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González, Eva; Rangel, Cindy; Torre, Leonardo; Salcedo, Alejandrina; Alvarado, Jorge

# Working Paper Disruptions in global supply chains and regional output in Mexico during the COVID-19 pandemic

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Eva González Banco de México Cindy Rangel Banco de México Leonardo Torre Banco de México

Alejandrina Salcedo Banco de México Alvarado Jorge Banco de México

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Documento de Investigación 2024-19

Working Paper 2024-19

# Disruptions in Global Supply Chains and Regional Output in Mexico during the COVID-19 Pandemic

Eva González<sup>†</sup> Banco de México

Cindy Rangel<sup>‡</sup> Banco de México Leonardo Torre<sup>§</sup> Banco de México

Alejandrina Salcedo\*\*

Banco de México

Alvarado Jorge<sup>±</sup> Banco de México

Abstract: The paper analyzes how the initial disruption in the supply of imported inputs associated to the COVID-19 pandemic may have induced heterogeneous responses in regional and sectoral gross output in México. Using the Regional Input-Output Matrices estimated by Banco de México, and the Supply Ghosh Model, the effects associated to the supply-side shock that ensued from the sudden reduction of imported inputs from China, the European Union, and the United States at the onset of the pandemic are calculated. The Northern region experienced the greatest contraction in gross output, while at the sectoral level, the manufacturing sector gross output was the most affected by the shock relative to a scenario with constant availability of inputs. These results are consistent with the fact that both, the Northern region and the manufacturing sector, are the most integrated to the global supply chain.

Keywords: COVID-19, Input-Output, Ghosh Model, Mexico JEL Classification: R11, R12, R15

Resumen: El trabajo analiza cómo la disrupción inicial en el suministro de insumos importados asociado con la pandemia de COVID-19 pudo haber inducido respuestas heterogéneas en la producción bruta regional y sectorial en México. Utilizando las Matrices Insumo-Producto Regionales 2013 del Banco de México, y el Modelo de Oferta de Ghosh, se calculan los efectos en la producción bruta de México derivados del choque de oferta que resultó de la súbita contracción en la importación de insumos de China, la Unión Europea y los Estados Unidos al inicio de la pandemia. La región norte experimentó la mayor contracción en la producción bruta, en tanto que, a nivel sectorial, el sector manufacturero fue el más afectado por el choque en relación con un escenario de disponibilidad de insumos constantes. Estos resultados son consistentes con el hecho de que tanto la región norte como el sector manufacturero son los más integrados a la cadena global de suministro.

Palabras Clave: COVID-19, Matriz Insumo-Producto, Modelo de Ghosh, México

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 <sup>†</sup> Dirección General de Investigación Económica. Email: egonzalezg@banxico.org.mx
 ‡ Dirección General de Investigación Económica. Email: cdy.rangel16@gmail.com

 <sup>§</sup> Dirección General de Investigación Económica. Email: leonardo.torre@banxico.org.mx
 \*\* Dirección General de Investigación Económica. Email: asalcedo@banxico.org.mx

<sup>±</sup> Dirección General de Investigación Económica. Email: alvarado.ruiz@gmail.com

#### 1. Introduction

The first case of COVID-19 in Mexico was registered in February 27, 2020, more than two months after it was first identified in China (November 17, 2019), and about a month after the first case was detected in the United States (January 21, 2020). As the virus spread around the world, there was an increasing number of countries implementing, at different times, temporary closures of economic activity, which in turn caused disruptions in global supply chains [Yu et al., 2021; Verschuur et al., 2021; Kejzar and Velic, 2020; Ferreira et al., 2021; CEPAL, 2020]. In the case of Mexico, these disruptions could have affected the amount of intermediate goods that could be imported across sectors even before the restrictions on non-essential activities were erected in the country in April 1<sup>st</sup>, 2020.<sup>1,2</sup>

The possibility that the COVID-19 pandemic, by disrupting the provision of intermediate goods imports in Mexico, had heterogeneous regional and sectoral effects is suggested, for instance, in Figure 1. This figure shows that the value of total accumulated national imports of intermediate goods from China during February-March 2020 contracted by 12.4% relative to the value of imports registered in the same period of 2019; while the value of total imports of intermediate goods from the United States and the European Union in April, 2020 decreased 43.1%, and 19.3% against their reported values of April 2019, respectively.<sup>3</sup>

<sup>&</sup>lt;sup>1</sup> The Federal Government published a list of "essential activities" in the *Diario Oficial de la Federación, March 21, 2020.* All other economic activities not considered in that list were deemed as "non-essential" and forced to close from April 1<sup>st</sup> up to April 30<sup>th</sup>. Hence, the contraction in the latter sectors during April may have been originated directly as a result of such measures, and not necessarily from the lack of the required inputs.

<sup>&</sup>lt;sup>2</sup> Banco de México (2020), p.26, shows that between March and June 2020, up to 52% of manufacturing firms, and up to 60% of non-manufacturing firms, registered partial or total shutdowns.

<sup>&</sup>lt;sup>3</sup> Table 1 shows the reductions in imports of intermediate goods at the sectoral level in Mexico for those periods.



Source: Own estimates using data from Banco de México.

Considering this information, this paper provides an estimation of the effects on regional and sectoral gross output that ensued from the supply shock that the Mexican economy experienced due to the lack of imported inputs at the onset of the pandemic of COVID-19 from its three principal providers: China, the European Union, and the United States.<sup>4, 5</sup> The supply side shock that the Mexican economy suffered is calculated as the change on the value of imported inputs from China during February and March 2020, against the value of imports of intermediate goods from that country during February and March 2019; in addition to the contractions on the value of intermediate imports from the European Union and the United States in April 2020, against their respective values registered in April 2019. The definition of these shocks assumes that, during such periods, imports of intermediate goods had not yet been significantly affected by demand factors. The latter assumption seems feasible as Mexican sanitary authorities declared the beginning of the pandemic in March 21, 2020, only

<sup>&</sup>lt;sup>4</sup> This paper builds on Box 2 of the Reporte sobre las Economías Regionales July-September 2020 of Banco de México (RER), incorporating a methodological refinement explained in Section 3. Consequently, the results presented here differ from those in Box 2.

<sup>&</sup>lt;sup>5</sup> In this paper, the estimates are based on Gross Output instead of Gross Domestic Product (GDP) since the first concept is the one used in the 2013 Regional Input-Output Matrixes estimated by Banco de México. As a reference, according to data from INEGI, national GDP and Manufacturing GDP experienced a contraction, with seasonally adjusted data in real terms, of 17.1% and 26.0%, respectively, during the second quarter of 2020 relative to the previous quarter. On the other hand, gross output of the manufacturing sector registered, with seasonally adjusted data, a contraction of 26.8% in the third quarter, relative to the second quarter of that year, according to the Monthly Indicator of Industrial Production from INEGI.

a month after the first case detected in the country, a period relatively short and in which Mexican households were probably starting to take measures against the spread of the virus.

With these supply shocks at hand, responses in gross output are obtained due to the reduction in the availability of imported inputs using the Ghosh Supply Model (Ghosh, 1958). This model, based on input-output techniques, identifies how the effects that exogenously specified changes in sectoral inputs are transmitted to gross sectoral outputs. Hence, this paper is in the spirit of Guerrieri et al (2020), who demonstrate that supply chains represent a significant channel through which a negative supply shock in a given sector that produces inputs travels upstream to other sectors as demand shocks, hence lessening output.

The estimates suggest that the contraction in imports of intermediate goods reduced national gross output by 1.11% in 2020, relative to a scenario with constant availability of inputs, most of it resulting from the reduction in imported inputs from the U.S., followed by those from China, and the European Union. It also suggests that the supply shock had heterogeneous interregional and intersectoral effects in Mexico. At the regional level, for instance, the North experienced the strongest effect; at the sectoral level, on the other hand, the manufacturing sector was the most affected by the shock.

The paper is organized as follows. Section 2 reviews the Ghosh Supply Model and the multiplier effects associated to the exogenous shocks on imports of intermediate goods at the regional level. Section 3 presents the methodology employed to measure the exogenous supply shocks on regional imports of intermediate goods, while Section 4 presents the results. Final comments are presented in Section 5.

#### 2. The Ghosh Model

The theoretical framework used to derive the effects on output at the sectoral and regional level resulting from changes in the availability of imported inputs is a traditional Ghosh Supply Model. As opposed to the Leontief model, in which production is determined as a function of final demand, given the production technology, in the Ghosh model (supply-side version), value added determines output, and producers must induce sales in order to achieve a desired level of income (Aroche y Márquez, 2013). Hence, the Ghosh model is adequate to

analyze the effects of shocks on components of value added, such as reductions of intermediate goods imports, on sectoral and regional gross output, which are the focus of this paper.

There is abundant literature about theoretical aspects and applications of the Ghosh model. About theoretical issues, consult Dietzenbacher (2002). Some practical examples of the model can be found in Galbusera y Giannopolus (2018). The applications of this methodology to the Mexican case at regional and sectoral levels, however, are scarce. Among the latter it is found Torre et al., (2023), who adopt the Ghosh model to estimate how Mexican value added linked to the economic activity in the United States is allocated among sectors and regions. Their results capture the existence of strong economic linkages between both economies at the aggregate level, as well as at its sectoral concentration.

Another example is Chapa (2021), who uses input-output techniques to identify, for the state of Nuevo León, productive sectors as strategic (i.e., strong buyers and sellers of intermediate goods), strategic forward (strong suppliers of intermediate goods), strategic backward (strong buyers of intermediate goods), and independent (sectors that are neither relevant buyers nor suppliers of intermediate goods). In her work, the author uses the Ghosh model to identify sectors with strong forward linkages, reporting that these correspond to Mining, Commercial Activity, and an aggregate of Professional Services, Other Services, and Government Activities.

More recently, Morales-López (2023) applies the Ghosh model to calculate the effects on gross output in 1,184 Mexican sectors (37 sectors in each of the 32 states) derived from a sectoral shock on the gross value added of a given sector, defined as the difference between the gross value added of that sector after its extraction of the forward technical coefficients matrix, and its value before the extraction. Some of the relevant results of his work indicate that the Electrical, electronic, and transportation sector shows considerable backward linkages across states; the Services sector is the one which appears more frequently among the sectors with the strongest forward linkages; while Oil mining is the sector with the most relevant forward linkages.

In this paper, the Ghosh Supply Model representation of Boundi-Chraki (2017) is adopted to estimate the effects on regional and sectoral gross output due to reductions on the availability of imported intermediate goods. In this version of the Ghosh model, an economy with "n" sectors is expressed in matrix notation as follows:

$$x^R = x^R B^R + v^r \tag{1}$$

in which:

 $x^{R}$ : Vector (1xn) of gross output by sector of region *R*, where "n" refers to the number of sectors.

 $v^R$ : Vector (1xn) is the row vector of gross value added -measured by the payments made to production factors, like labor and capital, thus including compensation of employees, profits and capital consumption allowances-, taxes, and consumption of intermediate goods that are imported, by sector of region *R*.

 $B^R$ : Matrix (nxn) of distribution coefficients of region R given by:

$$d_{ij}^R = \frac{z_{ij}^R}{x_i^R} \tag{2}$$

where the coefficients  $d_{ij}^R$  indicate the proportion that sales  $(z_{ij}^R)$  of sector *i* to sector *j* represents of the total sales  $(x_i^R)$  of sector *i* in region *R*, and are assumed constant. On the other hand,  $x^R B^R$  indicates the value of region *R* sales that are required to obtain a given amount of sectoral gross output in region *R*.

Solving for  $x^R$  in equation (1), it is obtained:

$$x^{R} = v^{R} (I - B^{R})^{-1}$$
(3)

where the matrix  $(I - B^R)^{-1}$  is the Inverse Supply Matrix (nxn), or Ghosh Inverse Matrix, whose elements  $\delta_{ij}^R$  indicate the change in the value of gross output of sector *j* of region *R*, which is registered in the event of a change of one unit in the value of any of the variables of sector *i* contained in  $v^R$ . Since the main interest of this paper is to analyze changes in sectoral and regional gross output as a result of a reduction in the consumption of intermediate goods that are imported by sector, the shock is captured in the vector  $v_i^R$ . The elements  $\delta_{ij}^R$  of the Ghosh Inverse Matrix represent the input multipliers, which capture the change on gross output of sector j as a result of a unit change in the supply of imported inputs from sector i.<sup>6</sup>

In this paper, we used the uniform expansion multipliers of primary inputs, calculated as the column-wise summation of the elements in the Inverse Supply Matrix, that capture the effect on the production of sector j when the supply of inputs decreases uniformly by one unit across all sectors within a region; in other words, interregional effects are not being considered.<sup>7</sup> This methodology enables the decomposition of the total output effect into direct and indirect effects, with their sum representing the total multiplier effect. The direct effect on gross output refers to the initial exogenous shock on sector j caused by the reduced availability of imported inputs needed to produce one unit of output, along with the associated distributional coefficient. The indirect effect, on the other hand, represents the feedback received by sector j through its intersectoral productive linkages, including second-order and higher-order impacts.<sup>8</sup> Hence, when sectors within a region are strongly linked among themselves, the indirect effects would be expected to be strong.

We use three main data sources in the estimations: (i) the Intermediate Goods Imports by Sector and Country of Origin from INEGI; (ii) Banco de México's monthly database of imports by product and country of origin, and (iii) the Input-Output Regional Matrices 2013 estimated by Banco de México.<sup>9</sup>

# **3.** Identification and Allocation of Supply Shocks in Intermediate Goods Imports and Estimation of their Impact on Regional Gross Output

In this paper, the supply shock in the Mexican regions will be defined as the contraction in imported intermediate goods that was observed during <u>the first months</u> of the COVID-19

<sup>&</sup>lt;sup>6</sup> These effects would be present to the extent that there are no inputs of national origin that can substitute, in the short term, those intermediate goods that are imported.

<sup>&</sup>lt;sup>7</sup> A different type of multiplier can also be estimated through the row-wise summation of the elements in the Ghosh Inverse Matrix. These multipliers indicate the effect on the economy's total production resulting from a one-unit increase in the value added of sector i

<sup>&</sup>lt;sup>8</sup> The Ghosh inverse matrix can be represented through its mathematical identity as the following geometric series:  $(I - B)^{-1} = I + B + B^2 + B^3 + \dots + B^n \dots = \sum_{k=0}^{\infty} A^k$ . This representation shows how the multipliers account for both direct and indirect effects. The term (I + B) indicates the direct requirement of inputs to produce one unit of output, while the successive terms  $(B^2 + B^3 + \dots + B^n \dots)$  represent the additional input requirements needed to supply the initial input required for producing one unit of output. The sum of the direct and indirect effects constitutes the total multiplier effect.

<sup>&</sup>lt;sup>9</sup> The 2013 Input-Output matrix was the latest matrix available at the time of writing this paper. The regional Input-Output matrices employed in the paper are, in turn, those in Chiquiar et al., (2017). That paper also shows the methodology to derive the regional Input-Output matrices for Mexico.

pandemic, considering that these imports could have responded to the disruption in supply chains even before the demand of imports was also affected negatively due to demand shocks.<sup>10</sup> Thus, the supply shock is calculated as the sum of: (i) the change in the level of imports of intermediate goods from China in February and March 2020 against its corresponding level in the same period of 2019; (ii) the change in the value of imports of intermediate goods from the United States in April 2020 relative to the value of such imports in the same month of 2019; and (iii) the change in imports of intermediate goods from the European Union during April 2020 against those imports during the same month of 2019.<sup>11,12</sup> In the estimates, it is assumed that the reduced availability of imported inputs from China is likely to be capturing a supply-side shock when producers in Mexico experienced shortages of Chinese imports of those goods during February-March 2020, this is, even before Mexican sanitary authorities ordered closures of economic activities. Regarding the plausibility of this shock, observers were reporting, at the end of February 2020, that Chinese ports were clogged with arriving shipping containers; warehouses were overflooded with goods that could not be exported for lack of trucks, and many factories were operating at a fraction of capacity, with their negative effects with all certainty extending up to March. The combination of these factors was deemed as responsible for the lack of intermediate goods that many countries experienced in that period.<sup>13</sup>

The contraction in imported inputs in the European Union and the United States, on the other hand, is assumed to have occurred in April, 2020, as the mandatory closure of economic activities dictated by sanitary authorities in these two economies were already in place.

<sup>&</sup>lt;sup>10</sup> It is likely that in April, 2020 the sanitary crisis in Mexico may have also induced demand shocks acting in opposite directions. For instance, a negative demand shock may have emerged if households reduced their consumption while increasing their savings for precautionary motives in an uncertain environment. A positive demand shock, on the other hand, may have materialized as households increased their demand for goods at a pace faster than normal before the virus spread extensively. On this subject, see Cuenca et al., (2021), who document how households in Spain and the Euro Zone increased their savings, and hence reduced consumption, during the pandemic. In this paper, however, the estimation would assume that, by April, such changes would have not yet affected the demand for inputs.

<sup>&</sup>lt;sup>11</sup> As a reference, in 2019, Mexican imports of intermediate goods from the United States, China, and the European Union accounted for 73.5% of Mexico's total imports of these goods. Imports from other countries were not considered for this analysis due to their reduced share in Mexico's total intermediate imports.

<sup>&</sup>lt;sup>12</sup> We do recognize that a fraction of the supply side shock from China may be also present after March 2020. However, the contribution of this shock, as suggested by the data, was not as strong as that of the United States. Additionally, we define the supply side shock from the United States and the European Union as occurring in April, when international trade in intermediate goods faced a significant contraction and we assume that, at this stage, imports of intermediate goods were primarily influenced by supply constraints rather than demand factors.

<sup>&</sup>lt;sup>13</sup> See, for instance, Virus Disrupts China's Shipping, The New York Times, February 27, 2020.

Hence, the availability of intermediate goods from these two economies to Mexico was experiencing a reduction in an environment already complicated by the difficulties to move goods internationally.

Given the lack of information on imports of intermediate goods by country of origin at the state level, and to the impossibility of identifying, at the same level of disaggregation, the imports of intermediate goods that each sector acquires from other sectors, it was necessary to assume that:

(1) The structure of imports of intermediate goods by sector and country of origin at the regional level is the same as that of the national level.

(2) The proportion of imported inputs purchased by sector j from sector i at the regional level is the same as such proportion at the national level.

(3) The percentage changes on regional intermediate imports are equal to the percentage changes in imports of intermediate goods at the national level <u>for</u> <u>each sector</u>.

The available data on imports of intermediate goods only records the type of inputs entering Mexico from other countries, but it does not identify the sector to which the imported input is allocated to obtain the proportion of imported inputs that each sector at the national level acquires directly from international sources, as well as the proportion they acquire from other sectors.<sup>14</sup> In this way, the magnitude of the shock that each sector will receive can be more precisely assigned according to how intensive it is in the use of imported inputs for its

<sup>&</sup>lt;sup>14</sup> In this paper, the percentages presented take as a basis of comparison gross output values corresponding to the Regional Input-Output Matrices 2013 in the absence of the shock, with the exception of those presented in Table 2, which refer to the observed percentage variation in the value of imports of intermediate goods between 2019 and 2020, with figures expressed in dollars.

production.<sup>15,16</sup> For instance, assume that the textile inputs that the Mexican apparel manufacturing sector imports from the United States, China, and the European Union registered hypothetical contractions of 10%, 5%, and 3%, respectively, in the periods analyzed. However, this sector not only imports textile inputs for its production process, but also buys inputs from other sectors. Hence, the estimated supply shock will be not only a function of the relative importance of the imported input for production, but also from the proportions that imports from the United States, China, and the European Union represent in the total imports of intermediate goods from each sector.

In order to distribute the estimated shock across the different sectors and regions, and to subsequently calculate its effects on sectoral gross output, the first step to estimate the proportion of imported inputs purchased by sector j from sector i at the regional level R based on assumption 2 as:

$$\gamma_{ij}^N = \frac{m_{ij}^N}{MI_i^N} = \gamma_{ij}^R \tag{4}$$

 $\gamma_{ij}^N$ : nxn matrix whose elements capture the proportion of imported inputs that sector *j* acquires from sector *i* at the national level.

 $\frac{m_{ij}^{N}}{M_{j}^{N}}$ : Inputs of imported origin from sector *i* going to sector *j* at the national level, divided by the total purchases that sector *j* makes of imported goods.

 $\gamma_{ij}^R$ : nxn matrix whose elements will capture according to the assumptions the proportion of imported inputs that sector *j* acquires from sector *i* in each region.

<sup>&</sup>lt;sup>15</sup> Results in this paper differ from those in Box 2 of the Reporte sobre las Economías Regionales July-September 2020 of Banco de México (RER) due to a methodological improvement. The difference relies on the use of the Input-Output Matrix of Imported Origin at the national level estimated by INEGI (https://www.inegi.org.mx/temas/mip/#tabulados), which details how Mexican economic sectors utilize imported goods and services in their production processes. We further disaggregated it by country of origin and Mexican region to allocate changes in intermediate imports based on each sector's reliance on foreign inputs from specific sectors. In contrast, the estimation presented in the Box relied on a vector of imports by sector, country of origin, and region, and therefore it did not account for sector-specific dependencies on foreign inputs. For instance, in the case of a decline in intermediate imports of chemical products, the Box estimated the impact on gross output of other sectors and the chemical sector itself based on their overall use of chemical inputs (both domestic and imported). However, some sectors may depend on imported chemical inputs to varying degrees—or not at all. This highlights the importance of more disaggregated data and the value of the input-output matrix. By using this matrix, we were able to more accurately estimate the impact of foreign intermediate goods supply shocks on gross production, according to each sector's reliance on specific imported inputs.

<sup>&</sup>lt;sup>16</sup> The structure of imports used was that of 2019. That year Mexico obtained 46.4% of its total imports of intermediate goods from the United States, 17.3% from China, and 9.7% from the European Union.

In this way, using  $\gamma_{ij}^R$  it is approximated, in monetary terms, an nxn matrix that contains the value of imported inputs that sector *j* acquires from sector *i* in region R ( $\theta_{ij}^R$ ):

$$\theta_{ij}^R = \gamma_{ij}^R * \beta_j^R \tag{5}$$

 $\beta_j^R$ : 1xn vector containing the total value of purchases made by sector *j* of imported inputs in region R. These values are taken directly from the Regional Input-Output Matrices 2013 estimated by Banco de México.

Once a matrix containing the inter-sectoral transactions of imports of intermediate goods in region  $R(\theta_{ij}^R)$  has been calculated, it is required to approximate the value of inputs that are imported from each of the countries analyzed, since the magnitude of the shock that arises from each country is different at the sectoral level. In this way, using  $\theta_{ij}^R$ , three sub-matrices of order nxn are estimated, each containing, respectively, the intermediate demand for imported inputs from the United States, China, and the European Union ( $\rho_{ij}^{R,C}$ ):

$$\rho_{ij}^{R,C} = \theta_{ij}^R * \alpha_i^{R,C} \tag{6}$$

 $\alpha_i^{N,C}$ : Vector of nx1 that indicates the percentage share that each country *C* has in total imports of intermediate goods at the <u>national</u> level by sector. That is:  $\alpha_i^{N,C} = \frac{k_i^C}{\kappa_i^N}$  where  $k_i^C$  are the imports of intermediate goods of sector *i* that come from country *C*, and  $K_i^N$  represent the total imports of intermediate goods made by the same sector *i*. Keep in mind that the calculations assume that the structure of intermediate goods that are imported, by sector and country of origin at the regional level, is the same as the structure at the national level:  $\alpha_i^{R,C} = \alpha_i^{N,C}$ .

Obtaining the sub-matrices of imports of intermediate goods from the United States, China, and the European Union for each region, an nxn matrix is calculated for each of them in order to capture the change in the import value of  $(\Delta v_{ij}^{R,C})$ , that is, the estimated supply shock in monetary terms:

$$\Delta v_{ij}^{R,C} = \rho_{ij}^{R,C} * \Delta \% k_i^{R,C} \tag{7}$$

In this expression,  $\Delta \% k_i^{R,C}$  represents the percentage change in imports of intermediate goods from the United States, the European Union, and China assumed for factor *i* in region R. For the first two economies, as previously mentioned, the difference between the value of imports in April 2020 and the April 2019 value is considered; while for China, the difference between the accumulated value of imports in the January- February 2020 period, and the accumulated value of imports of that same period of 2019. Also, according to assumption (3) described above, the percentage changes in regional inputs that are imported are equal to the respective percentage change in imports of intermediate goods at the national level, that is,  $\Delta \% k_i^{R,C} = \Delta \% k_i^{N,C}.^{17}$ 

Once the shock in intermediate goods imports in monetary terms has been identified, the Inverse Ghosh Matrix is applied. The  $\delta_{ij}^R$  elements of this matrix, referred as the input multipliers, will be the ones used to calculate the effects on gross output across regions and sectors due to the shocks on intermediate goods imports.

The assumptions made so far, and the usage of the Regional Input-Output Matrices 2013, would suggest, for instance, that a contraction in imports of vehicle parts could have a significant effect in regions in which the automotive activity is concentrated (such as the Northern, North-Central, and Central regions); while the impact would be negligible in a region where such activity does not have a relevant weight in their total output (as it would be the case of the Southern region). Further, since the productive structure of each region is different, the input multipliers may differ across sectors and regions and, therefore, they will indicate the degree of the differentiated impact on regional and sectoral gross output associated with the disruption in the supply chains.

<sup>&</sup>lt;sup>17</sup> The data on the value of intermediate goods imports by country of origin was originally obtained with the 6-digit classification of the Tariff of the General Import and Export Tax Law (TIGIE, by its acronym in Spanish). However, given that the 2013 Regional Input-Output Matrices estimated by Banco de México use the classification of the North American Industry Classification System (NAICS), a reclassification was necessary. Hence, the information with a 6-digit TIGIE classification was converted to the NAICS classification using the 6-digit TIGIE to NAICS 2019 Correlation Table. Then, 3-digit groupings were integrated since this is the breakdown of the 2013 Regional Input-Output Matrices; only the automotive industry and the auto-part industry were kept at the 6 and 4-digit levels, respectively, for analytical purposes. Likewise, given that the data of the Regional Input-Product Matrices is at 2013 prices, the values in current dollars of monthly 2019 and 2020 imports of intermediate goods were converted to constant 2013 pesos. This transformation required, first, to express the values in current USD to current pesos by multiplying the former by the monthly average of the FIX exchange rate reported by Banco de México. These figures were finally transformed to constant 2013 pesos using the implicit price deflators of INEGI for each activity, which were the ones used in the different estimates of this work.

The above allows us to obtain, by region, three square matrices of order nxn containing the sub-effects on gross output of sector j associated with a change in imports of intermediate goods from sector i originating from country C:

$$\Delta x_{ij}^{R,C} = \Delta v_{ij}^{R,C} * \delta_{ij}^R \tag{8}$$

Hence, the total change on gross output of sector j as a result of the initial supply shock on intermediate goods imports from all sectors of region R that come from the United States, the European Union and China, is given by the sum per column of the effects on sector j:

$$O_j^R = \sum_{C=1}^{3} \sum_{i=1}^{n} \Delta x_{ij}^{R,C}$$
(9)

Thus,  $O_j^R$  captures the overall effect on the gross output of sector *j* in region R as a result of the initial disruption in the supply chain of all sectors from which sector *j* buys intermediate goods for its production.

#### 4. Results

Table 1 presents the observed percentage declines on imports of intermediate goods, which represent the basis for calculating the initial shock associated with the disruption of supply chains indicated in equation 7. Figure 2 shows the overall effect that this initial shock has on Mexican gross output and the contributions to this effect of supply chain disruptions from the European Union, China, and the United States.<sup>18</sup> The estimates show that supply chain disruptions at the onset of the pandemic could have reduced national gross output by 1.11%.<sup>19</sup> As a reference, data from INEGI indicate that in the second quarter of 2020, seasonally adjusted real national gross output experienced a contraction of 17.1% relative to the previous quarter. The calculations indicate that out of the 1.11% contraction in national gross output, 0.10 percentage points correspond to the impact of China during the

<sup>&</sup>lt;sup>18</sup> In this section, the percentages presented take as a basis of comparison gross output values corresponding to the Regional Input-Output Matrices in the absence of the shock, with the exception of those presented in Table 2, which refer to the observed percentage variation in the value of imports of intermediate goods between 2019 and 2020, with figures expressed in dollars.

<sup>&</sup>lt;sup>19</sup> See Section 3 for the methodology to obtain the supply shocks, and footnote 13 for a review on why the results in this paper differ from those in Box 2 of the RER July-September.

February-March 2020 period, when the closure of non-essential activities in Mexico had not yet been decreed. In turn, the subsequent shocks from the United States and the European Union, both from April 2020, would have contributed 0.95 and 0.06 percentage points, respectively.

At the regional level, the North was the one that could have registered the greatest impact, with a 2.02% reduction in its gross output due to the shock on its imports of intermediate goods (Figure 3). This could be explained in terms of its greater dependence on imported inputs, and greater multiplier effect in sectors that experienced the largest reductions on such imports, for instance, in the vehicle parts manufacturing subsector.<sup>20</sup> The impact in the Northern region is followed by the estimated effects in the Central and North Central regions, each with a contraction of 0.90% and 0.81%, respectively, in their gross output due to the disruptions studied; while the South could have been the least affected, with a reduction of 0.49% in the same indicator. These differences in the total estimated effects at the regional level show the value of the Regional Input-Output Matrices 2013, as they reveal that the heterogeneity in productive structures and inter-sectoral technical relationships in each region capture differentiated effects on gross output, effects that would not be captured in a national input-output matrix.

The calculations reveal that the direct effects of the sudden contraction of imported inputs outweigh the indirect effects across all regions as shown in Figure 3.<sup>21</sup> It also highlights that the Northern region exhibits the highest indirect multiplier effect among all regions, reflecting its stronger integration with the global supply chains and intersectoral productive linkages.

<sup>&</sup>lt;sup>20</sup> According to the 2013 Regional Input-Product Matrices, the North is the one with the highest share of total imports of intermediate goods with 40.6%, followed by the Central region with 32.9%, the North-Central with 15.6%, and the South with 10.9%.

<sup>&</sup>lt;sup>21</sup> This is common when using regional input-output matrixes, as the indirect effects are estimated within the regions and do not account for indirect effects across regions.

#### Table 1

## Mexico: Intermediate Goods Imports by Sector and Country of Origin

Annual percentage change

Sector	Арі	Feb-Mar 2020 vs. Feb-Mar 2019	
	United States	European Union	China
Mining (except Oil and Gas)	-	-	-27.9
Utilities (generation, transmission, distribution and sales of electricity, water, and natural gas)	-53.2	-	-
Textile Mills and Textile Product Mills	-46.2	-26.3	-30.7
Apparel, Leather and Allied Product Manufacturing	-73.8	-41.7	-
Wood Product Manufacturing	-33.6	-26.6	-28.0
Paper Manufacturing/Printing and Related Support Activities	-18.7	-2.0	-5.0
Petroleum and Coal Products; Chemical, and Plastics and Rubber Products Manufacturing	-39.8	-7.9	-19.0
Nonmetallic Mineral Product Manufacturing	-43.9	-16.5	-18.4
Primary Metal and Fabricated Metal Product Manufacturing	-39.7	-22.2	-14.9
Machinery, Electronic, Electrical Products, and Transportation Equipment (except Motor Vehicle Parts) <sup>*/</sup>	-56.6	-26.8	-8.9
Motor Vehicle Parts Manufacturing	-87.8	-48.4	-58.4
Furniture and Related Product Manufacturing	-55.5	-28.8	-26.0
Miscellaneous Manufacturing	-27.5	-15.8	-42.1

Note: Empty spaces indicate the sector did not have any effect or had an increase in imports of intermediate goods in the period analyzed. In order to classify by SCIAN sectors, the TIGIE-SCIAN 2019 Correlation Table from INEGI was used. \*/ Machinery Manufacturing; Computer and Electronic Product Manufacturing, Electrical Equipment, Appliances, and

Component Manufacturing, Transportation Equipment Manufacturing; except Motor Vehicle Parts Manufacturing.

Source: Prepared by Banco de México with data from SAT, SE, Banco de México, INEGI. Commercial Balance of Goods of México. SNIEG. Information of National Interest.

#### Figure 2 Estimated Contributions of the Reductions in Intermediate Goods Imports to Mexican Gross Output Growth at the Onset of the Pandemic



Percentage change relative to a scenario without disruptions<sup>1/</sup>

1/ The graph shows the overall effect on Mexican gross output at the national level as percentage contributions of the reductions in intermediate goods imports from China, the European Union, and the United States to the 1.11% figure. Source: Own estimates using data from Banco de México and INEGI.

#### Figure 3

Estimated Direct, Indirect and Total Effects in Mexican Regional and National Gross Output Growth due to the Reduction in Intermediate Imports at the Onset of the Pandemic



Percentage change relative to a scenario without disruptions

Note: Figures in the graph show the direct, indirect and total effects in Mexican and regional gross output at the regional and national levels due to the decline in imports of intermediate goods from China, the European Union, and the United States. For instance, the contraction in imports of inputs led to a 1.11% decrease in Mexican gross output relative to what could have been observed in the absence of the disruptions in the supply of imported inputs at the onset of the pandemic. The direct effect accounted for a 0.98 percentage points of the contraction, while the indirect effect led to an additional 0.14 percentage points decline in Mexican gross output.

Source: Own estimates using data from Banco de México and INEGI.

Table 2 presents the indirect effects within each region expressed as a proportion of the total effect. At the sectoral level, a clear pattern emerges, as sectors that typically require a greater volume of inputs to produce goods and services, such as construction and manufacturing, experience stronger relative indirect effects. As mentioned earlier, these feedback effects capture the successive rounds of impacts on the gross output for a specific sector due to declines in the gross output of other sectors that also experienced a reduction in their supply of intermediate inputs. For example, in the Northern region, the indirect effect of the construction sector is primarily explained by reduced sales from the metallic and non-metallic mineral sectors, as well as the manufacturing of non-metallic mineral-based products such as cement. In the manufacturing sector, on the other hand, machinery and equipment, computer equipment, electronic devices, and transportation equipment exhibit the highest indirect effects. These impacts are primarily driven by the non-metallic mineral mining sector, followed by the basic metal industries and metal product manufacturing.

 Table 2

 Indirect Effects in Mexican Regional and National Gross Output due to the Reduction in Intermediate Imports at the Onset of the Pandemic<sup>1/</sup>

 Relative to the total effect on gross output in percent

Relative to the total effect on gross output in percent					
Sector	Northern	North Central	Central	Southern	National
Oil and gas extraction	0.5	0.0	0.1	1.8	1.8
Non-oil Mining	2.4	1.8	0.9	1.2	2.0
Utilities	4.6	3.3	4.1	3.7	4.0
Construction	14.8	11.9	13.5	12.0	13.1
Manufacturing	13.3	9.1	12.0	11.8	12.3
Commerce	7.4	5.9	8.6	4.8	7.3
Transportation	9.0	7.0	10.7	6.5	9.3
Other services	3.2	2.7	3.9	2.6	3.4
Total	13.3	9.1	12.0	11.7	12.2

1/ The relative measures are obtained by dividing the indirect effects by the total effects of the corresponding sector within each region.

Source: Own estimates using data from Banco de México and INEGI.

Figure 4 shows, in turn, that the Northern region reported the highest contribution in explaining the national contraction in national gross output due to the simulated negative shock on imports of intermediate goods caused by the pandemic of COVID-19, with 0.55 percentage points of the total. This regional contribution was followed by those of the Central, North Central, and Southern regions, with estimated contributions of 0.33, 0.14, and 0.09 percentage points, respectively.

#### Figure 4 Regional Contribution to the Estimated Contraction in Mexican Gross Output Due to the Reduction in Imports of Intermediate Goods at the Onset of the Pandemic of COVID-19



Note: Considering the Northern region as an example, the figure under the yellow bar indicates that this region contributed 0.55 percentage points to the 1.11% contraction in national gross production. Source: Own estimates using data from Banco de México and INEGI.

On the other hand, when analyzing the national reduction in gross output at the sectoral level, it is seen that the manufacturing activity was the most affected by the simulated shock on imports of intermediate goods, as expected, with a contraction of 1.10% (Table 3a). At the regional level, and focusing only in the manufacturing sector by region, it is estimated that the greatest relative decrease on gross output was that of the North, with a reduction of 3.98% due to the simulated shock. This result can be attributed to the greater integration of this region into global supply chains, as well as to the larger share of the affected sectors in their total gross manufacturing output. As a reference, the observed contractions in manufacturing output in the second quarter of 2020 compared to the previous quarter were 25.89% in the North, 23.27% in the North-Central, 33.39% in the Central, and 14.33% in the Southern region (Figure 5).<sup>22</sup> There are also reductions in the secondary sector excluding manufacturing production associated with the shock being analyzed here was the one that contributed the most to the reduction in national gross output, explaining 1.10 of the 1.11 percentage points of the latter (Table 3a and 3b).

<sup>&</sup>lt;sup>22</sup> Banco de México estimates based on INEGI's seasonally adjusted State Monthly Indicator of Manufacturing Activity.

#### Figure 5 Actual Contraction in Mexican Manufacturing Gross Output and Estimated Initial Contraction in Mexican Manufacturing Gross Output due to the Simulated Shock in Imports of Intermediate Goods at the Onset of the Pandemic Percentage change 2Q-2020 vs 1Q-2020



Note: Considering only the manufacturing sector by region, the relative decrease in gross output by region due to the simulated shock is estimated. The graph also presents the actual contractions in manufacturing output in the second quarter of 2020 relative to the previous quarter, using INEGI's seasonally adjusted State Monthly Indicator of Manufacturing Activity. Note that the estimated decline attributed to global supply chains disruptions reflects a specific shock channel of the COVID-19 pandemic (interruptions in the supply of imports of intermediate goods), whereas the actual decline during the second quarter of 2020 results from the combined impact of multiple factors, including demand shocks of the lockdown. Source: Own estimates using data from Banco de México and INEGI.

Within the manufacturing sector, the contributions to the contraction of national manufacturing gross output stand out due to the simulated initial supply shock in (i) motor vehicle and vehicle parts manufacturing, and in (ii) the sector of machinery and equipment, electrical industry, industrial electronics, and manufacturing of transportation equipment except for cars and trucks (Figure 6). In total, these activities account for 2.16 percentage points out of the 3.11% contraction in manufacturing gross output at the national level due to the simulated supply shock.

#### Table 3

# Estimated Effects in Mexican Gross Output due to the Simulated Shock in Imports of Intermediate Goods at the Onset of the Pandemic<sup>1/</sup>

#### a) Sector Contribution to the Estimated Contraction in Regional Gross Output Percentage points<sup>2/</sup>

Sector	North	North Central	Central	South	National
(1) Secondary, excluding manufactures	-0.01	-0.01	-0.01	-0.01	-0.01
(2) Manufacturing	-2.01	-0.79	-0.88	-0.47	-1.10
(3) Services	-0.01	-0.01	-0.01	-0.01	-0.01
(4) Contraction in Total Gross Output (%)	-2.02	-0.81	-0.90	-0.49	-1.11

## b) Estimated Contraction in Mexican Sector Gross Output at the Regional Level due to the Simulated Shock<sup>1</sup>

I ercent					
Sector	North	North Central	Central	South	National
(1) Secondary excluding manufactures	-0.06	-0.06	-0.08	-0.03	-0.05
(2) Manufacturing	-3.98	-2.47	-2.72	-2.22	-3.11
(3) Services	-0.02	-0.01	-0.02	-0.01	-0.02

1/ The simulated shock refers to the estimated contraction in imported inputs from China, the European Union, and the United States.

2/ Figures may not add up to the total due to rounding.

Source: Own estimates using data from Banco de México and INEGI.

Figure 6 also shows the implications of the heterogeneity of the initial shock in an environment of different productive structures in regional gross output. It is observed, for instance, that the Northern region was the most affected in sectors such as machinery and equipment, electrical industry, electronics, and transport equipment, with the exception of the motor vehicle and vehicle parts manufacturing; while the Central regions were mostly affected in motor vehicle and auto parts manufacturing. In the South, the manufacturing of petroleum products, the chemical industry, and the plastics and rubber industry were the ones with the largest reductions within regional gross manufacturing production. These results are relevant since, even though these sectors did not stop their operations as they were designated essential economic activities, the shortage of imported inputs would seem to have had a significant negative impact on their productive activity.

#### Figure 6 Sectoral Contribution to the Estimated Contraction on Mexican Manufacturing Gross Output due to the Initial Shock in Imports of Intermediate Goods at the Onset of the Pandemic



1/ Figures may not add up to the total due to rounding.

Note: The figures outside the columns denote the estimated contraction of the Mexican manufacturing gross output at both the regional and national levels expressed as a percentage relative to a scenario without disruptions. The numbers within the columns of the graph represent the contributions, by subsector, to the regional and national manufacturing gross output estimated contractions due to disruptions.

Source: Own estimates using data from Banco de México.

#### 5. Final Remarks

This paper uses data from INEGI on intermediate goods imports by sector and country of origin to estimate, employing the Ghosh Model, how the reductions in the availability of such imports from China, the European Union, and the United States at the onset of the pandemic affected regional and sectoral gross output in Mexico. The results suggest that the estimated supply shock associated with the lack of imported inputs due to the pandemic, relative to a scenario without disruptions, led to heterogenous reductions of regional and sectoral aggregate output, with such contractions being the largest in those regions and sectors more integrated to the global supply chains. In particular, it is found that the most internationally integrated region to the global supply chains, the North, was the most affected as a result of the shock, while the least integrated, the South, experienced the smallest contraction. At the sectoral level, in turn, is found that the most globally integrated one, the manufacturing sector, experienced the largest contraction from the shocks, particularly, Motor vehicle manufacturing.

The paper adds to the literature on how global supply shocks are transmitted to the local economies. In particular, it illustrates how these supply shocks end up affecting, to a greater extent, those regions and sectors with stronger linkages to the global production chains. Additionally, it also shows that regions with weaker linkages to global supply chains may also experience the negative effects of shocks through the indirect multiplier effect.

It should be stressed, however, that when defining the shocks to capture supply chains disruptions, it was assumed that they emerged from supply effects, and not from demand side effects. Since the shocks were defined during the early stages of the pandemic, and mobility restrictions in Mexico were implemented relatively later, we attribute the decline in intermediate imports primarily to a supply shock. However, we cannot entirely rule out the possibility that some demand factors were already affected. As a result, there is an opportunity for future research to refine the contributions of demand and supply factors to gross regional and sectoral gross output at the outset of the COVID-19 pandemic.

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