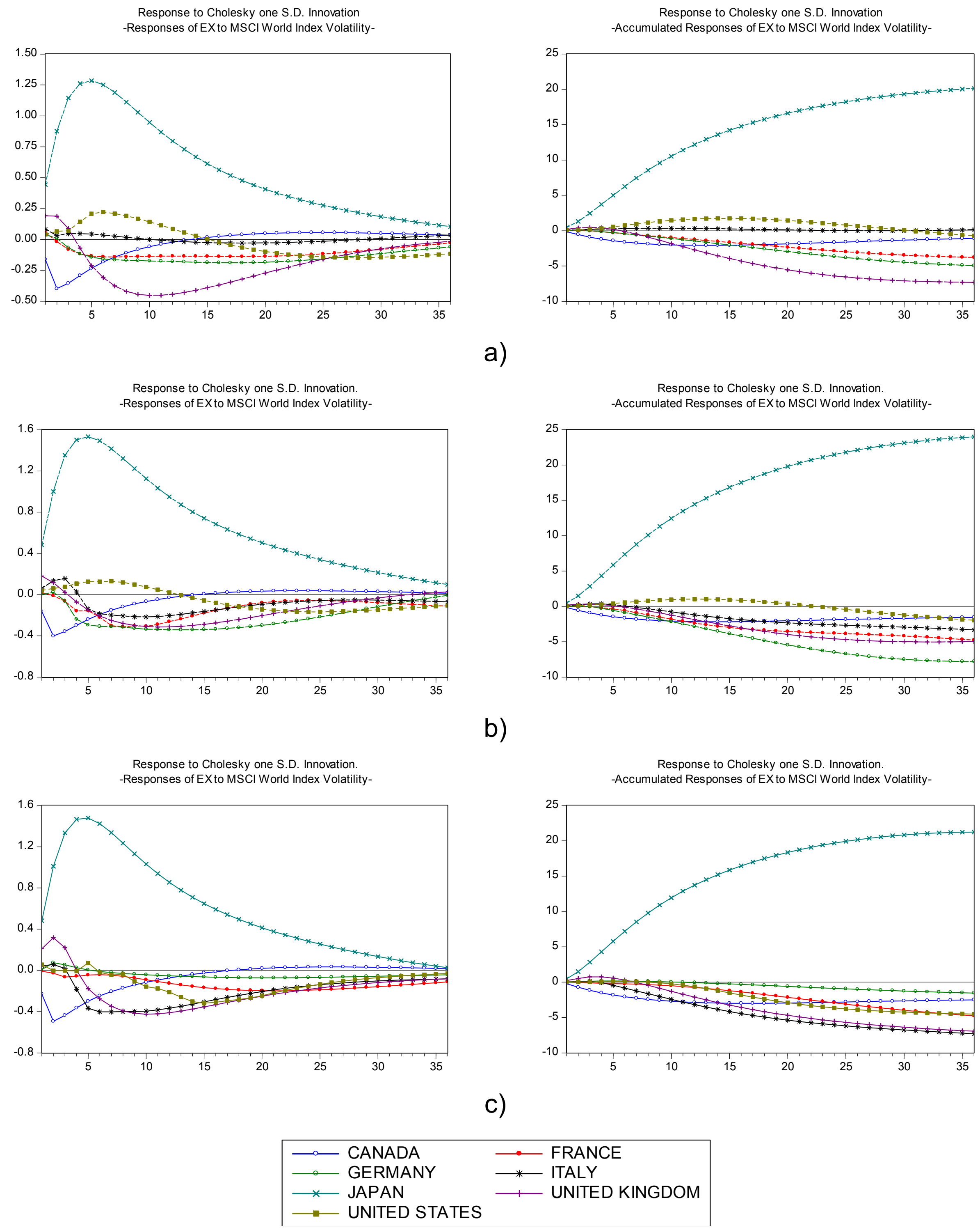

Figure 17 Impulse response functions (left) and accumulated responses (right) of Exchange Rates to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline, b) VAR with policy rates, c) VAR with reduced sample period. Data are monthly, sample is 1972M01-2015M07 in a) and b), 1985M01-2015M07 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields (short-term interest rates in c)), consumer price index, exchange rates, industrial production index.

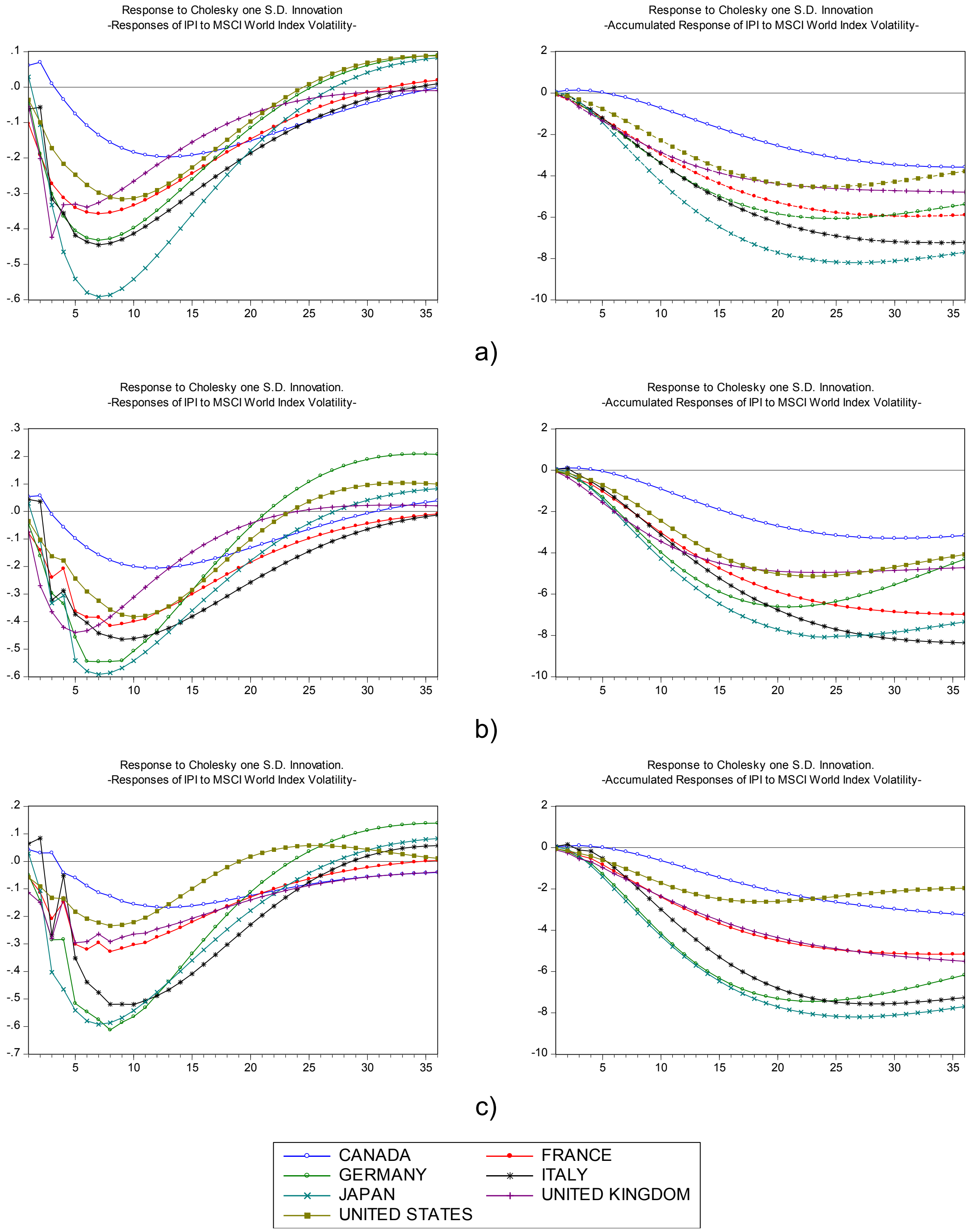

Figure 18 Impulse response functions (left) and accumulated responses (right) of Industrial Production Index to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline, b) VAR with policy rates, c) VAR with reduced sample period. Data are monthly, sample is 1972M01-2015M07 in a) and b), 1985M01-2015M07 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields (short-term interest rates in c)), consumer price index, exchange rates, industrial production index.

5.2 Change of disaster risk indicator

Until now, in VARs estimation as disaster risk indicator, the full MSCI world index volatility series is used (which does not require defining shocks). Here a disaster risk indicator in which shocks are defined will be used, and it will be constructed following Bloom (2009).

*5.2.1 **Disaster risk shocks identification***

In his work, (whose results have already been summarized in paragraph 2.2, in reference to the relation between disaster risk and uncertainty) to analyse the impact of uncertainty shocks, Bloom (2009) estimates a range of VARs which include the following variables (in this order): S&P500 stock market index, Federal Funds Rate, average hourly earnings, consumer price index, hours, employment and industrial production. He uses monthly data from June 1962 to June 2008. After S&P500 stock market index (which is included as the first variable in order to have the impact of stock market levels already controlled for when looking at the impact of volatility shocks) he includes his stock market volatility indicator. It is a measure he uses to define stock market volatility jumps: this indicator takes a value of 1 when shocks are identified (chosen as those events in which the level of stock market volatility series, previously Hodrick-Prescott detrended, rose significantly above the mean) and 0 otherwise The volatility series he uses is Chicago Board of Options Exchange VXO index of percentage implied volatility, on a hypothetical at the money S&P100 option 30 days to expiration (since the unavailability of VXO up to 1986, for previous periods he uses actual monthly returns volatilities, calculated as the monthly standard deviation of the daily S&P500 index, normalized to the same mean and variance as the VXO index for the overlapping periods).

The advantage of this indicator is that because of its construction it should ensure a disaster risk identification coming "only from large, and arguably exogenous, volatility shocks rather than from the smaller ongoing fluctuations".

So, a new disaster risk indicator will be constructed following Bloom (2009), and it will be inserted in the baseline analysis. At first, on our proxy for disaster risk, MSCI World Index volatility series, a Hodrick-Prescott filter (using λ=129,600) has been applied. Then a value of 1 has been assigned to every observation which is higher than 1.65 standard deviations above the mean of the detrended series (selected as the 5% one-tailed significance level), and a value of 0 to every observation which is lower.

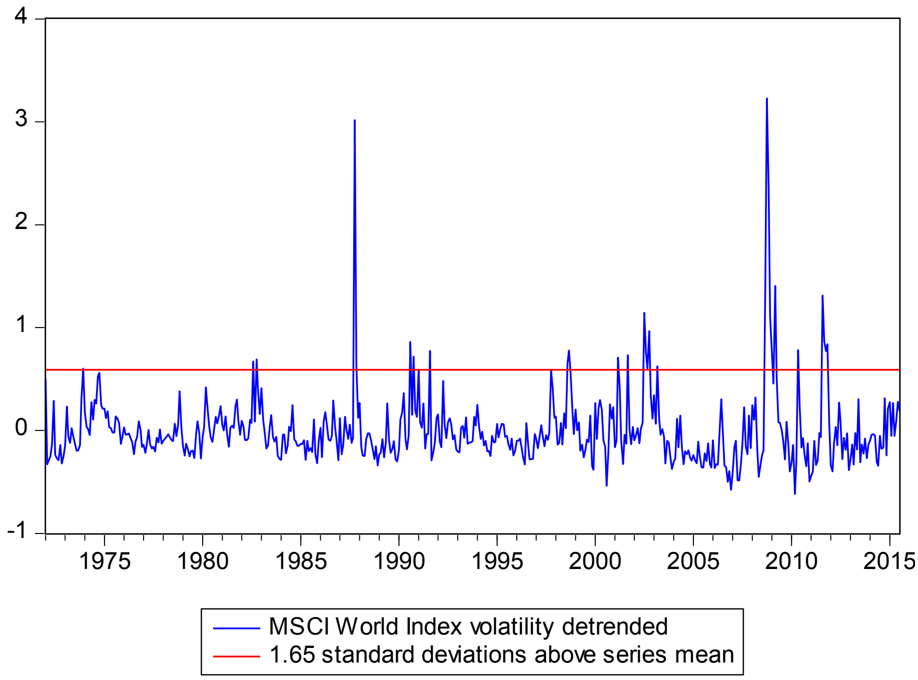

Figure 19 MSCI World Index volatility, calculated as standard deviations of daily returns over calendar months, Hodrick-Prescott detrended (λ=129,600). Red line plots 1.65 standard deviations above the mean of the series. Sample is 1972M01 – 2015M07.

Volatility Shocks	
Events	First Volatility
OPEC I, Arab–Israeli War	December 1973
Monetary cycle turning point	August 1982
Black Monday	October 1987
Gulf War I	September 1990
Asian Crisis	November 1997
Russian, LTCM default	September 1998
9/11 terrorist attack	September 2001
Worldcom and Enron	July 2002
Gulf War II	February 2003
Credit crunch	August 2007
European debt crisis	May 2010
United States debt-ceiling crisis	August 2011

Table 3 Shocks identified as 1.65 standard deviations above the mean of MSCI World Index volatility series, Hodrick-Prescott detrended. Shocks before 2008 are the same as in Bloom (2009).

When shocks do not occur in one month only, but span multiple months, a choice over the exact allocation of their timing has to be made. In Bloom, two approaches are presented: the choice of the month with the largest volatility spike for that event, or the choice of the month in which the first volatility shock occurs. This second approach is the one here adopted, to see the impact on the economy at the first shock, so disaster risk indicator takes the value of 1 in the first month.

In figure 19 the MSCI World Index volatility series detrended is reported, with the red line plotted 1.65 standard deviations above the mean of the series. Peaks, above the 1.65 standard deviations thresholds, are the shocks individuated, corresponding to events reported in table 3.
The shocks up to 2008 are the same volatility shocks identified by Bloom (2009) (its sample period goes until June 2008, while ours until July 2015).

5.2.2 ***Analysis and results***

VARs are estimated as in paragraph 4.2.1: data are the same, variables are expressed in the same way and maintaining the same order, but as variable identifying disaster probability shocks now the indicator calculated above is used. The sample period remains from January 1972 to July 2015 for all the countries involved, and the VAR order suggested by Akaike criterion is three for the United States and two for the other countries. Responses of the main variables to disaster risk shock, applying Cholesky decomposition, are plotted in figures 20 - 21.

Looking at long-term government bond yields (figure 20a), results are aligned with the baseline case, even if in all the countries the initial drop in the periods immediately following the shock is more pronounced.

Consumer price indices (figure 20b) are still negatively affected, of an amount that (even if slightly lower) does not significantly differ from the baseline. Of the impulse responses regarding the industrial production (figure 21a), an overall reduction of the growth rates is observable, as expected (except for Canada, where there is not any significant reduction). However also for this variable it is significantly lower in respect to the initial analysis (of around 3 percentage points, from a cumulative point of view).

The exchange rates (figure 21b) even in this case do not present any significant variation in Italy, France and Germany. Japan appreciates, as in baseline analysis, but qualitatively the results differ (at cumulative level, it is now 8.9 percentage points instead of 20), and also the depreciation of the Canadian dollar is less marked (see the maximum reduction three periods after the shock). Moreover, not any significant depreciation occurs in United Kingdom.

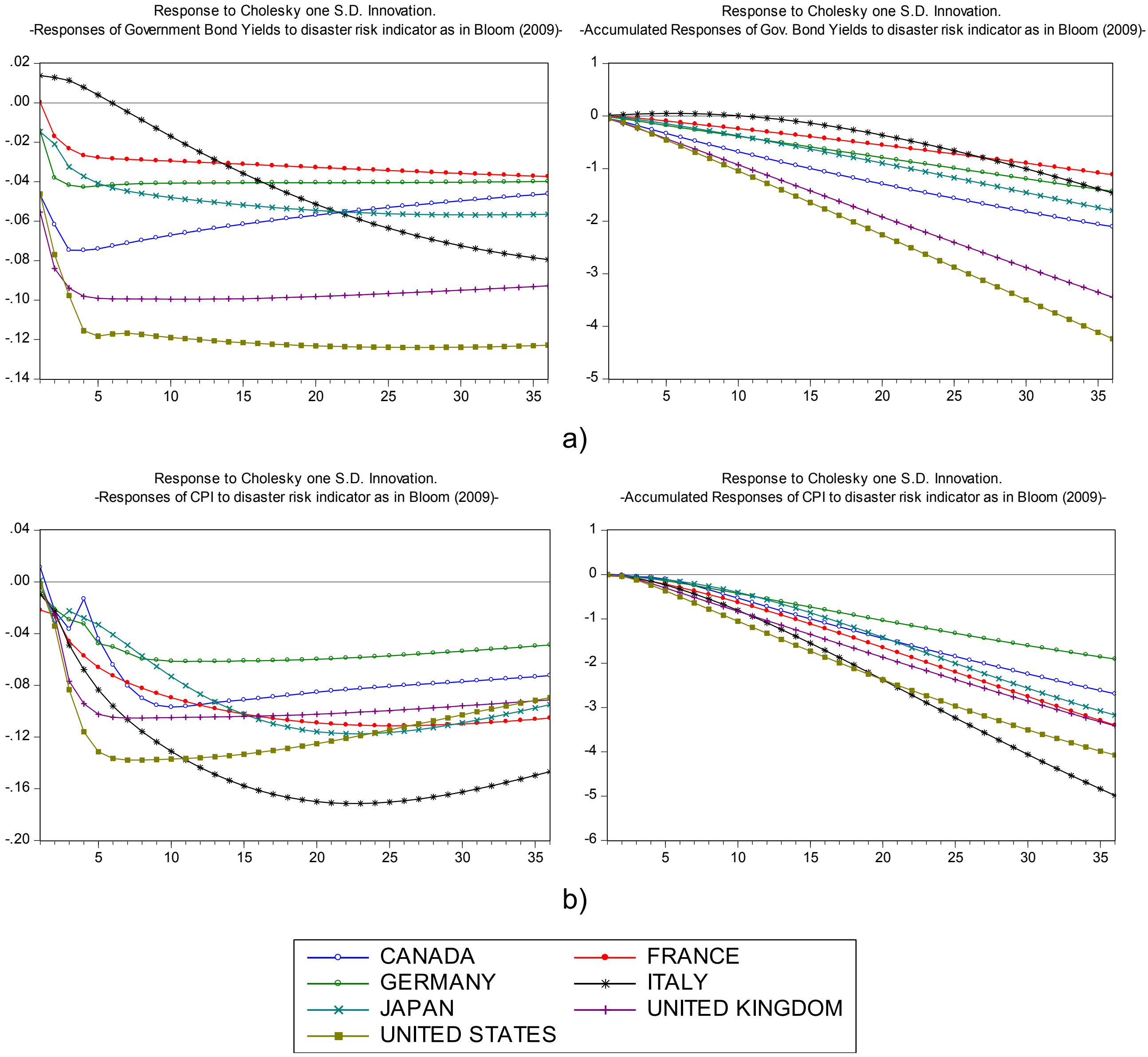

Figure 20 Impulse response functions (left) and accumulated responses (right) of a) Government Bond Yields and b) Consumer Price Index to a one standard deviation shock on disaster risk indicator (from MSCI World Index volatility, calculated as in Bloom, 2009) in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, disaster risk indicator as in Bloom (2009), long-term government bond yields, consumer price index, exchange rates, industrial production index.

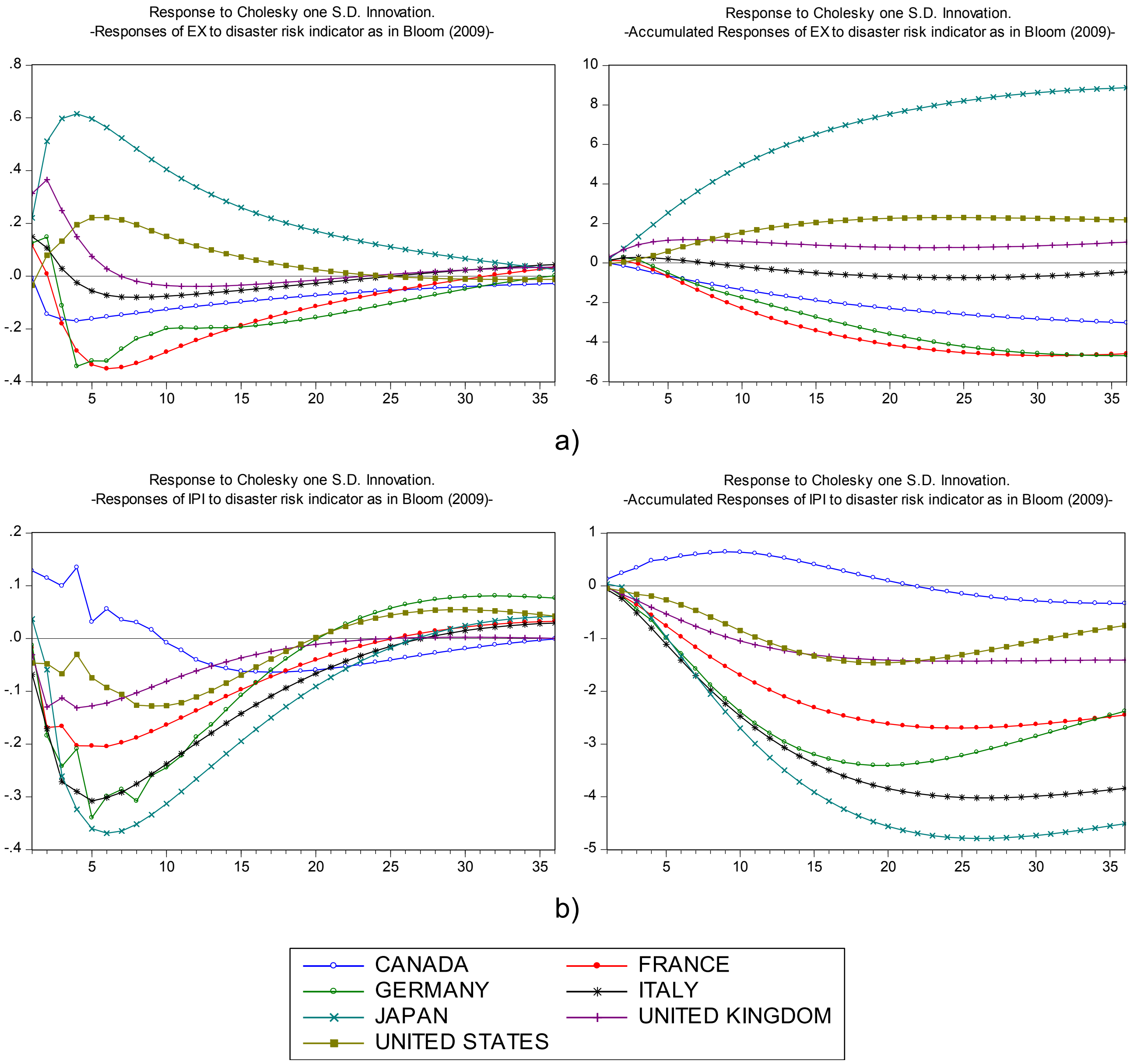

Figure 21 Impulse response functions (left) and accumulated responses (right) of a) Exchange Rates and b) Industrial Production Index to a one standard deviation shock on disaster risk indicator (from MSCI World Index volatility, calculated as in Bloom, 2009) in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, disaster risk indicator as in Bloom (2009), long-term government bond yields, consumer price index, exchange rates, industrial production index.

However, by lowering the threshold used for disaster risk shock definition from 1.65 standard deviation to 1 standard deviation above the mean, results are closer to the baseline case of about 0.5 percentage points on average in regard to industrial production index, and the United Kingdom experiences slight but statistically significant depreciation.

Generally, even if quantitatively the results in some case could vary, presenting different magnitude of impulse responses, qualitatively they are in line with our baseline analysis, that seems robust to this change in disaster risk indicator.

5.3 Change in variables ordering

In this variation of the baseline VARs, the Cholesky ordering of the variables is modified: the disaster risk indicator is ordered last. This implies that, by construction, MSCI World Index volatility does not have a potentially immediate impact on all other variables (i.e. all other variables do not react instantaneously to a disaster risk innovation, while disaster risk does in case of innovations in all other variables, see Lütkepohl, 2005). In this way, MSCI World Index volatility is considered net of other shocks, which could also involve the remaining variables included.

Except for this change in variables ordering, VAR setting and estimation are as in paragraphs 4.1 and 4.2. Akaike criterion suggests a VAR order of three for the United Kingdom and United States, and an order of two for the other countries.

Figures 22 and 23, which report impulse responses of the variables to one standard deviation volatility shock, suggest results which are close to the baseline analysis, with only few statistically significant differences. More specifically, the government bond yields (figure 22a) present the same decline as in the baseline, with the only exceptions for Italy, where there is now no increase immediately after the shock. Also looking at the consumer price index (figure 22b), accumulated responses appears to be about one percentage point lower in France and United States, but this difference remains negligible. The same considerations hold for Canada in reference to the industrial production index (figure 23b).

Finally, while exchange rates (figure 23a) are quantitatively comparable to the baseline case in all the other countries, in Japan the appreciation is still significant but of lower magnitude (the maximum peak is +0.81 percentage points, six periods following the shock, instead of 1.28, and at cumulative level it reaches +13 percentage points compared to the previous 20.1).

After looking at these outcomes, our VAR appears robust to a change in Cholesky ordering, since they present an evolution of the variables which is consistent with the baseline.

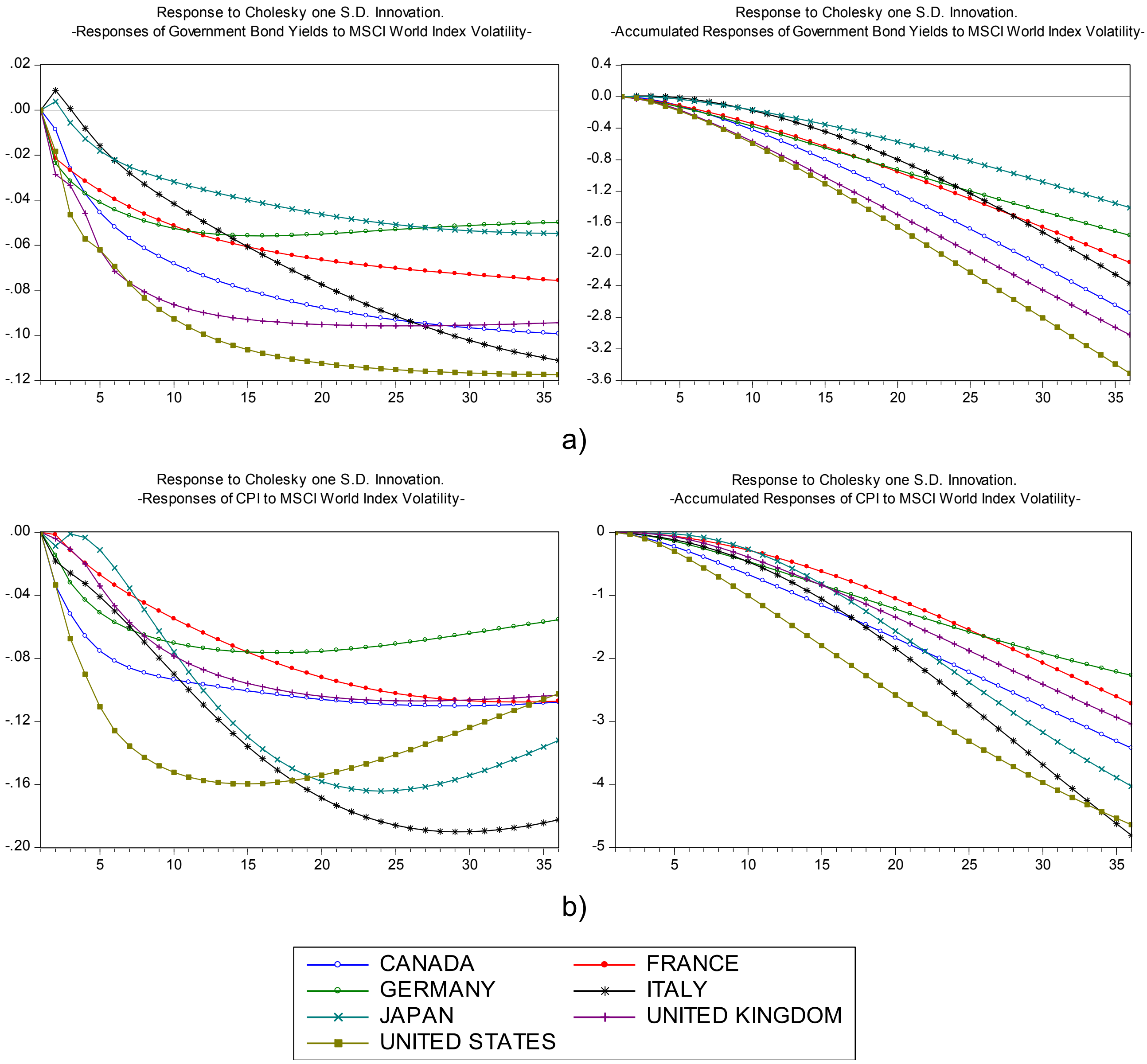

Figure 22 Impulse response functions (left) and accumulated responses (right) of a) Government Bond Yields and b) Consumer Price Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, long-term government bond yields, consumer price index, exchange rates, industrial production index, MSCI World Index volatility.

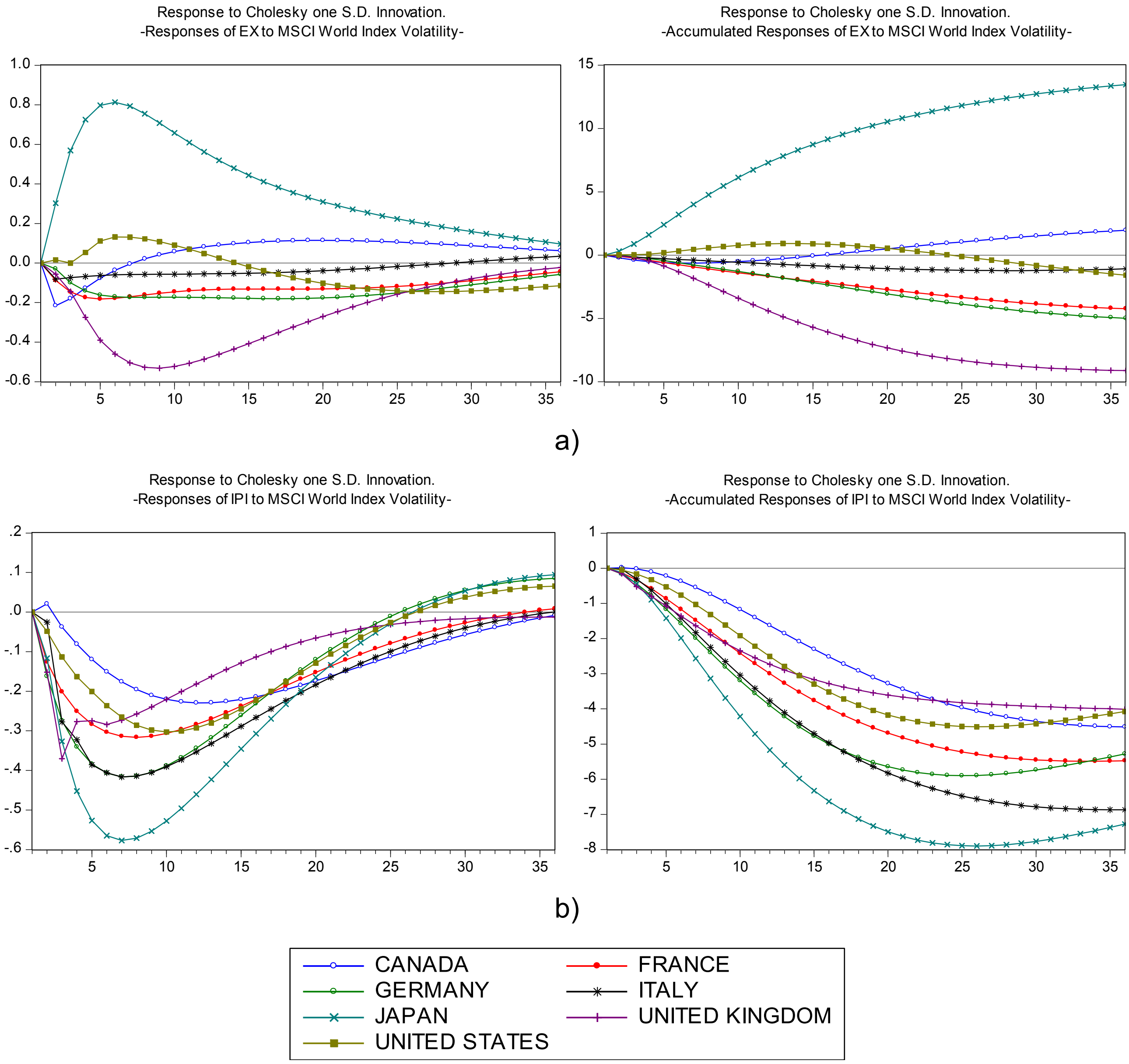

Figure 23 Impulse response functions (left) and accumulated responses (right) of a) Exchange Rates and b) Industrial Production Index to a one standard deviation shock on MSCI World Index volatility in G7 countries. Data are monthly, sample is 1972M01 - 2015M07. VARs contain the following variables: MSCI World Index, long-term government bond yields, consumer price index, exchange rates, industrial production index, MSCI World Index volatility.

5.4 Sample without Zero Lower Bound

5.4.1 Estimation

In the first variation of the baseline analysis presented in this paragraph, periods with the presence of zero lower bound affecting the United States are excluded. At the zero lower bound, risk exposure of countries could increase and the impact of disaster risk could be more marked, because monetary policy becomes unable to offset negative exogenous shocks (see Basu and Bundick, 2015, which examine the interactions between zero lower bound and uncertainty, and the fact that the presence of zero lower bound could magnify the effects of uncertainty shocks). So, by excluding the zero lower bound from the analysis, it will be possible to observe if our results suggest a risk exposure which is affected (increased) by the presence of zero lower bound, consistently with Basu and Bundick (2015). The new sample period goes from January 1972 to December 2007 (that means 432 observations included for each variable, before adjustments), and number of lags suggested by Akaike criterion is five for Japan, three for Germany and United States, two for the remaining countries.

In the second variation of the baseline, the zero lower bound is still excluded from the sample period, but now only the years of the Great Moderation are covered. As this period presents a lower macroeconomic volatility, also the effects of disaster risk shock, as one standard deviation MSCI World Index volatility shock, should be less pronounced, suggesting a lower riskiness. Here the sample goes from January 1985 to December 2007 (corresponding to 276 observations included before adjustments). According to Akaike criterion, VAR order is three for Canada, Japan and United Kingdom, two for the other countries. In both variations, except for these modifications in the time range, VARs estimation and variables involved are as in paragraphs 4.1 and 4.2.

5.4.2 Results

Figures 24 - 27 plot the impulse responses and accumulated responses of respectively long-term government bond yields, consumer price indices, exchange rates and industrial production indices to a one standard deviation shock on MSCI World Index volatility. The upper part of every figure reports the results of the baseline case, then are shown the results of the analysis with sample January 1972 - December 2007, and finally in the lower part the results for the sample January 1985 - December 2007.

Looking at the long-term government bond yields (figure 24), in both robustness checks it is possible to observe a general decrease after the shock, as in the baseline, but with a magnitude that is lower by considering the Great Moderation period (figure 24c). About the consumer price index (figure 25), there are no statistically significant (68% confidence interval) variations in growth, so it differs from the baseline analysis. The only exception is Japan during Great Moderation, but at cumulative level it presents a decrease in growth of 0.96 percentage points, so less pronounced than the baseline, with its 4.4 percentage points.

The more relevant difference between our initial VARs and these two robustness checks concerns the exchange rates (figure 26). In the analysis with sample period January 1972 - December 2007, there is a statistically significant depreciation in the United States (with a decrease in growth of -5.7 percentage points at cumulative level), and an appreciation not only in Japan, as in the baseline, but also in the other countries. In fact, not only France, Germany and Italy (which previously did not experience any significant variation in exchange rates growth subsequent to disaster risk shock) now report a significant appreciation, with maximum peak two periods after the shock, but also Canada and United Kingdom (that in the baseline depreciates, as shown in figure 26a) with a peak of 0.2 and 0.53 percentage points respectively. The same results appear from the analysis covering the Great Moderation years, even if here the country which experiences the higher increase in exchange rates growth is Italy (20 percentage points at cumulative level), and not Japan as in the previous case.

Finally, in the industrial production (figure 27), for the sample January 1985 - December 2007 there is no significant variation in growth, except for Italy with -0.22 percentage points three periods after shock, but that shows a recovery in following periods. From the analysis adopting the sample period from January 1972 to December 2007, the results differ: they are consistent with the baseline case from a qualitative point of view (there is a drop in industrial production growth), while quantitatively they present a lower magnitude (about 50% less at cumulative level, except for Canada, where they do not differ significantly).

Generally, these results are consistent with the assumption that the exclusion of the zero lower bound from the sample determines a decrease in riskiness: the United States, now less exposed to global risk, experience a depreciation: result that is in line with disaster risk theories. Moreover, also the lower magnitude of responses in the analysis without zero lower bound (but especially by considering only Great Moderation years and their characteristic low volatility), can be interpreted as a decline in riskiness: government bond yields do not decrease as much as in the baseline case, (fact that could be interpreted as a lower demand for safe assets), and the recessionary effects of disaster risk shock are less pronounced, with weaker consequences on industrial production and prices.

Having highlighted the relevance of zero lower bound for countries' riskiness, it is worth recalling the case of Japan. In fact, as already examined in paragraph 4.3, Japan is the country with the lowest level of interest rates, and the one considered the most exposed to disaster risk. But it appears to be also the country with the presence of zero lower bound for the higher number of periods: since 1999, its policy rate is between zero and 0.25 (except for 2007 - 2008, in which it reaches 0.5). So, consistently, the zero lower bound could be a determinant of its higher riskiness and magnitude of disaster risk impact.

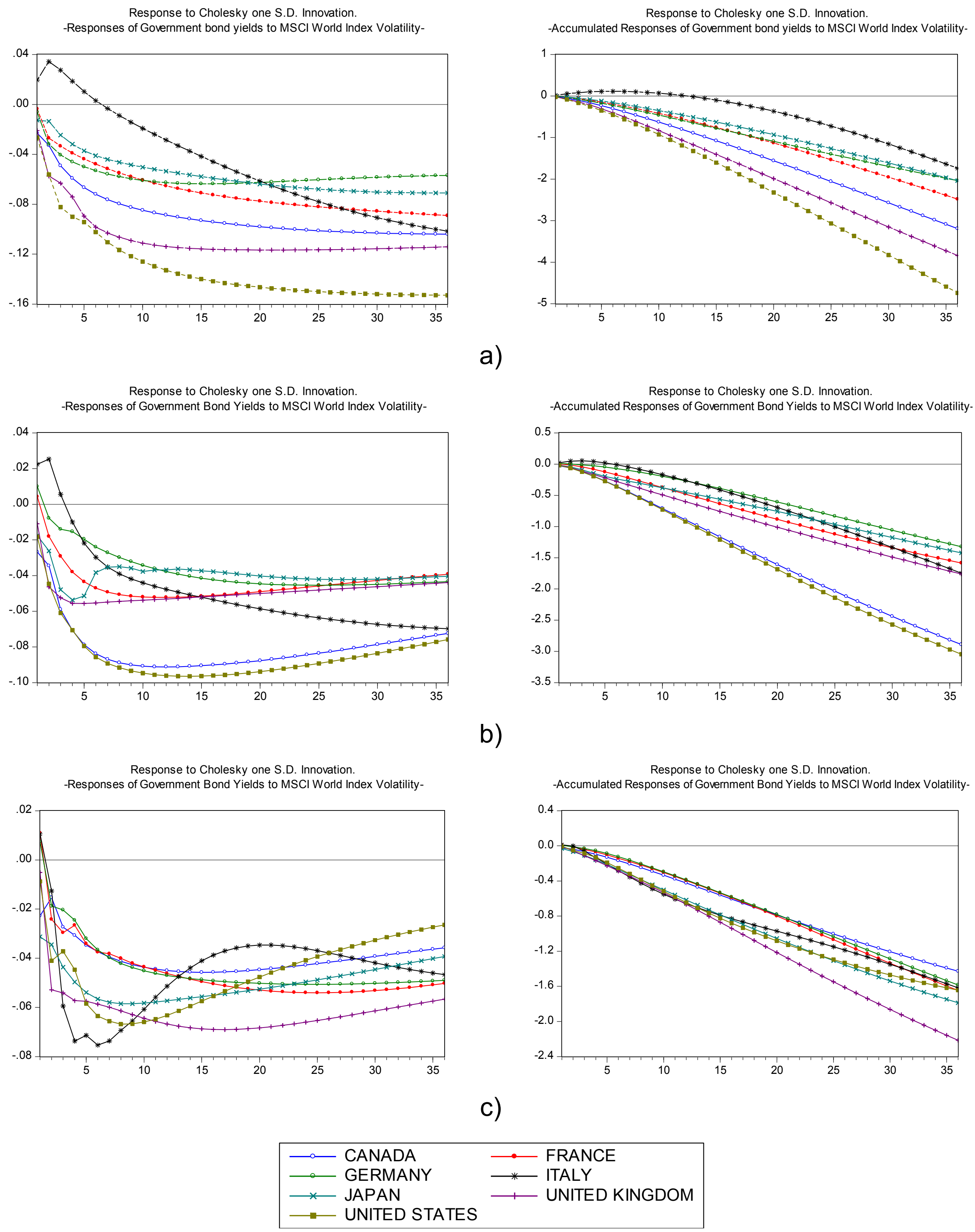

Figure 24 Impulse response functions (left) and accumulated responses (right) of Government Bond Yields to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline model, b) VAR without ZLB, c) VAR for period of Great Moderation. Data are monthly, sample is 1972M01-2015M07 in a), 1972M01-2007M12 in b), 1985M01-2007M12 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

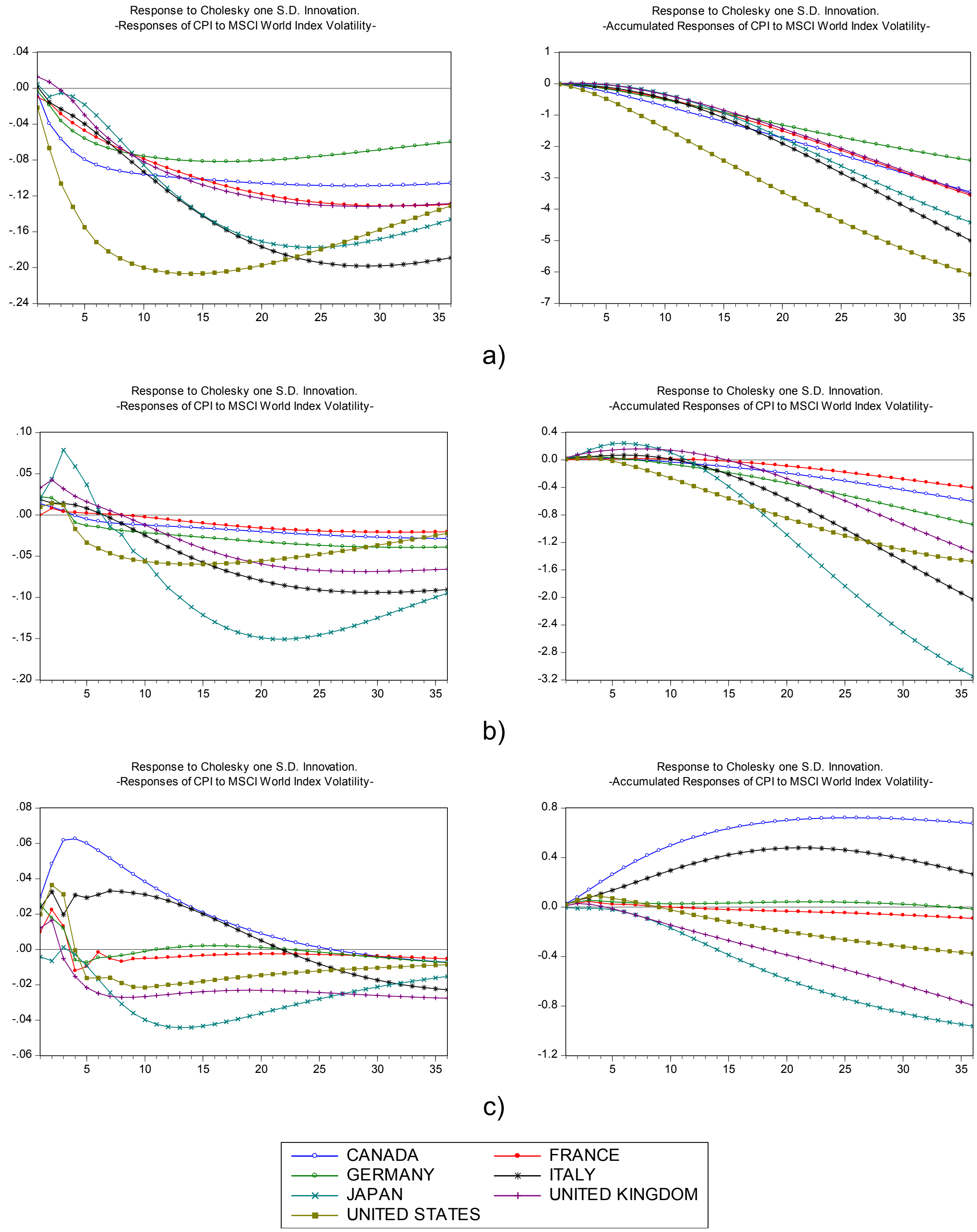

Figure 25 Impulse response functions (left) and accumulated responses (right) of Consumer Price Index to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline model, b) VAR without ZLB, c) VAR for period of Great Moderation. Data are monthly, sample is 1972M01-2015M07 in a), 1972M01-2007M12 in b), 1985M01-2007M12 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

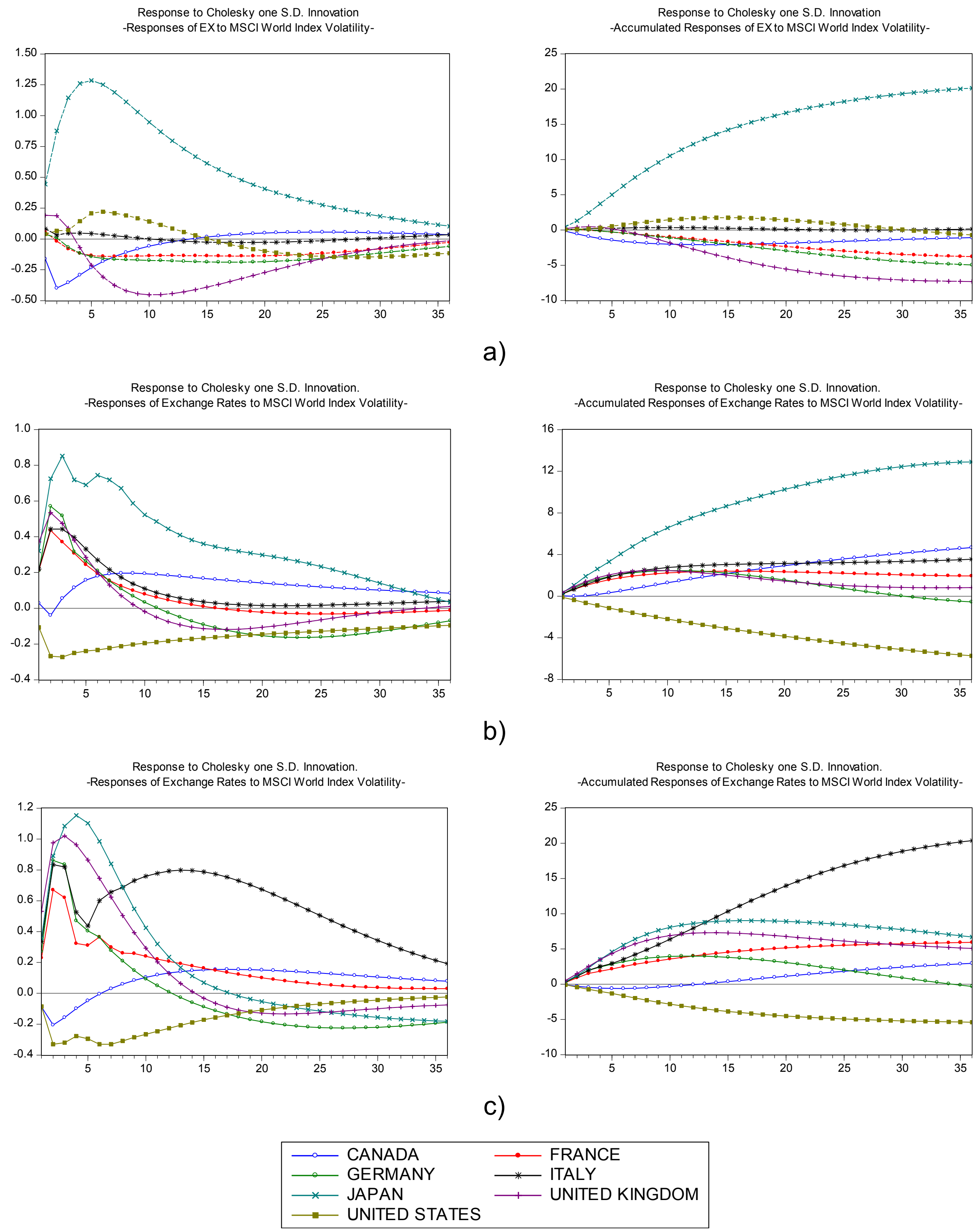

Figure 26 Impulse response functions (left) and accumulated responses (right) of Exchange Rates to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline model, b) VAR without ZLB, c) VAR for period of Great Moderation. Data are monthly, sample is 1972M01-2015M07 in a), 1972M01-2007M12 in b), 1985M01-2007M12 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

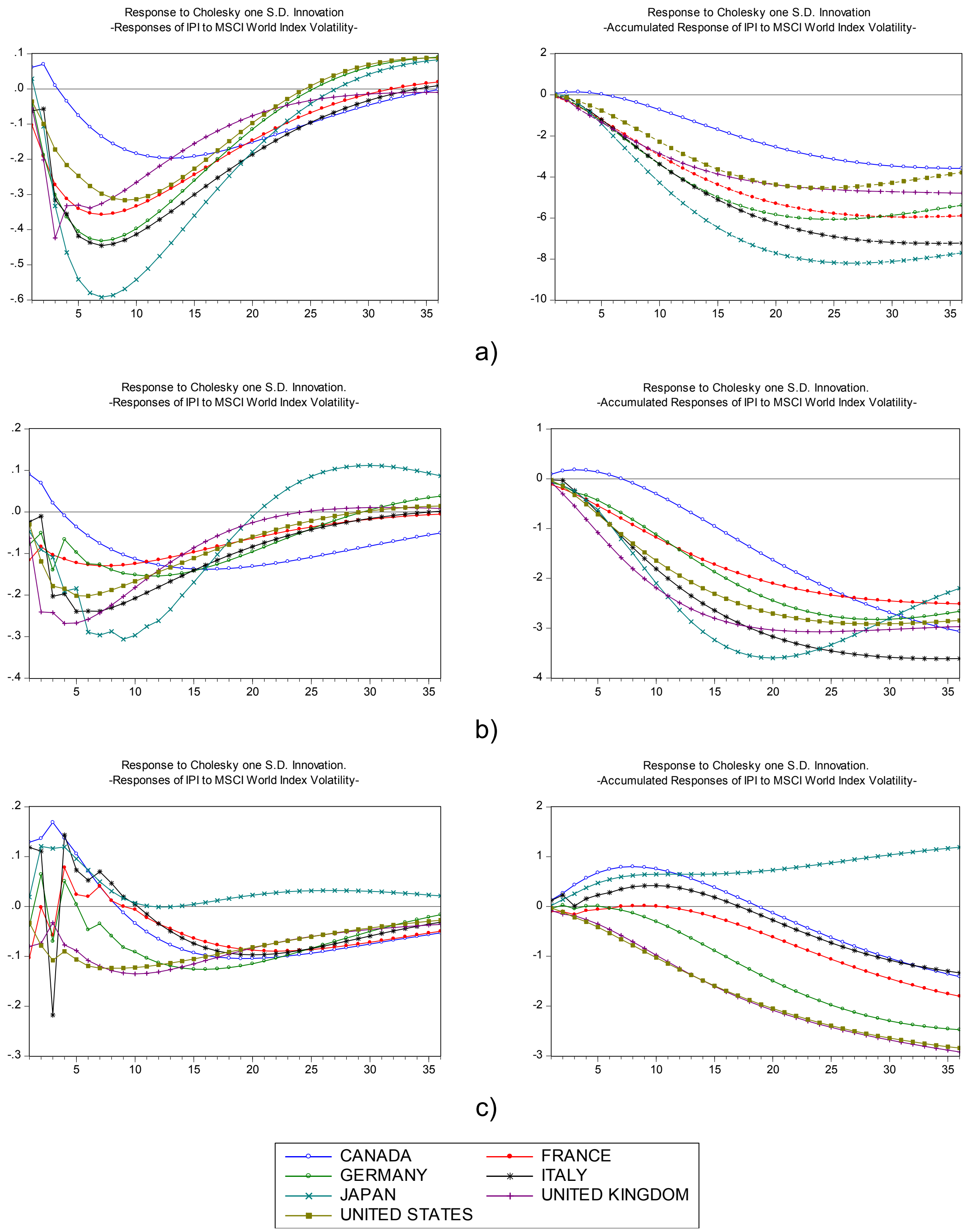

Figure 27 Impulse response functions (left) and accumulated responses (right) of Industrial Production Index to a one standard deviation shock on MSCI World Index volatility in G7 countries, of a) baseline model, b) VAR without ZLB, c) VAR for period of Great Moderation. Data are monthly, sample is 1972M01-2015M07 in a), 1972M01-2007M12 in b), 1985M01-2007M12 in c). VARs contain the following variables: MSCI World Index, MSCI World Index volatility, long-term government bond yields, consumer price index, exchange rates, industrial production index.

6 Conclusions

Since Rietz (1988) and Barro (2006), many works have considered the possibility of rare but extreme disaster as an important determinant of macroeconomic dynamics and risk premia in asset markets.

Our empirical analysis, consisting in VARs focused on the G7 countries, investigates the effects of disaster risk shocks in open economies, and to which extent a different level of exposure to disaster risk can be considered as an explanation for heterogeneous effects across countries.

VARs responses to volatility shocks are in line with the reference literature on disaster risk, (especially Gourio2008a, 2008b, 2012, 2013 and Gabaix 2011, 2012) supporting the hypothesis of a recession following a disaster shock. Industrial production and consumers prices show a decline in growth in all countries involved in the analysis, and the same happens to interest rates, facts consistent with the assumption that an increase in disaster probability can affect the economy by lowering expectations, and by increasing risk, leading risk-averse agents to shift their preference toward safer assets. These results can also be considered as a consequence of flight to quality or flight to liquidity episodes (phenomena which in periods of high uncertainty can be observed, as explained in Caballero and Kurlat, 2008, Caballero and Krishnamurthy, 2008, Longstaff, 2004).

Differences in exchange rate dynamics across countries emerge from our analysis, and they can be explained in the light of heterogeneous exposure of countries to a disaster risk which is global, as in Gourio et al. (2013). Our results are consistent with their theoretical model, suggesting an exchange rates appreciation in more risky countries (which are assumed to be the ones with lower interest rate levels).

Results appear to be robust to various modifications of the baseline case, as the change of variables included, of variables ordering and of disaster risk indicator, and the elimination of zero lower bound from the sample. From this latter case emerges the fact that disaster risk effects seem to be more pronounced in the presence of zero lower bound (observation consistent with Basu and Bundick, 2015).

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Software used

- Microsoft Office Excel 2010
- EViews 7