Asymmetries in the Response of Economic Activity to Oil Price Increases and Decreases?*

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Abstract

It has been common to assume that the relationship between economic activity and oil prices is asymmetric. Theoretical underpinnings for this asymmetry include costly sectoral reallocation, partial equilibrium models of irreversible investment, and some version of precautionary savings. Yet, recent studies that use new methodologies to test for asymmetries in U.S. data have cast some doubts on that premise. In this paper, we use state-of-the-art techniques to evaluate the presence of asymmetries for a set of OECD countries containing both oil exporters and oil importers. We find very little support for the hypothesis that the response of industrial production to oil price increases and decreases is asymmetric. Our results have important implications for theoretical models of the transmission of oil price shocks: they point towards the importance of direct-supply and direct-demand transmission channels, as well as indirect transmission channels that imply a symmetric response.

1 Introduction

How does economic activity respond to oil price shocks? Does economic activity contract when oil prices increase, but no boom ensues when oil prices fall? Until recently, a consensus seemed to

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exist regarding the asymmetric nature of the relationship between oil prices and the macroeconomy. Indeed, discussions in academic and policy circles often refer –explicitly or implicitly– to the asymmetric nature of the relationship between GDP growth and oil price shocks (see, e.g., Bernanke, Gertler and Watson 1997; Bernanke 2006). However, recent work by Kilian and Vigfusson (2011a) has called into question the view that oil price innovations have an asymmetric effect on U.S. GDP growth. In particular, they prove that the methodology commonly used in the empirical literature to assess the possible asymmetry in the response of economic activity to oil price shocks may lead to inconsistent parameter estimates due to a censoring bias. Moreover, they show that the slope based tests carried out in most studies are not informative about the presence of asymmetry in the impulse response functions.

Evaluating whether the relationship between oil prices and economic activity is symmetric constitutes a crucial step in deciding how to model oil prices, in selecting among alternative models of the transmission of oil price shocks, and in getting a good grasp on the magnitude of the macroeconomic effect that positive and negative innovations entail. Despite the large number of studies on the relationship between oil prices and the macroeconomy, almost all we know regarding the importance of the asymmetric channels of oil price transmission has been informed by U.S. data (e.g., Kilian and Vigfusson 2011a,b) or stems from estimating censored models with international data, which may lead to inconsistent estimates of the impulse response functions.[1] One thus has to wonder whether the results obtained for the U.S. are just a figment of the particular data set or whether it is a result that generalizes to other countries. If it is the former, then there is no need to revise the way in which we model asymmetries; yet, if it is not, then we should re-think not only the estimation techniques, but also our theoretical models of the transmission of oil price shocks.

[1] Although research into the question of symmetry using OECD data is not new (see, for instance, Mork, Olsen, and Mysen 1994; Cuñado and Pérez de Gracia 2003; Jiménez-Rodríguez and Sánchez 2005), most papers test for symmetry using slope based tests.

Our aim is to explore whether the empirical implications of different models of the transmission of oil price shocks are borne out by the country-level responses to positive and negative oil price innovations. To do so we examine the estimated responses of industrial production for 18 countries belonging to the Organization for Economic Co-operation and Development (OECD). We believe this data set provides a good testing ground for several reasons. First, theoretical explanations for an asymmetric response apply both to oil producers and oil importers, but have only been explored using impulse response based tests for U.S. data. Clearly, the theoretical underpinnings for an asymmetric response apply not only to the U.S., but also to other large net oil importers such as Japan and Germany (see Figure 1).

Second, data for oil exporting countries is particularly valuable. In particular, crude oil production represents a large part of GDP for Norway and Canada (see Figure 2); hence, conditions for an unexpected oil price innovation to have a large economic impact hold by construction. These data allow us to evaluate whether the presence (or absence) of asymmetry in the industrial production-oil price relationship is related to the share of crude oil production in aggregate output.

Finally, the degree of energy intensity in consumption varies greatly across OECD countries. For instance, among oil exporters, whereas energy intensity measured in total primary energy consumption (in BTU) per dollar of 2000 GDP was 13,097 for Canada in 2006, it was only 5,267 for Denmark (see Figure 3). During the same year, energy intensity was about 36% higher for the U.S. than for Japan, the largest and second largest oil importers in the sample, respectively. This disparity in the degree of energy intensity suggests that the magnitude of the response of consumption –and thus production– to positive and negative oil price shocks might vary significantly across countries.

The contribution of this paper to the ongoing debate is threefold. First, we shift the focus from the U.S. data used in the current debate (see, e.g., Kilian and Vigfusson 2011a,b; Hamilton 2011; Herrera, Lagalo and Wada 2011) to a larger sample including both net oil importing and exporting countries. Second, we propose a measure of the distance between impulse response functions, which allows us to evaluate the magnitude of the asymmetry between the response to a positive and a negative oil price innovation. This measure of distance is the cumulative Euclidean norm and provides additional insights into the economic significance of the asymmetry. Third, we use state-of-the-art econometric techniques to test for symmetry in the impulse response functions.[2]

We find very little evidence of asymmetry in the response of industrial production to positive and negative oil price innovations. We reject the null of symmetry in response to a one standard deviation –hereafter 1 s.d.– innovation for the G7 when we use the oil price increase. Similarly, we reject the null for Greece, Sweden, and the U.S. when we use the net oil price increase relative to the previous three-year maximum. For a two standard deviation –hereafter 2 s.d.– innovation, we reject the null of symmetry for the U.S. when we use the net oil price increase relative to the previous year maximum. Our results suggest that the transmission of oil price shocks to the macroeconomy takes place mainly through transmission channels that do not imply an asymmetric response.

Despite the fact that the statistical test very rarely rejects the hypothesis that the asymmetric impulse response estimates equal the impulse response estimates from the symmetric model, this finding does not imply that we should rule out alternative nonlinear models. In particular, we only consider the three particular forms of nonlinearity most commonly used in the literature. Yet, the test may have low power against alternative forms of nonlinearity such as those stemming from an asymmetric response to changes in oil uncertainty (measured as an increase in the standard

[2] For the sake of completeness we report the results of the slope based tests in Table A.1 of the on-line appendix made available at http://gatton.uky.edu/faculty/herrera/documents/HLWcou_appendix.pdf. However, the reader should bear in mind that these test results are by no means indicative of asymmetry in the impulse response functions (see Kilian and Vigfusson 2011a).

deviation) of the real oil price.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical underpinnings behind the transmission of oil price shocks, with particular emphasis on the empirical implications regarding asymmetry. The data on industrial production and oil prices are described in section 3. Section 4.1 describes the response of industrial production growth to positive and negative oil price shocks, section 4.2 discusses the magnitude of the asymmetry, and section 4.3 presents the results for an impulse response based test of symmetry. We present our conclusions in section 5.

2 Asymmetries in the Transmission of Oil Price Shocks: Theoretical Underpinnings

This section briefly reviews the theoretical literature on the transmission of oil price shocks. Given our object of interest, we focus on whether a particular channel leads to an asymmetric response in economic activity.

2.1 Symmetry

An increase in the price of crude oil has a *direct* impact on the *supply* of goods that are produced using energy and on the production of crude oil. Consider the case of an oil importing country where a representative firm uses labor, capital, and energy to generate gross output and faces perfectly competitive markets. Hamilton (2008) shows that if the production function is assumed to be continuous and differentiable in energy use, it is unlikely to see large fluctuations in output without a great deal of variation in energy prices and firms' adjustment of inputs (both energy and other factors of production). Indeed, the elasticity of output with respect to changes in oil usage will be bounded by the share of energy expenditure in total output. In addition, *ceteris paribus*, assuming a smooth production function implies a symmetric response of output to changes in the energy input.

As for oil exporting economies, the *direct-supply* effect is symmetric but its sign is ambiguous. On one hand, industries that use energy intensively in their production process will experience a contraction as capital and labor reallocate away from energy-intensive sectors. This effect, in turn, will lead to a downturn in aggregate production. On the other hand, an increase in oil prices will foster exploration and extraction of crude oil, yet production is likely to respond with a long lag (see for instance, Favero, Pesaran and Sharma, 1994). Furthermore, productivity spillovers between the oil sector and the rest of the economy might result in increased production across oil and non-oil industries in response to demand-driven oil price shocks (Bjørnland and Thorsrud 2013). Therefore, the sign of the effect will depend on: (a) the importance of the oil sector in the country's aggregate GDP, (b) the lag in the response of oil production, and (c) productivity spillovers between oil and non-oil industries.

But, how large is the share of oil production in the OECD economies under study? Among net oil importers, the share fluctuated between 3% and 4.3% for the U.S. –the importer with the largest share of oil production in GDP– between 1974 and 1984, but it dropped below 1.5% in the following years. For none of the other importing countries did the share exceed 1% of GDP. As for the oil exporters, the share reached a maximum of 26% for Norway, 8% in Canada, and 4.7% in Denmark in 2008 (see Figure 2).[3] These numbers suggest that the direct supply impact of an oil price shock should be largest for Norway and Canada, among oil exporting countries, and for the U.S., among oil importing countries.

[3] The U.K. established itself as a net oil exporter in 1981 and continued to be so for over two decades. However, it was a net importer in 2006, 2008 and 2009.

Oil price shocks can also be transmitted to the macroeconomy via a *direct demand-side channel*. An increase in the price of crude oil leads to an income transfer from oil exporting countries to oil importing countries and, thus, to a change in consumers' purchasing power. Therefore, while oil exporting countries would experience an increase in production due to a demand push, oil importing countries would face a contraction (see Edelstein and Kilian 2007, 2009; Hamilton, 2011). This demand-side effect is symmetric, and bounded by the share of energy expenditures on total expenditures, which averaged about 10% for the countries in the sample.

2.2 Amplification and Asymmetry

In order to account for a larger impact of crude oil prices than implied by the direct channels, researchers have developed models that involve indirect transmission channels. These transmission mechanisms amplify the effect of an oil price shock and may lead to asymmetry.

Davis (1987a,b), Bresnahan and Ramey (1993), and Davis and Haltiwanger (2001) suggest that *sectoral reallocation* could result in an asymmetric response of economic activity to positive and negative oil price innovations. According to this literature, oil price innovations would bring about labor and capital reallocation from declining sectors to expanding sectors. Therefore, for oil importing (exporting) countries, costly sectoral reallocation would amplify the recessionary effect of a positive (negative) oil price shock and mitigate the expansionary effect of a negative (positive) shock.

A different type of reallocation disturbance was proposed by Hamilton (1988). In his model, unemployment and lower production result from workers who, given a positive probability that conditions will improve in their sector, choose not to relocate even if they are offered a job in a different sector at a wage that exceeds their marginal utility of leisure. Note that, for oil importing (exporting) countries, this type of disturbance would also amplify the negative effect of an oil price increase (decrease) and mitigate the expansionary effect of a decrease (increase). All in all, both types of reallocation disturbances would lead to an asymmetric effect of positive and negative oil price innovations on aggregate production.

Precautionary saving has also been posited as a motivation for asymmetry (see Edelstein and Kilian 2007, 2009). For an oil importing economy, an increase in the price of oil may cause concern regarding future reductions in employment and real income, inducing an increase in precautionary saving, which then leads to a demand-driven decline in production. Because, a decrease in the price of oil would not be associated with higher uncertainty about the future, this channel implies asymmetry. A similar argument could be made for an oil exporting economy that faces a reduction in the price of oil.[4]

Another theoretical justification relies on the asymmetric response of *monetary policy* to oil price increases and decreases. Specifically, in the case of the U.S., it has been argued that the Federal Reserve responds more aggressively to rises in crude oil prices than it does to falls (e.g., Bernanke, Gertler and Watson 1997). Yet, empirical evidence regarding the role of monetary policy in amplifying the recessionary effect of oil price shocks is rather weak if it exists at all (see, e.g., Hamilton and Herrera 2004; Herrera and Pesavento 2009; Kilian and Lewis 2011; Kilian and Vigfusson 2011a).

Asymmetry may stem from the *irreversibility of the capital-labor ratio or investment*. For instance, in Atkeson and Kehoe's (1999) general equilibrium model of energy use, where capital is putty-clay in terms of energy, changes in the price of the latter can have an asymmetric effect on output. Partial equilibrium models of irreversible investment also suggest an asymmetric response (see, e.g. Bernanke 1983; Pindyck 1991). In these models, increased uncertainty regarding energy

[4]The magnitude of this effect on aggregate production would depend on the composition of the economy, on the degree of energy intensity in consumption, and relies on the assumption that future employment levels are uncertain.

prices and oil supply causes individuals to abstain from purchasing energy-intensive consumer durables such as automobiles, and investors to postpone their purchases of capital goods. Therefore, for an oil importing country, increased uncertainty would amplify the recessionary effect of an oil price increase and mitigate the expansionary impact of an oil price decrease. In contrast, for an oil exporting country, heightened uncertainty would dampen the direct expansionary effect of an oil price increase and exacerbate the direct recessionary effect of a price decrease.

Recent studies have demonstrated that heightened uncertainty could imply asymmetry under general equilibrium. Plante and Traum (2012) examine a DSGE model that allows for precautionary saving. In their model, output initially declines in response to higher oil price volatility. Hence, in the short-run, heightened uncertainty could amplify the negative impact of an increase in the level of oil prices and dampen the effect of a decrease in the price level. Başkaya, Hülagü and Küçük (2013) construct a small open economy model with incomplete asset markets where households and firms demand imported oil at an exogenously determined price. They find a negative effect of higher oil price volatility and increased oil price levels on output under financial integration although, "[q]uantitatively, the distinct effects of volatility shocks are much smaller compared with that of level shocks" (Başkaya et al. 2013, pp. 189). Moreover, they show that the impact of a level shock is considerably amplified, when it occurs in conjunction with greater uncertainty. Başkaya et al. (2013) do not explicitly address the issue of asymmetry; however, one may conjecture that lower oil prices in conjunction with higher volatility might not result in a symmetric response of output.[5]

General equilibrium models that produce amplification but do not result in asymmetry are

[5] Both Elder and Serletis (2010) and Jo (2013) find a negative and statistically significant effect of oil price uncertainty on economic activity. Jo's (2013) estimates point toward a smaller effect of volatility shocks. This difference is possibly driven by the use of a different measure of output, namely U.S. real GDP growth in Elder and Serletis (2010) versus an index of global real economic activity in Jo (2013).

proposed by Rotemberg and Woodford (1996), Finn (2000), and Leduc and Sill (2004). Rotemberg and Woodford (1996) show that in the presence of mark-up pricing the response of labor utilization to oil price shocks amplifies the effect of the shock. Finn (2000) develops a model in which capital utilization and the flow of capital services vary endogenously with energy price shocks. Leduc and Sill (2004) build on Finn's (2000) model by adding wage rigidities.

Finally, another view of the *precautionary saving* channel posits that households perceptions regarding oil price increases and decreases are symmetric. That is, while a run up in oil prices would increase precautionary saving and curtail consumption, news of a decline in oil prices would cause the opposite effect (see Edelstein and Kilian 2007, 2009).

To summarize, the discussed theoretical models can be classified into two groups according to their empirical implications regarding asymmetry:

- Models that imply *symmetry* focus on the direct transmission channels, consider indirect transmission via mark-up pricing or changes in capital utilization, analyze precautionary saving under the assumption that households perceive oil price increases and decreases symmetrically.

- Models that imply *asymmetry* emphasize the importance of reallocation disturbances (due to costly sectoral reallocation or to idle labor), consider precautionary savings in a setup where the future level of employment is uncertain, or simultaneously model the effect of changes in the oil price level and heightened oil price uncertainty.

3 Data

To investigate the presence of asymmetries in the relationship between oil price shocks and economic activity, we use monthly data on oil prices and industrial production (IP) indices for eighteen OECD countries. These countries are Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, the UK, and the U.S. We also consider 3 groups of countries: the G-7, OECD-Europe and OECD-Total. There are various reasons for using the IP index instead of GDP as a measure of economic activity. First, the exercise of testing for asymmetry in the response of economic activity is only meaningful if one chooses a long sample –necessary to capture possible nonlinearities—and the same observation period for all the countries.[6] Quarterly GDP for the 1970s and 1980s is only available for a small number of OECD countries (see OECD statistics or the IMF-IFS). Indeed, for most non-OECD countries, quarterly GDP only became available in the 1980s. Second, the IP index is closer to the notion of production in theoretical models used to analyze asymmetries in the transmission of oil prices. On the production side, asymmetric transmission is thought to operate via the manufacturing sector and not the service sector. On the demand side, asymmetries are also modeled as a result of changes in the household's consumption of *goods* and the firm's investment decisions. Third, industrial production is available at monthly frequency and thus allows for a cleaner identification when constructing the impulse response functions.[7] Last but not least, the use of industrial production is standard in the literature (see, for instance, Baumeister and Peersman 2013a,b; Jo

[6]Data for countries that joined the OECD more recently (e.g., Mexico and Brazil) is not available for the same sample period.

[7]For identification purposes we assume that oil prices do not respond to industrial production within a month. This assumption is consistent with Kilian and Vega's (2011) work who find that, in daily data, U.S. macroeconomic news do not predict changes in the price of oil within a month, whereas they do predict changes in various asset returns. However, Elder, Miao and Ramchander (2013) find a strong relationship between high frequency (five minute intervals) jumps in oil prices and the arrival of economic news. These findings are suggestive of an alternative identification strategy where there is no contemporaneous feedback from oil prices to industrial production.

2013).

We restrict the period of analysis to the months spanned between January 1974 and July 2010 for the following reason. Between the 1930s and 1960s, the Texas Railroad Commission largely set world oil prices, but was displaced by the Organization of Petroleum Exporting Countries (OPEC) in 1973. Periods of no change in the nominal price of crude oil were common during the 1960s and early 1970s. However, since the mid-1970s, nominal oil prices have become more flexible and responsive to world market conditions. In fact, Kilian and Vigfusson (2011a,b) and Herrera, Lagalo and Wada (2011) argue that, in the U.S., the transmission mechanism of real oil price innovations changed in the 1970s. Estimation results reported in Table A.2 of the on-line appendix suggest that a similar change took place in the transmission of oil price shocks in the other OECD countries under study.[8]

To measure oil prices we use the Refiners Acquisition Cost –hereafter RAC– for crude oil imported into the U.S. and reported by the Energy Information Agency. Because macroeconomic models of the transmission of oil price shocks are typically specified in terms of the price of imported crude oil, it is common in the literature to use this measure (see, e.g. Kilian and Vigfusson 2011a; Baumeister and Peersman 2013a,b; Baumeister and Kilian 2013.) There are additional reasons why the RAC constitutes a better measure than the UK Brent price. First, the UK Brent spot price was not available in the 1970s (see, the Energy Information Agency's webpage and Baumeister and Kilian 2013).[9] Second, because the definition of the crude oil fields that comprise the Brent prices changes frequently –partly due to the decline in the production of the Brent field-, this price is more

[8] Results using a sample starting in January of 1961 indicate stronger evidence of asymmetry than for the post-1973 sample. Such results are consistent with a structural change in the oil price-industrial production relationship due to the increased flexibility of oil prices. However, note that data for Denmark and OECD-Total are only available from January 1974 and January 1975 onwards, respectively.

[9] However, the correlation between the rate of growth for the UK Brent spot price and the rate of growth for the RAC price for imported crude oil is rather high (0.94) for the period where both prices are available.

subject to structural changes. Finally, the Brent price represents a small quantity of oil relative to the amount that is traded in the market, thus it is not clear that it would constitute a better representation of the prices faced by all the countries in our sample.

In order to compute a measure of the price faced by consumers and investors in each country we multiply the RAC price by the nominal exchange rate and deflate it by each country's Consumer Price Index (CPI). The exchange rate and the CPI for each country are provided by the International Financial Statistics (IFS) of the International Monetary Fund. The base year for the CPI data is 2005. For country groups such as OECD-Europe, OECD-Total, and G-7, the real price of oil is calculated using the U.S. CPI. For countries that switched to the Euro after 1998, the conversion factor provided by the IFS of the International Monetary Fund is used to adjust the exchange rate. This is done in order to maintain historical continuity. Data for the countries of the Euro-area have been converted to national currency by applying the official irrevocably fixed Euro/national currency conversion rates to the years following the introduction of the Euro. Data for Germany are merged in 1991 with data that pertain to the former West Germany.

To evaluate the presence of asymmetries, we use the three main nonlinear transformations of oil prices proposed in the literature.[10] The first of these measures is Mork's (1989) oil price increase, which is defined as:

$$x_t^1 = \max\left\{0, o_t - o_{t-1}\right\}, \tag{1}$$

where o_t is the logarithm of the real oil price. This censoring of the oil price series was proposed by Mork (1989) after the 1985-86 fall in oil prices failed to lead to a boom in real GDP growth.

The second measure used in our paper is the net oil price increase over the previous 12-month

[10] Although other non-linear transformations have been used in the literature (e.g., the scaled oil price increase), we focus on the three measures that have been more widely employed.

maximum (Hamilton 1996)

$$x_t^{12} = \max\left\{0, o_t - \max\left\{o_{t-1}, ..., o_{t-12}\right\}\right\}, \tag{2}$$

and the last transformation is the net oil price increase over the previous 36-month maximum (Hamilton, 2003)

$$x_t^{36} = \max\left\{0, o_t - \max\left\{o_{t-1}, ..., o_{t-36}\right\}\right\}. \tag{3}$$

These two nonlinear transformations are intended to filter out increases in the price of oil that represent corrections for recent declines, and thus take into account the previous history of the crude oil price. Note that in both cases, in addition to censoring the oil price decreases (i.e. setting the value of the variable to zero when a decline takes place), increases that did not exceed the maximum price observed in the past 12 or 36 months are also censored at zero. Both transformations have been used in the literature on the macroeconomic effects of oil prices as a measure of oil price increases that are thought to affect the behavior of consumers and firms (see for instance Bernanke, Gertler and Watson 1997; Davis and Haltiwanger 2001; Lee and Ni 2002; Cuñado and Pérez de Gracia 2003; Jiménez-Rodríguez 2008).[11]

4 The Response of Industrial Production Growth to Oil Price Shocks

In this section, we evaluate the economic importance and test for the statistical significance of asymmetries in the relationship between oil price changes and industrial production growth.

[11] Although Hamilton (1996, 2003) originally proposed a nonlinear transformation of the nominal oil price, we here report the results for the real oil price because it corresponds to the measure more commonly used in theoretical models.

4.1 Impulse Responses

To study the response of industrial production to oil price innovations we estimate the following simultaneous equation model via OLS equation-by-equation for each of the 18 countries and the 3 country groups ($i = 1, 2, ..., 21$):

$$x_t = a_{10} + \sum_{j=1}^{12} a_{11,j} x_{t-j} + \sum_{j=1}^{12} a_{12,j} y_{i,t-j} + \varepsilon_{1t} \tag{4a}$$

$$y_{i,t} = a_{20,i} + \sum_{j=0}^{12} a_{21,ij} x_{t-j} + \sum_{j=1}^{12} a_{22,ij} y_{i,t-j} + \sum_{j=0}^{12} g_{21,ij} x_{t-j}^{\#} + \varepsilon_{2,it}. \tag{4b}$$

where x_t is the log growth in the oil price at time t, $x_t^{\#}$ is one of the three described non-linear transformations of the oil price, and $y_{i,t}$ is the log growth of industrial production for country i at time t. We follow the literature in postulating that the real price of oil is predetermined with respect to industrial production. Support for this assumption is provided in Kilian and Vega (2011).[12] The model in (4a)-(4b) –hereafter (4)– nests specifications with symmetric and asymmetric effects of oil price shocks on industrial production growth. The choice of a 12-month lag length is driven by various motives. First, Hamilton and Herrera (2004) show that using a smaller number of lags leads to underestimating the effect of oil prices as the response of economic activity to these shocks is very sluggish. Second, it is necessary to include sufficiently long lags for the results of nonlinear models to be robust. Third, lag selection criteria such as the AIC or BIC, which result in more parsimonious models, lead to misleading results in small samples and invalidate the inference from these nonlinear models.

Note that because the corresponding response functions are nonlinear functions of the para-

[12] Note that for the sake of comparison, we use the same simultaneous equation model and identification assumptions for all countries and country groups. However, the reader should bear in mind that the assumption of predetermined oil prices could be called into question for broad aggregates such as G-7, OECD-Europe or OECD-Total.

meters $g_{21,i0}$, $g_{21,i1}$,..., $g_{21,i12}$, as well as of the other parameters in (4), we compute the impulse response functions (hereafter $IRFs$) by Monte Carlo integration. That is, we first calculate the $IRFs$ to an innovation of size δ in ε_{1t} for a given horizon h conditional on the history Ω^t. We denote these conditional $IRFs$ by $I_y\left(h, \delta, \Omega^t\right)$. We then take the average over all the histories to obtain the unconditional IRF, $I_y\left(h, \delta\right)$. Similarly for a negative shock of size $-\delta$, we first compute the conditional $IRFs$, $I_y\left(h, -\delta, \Omega^t\right)$, and then average over all the histories to obtain the unconditional IRF, $I_y\left(h, -\delta\right)$ (see. e.g., Gallant, Rossi and Tauchen 1993; Koop, Pesaran and Potter 1996; and Kilian and Vigfusson 2011a).[13]

Figure 4 plots the responses $I_y\left(h, \delta\right)$ and $-I_y\left(h, -\delta\right)$ to a 1 s.d. innovation in ε_{1t}. Figure 5 plots the responses to a 2 s.d. innovation.[14] Significance at the 5% and 10% level are denoted by $\Diamond$ and $\circ$, respectively, and are computed by first bootstrapping the distribution of the impulse response functions and then calculating the point-wise critical values. Note that to facilitate the comparison, we plot the response to a positive innovation, $I_y\left(h, \delta\right)$, and the negative of the response to a negative innovation, $-I_y\left(h, -\delta\right)$. The responses measure the percentage change in industrial production on the vertical axis, and the horizontal axis represents months after the shock.

To economize space, we will focus our discussion on the two largest exporters, Canada and Norway, and the two largest importers, the U.S. and Japan.[15] Consider first the results obtained using the oil price increase (left panel of Figure 4). For Canada and Norway the response to a 1 s.d. negative shock is at least as big –in absolute terms– as the response to a positive shock. However, whereas a decrease in oil prices has a negative and statistically significant effect in the short-run,

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[13] See appendix for a more detailed description of the computation.

[14] Shocks of 1 and 2 s.d. are of particular interest for the following reasons: (a) the typical size of an oil price innovation in the sample is 1 s.d.; (b) large shocks of about 2 s.d. have been posited as the drivers of recessions in the U.S. and other industrialized countries; and (c) in contrast, shocks of larger magnitudes (e.g. 5 s.d.) have not occurred historically and, thus, extrapolating from our structural model to such extreme shocks is simply not econometrically feasible.

[15] Impulse response functions for the remaining countries can be found on Figures A-3 and A-4 of the on-line appendix. The cumulative impulse response functions are provided in Figures A-5 and A-6 of the same appendix.

the effect of an unexpected increase in oil prices is statistically insignificant. The estimates suggest that, after a year, the cumulative effect of a 1 s.d. positive innovation is a 0.02% and a 0.40% contraction of industrial production for Canada and Norway, respectively. A negative innovation of the same magnitude would result in a 1-year cumulative contraction of 0.17% in Canada and a 0.23% expansion in Norway. The disparity in the response of these two countries is possibly driven by differences in the importance of the oil sector, as well as differences in their energy intensity. Recall that petroleum production represented 26% of GDP in 2008 for Norway, but only 8% in Canada (see Figure 2). In contrast, total primary energy consumption per dollar of GDP was 32% higher, on average, for Canada than for Norway between 1980 and 2006 (Figure 3).

Consider now the two largest net oil importers –according to the number of barrels of oil imported per day–, which are also the two economies with the largest GDP in the OECD: Japan and the U.S. The left panel of Figure 4 suggests that, in the short run ($h = 0, 1, ..., 6$), the response to a positive shock is larger than the response to a negative shock for the U.S. Instead, for Japan the short-run response to a negative shock is at least as large as the response to a positive shock. The estimates indicate, that, after a year, the cumulative effect of 1 s.d. positive innovation is a 0.26% contraction for industrial production in the U.S. and a 0.27% expansion in Japan. A negative innovation of the same magnitude would result in a 1-year cumulative expansion of a 0.13% and a 0.48% contraction in Japan. Whereas the responses of industrial production for the U.S. are consistent with the expected effect for an oil importing country, Japan's responses are somewhat puzzling but consistent with previous literature (see, e.g. Blanchard and Galí 2010; Jiménez-Rodríguez and Sánchez 2005; Fukunaga, Hirakata, and Sudo 2011). One could conjecture that the nonlinear transformations considered in this paper are not able to capture the time variation in Japan's response. In particular, Hutchison (1993) estimates a positive response for Japan's real

GNP during the 1981:Q1-1990:Q1 period, as do Jiménez-Rodríguez and Sánchez (2005) for real GDP with a sample spanning the period between 1972:Q1 and 2001:Q4. In contrast, once structural breaks are allowed, Jiménez-Rodríguez and Sánchez (2012) find a negative effect of sharp oil price increases on industrial production during the late 1970s and early 1980s, and no effect afterwards.[16]

Alternatively, one might argue that because we measure oil prices in the local currency –so as to better capture the price faced by consumers and firms–, oil price innovations compound variations in the real oil price and the exchange rate. In particular, oil price innovations might have a different effect depending on the country's trade-balance position (see, for instance, Kilian, Rebucci and Spatafora 2009). To further investigate whether Japan's positive response to oil price innovations is related to the role played by fluctuations in the exchange rate –and to gather additional insight into the role of these fluctuations– we first decompose the real oil price (measured in the local currency) as

$$\exp(o_t) = \underbrace{\frac{O_t \times E_{it}}{P_{it}}}_{\text{Real oil price in domestic currency}} = \underbrace{\frac{O_t}{P_t^*}}_{\text{Real oil price in U.S. dollars}} \times \underbrace{\frac{P_t^* \times E_{it}}{P_{it}}}_{\text{Real exchange rate}},$$

where O_t is the oil price measured in U.S. dollars, E_{it} is the local currency price of the U.S. dollar for country i, P_{it} is the local price level for country i, and P_t^* is the U.S. price level. Thus, an increase in the oil price occurs not only when the U.S. dollar price of oil rises, but also when the real exchange rate depreciates (against the U.S. dollar). It is thus conceivable that industrial production increases when one country's currency faces a real depreciation if the country relies

[16] To investigate whether the positive response of Japanese industrial production is due to structural instability we implemented Qu and Perron's (2007) test for structural breaks of unknown timing. Regardless of the nonlinear measure of oil prices, we fail to reject the null of no break against the alternative of one break in $g_{21,i0}$, $g_{21,i1}$,..., $g_{21,i12}$. While this result certainly does not rule out the possibility of a structural break in some of the other parameters –in fact, we are able to reject the null hypothesis of no structural break when all the parameters are allowed to change– it suggests the positive response of industrial production does not stem from a change in the nonlinear parameters that govern the nonlinear effect of oil price shocks.

heavily on international trade. This is because real depreciations normally facilitate exports for an export-dependent country. Then, to evaluate this hypothesis we estimate a simultaneous equation model as in (4a)-(4b) where we replace the percentage change in the real oil price and its non-linear transformation, x_t and $x_t^{\#}$ respectively, with (the log growth in) the real exchange rate and its non-linear transformation.[17] The impulse responses to one and two standard deviations in the real exchange rate, plotted in Figures 6 and 7 respectively, reveal that our conjecture is indeed correct. For Japan, a real depreciation (appreciation) increases (decreases) industrial production.[18]

Finally, an alternative explanation is advanced by Fukunaga, Hirakata and Sudo (2011). They find that oil-specific demand shocks and global demand shocks act as positive demand shocks –increasing industry-level production and prices– for various Japanese industries instead of acting as supply shocks. They posit that the higher oil-efficiency of Japanese products –especially automobiles– might constitute and explanation for why U.S. and Japanese industrial production differ in their response to unexpected oil price increases.

Using the net oil price increase relative to the previous one-year or three-year maximum leads to similar conclusions regarding the effect of oil price shocks on industrial production (see middle and right panels of Figure 4). For instance, the actual difference between the two lines is quite small for Canada and Norway. Similarly, for the two largest oil importers, the response to a positive shock, $I_y(h, \delta)$, lies almost always on top of the negative of the response to a negative oil price shock, $-I_y(h, -\delta)$. Hence, it would be difficult to make the case for an asymmetric model on the basis of the results for the net oil price increase, either with respect to the previous one-year maximum or the previous three-year maximum.

[17] However, estimation results depicted in Figure A-9 of the on-line Appendix indicate that measuring the real oil price in U.S. dollars instead of Yen does not affect the Japanese impulse response functions in a substantial manner.

[18] Our results are mostly suggestive of symmetry in the response of industrial production growth to positive and negative exchange rate innovations. For the sake of brevity we have relegated the plots of the responses in industrial production growth and the cumulative impulse response functions to Figures A-7 and A-8 of the on-line appendix.

A glance at Figure 5 reveals larger differences between $I_y(h, \delta)$ and $-I_y(h, -\delta)$ for a large 2 s.d. innovation. These differences appear to be greater for the oil price increase than for the net oil price increase. In particular, for Canada and Norway, the impulse response functions do not lie exactly on top of each other for at least two oil price transformations. This is also the case for Japan and the U.S.

All in all, the impulse response functions in Figure 4 suggest that symmetry is a reasonable assumption for most OECD countries when we consider a typical 1 s.d. innovation, possibly with the only exception of Norway. In contrast, Figure 5 might persuade some readers that theoretical models incorporating asymmetries are relevant for the study of the propagation and transmission of large 2 s.d. oil price innovations. But, how big is the difference between the response of industrial production growth to positive and negative shocks and are these differences statistically significant? We address these questions in the following sections.

4.2 A Measure of Asymmetry: The Cumulative Distance

To gain some insight into the magnitude of the asymmetry we define the cumulative distance between the response to a positive shock and that of a negative shock as

$$d_H = \sum_{h=0}^{H} \sqrt{\left[\{I_y(h, \delta)\} - \{-I_y(h, -\delta)\}\right]^2}. \tag{5}$$

That is, d_H measures the distance between the impulse responses in terms of percentage points, accumulated from the month of the shock's impact ($h = 0$) up to horizon $h = H$. Note that if d_H greatly increases with the horizon, h, then the degree of asymmetry is amplified as time goes by. Instead, if d_H does not change as the horizon increases, then the degree of asymmetry dies down a few months after the shock. In fact, this measure of distance is the cumulative of the Euclidean norm, which can be equivalently written as $d_H = \sum_{h=0}^{H} |\{I_y(h,\delta)\} - \{-I_y(h,-\delta)\}|$.

Let us first focus on the results for the oil price increase, x_t^1 (see third column on the left panel of Table 1). Among oil exporting countries, the one-year cumulative distance between the response to a positive and a negative shock, d_{12}, is largest for Norway (2.16 percentage points). For the other oil exporters in the sample, d_{12} fluctuates between 0.42 percentage points for Canada and 1.22 percentage points for Denmark.[19] Regarding the oil importing countries, the one-year cumulative distance is largest for Greece (1.47 percentage points). For the remaining countries, d_{12} averages 0.77 percentage points. The magnitude of the asymmetry for the G-7, OECD-Europe and OECD-Total is similar to that of the U.S.

Using the net oil price increase with respect to the 12-month maximum, x_t^{12}, or the 36-month maximum, x_t^{36}, suggests a smaller degree of asymmetry a year after the shock (see third column on middle and right panels of Table 1). In fact, if we use x_t^{12}, the non-cumulative distance appears to be economically insignificant at all h for the UK and Canada (i.e., 0.05 percentage points or less), among oil exporters. Regarding the oil importers, using x_t^{12} generates smaller asymmetries a year after the shock for all countries, but a greater distance between impact responses for Finland.[20] The results using x_t^{36} generally produce a smaller cumulative distance a year after the shock than x_t^{12}.

Not surprisingly, the one-year cumulative distances, d_{12}, are greater for a 2 s.d. innovation (see Table 2). As it is the case for a 1 s.d. innovation, for all transformations but x_t^{12}, d_{12} is considerably larger for Norway (11.56 percentage points) than for the other oil exporters (2.48, 6.59, and 2.39 percentage points for Canada, Denmark and the UK, respectively). Among oil importers, d_{12} is largest for Greece (x_t^1 and x_t^{12}) and Luxembourg (x_t^{36}). The difference between the response to a

[19] For these three countries, the non-cumulative distances for each horizon h tabulated in Table A.3 of the on-line appendix, appear to be all non-zero; yet the magnitudes are considerably smaller.

[20] See Tables A.4 and A.5 of the on-line appendix.

large positive and a large negative innovation appears to be economically significant for all the oil importing countries.[21] Both for oil exporters and importers, d_{12} tends to be greater for the oil price increase x_t^1, than for the net oil price increase, x_t^{12} or x_t^{36}.

To gain some additional insight into the factors that drive the magnitude of the asymmetry we computed Spearman's rank correlation coefficients between the one-year cumulative distance, d_{12}, and the share of oil in GDP, the energy intensity, and net oil imports. We found a significant negative correlation between net imports and d_{12} across all oil price measures for both 1 s.d. and 2 s.d. innovations. These results suggest that countries that depend heavily on oil imports might exhibit a higher degree of asymmetry in the response to oil price shocks. The Spearman's rank correlation with the share of oil in GDP is statistically significant at a 5% level only for a 1 s.d. when we use x^{36}; that with energy intensity is always insignificant.

4.3 Testing for Symmetry in the Oil Price-Industrial Production Relationship

Estimates of the impulse response functions are subject to substantial sampling uncertainty, especially when considering a 2 s.d. innovation. To formally test for symmetry in the response of industrial production growth to positive and negative oil price innovations, we implement the impulse response based test proposed by Kilian and Vigfusson (2011a). We compute the Wald test of the null of symmetric response functions:

$$I_y(h, \delta) = -I_y(h, -\delta) \text{ for } h = 0, 1, 2, ..., H.$$

Note that this test jointly evaluates whether the response of industrial production to a positive shock of size δ equals the negative of the response to a negative shock of the same size, $-\delta$, for

[21] See also Tables A.6 to A.8 of the on-line appendix.

horizons $h = 0, 1, 2, ..., H$.

Table 3 reports the p-values from the χ^2_{H+1} distribution for the test of symmetry in the response to positive and negative innovations in the oil price for horizon $H = 12$. We choose to focus on the one-year horizon for two reasons. First, Hamilton and Herrera (2004) and references therein, note that oil price shocks tend to have a lagged effect on aggregate production growth that reaches a through about a year after the shock. Thus, by focusing on this horizon, we take into account the period where oil price shocks have been reported to have the largest impact on aggregate production. Second, the choice to fix $H = 12$ allows us to avoid the possible effect of data mining that would stem from repeating the test over H different horizons.

An additional data mining concern arises when repeating the impulse response based test for 21 IP indices (18 countries plus 3 country groups): there is always the possibility that any rejection of symmetry might be obtained simply by chance. For example, after 21 times of repetitive Wald tests with a 5% size, the probability of finding at least one rejection is theoretically more than 5% under the null. Put differently, the expected number of rejections will grow as the number of series to be tested increases. To avoid this potential problem, we compute data mining robust critical values by simulating the distribution of the supremum of the bootstrap test statistic, under the null, across all countries for each of the oil price measures.[22] The robust critical values are based on first using 100 replications for each of the 100 different histories to obtain the conditional impulse response functions, and then repeating this procedure 100 times to compute the bootstrapped sup-Wald test statistic.[23]

[22] See Inoue and Kilian(2004) and Kilian and Vega (2011) for the effect of data mining and solutions to the problem of data mining in the related context of tests of predictability.

[23] We restricted the number of replications due to the high computation cost involved in calculating this bootstrapped distribution (i.e., $100 \times 100 \times 100$ replications take over a week if we are able to run at least 10 parallel codes using a high performance Grid enabled computing system, where each node is made of quad core dual Intel Xeon processors with 2.66GHz). We experimented by increasing the number of replications in a smaller sample and the qualitative results remained unchanged.

Basing our inference on these data-mining robust critical values also allows us to sidestep an issue that arises with the Wald test when the number of restrictions is high: the χ^2_{H+1} distribution becomes a less accurate approximation under the null. Indeed, as Kilian and Vigfusson (2011a) show, in the presence of a large number of lags H, the actual size of the symmetry test is about twice the nominal size.

Table 3 reports the p-values for the Wald test of symmetry, calculated from the χ^2_{13} distribution. Significance at the 5% level –using the robust critical values– is denoted by **. We find very little evidence of asymmetry in the response to a 1 s.d. innovation for $H = 12$ (see left panel of Table 3). Note that using the robust critical values, we only reject the null of symmetry in the response to a 1 s.d. innovation for the G7 when we use x_t^1, and we reject for Greece, Sweden, and the U.S. using x_t^{36}. These results suggest that a linear model constitutes a good approximation to the response of industrial production to oil price shocks in most of the 18 OECD countries under analysis. Furthermore, it falls in line with Kilian and Vigfusson's (2011a) and Herrera, Lagalo and Wada's (2011) findings for U.S. aggregate GDP and total industrial production, respectively.

However, the reader may wonder whether the response of industrial production to 2 s.d. innovations is symmetric. After all, although shocks of that magnitude seldom occur, past disturbances in the Middle East did result in large unexpected increases in the real price of oil that largely exceeded 1 s.d. The right panel of Table 3 reports the results for the impulse response based tests to a 2 s.d. shock. As the table shows, evidence of asymmetry in the response of industrial production to a 2 s.d. shock is about as elusive as to a 1 s.d. shock when we control for data mining, but a bit more prevalent if we use the usual critical values. This difference between inferences based on the data-mining robust critical values and the usual critical values is not surprising as the latter implies a high hurdle for rejecting the null of symmetry. Using the robust critical values, we are unable to reject the null of symmetry for $H = 12$ at the 5% significance level when we use the oil price increase. We only reject the null of symmetry for the U.S. when we use the net oil price increase over the 12-month maximum, x_t^{12}; no rejections are obtained for the other two transformations, x_t^1 and x_t^{36}. In brief, statistical evidence of asymmetry in the response to positive and negative oil price shocks is limited to a small number of countries. Indeed, for the few countries where the null of symmetry is rejected, rejection is not consistent across the nonlinear transformations considered in this paper.

We conclude this section with a caveat. Despite the fact that the impulse response based test of symmetry rarely rejects the null, this finding does not rule out alternative nonlinear models. In particular, further research is needed to assert whether models that explicitly consider the effects of volatility shocks better fit the international data analyzed here.

5 Conclusions

How does economic activity respond to oil price shocks? Until recently, the consensus was that oil price increases lead to recessions in oil importing countries, but price decreases did not lead to expansions. More precisely, a number of empirical studies showed that slope based tests rejected the null of symmetry for U.S. GDP growth. These findings were confirmed by Mork, Olsen and Mysen (1994), Cuñado and Pérez de Gracia (2003), and Jiménez-Rodríguez and Sánchez (2005) using data for OECD countries.

Yet, the premise that slope based tests are enough to quantify the degree of asymmetry in the response of economic activity to real oil price innovations has been recently questioned by Kilian and Vigfusson (2011a). They show that the estimation methods used in VAR studies of the macroeconomic effect of oil price innovations generally produce inconsistent estimates of the true effects of unanticipated increases in the price of oil due to the censoring applied to the oil price variable. More importantly, such tests do not address the question of interest for most researchers and policy analysts. That is, whether the response of economic activity to oil price innovations, say a year after a shock, is symmetric.

To explore the question of asymmetry we used data on 18 OECD countries and 3 country groups to estimate a simultaneous equations model that nests both symmetric and asymmetric effects of oil prices on industrial production growth. This data set included both net oil importing and net oil exporting countries. First, we computed the impulse response functions to both positive and negative oil price shocks taking into account the past history and the size of the shock (i.e. 1 or 2 s.d.). Then, to gain some intuition into the magnitude of the asymmetry, we proposed a measure of the difference between the responses to positive and negative innovations: the cumulative distance. Both an examination of the impulse response functions and our measure of the cumulative distance provided some evidence of asymmetry for a few countries that are either large oil exporters or oil importers. Not surprisingly, the magnitude of the asymmetry was found to be greater for a 2 s.d. than for a 1 s.d. innovation.

We then followed Kilian and Vigfusson (2011a) to test the null of joint symmetry in the response of industrial production growth to oil price increases and decreases from impact to a year after the shock. Using data mining robust critical values, we found very little evidence of asymmetry. Our results suggested that for most of the 18 OECD countries, a linear model constitutes a good approximation for the response of industrial production to an oil price shock. This evidence is consistent with Kilian and Vigfusson's (2011a) and Herrera, Lagalo and Wada's (2011) findings for U.S. real GDP and industrial production, respectively, as well as with Edelstein and Kilian's (2007, 2009) results for aggregate U.S. consumption.

Theoretical models of oil price shocks diverge regarding the functional form of the oil price-macroeconomy relationship. In particular, whereas some transmission mechanisms generate asymmetry others do not. Our results have implications regarding which theory better fits the observed responses for both oil importing and oil exporting countries. As mentioned, theoretical models that (a) stress the importance of reallocation disturbances, (b) consider the role of precautionary savings when future employment levels are uncertain, (c) model irreversible investment in a partial equilibrium framework, or (d) consider changes in the oil price level and oil price uncertainty simultaneously, imply an asymmetric response. This is not the case here. Instead, our results point towards theoretical underpinning that do not imply the forms of asymmetry considered in this paper. Further empirical research is needed to evaluate the role of volatility shocks on the functional form of the impulse responses of industrial production.

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Table 1. Cumulative distance between IRFs: 1 s.d. shock to the real oil price

	$x_t^{\#} = x_t^1$			$x_t^{\#} = x_t^{12}$			$x_t^{\#} = x_t^{36}$		
Horizon	0	6	12	0	6	12	0	6	12
Net Exporters									
Canada	0.07	0.22	0.42	0.03	0.07	0.16	0.01	0.03	0.08
Denmark	0.00	0.59	1.22	0.02	0.22	0.34	0.00	0.10	0.19
Norway	0.14	1.35	2.16	0.00	0.11	0.35	0.00	0.06	0.21
UK	0.04	0.31	0.43	0.01	0.06	0.11	0.00	0.03	0.06
Net Importers									
Austria	0.04	0.35	0.76	0.01	0.15	0.22	0.01	0.16	0.20
Belgium	0.12	0.67	1.10	0.02	0.23	0.43	0.01	0.18	0.29
Finland	0.08	0.48	0.85	0.07	0.20	0.40	0.03	0.15	0.29
France	0.04	0.23	0.51	0.02	0.12	0.19	0.01	0.08	0.13
Germany	0.04	0.48	0.69	0.01	0.08	0.15	0.01	0.06	0.12
Greece	0.12	1.00	1.47	0.11	0.31	0.41	0.10	0.38	0.53
Italy	0.09	0.32	0.73	0.02	0.08	0.16	0.00	0.05	0.11
Japan	0.03	0.43	0.54	0.01	0.08	0.15	0.01	0.04	0.10
Luxembourg	0.02	0.57	0.92	0.03	0.19	0.38	0.05	0.20	0.41
Netherlands	0.04	0.53	1.33	0.01	0.12	0.22	0.00	0.08	0.20
Portugal	0.05	0.42	0.74	0.00	0.10	0.19	0.00	0.08	0.23
Spain	0.08	0.24	0.72	0.00	0.12	0.20	0.00	0.08	0.16
Sweden	0.02	0.29	0.65	0.01	0.10	0.20	0.01	0.15	0.26
U.S.	0.01	0.18	0.27	0.01	0.06	0.09	0.00	0.04	0.07
G7	0.03	0.21	0.28	0.01	0.05	0.08	0.01	0.03	0.05
OECD-Europe	0.03	0.09	0.22	0.01	0.04	0.07	0.01	0.02	0.06
OECD-Total	0.03	0.16	0.23	0.01	0.05	0.07	0.01	0.02	0.05

Notes: Cumulative distances are computed using equation(5) and are based in estimated impulse response functions computed using 1000 replications of the simultaneous equation model on (4) for 100 different histories.

Table 2. Cumulative distance between IRFs: 2 s.d. shock to the real oil price

	$x_t^{\#} = x_t^1$			$x_t^{\#} = x_t^{12}$			$x_t^{\#} = x_t^{36}$		
Horizon	0	6	12	0	6	12	0	6	12
Net Exporters									
Canada	0.39	1.43	2.48	0.22	0.80	1.53	0.11	0.49	0.99
Denmark	0.03	3.27	6.59	0.14	1.91	2.84	0.01	0.91	1.91
Norway	0.84	7.30	11.56	0.03	0.97	3.00	0.00	0.86	2.11
UK	0.23	1.78	2.39	0.08	0.60	1.22	0.06	0.44	1.10
Net Importers									
Austria	0.26	1.83	3.96	0.11	1.40	2.04	0.07	1.27	1.69
Belgium	0.70	3.57	6.10	0.14	1.70	3.45	0.13	1.39	2.35
Finland	0.45	2.88	5.06	0.66	1.75	3.39	0.23	0.84	2.07
France	0.25	1.38	2.90	0.21	1.12	1.79	0.13	0.85	1.43
Germany	0.22	2.54	3.60	0.07	0.86	1.48	0.11	0.67	1.37
Greece	0.70	5.43	8.05	1.03	2.64	3.47	0.76	2.03	2.87
Italy	0.51	1.83	3.97	0.23	0.84	1.57	0.05	0.57	1.31
Japan	0.19	2.89	3.60	0.12	0.99	1.48	0.08	0.65	1.39
Luxembourg	0.13	3.23	5.00	0.27	1.61	3.30	0.50	1.52	3.77
Netherlands	0.22	2.60	6.73	0.08	1.18	2.22	0.02	0.77	1.55
Portugal	0.27	2.37	4.13	0.04	0.85	1.60	0.04	0.62	1.72
Spain	0.49	1.24	3.69	0.02	1.15	1.72	0.05	0.95	1.81
Sweden	0.14	1.72	3.68	0.07	1.03	1.59	0.12	1.35	2.17
U.S.	0.09	1.31	1.82	0.07	0.90	1.34	0.00	0.59	0.89
G7	0.16	1.42	1.79	0.13	0.79	1.15	0.06	0.41	0.82
OECD-Europe	0.18	0.67	1.41	0.07	0.51	0.90	0.07	0.26	0.77
OECD-Total	0.20	1.10	1.51	0.12	0.64	0.92	0.08	0.37	0.76

Notes: Cumulative distances are computed using equation(5) and are based in estimated impulse response functions computed using 1000 replications of the simultaneous equation model on (4) for 100 different histories.

Table 3. Test of symmetry in the response to a real oil price shock

	1 s.d. shock			2 s.d. shock		
	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$	$x_t^{\#} = x_t^1$	$x_t^{\#} = x_t^{12}$	$x_t^{\#} = x_t^{36}$
Net exporters						
Canada	0.26	0.54	0.99	**0.01**	**0.04**	0.64
Denmark	0.52	0.76	0.99	0.28	0.19	0.58
Norway	0.21	0.95	1.00	**0.03**	0.45	0.87
UK	0.65	0.96	1.00	0.34	*0.06*	0.17
Net importers						
Austria	0.49	0.91	0.93	0.13	**0.03**	0.53
Belgium	0.42	0.94	0.97	0.34	*0.10*	0.66
Finland	0.50	0.42	0.74	0.12	**0.01**	0.53
France	0.33	0.90	0.89	*0.10*	*0.05*	0.20
Germany	0.55	0.96	0.96	0.20	0.38	0.54
Greece	0.31	0.73	0.26**	**0.00**	*0.07*	0.37
Italy	0.24	0.97	0.96	**0.03**	0.32	0.74
Japan	0.28	0.66	0.96	**0.00**	*0.06*	0.16
Luxembourg	0.88	0.94	0.96	0.66	0.11	0.41
Netherlands	0.21	0.98	0.95	**0.05**	0.26	0.45
Portugal	0.84	0.99	0.88	0.71	0.76	0.63
Spain	0.45	0.95	0.96	0.25	0.29	0.32
Sweden	0.59	0.72	0.26**	0.25	0.19	0.24
U.S.	0.25	0.73	0.41**	**0.02**	**0.00****	0.36
G7	0.16**	0.87	0.75	**0.00**	**0.00**	0.33
OECD-Europe	0.62	0.98	0.90	0.50	0.12	0.53
OECD-Total	0.25	0.86	0.67	**0.00**	**0.00**	0.37

Notes: Tests are based on 1000 simulations of model (4). p-values are based on the χ^2_{H+1} with $H = 12$. Bold and italics denote significance at the 5% and 10% level, respectively. * denotes significance after accounting for data mining at the 10% level.

Figure 1. Total Net Petroleum (Oil) Imports

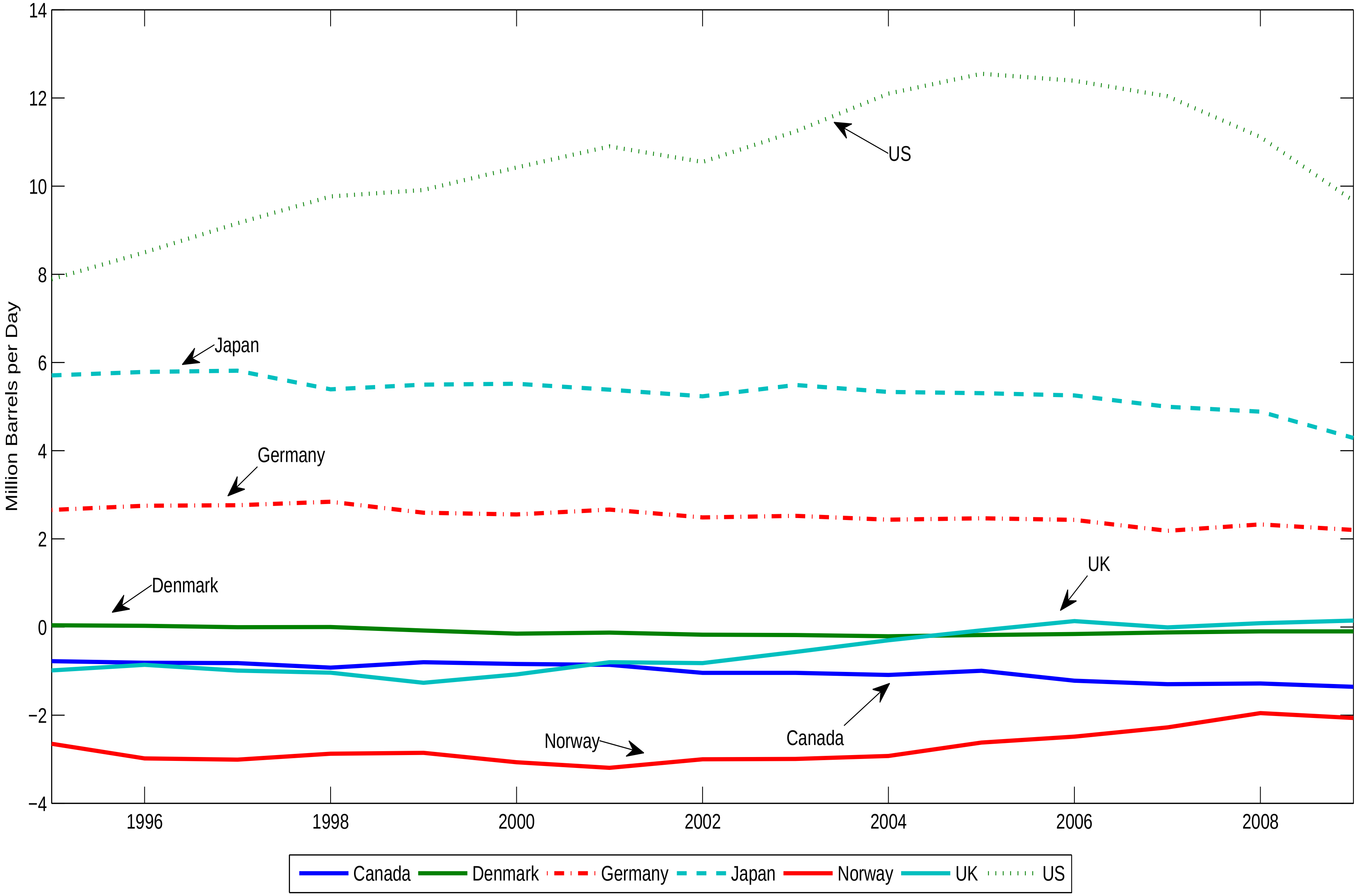


Figure 2. Production of crude oil, Percentage of GDP

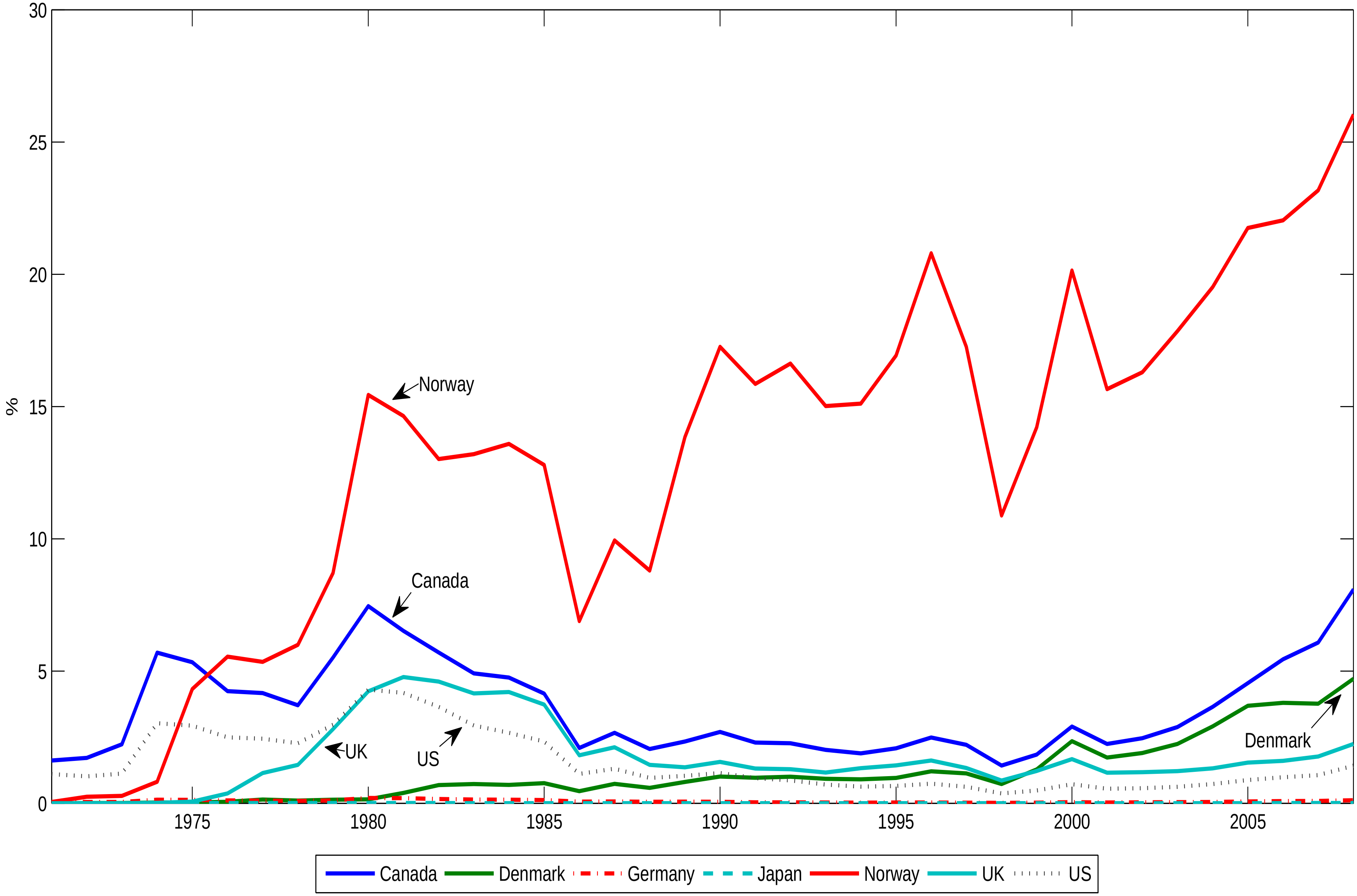


Figure 3. Total Primary Energy Consumption per Dollar of Gross Domestic Product

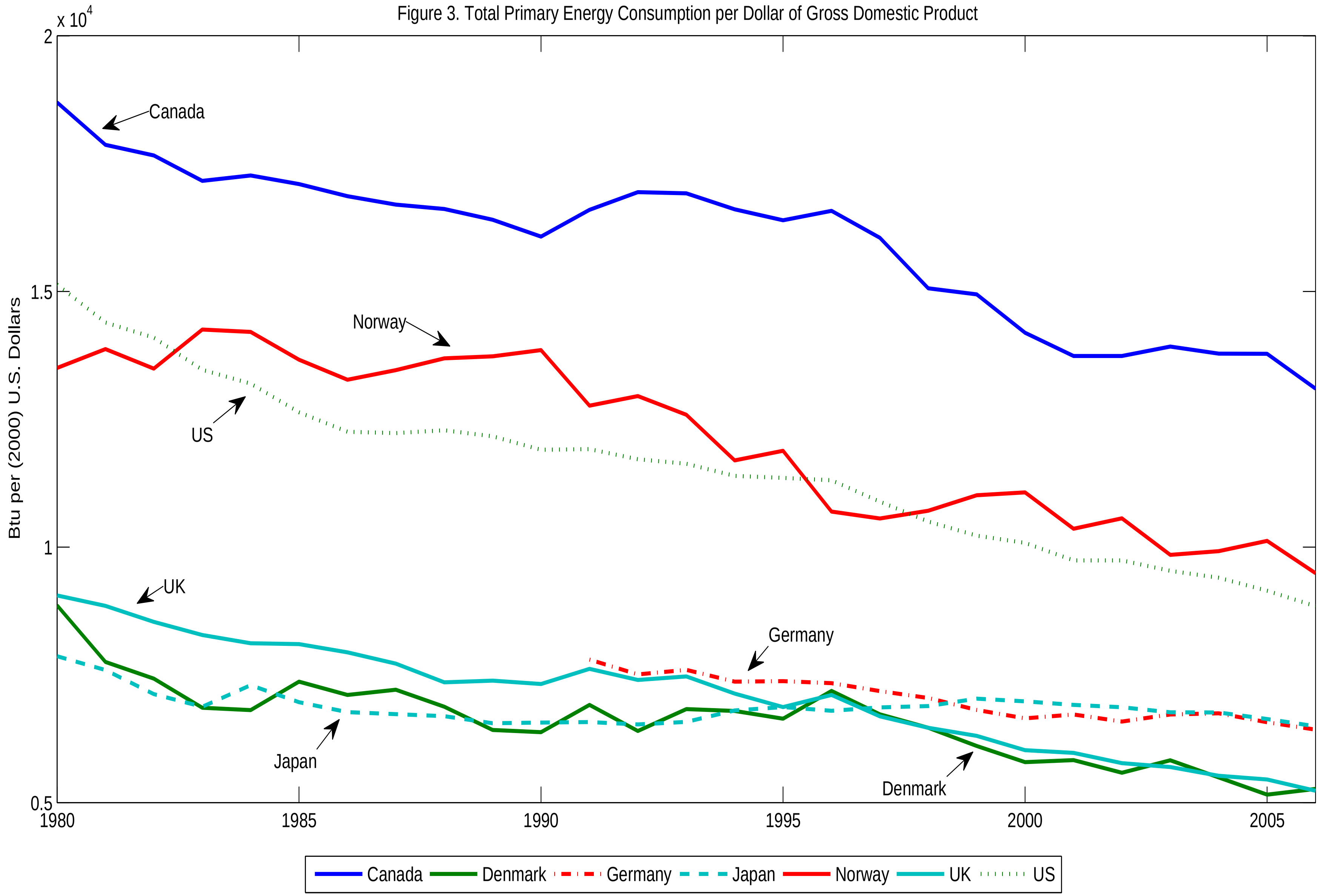
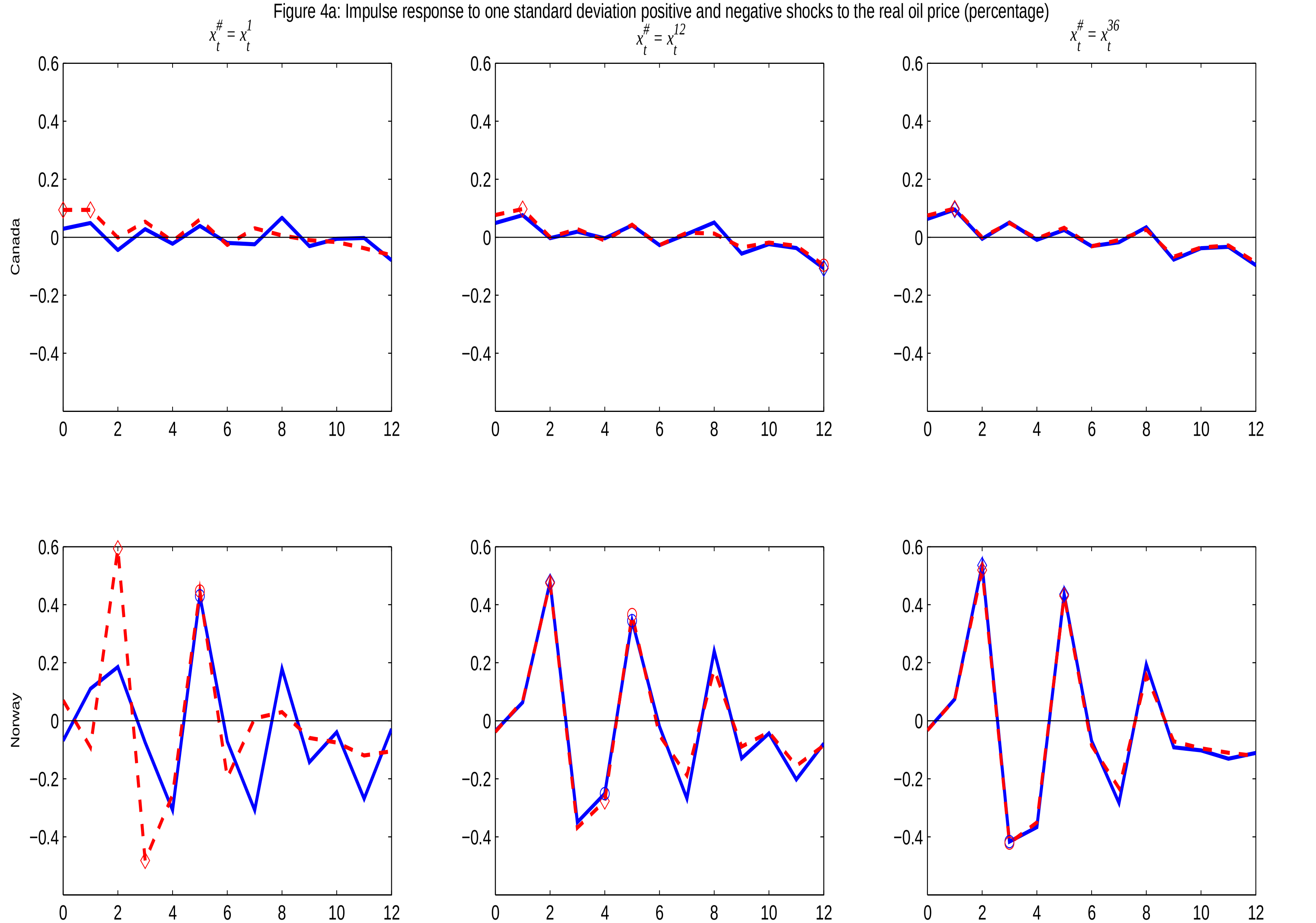
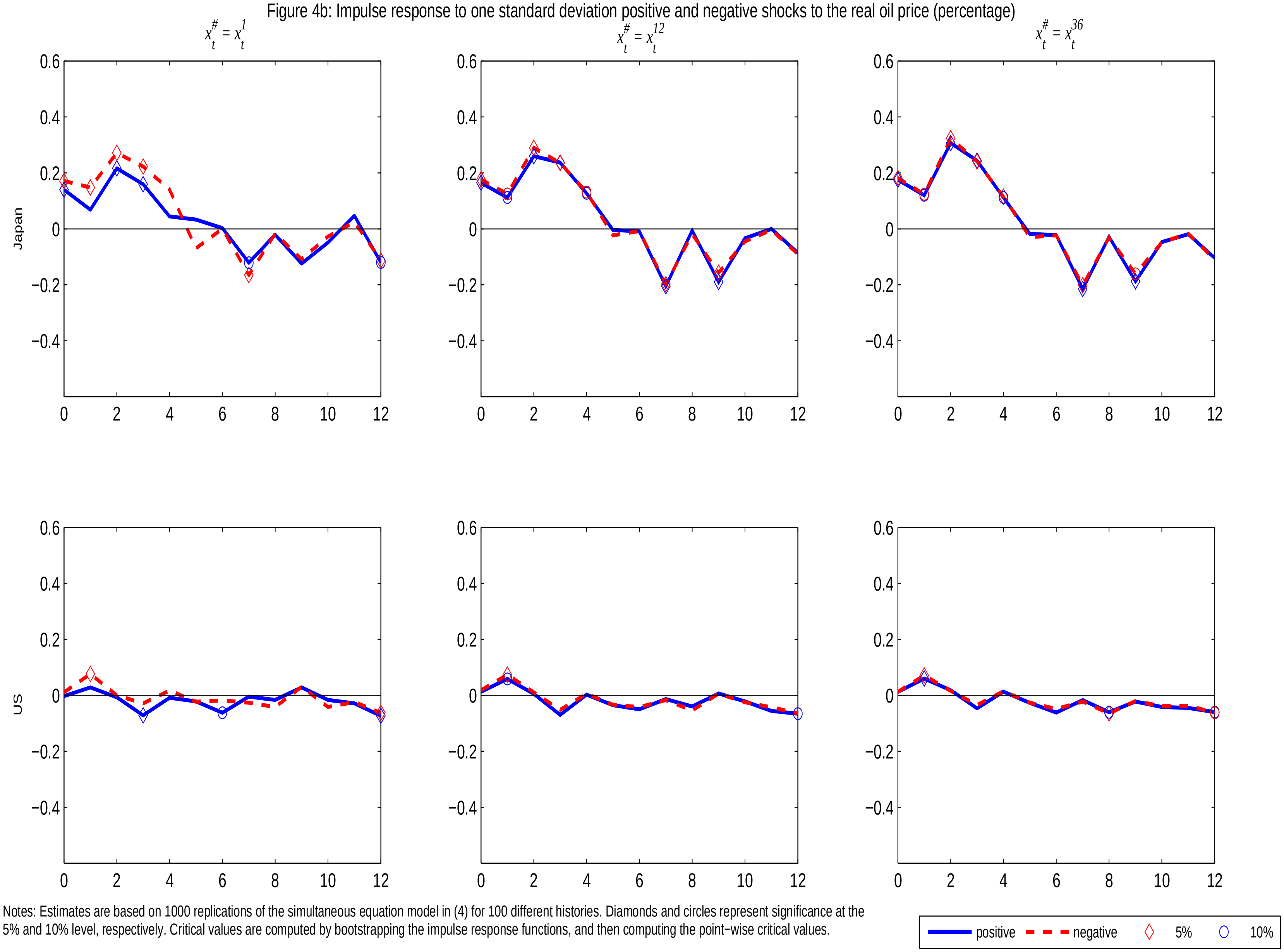


Figure 4a: Impulse response to one standard deviation positive and negative shocks to the real oil price (percentage)



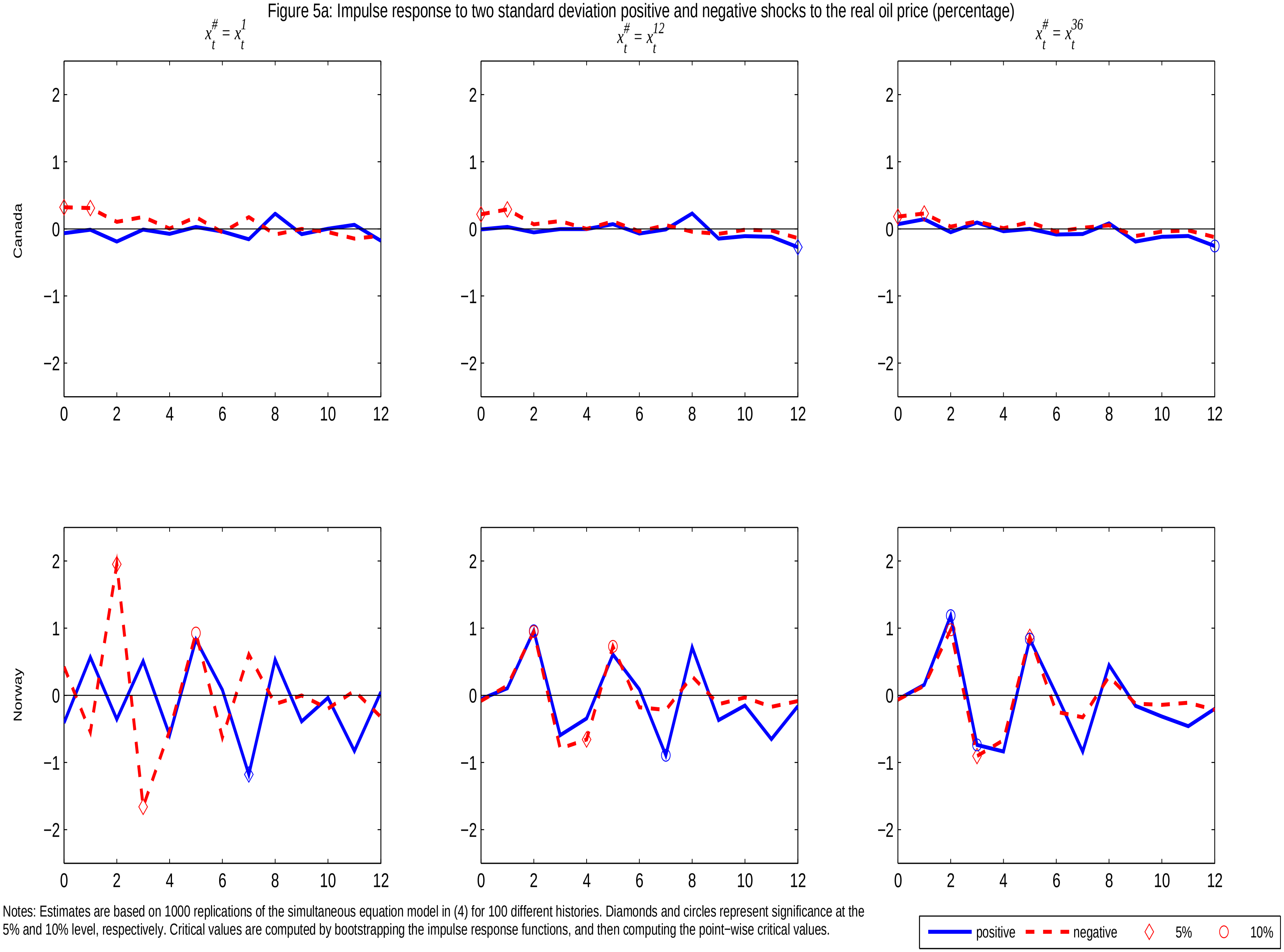
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 4b: Impulse response to one standard deviation positive and negative shocks to the real oil price (percentage)



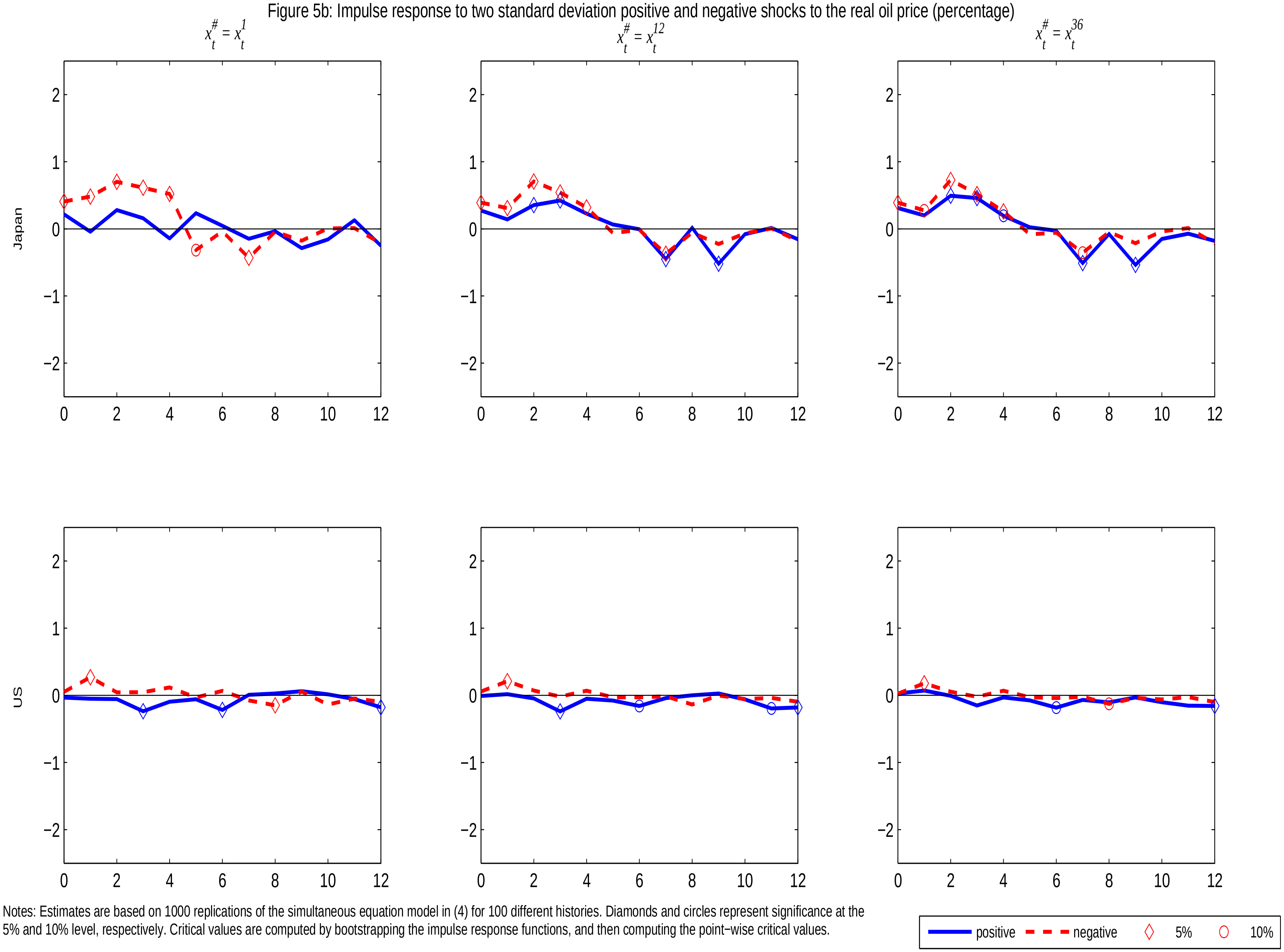
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 5a: Impulse response to two standard deviation positive and negative shocks to the real oil price (percentage)



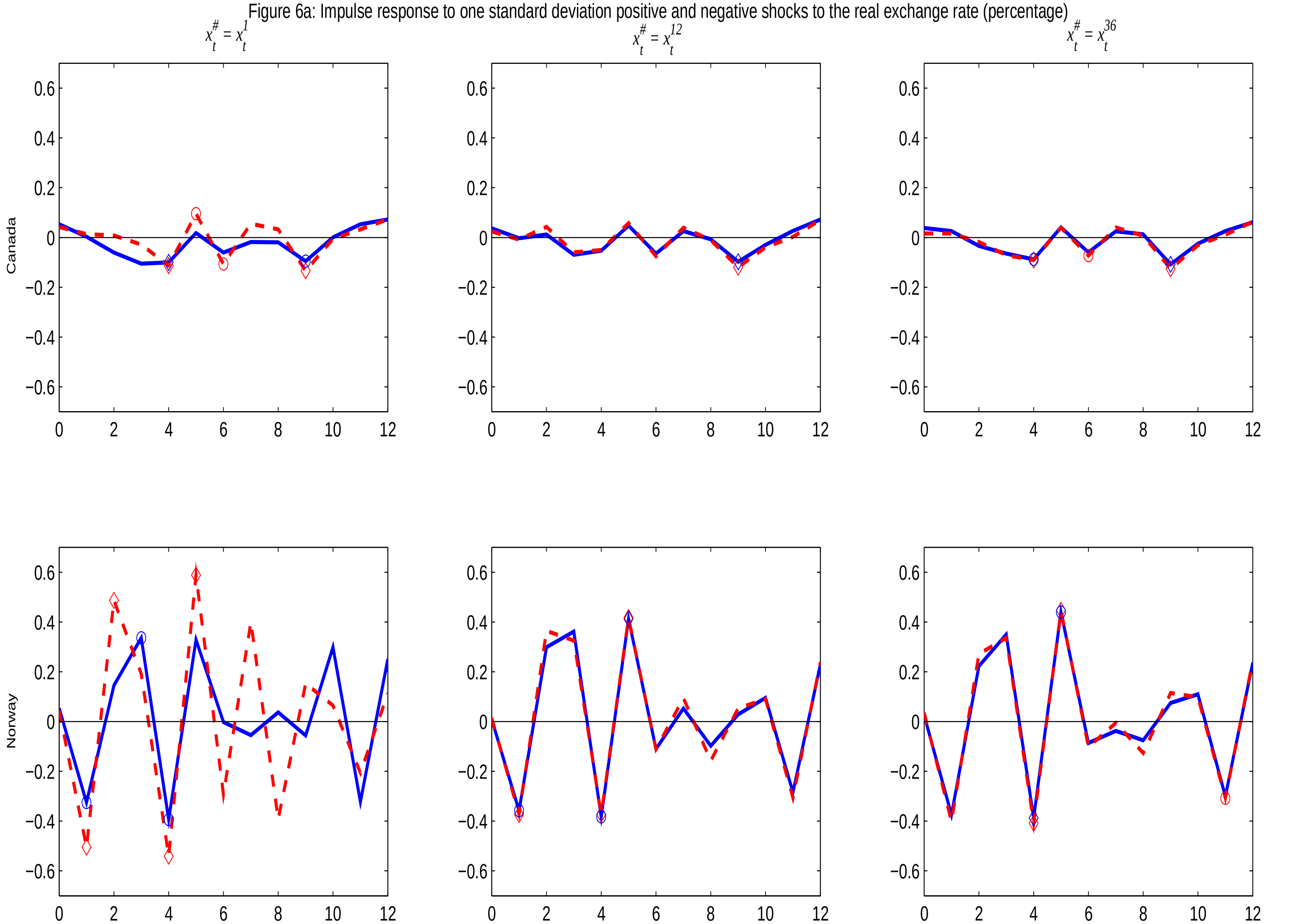
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 5b: Impulse response to two standard deviation positive and negative shocks to the real oil price (percentage)



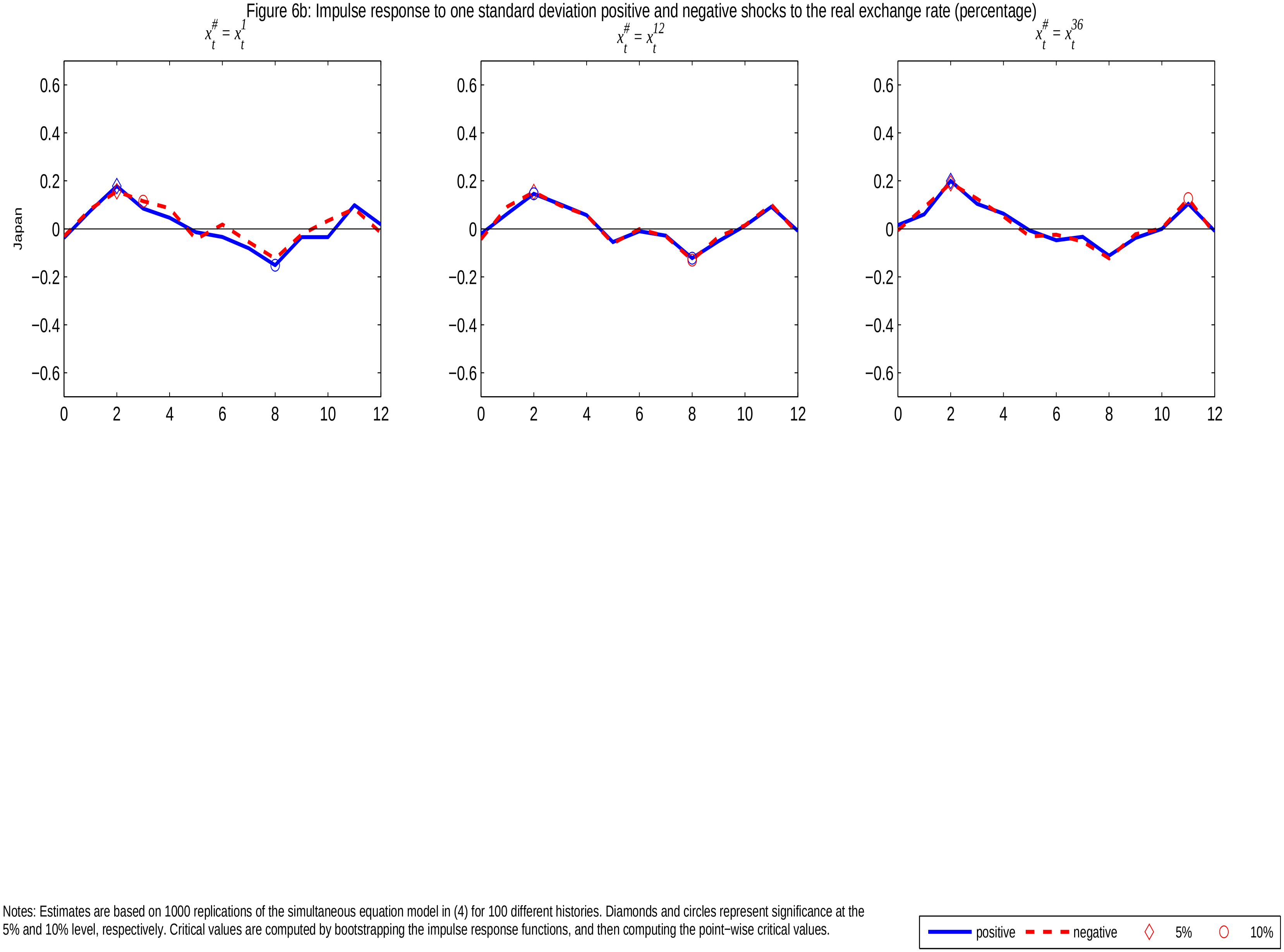
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 6a: Impulse response to one standard deviation positive and negative shocks to the real exchange rate (percentage)



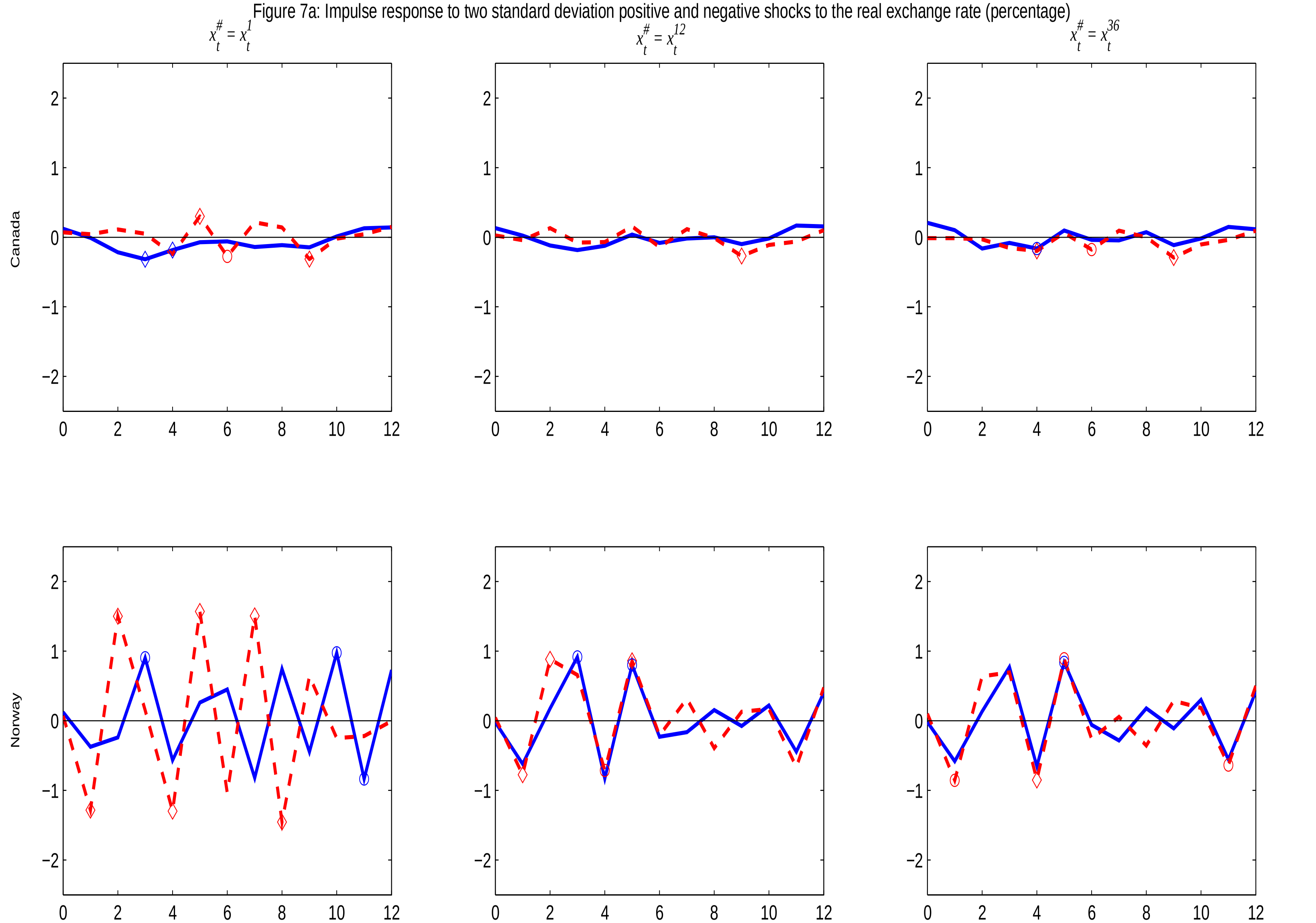
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 6b: Impulse response to one standard deviation positive and negative shocks to the real exchange rate (percentage)



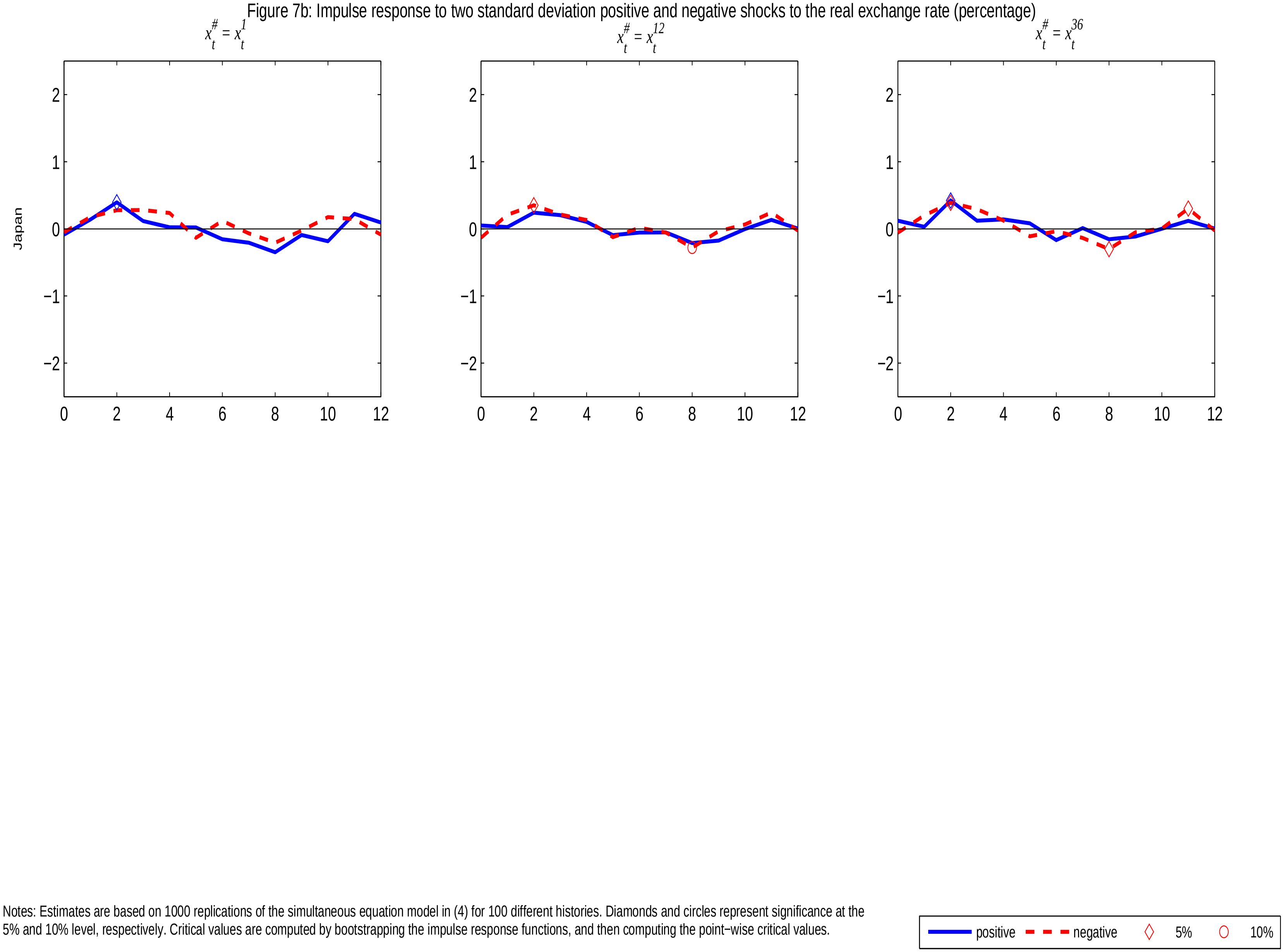
Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 7a: Impulse response to two standard deviation positive and negative shocks to the real exchange rate (percentage)



Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.

Figure 7b: Impulse response to two standard deviation positive and negative shocks to the real exchange rate (percentage)



Notes: Estimates are based on 1000 replications of the simultaneous equation model in (4) for 100 different histories. Diamonds and circles represent significance at the 5% and 10% level, respectively. Critical values are computed by bootstrapping the impulse response functions, and then computing the point−wise critical values.