

Investigating the Nexus among Sulfur Dioxide Emission, Energy Consumption and Economic Growth: Empirical Evidence from Pakistan

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1 **Investigating the Nexus among Sulfur Dioxide Emission, Energy Consumption and**
2 **Economic Growth: Empirical Evidence from Pakistan**

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16 **Abstract**

17 Developing countries like Pakistan majorly depends on fossil fuels for achieving higher
18 economic growth but have sloppy environmental rules and regulations in order to attract
19 foreign direct investment (FDI). As a result, energy consumption is considered as the
20 primary cause of environmental degradation. Besides CO₂ emission, environmental
21 degradation is also associated with emission of sulfur dioxide (SO₂). The purpose of this
22 study was to investigate the relationship among SO₂ emissions, energy consumption,
23 economic growth and FDI in Pakistan. By applying the 3SLS method study has estimated
24 the scale effect, composition effect and technique effect. The scale effect and technique
25 effect findings indicated that capital stock, FDI, and SO₂ emissions all had a significant
26 impact on GDP. When the capital accumulation effects of FDI were considered, the

27 relationship between FDI and stock of capital was found to be positive. According to the
28 technique effect results, FDI, population density, and energy consumption were all
29 significantly related to SO₂ emissions. The study came to a conclusion with significant
30 policy implications.

31 **Keywords:** SO₂ emission; Energy consumption; Economic growth; FDI; Pakistan

32

33 **1. Introduction**

34 Rapid economic growth in developing countries like China, India and Pakistan has led to
35 increased energy consumption. Developing countries heavily depend on fossil fuels for
36 energy generation and consumption. The massive use of the energy especially from fossil
37 fuels causes severe environmental degradation. Emitters such as CO₂, SO₂ and
38 particulate matter from energy consumption lead to air pollution. Although other factors
39 also contribute in pollution emission, fossil fuel consumption causes the larger amount of
40 pollution emissions. Yilanci et al. (2020) assert that long-term impact of energy
41 consumption leads to pollution emission. Literature showing the role of energy
42 consumption in CO₂ emission is rich and recent (Bakhsh et al., 2017, Guzel and Okumus,
43 2020, Salahuddin et al., 2020, Udenba et al., 2020). Considering SO₂ emission, it
44 depends on the sulfur content of the fossil fuels, in addition to the sectoral processes
45 leading to pollutant emission. SO₂ oxidizes in the atmosphere to form aerosol thereby
46 influencing climate.

47 Major sources of SO₂ emission are energy, transportation, industries, agriculture, forest
48 and livestock. Fig. 1 shows different sources of SO₂ emission. Electric utilities including
49 electric power plants and refineries are the major sources of SO₂ emission. Point sources
50 excluding electric utilities are vehicles operating on roads, highways and streets. These
51 are among the second major sources of SO₂ emission. Residential wood burning,
52 gasoline service stations, dry cleaners, wildfires and agriculture tilling are among the
53 non-point sources of SO₂ emission. Non-road sources of So₂ emission include lawn and
54 garden equipment, aircrafts, locomotives, construction equipment and recreational
55 equipment.

56 The main economic source of SO₂ emission is the industrial sector as it consumers a
57 larger quantity of energy sources. This sector highly relies on the consumption of fossil
58 fuels in developing countries including Pakistan. Further, industrial processes containing
59 sulfur such as electricity generation from oil, gas and coal cause SO₂ emission. Thus
60 industrial sector is highly related to SO₂ emission to the environment in Pakistan and
61 other developing countries. Yang and Shan (2019) argue that industrialization, economic
62 scale and energy consumption effects are major contributing factors of SO₂ emission

63 developing countries are facing challenge of increasing economic growth and reducing
64 pollutant emissions to realize sustainable economic development with clean environment
65 and prosperous economy. Increasing renewable energy consumption and energy
66 efficiency can reduce pollution emission. Contrary to renewable energy consumption,
67 non-renewable energy consumptions lead to environmental degradation (Nathaniel et al.,
68 219; Hu et al., 2019; Zafar et al., 2019; Destek and Sinha, 2020). Technology, energy
69 mix, sulfur efficiency, industrial structure and energy efficiency effects are associated
70 with a dwindling SO₂ emission (Yang and Shan, 2019). Energy prices are also important
71 in mitigating pollutant emissions (Hanif et al., 2019, Ngugen et al., 2020). Stringent
72 energy policy with strong control on energy prices can reduce energy consumption,
73 increase energy efficiency and decrease pollutant emissions.

74 The role of foreign direct investment inflows in developing countries is of paramount
75 importance in increasing economic growth. There is rich literature examining relationship
76 between economic growth and FDI (see Anwar and Nguyen, 2010, Bakhsh et al., 2017,
77 Nadeem et al., 2020, Tsang and Yip, 2007). Shahbaz et al. (2018) and Hanif et al. (2019)
78 find huge contribution of FDI to economic growth in the host countries. Increasing
79 economic growth happens at the cost of environmental pollution. Many studies show a
80 positive relationship between economic growth and SO₂ emission (Coggin, 2019, Hu et
81 al., 2019, Nadeem et al., 2020, Ramakrishnan et al., 2016, Wu, 2019). Ru et al. (2018)
82 and Wang et al. (2016) argue that there exists environmental Kuznet Curve (EKC) pattern
83 of relationship between economic growth and SO₂ emission. This implies that SO₂
84 emission increases with an increase in economic growth, reaches a maximum point and
85 then pollution emission starts declining with further economic progression.

86 Developing countries relax environmental rules and regulations to attract FDI inflows in
87 order to boost economic growth. Most importantly, FDI inflows are made in energy and
88 industrial sectors using natural resources namely oil, gas and coal. Hassaballa (2014)
89 shows bidirectional causality between FDI and energy consumption in the developing
90 nations. Resultantly, FDI has positive impact on SO₂ emission in the host country (Zhu et
91 al., 2017). Thus FDI is related to pollution emissions thereby adversely affecting
92 environment (Omri et al., 2014; Tang and Tan, 2015; Shahbaz et al., 2015). However,

93 Nadeem et al. (2020) find a negative long-term relationship between FDI and SO₂
94 emission. This happens because pollutant emission rises with the progression of the
95 economy, reaches a maximum point and then starts declining with further economic
96 growth (Shahbaz and Sinha, 2019, Shahbaz et al., 2019). In addition to adverse impacts,
97 FDI inflows are also considered to have an important contribution in promoting better
98 environmental awareness and environmental friendly technology in the developing
99 countries (Zeng and Easten, 2012).

100 The relationship between FDI and pollution emission through an increase in income or
101 energy consumption in the existing literature is still debatable because of mixed findings
102 with regards to directionality (, Saboori et al., 2012, Omri and Kahouli, 2014; Shahbaz et
103 al. 2015). There are some studies showing unidirectional relationship between FDI and
104 pollution emission (Jaunky, 2010, Nasir and Rehman, 2011), others find bidirectional
105 relationship (Halicioglu, 2009, Soytas and Sari, 2009) and there are some studies
106 showing no relationship (Richmond and Kaufmann, 2006).and Zhang (2011) and Apergis
107 Payne (2009) show mixed results of relationship between carbon emissions and income
108 level of countries. Inconclusive relationship between FDI, pollutant emission and
109 economic growth can be because of regional differences in environmental regulation,
110 given the different sources, processes and economic factors. Zho et al. (2017) asserted
111 that environmental regulation and land use are significant factors on the spatial pattern of
112 SO₂ emission. Thus the effects of FDI on pollutant emission can be heterogeneous across
113 countries. Pakistan is a developing country and it has diverse customized energy sources,
114 processes, environmental regulation and economic conditions compared to other
115 developed countries. Therefore, SO₂ emission can have distinct emission trajectories.
116 Further, industrial sector is considered the main economic source of SO₂ emission as it
117 consumes electricity 25%, oil 19% and gas 8%. Contribution of industrial sector in gross
118 domestic product is 20.19% (GoP, 2018). CO₂ and SO₂ are among the major pollutants
119 emitted from industrial processes and other economic activities. SO₂ emission
120 deteriorates ambient environment quality causing greater threats to human health whereas
121 CO₂ emission causes global warming, in addition to threatening human health. Thus it is
122 imperative to understand the economic growth, energy consumption and SO₂ emission
123 nexus at country level. Nordhaus (2010) and Stern and van Dijk (2017) maintain that it is

124 the useful way to examine the emissions associated with social and economic
125 development.

126 This study has several departures from the earlier work on FDI, economic growth and
127 pollution emission. First, we look into SO₂ emission instead of CO₂ because of ambient
128 effects of SO₂ emission. We used SO₂ for two main reasons. Firstly, there is direct link
129 between SO₂ emission and industrial output. Cherniwachan (2012) asserted that 1%
130 increase in industrial share of output leads to 11.8% increase in per capita SO₂ emission.
131 Secondly, the effects of SO₂ emission are ambient rather than global. Second departure
132 from the literature is that we employ three stage least square (3SLS) method which is
133 conceptually stronger and empirically robust, besides being more appropriate to find out
134 trilateral nexus of FDI, environmental pollution and economic growth. Many studies
135 relating to Pakistan determined relation between FDI and economic growth but very few
136 studies estimated the relation between FDI, economic growth and environmental
137 pollution (Mahmood and Chaudhry, 2012; Bakhsh et al., 2017; Yasmeen et al., 2019,
138 Wang et al., 2019). However, we find that these studies don't consider the mechanisms
139 through which foreign investment impacts environmental pollution particularly SO₂
140 emission. SO₂ emission leading to environmental degradation causes huge losses to
141 human health and economic growth. The present study is contributing in the form of
142 considering the effects of FDI inflows on pollution emission, economic growth and capital
143 accumulation employing three stages least square (3SLS) method for solving
144 simultaneous equation system. This econometric method is considered more efficient
145 than two stage least square (2SLS) method because correlation between unobserved
146 disturbances across various equations in the system is allowed in 3SLS. Because of this
147 advantage, we employed 3SLS method in the present study. Findings of the 3SLS method
148 provide important policy insights for regulating FDI for environmental friendly and
149 efficient economic growth. This study also sheds light on the role of FDI in capital
150 accumulation. Thus, the country like Pakistan can gain the benefits of FDI in the
151 economic growth in the long-run while working on and designing environmental friendly
152 policies to pave the way for environmental sustainability.

153 The remaining paper is arranged as follows: The first sub-section of section
154 2 describes data and sources. Second sub-section provides details on 3SLS method
155 employed in the present study. Sections 3 contain findings of 3SLS method including
156 technique effect, scale effect and composition effect findings of the study are compared
157 with the literature in this section as well. Section 4 gives conclusions and
158 recommendations.

159 **2. Material and Methods**

160 **2.1 Data and source**

161 There are different sources of SO₂ emission in Pakistan. They include energy, industrial
162 processes, agriculture, land use change and forestry, and wastes. SO₂ emission has
163 increased from 775 thousand tons in 1994 to 1041 thousand tons in 2015 recording an
164 increase of 34.3%. Since industrial and agricultural sectors are the major consumers of
165 oil, gas and coal, these are the main economic sources of SO₂ emission in the country.
166 Economic growth thus substantially depends on performance of agricultural and
167 industrial sectors. Further, economic growth is function of capital formation, employment
168 and FDI. FDI embodies some indirect benefits and costs in the form of bad
169 environmental quality (Lucas, 1988; Romer, 1990). In order to explore the empirical
170 relation among FDI, energy consumption, SO₂ emission and economic growth, annual
171 data was used for the period of 1975 to 2015. We were interested to consider the
172 relationship between SO₂ emission, energy consumption and economic growth at
173 different sector levels. However, the data on SO₂ emission is not available on sector
174 levels from 2011 to onward. Therefore, we planned the study at country level. Table 1
175 provides information on definition of variables and sources of data. Different sources
176 were used to collect data on the real gross domestic product (US\$ million), gross fixed
177 capital formation (US million dollar), capital intensity, investment (US\$ million),
178 industrialization (% of GDP), FDI (US\$ million) and population density (persons living
179 in one square kilometer). Data on energy (kt as energy use equivalent to oil) was taken
180 from World Development Indicators (WDI). Data on SO₂ emissions (giga tons) was
181 taken from two sources. WDI was used to collect data from 1975-2010 whereas the
182 remaining data from 2011 to 2015 was obtained from GoP (2018a). Standard method was

183 used to generate missing values of SO2 emission for some years. For smooth and easy
184 interpretation of the results, log form of data was used in the estimation.

185 **2.2 Empirical Methods**

186 Copeland and Taylor (2003) suggest that emission can have three types of effects namely
187 scale effect, technique effect and composition effect. Scale effect refers gross domestic
188 product whereas ratio of industrial output to gross domestic product is known as
189 composition effect. Technique effect is defined as the ratio of pollution to industrial value
190 added. In the present study, sulphur dioxide (SO₂) is used as a pollutant. When we
191 examine the scale effect, technique effect and composition effect, there is a problem of
192 simultaneity. Hausman test was used to find simultaneity problem while rank and order
193 conditions were used for identification problem. Because of the existence of correlation
194 between unobserved disturbances across a simultaneous equations system as it is the case
195 in the present study, 3SLS technique was employed to estimate environmental effects of
196 FDI. Fig. 2 shows steps used in 3SLS empirical method. 3SLS technique has advantages
197 over single equation estimates and 2SLS (see Bakhsh et al., 2017, Bao et al., 2010).
198 Decomposition of pollution emission into three effects can be written as:

$$199 \quad \text{pol} = \text{gdp} + \text{tech} + \text{comp} \quad (1)$$

200 Eq. 1 is the identical equation showing pollution indicators resulting from FDI (Bakhsh et
201 al., 2017, Bao et al. 2010). Sulfur dioxide (SO₂) is taken as pollution indicator. SO₂ is
202 dependent variable in Eq. 1 whereas explanatory variables include scale effect,
203 composition effect and technique effect.

204 A system of six equations is used to simultaneously estimate three effects of FDI on
205 emissions and growth in Pakistan. The impact of FDI on the economic scale is measured
206 by using Eq. 2(Bakhsh et al., 2017, Bao et al. 2010).

$$207 \quad \text{gdp} = \alpha_0 + \alpha_1 \text{fdi} + \alpha_2 k + \alpha_3 \text{polu} + \alpha_4 \text{pol}_{t-1} + \alpha_5 \text{time} + \varepsilon_1 \quad (2)$$

208 Here *gdp* shows gross domestic product of Pakistan, FDI is shown by *fdi*, stock of
209 capital is represented by *k*, and *polu* is SO₂ emission in Pakistan. α_0 to α_5 are parameters
210 to be predictable. ε_1 is white noise error term. We expect a negative sign for coefficient of
211 pollution emission variable because of its damaging effect. FDI is directly related to
212 economic growth as indicated by Cole et al. (2011) whereas physical capital in the

213 country also increases indirectly with an increase in FDI (Zhang et al., 2004). Eq. 3
 214 shows estimation procedure of the indirect effect of FDI on financial advancement
 215 (Bakhsh et al., 2017, Bao et al. 2010).

$$216 \quad k = d_0 + d_1 fdi + d_2 (gdp_{t-1}) + d_3 (gdp_{t-2}) + \alpha_4 time + \varepsilon_2 \quad (3)$$

217 One and two periods of lagged GDP values are used to measure the impact of economic
 218 growth and environmental asymmetries on development. We employed Eq. 4 for
 219 estimating technique effect (Bakhsh et al., 2017, Bao et al. 2010).

$$220 \quad tech = \beta_0 + \beta_1 fdi + \beta_2 gdp + \beta_3 pd + \beta_4 eng + \beta_5 time + \varepsilon_3 \quad (4)$$

221 Here technique effect is shown by *tech*, *fdi* shows FDI, *pd* represents population
 222 density, *eng* is energy consumed in Pakistan, *time* is time period as a proxy for
 223 technology development in the country. β_0 to β_5 are parameters to be estimated. The
 224 increase in per capita income is expected to increase economic activity, which in turn
 225 leads to an increase in demand for a healthier environment. Further, an increase per capita
 226 income also implies allocation of resources for protecting the environment and abating
 227 pollution as indicated by Grossman and Kruger (1995) and Pao and Tsi (2010). Eq. 5 is
 228 used to estimate this type of the effect while considering composition effect (Bakhsh et
 229 al., 2017, Bao et al. 2010).

$$230 \quad comp = \delta_0 + \delta_1 fdi + \delta_2 k/l + \delta_3 gdp + \delta_4 time + \varepsilon_4 \quad (5)$$

231 *comp* shows composition effect and it is measured as industrial output to GDP, *k/l* is
 232 capital to labor ratio, δ_0 to δ_4 are parameters to be estimated. Higher physical capital
 233 stock increases industrial output, which leads to rising level of SO2 emission. The effect
 234 of GDP on dependent variable can be of two types. First it indicates higher level of
 235 industrialization in the country and second, it represents the increased demand for cleaner
 236 environment when per capita GDP rises due to industrialization.

237 Before taking decision about FDI inflows in any developing host country, the developed
 238 countries consider time and country specific factors. Eq. 6 is used to examine the factors
 239 affecting FDI inflows in Pakistan (Bakhsh et al., 2017, Bao et al. 2010).

$$240 \quad fdi = \gamma_0 + \gamma_1 fdi_{t-1} + \gamma_2 ind_{t-1} + \gamma_3 inv_{t-1} + \gamma_4 pol + \gamma_5 time + \varepsilon_5 \quad (6)$$

241 System of equations have endogeneity issue, thus we have taken one period lagged value
 242 of FDI in the model to avoid endogeneity. We include domestic investment,

243 industrialization and pollution emission level to see the effect of decision to invest in
 244 Pakistan.

245 The above system of equations shows mechanisms by which FDI may have influence on
 246 pollution emissions in the host nation. The direct effects of FDI on pollution emission can
 247 be measured by the coefficients namely d_1 , β_1 and δ_1 . FDI affects indirectly pollution
 248 emissions through its effect on GDP when greenhouse gas emissions and industrial
 249 composition vary with economic development. The indirect effect can be jointly
 250 measured by a_1 and $\beta_5(\delta_4)$. In addition, the indirect impact of FDI on toxic greenhouse
 251 gas emissions can be measured by the adverse effect on economic development, which
 252 has effects on both the scale effect and the composition effect. Furthermore, feedback
 253 implication of emissions (SO₂ in the present study) on economic growth is also
 254 considered.

255 We also estimated the composite effect of foreign direct investment on the emission of
 256 SO₂ in Pakistan using methods used by Bao et al. (2010). The total effect of FDI on SO₂
 257 emission can be estimated using Eq. 7 as under:

$$258 \quad \frac{\partial polu}{\partial fdi} = \frac{(\beta_1 + \delta_1 + \delta_2 d_1) + (1 + \beta_2 + \delta_3)(a_1 + a_2 d_1)}{1 - (1 + \beta_2 + \delta_3)a_4} \quad (7)$$

259 Scale effect is estimated using Eq. 8. All identities given in equation are defined earlier.

$$260 \quad \frac{\partial gdp}{\partial fdi} = \frac{(\beta_1 + \delta_1 + \delta_2 d_1)a_4 + (a_1 + a_2 d_1)}{1 - (1 + \beta_2 + \delta_3)a_4} \quad (8)$$

261 The technique effect is determined using Eq. 9 as under:

$$262 \quad \frac{\partial tech}{\partial fdi} = \beta_1 + \frac{(\beta_1 + \delta_1 + \delta_2 d_1)a_4 + (a_1 + a_2 d_1)}{1 - (1 + \beta_2 + \delta_3)a_4} \beta_2 \quad (9)$$

263 The composition effect of FDI on (SO₂) emissions is appraised by using Eq. 10:

$$264 \quad \frac{\partial comp}{\partial fdi} = \frac{(d_1 + d_2 b_1)(1 - a_4 - a_4 \beta_2) + \delta_3(a_1 + a_2 d_1) + \beta_1 a_4 \delta_3}{1 - (1 + \beta_2 + \delta_3)a_4} \quad (10)$$

265 a_1, β_1 and δ_1 are the direct parameters of the scale, technique and composition effects of the
 266 FDI respectively. Capital accumulation emphasizes the importance of FDI inflows in the
 267 country. It is given by the coefficient of capital accumulations. Thus, capital

268 accumulation accelerates economic activity through scale effect. The formula
269 $d_1(a_2 + \delta_2)$ being measured indirect effect of capital accumulation of FDI in the country.
270 The technical and compositional effects are used to show the level of economic growth
271 and emissions of pollution. Scale effect is used to show the feedback impact of pollution
272 emissions on economic growth. The scale effect can have impact on technique effect and
273 composition effect $(\beta_2 + \delta_3)$ and we can see the total feedback effect by the measure
274 $\beta_2(1 + \beta_2 + \delta_3)$. All notations used in the above equations are defined in Appendix A.

275 **3. Results and discussions**

276 Foreign direct investment is associated with toxic greenhouse gas emissions and
277 economic development in the host country. To examine these effects, we employed
278 3SLS. A system of six equations are considered in the present study, however, Eq. 1 is
279 identity equation, so it is not possible to estimate it directly. The remaining five equations
280 are measured to determine the impact of FDI on growth and emissions of SO₂. Table 2
281 shows estimates of scale effect. We find that the coefficient of (*fdi*) is negative and
282 statistically significant. Increased pollution in the country causes various environmental
283 and health hazards and erodes PakRs450 billion per year (GOP, 2014). Although all
284 economic sectors are recipient of FDI in Pakistan, major FDI inflow is recorded in
285 industrial sector. Weak institutions and less political stability are some of the reasons for
286 no or little control on pollution emission. The findings of the study vary considerably
287 from those of the studies Shahbaz et al., 2018 and Hanif et al., 2019,) which show a
288 positive impact of FDI on economic growth. However, Omri et al. (2014) found a bi-
289 directional causal relationship between emissions, economic growth and FDI.

290 Pollution variable i.e. The emission of SO₂ is an important factor in the growth of GDP
291 and therefore is the key concern of the present study. Copeland and Taylor (2003) point
292 out that pollution is important factor of production in the country, besides labor and
293 capital. An increase in SO₂ emission increases economic growth significantly. Pollution
294 emission in developing countries including Pakistan is positively to with economic
295 growth. Ample evidence of empirical work show that economic growth and greenhouse
296 gas emissions are positively associated (Chaabouni, Zghidi and Mbrake, 2016; Ahmad
297 and Du, 2017; Alvarado et al., 2018; Ma et al., 2016; Ali et al., 2019; Nadeem et al., 2020,

298 Saidi and Mbarek, 2016, Wang et al., 2016). Lax environmental rules and regulations in
299 Pakistan induces firms to emit pollutants in the environment. Capital (k) is also
300 statistically significant implying that it has positive relation with economic growth.

301 Table 3 shows the estimates of capital accumulation effect of FDI in Pakistan. We
302 observe a positive association between FDI and capital accumulation which is
303 statistically significant. Bakhsh et al. (2017) also found similar relationship in their study.
304 Economic growth during the previous year also affects physical capital accumulation in
305 the present year. To consider this effect, we have taken lagged value of gross domestic
306 product in the capital accumulation effect (see Eq. 3). We find that previous year
307 economic growth is significant and negatively related with capital accumulation in
308 Pakistan. To see the influence of FDI on economic growth, it is estimated by using Eq. 3,
309 we find 0.1287 total scale effect of foreign direct investment while considering SO₂
310 emission. This scale effect is larger than estimate of Bakhsh et al. (2017) for CO₂
311 emission.

312 Results of technique effect for SO₂ emission and FDI are given in Table 4. A positive
313 and significant coefficient of FDI implies that FDI inflows in the country increase
314 marginal pollution damage. Foreign investors don't use environmental friendly
315 technology in the developing countries because they are more interested in low cost
316 production benefits (Lan *et al.*, 2012). Thus FDI causes a significant environmental
317 degradation in the host countries due to lax environmental monitoring and regulations.
318 Countries with slow rates of increasing consumption activities found moderate economic
319 growth rates and emissions (Díaz and Cancelo, 2009, Luqman et al., 2019). Wang et al.
320 (2016) argue that environmental degradation is related with positive association between
321 high energy consumption and emissions. Population density has a strong and substantial
322 effect on SO₂ emissions. This significant positive relationship shows that a rise in
323 population density also increases marginal environmental damage. Increased
324 environmental damage associated with increasing population density warrants for
325 pollution control measures to protect environment. Many studies also find this type of
326 relationship (Doytch and Uctum, 2016, Zhang and Zhu, 2016). Gross domestic product
327 (gdp) is negatively related with marginal pollution damage. Yavuz (2014) finds a long-
328 term reverse effect of economic growth on pollution emissions and suggests that the

329 economic activity itself would contribute to a decrease in emissions from pollution.
330 Energy consumption is positively related with marginal environmental damage in the
331 present study. Alvarado et al. (2018) and Cherni and Jounini (2017) explains a rise in
332 fossil fuel consumption as being related to economic growth. Ample evidence shows an
333 increase in energy consumption leading to pollution emission (Zhu et al., 2016; Behera
334 and Dash, 2017, Baek, 2016, Tang and Tan, 2015). The use of fossil fuels is the primary
335 source of pollution emissions namely SO₂ and CO₂. Based on the above topic, FDI raises
336 pollution, demonstrating that the technological impact is incapable of regulating or
337 reducing industrial pollution emissions, like SO₂ as foreign firms use obsolete
338 technologies in the manufacturing process due to weak environmental regulations.
339 Although environmental laws for preventing or reducing pollution emissions exist, these
340 laws are not implemented in true letter and spirit in order to attract FDI in the country.
341 All this would have a detrimental long-term impact on economic growth
342 (Jayanthakumaran et al., 2012).

343 Estimates of composition effects are reported in Table 5. Results show that a rise in FDI
344 and a contribution of industrial production in the economy has positive and statistically
345 significant impacts. The ratio of capital labor is an important compositional impact
346 indicator. Taking into account the k / l coefficient, we find that this vector induces an rise
347 in the share of industrial production in the economy. It happens primarily because the
348 manufacturing sector produces more toxic contamination as a result of capital-intensive
349 products production (Antweiler et al., 2001)

350 Table 6 shows the estimates of determinants of FDI. Coefficient of investment implies
351 that more investment by public and private sectors attracts more investment, possibly due
352 to indication of conducive environment for production and cost advantages. Self-
353 accumulation effects of FDI are estimated by taking lagged value of FDI. Statistically
354 significant and positive coefficient shows that economic conditions of the country during
355 the previous years attracted more FDI. Low cost of production and slack environmental
356 standard operating procedures are the possible reasons.

357 Table 7 reports various effects of FDI on SO₂ emission and these estimates are based on
358 Bao et al. (2010) formulae discussed in the previous section. We find a negative estimate
359 of total effect of FDI on SO₂ emission in the country. In the present study, the scale

360 effect of FDI is positive. It indicated that an increase in FDI is causing a rise in gross
361 domestic product. Our finding is consistent with that of Bao et al. (2010), who also find
362 negative relationships between environmental pollution and FDI. The country with lax
363 environmental rules, regulations and management always exhibits negative technique
364 effect even it is economically progressing (Mahmood and Chaudhary, 2012). However,
365 indirect composition effect is positive, implying that FDI inclusively increase the increase
366 the host country's share of industrial sector in GDP.

367 The present study has a few limitations. It considered data at country level to examine
368 economic growth, energy consumption and SO₂ emission. It would have been great if
369 SO₂ emission at different sector and or provincial level were considered. Since the data
370 on SO₂ emission at sectoral and provincial levels is not available, future research should
371 consider this limitation when the data becomes available. This study is limited to only
372 Pakistan. Expanding the study at South Asian level can yield interesting findings. Taking
373 only SO₂ emission is another limitation of the study. In future, all greenhouse gas
374 emissions should be considered while examining the economic growth, SO₂ emission
375 and energy consumption nexus.

376 **4. Conclusions and policy implications**

377 Economic growth and FDI are significantly related in the host country. FDI increases
378 environmental pollution such as SO₂ and CO₂ emissions. The present study explored
379 relations of FDI, SO₂ emission, energy use and economic growth using 3SLS in Pakistan.
380 Results of technique effect showed that SO₂ emission and capital had positive effect on
381 gross domestic product whereas FDI was negatively related to economic growth.
382 Technique effect method showed that FDI, population density and energy consumption
383 are positively related with SO₂ emission and gross domestic product is negatively
384 associated with SO₂ emission. In composition effect, FDI is positively related with
385 industrial output. FDI in the previous years and investment by public and private sector in
386 the host country were significant factors of FDI inflows. However, we found the negative
387 impact of SO₂ emission on FDI inflows in the present study.

388 In spite of environmental degradation linked with FDI inflows, the developing countries
389 provide various incentives including lax environmental rules to foreign investors for
390 speeding economic growth, building capital stock and generating opportunities to the

391 skilled and unskilled labor force. Findings of the study reveal that the recipient of FDI
392 should emphasize the impacts of FDI on environmental quality because degrading
393 environment costs the economy in the long-run. The need is also to develop
394 environmental friendly technology required during production processes. This
395 necessitates the role of research and development activities to move in this direction.
396 Recent estimates showing annual loss of PakRs450 billion owing to environmental
397 degradation sensitize policymakers and other concerned to recognize the importance of
398 environmental concerns in Pakistan. Therefore, Pakistan has started taking strategic
399 measures to control environmental degradation. Similarly private sector especially
400 industrial sector has to play a crucial role in overcoming SO₂ emission. Although
401 regulatory bodies exist to monitor pollution emissions, there is still need to strengthen
402 these institutions for effective implementation of environmental rules and regulations.

403

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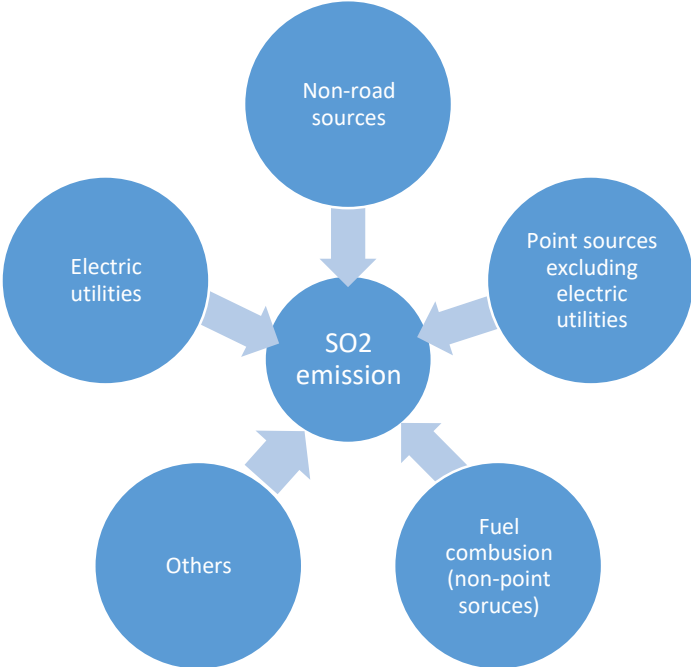
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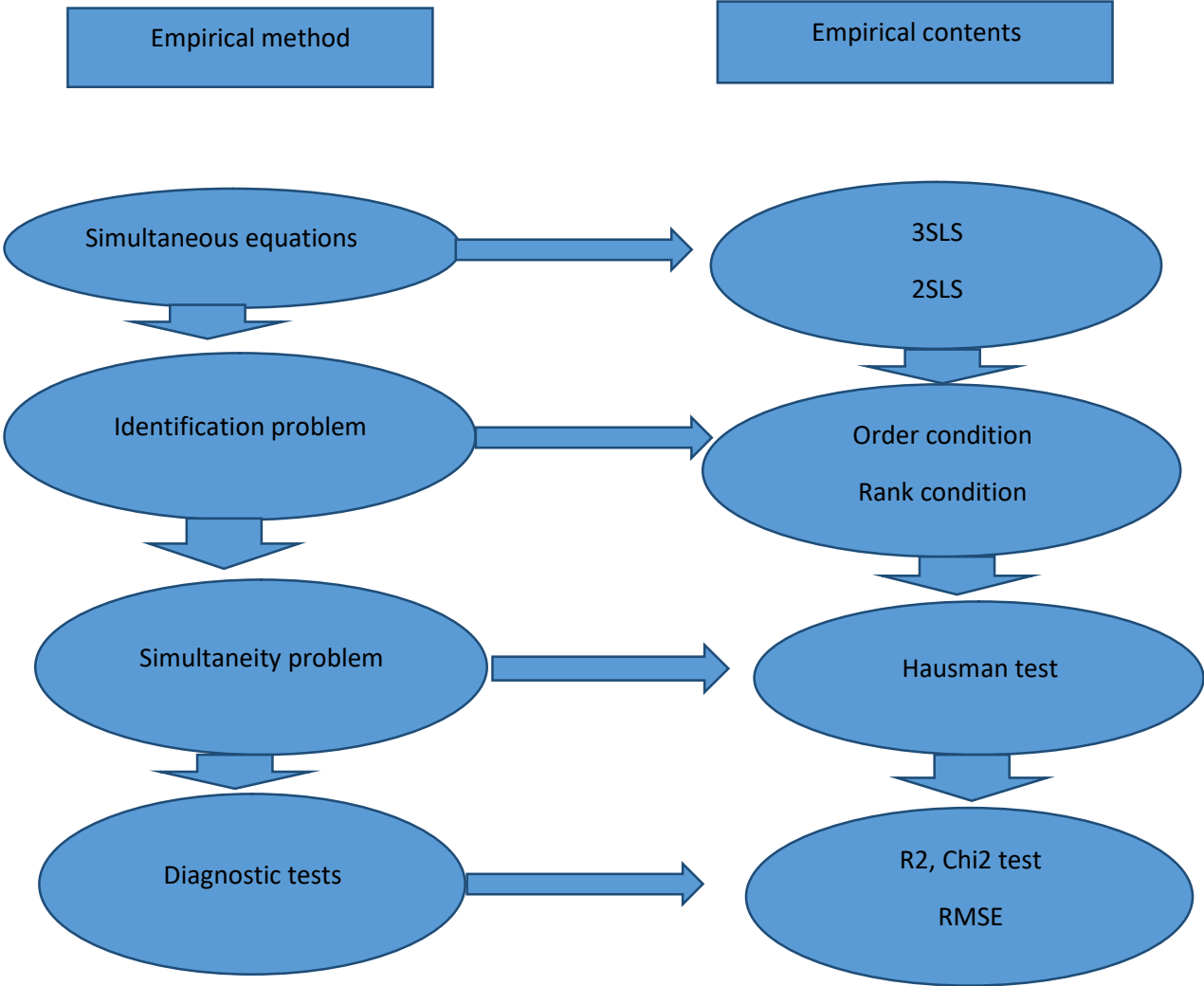
641 **Fig. 1 Sources of SO2 emission**



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643 **Fig. 2 Flow diagram of empirical method**

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645 **Table 1. Definition of variables and the data sources**

Variables	Unit	Definitions	Source
GDP	US\$ Million	Gross domestic product	SBP
Energy	kt	Total energy use equitant to oil	WDI
Capital	Million US\$	Total gross fixed capital formation	SBP
Investment	US\$ Million	Gross total investment	SBP
SO ₂	Giga	Total SO ₂ emission	WDI
Capital intensity	US\$ Million	Total capital stock divided by labor force	SBP
Industrialization	% GDP	Industrial value added scaled by GDP	Index Mundi
FDI	US\$ million	Foreign direct investment inflow	SBP
Pop. Density	Number	Population per square km	WDI

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649 **Table 2: Results for scale effect**

Variables	Coefficient	St. error
Constant	8.1947***	1.2845
Fdi	-0.0599***	.0164
K	0.7598***	0.0648
Polu	0.0542**	0.0253
lag_polu	-0.1234***	0.0284
Time	0.0363***	0.0024
R ²	0.9946	
RMSE	0.0323	
Chi ²	8241.7500***	

650 ***and** shows 1% and 5% level of significance

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670 **Table 3. Estimates of capital accumulation effect of FDI**

Variables	Coefficient	St. error
Constant	-10.2678***	2.5771
Fdi	0.0904***	0.0186
gdp _{t-1}	0.75876***	0.2573
gdp _{t-2}	0.5489**	0.2397
Time	-0.0429***	0.0055
R ²	0.9828	
RMSE	0.0433	
Chi ²	2152.9300***	

671 ***and ** are level of significance at 1% and 5%

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691 **Table 4: Estimates of the technique effect**

Variables	Coefficient	St. error
Constant	25.4240	18.8107
Fdi	0.5375***	0.1797
Gdp	-9.3192***	1.7978
Pd	30.5398***	6.7529
Energy	6.5854***	2.0371
Time	-0.5916***	0.1360
R ²	0.4329	
RMSE	0.2220	
Chi ²	85.3300***	

692 *** is significance level at 1%

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694 **Table 5: Estimates of composition effect**

Variables	Coefficient	St. error
Constant	-14.1269***	1.8069
Fdi	0.0295***	0.0081
Gdp	1.7085***	0.1121
k/l	-0.2786***	0.0551
Time	-0.0267***	0.0048
R ²	0.9989	
RMSE	0.0176	
Chi ²	32910.50***	

695 *** shows 1% level of significance

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716 **Table 6: Estimates of FDI determinants**

Variables	Coefficient	St. error
Constant	-39.5710*	22.8250
fdi _{t-1}	0.3450**	0.1423
ind _{t-1}	-1.1389	1.5859
inv _{t-1}	3.4730***	1.4164
Polu	-0.7443**	0.3302
Time	0.0971	0.0637
RMSE	0.3920	
R ²	0.9197	
Chi ²	404.8800***	

717 ***, ** and * are level of significance at 1%, 5% and 10% respectively

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Table 7. Effects of FDI on pollution emission

Variables	Effects of FDI on SO2 emission
Total effect	-0.5393
Scale effect	0.1287
Technique effect	-0.6622
Composition effect	0.1610

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763 **Appendix A. Glossary of notations used in system of equations**

Notations	Description
Fdi	fdi stands for foreign direct investment. An individual or a company residing in one country makes investment in another country is known as FDI. It can be in the form of establishing business operations or buying assets in the target country.
Inv	inv stands for investment. It is the investment made by public and private sources in a country. This is used to attract FDI in the country.
Gdp	gdp shows gross domestic product. It is the value of all final goods and services produced in a country during the specific period of time like during one year.
Pol	polu indicates SO ₂ emission. This greenhouse gas is a colorless and it is emitted from burning of oil and coal and industrial processes containing sulfur.
Eng	Energy is the power we derive from using physical or chemical resources to be used for heating, cooling and lighting purposes or for running machines.
k	k shows gross fixed capital formation. It shows availability of building, machinery, equipment, etc. to be used in the production process. It is among factors of production.
k/l	It represents capital intensity. It shows the amount of capital in relation to other factors of production like labor, land, etc.
Ind	It is used for industrialization in the country. This shows the transformation of economy from primary goods production to manufacturing goods. We can say transformation of economy from agricultural goods production to manufactured goods.
Pd	It represents population density. This shows number of persons living per square km in the country.
Tech	It shows technique effect. It is the ratio of pollution to industrial value added in the country.
Scale	It is scale effect. It is used to see the impact of FDI on gross domestic production.
Comp	comp is used to represent composition effect. It is estimated by taking ratio of industrial output to gross domestic product.

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767 **Declarations**

768 **Ethics approval**

769 Not applicable

770 **Consent to participate**

771 Not applicable

772 **Consent for publication**

773 Not applicable

774 **Competing interests**

775 The authors declare that they have no competing interests

776 **Authors' contributions**

777 KB interpreted the data, reviewed the literature and was the major contributor in writing

778 the manuscript. TA1 contributed in the research article in collecting data from different

779 sources, and reviewed the literature. Reviewing the final manuscript was done by TA2.

780 QA contributed in modeling and data analyzing.

781 **Funding**

782 Not applicable

783 **Availability of data and materials**

784 The datasets used and /or analyzed during the current study are available from the

785 corresponding author on reasonable request.

Figures

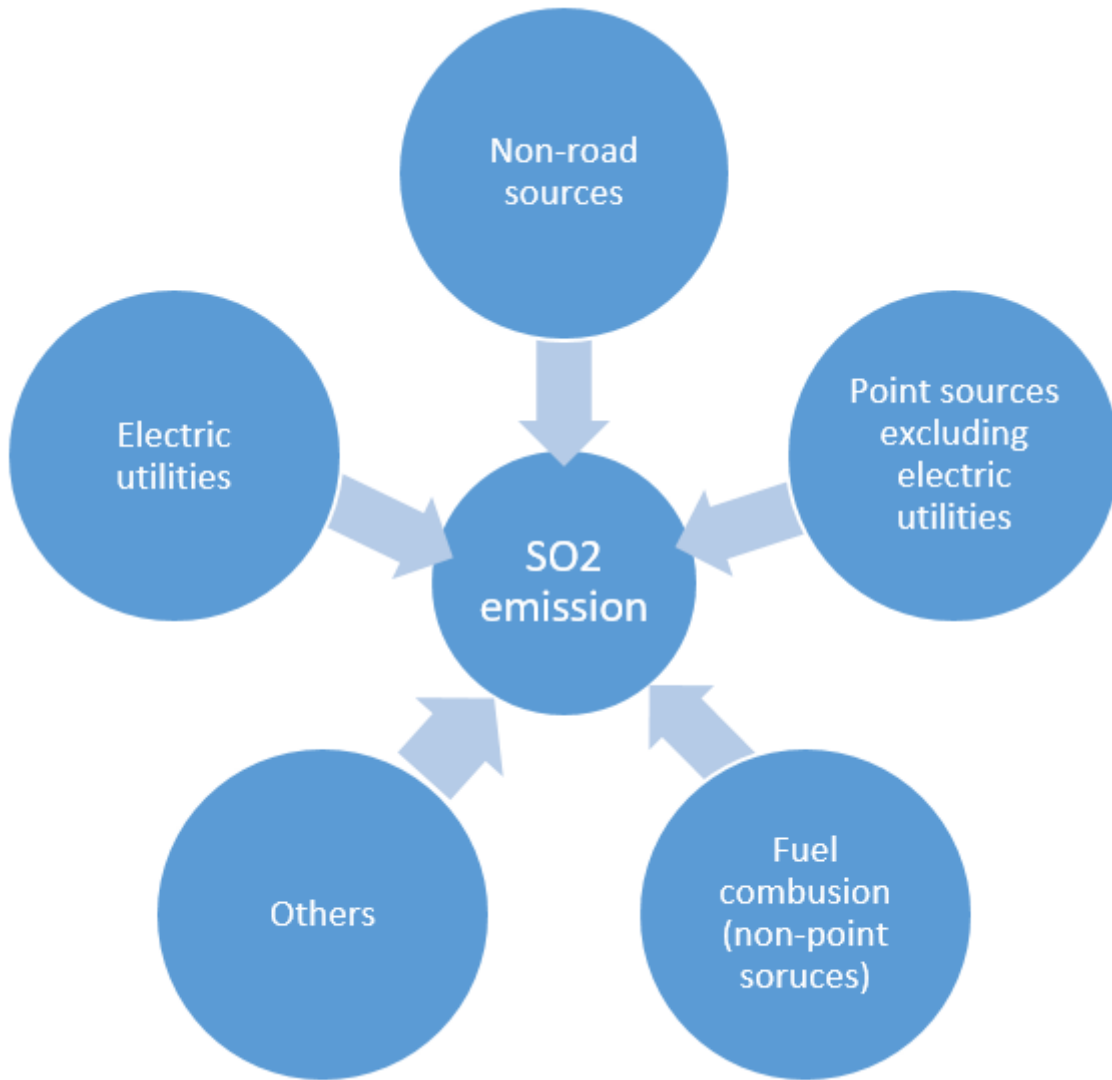


Figure 1

Sources of SO₂ emission

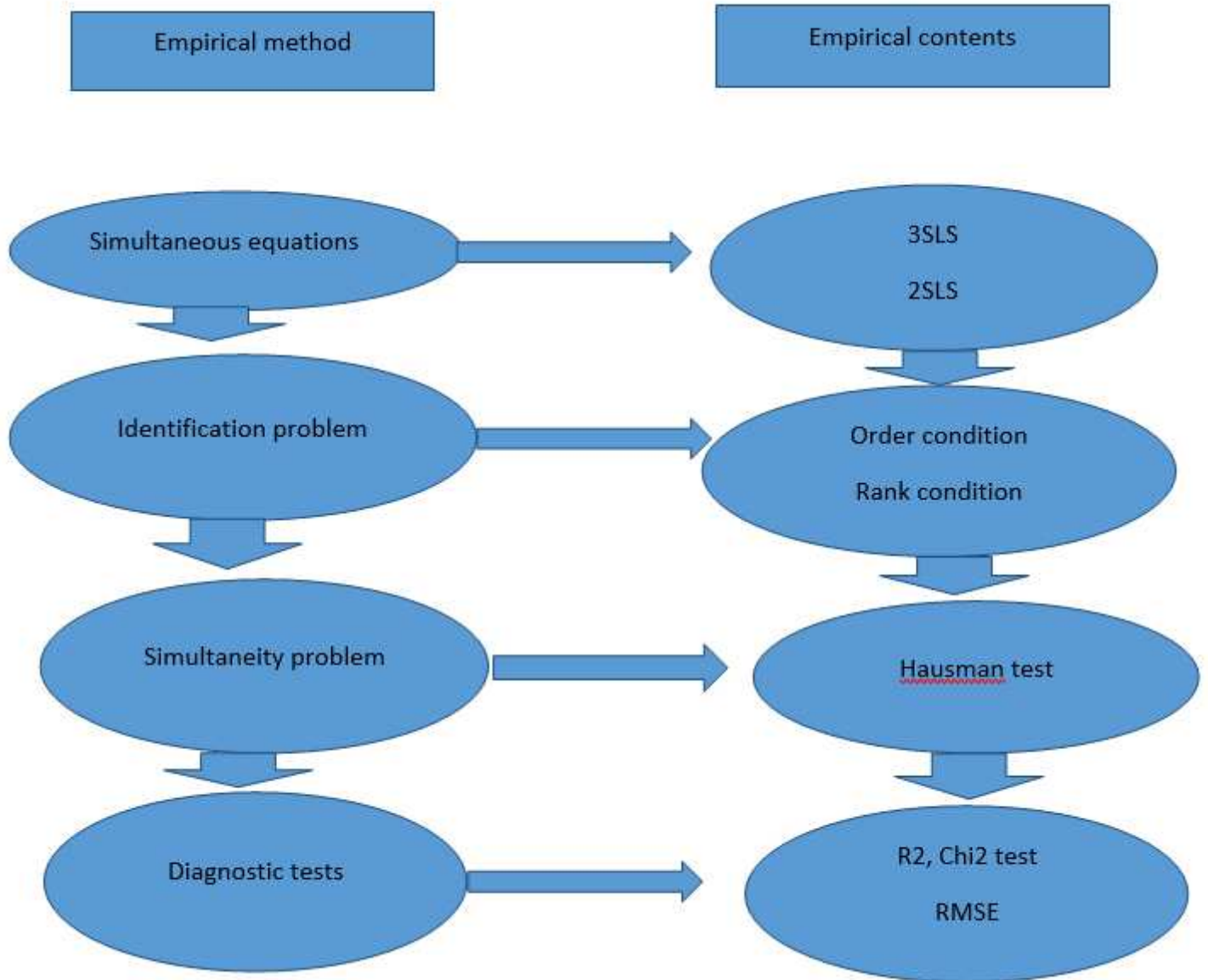


Figure 2

Flow diagram of empirical method