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Non-linear impact of exchange rate changes on U.S. industrial production

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Abstract

This paper contributes to the literature on the nexus between production and exchange rate in the United States (U.S.) by considering non-linear adjustments of exchange rate effects on industrial production in several sectors of the U.S. economy. We employ a Non-linear Autoregressive Distributed Lags (NARDL) model which is built upon the Solow model. We show that there exists a non-linear relationship between these two variables in some of the MMIGs. We document short-run non-linear effects of exchange rate on production of non-energy materials, durable manufacturing, consumer goods and business equipment. The short-run effects last into the long-run for all the sectors. While exchange rate changes have short-run linear effects on production of electricity in the U.S., there are no effects of exchange rate movements on the production of mining, and energy materials. Moreover, the paper finds misspecification error of the model for the case of durable manufacturing. The existence of non-linearities considering import content of exports, support our hypothesis and conclusions. Further, the factors that influence demand provide justifications for our results.

Keywords: Exchange rates, Production, Non-linear ARDL, Asymmetries

1 Introduction

Studying the production of U.S. industries have taken on new importance in the context of the U.S. economy. Exchange rate changes impact the production level of industries through trade channel effects and variation of the prices of inputs and outputs. Moreover, production is a building brick of an economy, makes industrial production index (IPI) essential for the U.S. capital market as well. The presence of a positive and significant relationship between the Dow Jones index and IPI in the U.S. has been recognised in the literature (Jareño and Negrut 2016). Movement in Dow Jones[1] exhibits the movement of the largest publicly traded companies in the U.S. Therefore IPI works as a benchmark of how the U.S. capital market performs.

The present study provides an empirical analysis to find out the impact of USD exchange rate on the production of selected U.S. sectors. In analysing the impacts of the exchange rate, we account for the existence of non-linear impacts of the USD exchange rate. By considering the non-linearities, our analysis is intended to capture

[1] Dow Jones index is a stock market index that represents the value of top 30 publically owned companies in the U.S. by market capitalization.

the full effect of exchange rate movements. The adopted model enables us to capture short-run and long-run effects of positive and negative changes of exchange rate on industrial production in several sectors of the U.S. economy. Our hypothesis in this model is that there are non-linear effects of exchange rate on the production due to some level of import contents of exports.

Our first contribution to the existing literature is that we suggest consideration of non-linear framework to measure the effects of exchange rate on the production of U.S. sectors due to the role of import content of exports. Secondly, we provide new empirical evidence of non-linearities in the relationship between USD exchange rate and industrial production in several sectors of the U.S. economy. It is widely acknowledged that the depreciation of currencies helps to boost exports and outputs. Based on this idea, governments can intervene in the market by depreciating currencies to gain international market and increase employment. Existing literature assume a linear relationship between exchange rate changes and output. That is, if depreciation is expansionary, appreciation is contractionary. However, it is possible that exchange rate changes to have ambiguous effects on production.

In order to develop the notion of non-linearity, we rely on the ratio of import content of exports by each sector. The main idea that justifies the existence of such ambiguous effects is the dependency of industrial production on imports. Due to existence of some level of import content of exports, there could be non-linear effects of exchange rates on production. Therefore based on this idea, depreciation is expansionary, and appreciation is contractionary by having cheaper and more expensive exports, respectively. The opposite can be argued by having more expensive imports and cheaper imports respectively. For our empirical analysis, we selected eight sectors: consumer goods, business equipment, non-energy materials, energy materials, durable manufacturing, non-durable manufacturing, mining and electricity. This selection is based on the priorities for our model such as availability of appropriate monthly production data or suitability of the available data for our consideration.

This paper is motivated by the nature of trade and production in these sectors and how exchange rate changes impact trade flows. First, we are interested in the import content of exports. The degree for import content of exports can facilitate the ambiguous effect of exchange rate on production in these sectors. Further, demand elasticities of inputs and outputs is another factor that might explain the nexus between exchange rate changes and production in these sectors. The elasticities of inputs in the U.S. is affected by the nature of the goods produced (necessities vs veblen goods). These factors along with others that affect the production in each sector will be used in the analysis of the results.

According to OECD (2012), the import content of exports is defined as the degree of vertical specification. In other words, the import content of exports can be outlined as the contribution of imports in the production of exports of goods and services OECD (2012). Figure 1 shows the import content of exports for fifteen industries. The bar charts presented in the figure are based on (OECD 2012). Figure 1 reports data for three periods of mid-1990s, early 2000s and mid-2000s for 14 industries. In Fig. 1, the first group from the left represents mining. The second and third group are the sectors in consumer goods, the fourth group represents a significant portion

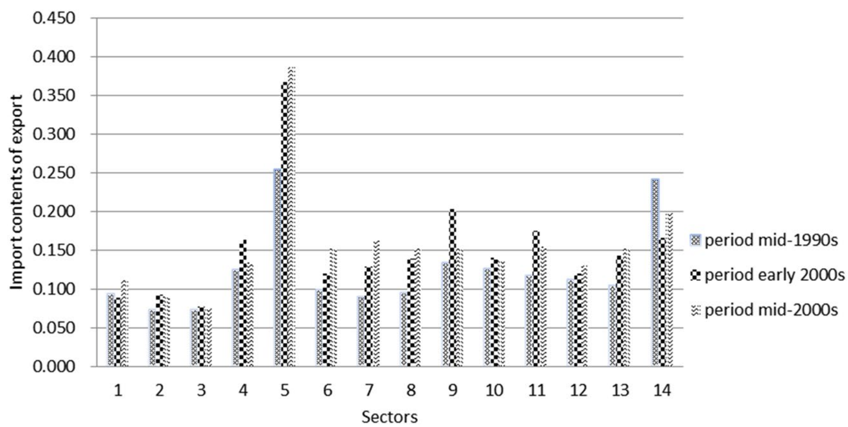

Fig. 1 Import content of exports (fraction of 1) (OECD 2012)

of non-energy materials. The next three groups (5th, 6th and 7th) are components of non-durable manufacturing. Lastly, groups 8 to 12 represent durable manufacturing while groups 13 and 14 are classified as part of business equipment.

We find that (1) USD exchange rate appreciation and depreciation both have positive effects on the production of non-energy materials with a significant but not high import content of exports, although the amount of effect for appreciation is higher than that of depreciation (2) the exchange rate appreciation has positive effects on production in the sectors with high import content of exports, (3) the exchange rate depreciation has positive long-run effects on production of consumer goods with close to 0 import content of exports, (4) the exchange rate changes do not play a significant role in the production of sectors that their output prices are controlled by other factors or demands are price inelastic.

The rest of the paper is organised as follows. Section 2 introduces the literature review and discusses the existing literature relating to the present study. Section 3 develops the methodology by discussing the economic model, data and assumptions. The results are brought forth in Sect. 4. In this section, we provide tables that summarise the empirical results from the analysis. Lastly, Sect. 5 offers concluding remarks and recommendations.

2 Literature review

2.1 Trade and exchange rates

Exchange rate affects production through trade flows. Bahmani-Oskooee and Hegerty (2007) provides opposing views on the relationship between exchange rates volatility and trade. While some studies argue exchange rate volatility to hurt trade, the other oppose their view. By studying the literature on this topic, Bahmani-Oskooee and Hegerty (2007) suggest that Bounds testing by (Pesaran et al. 2001) is the most suitable tool to measure short-run and long-run exchange rate volatility.

Governments intervene in the markets by altering money supply to reach their desired trade flows. Batten and Ott (1985) show that there is a short-run causal relationship between U.S. money supply growth and most countries' money supply. Based on this paper a short-run increase (or decrease) of the money supply in the U.S. causes a short-run increase (or decrease) in the money supply of foreign countries. This finding indicates the effects of exchange rates on trade. Guzman et al. (2018) agree with the importance of monetary policy on industrial growth through changes in trades. Monetary policies that aim to alter exchange rates to increase production and result in economic growth are better suited for countries with higher unexploited learning. These countries tend to have higher learning spillover by having "infant industries". According to this paper, a competitive exchange rate is a tool to cultivate industries. Governments can use this tool to either grow local or foreign demand.

The foreign demand is highly related to the price of the commodity and the bilateral exchange rate among the U.S. and the importing country (Sapsford 1987). Fair (1982) explains that effect of monetary policy on the exchange rate is to aim demand changes by altering inflation. According to this paper, fiscal policies are used to influence import prices. As import is a vital part of the production, output prices will vary accordingly resulting in demand changes. Nevertheless, Adhikari (2016) shows that the implication of monetary policy by the federal reserve system does not affect the U.S. trade balance. The empirical study tested relevant dataset from 1995–2014 by using an applicable model that considers exchange rate, monetary policy as well as domestic and foreign demand. In like manner earlier findings by Engel (1999) concludes that real exchange rate movements in the U.S. do not alter the relative prices of non-traded goods in this country.

From the stated literature the following question arises. If not monetary policy, what could be other factors that alter the exchange rate in the U.S.? The study by Nakibullah (2007) shows that there might be a strong positive correlation among the budget deficit in the U.S. and the exchange rate. This study also finds a weak relationship between currency appreciation and the export of traded goods. The finding is in line with the hypothesis of the paper suggesting a non-linear relationship between exchange rate and industrial production in the U.S.

2.2 Exchange rate and sectoral production

Exchange rate changes have important implications for sectoral production. Trade has been identified as the channel that affects the production of different sectors in an economy. Guzman et al. (2018) demonstrates that a competitive exchange rate can be used as an instrument for industrial policy making. Previous literature that considered the effect of exchange rate on sectoral output has analysed the impact of bilateral exchange rates instead of effective exchange rate (Klein 1990) and did not consider the nonlinear impact of exchange rate (Golub 1994; Broz and Werfel 2014; Caglayan and Di 2010). This paper argues that the use of effective exchange rate is a better measure in this era of globalisation where various stages of production are outsourced from a chain of countries (global value chains) (OECD 2019). To the best of our knowledge, our analysis is the first to consider the nonlinear effect of the US exchange rate on the sectoral production of the US.

We confirm the importance of studying the desegregated production by varying import content of export in each sector (shown in Fig. 1).

3 Methodology

In order to capture the non-linear relationship among exchange rate movement and production, this study employs NARDL, which is built upon Autoregressive Distributed Lags model developed by Shin et al. (2014). NARDL is based on the well known bound testing approach by Pesaran et al. (2001) which is a test for cointegration. The NARDL framework allows us to capture the the effect of appreciation and depreciation of effective exchange rate of USD on industrial production of several sectors in the U.S. economy.

3.1 Economic model

We have built our regression model based on the standard neoclassical production function by Solow (1956). The Solow model (Eq. 1) is a descriptive model for a closed economy where sectoral output or production (Y) is a function of sectoral inputs which are labour (L), capital (K) and productivity (A).

$$Y_t = f(k_t L_t A_t) \tag{1}$$

The United States is far from a closed economy. First, we consider the addition of two main variables, namely, nominal effective exchange rate (NEER) and money supply (M2). The variable NEER is added to capture the effect of changes on the purchasing power of the US and its trading partners, which results in higher or lower US industrial output through the export of output and the import of input content of exports. NEER is used instead of REER based on Lal and Lowinger (2002) which shows the existence of both short run and long run relationship between nominal effective exchange rates (NEER) and trade balances. Moreover, we follow Bahmani-Oskooee and Mohammadian (2017) which uses the variable money supply as one of the independent variables to study the effect of Yen on domestic output of Japan. Money supply is a good measure for investment and a measure for monetary policy in the US economy as increases and decreases in money supply alter interest rates in the US. Therefore, with the addition of variables NEER and M2, Eq. (1) can be extended and written as Eq. (2).

$$Y_t = f(k_t L_t A_t NEER_t M2_t) \tag{2}$$

At this point, we use the Consumer Price Index (CPI) in the US as a measure of productivity (A) to further modify Eq. (2). We borrow the assumption of Balassa Samuelson effect (BS-effect) to use CPI in place of productivity (A) in Eq. (2) and arrive at Eq. (6) as explained below (Samuelson 1994; Kravis and Lipsey 1978). The general idea behind the BS-effect is that economies of the US and its trading partners are separated to tradable (t) and non-tradable (nt) sectors (Samuelson 1994). Tradable sector concerns goods that can be traded among countries; hence the law of one price or purchasing power parity holds for them. The non-tradable sector, on the other hand, concerns goods such as housing and Big Mac (that can not be traded).

To explain the BS-effect (Samuelson 1994), we assume that there are no productivity differential for non-tradable sectors between the US and its trading partners (TP) (Eq. 3).

$$A_{\mathrm{nt,US}} = A_{\mathrm{nt,TP}} \tag{3}$$

Further, we assume that labours can freely move between the two sectors of tradable and non-tradable. Labours move to maximise their wage (w) based on the assumption of competition in the labour market. Because of the competition in the labour market, the wage between the two sectors may be assumed equal. Lastly, we assume that wage is a function of price (P) and productivity in both sectors of the US and its trading partners. Therefore, we can write relations for wages (expressed in Eqs. 4 and 5).

$$w_{\mathrm{US}} = P_{\mathrm{nt}} \times A_{\mathrm{nt,US}} = P_t \times A_{t,\mathrm{US}} \tag{4}$$

$$w_{\mathrm{TP}} = P_{\mathrm{nt}} \times A_{\mathrm{nt,TP}} = P_t \times A_{t,\mathrm{TP}} \tag{5}$$

If the US has a more productive tradable sector than its trading partners, due to the law of one price for the tradable sector, the prices for the tradable sector will not change, but the prices for non-tradable will have to increase to maintain the labour in the non-tradable sector. Therefore according to the BS-effect, higher productivity results in higher overall prices. That is why in this study we may use consumer price index (CPI) in the US as a measure for the productivity (A) as expressed in Eq. (6). A similar approach has been used by the Czech National Bank to explain inflation in the Czech Republic (CNB 2016).

$$Y_t = f(k_t L_t CPI_t NEER_t M2_t) \tag{6}$$

3.2 Assumptions

In our analysis we have used industrial production index (IPI) to represent output (Y), and gross fixed capital formation (GFCF) to represent capital (K) in Eq. 6. After linearising, Eq. (6) may be written as a simple linear regression model (Eq. 7). Disaggregated data for labour force and gross fixed capital formation are not available with the same level of aggregation as the chosen industrial production indices (IPIs). Therefore, we have assumed that labour force, gross fixed capital formation and consumer price for each sector is a fraction of it's national levels. A similar approach can be seen in the literature (Blau et al. 2011) where aggregate level proxies have been chosen for disaggregated level variables. Our assumption is reasonable since the IPIs of the sectors chosen are significant fractions of the total national production index. Therefore, as we are using a cointegration model to capture the effects of exchange rate on IPIs, National level statistics can replace the actual statistics about each sector. Based on the database provided by of Labor Statistics (of Labor Statistics 2018), the employment level of industries are fractions of the total employment level, and these fractions move together.

3.3 Framework

Equation (7) is then created based on the previous function which is the next step before creating the ARDL model (Eq. 8) and NARDL model (Eq. 9). In Eq. (7) the concept of the natural logarithm (LN) is used so that the evaluation of variables will be based on elasticities. Moreover, building ARDL model allows for capturing both the short-run and long-run effects of independent variables on the dependent variable (IPIs) by use of lags.

NARDL model replaces the ARDL model to separately measure negative changes and positive changes (non-linear effects) of exchange rates on production. Positive changes are estimated through the partial sum of positive values $\mathrm{POS} = \sum^{t}{}_{j=1} \triangle \mathrm{LnNEER}_j^+$. Negative changes are calculated by getting the partial sum of negative values $\mathrm{NEG} = \sum^{t}{}_{j=1} \triangle LnNEER^{-}{}_{j}$. These two newly created variables (POS and NEG) replace the terms related to LnNEER in Eq. (8). The first part of the ARDL and NARDL equations (Eqs. 8 and 9) capture the short-run effects of independent variables on the IPIs of various sectors while the second parts of the equations capture the effects for the long-run. Therefore in Eq. (8), estimates of $\beta_k, \delta_k, \varphi_k, \theta_k, \pi_k, \Omega_k$ are short-run estimates while estimates of $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6$ are the long-run estimates. Similarly in Eq. (9), short-run estimates consist of $\beta_k, \delta_{1,k}, \delta_{2,k}, \varphi_k, \theta_k, \pi_k, \Omega_k$, while long-run estimates consist of $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6$ and λ_7. Any difference in the values or the statistical significance between the estimates of $\delta_{1,k}, \delta_{2,k}$ and λ_1, λ_2 is a sign of non-linearity on the effect of exchange rate on industrial production in the short-run and long-run, respectively.

$$\mathrm{LNIPI} = \beta_0 + \beta_1 \mathrm{LnNEER} + \beta_2 \mathrm{CPI} + \beta_3 \mathrm{GFCF} + \beta_4 \mathrm{M2} + \beta_5 L + \varepsilon \tag{7}$$

$$\begin{aligned} \triangle \mathrm{LnIPI}_t = a &+ \sum_{k=1}^{n1} \beta_k \triangle \mathrm{LnIPI}_{t-k} + \sum_{k=0}^{n2} \delta_k \triangle \mathrm{LnNEER}_{t-k} \\ &+ \sum_{k=0}^{n3} \varphi_k \triangle \mathrm{LnCPI}_{t-k} + \sum_{k=0}^{n4} \theta_k \triangle \mathrm{LnGFCF}_{t-k} \\ &+ \sum_{k=0}^{n5} \pi_k \triangle \mathrm{LnM2}_{t-k} + \sum_{k=0}^{n6} \Omega_k \triangle \mathrm{LnL}_{t-k} + \lambda_1 \mathrm{LnIPI}_{t-1} \\ &+ \lambda_2 \mathrm{LnNEER}_{t-1} + \lambda_3 \mathrm{LnCPI}_{t-1} + \lambda_4 \mathrm{LnGFCF}_{t-1} \\ &+ \lambda_5 \mathrm{LnM2}_{t-1} + \lambda_6 \mathrm{LnL}_{t-1} + \mu_t \end{aligned} \tag{8}$$

$$\begin{aligned} \triangle \mathrm{LnIPI}_t = a &+ \sum_{k=1}^{n1} \beta_k \triangle \mathrm{LnIPI}_{t-k} + \sum_{k=0}^{n2} \delta_{1,k} \triangle \mathrm{LnPOS}_{t-k} \\ &+ \sum_{k=0}^{n3} \delta_{2,k} \triangle \mathrm{LnNEG}_{t-k} + \sum_{k=0}^{n4} \varphi_k \triangle \mathrm{LnCPI}_{t-k} \\ &+ \sum_{k=0}^{n5} \theta_k \triangle \mathrm{LnGFCF}_{t-k} + \sum_{k=0}^{n6} \pi_k \triangle \mathrm{LnM2}_{t-k} \\ &+ \sum_{k=0}^{n7} \Omega_k \triangle \mathrm{LnL}_{t-k} + \lambda_1 \mathrm{LnIPI}_{t-1} \\ &+ \lambda_2 \mathrm{LnPOS}_{t-1} + \lambda_3 \mathrm{LnNEG}_{t-1} \\ &+ \lambda_4 \mathrm{LnCPI}_{t-1} + \lambda_5 \mathrm{LnGFCF}_{t-1} \\ &+ \lambda_6 \mathrm{LnM2}_{t-1} + \lambda_7 \mathrm{LnL}_{t-1} + \mu_t \end{aligned} \tag{9}$$

3.4 Data

For our empirical analysis, we choose eight sectors: consumer goods, business equipment, non-energy materials, energy materials, durable manufacturing, non-durable manufacturing, mining and electricity. The selection is based on the following reasons: (i) monthly data for production indices (IPIs) enable us to find out the short run effects from 6 to 12 lags based on the literature (Caglayan and Di 2010). (ii) Additionally, we avoid

Table 1 Augmented Dickey Fuller test results

Variables	Level	First difference
IPI for non-energy materials	− 2.3708	− 4.8***
IPI for non-durable manufacturing	− 1.7651	− 7.9***
IPI for mining	− 0.6497	− 14***
IPI for energy materials	− 2.3708	− 4.8***
IPI for electricity	− 2.1137	− 16.9***
IPI for durable manufacturing	− 2.3841	− 5.0***
IPI for consumer goods	− 2.5215	− 20.6***
IPI for business equipment	− 2.7097*	− 6.01***
Nominal effective exchange rate index	− 1.973332	− 10.9***
Consumer price index	− 1.44903	− 10.0***
Gross fixed capital formation	− 1.3301	− 3.0***
Money supply (M2)	1.033065	− 12.08***
Labour	− 2.5828	− 19.5***

Significant estimates at the 10%, 5% and 1% level are represented by *, **, *** respectively

using data with higher level of disaggregation. Country level data were used as proxies for labour (*L*), gross fixed capital formation (GFCF) and consumer price index (CPI) because to the best of out knowledge data for these variables with the same level of aggregation as industrial production index are not available. (iii) Moreover, we consider aggregated trade weights used in the calculation of NEER by the bank of international settlements.

This study uses a time series dataset with monthly frequency covering the period from February 1994 to September 2017. There are 285 observations for each variable. Observations for the variables Industrial production indices (IPI), as well as gross fixed capital formation (GFCF), are collected from the Federal Reserve Bank of St. Louis. IPIs are collected for consumer goods (IPCG), business equipment (IPBEQ), durable manufacturing (IPDM), non-durable manufacturing (IPNDM), electricity (IPELE), durable manufacturing (IPDM), energy materials (IPEN), and non-energy materials (IPNEN). The dataset does not cover the industrialisation era hence there is no structural break in the dataset. Data for nominal effective exchange Rates (NEERs), consumer price index (CPI), as well as money supply (M2), are collected from the Bank of International Settlements. Data related to labour (*L*) are obtained from the RI Department of Labor and Training.

As only quarterly data were available, the frequency of data related to GFCF is transformed into monthly observations using cubic interpolation originally developed by Birkhoff and Garabedian (1960). The Base year for NEER is changed from 2010 to 2012 to match the base year of IPIs. Therefore, the dataset that contains all the observations for all the variables is consistent and reliable.

4 Results and discussion

4.1 Results of NARDL runs

First Augmented Dickey-Fuller tests (ADF) need to be done for all the data. ADF detects unit roots in the sample series. Table 1 reports the result for ADF tests both at the level and at the first difference. Based on ARDL assumptions, it is not necessary to have all variables in the same order. Therefore, having variables with a mixture of $I\,(1)$ and $I\,(0)$ is acceptable for the chosen model.

Table 2 Short-run NARDL estimates

IPIs for sectors	Independent Variables	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
Non-energy	NEG	0.02** (0.14)					
Materials	POS	0.17*** (0.05)	− 0.11 (0.10)	0.04 (0.10)	− 0.14** (0.06)		
(5, 0, 4, 6, 1, 1, 0)	Ln (CPI)	− 0.01 (0.15)	0.61** (0.27)	− 0.44 (0.28)	− 0.06 (0.28)	0.38 (0.25)	− 0.34** (0.14)
	Ln (GFCF)	0.75*** (0.11)					
	Ln (M2)	− 0.35*** (0.13)					
	Ln (L)	0.03 (0.06)					
Non-durable	NEG	− 0.00 (0.01)					
Manufacturing	POS	0.11** (0.05)	− 0.06 (0.50)	0.08 (0.08)	− 0.12*** (0.01)		
(4, 0, 4, 6, 1, 0, 0)	Ln (CPI)	− 0.34** (0.13)	0.41* (0.24)	0.01 (0.24)	− 0.51** (0.24)	0.62***(0.22)	− 0.30** (0.01)
	Ln (GFCF)	0.42*** (0.09)					
	Ln (M2)	− 0.02 (0.01)					
	Ln (L)	0.10 (0.06)					
Mining	NEG	0.01 (0.02)					
(3, 0, 0, 3, 4, 0, 0)	POS	− 0.00 (0.02)					
	Ln (CPI)	−0.81** (0.31)	1.36** (0.54)	− 0.74** (0.30)	0.74** (0.30)		
	Ln (GFCF)	0.15 (0.36)	3.00*** (0.84)	− 2.09*** (0.79)	0.59 (0.37)		
	Ln (M2)	− 0.01 (0.30)					
	Ln (L)	− 0.45* (0.24)					
Energy materials	NEG	− 0.002 (0.02)					
(3, 0, 0, 1, 4, 0, 0)	POS	− 0.00 (0.01)					
	Ln (CPI)	− 0.64*** (0.21)					
	Ln (GFCF)	− 0.20 (0.29)	2.32*** (0.68)	− 1.68*** (0.64)	0.55* (0.30)		
	Ln (M2)	0.03 (0.03)					
	Ln (L)	− 0.36* (0.19)					
Electricity	NEG	0.15 (0.17)	0.36** (0.17)				
(4, 2, 3, 0, 4, 1, 6)	POS	− 0.15 (0.15)	0.52(0.24)	− 0.33** (0.14)			
	Ln (CPI)	− 0.26* (0.13)					
	Ln (GFCF)	− 0.40 (0.44)	− 0.24 (0.98)	− 1.08 (0.91)	1.18*** (0.43)		
	Ln (M2)	0.67** (0.30)					

Table 2 (continued)

IPIs for sectors	Independent Variables	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
	Ln (L)	− 1.20** (0.49)	1.61** (0.62)	− 1.31** (0.63)	− 0.97(0.63)	1.04* (0.62)	− 1.11** (0.49)
Durable	NEG	0.00 (0.01)					
Manufacturing	POS	0.06 (0.06)	− 0.08 (0.12)	0.12 (0.11)	− 0.16** (0.06)		
(4, 0, 4, 0, 2, 2, 0)	Ln (CPI)	0.08 (0.06)					
	Ln (GFCF)	0.54** (0.21)	0.37* (0.22)				
	Ln (M2)	− 0.21 (0.15)	− 0.24 (0.15)				
	Ln (L)	0.08 (0.07)					
Consumer goods	NEG	− 0.00 (0.06)	0.19*** (0.09)	− 0.01 (0.09)	0.04 (0.09)	− 0.20*** (0.06)	
(2, 5, 1, 0, 5, 0, 1)	POS	0.08 (0.05)					
	Ln (CPI)	− 0.00 (0.05)					
	Ln (GFCF)	0.27 (0.17)	0.30 (0.37)	− 0.20 (0.37)	− 0.16 (0.35)	0.26 (0.17)	
	Ln (M2)	− 0.00 (0.07)					
	Ln (L)	− 0.35* (0.18)					
Business	NEG	− 0.00 (0.10)	0.41*** (0.15)	− 0.18* (0.10)			
Equipments	POS	0.02 (0.01)					
(1, 3, 0, 0, 5, 0, 0)	Ln (CPI)	− 0.09 (0.09)					
	Ln (GFCF)	0.25 (0.27)	1.34** (0.62)	− 0.70 (0.62)	− 0.44 (0.58)	0.58** (0.27)	
	Ln (M2)	− 0.09 (0.03)***					
	Ln (L)	0.29 (0.12)**					

Significant estimates at the 10%, 5% and 1% level are represented by *,**,*** respectively. The selected NARDL model based on automatic lag selection is written after each respective sector

Tables 2 and 3 show the result of running the NARDL model. Due to the large volume of results, the short-run estimates results are reported in Table 2 while the long-run estimates are reported in Table 3. The coefficients for all the variables are reported with six lags. Based on Caglayan and Di (2010), a maximum of six lags could be analysed based on Akaike's information criterion (AIC) using monthly datasets. In the presentation of the results and tables different critical values for diagnostic statistics and estimates have been considered in identifying the significant estimates at the 10%, 5% and 1% level (represented by *,**,*** in the tables).

4.2 Diagnostic tests

In this section, we aim to explore the suitability of the non-linear model (Eq. 9) to explain the effects of USD exchange rate on the production of sectors in the U.S. In order to ascertain the reliability of the chosen model, we perform diagnostic tests similar to Verheyen (2013).

Table 3 Long-run NARDL estimates

IPIs for sectors	NEG	POS	Ln(CPI)	Ln(GFCF)	Ln(M2)	Ln(L)
Non-energy materials (5, 0, 4, 6, 1, 1, 0)	0.44** (0.20)	0.53*** (0.17)	2.47*** (0.83)	0.36*** (0.12)	−1.02*** (0.3)	0.54 (1.03)
Non-durable manufacturing (4, 0, 4, 6, 1, 0, 0)	−0.06 (0.10)	0.02 (0.08)	−0.68 (0.43)	0.32 (0.06)	−0.17 (0.14)	0.96* (0.52)
Mining (3, 0, 0, 3, 4, 0, 0)	0.22 (0.44)	−0.03 (0.34)	3.98** (1.91)	0.18 (1.91)	−0.16 (0.64)	−7.18*** (2.30)
Energy materials (3, 0, 0, 1, 4, 0, 0)	−0.02 (0.27)	−0.09 (0.21)	0.84 (0.99)	0.20 (0.17)	0.45 (0.36)	−4.37*** (1.43)
Electricity (1, 3, 3, 0, 2)	−0.14 (0.10)	−0.08 (0.07)	−0.72* (0.42)	0.06 (0.05)	−0.03 (0.12)	3.002 (0.55)
Durable manufacturing (4, 0, 4, 2, 2, 0)	0.06 (0.35)	0.85*** (0.32)	1.91 (1.25)	0.40* (0.22)	−1.57*** (0.56)	1.89 (1.83)
Consumer goods (2, 5, 1, 0, 5, 0, 1)	0.26*** (0.07)	0.04 (0.05)	−0.04 (0.27)	0.29*** (0.04)	−0.03 (0.09)	0.93** (0.42)
Business equipments (1, 3, 0, 0, 5, 0, 0)	−1.77** (0.87)	0.76 (0.42)	−2.42 (2.88)	0.68* (0.35)	−2.58*** (0.79)	7.65 (4.70)

Significant estimates at the 10%, 5% and 1% level are represented by *,**,*** respectively. The selected NARDL model based on automatic lag selection is written after each respective sector

Table 4 Diagnostic tests for NARDL estimates

Sectors	Bounds test (F-statistic)	LM (Prob. chi-square)	RESET (FITTED^2)	CUSUM (CUSUM^2)	ECM (*t*-1)	Adjusted R^2
Non-energy materials	4.763429***	0.4296	0.1630	S (S)	− 0.06*** (0.14)	0.99
Non-durable manufacturing	2.290364***	0.2448	0.0276	S (S)	t0.11*** (0.03)	0.97
Mining	3.316104***	0.3947	0.4421	S (U)	− 0.06*** (0.02)	0.97
Energy materials	2.323125***	0.2753	0.1954	S (U)	− 0.08*** (0.02)	0.98
Electricity	7.036801***	0.0857	0.0316	S (S)	− 0.36*** (0.06)	0.96
Durable manufacturing	2.955711***	0.7754	0.3426	S (S)	− 0.04*** (0.01)	0.99
Consumer goods	5.481891***	0.9670	0.4172	S (S)	− 0.18*** (0.03)	0.98
Business equipments	3.820781***	0.4374	0.9766	S (U)	− 0.03 (0.01)***	0.99

Significant estimates at the 10%, 5% and 1% level are represented by *,**,*** respectively

We perform LM test, Ramsey Reset test, CUSUM and CUSUM square test. These diagnostic tests check for autocorrelation, misspecification and stability of the model. Additionally, we provide Bounds test to find out if there exist cointegrating relationship between independent variables and the dependent variable for each sector. Moreover, we provide adjusted R-squared to check the fitness of our ARDL and NARDL cointegration models.

Tables 4 and 7 show the results. The first column represent Bounds tests. Bounds tests that are statistically significant enable us to conclude, that there are cointegrating relationship between independent variables and the dependent variable for the respective sector. The second column in these tables represent LM test. Statistically insignificant probability chi-squared for LM test is an indication that the residuals in the respective model are uncorrelated and there is no problem of autocorrelation. The third column of these tables provide Ramsey RESET fitted squared values. Models with fitted squared values that are less than 10% have a problem of misspecification. The fourth column of these tables are specified for CUSUM and CUSUM square tests which examine the stability, i.e., finding out if coefficient of the regressors are changing systematically (CUSUM) and suddenly (CUSUM square). Lastly, Tables 4 and 7 provide estimates for ECM ($t-1$), an error correction term which indicates how much of the movements into disequilibrium are corrected for within one period.

4.3 Discussion of results

The findings imply the industry-specific effects of exchange rates on production. Therefore, it is essential that the results for each sector are explained separately. The first row of Table 2 shows the short-run effects of selected independent variables on the production of non-energy materials. According to Table 2, both appreciation and depreciation of the currency have significant short-run effects on the production of non-energy materials, since non-energy materials are traded materials (both exportable and importable in the U.S.) and work directly with changes in the exchange rates. From the results, it is clear that there is evidence of the non-linear effects of exchange rate changes on the production of non-energy materials which is supported by import content of exports in this sector.

In like manner, both POS (appreciation) and NEG (depreciation) affect the production of electricity. While currency depreciation has positive impacts, currency appreciation has negative effects on the production of electricity. These effects conform to each other and point out to the importance of export of electricity in the U.S. However, by looking at the diagnostic tests in Table 4, there is a misspecification problem pointed out by the Ramsey RESET test. Similar misspecification error has been reported in Table 4 for durable manufacturing.

Table 2 also shows that only appreciations of the USD have effect on the production of durable manufacturing. Durable manufacturing consist of wood products, non-metallic, mineral products, primary metals, fabricated metal products, machinery, computer and electronic products, electrical equipment, appliances and component, motor vehicles and parts aerospace and miscellaneous, transportation equipment, furniture related products and miscellaneous. According to Kilesen and Tatom (2013), durable goods hold a large share of exports by the U.S. Although these goods are primarily exported; however, the intermediate goods imported to produce the outputs equal more than hundred per cent of manufacturing value added Kilesen and Tatom (2013). The results of NARDL in both short-run and long-run are in direction with the study by Kilesen and Tatom (2013).

Appreciation of the USD has negative effect in the short-run (with some lags) on the production of non-durable goods. However, in the long-run (shown in Table 3) appreciation of the USD has strong positive effect, which implies the importance of purchasing power to import intermediate goods for the means of production of non-durable manufacturing.

Furthermore, it can be seen in Tables 2 and 3 that depreciation of USD (NEG) has short-run positive effect of the exchange rate on the production of consumer goods lasts into the long-run. In contrast, depreciation of the exchange rate (NEG) has negative short-run effect on the production of business equipment which holds into the long -run. From these findings, it can be concluded that import content of exports in the production of business equipment and consumer goods play a crucial role. Currency depreciation has both positive short-run and long-run effect on the production of consumer goods which is suggested by the low import content of exports in this market group. Therefore, depreciation of the USD provides cheaper goods for importers and resulting in more demand for exports and more productions to fulfill these demands.

Exchange rate changes [both appreciations (POS) and depreciation (NEG)] do not have any effect on the production of energy materials and mining in neither short-run nor long-run. One can assume that this is due to the nature of the selected model, and exchange rate changes have "linear" (rather than non-linear) effect in the production of these sectors. A similar assumption can be used for electricity and non-durable manufacturing based on the findings of misspecifications in their models. Next, we present the estimates for the linear model (2.4). Similarly, due to the volume of results, the estimates and diagnostic tests for the ARDL model will be presented in 3 tables. Tables 5 and 6 show the results for short-run and long-run ARDL model respectively (with the assumption of linearity for these sectors). Table 7 reports the diagnostic checks for the ARDL model. The results provide evidence that misspecification of error continues to the ARDL for the case of non-durable manufacturing while interestingly exchange rate changes have significant effects (using linear model) on the production of electricity in the short-run.

4.4 Discussion of major findings

Based on the findings there is a positive long-run effect of appreciations and depreciation of USD on the production of non-energy materials. The result shows as USD appreciates, the inputs that are being imported for production become cheaper. The production also increases with the USD depreciation, explaining the positive impact of higher demand for exports as domestically produced goods in the U.S. get cheaper for foreign importers. This finding is also consistent with OECD (2012) report on this sector with significant but not high import content of exports. The exchange rate is found to have a different effect on the other sectors with relatively high import content of exports such as business equipment and consumer goods. In these sectors, USD appreciation is better for production, as USD depreciation has negative effect and no significant effect on the production of business equipment and durable manufacturing, respectively. The level of import content of exports is also an explaining factor for consumer goods. Based on the OECD (2012) the import content of exports is close to 0 for consumer goods. The findings reflect such level of import content of exports by showing positive effect of USD on the production of consumer goods in the long-run. An interesting finding is the insignificance effect of the exchange rate on the production of mining and energy materials. The nature of goods produced could explain the findings for these sectors. Production of mining is affected by the prices of minerals such as oil prices respectively (Golub 1994). Similarly, the insignificance of the exchange rate changes on energy materials may imply that exchange rate changes do not alter the production of these materials. Energy materials consist of photovoltaics, energy storages and hydrogen storages (Stanford University 2018). Consequently, productions of these goods are related to the production

Table 5 Short-run ARDL estimates

IPIs for sectors	Independent variables	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
Energy	LNEER	− 0.005 (0.01)					
Materials	Ln(CPI)	− 0.64*** (0.21)					
(3, 0, 1, 4, 0, 0)	Ln (GFCF)	− 0.20 (0.29)	2.32*** (0.67)	− 1.68*** (0.63)	0.55* (0.30)		
	Ln (LM2)	0.03 (0.02)					
	Ln (L)	− 0.35* (0.18)					
Mining	LNEER	0.003 (0.01)					
(3, 0, 3, 4, 0, 0)	Ln(CPI)	− 0.83 (0.31)	1.36** (0.54)	− 0.73** (0.30)			
	Ln (GFCF)	0.14 (0.36)	3.005 (0.84)	− 2.09 (0.79)	0.59 (0.37)		
	Ln (LM2)	− 0.02 (0.02)					
	Ln (L)	− 0.42* (0.23)					
Non-durable	LNEER	0.05 (0.03)	− 0.01 (0.05)	0.04 (0.05)	− 0.07** (0.03)		
Manufacturing	Ln(CPI)	− 0.33** (0.13)	0.42* (0.24)	0.05 (0.24)	− 0.58** (0.24)	0.69*** (0.22)	− 0.32** (0.12)
(4, 4, 6, 1, 0, 0)	Ln (GFCF)	0.45*** (0.08)					
	Ln (LM2)	− 0.01 (0.01)					
	Ln (L)	0.08 (0.06)					
Electricity	LNEER	0.02 (0.09)	0.32** (0.16)	− 0.01 (0.16)	0.002 (0.15)	− 0.16* (0.09)	
(4, 5, 6, 4, 6, 4)	Ln(CPI)	1.66 (1.70)	− 5.54* (3.26)	3.29 (3.16)	0.98 (3.10)	0.49 (2.89)	− 3.48** (1.65)
	Ln (GFCF)	− 0.37 (0.45)	0.10 (1.04)	− 1.80* (0.95)	1.55*** (0.44)		
	Ln (LM2)	0.71** (0.33)	0.20 (0.51)	0.61 (0.48)	0.88* (0.48)	− 0.88* (0.49)	0.67** (0.31)
	Ln (L)	− 1.05 (0.49)	1.09 (0.62)	− 1.60** (0.62)	− 1.35** (0.63)	− 0.81 (0.51)	

Significant estimates at the 10%, 5% and 1% level are represented by *, **, *** respectively. The selected ARDL model based on automatic lag selection is written after each respective sector

Table 6 Long-run ARDL estimates

IPIs for sectors	LNEER	Ln (CPI)	Ln (GFCF)	Ln (M2)	Ln (*L*)
energy materials (3, 0, 1, 4, 0, 0)	L0.06 (0.17)	0.77 (0.91)	0.21 (0.16)	0.40* (0.23)	L4.29 (1.38)
Mining (3, 0, 3, 4, 0, 0)	0.06 (0.26)	3.69** (1.79)	0.22 (0.27)	L0.37 (0.50)	L6.84*** (2.25)
Non-durable manufacturing (4, 4, 6, 1, 0, 0)	L0.003 (0.06)	L0.46 (0.41)	0.32*** (-0.05)	L0.13 (0.10)	0.70 (0.54)
Electricity (4, 5, 6, 4, 6, 4)	0.03 (0.06)	1.45 (1.93)	0.07 (0.05)	L0.21** (0.09)	1.73*** (0.62)

Significant estimates at the 10%, 5% and 1% level are represented by *, **, *** respectively. The selected ARDL model based on automatic lag selection is written after each respective sector

Table 7 Diagnostic tests for ARDL estimates

Sectors	Bounds test (F-statistic)	LM (Prob. chi-square)	RESET (FITTED^2)	CUSUM (CUSUM^2)	ECM ($t-1$)	Adjusted R^2
Energy materials	2.720358**	0.2725	0.1815	S (U)	− 0.08*** (0.02)	0.98
Mining	3.794992***	0.3147	0.3813	S (U)	− 0.06*** (0.02)	0.97
Non-durable manufacturing	2.757674***	0.1052	0.0247	S (S)	− 0.11*** (0.03)	0.98
Electricity	6.840694***	0.3731	− 0.4676	S (S)	− 0.34*** (0.05)	0.97

Significant estimates at the 10%, 5% and 1% level are represented by *, **, *** respectively

of green energy. Therefore, this is not surprising to find no relationship between USD changes and production in this sector, as the productions of these goods respond to the policies that encourage countries to produce green energy such as the Paris agreement. One interesting finding is the existence of misspecification error for the case of electricity using NARDL. However, there exists a linear short-run effect of USD changes on production for electricity which does not last into the long-run. The possible explanation for these findings could be due to the nature of electricity. Zohuri (2015) defines electricity as a necessity. Necessity goods are relatively price inelastic which further explains the findings. Additionally, our findings for non-durable manufacturing suggest misspecification error. Non-durable manufactured goods, such as food and clothes are frequently consumed. As a result, the nature of the production of non-durable goods heavily relies on seasonal variation. Although the data used are seasonally adjusted, however, apart from seasonal cyclical and secular forces, there are nonrecurring events such as unusual weather, or natural disasters or regulatory changes that could affect the production of these types of goods (McKelvey 2008). According to McKelvey (2008), seasonal adjustments are not well handled in some cases, For example, non-durable manufactured goods such as clothing are purchased relatively higher when Easter approaches, and the demand will go back to normal after this period. The problem arises when such impacts are hard to be accounted for (e.g. as the time of Easter varies from one year to another).

5 Concluding remarks

In this study, we were inspired to capture non-linearities in the nexus between exchange rate and production of eight sectors. Therefore, we build a NARDL model based on the standard neoclassical production function by Solow (1956). We conclude that exchange rate changes only affect the production of sectors for which the output prices are not controlled by other factors such as commodity prices, the nature of the good produced and price elasticity of demand. We conclude that USD appreciation and depreciation have different but positive effect on the production of non-energy materials with a significant but not high import content of exports. We also show that USD appreciation has positive effect on production in the sectors with high import content of exports. Additionally, the results show that the exchange rate depreciation has positive long-run effect on the production of consumer goods with close to zero import content of exports.

We support the assumption and implications of our model with the level of import content of exports reported by OECD (2012) as well as formal statistical inference.

Our empirical results support the predictions of our theoretical model by measuring the effects of USD depreciation and appreciation separately. We document that USD exchange rate changes have non-linear short-run effects on the production of non-energy materials, durable manufacturing, consumer goods and business equipment and these effects last into the long-run. On the contrary, exchange rate movements have merely a short-run "linear" effect on the production of electricity. There are no effects of exchange rate changes for the sectors related to energy such as energy material, and mining. Implicitly, these findings are justified with the nature of production in each sector.

The findings carry essential implication for the optimal exchange rate regime in the U.S. We recommend keeping the free float exchange rate regime. Our recommendation is based on the effects of U.S. dollar movement on the selected sectors which differ significantly due to the structure of import content of exports and trade value added as well as other variables. Therefore, any attempt to peg, increase or decrease the value of the U.S. dollar to positively influence any sectors might have adverse effects on other sectors. Moreover, sustaining a free float regime in the U.S. without any interventions would result in the natural growth of all sectors. One might argue that the export share of one or a combination of sectors to the aggregate export might be significant enough to intervene in the market. However, for a healthy economy that does not solely depend on any sector for growth, development of all the sectors are of importance.

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Authors' contributions
Our first contribution to the existing literature is that we suggest consideration of non-linear framework to measure the effects of exchange rates on the production of U.S. sectors due to the role of import content of exports. Secondly, we provide new empirical evidence of non-linearities in the relationship between USD exchange rate and industrial production in several sectors of the U.S. economy. It is widely acknowledged that the depreciation of currencies helps to boost exports and outputs. Based on this idea, governments can intervene in the market by depreciating currencies to gain international market and increase employment. Existing literature assume a linear relationship between exchange rate changes and output. That is, if depreciation is expansionary, appreciation is contractionary. However, it is possible that exchange rate changes to have ambiguous effects on production. The author read and approved the final manuscript.

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Availability of data and materials
The datasets generated and/or analysed during the current study are publically available. Observations for the variables Industrial production indices(IPI), as well as gross fixed capital formation (GFCF), are collected from the Federal Reserve Bank of St. Data for nominal effective exchange Rates (NEERs), consumer price index (CPI), as well as money supply (M2), are collected from the Bank of International Settlements. Data related to labour (*L*) are obtained from the RI Department of Labor and Training. Data for import content of exports that support the findings of this study are available from OECD website.

Competing interests
The author declares no competing interests.

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References

Adhikari DR (2016) Effect of recent U.S. monetary policy on its balance of trade. J Dev Areas 50(3):381–388. https://doi.org/10.1353/jda.2016.0101

Bahman Z (2015) Application of compact heat exchangers for combined cycle driven efficiency in next generation nuclear power plants: a novel approach. Springer, New York

Bahmani-Oskooee M, Hegerty SW (2007) Exchange rate volatility and trade flows: a review article. J Econ Stud 34(3):211–255. https://doi.org/10.1108/01443580710772777

Bahmani-Oskooee M, Mohammadian A (2017) Asymmetry effects of exchange rate changes on domestic production in japan. Int Rev Appl Econ 31(6):774–790

Batten DS, Ott M (1985) The interrelationship of monetary policies under floating rxchange rates: note. J Money Credit Bank 17(1):103–110. https://doi.org/10.2307/1992510
Birkhoff G, Garabedian HL (1960) Smooth surface interpolation. J Math Phys 39(1–4):258–268. https://doi.org/10.1002/sapm1960391258
Blau FD, Kahn LM, Papps KL (2011) Gender, source country characteristics, and labor market assimilation among Immigrants. Rev Econ Stat 93(1):43–58. https://doi.org/10.1162/REST_a_00064
Broz JL, Werfel SH (2014) Exchange rates and industry demands for trade protection. Int Organ 68(2):393–416. https://doi.org/10.1017/S002081831300043X
Bureau of Labor Statistics (2018) Employment by industry, 10 2018. URL https://www.bls.gov/charts/employment-situation/employment-levels-by-industry.htm
CNB (2016) The impact of the Balassa-Samuelson effect on prices in the domestic economy. URL https://www.cnb.cz/en/monetary-policy/inflation-reports/boxes-and-annexes-contained-in-inflation-reports/The-impact-of-the-Balassa-Samuelson-effect-on-prices-in-the-domestic-economy
Caglayan M, Di J (2010) Does real exchange rate volatility affect sectoral trade flows? South Econ J 77(2):313–335
Engel C (1999) Accounting for U.S. real exchange rate changes. J Polit Econ 107(3):507–538. https://doi.org/10.3386/w5394
Fair RC (1982) Estimated output, price, interest rate, and exchange rate linkages among countries. J Polit Econ 90(3):507–535
Golub SS (1994) Comparative advantage, exchange rates, and sectoral trade balances of major industrial countries. Staff Papers 41(2):286–313
Guzman M, Ocampo JA, Stiglitz JE (2018) Real exchange rate policies for economic development. World Dev 110:51–62. https://doi.org/10.1016/j.worlddev.2018.05.017
Jareño F, Negrut L (2016) Us stock market and macroeconomic factors. J Appl Bus Res 32(1):325
Kilesen KL, Tatom JA (2013) US. manufacturing and the importance of international trade: it's not what you think. Federal Reserve Bank of St. Louis Rev 95(1):27–49
Klein Michael W (1990) Sectoral effects of exchange rate volatility on united states exports. J Int Money Finan 9(3):299–308
Kravis Irving B, Lipsey Robert E (1978) Price behavior in the light of balance of payments theories. J Int Econ 8(2):193–246. https://doi.org/10.1016/0022-1996(78)90022-3
Lal AK, Lowinger TC (2002) Nominal effective exchange rate and trade balance adjustment in south asia countries. J Asian Econ 13(3):371–383
McKelvey EF (2008) Understanding US economic statistics. Goldman Sachs Economic Research Group, New York
Nakibullah A (2007) Comovements of budget deficits, exchange rates, and outputs of traded and non-traded goods. Econ Inquiry 31(2):298–313. https://doi.org/10.1111/j.1465-7295.1993.tb00884.x
OECD (2019) Global Value Chains (GVCs). URL https://www.oecd.org/sti/ind/global-value-chains.htm
OECD (2012) STAN input-output: imports content of exports. https://doi.org/10.1787/data-00578-en
Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16(3):289–326
Samuelson PA (1994) Facets of Balassa–Samuelson thirty years later. Rev Int Econ 2(3):201–226. https://doi.org/10.1111/j.1467-9396.1994.tb00041.x
Sapsford D (1987) The determinants of the demand for internationally traded primary commodities: an empirical analysis. J Econ Stud 14:55–60. https://doi.org/10.1108/eb002648
Shin Y, Yu B, Greenwood-Nimmo M (2014) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ardl framework. Festschrift in honor of Peter Schmidt. Springer, New York, pp 281–314
Solow R (1956) A contribution to the theory of economic growth. Q J Econ 70(1):65–94
Stanford University (2018) Energy materials & environmental materials. URL https://mse.stanford.edu/research/energy-materials-environmental-materials
Verheyen F (2013) Exchange rate nonlinearities in emu exports to the us. Econ Model 32:66–76

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