How the U.S. Shale Boom Has Changed the Impact of Oil Supply Shocks*

Myunghyun Kim† Sanha Noh‡ Christopher Otrok§

November 11, 2025

Abstract

Since 2010, the U.S. shale boom has led to a significant increase in U.S. oil production, enabling the U.S. to reduce its dependence on oil imports and lift the oil export ban. This paper examines how this large structural change in the U.S. oil industry and the global oil market has affected the transmission of oil supply shocks to the U.S., oil exporters, and oil importers. Our empirical analysis shows that the adverse impact of an oil supply shock (rising oil prices) on the U.S. is dampened in the post-shale boom period, while the negative impact on oil exporters is strengthened. However, the impact of the shock on oil importers does not change significantly between the pre- and post-shale boom periods. We then construct a three-country model consisting of the U.S., a non-U.S. oil importer, and an oil exporter. We show that the model's responses to an oil supply shock are consistent with our empirical evidence. The model simulation indicates that the reduced U.S. dependence on oil imports and U.S. oil exports in the post-shale boom period play key roles in the changes in the impact of oil supply shocks on the U.S. and the oil exporter over the two periods.

JEL Classification: F40, F41, Q43

Keywords: U.S. shale boom; reduced U.S. dependence on oil imports; lifting of the U.S. oil export ban; oil supply shocks; oil exporters; oil importers

* We would like to thank Sungjun Huh, Lutz Kilian, Michael Plante, Wonmun Shin, and the participants of the seminars at the 2024 Korea Environmental Economic Association Conference, Sungkyunkwan University, Jeonbuk National University, and Konkuk University.

† Department of Economics, Sungkyunkwan University, Republic of Korea (e-mail: mhkim7812@gmail.com).

‡ Department of Economics, Jeonbuk National University, Republic of Korea (e-mail: brownians84@jbnu.ac.kr).

§ Research Department, Federal Reserve Bank of Dallas, United States (e-mail: chris.otrok@dal.frb.org).

1 Introduction

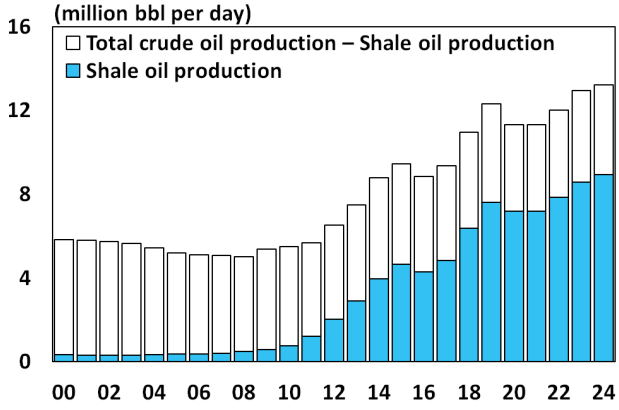
Advances in hydraulic fracturing (fracking) and horizontal drilling technologies have led to a sharp increase in U.S. shale oil production since the late 2000s.[1] These developments are known as the "U.S. shale boom" or the "shale or fracking revolution." As Figure 1 shows, the U.S. shale boom has led to a massive increase in U.S. oil production, allowing the U.S. to become less dependent on oil imports. Additionally, the surge in U.S. oil production resulted in the lifting of the U.S. oil export ban in December 2015.[2] As a result, since the boom, U.S. oil exports have increased significantly, whereas U.S. oil imports have fallen sharply.[3]

In other words, the shale boom has led to a sharp increase in U.S. oil production capacity, which has allowed the U.S. to lift the oil export ban. Therefore, after the shale boom, the U.S. has become less dependent on oil imports and has been able to export oil to other countries. Accordingly, in this paper, we consider i) the reduced U.S. dependence on oil imports and ii) U.S. oil exports to other countries as the two main features in the post-shale boom period compared to the pre-shale boom period.

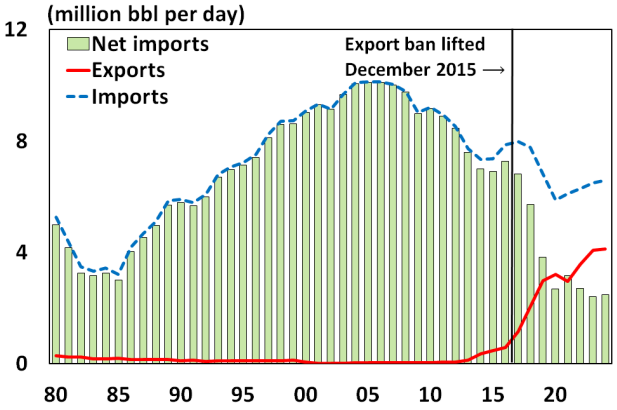
Before the shale boom, the U.S. was the world's largest oil importer and unable to export oil.[4] Therefore, the reduced dependence of the U.S. on oil imports and its oil exports to

Figure 1: U.S. shale oil production and net oil imports

(a) U.S. shale oil production



(b) U.S. net oil imports



Source: U.S. Energy Information Administration (EIA)

[1] Note that hydraulic fracturing and horizontal drilling were initially used for producing natural gas and natural gas liquids, which is why their production has also increased significantly. However, the market structures for gas and oil are very different, and considering gas together with oil makes the analysis much more intractable. We therefore focus on oil alone.

[2] Implemented in 1975, the ban prohibited the export of crude oil (except Alaskan crude) from the U.S. to other countries, with the exception of Canada.

[3] It should be noted that, according to the U.S. Energy Information Administration (EIA) data, the U.S. became a net energy exporter in 2019 thanks to the boom.

[4] According to the EIA, the average ratio of U.S. oil imports to global oil imports was 21% from 1980 to 2009.

other countries resulting from the shale boom may significantly impact the transmission of oil supply shocks not only to the U.S., but also to oil exporters and importers. Thus, we examine whether the impact of oil supply shocks differs for the U.S., oil exporters, and oil importers in the pre- and post-shale boom periods.[5]

We begin by presenting empirical evidence. Specifically, using structural vector autoregression (SVAR) models with sign restrictions, we first show that the adverse effect of an oil supply shock—which reduces world oil production, increases the real price of oil, and decreases world industrial production—on U.S. industrial production is much weaker in the post-shale boom period than in the pre-shale boom period, while the negative impact of the shock on the industrial production of oil exporters tends to be stronger in the latter period. Meanwhile, the shock has a similar impact on the industrial production of oil importers in the two periods. We also show that the trade balance and the terms of trade (the relative price of exports to imports) in the U.S. respond less negatively to the shock in the latter period than in the former, whereas the shock has a more negative effect on the export value of oil exporters in the latter period.[6]

To investigate the mechanism of the different effects of oil supply shocks in the two periods, we then construct a three-country model, including the U.S., a non-U.S. oil importer, and a oil exporter, and use the model's impulse response functions (IRFs). Specifically, the three countries are symmetric except for their size and oil production and trade structures. Each country has manufacturing and oil sectors. Households consume oil, and oil is used as an input in the production of manufacturing goods, but not in oil production. We consider an oil supply shock to be one that decreases oil production in the oil exporter. More importantly, we assume that the U.S. is less dependent on oil imports in the post-shale boom period than in the pre-shale boom period. Furthermore, the U.S. can export oil to the non-U.S. oil importer in the latter period, whereas it cannot in the former. We estimate the parameters of the model using the IRF matching approach.

According to the model simulation, an oil supply shock decreases U.S. gross domestic product (GDP) and the terms of trade much less and increases its trade balance more in the post-shale boom period than in the pre-shale boom period. The shock decreases the GDP, real export value, and oil production of the oil exporter more in the latter period than in the former period. The GDP of the non-U.S. oil importer responds similarly to the shock in both periods.[7] These simulation results are consistent with the empirical evidence.

[5] We define the pre-shale boom period as 1995–2009 and the post-shale boom period as 2010–2024. Section 2.1 explains why we define these periods as such.

[6] For robustness, we also estimate SVAR models with traditional and narrative sign restrictions, as in Antolín-Díaz and Rubio-Ramírez (2018), and show that the two estimation results are very similar.

[7] Since the responses of the importer's GDP in both the model simulation and the empirical evidence are similar in the two periods, we focus on the U.S. and the oil exporter in the following.

To explain the mechanism, let us first consider the pre-shale boom period. An oil supply shock reduces oil production in the oil exporter and increases the price of oil in all three countries. A fall in oil production leads to a decrease in exporter's GDP. Since the oil price increases, GDPs in oil-importing countries (the U.S. and the non-U.S. oil importer) fall as usual.

Next, consider the case of an oil supply shock hitting the world economy in the post-shale boom period, during which the U.S. is much less dependent on oil imports and can export oil to the non-U.S. oil importer. Since the U.S. depends less on oil imports, the weight of the imported oil price in the U.S. import price is lower in this period compared to the pre-shale boom period. Hence, the U.S. terms of trade decline less in response to an increase in the imported oil price triggered by the shock. It implies that the market value of U.S. output decreases less, and therefore its income falls less. Consequently, U.S. consumption decreases less. Furthermore, the real price of U.S. oil increases by a smaller amount in response to the shock than the real price of imported oil.[8] Since the U.S. can export oil to the oil importer in the post-shale boom period, thanks to the lifting of the U.S. oil export ban, U.S. oil exports go up. In addition, U.S. oil imports fall more in the latter period due to the reduced dependence on oil imports. As a result, the U.S. trade balance rises more in the post-shale boom period than in the pre-shale boom period in response to the shock. Taken together, U.S. GDP declines less in the pre-shale boom period than in the latter period.

Regarding the oil exporter, in response to an oil supply shock, U.S. oil imports fall more in the latter period than in the former period due to reduced dependence on oil imports. The oil exporter's real export value to the U.S. goes down more in the post-shale boom period. Accordingly, the real value of total exports in the oil exporter falls more in the post-shale boom period, which leads to a greater reduction in oil production. Therefore, GDP in the oil exporter decreases more in the post-shale boom period than in the pre-shale boom period.

We also consider two extensions of the baseline model. Since the oil trade is the clearest example of dollar pricing (DP), the first extension is a model under DP in international oil trade. In addition, because oil production in reality requires oil as an input, unlike our baseline model, the second extension is a model in which oil is used as an input in oil production. The simulation results of the two models also indicate that, in the post-shale boom period, the negative impact of an oil supply shock on the U.S. is reduced, while the adverse impact on the oil exporter is amplified. Furthermore, the models show that the shock has a similar impact on the oil importer in both periods.

Two strands of literature are related to this paper. The first analyzes the effects of the U.S. shale boom on oil (or energy) prices and the macroeconomy. For instance, Mănescu and Nuño (2015) show that during 2010–2018, the shale boom led to an additional 0.2%

[8] This is because the oil supply shock originates from the oil exporter.

increase in the GDP of oil importers. Kilian (2016) studies the impact of the shale boom on the evolution of U.S. gasoline and crude oil prices. Feyrer, Mansur, and Sacerdote (2017) and Allcott and Keniston (2018) demonstrate that the shale boom has positive effects on regional or local economies. Melek, Plante, and Yücel (2021) report that during 2010–2015, the shale boom increased U.S. GDP by about 1 percent, improved the oil trade balance, and decreased oil and fuel prices. Bornstein, Krusell, and Rebelo (2023) find that fracking reduces oil price volatility in the long run. This is because fracking firms are able to respond more quickly to changes in oil demand. Finally, using a time-varying parameter factor-augmented VAR model, Bjørnland and Skretting (2024) show that an oil-specific shock has positive effects on investment, income, industrial production, and (non-oil) employment in most oil-producing and some manufacturing-intensive U.S. states during the post-shale boom period.

The literature on oil (or energy) and international macroeconomic interactions is the second strand. In particular, Backus and Crucini (2000) show that extreme changes in oil prices can account for much of the fluctuations in the terms of trade. Bodenstein, Erceg, and Guerrieri (2011) show that an oil market-specific shock that increases the oil price causes a wealth transfer toward oil exporters and decreases consumption in oil importers. Although the oil trade balance in the oil importer deteriorates, an improvement in its non-oil balance substantially dampens the effects on the overall trade balance. Kim (2022) shows that the shale boom leads to stronger effects of U.S. monetary policy on commodity importers but weaker effects on commodity exporters. Kim (2024a) shows that U.S. GDP correlations with energy exporters are stronger than with energy importers. Finally, Kim (2025) shows that the correlations of U.S. GDP with net exports and the terms of trade in the post-shale boom period are significantly different from those in the pre-shale boom period and that the changed structures of U.S. oil production and trade resulting from the shale boom account for much of the variation in the correlations between the two periods.

However, unlike the present study, the above studies do not consider the changes in the transmission of oil supply shocks to the U.S., oil exporters, and oil importers resulting from the U.S. shale boom. Hence, this paper contributes to the literature by analyzing whether the effects of oil supply shocks on the U.S., oil exporters, and oil importers in the post-shale boom period are different from those in the pre-shale boom period.

The remainder of this paper is organized as follows. In Section 2, we empirically show that in the post-shale boom period, the negative impact of an oil supply shock on the U.S. is dampened and the adverse impact of the shock on oil exporters is more likely to be strengthened compared to the pre-shale boom period. We also show in this section that the impact of the shock on oil importers is similar in the two periods. Section 3 describes the three-country model in which the U.S., a non-U.S. oil importer, and an oil exporter exist. We also estimate parameters in the model using the IRF matching approach in this section.

Section 4 presents the simulation results of the model. Section 5 extends the three-country model. Finally, Section 6 concludes the paper.

2 Empirical evidence

In this section, we first define the pre- and post-shale boom periods, introduce our sample countries, and present the data used for estimation. Then, we present empirical evidence of the different effects of an oil supply shock—reducing world oil production and world industrial production and increasing the real oil price—on the U.S. and on oil exporters and importers during the pre- and post-shale boom periods. Specifically, we use sign-restricted SVAR models to show that, during the post-shale boom period, the negative effects of an oil supply shock on the U.S. are dampened, while the negative effects on oil exporters are increased. We also show that the impact on oil importers remains similar to that in the pre-shale boom period.

2.1 Definitions of the two periods, sample countries, and database

To examine whether the impact of oil supply shocks on the U.S., oil exporters, and oil importers differs between the pre- and post-shale boom periods, we first define these two periods precisely. Regarding the pre-shale boom period, the impact of oil prices on the macroeconomy has been decreased since the late 1980s or 2000s (Blanchard and Galí, 2010; Katayama, 2013; and Kim, 2020). Furthermore, it is clear from Figure 1 that U.S. shale oil production has increased sharply since 2010. Accordingly, we define the pre-shale boom period as 1995-2009 and the post-shale boom period as 2010-2024. This classification aligns with that used by Melek, Plante, and Yücel (2021), Bjørnland and Skretting (2024), and Kim (2025).

We consider the U.S., the six major oil-exporting countries, and the eight major oil-importing countries in this section. The six major oil exporters are Canada, Colombia, Denmark, Mexico, Norway, and Russia. The eight major oil importers are Austria, Belgium, France, Germany, Italy, Japan, Portugal, and Spain. Note that the U.K. was an oil exporter during the pre-shale boom period but an oil importer during the latter period. Conversely, Brazil was an oil importer during the former period but an oil exporter during the latter period. Therefore, we exclude the U.K. and Brazil from our sample countries.

In line with earlier studies, this study employs the log of world oil production, the log of the real oil price, and the log of world industrial production as global oil market variables. World oil production is the production of crude oil, including lease condensate production, in millions of barrels pumped per day. The real oil price is the U.S. refiners' acquisition cost of imported crude oil deflated by the U.S. consumer price index (CPI). World industrial production is the industrial production of OECD countries and six other major economies.

Regarding the country-specific variables, we use the industrial production index and the CPI for all sample countries.[9] To estimate the SVAR model for the U.S., we also use the terms of trade (the ratio of export prices to import prices) and the trade balance (the ratio of export value to import value). Export value is also used for SVAR models of oil exporters. All variables used to estimate the SVAR models are based on monthly data. The data for oil production and oil prices are sourced from the EIA; world industrial production data is obtained from Baumeister and Hamilton (2019); the trade data is taken from the OECD; the data for the U.S. export and import prices are sourced from FRED; and the data for the CPI and industrial production index are taken from the OECD or FRED. Finally, note that, due to data availability, we set the end months of the post-shale boom period for Japan, Mexico, and Russia as December 2021, 2021, and 2023, respectively.

2.2 Effects of an oil supply shock on output

First, we examine the effects of oil supply shocks on the output of the U.S., oil exporters, and oil importers in the two periods. Specifically, we estimate the following SVAR model for each country:

$$y_t' A_0 = \sum_{s=1}^{p} y_{t-s}' A_s + \varepsilon_{t.}$$

where y_t includes three global oil market variables and two country-specific variables. The three global oil market variables are the logs of the real oil price, world industrial production, and world oil production. The two country-specific variables are the logs of the industrial production index and CPI. Based on the information criteria, we set the lag length p to between two and six months.

In order to identify structural oil supply shocks, we impose sign restrictions similar to those imposed in Peersman and Van Robays (2012), Baumeister and Peersman (2013), and Kim (2020).[10] An oil supply shock decreases world oil production and world industrial production but increases the real oil price for one year. No other restrictions are imposed.

Figure 2 shows the IRFs of industrial production in the U.S., oil exporters (averaged across the sample oil-exporting countries), and oil importers (averaged across the sample oil-importing countries) in the pre- and post-shale boom periods to an oil supply shock.[11]

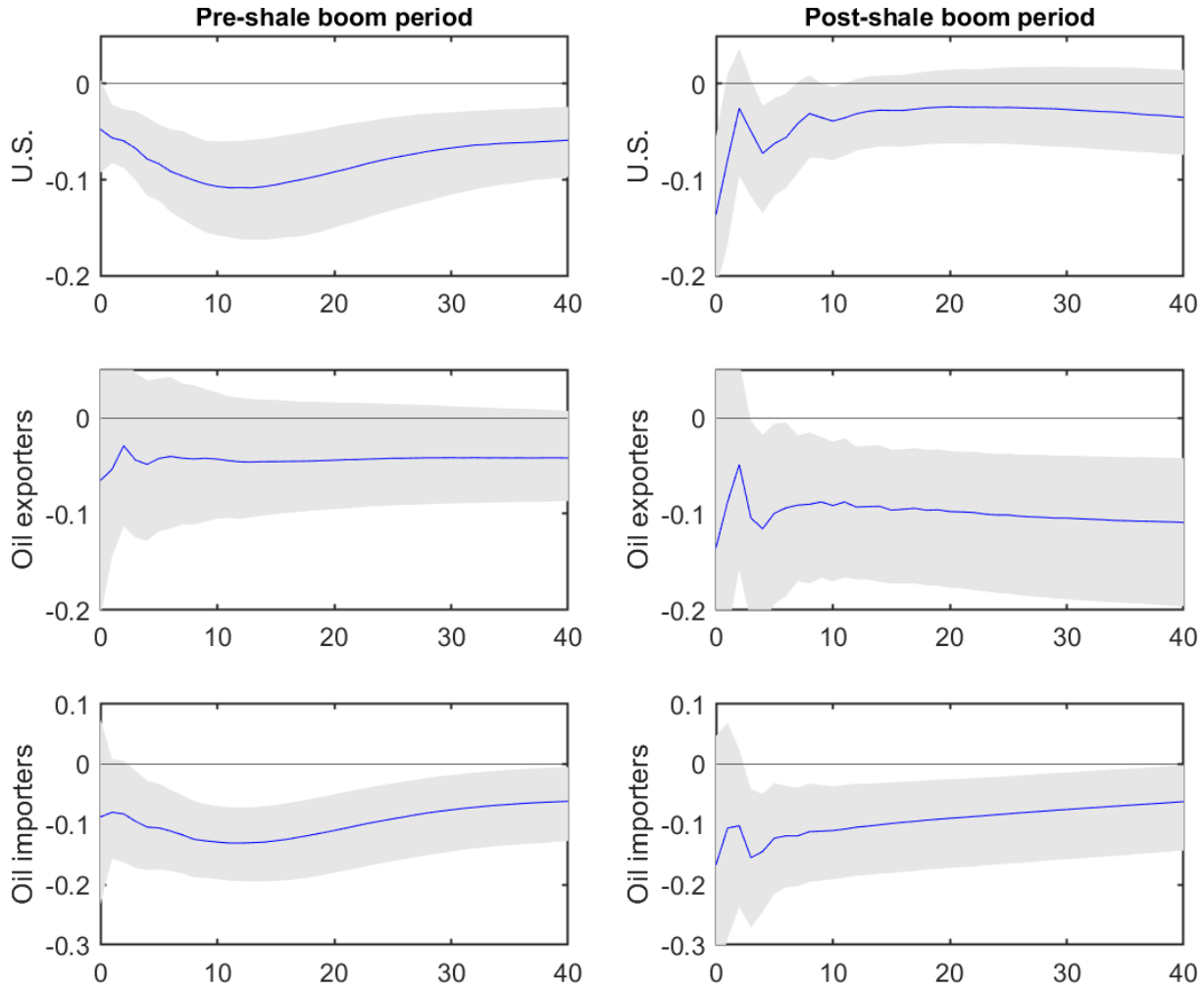
[9] Since Colombia's industrial production data is unavailable, we use the total manufacturing production index in the SVAR model for Colombia.

[10] Note that some studies, such as Kilian (2009) and Kilian, Rebucci, and Spatafora (2009), use recursive restrictions in SVAR models rather than the sign restrictions used in this study to identify oil supply shocks.

[11] All of the IRFs are obtained from 2,000 draws that satisfy the sign restrictions. To estimate the SVAR model, we use the Bayesian method and the Matlab program of Antolín-Díaz and Rubio-Ramírez (2018). Hence, for the detailed methodology of the SVAR model with sign restrictions, see Antolín-Díaz and Rubio-Ramírez (2018). The IRF of industrial production in each country to an oil supply shock is presented in Online Appendix A.

The shock is normalized to decrease world oil production by 0.1% in period 0 in both sample periods. Specifically, an oil supply shock (which reduces world oil production and world industrial production and increases the real oil price) decreases U.S. industrial production in both periods. However, the decrease in the latter period is generally smaller than that in the former period. In response to the shock, in the pre-shale boom period, there is a fall in industrial production in oil exporters, but the response is not statistically different from zero. In the post-shale boom period, the shock decreases industrial production in oil exporters, and the decrease is statistically significant and larger than in the pre-shale boom period. The shock leads to a statistically significant decrease in industrial production in oil-importing countries in both periods, and the magnitude of the decrease is similar in both periods.

Figure 2: IRFs of industrial production to an oil supply shock



Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.

In short, the adverse effects of an oil supply shock—which increases the real oil price, decreases world oil production, and decreases world industrial production—on the U.S. are mitigated in the post-shale boom period, when the U.S. is less dependent on oil imports and can export oil. Conversely, the negative impact of an oil supply shock on oil exporters tends to be exacerbated in the post-shale boom period. Estimation results indicate no significant difference in the effects of an oil supply shock on oil importers in the two periods.

2.3 Impact of an oil supply shock on terms of trade, trade balance, and exports

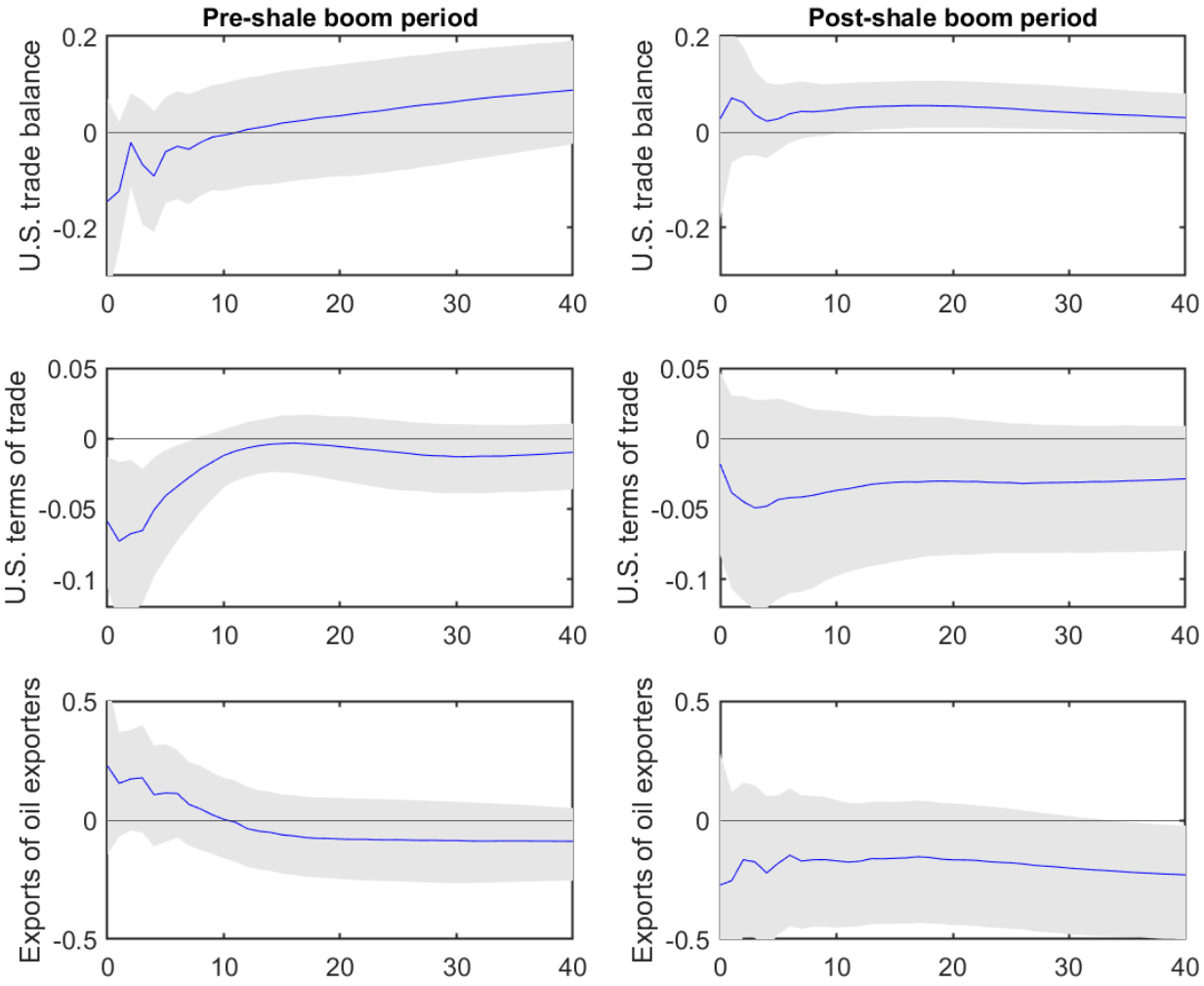
In this subsection, to investigate how the negative impact of an oil supply shock on U.S. output weakens and how the negative impact on oil exporters' output strengthens in the post-shale boom period, we estimate SVAR models for the U.S. and oil exporters by adding more variables. Specifically, we add logs of the terms of trade and the trade balance to the U.S. SVAR model and log export value to the SVAR models of the oil exporters. Everything is the same as in the previous subsection, except for the newly included variables and lag lengths in the SVAR models.[12]

The estimated IRFs of three variables—the U.S. trade balance, the U.S. terms of trade, and the export value of oil exporters—to an oil supply shock are presented in Figure 3. In the pre-shale boom period, the response of the U.S. trade balance is not statistically different from zero. However, in the post-shale boom period, the shock increases the U.S. trade balance, and this increase is statistically significant. This may be because the U.S. can export oil to other countries in the post-shale boom period thanks to the lifting of the oil export ban. In response to the shock, there is a statistically significant decline in U.S. terms of trade in the former period. In the latter period, however, although U.S. terms of trade decrease in response to the shock, the decrease is not statistically significant and is generally smaller than in the former period. Finally, the export value of oil exporters tends to increase in response to the shock in the pre-shale boom period, but this increase is not statistically significant. In contrast, the shock decreases the export value of oil exporters in the post-shale boom period, and this decrease is statistically significant.

In a nutshell, the estimation results show that oil supply shocks become more favorable to the U.S. trade balance and terms of trade in the post-shale boom period compared to the pre-shale boom period. Conversely, the shocks become more harmful to the export value of oil exporters in the latter period. These results are also consistent with our hypothesis, as explained in the previous section.

[12] Based on the information criteria, we again set the lag length for each SVAR model to between three and six months.

Figure 3: IRFs of U.S. trade balance, U.S. terms of trade, and export value of oil exporters



Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.

2.4 Further considerations

One might think that, in order to precisely estimate the impact of an oil supply shock on the three groups of countries, the periods of the global financial crisis and the COVID-19 pandemic should be excluded from the sample period. This is because the estimated changes in the impact of an oil supply shock between the pre- and post-shale boom periods may originate from these two crises. Furthermore, since only traditional sign restrictions are used to identify oil supply shocks, one might also argue that oil supply shocks could be more accurately identified by augmenting the traditional sign restrictions with narrative sign restrictions.

In Online Appendix B, we present the estimation results when the periods of the global financial crisis and the COVID-19 pandemic are excluded from the sample period. In this

exercise, the pre-shale boom period is from January 1995 to June 2008, and the post-shale boom period is from January 2010 to December 2019. We also provide the estimation results of the IRFs of the SVAR models with traditional and narrative sign restrictions in Online Appendix C. The estimation results of both cases are very similar to those of the SVAR models in this section.

3 Description of the three-country model

In this section, we describe the three-country model. There are country A (the U.S., an oil importer), country B (a representative non-U.S. oil importer), and country C (a representative oil exporter) in the world economy. The three countries are symmetric except for their size and oil production and trade structures. Countries A and B can produce oil, but their oil production capacity is too low to meet their domestic demand for oil. Thus, they import oil from country C. Country C has enough oil production capacity to meet both its domestic demand and foreign import demand for oil, and hence it does not import oil but exports oil to the two oil importers. More importantly, unlike in the pre-shale boom period, in the post-shale boom period, country A (the U.S.) depends less on oil imports due to increased oil production capacity and can export oil to country B thanks to the repeal of the oil export ban. Every country has a manufacturing sector and an oil sector. Households consume oil, and manufacturing firms use it as an input in their production. However, oil-producing firms do not use oil in their production.

Hereafter, we describe the equations for country A. If there is no other explanation, the equations for the other two countries are symmetric with those for country A. The superscripts B and C refer to the variables in countries B and C, respectively. U.S. (country A) variables have no superscript. The subscripts A, B and C refer to the variables produced in countries A, B and C, respectively.[13]

3.1 Households

The representative household maximizes the following present discounted value of expected lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln \left(C_t - bC_{t-1} \right) - \frac{N_t^{1+\chi}}{1+\chi} \right], \tag{1}$$

where $\mathbb{E}$ is the expectations operator, C_t refers to the aggregate consumption, and N_t represents aggregate labor supply, defined as $N_t = \sum_s N_{s,t}$, $s \in \{m, o\}$, with m and o denoting

[13] We list the equilibrium conditions of the model in Online Appendix D.

the manufacturing and oil sectors, respectively.[14] Her budget constraint in real terms is as follows:

$$C_t + Q_t B_t + \frac{1}{2}\zeta B_t^2 + D_t = W_t N_t + B_{t-1} + R_{t-1} D_{t-1} + \Pi_t, \tag{2}$$

where B_t is the quantity of the non-contingent international bond, and Q_t is the price of this bond. As in Schmitt-Grohé and Uribe (2003), we introduce a quadratic bond holding cost, $\frac{1}{2}\zeta B_t^2$, for stationarity of the model. W_t, R_t, and Π_t are the real wage, the risk-free real return on deposits D_t, and the real profits remitted by firms, respectively.

The aggregate consumption (C_t) consists of the manufacturing consumption ($C_{m,t}$) and the oil consumption ($C_{o,t}$), using the constant elasticity of substitution (CES) aggregator.

$$C_t = \left\{ (1-\gamma_0)^{\frac{1}{\eta_0}} C_{m,t}^{\frac{\eta_0-1}{\eta_0}} + \gamma_0^{\frac{1}{\eta_0}} C_{o,t}^{\frac{\eta_0-1}{\eta_0}} \right\}^{\frac{\eta_0}{\eta_0-1}}. \tag{3}$$

The manufacturing consumption ($C_{m,t}$) is a function of domestically produced manufacturing consumption goods ($C_{A,t}$) and imported manufacturing consumption goods from countries B and C ($C_{B,t}$ and $C_{C,t}$).

$$C_{m,t} = \left\{ (1-\gamma_1)^{\frac{1}{\eta_1}} C_{A,t}^{\frac{\eta_1-1}{\eta_1}} + \gamma_{1,B}^{\frac{1}{\eta_1}} C_{B,t}^{\frac{\eta_1-1}{\eta_1}} + \gamma_{1,C}^{\frac{1}{\eta_1}} C_{C,t}^{\frac{\eta_1-1}{\eta_1}} \right\}^{\frac{\eta_1}{\eta_1-1}}, \tag{4}$$

with $\gamma_1 = \gamma_{1,B} + \gamma_{1,C}$.

Since only country C exports oil in the pre-shale boom period, the oil consumption ($C_{o,t}$) in this period is defined by domestically produced oil ($C_{O,A,t}$) and oil imported from country C ($C_{o,C,t}$).

$$C_{o,t} = \left\{ (1-\gamma_2)^{\frac{1}{\eta_2}} C_{o,A,t}^{\frac{\eta_2-1}{\eta_2}} + \gamma_2^{\frac{1}{\eta_2}} C_{o,C,t}^{\frac{\eta_2-1}{\eta_2}} \right\}^{\frac{\eta_2}{\eta_2-1}}. \tag{5}$$

Moreover, country C has sufficient oil production capacity to meet its domestic demand for oil consumption, and therefore, it does not need to import oil (i.e., $C_{o,t}^C = C_{o,C,t}^C$). Recall that unlike in the pre-shale boom period, since country A (the U.S.) can export oil to country B in the post-shale boom period, oil consumption in country B ($C_{o,t}^B$) in that period is altered to $C_{o,t}^B = \left\{ (1-\gamma_2^B)^{\frac{1}{\eta_2}} C_{o,B,t}^{B\,\frac{\eta_2-1}{\eta_2}} + \gamma_{2,A}^{B\,\frac{1}{\eta_2}} C_{o,A,t}^{B\,\frac{\eta_2-1}{\eta_2}} + \gamma_{2,C}^{B\,\frac{1}{\eta_2}} C_{o,C,t}^{B\,\frac{\eta_2-1}{\eta_2}} \right\}^{\frac{\eta_2}{\eta_2-1}}$ with $\gamma_2 = \gamma_{2,A}^B + \gamma_{2,C}^B$. Note that $C_{o,t}^B = \left\{ (1-\gamma_2^B)^{\frac{1}{\eta_2}} C_{o,B,t}^{B\,\frac{\eta_2-1}{\eta_2}} + \gamma_2^{B\,\frac{1}{\eta_2}} C_{o,C,t}^{B\,\frac{\eta_2-1}{\eta_2}} \right\}^{\frac{\eta_2}{\eta_2-1}}$ in the pre-shale boom period.

[14] Throughout the paper, the subscripts s, m, and o denote sectors, manufactures, and oil, respectively.

3.2 Firms

In each sector, there are a representative competitive final goods firm, a continuum of intermediate goods firms, and a capital producer. The final goods firm aggregates differentiated intermediate inputs with a CES technology to produce final goods. Intermediate goods firms that operate in monopolistic competition supply many differentiated intermediates to the final goods firm, and they cannot freely adjust prices each period. That is, in each period, only a fraction $(1-\theta_s)$ of firms can adjust their prices. The capital producer has the technology to convert final goods into capital.

3.2.1 Final goods firm

The final goods firm in sector s aggregates intermediate goods, $Y_{s,t}(i_s)$, where $i_s \in [0,1]$, to produce final goods, $Y_{s,t}$, according to the following technology:

$$Y_{s,t} = \left(\int_0^1 Y_{s,t}(i_s)^{\frac{\varepsilon-1}{\varepsilon}} di_s \right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{6}$$

Profit maximization gives the demand for the i_sth intermediate good:

$$Y_{s,t}(i_s) = \left(\frac{P_{s,t}(i_s)}{P_{s,t}} \right)^{-\varepsilon} Y_{s,t}, \tag{7}$$

where $P_{s,t}(i_s)$ is the nominal price of the i_sth intermediate good, and $P_{s,t}$ is the nominal price of final goods.

3.2.2 Intermediate goods firms

Intermediate oil producers. Intermediate oil is produced using labor and capital. The production function of intermediate oil producers is Cobb-Douglas, as in Kim (2022):

$$Y_{o,t}(i_o) = A_{o,t} K_{o,t}(i_o)^{\alpha_o} N_{o,t}(i_o)^{1-\alpha_o} + \ln \psi_t, \tag{8}$$

where $Y_{o,t}(i_o)$, $A_{o,t}$, $K_{o,t}(i_o)$, and $N_{o,t}(i_o)$ are the output of firm i_o, the common productivity in the sector, the firm's capital input, and the firm's labor input, respectively. ψ_t for the three countries follows a vector-autoregressive process:

$$\begin{bmatrix} \ln \psi_t \\ \ln \psi_t^B \\ \ln \psi_t^C \end{bmatrix} = \begin{bmatrix} \rho & \upsilon_B^A & \upsilon_C^A \\ \upsilon_A^B & \rho^B & \upsilon_C^B \\ \upsilon_A^C & \upsilon_B^C & \rho^C \end{bmatrix} \begin{bmatrix} \ln \psi_{t-1} \\ \ln \psi_{t-1}^B \\ \ln \psi_{t-1}^C \end{bmatrix} + \begin{bmatrix} \epsilon_t \\ \epsilon_t^B \\ \epsilon_t^C \end{bmatrix}, \tag{9}$$

where the innovation ϵ_t is assumed to be exogenous, independently and identically distributed $N(0, \sigma^2)$. Supply disruptions in the oil market can be captured by a fall in ϵ_t, which decreases ψ_t and thus reduces intermediate oil production. We consider oil supply shocks as supply disruptions in the oil markets of oil exporters (Country C). In other words, we interpret a fall in ϵ_t^C as the oil supply shock.

Intermediate manufacturing goods producers. Labor, capital, and oil are used in the production of intermediate manufacturing goods. The production function of them is a nested CES as in Kim and Loungani (1992) and Kim (2022):

$$Y_{m,t}(i_m) = A_{m,t}\left\{(1-a)K_{m,t}(i_m)^{-\nu} + aO_t(i_m)^{-\nu}\right\}^{-\frac{\alpha}{\nu}} N_{m,t}(i_m)^{1-\alpha}, \tag{10}$$

where $Y_{m,t}(i_m)$, $A_{m,t}$, $K_{m,t}(i_m)$, $O_t(i_m)$, and $N_{m,t}(i_m)$ denote to the output of firm i_m, the common productivity in the sector, the firm's capital input, the firm's oil input, and the firm's labor input, respectively. a is related to the weight of oil, and $\nu = \frac{1-\varsigma}{\varsigma}$, where ς is the elasticity of substitution between oil and capital in manufacturing production.

Similar to oil consumption, the oil input is defined by domestically produced oil and imported oil from country C, $O_t(i_m) = \left\{(1-\gamma_2)^{\frac{1}{\eta_2}} O_{A,t}(i_m)^{\frac{\eta_2-1}{\eta_2}} + \gamma_2^{\frac{1}{\eta_2}} O_{C,t}(i_m)^{\frac{\eta_2-1}{\eta_2}}\right\}^{\frac{\eta_2}{\eta_2-1}}$. Therefore, γ_2 governs the steady-state value of the net oil imports for production and consumption in the former period. Country C can fully produce the oil input used to produce manufactures in them ($O_t^C = O_{C,t}^C$) plus oil imports in countries A and B for manufacturing production ($O_{C,t} + O_{C,t}^B$). More importantly, country A (the U.S.) can export oil to country B during the post-shale boom period. Thus, oil input in country B (O_t^B) is $O_t^B(i_m^B) = \left\{(1-\gamma_2^B)^{\frac{1}{\eta_2}} O_{B,t}^B(i_m^B)^{\frac{\eta_2-1}{\eta_2}} + \gamma_2^{B\frac{1}{\eta_2}} O_{C,t}^B(i_m^B)^{\frac{\eta_2-1}{\eta_2}}\right\}^{\frac{\eta_2}{\eta_2-1}}$ in the former period, but it is $O_t^B(i_m^B) = \left\{(1-\gamma_2^B)^{\frac{1}{\eta_2}} O_{B,t}^B(i_m^B)^{\frac{\eta_2-1}{\eta_2}} + \gamma_{2,A}^{B\frac{1}{\eta_2}} O_{A,t}^B(i_m^B)^{\frac{\eta_2-1}{\eta_2}} + \gamma_{2,C}^{B\frac{1}{\eta_2}} O_{C,t}^B(i_m^B)^{\frac{\eta_2-1}{\eta_2}}\right\}^{\frac{\eta_2}{\eta_2-1}}$ in the post-shale boom period.

3.2.3 Capital producers

In each period, capital producers purchase $I_{s,t}$ of final goods at price $p_{s,t}$ and $(1-\delta)K_{s,t}$ of used capital at price $q_{s,t}$ and produce new capital $K_{s,t+1}$ using $I_{s,t}$ and $(1-\delta)K_{s,t}$.[15] Accordingly, their problem is as follows:

$$\max_{I_{s,t}} \mathbb{E}_t \sum_{h=0}^{\infty} \lambda_{t+h}\left[q_{s,t+h}\left(1 - \frac{\phi}{2}\left(I_{s,t+h}/I_{s,t+h-1} - 1\right)^2\right) I_{s,t+h} - p_{s,t} I_{s,t+h}\right], \tag{11}$$

[15] Throughout the paper, the capital P_s refers to nominal prices and the lowercase $p_s \equiv P_s/P$ denotes real prices deflated by CPI P_t.

subject to the law of motion for capital:

$$K_{s,t} = (1-\delta)K_{s,t-1} + \left[1 - \frac{\phi}{2}\left(\frac{I_{s,t}}{I_{s,t-1}} - 1\right)^2\right] I_{s,t}. \tag{12}$$

3.3 Monetary policy and resource constraints

The monetary authority in each country follows a standard Taylor-type rule,

$$\frac{R_t^n}{R^n} = \left(\frac{R_{t-1}^n}{R^n}\right)^{\rho_r} \left(\frac{\pi_t}{\pi}\right)^{(1-\rho_r)\phi_\pi} \left(\frac{Y_t}{Y}\right)^{(1-\rho_r)\phi_y}, \tag{13}$$

where R_t^n is the nominal interest rate, $\pi_t \equiv P_t/P_{t-1}$ is CPI inflation, Y_t is real GDP, and variables without a time subscript t denote their steady-state values.

Output in the manufacturing sector must be equated with world consumption plus investment. Output in the oil sector must be equal to the sum of domestically produced oil consumption and inputs, and investment.[16]

$$n_A Y_{m,t} = n_A C_{A,t} + n_B C_{A,t}^B + n_C C_{A,t}^C + n_A I_{m,t} \tag{14}$$

$$\text{and } n_A Y_{o,t} = n_A C_{o,A,t} + n_A O_{A,t} + n_A I_{o,t}. \tag{15}$$

where n_i, $i \in \{A, B, C\}$, denotes the number of households in country i. Recall that country A can export oil to country B in the post-shale boom period. Therefore, output in the oil sector in country A in the post-shale boom period is $n_A Y_{o,t} = n_A\left(C_{o,A,t} + O_{A,t} + I_{o,t}\right) + n_B\left(C_{o,A,t}^B + O_{A,t}^B\right)$.

3.4 Additional variables of interest

Since we are interested in real GDP, the trade balance, and the terms of trade, this subsection provides their definitions. First, real GDP, Y_t, is the real value added in the oil and manufacturing sectors:

$$Y_t = n_A\left(p_{A,t}Y_{m,t} + p_{o,A,t}Y_{o,t} - p_{o,t}O_t\right). \tag{16}$$

The trade balance, tb_t, is defined as the ratio of export value to import value consistent with the empirical analysis:

$$tb_t = \frac{EXP_t}{IMP_t}, \tag{17}$$

[16] As country C exports oil, its resource constraint for the oil sector differs from those of countries A and B. Specifically, country C's constraint is $n_C Y_{o,t}^C = n_A\left(C_{o,C,t} + O_{C,t}\right) + n_B\left(C_{o,C,t}^B + O_{C,t}^B\right) + n_C\left(C_{o,t}^C + O_t^C + I_{o,t}^C\right)$.

where $EXP_t = P_{A,t}\left(n_B C^B_{A,t} + n_C C^C_{A,t}\right)$ and $IMP_t = n_A[P_{o,C,t}\left(C_{o,C,t} + O_{C,t}\right) + P_{B,t}C_{B,t} + P_{C,t}C_{C,t}]$ are the nominal values of exports and imports, respectively.[17] Note that since it is possible for country A to export oil to country B in the post-shale boom period, the nominal value of exports in country A and that of imports in country B in that period are $EXP_t = P_{A,t}\left(n_B C^B_{A,t} + n_C C^C_{A,t}\right) + P_{o,A,t}\left(n_B C^B_{o,A,t} + n_B O^B_{A,t}\right)$ and $IMP^B_t = n_B[P^B_{A,t}C^B_{A,t} + P^B_{C,t}C^B_{C,t} + P^B_{o,A,t}\left(C^B_{o,A,t} + O^B_{A,t}\right) + P^B_{o,C,t}\left(C^B_{o,C,t} + O^B_{C,t}\right)]$, respectively.

The terms of trade are defined as the export price ($P_{EXP,t}$) divided by the import price ($P_{IMP,t}$). The export price is the price of domestically produced manufacturing goods ($P_{A,t}$), and the import price can be expressed by the weighted average of the prices of imported manufactures and oil. That is, the terms of trade (τ_t) can be written as follows:

$$\tau_t = \frac{P_{EXP,t}}{P_{IMP,t}}, \tag{18}$$

with $P_{EXP,t} = P_{A,t}$, and $P_{IMP,t} = \omega_{B,t}P_{B,t} + \omega_{C,t}P_{C,t} + (1 - \omega_{B,t} - \omega_{C,t})\,P_{o,C,t}$, where $\omega_{B,t} = \frac{P_{B,t}C_{B,t}}{IMP_t}$ and $\omega_{C,t} = \frac{P_{C,t}C_{C,t}}{IMP_t}$.[18] In the post-shale boom, the U.S. can export oil to country B, U.S. export price and the import price of country B differ. Specifically, $P_{EXP,t} = \frac{P_{A,t}\left(n_B C^B_{A,t} + n_C C^C_{A,t}\right)}{EXP_t}P_{A,t} + \left(1 - \frac{P_{A,t}\left(n_B C^B_{A,t} + n_C C^C_{A,t}\right)}{EXP_t}\right)P_{o,A,t}$ and $P^B_{IMP,t} = \frac{P^B_{A,t}C^B_{A,t}}{IMP^B_t}P^B_{A,t} + \frac{P^B_{C,t}C^B_{C,t}}{IMP^B_t}P^B_{C,t} + \frac{P^B_{o,A,t}(C^B_{o,A,t} + O^B_{A,t})}{IMP^B_t}P^B_{o,A,t} + \frac{P^B_{o,C,t}(C^B_{o,C,t} + O^B_{C,t})}{IMP^B_t}P^B_{o,C,t}$.

3.5 Parameter values

In this subsection, we assign values to the parameters in the model. A period in the model is a quarter. The parameter values for the pre-shale boom period are given first, and then we provide those for the post-shale boom period.

3.5.1 Parameter values for the pre-shale boom period

We estimate the parameter values in the pre-shale boom period using the IRF matching approach of Christiano, Eichenbaum, and Evans (2005). Specifically, we treat the empirical IRFs in Section 2 as data and choose 18 model parameters that minimize the distance between the model IRFs and the empirical IRFs.

[17] The trade balances of countries B and C are defined equally. However, the nominal values of exports and imports are different in country C. Specifically, $EXP^C_t = P^C_{C,t}\left(n_A C_{C,t} + n_B C^B_{C,t}\right) + P^C_{o,C,t}\left(n_A C_{o,C,t} + n_B C^B_{o,C,t} + n_A O_{C,t} + n_B O^B_{C,t}\right)$, and $IMP^C_t = n_C\left[P^C_{A,t}C^C_{A,t} + P^C_{B,t}C^C_{B,t}\right]$.

[18] The terms of trade in countries B and C are equally defined, but they have different export and import prices. That is, $P^C_{EXP,t} = \frac{P^C_{C,t}\left(n_A C_{C,t} + n_B C^B_{C,t}\right)}{EXP^C_t}P^C_{C,t} + \left(1 - \frac{P^C_{C,t}\left(n_A C_{C,t} + n_B C^B_{C,t}\right)}{EXP^C_t}\right)P^C_{o,C,t}$, and $P^C_{IMP,t} = \frac{P^C_{A,t}C^C_{A,t}}{IMP^C_t}P^C_{A,t} + \frac{P^C_{B,t}C^C_{B,t}}{IMP^C_t}P^C_{B,t}$. Export and import prices in country B is symmetric with those in country A.

Calibrated parameters. We calibrate the parameters are either uncontroversial or easy to infer from the data. We also calibrate the parameters that have limited influence on the dynamics of the model. The calibrated parameter values for the pre-shale boom period are listed in Table 1.

Some calibrated parameter values are borrowed from existing literature. Specifically, the discount factor β is 0.99, the depreciation rate of capital δ is 0.025, and the labor share of income in the manufacturing sector, $1-\alpha$, and that in the oil sector, $1-\alpha_o$, are is 0.67 and 0.68, respectively.[19]

It is assumed that the number of households in countries A, B, and C are 0.27, 0.6, and 0.13, respectively. Under this assumption, the steady-state ratios of the GDPs of countries A, B, and C to the world GDP are 0.27, 0.6, and 0.13, respectively. These ratios closely match the average ratios of U.S. and non-U.S. oil importers' and exporters' GDPs to world GDP from 1995 to 2009, based on data from the IMF World Economic Outlook.[20]

We assume that the steady-state ratio of capital to oil in the manufacturing production K_m/O is 600. Accordingly, the parameter related to the weight of oil in the manufacturing production a is 0.0001, which is determined by ν, K_m/O, β and δ. We set the steady-state weight of oil consumption in the aggregate consumption γ_0 to 0.038, which is consistent with the average relative importance of oil in the U.S. CPI from 1995 to 2009 (3.8%), according to

Table 1: Calibrated parameter values for the pre-shale boom period

Definition	Parameter	Values
Discount factor	β	0.99
Depreciation rate of capital	δ	0.025
Labor share of income in the manufacturing sector	$1-\alpha$	0.67
Labor share of income in the oil sector	$1-\alpha_o$	0.68
Relative number of households in country A	n_A	0.27
Relative number of households in country B	n_B	0.6
Relative number of households in country C	n_C	0.13
Parameter related to the weight of oil in the manufacturing production	a	0.0001
Steady-state weight of oil consumption in aggregate consumption	γ_0	0.038
Steady-state weight of imported manufactures in the manu. consumption in country A	γ_1	0.135
Steady-state weight of imported manu. from country B in the manu. consumption in country A	$\gamma_{1,B}$	0.11
Steady-state weight of imported manu. from country C in the manu. consumption in country A	$\gamma_{1,C}$	0.02
Fraction of imported oil in consumption and production in countries A and B	γ_2	0.85
Degree of price stickiness in the oil sector	θ_o	0

[19] As we assume that α is 0.33 in all countries, that steady-state trade balance in the three countries is zero, and that steady-state aggregate consumption, aggregate labor, and wages in all sectors are equal in all countries, the value of α_o is determined to be 0.32.

[20] During this period, these ratios were 0.27, 0.6, and 0.13, respectively.

data from the U.S. Bureau of Labor Statistics (BLS).[21] The steady-state weight of imported manufactures in the manufacturing consumption in country A γ_1 is set to 0.135. The weight of imported manufactures from countries B and C in the manufacturing consumption in country A ($\gamma_{1,B}$ and $\gamma_{1,C}$, respectively) are 0.11 and 0.02, respectively. The steady-state fraction of imported oil in oil consumption and oil input in countries A and B γ_2 is set to 0.85.[22] Considering oil prices are highly flexible, we assume that the degree of price stickiness in the oil sector is zero (i.e., $\theta_o = 0$).

Under these parameter values, the steady-state ratio of oil output to GDP, Y_o/Y, is 1%, the steady-state ratio of oil expenditures to GDP, $(C_o + O)/Y$, is 4%, and the steady-state import share, IMP/Y, is 14%. These ratios are consistent with U.S. data. Specifically, from 1995 to 2009, the average ratio of oil output to gross output in the U.S., based on U.S. Bureau of Economic Analysis (BEA) data, was about 1%; the average ratio of oil expenditures to GDP, based on EIA data, was about 4%; and the average ratio of import value to GDP, based on World Bank data, was about 14%.[23]

Estimated parameters. The remaining parameters are estimated using the IRF matching approach of Christiano, Eichenbaum, and Evans (2005). Let $\hat{\Psi}$ be the empirical IRFs from the SVAR models. We then choose values of parameters, $\boldsymbol{\theta}$, so that the distance between the model IRFs, $\Psi(\boldsymbol{\theta})$, and $\hat{\Psi}$ is as close as possible. We have six empirical IRFs of interest: output of the U.S., oil exporters, and oil importers; U.S. trade balance and terms of trade; and export value of oil exporters to an oil supply shock. Each IRF has 13 elements.[24] Our estimator of $\boldsymbol{\theta}$ can be found by solving the following minimization problem:

$$\min_{\boldsymbol{\theta}} \left[\hat{\Psi} - \Psi(\boldsymbol{\theta})\right]' V^{-1} \left[\hat{\Psi} - \Psi(\boldsymbol{\theta})\right],$$

where V^{-1} is the weighting matrix.[25]

The parameter estimates are reported in Table 2. Specifically, the degree of habit formation in consumption, b, and the inverse of Frisch elasticity of labor supply, χ, are estimated to be 0.48 and 1.93, respectively, which are in the range of values used in previous studies.

[21] In the BLS data, we consider fuel oil, other fuels, and motor fuel as oil.

[22] Note that the steady-state weights of manufacturing goods produced in the three countries in manufacturing consumption in countries B and C are different due to the assumption that the steady-state values of aggregate consumption in all countries are equal and that the steady-state trade balance is zero. Specifically, γ_1^B, $\gamma_{1,A}^B$, $\gamma_{1,C}^B$, γ_1^C, $\gamma_{1,A}^C$, and $\gamma_{1,B}^C$ are 0.06, 0.135, 0.05, 0.085, 0.758, 0.148, and 0.61, respectively.

[23] We use output in the oil and gas extraction sector as oil output in the BEA data.

[24] Unlike the previous section, where one period corresponds to one month, one period in the model corresponds to one quarter. For IRF matching, we sum the monthly empirical IRFs of U.S. terms of trade and average the monthly empirical IRFs of the other five variables.

[25] We use a diagonal matrix for V^{-1} in which the diagonal elements corresponding to the IRFs of output are 10 and other diagonal elements are 1, since the IRFs of output in the three groups of countries are our main interest.

Our estimate of the elasticity of substitution between oil and manufactures in consumption, η_0, is 0.6, which means that it is difficult to substitute between oil and manufactures. The elasticity of substitution between domestic and foreign manufactures in consumption, η_1, is estimated to be 0.8, which is slightly smaller than the values from related studies (i.e., 0.8 to 2). The estimate of the elasticity of substitution between oil in consumption, η_2, is very high (45), which is consistent with the intuition that the substitutability between oil produced in different places is very high.

The parameters related to the bond holding costs and investment adjustment costs, ζ and ϕ, are estimated to be 0.18 and 4.15, respectively. The parameter related to the elasticity of substitution between oil and capital in production, ν, is estimated to be 0.99, which implies that the elasticity of substitution between oil and capital in production (ς) is 0.5. This value for ν is slightly higher than that used in existing studies such as Kim and Loungani (1992) and Kim (2022) (0.7). Our estimate of the degree of price stickiness in the manufacturing sector, θ_m, is 0.39, which is lower than that often used in the literature (0.75). The next three parameters are associated with the Taylor rule. The interest rate smoothing parameter, ρ_r, is estimated at 0.54, and the inflation and output coefficients, ϕ_π and ϕ_y, are estimated at 1.77 and 0, respectively. Finally, the persistence parameters of the shocks to intermediate oil production in the three countries, ρ, ρ^B, and ρ^C, are estimated to be 0.9, the estimates of the parameters for shock spillovers from country C to countries A and B, υ_C^A and υ_C^B, are 0.01 and 0, respectively, and the parameter for the standard deviation of the shocks in country C, σ^C, is estimated to be 1.4%. Note that since we consider a negative shock to intermediate oil production in the oil exporter (country C) as an oil supply shock, we do not estimate the parameters for the standard deviations of the shocks in countries A and B, σ and σ^B, and

Table 2: Estimated parameter values for the pre-shale boom period

Parameter	b	χ	η_0	η_1	η_2	ζ
Estimate	0.48	1.93	0.6	0.8	45	0.18
Standard error	(0.51)	(0.49)	(0.59)	(0.60)	(249)	(0.22)
Parameter	ϕ	ν	θ_m	ρ_r	ϕ_π	ϕ_y
Estimate	4.15	0.99	0.39	0.54	1.77	0.0
Standard error	(2.11)	(0.30)	(1.35)	(3.30)	(28.3)	(6.43)
Parameter	ρ	ρ^B	ρ^C	υ_C^A	υ_C^B	σ^C
Estimate	0.9	0.9	0.9	0.01	0.0	1.4
Standard error	(0.12)	(6317)	(0.02)	(0.0)	(0.0)	(0.25)

Note: Estimate of σ^C is expressed in percentages.

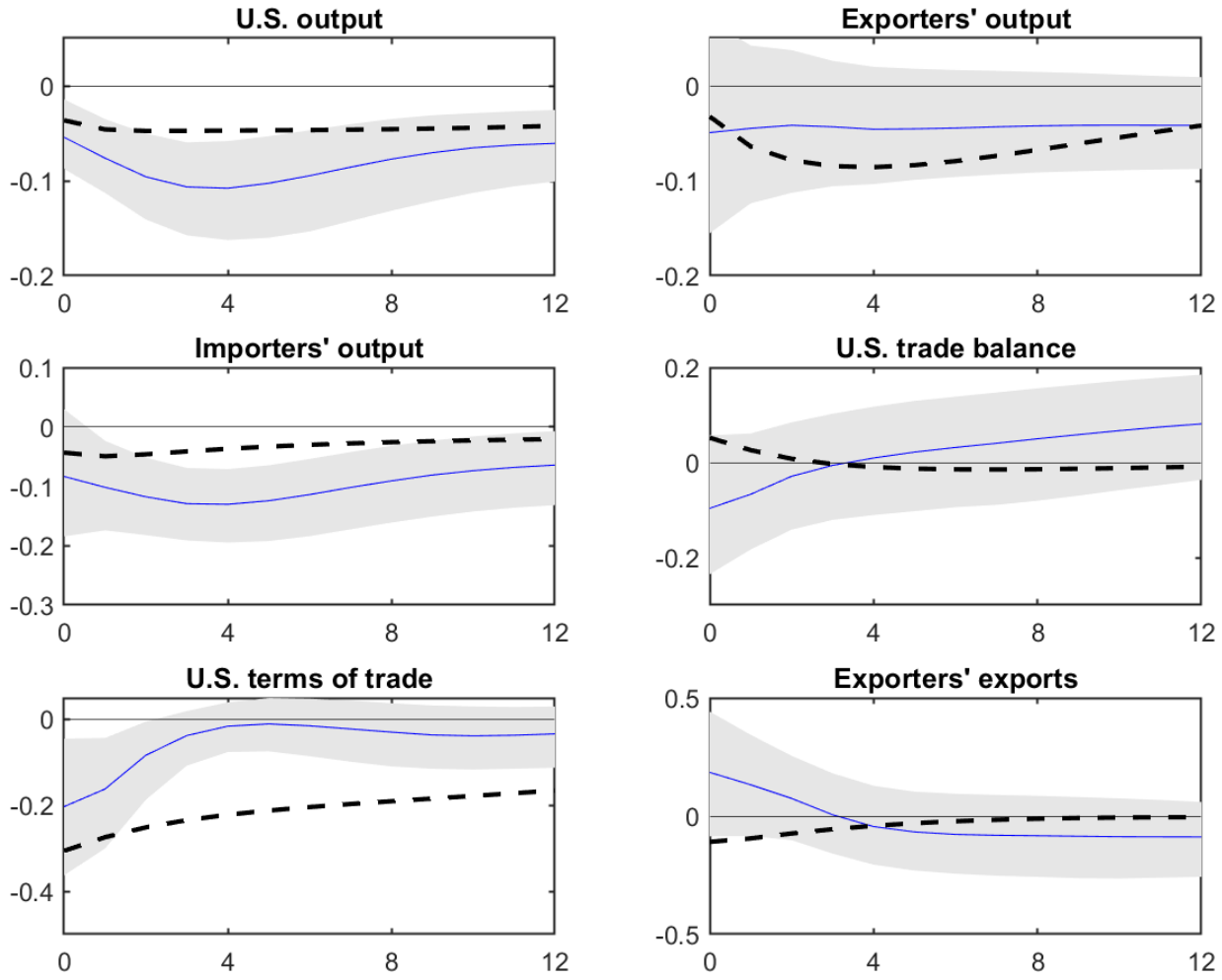
the parameters for shock spillovers from countries A and B, υ_A^B, υ_A^C, υ_B^A, and υ_B^C.

Figure 4 shows the empirical and model IRFs of three countries' output, the U.S. trade balance and terms of trade, and the export value of the oil exporter to an oil supply shock. Overall, the model IRFs capture the empirical IRFs quite well. All of the model IRFs fall within the 68% highest posterior density sets of the empirical IRFs at most horizons, except for the IRF of U.S. terms of trade, which is below the density set after the second quarter.

3.5.2 Parameter values for the post-shale boom period

As explained above, we regard reduced U.S. dependence on oil imports and U.S. oil exports to other countries as the two main features of the post-shale boom period. Therefore, we assume that in the post-shale boom period, the steady-state value of U.S. net oil imports is

Figure 4: Empirical and model IRFs to an oil supply shock



Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses of the SVAR model. The dashed lines are the impulse responses of the model. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

much smaller and the U.S. can export oil to the non-U.S. oil importer (country B).

Specifically, average U.S. net oil imports in the post-shale boom period fell by about 40% compared to the pre-shale boom period.[26] Therefore, we assume that the parameter γ_2 for the U.S., which determines the steady-state U.S. net oil imports, decreases from 0.85 (pre-shale boom period) to 0.54 (post-shale boom period). However, γ_2 for country B (γ_2^B) remains at 0.85. Since the U.S. can export oil to country B in the post-shale boom period, we need to set the parameter values associated with the steady-state ratio of imported oil from the U.S. to total oil imports in country B ($\gamma_{2,A}^B/\gamma_2^B$), which is included in country B's oil consumption and oil input in production. We assume that $\gamma_{2,A}^B/\gamma_2^B$ is 0.016, which is consistent with the average ratio of U.S. oil exports to importers' total oil imports during 2010–2020 from EIA data (about 1.6%). The primary distinction between the two periods' parameter values is outlined in Table 3.

Finally, it should be noted that we do not estimate the remaining parameters using IRF matching for the post-shale boom period. Rather, we use the same values for these parameters in the post-shale boom period as in the pre-shale boom period.[27] This is because our main goal in this study is to examine whether the two main features of the post-shale boom can explain the changes in the effects of oil supply shocks on the U.S. and oil exporters and importers in the two periods. Therefore, if we estimate the remaining parameters for the post-shale boom period, their values will be different from those for the pre-shale boom period. In this case, it would be difficult to identify whether the two main features lead to the changes in the effects between the two periods.

Table 3: Parameter values for the post-shale boom period

Definition	Parameter	Pre-shale boom	Post-shale boom	Description
Steady-state weight of imported oil in oil consumption and input in the U.S.	γ_2	0.85	0.54	Reduced U.S. dependence on oil imports
Steady-state weight of imported oil from the U.S. in oil consumption and input in country B	$\gamma_{2,A}^B$	0	0.014	Lifting of the U.S. oil export ban
α_o^A, $\gamma_{1,B}$, $\gamma_{1,C}$, $\gamma_{1,A}^C$, $\gamma_{1,B}^C$, $\gamma_{1,C}^C$, and $\gamma_{2,C}^B$ change slightly.				
The values of the other parameters remain the same across both periods.				

[26] According to EIA data, average U.S. net imports of crude oil were about 9,063 thousand barrels per day during the 1995–2009 period and about 5,668 thousand barrels per day during the 2010–2024 period.

[27] In fact, as γ_2 for the U.S. in the post-shale boom period decreases, some parameter values, such as the steady-state weights of manufacturing goods produced in the three countries in the manufacturing consumption in countries A, B, and C, slightly change.

4 Results

In this section, we analyze the impact of an oil supply shock, a negative shock to intermediate oil production in the oil exporter (country C), on the U.S. (country A), the non-U.S. oil importer (country B), and the oil exporter, using the simulation results of the model. We first show the negative impact of the shock on the U.S. in the post-shale boom period is weaker than in the pre-shale boom period. Then, we demonstrate that the shock's impact on the oil exporter is amplified in the latter period. Finally, we show that the impact of the shock on the oil importer remains nearly unchanged in both periods.

4.1 Dampened impact of an oil supply shock on the U.S.

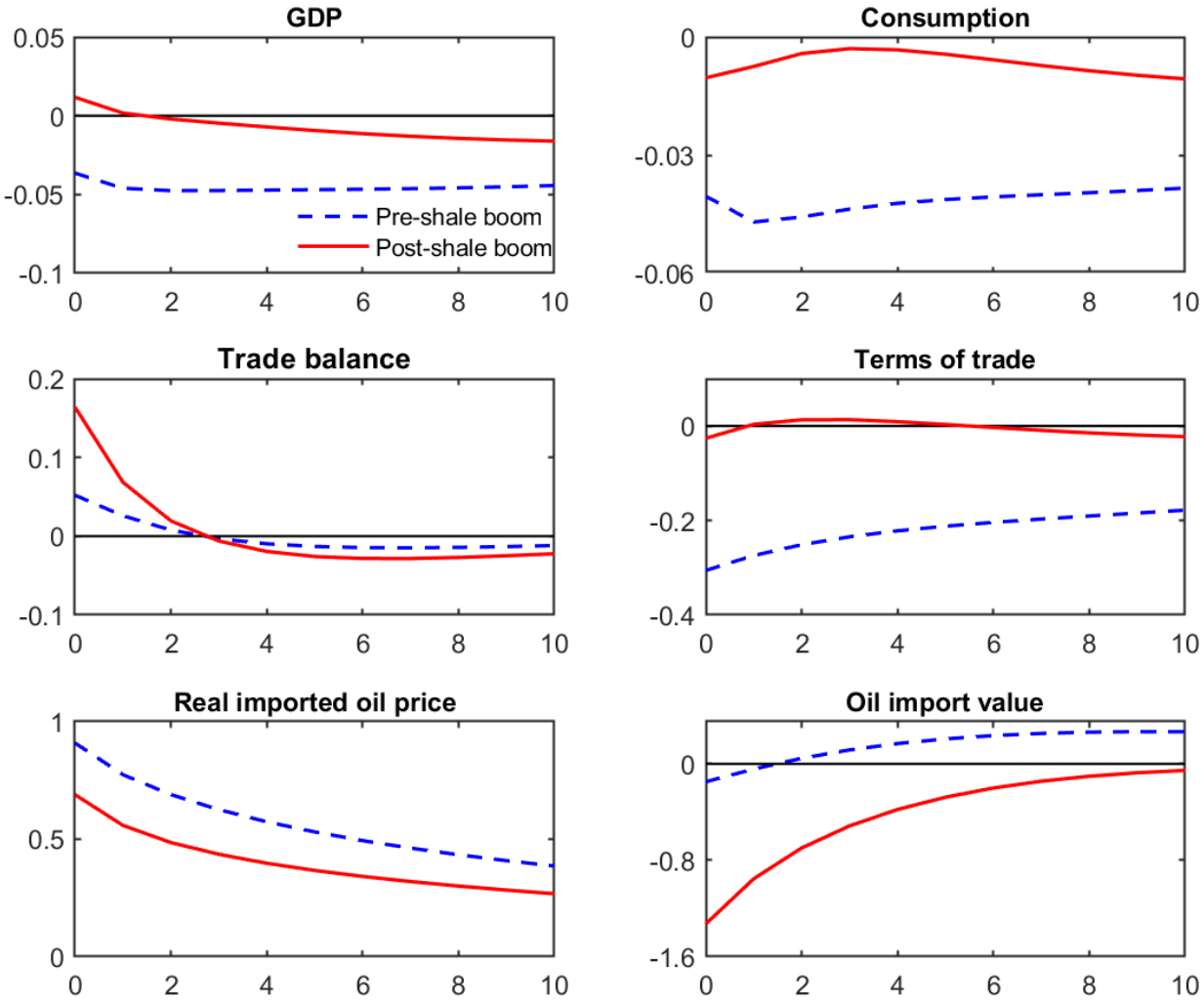
The responses of U.S. variables to an oil supply shock, a negative one-standard-deviation shock to $\ln \psi_t^C$, in the two periods are shown in Figure 5. To be specific, the shock increases the U.S. real imported oil price in both periods. U.S. GDP falls in response to the shock in the pre-shale boom period, but increases for the first quarter in the latter period. This is mainly because consumption decreases much less and the trade balance increases more in the latter period than in the former.

To explain, since the U.S. is much less dependent on oil imports in the post-shale boom period than in the pre-shale boom period, the weight of the imported oil price in the U.S. import price is much lower in the latter period. Consequently, a rise in the oil price results in a far smaller decline in the terms of trade in the post-shale period than in the pre-shale boom period. This implies that the market value of U.S. output decreases less in the post-shale boom period, and therefore its income falls less. As a result, U.S. consumption also declines by a smaller amount during this period.

Since the oil supply shock originates from the oil exporter, the real price of oil produced in the U.S. increases by a smaller amount in response to the shock than the real price of imported oil. In other words, the real price of U.S.-produced oil becomes relatively cheap. Furthermore, the U.S. can export oil to country B in the post-shale boom period thanks to the lifting of the U.S. oil export ban. Hence, U.S. oil exports to country B increase in the latter period. In addition, the quantity of U.S. oil imports decreases more in the latter period due to the reduced dependence on oil imports and the relatively lower price of U.S. oil, so the real price of imported oil in the U.S. increases less in the post-shale boom period. The real value of U.S. oil imports decreases much more in the latter period. Consequently, the U.S. trade balance increases more in the post-shale boom period than in the pre-shale boom period in response to the shock.

In summary, the simulation results indicate that the negative impact of an oil supply

Figure 5: Responses of U.S. variables to an oil supply shock



Note: The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

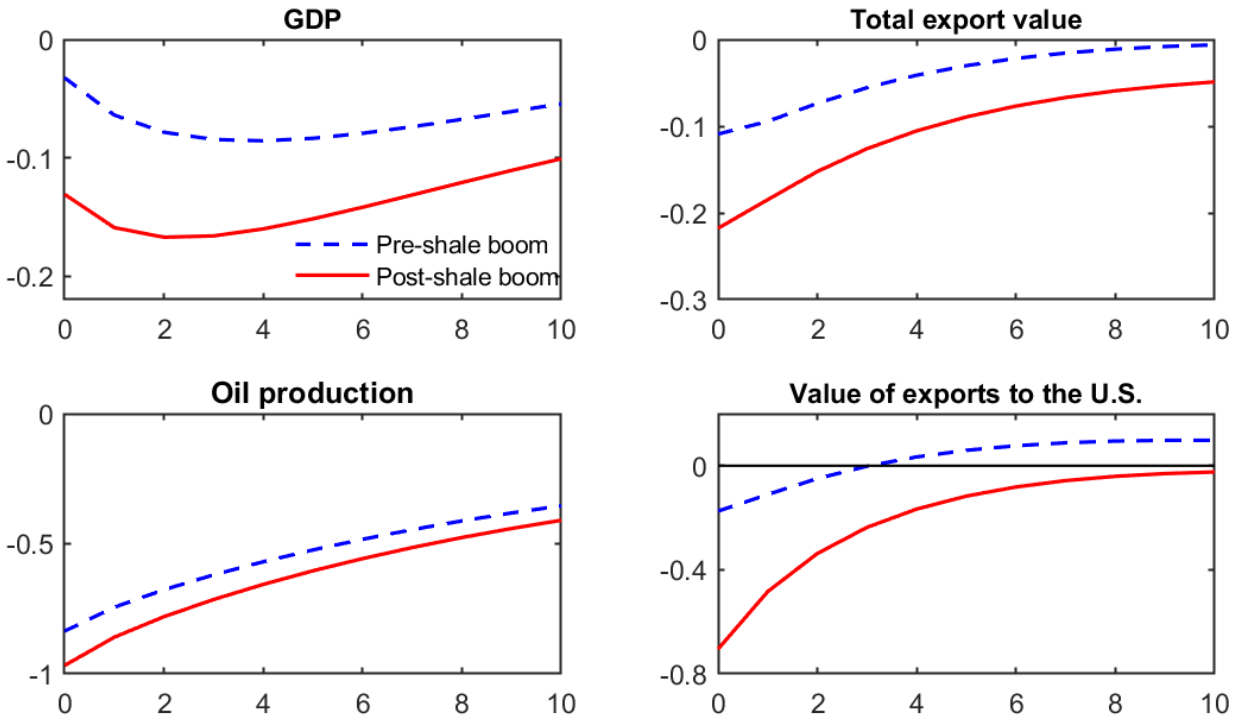
shock on the U.S. is much weaker in the post-shale boom period than in the pre-shale boom period. This is mainly due to the U.S.'s reduced dependence on oil imports and the lifting of the oil export ban resulting from the shale boom.

4.2 Strengthened impact of an oil supply shock on the oil exporter

Figure 6 shows how some variables in the oil exporter (country C) respond to an oil supply shock. The shock reduces the oil exporter's GDP more in the post-shale boom period than in the pre-shale boom period because the real value of total exports and oil production decrease more in response to the shock in the latter period.

Since the U.S. imports less oil due to reduced dependence on oil imports in the post-shale boom period, the real export value of the oil exporter to the U.S. decreases more in

Figure 6: Responses of the oil exporter's variables to an oil supply shock



Note: The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

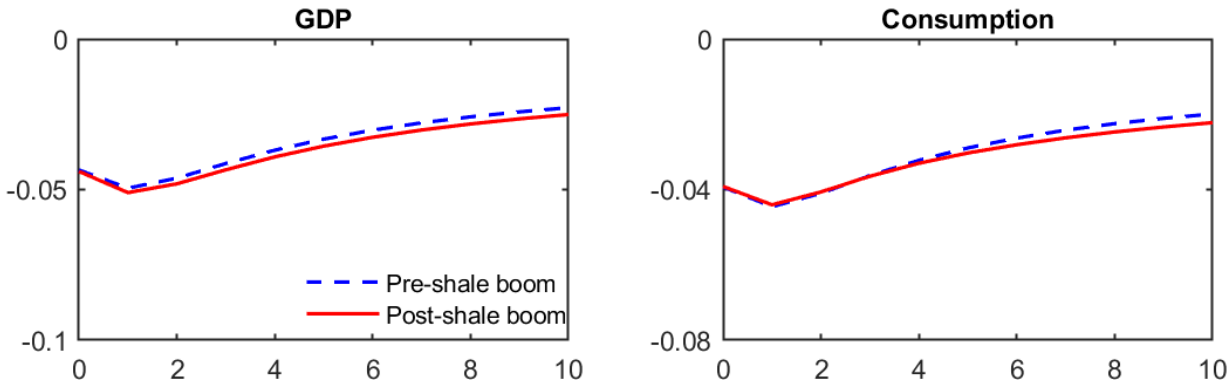
the latter period than in the former. Consequently, the real value of the oil exporter's total exports decreases significantly more in the post-shale boom period than in the pre-shale boom period, resulting in a greater reduction in oil production in the post-shale boom period.

In a nutshell, the model simulation shows that oil supply shocks have a stronger adverse impact on the oil exporter in the post-shale boom period than in the pre-shale boom period. This is primarily because the U.S. imports less oil from the exporter due to reduced dependence on oil imports thanks to the shale boom.

4.3 Nearly unchanged impact of an oil supply shock on the oil importer

We now present the responses of the variables of the oil importer to an oil supply shock in Figure 7. The negative impact of the shock is nearly identical in the pre- and post-shale boom periods, as in the empirical evidence in Section 2.

Figure 7: Responses of the oil importer's variables to an oil supply shock



Note: The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

5 Model extensions

In this section, we consider two extensions of the model. First, we examine dollar pricing (DP) in international oil trade, which is the clearest example of DP. Then, unlike in the previous section in which oil is not used in oil production, we assume that oil production requires the use of oil as an input.

5.1 Dollar pricing in international oil trade

Until now, it is assumed that all firms in the model use producer currency pricing (PCP). In other words, firms set all prices in their own currency. However, many recent studies have emphasized that most international trade transactions are invoiced in U.S. dollars (i.e., DP).[28] Since the international oil trade is the most evident example of DP, we assume that firms in the U.S. and the oil importer use PCP. Meanwhile, firms in the oil sector of the oil exporter set export prices in U.S. dollars and domestic prices in their local currency. Under this assumption, since the oil exporter is the only one, which exports oil, in the pre-shale boom period, and since the oil exporter and the U.S. export oil in the post-shale boom period, all international oil trades are invoiced in U.S. dollars, even when the U.S. is not involved in oil trade.

Under DP in international oil trade, the pricing of firms in the oil sector of the oil exporter changes, while the pricing of the other firms remains the same as in the previous section.

[28] Gopinath and Rigobon (2008) find that, from 1994 to 2005, 90% of U.S. imports and 97% of exports were priced in U.S. dollars. Gopinath (2015) shows that, from 1990 to 2014, 71% of Japanese imports and 60% of Turkish imports were invoiced in U.S. dollars. Gopinath, Boz, Casas, and Díez (2020) document that, from 2005 to 2015, 98% of Colombian exports were priced in U.S. dollars. More recent studies include Mukhin (2022), Chen, Chung, and Novy (2022), Amiti, Itskhoki, and Konings (2022), Kim (2023), and Egorov and Mukhin (2023).

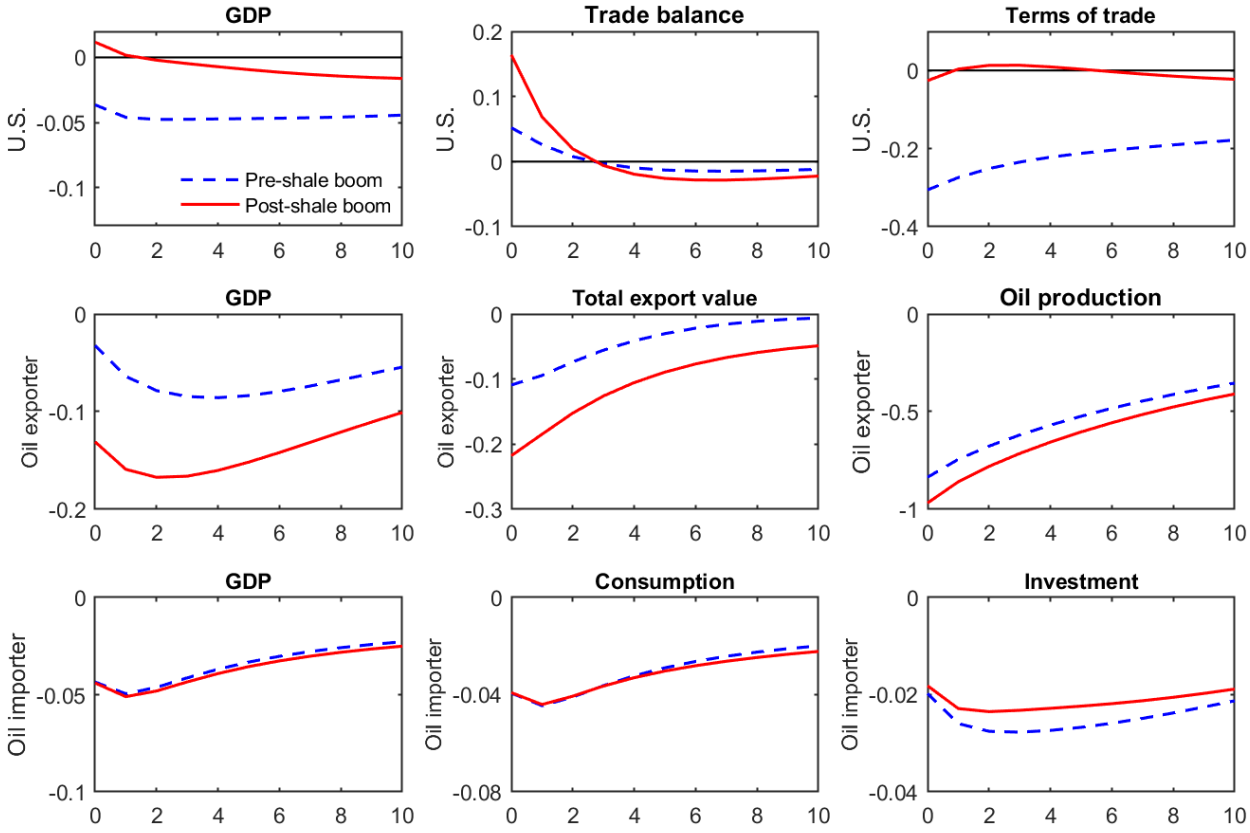
Specifically, a typical firm in the oil sector in country C, i_o^C, maximizes the following expected present discounted value of its profits:

$$\mathbb{E}_t \sum_{h=0}^{\infty} (\beta\theta_o)^h \frac{\lambda_{t+h}^C}{\lambda_t^C} \left[n^C \frac{P_{o,C,t}^C(i_o^C)}{P_{t+h}^C} D_{o,t+h}^C(i_o^C) + \frac{P_{o,C,t}(i_o^C)}{P_{t+h}^C S_{t+h}^C} \left(n^A X_{o,t+h}(i_o^C) + n^B X_{o,t+h}^B(i_o^C) \right) - mc_{o,t+h}^C n^C Y_{o,t+h}^C(i_o^C) \right],$$

where λ_t^C is the Lagrange multiplier on the household budget constraint. $D_{o,t}^C(i_o^C)$, $X_{o,t}(i_o^C)$, and $X_{o,t}^B(i_o^C)$ are the oil produced for the domestic, U.S., and oil importer markets, respectively. $P_{o,C,t}^C(i_o^C)$, $P_{o,C,t}(i_o^C)$, and P_t^C denote the nominal price of the firm's oil in country C, the nominal price of the firm's oil in the U.S. (expressed in U.S. dollars), and the CPI in country C, respectively. S_t^C denotes the oil exporter's nominal exchange rate against the U.S., and $mc_{o,t}^C$ is the real marginal cost deflated by the CPI.

Figure 8 shows how several variables in the model under DP in international oil trade respond to an oil supply shock. The variables' responses are very similar to those in the

Figure 8: Responses of the model under DP in oil trade to an oil supply shock



Note: The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

previous section, although the magnitudes of the responses differ slightly. In short, our main results remain the same even when we assume DP in oil trade.

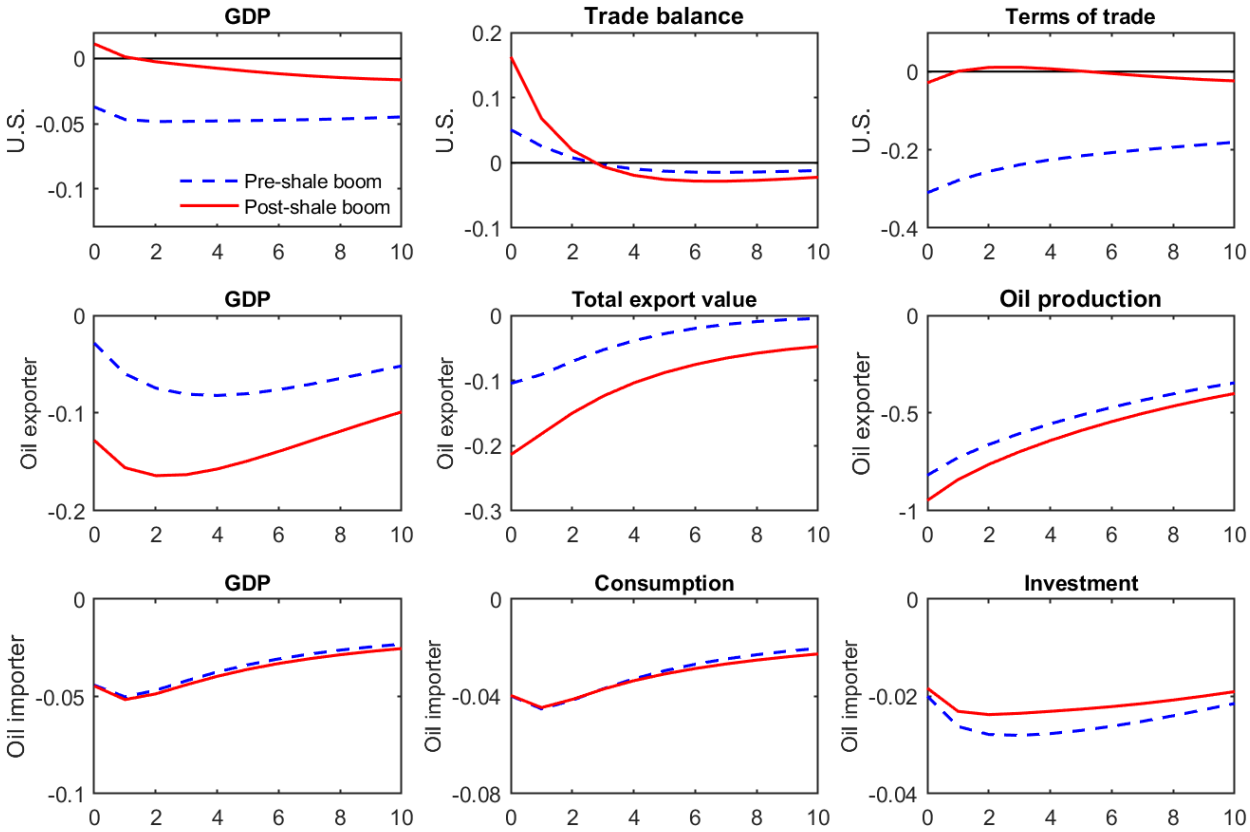
5.2 Oil input in oil production

So far, we have assumed that oil is not used in oil production. However, it is more reasonable and plausible to assume that oil is used as an input in oil production. Therefore, we assume that the production function of intermediate oil producers includes an oil input. Specifically, the form of their production function is the same as that of intermediate manufacturing goods producers (nested CES):

$$Y_{o,t}(i_o) = A_{o,t}\left\{(1-a_o)K_{o,t}(i_o)^{-\nu_o} + a_o O_{o,t}(i_o)^{-\nu}\right\}^{-\frac{\alpha_o}{\nu_o}} N_{o,t}(i_o)^{1-\alpha_o} + \ln\psi_t,$$

where $O_{o,t}(i_o)$ is the oil input of firm i_o. The oil input is defined in the same way as in the production of intermediate manufacturing goods. For simplicity, we assume that the parameters related to the weight of oil (a_o) and the elasticity of substitution between oil and

Figure 9: Responses of the model with oil input in oil production to an oil supply shock



Note: The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of quarters after the shock.

capital (ν_o) have the same values as those in the production of intermediate manufacturing goods.

Figure 9 presents the responses of several variables in the model with oil input in oil production to an oil supply shock. There are no notable differences between the responses of the model in the previous section and the model with oil input in oil production. In other words, our main results hold true even when oil is used as an input in oil production, unlike in the previous section.

6 Conclusion

In this study, we examine the differences in the effects of oil supply shocks on the U.S., oil importers, and oil exporters in pre- and post-shale boom periods. Using SVAR models, we first empirically show that, across the two periods, there are significant differences in the effects of oil supply shocks on the U.S. and oil exporters, but no notable differences on oil importers. Specifically, in the post-shale boom period, the adverse impact of the shocks on the U.S. is dampened, while the negative influence on oil exporters tends to be amplified. The impact of the shocks on oil importers is similar in both periods. Next, we construct a three-country model consisting of the U.S., a non-U.S. oil importer, and an oil exporter. According to the model simulation results, consistent with the empirical evidence, oil supply shocks have a weaker negative influence on the U.S. and a stronger adverse impact on the oil exporter in the post-shale boom period. Meanwhile, the shocks have a similar impact on the non-U.S. oil importer in both periods.

Finally, it should be noted that this study does not consider the international transmission of monetary and fiscal policies. Our focus is solely on the transmission of oil supply shocks. Hence, it would be interesting to analyze whether the international transmission of U.S. monetary and fiscal policies differs between the pre- and post-shale boom periods. Additionally, our analysis is limited to asymmetries in oil production and trade structures, country sizes, and export pricing. Adding other asymmetries to the model in this paper, such as asymmetric demographic structures, as in Kim (2024b), as well as the valuation channel highlighted by Ghironi, Lee, and Rebucci (2015), would allow for a richer analysis. However, considering these issues is beyond the scope of this paper, so we leave them for future research.

References

Allcott, H. and D. Keniston (2018). Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America. *Review of Economic Studies 85(2)*, 695–731.

Amiti, M., O. Itskhoki, and J. Konings (2022). Dominant currencies: How firms choose currency invoicing and why it matters. *Quarterly Journal of Economics 137(3)*, 1435–1493.

Antolín-Díaz, J. and J. F. Rubio-Ramírez (2018). Narrative sign restrictions for SVARs. *American Economic Review 108(10)*, 2802–2829.

Backus, D. K. and M. J. Crucini (2000). Oil prices and the terms of trade. *Journal of International Economics 50*, 185–213.

Baumeister, C. and J. D. Hamilton (2019). Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks. *American Economic Review 109(5)*, 1873–1910.

Baumeister, C. and G. Peersman (2013). Time-varying effects of oil supply shocks on the US economy. *American Economic Journal: Macroeconomics 5*, 1–28.

Bjørnland, H. C. and J. Skretting (2024). The shale oil boom and the US economy: Spillovers and time-varying effects. *Journal of Applied Econometrics 39(6)*, 1000–1020.

Blanchard, O. J. and J. Galí (2010). The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? *International Dimensions of Monetary Policy*, edited by Jordi Galí and Mark J. Gertler, University of Chicago Press, 373–421.

Bodenstein, M., C. J. Erceg, and L. Guerrieri (2011). Oil shocks and external adjustment. *Journal of International Economics 83*, 168–184.

Bornstein, G., P. Krusell, and S. Rebelo (2023). A world equilibrium model of the oil market. *Review of Economic Studies 90(1)*, 132–164.

Chen, N., W. Chung, and D. Novy (2022). Vehicle currency pricing and exchange rate pass-through. *Journal of the European Economic Association 20(1)*, 312–351.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113(1)*, 1–45.

Egorov, K. and D. Mukhin (2023). Optimal policy under dollar pricing. *American Economic Review 113(7)*, 1783–1824.

Feyrer, J., E. T. Mansur, and B. Sacerdote (2017). Geographic dispersion of economic shocks: Evidence from the fracking revolution. *American Economic Review 107(4)*, 1313–1334.

Ghironi, F., J. Lee, and A. Rebucci (2015). The valuation channel of external adjustment. *Journal of International Money and Finance 57*, 86–114.

Gopinath, G. (2015). The international price system. *NBER Working Paper 21646*.

Gopinath, G., E. Boz, C. Casas, and F. J. Díez (2020). Dominant currency paradigm. *American Economic Review 110*, 677–719.

Gopinath, G. and R. Rigobon (2008). Sticky borders. *Quarterly Journal of Economics 123*, 531–575.

Katayama, M. (2013). Declining effects of oil price shocks. *Journal of Money, Credit and Banking 45*, 977–1016.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review 99*, 1053–1069.

Kilian, L. (2016). The impact of the shale oil revolution on U.S. oil and gasoline prices. *Review of Environmental Economics and Policy 10(2)*, 185–205.

Kilian, L., A. Rebucci, and N. Spatafora (2009). Oil shocks and external balances. *Journal International Economics 77(2)*, 181–194.

Kim, I. and P. Loungani (1992). The role of energy in real business cycle models. *Journal of Monetary Economics 29*, 173–189.

Kim, M. (2020). How the financial market can dampen the effects of commodity price shocks. *European Economic Review 121*, 103340.

Kim, M. (2022). Transmission of U.S. monetary policy to commodity exporters and importers. *Review of Economic Dynamics 43*, 152–167.

Kim, M. (2023). Gains from monetary policy cooperation under asymmetric currency pricing. *European Economic Review 151*, 104357.

Kim, M. (2024a). Energy and international business cycles. *Macroeconomic Dynamics 28(2)*, 325–344.

Kim, M. (2024b). Population aging and international monetary transmission. *Journal of Money, Credit and Banking 56(1)*, 279–304.

Kim, M. (2025). U.S. shale oil boom, terms of trade, and net exports. Unpublished manuscript.

Melek, N., M. Plante, and M. Yücel (2021). Resource booms and the macroeconomy: The case of U.S. shale oil. *Review of Economic Dynamics 42*, 307–332.

Mănescu, C. B. and G. Nuño (2015). Quantitative effects of the shale oil revolution. *Energy Policy 86*, 855–866.

Mukhin, D. (2022). An equilibrium model of the international price system. *American Economic Review 112(2)*, 650–688.

Peersman, G. and I. Van Robays (2012). Cross-country differences in the effects of oil shocks. *Energy Economics 34*, 1532–1547.

Schmitt-Grohé, S. and M. Uribe (2003). Closing small open economy models. *Journal of International Economics 61*, 163–185.

Online Appendix for "How the U.S. Shale Boom Has Changed the Impact of Oil Supply Shocks"

Myunghyun Kim[a] Sanha Noh[b] Christopher Otrok[c]

Not for Publication

This appendix contains:

A. IRF of industrial production in each country

B. IRFs to an oil supply shock, excluding the periods of the global financial crisis and COVID-19 pendamic

C. SVAR models with traditional and narrative sign restrictions

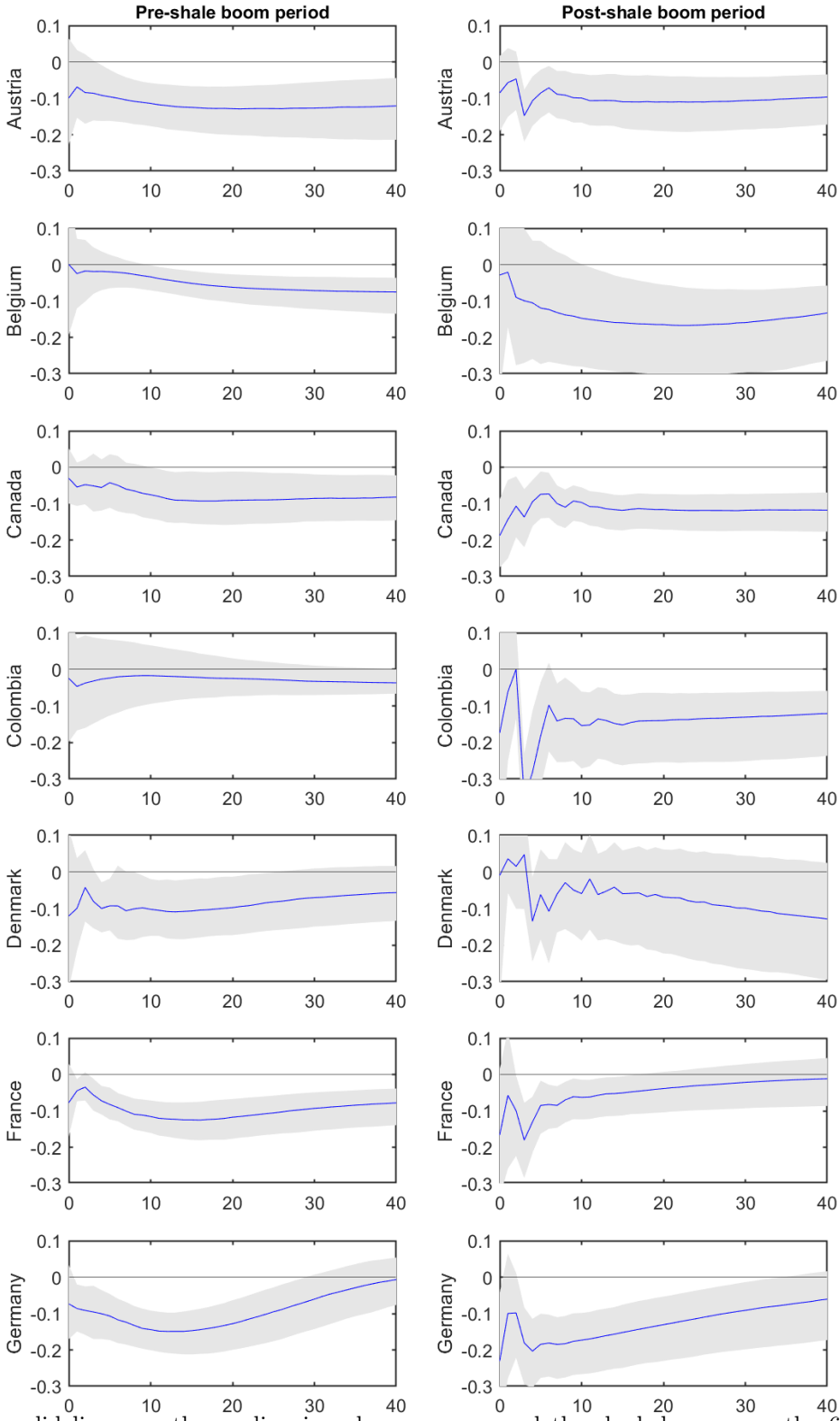
D. Equilibrium conditions of the model

[a] Department of Economics, Sungkyunkwan University, Republic of Korea (e-mail: mhkim7812@gmail.com).

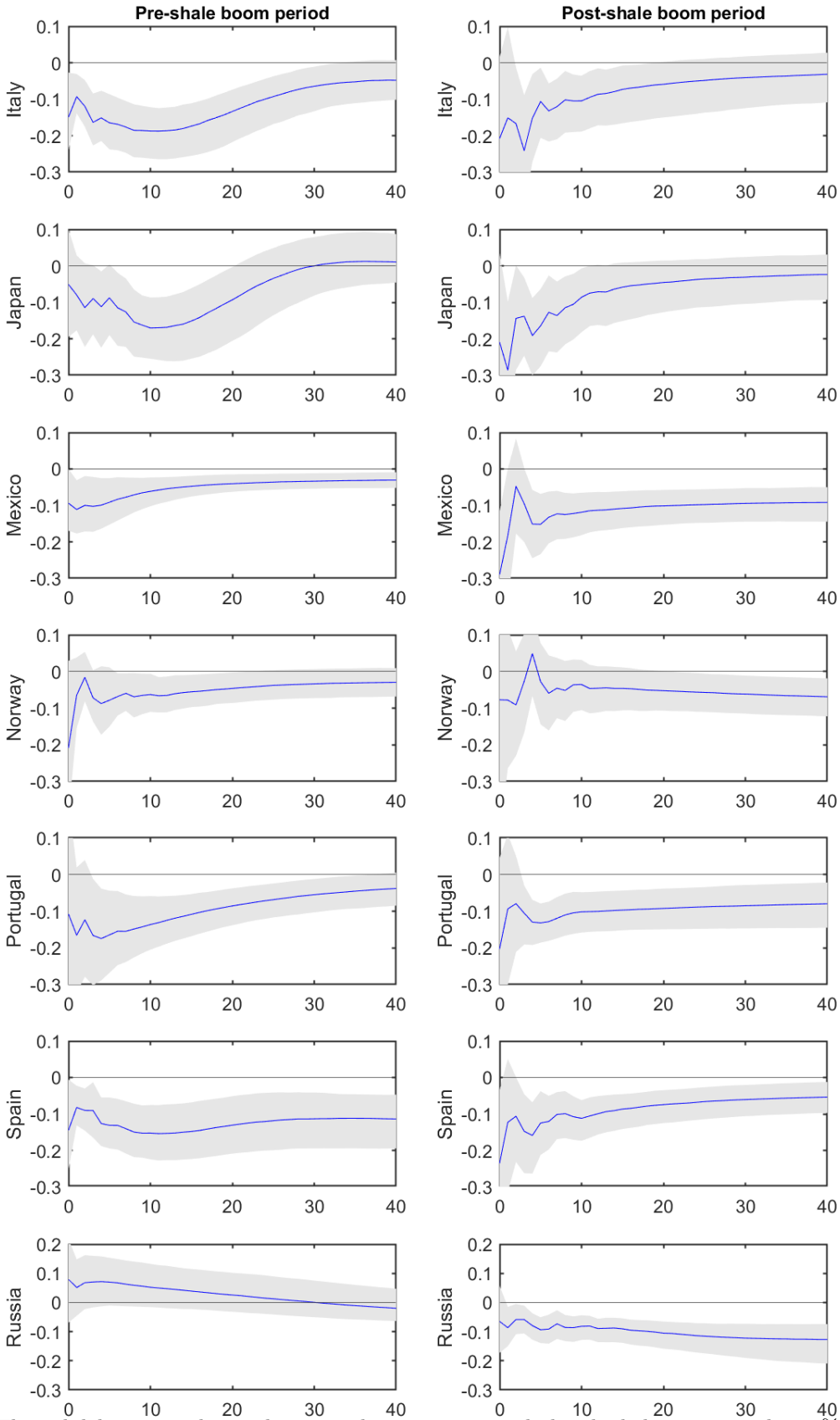
[b] Department of Economics, Jeonbuk National University, Republic of Korea (e-mail: brownians84@jbnu.ac.kr).

[c] Research Department, Federal Reserve Bank of Dallas, United States (e-mail: chris.otrok@dal.frb.org).

A IRF of industrial production in each country



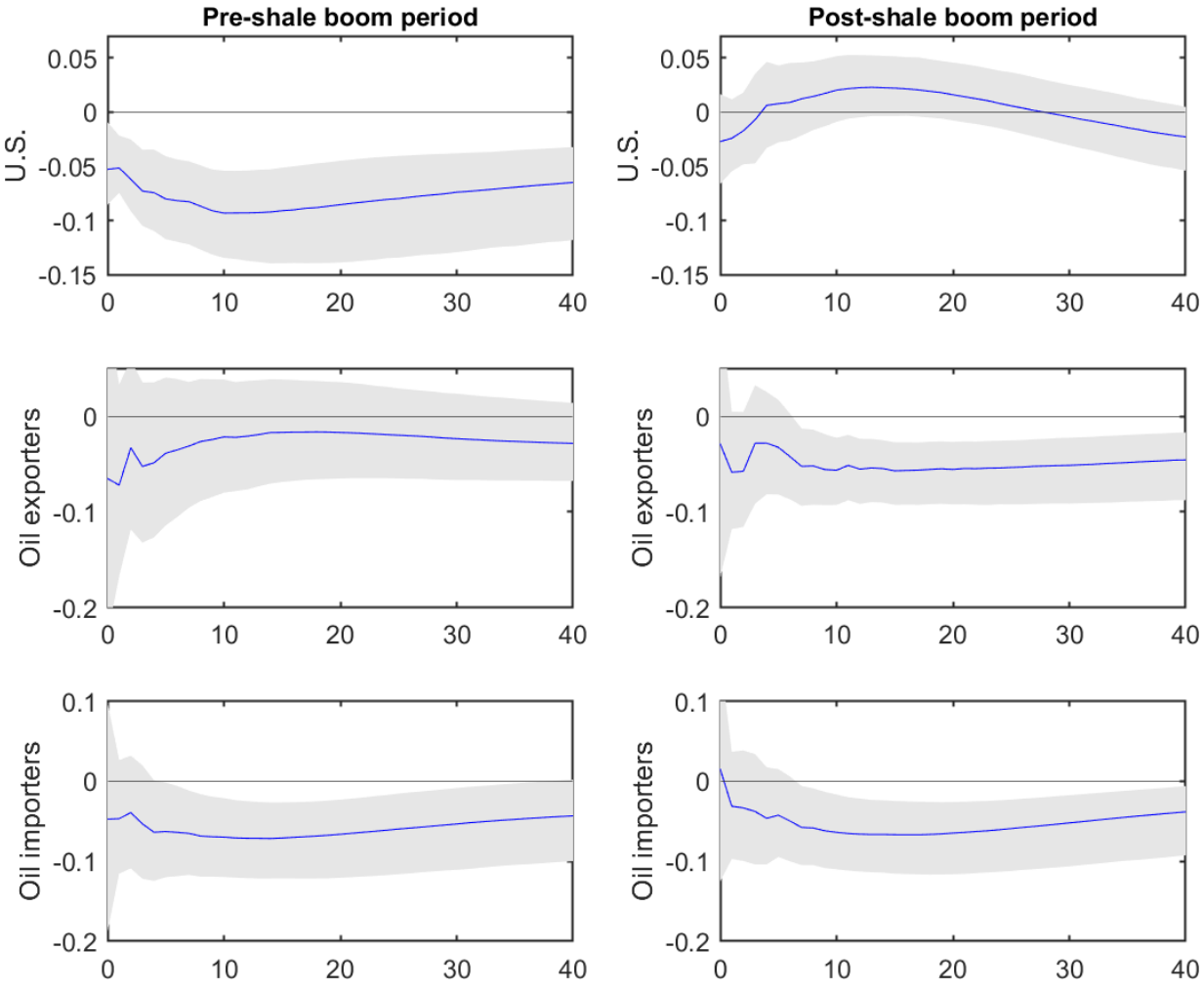
Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.



Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.

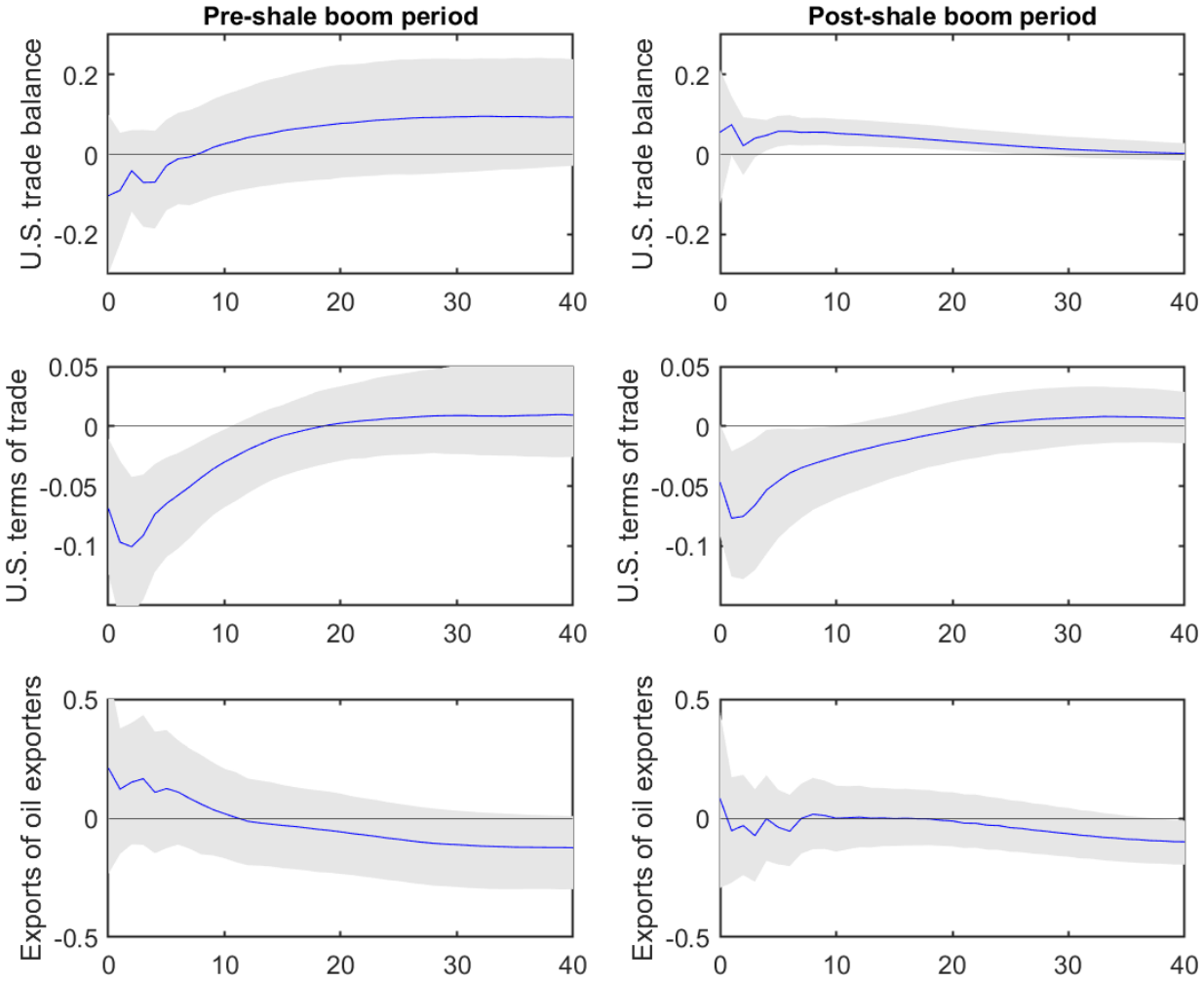
B IRFs to an oil supply shock, excluding the periods of the global financial crisis and COVID-19 pandemic

Figure B.1: IRFs of industrial production to an oil supply shock



Notes: The solid lines are median impulse responses and the shaded areas are the 68% highest posterior density credible sets for impulse responses. The units on the x-axes are months. The units on the y-axes are in percent.

Figure B.2: IRFs of U.S. trade balance, U.S. terms of trade, and export value of oil exporters



Notes: The solid lines are median impulse responses and the shaded areas are the 68% highest posterior density credible sets for impulse responses. The units on the x-axes are months. The units on the y-axes are in percent.

C SVAR models with traditional and narrative sign restrictions

To check the robustness of the estimation results in Section 2 and to identify the oil supply shock more precisely, we estimate SVAR models with both traditional and narrative sign restrictions, following Antolín-Díaz and Rubio-Ramírez (2018) in this appendix. The traditional sign restrictions refer to the sign restrictions on the IRFs and structural parameters of our SVAR models in Section 2, while the narrative sign restrictions constrain the structural parameters to ensure that the structural shocks and historical decomposition agree with the established narrative around key historical events. We add these narrative sign restrictions to our SVAR models for robustness.

To identify structural oil supply shocks, we exploit major historical events that were exogenous to macroeconomic determinants and reduced world oil production. We use the fact that this unexpected decline in world oil production is attributed to positive oil supply shocks. Specifically, based on Antolín-Díaz and Rubio-Ramírez (2018), we add the following narrative sign restriction to the traditional sign restrictions in Section 2: The oil supply shock must be positive in December 2002 (oil strike in Venezuela), March 2003 (Iraq War), February 2011 (Libyan Civil War), and February 2022 (Russia–Ukraine war).[1]

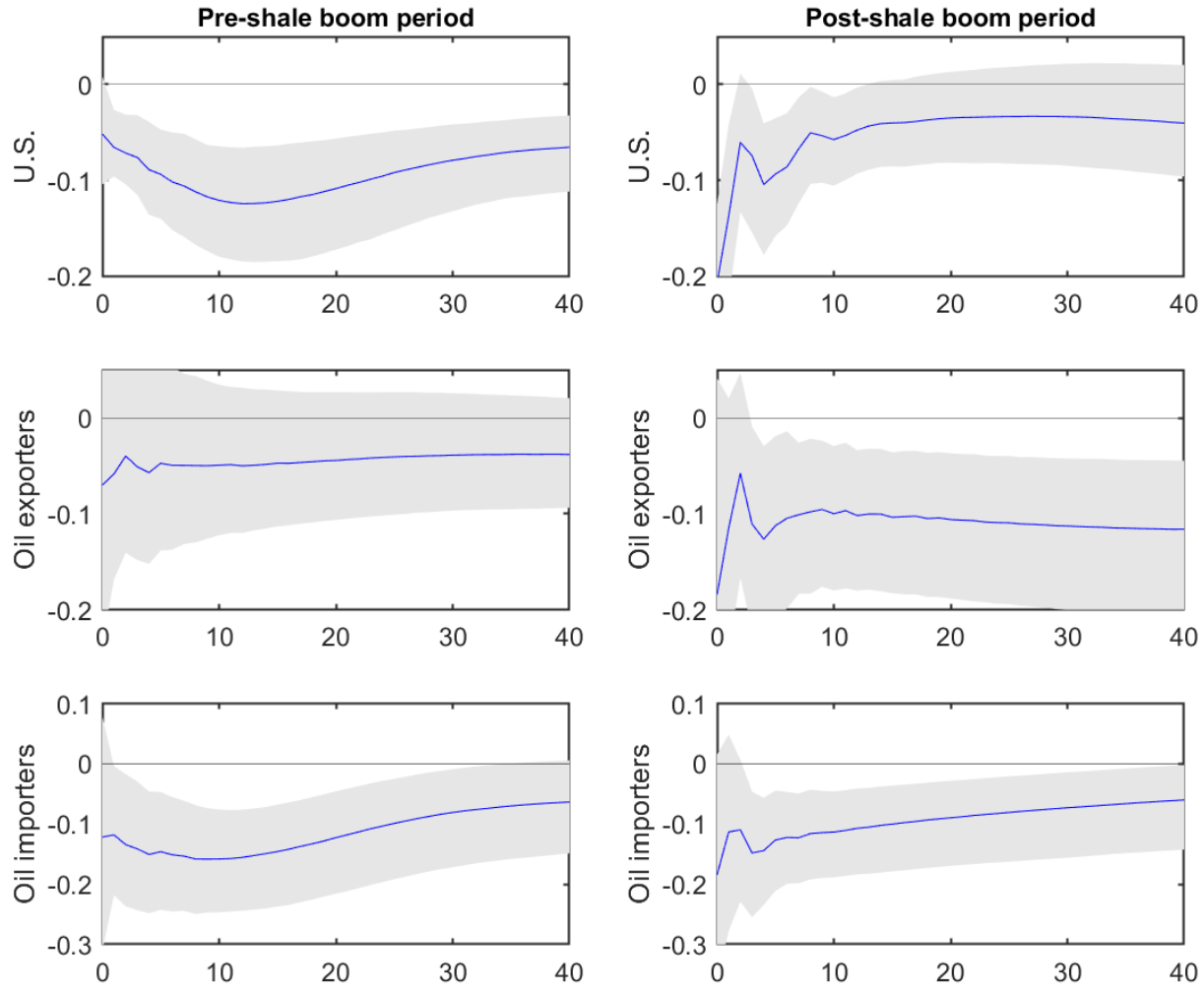
The IRFs of industrial production in the U.S., oil exporters, and oil importers in the SVAR models with traditional and narrative sign restrictions to an oil supply shock are presented in Figure C.1.[2] As before, the shock is normalized to decrease world oil production by 0.1% in period 0 in the two sample periods. The estimated IRFs are very similar to those in Section 2. Specifically, an oil supply shock leads to a decline in U.S. industrial production in both the pre- and post-shale boom periods. However, the decline is generally smaller in the post-shale boom period. For oil exporters, industrial production also falls in response to the shock, but the response is not statistically significant in the pre-shale boom period. In contrast, the decline becomes statistically significant and larger in the post-shale boom period. For oil-importing countries, the shock results in a statistically significant drop in industrial production in both periods, with the magnitude of the decline remaining broadly unchanged across the two periods.

Figure C.2 displays the estimated IRFs of the U.S. trade balance, the U.S. terms of trade, and the export value of oil exporters to an oil supply shock. The responses are very similar to those in Section 2. During the pre-shale boom period, the U.S. trade balance falls, and the fall is not statistically significant. However, in the post-shale boom period, the U.S. trade

[1] Note that unlike Antolín-Díaz and Rubio-Ramírez (2018), we do not identify other structural shocks, such as aggregate demand and oil-specific demand shocks. Therefore, it is impossible to compare the contributions of the oil supply shocks with those of other shocks. Accordingly, we do not consider the contribution of the oil supply shocks during the outlined time periods in the above restrictions as narrative sign restrictions.

[2] The IRFs are obtained from at least 2000 draws that satisfy both the traditional and the narrative sign restrictions.

Figure C.1: IRFs of industrial production in the SVAR models with traditional and narrative sign restrictions

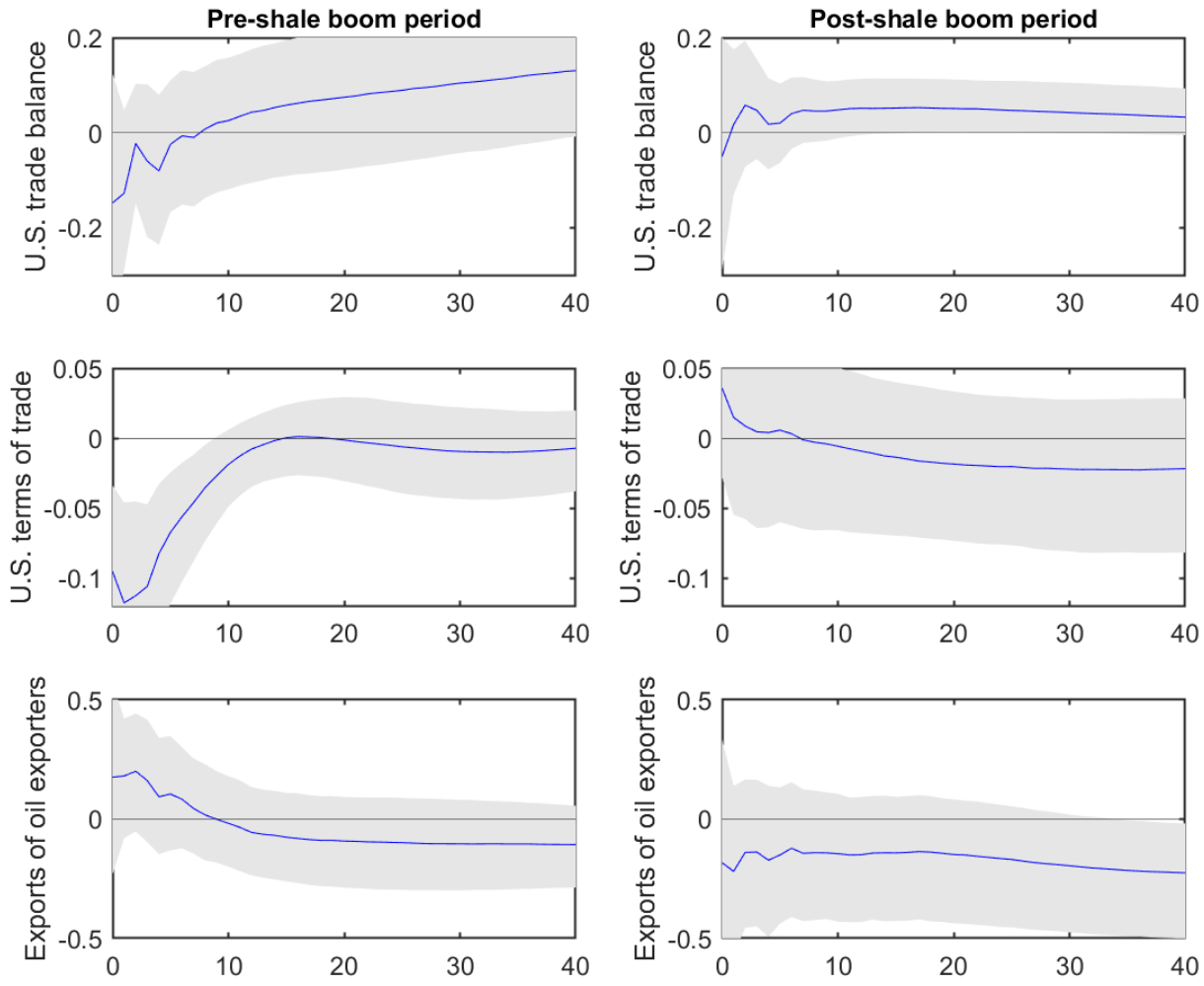


Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.

balance increases at most horizons. Regarding the U.S. terms of trade, the shock causes a statistically significant decline in the pre-shale boom period. In the post-shale boom period, the response of the U.S. terms of trade is smaller and not statistically significant compared to the decline in the pre-shale boom period. Lastly, the export value of oil exporters rises in response to the shock in the pre-shale boom period. By contrast, in the post-shale boom period, the shock leads to a decline in the export value of oil exporters.

In short, these findings confirm the robustness of our baseline empirical results: the post-shale boom period is marked by a muted adverse impact of oil supply shocks on the U.S., a stronger negative response in oil exporters, and a broadly unchanged response in oil importers. These results are consistent with our baseline results in Section 2. This implies that our estimation results are robust to the identification methods in the SVAR model.

Figure C.2: IRFs of U.S. trade balance, U.S. terms of trade, and export value of oil exporters in the SVAR models with traditional and narrative sign restrictions



Notes: The solid lines are the median impulse responses and the shaded areas are the 68% highest posterior density credible sets for the impulse responses. The vertical axis indicates the percentage or percentage point, and the horizontal axis indicates the number of months after the shock.

D Equilibrium conditions of the model

In this appendix, we provide the equilibrium conditions of the model in the two periods.

- Pre-shale boom period:

$$\lambda_t = \frac{1}{C_t - bC_{t-1}} - \beta b \mathbb{E}_t \left[\frac{1}{C_{t+1} - bC_t} \right], \tag{D.1}$$

$$\lambda_t^B = \frac{1}{C_t^B - bC_{t-1}^B} - \beta b \mathbb{E}_t \left[\frac{1}{C_{t+1}^B - bC_t^B} \right], \tag{D.2}$$

$$\lambda_t^C = \frac{1}{C_t^C - bC_{t-1}^C} - \beta b \mathbb{E}_t \left[\frac{1}{C_{t+1}^C - bC_t^C} \right], \tag{D.3}$$

$$W_t \lambda_t = N_t^\chi, \tag{D.4}$$

$$W_t^B \lambda_t^B = N_t^{B^\chi}, \tag{D.5}$$

$$W_t^C \lambda_t^C = N_t^{C^\chi}, \tag{D.6}$$

$$1 = \beta \mathbb{E}_t \left[R_t \frac{\lambda_{t+1}}{\lambda_t} \right], \tag{D.7}$$

$$1 = \beta \mathbb{E}_t \left[R_t^B \frac{\lambda_{t+1}^B}{\lambda_t^B} \right], \tag{D.8}$$

$$1 = \beta \mathbb{E}_t \left[R_t^C \frac{\lambda_{t+1}^C}{\lambda_t^C} \right], \tag{D.9}$$

$$Q_t = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \right] - \zeta B_t, \tag{D.10}$$

$$Q_t = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}^B e_t^B}{\lambda_t^B e_{t+1}^B} \right] - \zeta B_t^B, \tag{D.11}$$

$$Q_t = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}^C e_t^C}{\lambda_t^C e_{t+1}^C} \right] - \zeta B_t^C, \tag{D.12}$$

$$1 = (1-\gamma_0) p_{m,t}^{1-\eta_0} + \gamma_0 p_{o,t}^{1-\eta_0}, \tag{D.13}$$

$$1 = (1-\gamma_0) p_{m,t}^{B^{1-\eta_0}} + \gamma_0 p_{o,t}^{B^{1-\eta_0}}, \tag{D.14}$$

$$1 = (1-\gamma_0) p_{m,t}^{C^{1-\eta_0}} + \gamma_0 p_{o,t}^{C^{1-\eta_0}}, \tag{D.15}$$

$$p_{m,t}^{1-\eta_1} = (1-\gamma_1) p_{A,t}^{1-\eta_1} + \gamma_{1,B} p_{B,t}^{1-\eta_1} + \gamma_{1,C} p_{C,t}^{1-\eta_1}, \tag{D.16}$$

$$p_{m,t}^{B^{1-\eta_1}} = (1-\gamma_1) p_{B,t}^{B^{1-\eta_1}} + \gamma_{1,A}^B p_{A,t}^{B^{1-\eta_1}} + \gamma_{1,C}^B p_{C,t}^{B^{1-\eta_1}}, \tag{D.17}$$

$$p_{m,t}^{C^{1-\eta_1}} = (1-\gamma_1^C) p_{C,t}^{C^{1-\eta_1}} + \gamma_{1,A}^C p_{A,t}^{C^{1-\eta_1}} + \gamma_{1,B}^C p_{B,t}^{C^{1-\eta_1}}, \tag{D.18}$$

$$p_{o,t}^{1-\eta_2} = (1-\gamma_2) p_{o,A,t}^{1-\eta_2} + \gamma_2 p_{o,C,t}^{1-\eta_2}, \tag{D.19}$$

$$p_{o,t}^{B^{1-\eta_2}} = (1-\gamma_2^B) p_{o,B,t}^{B^{1-\eta_2}} + \gamma_2^B p_{o,C,t}^{B^{1-\eta_2}}, \tag{D.20}$$

$$p_{o,t}^C = p_{o,C,t}^C, \tag{D.21}$$

$$C_{m,t} = (1-\gamma_0) p_{m,t}^{-\eta_0} C_t, \tag{D.22}$$

$$C^B_{m,t} = (1-\gamma_0) p^{B^{-\eta_0}}_{m,t} C^B_t, \tag{D.23}$$

$$C^C_{m,t} = (1-\gamma_0) p^{C^{-\eta_0}}_{m,t} C^C_t, \tag{D.24}$$

$$C_{o,t} = \gamma_0 p^{-\eta_0}_{o,t} C_t, \tag{D.25}$$

$$C^B_{o,t} = \gamma_0 p^{B^{-\eta_0}}_{o,t} C^B_t, \tag{D.26}$$

$$C^C_{o,t} = \gamma_0 p^{C^{-\eta_0}}_{o,t} C^C_t, \tag{D.27}$$

$$C_{A,t} = (1-\gamma_1) \left(\frac{p_{A,t}}{p_{m,t}} \right)^{-\eta_1} C_{m,t}, \tag{D.28}$$

$$C^B_{B,t} = (1-\gamma_1) \left(\frac{p^B_{B,t}}{p^B_{m,t}} \right)^{-\eta_1} C^B_{m,t}, \tag{D.29}$$

$$C^C_{C,t} = (1-\gamma^C_1) \left(\frac{p^C_{C,t}}{p^C_{m,t}} \right)^{-\eta_1} C^C_{m,t}, \tag{D.30}$$

$$C_{B,t} = \gamma_{1,B} \left(\frac{p_{B,t}}{p_{m,t}} \right)^{-\eta_1} C_{m,t}, \tag{D.31}$$

$$C^B_{A,t} = \gamma^B_{1,A} \left(\frac{p^B_{A,t}}{p^B_{m,t}} \right)^{-\eta_1} C^B_{m,t}, \tag{D.32}$$

$$C^C_{B,t} = \gamma^C_{1,B} \left(\frac{p^C_{B,t}}{p^C_{m,t}} \right)^{-\eta_1} C^C_{m,t}, \tag{D.33}$$

$$C_{C,t} = \gamma_{1,C} \left(\frac{p_{C,t}}{p_{m,t}} \right)^{-\eta_1} C_{m,t}, \tag{D.34}$$

$$C^B_{C,t} = \gamma^B_{1,C} \left(\frac{p^B_{C,t}}{p^B_{m,t}} \right)^{-\eta_1} C^B_{m,t}, \tag{D.35}$$

$$C^C_{A,t} = \gamma^C_{1,A} \left(\frac{p^C_{A,t}}{p^C_{m,t}} \right)^{-\eta_1} C^C_{m,t}, \tag{D.36}$$

$$C_{o,A,t} = (1-\gamma_2) \left(\frac{p_{o,A,t}}{p_{o,t}} \right)^{-\eta_2} C_{o,t}, \tag{D.37}$$

$$C^B_{o,B,t} = (1-\gamma^B_2) \left(\frac{p^B_{o,B,t}}{p^B_{o,t}} \right)^{-\eta_2} C^B_{o,t}, \tag{D.38}$$

$$C_{o,C,t} = \gamma_2 \left(\frac{p_{o,C,t}}{p_{o,t}} \right)^{-\eta_2} C_{o,t}, \tag{D.39}$$

$$C^B_{o,C,t} = \gamma^B_2 \left(\frac{p^B_{o,C,t}}{p^B_{o,t}} \right)^{-\eta_2} C^B_{o,t}, \tag{D.40}$$

$$C^C_{o,t} = C^C_{o,C,t}, \tag{D.41}$$

$$p_{A,t} = e^B_t p^B_{A,t}, \tag{D.42}$$

$$p_{B,t} = e^B_t p^B_{B,t}, \tag{D.43}$$

$$p_{C,t} = e_t^B p_{C,t}^B, \tag{D.44}$$

$$p_{A,t} = e_t^C p_{A,t}^C, \tag{D.45}$$

$$p_{B,t} = e_t^C p_{B,t}^C, \tag{D.46}$$

$$p_{C,t} = e_t^C p_{C,t}^C, \tag{D.47}$$

$$p_{o,C,t} = e_t^C p_{o,C,t}^C, \tag{D.48}$$

$$p_{o,C,t} = e_t^B p_{o,C,t}^B, \tag{D.49}$$

$$K_{m,t} = (1-\delta)K_{m,t-1} + \left[1 - \frac{\phi}{2}\left(\frac{I_{m,t}}{I_{m,t-1}} - 1\right)^2\right] I_{m,t}, \tag{D.50}$$

$$K_{m,t}^B = (1-\delta)K_{m,t-1}^B + \left[1 - \frac{\phi}{2}\left(\frac{I_{m,t}^B}{I_{m,t-1}^B} - 1\right)^2\right] I_{m,t}^B, \tag{D.51}$$

$$K_{m,t}^C = (1-\delta)K_{m,t-1}^C + \left[1 - \frac{\phi}{2}\left(\frac{I_{m,t}^C}{I_{m,t-1}^C} - 1\right)^2\right] I_{m,t}^C, \tag{D.52}$$

$$\begin{aligned} p_{m,A,t} = q_{m,t}\Bigg[1 - \frac{\phi}{2}\left(\frac{I_{m,t}}{I_{m,t-1}} - 1\right)^2 - \phi\left(\frac{I_{m,t}}{I_{m,t-1}} - 1\right)\frac{I_{m,t}}{I_{m,t-1}}\Bigg] \\ +\phi\beta\mathbb{E}_t\left[\frac{\lambda_{t+1}}{\lambda_t} q_{m,t+1}\left(\frac{I_{m,t+1}}{I_{m,t}} - 1\right)\frac{I_{m,t+1}^2}{I_{m,t}^2}\right], \end{aligned} \tag{D.53}$$

$$\begin{aligned} p_{m,B,t}^B = q_{m,t}^B\Bigg[1 - \frac{\phi}{2}\left(\frac{I_{m,t}^B}{I_{m,t-1}^B} - 1\right)^2 - \phi\left(\frac{I_{m,t}^B}{I_{m,t-1}^B} - 1\right)\frac{I_{m,t}^B}{I_{m,t-1}^B}\Bigg] \\ +\phi\beta\mathbb{E}_t\left[\frac{\lambda_{t+1}^B}{\lambda_t^B} q_{m,t+1}^B\left(\frac{I_{m,t+1}^B}{I_{m,t}^B} - 1\right)\frac{I_{m,t+1}^{B^2}}{I_{m,t}^{B^2}}\right], \end{aligned} \tag{D.54}$$

$$\begin{aligned} p_{m,C,t}^C = q_{m,t}^C\Bigg[1 - \frac{\phi}{2}\left(\frac{I_{m,t}^C}{I_{m,t-1}^C} - 1\right)^2 - \phi\left(\frac{I_{m,t}^C}{I_{m,t-1}^C} - 1\right)\frac{I_{m,t}^C}{I_{m,t-1}^C}\Bigg] \\ +\phi\beta\mathbb{E}_t\left[\frac{\lambda_{t+1}^C}{\lambda_t^C} q_{m,t+1}^C\left(\frac{I_{m,t+1}^C}{I_{m,t}^C} - 1\right)\frac{I_{m,t+1}^{C^2}}{I_{m,t}^{C^2}}\right], \end{aligned} \tag{D.55}$$

$$K_{o,t} = (1-\delta)K_{o,t-1} + \left[1 - \frac{\phi}{2}\left(\frac{I_{o,t}}{I_{o,t-1}} - 1\right)^2\right] I_{o,t}, \tag{D.56}$$

$$K_{o,t}^B = (1-\delta)K_{o,t-1}^B + \left[1 - \frac{\phi}{2}\left(\frac{I_{o,t}^B}{I_{o,t-1}^B} - 1\right)^2\right] I_{o,t}^B, \tag{D.57}$$

$$K_{o,t}^C = (1-\delta)K_{o,t-1}^C + \left[1 - \frac{\phi}{2}\left(\frac{I_{o,t}^C}{I_{o,t-1}^C} - 1\right)^2\right] I_{o,t}^C, \tag{D.58}$$

$$p_{o,A,t} = q_{o,t}\left[1 - \frac{\phi}{2}\left(\frac{I_{o,t}}{I_{o,t-1}} - 1\right)^2 - \phi\left(\frac{I_{o,t}}{I_{o,t-1}} - 1\right)\frac{I_{o,t}}{I_{o,t-1}}\right] + \phi\beta\mathbb{E}_t\left[\frac{\lambda_{t+1}}{\lambda_t} q_{o,t+1}\left(\frac{I_{o,t+1}}{I_{o,t}} - 1\right)\frac{I_{o,t+1}^2}{I_{o,t}^2}\right], \tag{D.59}$$

$$p^B_{o,B,t} = q^B_{o,t}\left[1 - \frac{\phi}{2}\left(\frac{I^B_{o,t}}{I^B_{o,t-1}} - 1\right)^2 - \phi\left(\frac{I^B_{o,t}}{I^B_{o,t-1}} - 1\right)\frac{I^B_{o,t}}{I^B_{o,t-1}}\right] + \phi\beta\mathbb{E}_t\left[\frac{\lambda^B_{t+1}}{\lambda^B_t} q^B_{o,t+1}\left(\frac{I^B_{o,t+1}}{I^B_{o,t}} - 1\right)\frac{I^{B^2}_{o,t+1}}{I^{B^2}_{o,t}}\right], \tag{D.60}$$

$$p^C_{o,C,t} = q^C_{o,t}\left[1 - \frac{\phi}{2}\left(\frac{I^C_{o,t}}{I^C_{o,t-1}} - 1\right)^2 - \phi\left(\frac{I^C_{o,t}}{I^C_{o,t-1}} - 1\right)\frac{I^C_{o,t}}{I^C_{o,t-1}}\right] + \phi\beta\mathbb{E}_t\left[\frac{\lambda^C_{t+1}}{\lambda^C_t} q^C_{o,t+1}\left(\frac{I^C_{o,t+1}}{I^C_{o,t}} - 1\right)\frac{I^{C^2}_{o,t+1}}{I^{C^2}_{o,t}}\right], \tag{D.61}$$

$$Y_{m,t}v^p_{m,t} = A_t\{(1-a)K^{-\nu}_{m,t} + aO^{-\nu}_t\}^{-\frac{\alpha}{\nu}} N^{1-\alpha}_{m,t}, \tag{D.62}$$

$$Y^B_{m,t}v^{p^B}_{m,t} = A^B_t\{(1-a)K^{B^{-\nu}}_{m,t} + aO^{B^{-\nu}}_t\}^{-\frac{\alpha}{\nu}} N^{B^{1-\alpha}}_{m,t}, \tag{D.63}$$

$$Y^C_{m,t}v^{p^C}_{m,t} = A^C_t\{(1-a)K^{C^{-\nu}}_{m,t} + aO^{C^{-\nu}}_t\}^{-\frac{\alpha}{\nu}} N^{C^{1-\alpha}}_{m,t}, \tag{D.64}$$

$$W_t = (1-\alpha)mc_{m,t}\frac{Y_{m,t}v^p_{m,t}}{N_{m,t}}, \tag{D.65}$$

$$W^B_t = (1-\alpha)mc^B_{m,t}\frac{Y^B_{m,t}v^{p^B}_{m,t}}{N^B_{m,t}}, \tag{D.66}$$

$$W^C_t = (1-\alpha)mc^C_{m,t}\frac{Y^C_{m,t}v^{p^C}_{m,t}}{N^C_{m,t}}, \tag{D.67}$$

$$R_{t-1}q_{m,t-1} = (1-\delta)q_{m,t} + \frac{\alpha(1-a)mc_{m,t}K^{-\nu-1}_{m,t}Y_{m,t}v^p_{m,t}}{(1-a)K^{-\nu}_{m,t} + aO^{-\nu}_t}, \tag{D.68}$$

$$R^B_{t-1}q^B_{m,t-1} = (1-\delta)q^B_{m,t} + \frac{\alpha(1-a)mc^B_{m,t}K^{B^{-\nu-1}}_{m,t}Y^B_{m,t}v^{p^B}_{m,t}}{(1-a)K^{B^{-\nu}}_{m,t} + aO^{B^{-\nu}}_t}, \tag{D.69}$$

$$R^C_{t-1}q^C_{m,t-1} = (1-\delta)q^C_{m,t} + \frac{\alpha(1-a)mc^C_{m,t}K^{C^{-\nu-1}}_{m,t}Y^C_{m,t}v^{p^C}_{m,t}}{(1-a)K^{C^{-\nu}}_{m,t} + aO^{C^{-\nu}}_t}, \tag{D.70}$$

$$p_{o,t} = a\alpha mc_{m,t}O^{-\nu-1}_t\frac{Y_{m,t}v^p_{m,t}}{(1-a)K^{-\nu}_{m,t} + aO^{-\nu}_t}, \tag{D.71}$$

$$p^B_{o,t} = a\alpha mc^B_{m,t}O^{B^{-\nu-1}}_t\frac{Y^B_{m,t}v^{p^B}_{m,t}}{(1-a)K^{B^{-\nu}}_{m,t} + aO^{B^{-\nu}}_t}, \tag{D.72}$$

$$p^C_{o,t} = a\alpha mc^C_{m,t}O^{C^{-\nu-1}}_t\frac{Y^C_{m,t}v^{p^C}_{m,t}}{(1-a)K^{C^{-\nu}}_{m,t} + aO^{C^{-\nu}}_t}, \tag{D.73}$$

$$O_{A,t} = (1-\gamma_2)\left(\frac{p_{o,A,t}}{p_{o,t}}\right)^{-\eta_2} O_t, \tag{D.74}$$

$$O^B_{B,t} = (1-\gamma^B_2)\left(\frac{p^B_{o,B,t}}{p^B_{o,t}}\right)^{-\eta_2} O^B_t, \tag{D.75}$$

$$O_{C,t} = \gamma_2\left(\frac{p_{o,C,t}}{p_{o,t}}\right)^{-\eta_2} O_t, \tag{D.76}$$

$$O^B_{C,t} = \gamma^B_2\left(\frac{p^B_{o,C,t}}{p^B_{o,t}}\right)^{-\eta_2} O^B_t, \tag{D.77}$$

$$O^C_{C,t} = O^C_t, \tag{D.78}$$

$$x_{1,m,t} = \lambda_t Y_{m,t} mc_{m,t} + \beta\theta_m \mathbb{E}_t\left[x_{1,m,t+1}\pi^{\varepsilon}_{m,A,t+1}\right], \tag{D.79}$$

$$x^B_{1,m,t} = \lambda^B_t Y^B_{m,t} mc^B_{m,t} + \beta\theta_m \mathbb{E}_t\left[x^B_{1,m,t+1}\pi^{B^{\varepsilon}}_{m,B,t+1}\right], \tag{D.80}$$

$$x^C_{1,m,t} = \lambda^C_t Y^C_{m,t} mc^C_{m,t} + \beta\theta_m \mathbb{E}_t\left[x^C_{1,m,t+1}\pi^{C^{\varepsilon}}_{m,C,t+1}\right], \tag{D.81}$$

$$x_{2,m,t} = \lambda_t Y_{m,t} + \beta\theta_m \mathbb{E}_t\left[x_{2,m,t+1}\frac{\pi^{\varepsilon}_{m,A,t+1}}{\pi_{t+1}}\right], \tag{D.82}$$

$$x^B_{2,m,t} = \lambda^B_t Y^B_{m,t} + \beta\theta_m \mathbb{E}_t\left[x^B_{2,m,t+1}\frac{\pi^{B^{\varepsilon}}_{m,B,t+1}}{\pi^B_{t+1}}\right], \tag{D.83}$$

$$x^C_{2,m,t} = \lambda^C_t Y^C_{m,t} + \beta\theta_m \mathbb{E}_t\left[x^C_{2,m,t+1}\frac{\pi^{C^{\varepsilon}}_{m,C,t+1}}{\pi^C_{t+1}}\right], \tag{D.84}$$

$$\pi^{1-\varepsilon}_{m,A,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\pi_{m,A,t}}{p_{m,A,t}}\frac{x_{1,m,t}}{x_{2,m,t}}\right]^{1-\varepsilon} + \theta_m, \tag{D.85}$$

$$\pi^{B^{1-\varepsilon}}_{m,A,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\pi^B_{m,B,t}}{p^B_{m,B,t}}\frac{x^B_{1,m,t}}{x^B_{2,m,t}}\right]^{1-\varepsilon} + \theta_m, \tag{D.86}$$

$$\pi^{C^{1-\varepsilon}}_{m,C,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{\pi^C_{m,C,t}}{p^C_{m,C,t}}\frac{x^C_{1,m,t}}{x^C_{2,m,t}}\right]^{1-\varepsilon} + \theta_m, \tag{D.87}$$

$$v^p_{m,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{x_{1,m,t}}{p_{m,A,t}x_{2,m,t}}\right]^{-\varepsilon} + \theta_m\pi^{\varepsilon}_{m,A,t}v^p_{m,t-1}, \tag{D.88}$$

$$v^{p^B}_{m,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{x^B_{1,m,t}}{p^B_{m,B,t}x^B_{2,m,t}}\right]^{-\varepsilon} + \theta_m\pi^{B^{\varepsilon}}_{m,B,t}v^{p^B}_{m,t-1}, \tag{D.89}$$

$$v^{p^C}_{m,t} = (1-\theta_m)\left[\frac{\varepsilon}{\varepsilon-1}\frac{x^C_{1,m,t}}{p^C_{m,C,t}x^C_{2,m,t}}\right]^{-\varepsilon} + \theta_m\pi^{C^{\varepsilon}}_{m,C,t}v^{p^C}_{m,t-1}, \tag{D.90}$$

$$Y_{o,t}v^p_{o,t} = A_{o,t}K^{\alpha_o}_{o,t}N^{1-\alpha_o}_{o,t} + \ln\psi_t, \tag{D.91}$$

$$Y^B_{o,t}v^{p^B}_{o,t} = A^B_{o,t}K^{B^{\alpha_o}}_{o,t}N^{B^{1-\alpha_o}}_{o,t} + \ln\psi^B_t, \tag{D.92}$$

$$Y^C_{o,t}v^{p^C}_{o,t} = A^C_{o,t}K^{C^{\alpha_o}}_{o,t}N^{C^{1-\alpha_o}}_{o,t} + \ln\psi^C_t, \tag{D.93}$$

$$W_t = (1-\alpha_o) mc_{o,t} \frac{Y_{o,t} v^p_{o,t} + \ln \psi_t}{N_{o,t}}, \tag{D.94}$$

$$W^B_t = (1-\alpha_o) mc^B_{o,t} \frac{Y^B_{o,t} v^{p^B}_{o,t} + \ln \psi^B_t}{N^B_{o,t}}, \tag{D.95}$$

$$W^C_t = (1-\alpha_o) mc^C_{o,t} \frac{Y^C_{o,t} v^{p^C}_{o,t} + \ln \psi^C_t}{N^C_{o,t}}, \tag{D.96}$$

$$R_{t-1} q_{o,t-1} = (1-\delta) q_{o,t} + \alpha_o mc_{o,t} \frac{Y_{o,t} v^p_{o,t} + \ln \psi_t}{K^{-\nu}_{o,t}}, \tag{D.97}$$

$$R^B_{t-1} q^B_{o,t-1} = (1-\delta) q^B_{o,t} + \alpha_o mc^B_{o,t} \frac{Y^B_{o,t} v^{p^B}_{o,t} + \ln \psi^B_t}{K^{B^{-\nu}}_{o,t}}, \tag{D.98}$$

$$R^C_{t-1} q^C_{o,t-1} = (1-\delta) q^C_{o,t} + \alpha_o mc^C_{o,t} \frac{Y^C_{o,t} v^{p^C}_{o,t} + \ln \psi^C_t}{K^{C^{-\nu}}_{o,t}}, \tag{D.99}$$

$$x_{1,o,t} = \lambda_t Y_{o,t} mc_{o,t} + \beta \theta_o \mathbb{E}_t \left[x_{1,o,t+1} \pi^{\varepsilon}_{o,A,t+1} \right], \tag{D.100}$$

$$x^B_{1,o,t} = \lambda^B_t Y^B_{o,t} mc^B_{o,t} + \beta \theta_o \mathbb{E}_t \left[x^B_{1,o,t+1} \pi^{B^{\varepsilon}}_{o,B,t+1} \right], \tag{D.101}$$

$$x^C_{1,o,t} = \lambda^C_t Y^C_{o,t} mc^C_{o,t} + \beta \theta_o \mathbb{E}_t \left[x^C_{1,o,t+1} \pi^{C^{\varepsilon}}_{o,C,t+1} \right], \tag{D.102}$$

$$x_{2,o,t} = \lambda_t Y_{o,t} + \beta \theta_o \mathbb{E}_t \left[x_{2,o,t+1} \frac{\pi^{\varepsilon}_{o,A,t+1}}{\pi_{t+1}} \right], \tag{D.103}$$

$$x^B_{2,o,t} = \lambda^B_t Y^B_{o,t} + \beta \theta_o \mathbb{E}_t \left[x^B_{2,o,t+1} \frac{\pi^{B^{\varepsilon}}_{o,B,t+1}}{\pi^B_{t+1}} \right], \tag{D.104}$$

$$x^C_{2,o,t} = \lambda^C_t Y^C_{o,t} + \beta \theta_o \mathbb{E}_t \left[x^C_{2,o,t+1} \frac{\pi^{C^{\varepsilon}}_{o,C,t+1}}{\pi^C_{t+1}} \right], \tag{D.105}$$

$$\pi^{1-\varepsilon}_{o,A,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{\pi_{o,A,t}}{p_{o,A,t}} \frac{x_{1,o,t}}{x_{2,o,t}} \right]^{1-\varepsilon} + \theta_o, \tag{D.106}$$

$$\pi^{B^{1-\varepsilon}}_{o,B,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{\pi^B_{o,B,t}}{p^B_{o,B,t}} \frac{x^B_{1,o,t}}{x^B_{2,o,t}} \right]^{1-\varepsilon} + \theta_o, \tag{D.107}$$

$$\pi^{C^{1-\varepsilon}}_{o,C,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{\pi^C_{o,C,t}}{p^C_{o,C,t}} \frac{x^C_{1,o,t}}{x^C_{2,o,t}} \right]^{1-\varepsilon} + \theta_o, \tag{D.108}$$

$$v^p_{o,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{x_{1,o,t}}{p_{o,A,t} x_{2,o,t}} \right]^{-\varepsilon} + \theta_o \pi^{\varepsilon}_{o,A,t} v^p_{o,t-1}, \tag{D.109}$$

$$v^{p^B}_{o,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{x^B_{1,o,t}}{p^B_{o,B,t} x^B_{2,o,t}} \right]^{-\varepsilon} + \theta_o \pi^{B^{\varepsilon}}_{o,B,t} v^{p^B}_{o,t-1}, \tag{D.110}$$

$$v^{p^C}_{o,t} = (1-\theta_o) \left[\frac{\varepsilon}{\varepsilon - 1} \frac{x^C_{1,o,t}}{p^C_{o,C,t} x^C_{2,o,t}} \right]^{-\varepsilon} + \theta_o \pi^{C^{\varepsilon}}_{o,C,t} v^{p^C}_{o,t-1}, \tag{D.111}$$

$$\frac{R^n_t}{R^n} = \left(\frac{R^n_{t-1}}{R^n} \right)^{\rho_r} \left(\frac{\pi_t}{\pi} \right)^{(1-\rho_r)\phi_\pi} \left(\frac{Y_t}{Y} \right)^{(1-\rho_r)\phi_y}, \tag{D.112}$$

$$\frac{R_t^{n^B}}{R^{n^B}} = \left(\frac{R_{t-1}^{n^B}}{R^{n^B}}\right)^{\rho_r} \left(\frac{\pi_t^B}{\pi^B}\right)^{(1-\rho_r)\phi_\pi} \left(\frac{Y_t^B}{Y^B}\right)^{(1-\rho_r)\phi_y}, \tag{D.113}$$

$$\frac{R_t^{n^C}}{R^{n^C}} = \left(\frac{R_{t-1}^{n^C}}{R^{n^C}}\right)^{\rho_r} \left(\frac{\pi_t^C}{\pi^C}\right)^{(1-\rho_r)\phi_\pi} \left(\frac{Y_t^C}{Y^C}\right)^{(1-\rho_r)\phi_y}, \tag{D.114}$$

$$R_t = \mathbb{E}_t\left[R_t^n/\pi_{t+1}\right], \tag{D.115}$$

$$R_t^B = \mathbb{E}_t\left[R_t^{n^B}/\pi_{t+1}^B\right], \tag{D.116}$$

$$R_t^C = \mathbb{E}_t\left[R_t^{n^C}/\pi_{t+1}^C\right], \tag{D.117}$$

$$\pi_{m,A,t} = \pi_t\left(p_{m,A,t}/p_{m,A,t-1}\right), \tag{D.118}$$

$$\pi_{m,B,t}^B = \pi_t^B\left(p_{m,B,t}^B/p_{m,B,t-1}^B\right), \tag{D.119}$$

$$\pi_{m,C,t}^C = \pi_t^C\left(p_{m,C,t}^C/p_{m,C,t-1}^C\right), \tag{D.120}$$

$$\pi_{o,A,t} = \pi_t\left(p_{o,A,t}/p_{o,A,t-1}\right), \tag{D.121}$$

$$\pi_{o,B,t}^B = \pi_t^B\left(p_{o,B,t}^B/p_{o,B,t-1}^B\right), \tag{D.122}$$

$$\pi_{o,C,t}^C = \pi_t^C\left(p_{o,C,t}^C/p_{o,C,t-1}^C\right), \tag{D.123}$$

$$N_t = N_{o,t} + N_{m,t}, \tag{D.124}$$

$$N_t^B = N_{o,t}^B + N_{m,t}^B, \tag{D.125}$$

$$N_t^C = N_{o,t}^C + N_{m,t}^C, \tag{D.126}$$

$$n_A Y_{m,t} = n_A C_{A,t} + n_B C_{A,t}^B + n_C C_{A,t}^C + n_A I_{m,t}, \tag{D.127}$$

$$n_B Y_{m,t}^B = n_A C_{B,t} + n_B C_{B,t}^B + n_C C_{B,t}^C + n_B I_{m,t}^B, \tag{D.128}$$

$$n_C Y_{m,t}^C = n_A C_{C,t} + n_B C_{C,t}^B + n_C C_{C,t}^C + n_C I_{m,t}^C, \tag{D.129}$$

$$Y_{o,t} = C_{o,A,t} + O_{A,t} + I_{o,t}, \tag{D.130}$$

$$Y_{o,t}^B = C_{o,B,t}^B + O_{B,t}^B + I_{o,t}^B, \tag{D.131}$$

$$n_C Y_{o,t}^C = n_A\left(C_{o,C,t} + O_{C,t}\right) + n_B\left(C_{o,C,t}^B + O_{C,t}^B\right) + n_C\left(C_{o,t}^C + O_t^C + I_{o,t}^C\right), \tag{D.132}$$

$$Y_t = n_A\left(p_{A,t}Y_{m,t} + p_{o,A,t}Y_{o,t} - p_{o,t}O_t\right), \tag{D.133}$$

$$Y_t^B = n_B\left(p_{B,t}^B Y_{m,t}^B + p_{o,B,t}^B Y_{o,t}^B - p_{o,t}^B O_t^B\right), \tag{D.134}$$

$$Y_t^C = n_C\left(p_{C,t}^C Y_{m,t}^C + p_{o,C,t}^C Y_{o,t}^C - p_{o,t}^C O_t^C\right), \tag{D.135}$$

$$\begin{aligned} &p_{A,t}\left(n_B C_{A,t}^B + n_C C_{A,t}^C\right) - n_A\left\{p_{B,t}C_{B,t} + p_{C,t}C_{C,t}\right. \\ &\left.+p_{o,C,t}\left(C_{o,C,t} + O_{C,t}\right)\right\} + n_A B_{t-1} = n_A\left(Q_t B_t + \frac{\zeta}{2}B_t^2\right), \end{aligned} \tag{D.136}$$

$$\begin{aligned} &p_{B,t}^B\left(n_A C_{B,t} + n_C C_{B,t}^C\right) - n_B\left\{p_{A,t}^B C_{A,t}^B + p_{C,t}^B C_{C,t}^B\right. \\ &\left.+p_{o,C,t}^B\left(C_{o,C,t}^B + O_{C,t}^B\right)\right\} + n_B B_{t-1}^B/e_t^B = n_B\left(Q_t B_t^B/e_t^B + \frac{\zeta}{2}B_t^{B^2}\right), \end{aligned} \tag{D.137}$$

$$\text{and } n_A B_t + n_B B_t^B + n_C B_t^C = 0, \tag{D.138}$$

where e_t^i, $i \in \{B, C\}$ denotes the real exchange rates between countries A and i.

- The equilibrium conditions for the post-shale boom period are Equations (D.1)–(D.19), (D.21)–(D.39), (D.41)–(D.76), (D.78)–(D.129), (D.131)–(D.135), (D.138), and the following nine equations:

$$p_{o,t}^{B^{1-\eta_2}} = (1-\gamma_2^B) p_{o,B,t}^{B^{1-\eta_2}} + \gamma_{2,A}^B p_{o,A,t}^{B^{1-\eta_2}} + \gamma_{2,C}^B p_{o,C,t}^{B^{1-\eta_2}}, \tag{D.139}$$

$$C_{o,C,t}^B = \gamma_{2,C}^B \left(\frac{p_{o,C,t}^B}{p_{o,t}^B} \right)^{-\eta_2} C_{o,t}^B, \tag{D.140}$$

$$C_{o,A,t}^B = \gamma_{2,A}^B \left(\frac{p_{o,A,t}^B}{p_{o,t}^B} \right)^{-\eta_1} C_{o,t}^B, \tag{D.141}$$

$$p_{o,A,t} = e_t^B p_{o,A,t}^B, \tag{D.142}$$

$$O_{C,t}^B = \gamma_{2,C}^B \left(\frac{p_{o,C,t}^B}{p_{o,t}^B} \right)^{-\eta_2} O_t^B, \tag{D.143}$$

$$O_{A,t}^B = \gamma_{2,A}^B \left(\frac{p_{o,A,t}^B}{p_{o,t}^B} \right)^{-\eta_1} O_t^B, \tag{D.144}$$

$$n_A Y_{o,t} = n_A \left(C_{o,A,t} + O_{A,t} + I_{o,t} \right) + n_B \left(C_{o,A,t}^B + O_{A,t}^B \right), \tag{D.145}$$

$$\begin{aligned} & p_{A,t} \left(n_B C_{A,t}^B + n_C C_{A,t}^C \right) + p_{o,A,t} n_B \left(C_{o,A,t}^B + O_{A,t}^B \right) - n_A \left\{ p_{B,t} C_{B,t} \right. \\ & \left. + p_{C,t} C_{C,t} + p_{o,C,t} \left(C_{o,C,t} + O_{C,t} \right) \right\} + n_A B_{t-1} = n_A \left(Q_t B_t + \frac{\zeta}{2} B_t^2 \right), \end{aligned} \tag{D.146}$$

$$\begin{aligned} & p_{B,t}^B \left(n_A C_{B,t} + n_C C_{B,t}^C \right) - p_{o,A,t}^B n_B \left(C_{o,A,t}^B + O_{A,t}^B \right) \\ \text{and } & -n_B \left\{ p_{A,t}^B C_{A,t}^B + p_{C,t}^B C_{C,t}^B + p_{o,C,t}^B \left(C_{o,C,t}^B + O_{C,t}^B \right) \right\} \\ & + n_B B_{t-1}^B / e_t^B = n_B \left(Q_t B_t^B / e_t^B + \frac{\zeta}{2} B_t^{B^2} \right). \end{aligned} \tag{D.147}$$