





Analysis of national and international tomato trade routes through the simplex method

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ABSTRACT

Objective: To find the optimal national and international tomato trade routes through the simplex method to maximize profit.

Design/methodology/approach: The apparent national consumption was determined from the production, the volume of exports, the imports, and the population of each state in the Mexican republic; based on this, the points of origin and destinations were established, to later optimize the routes through the simplex method taking into account two scenarios, a closed market economy and an open market economy.

Results: Of the total offer, 21% is destined to the national market, where only 64% of the offerors supply tomato to national consumers. On the other hand, in the open economy it is evident that only 45% of the destinations through which tomato can be exported to North American territory are optimal, and it is also clear that 79% of national surpluses are destined to trade in a foreign market.

Limitations on study/implications: The model was designed with data from 2020, considering all the tomato variants produced and exported in Mexico contained in the tariff classification 070200; the independent variable was the distance between offerors and destinations.

Findings/conclusions: In conditions of closed market there is surplus production of tomato in 19 states that allows supplying the states with negative balance. Estado de México, Mexico City, and Veracruz concentrate the greatest demand due to their large population density. The two states with greatest surplus, Sinaloa and San Luis Potosí, destined the total of their offer to the foreign market, primarily because of their proximity to border customs.

Keywords: simplex method, optimization of agricultural routes, tomato, open and closed economy.

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INTRODUCTION

Presently, tomato (*Solanum lycopersicum*) is considered one of the strategic products for the development of the agricultural sector in Mexico (Bustamante *et al.*, 2022), since it occupies the 9th place among vegetables with highest production in the country (SIAP, 2021); in addition, it is a basic ingredient in Mexican cuisine that has managed to earn a prominent place in other parts of the world (Gobierno de México, 2022). According to the *Revista Industrial del Campo* (2020), among its characteristics those that stand out are that it is an important source of vitamins (A, B1, B2 and C), minerals (calcium, phosphorus, potassium, sodium), and antioxidants.

Because of its nature and characteristics, tomato has medicinal properties among which the following functions stand out: antiseptic, alkalizing, depurative, diuretic, digestive, laxative, anti-inflammatory, and remineralizing (Revista Industrial del Campo, 2020); likewise, it represents a role of utmost importance within the Mexican economy since it acts as a balm for society to generate sources of employment and income (Velasco *et al.*, 2011).

Mexico is considered as the main place where this vegetable was domesticated, with the state of Sinaloa being the principal one, followed by Querétaro, Coahuila, Nuevo León and Puebla; these regions stand out because they present better yields attributed to their investment in irrigation systems and technologies that protect the crop (USDA, 2022).

Within these techniques of crop protection, there are greenhouses, since there are environmental factors that reduce the life cycle of tomato, so that production through greenhouses is gaining territory (Mundo *et al.*, 2019), the main reason being the optimization of production sustained with the use of technology, which helps to save water and to reduce the level of pesticides used (Sánchez, 1999; Galbraith, 1969).

Global integration allows for actors such as producers, distributors, and consumers of the merchandise to remain in the same tenor by establishing a supply chain, where the international division of labor is established based on the capacities of a certain region (Gereffi and Korzeniewicz, 1994). Mexico is identified as one of the 10 main tomato suppliers due to its favorable climatological conditions, making it the third most exported product (Infografo, 2019).

Tomato is considered the vegetable of highest economic value since at the national level it is the one that is destined the most to exports. Evidence of this is that the amount exported denoted 18% of the total production of the country (SIAP, 2021), and according to FAOSTAT (2020) the country occupies the first place at the global level in exports of the product. In addition, it is due to the number of direct and indirect jobs generated by its cultivation and the currencies that enter the country as a result of its trade (Secretaría del campo, 2022).

Because of the surface destined to its cultivation (open air and greenhouse) and the production value, tomato is one of the most important crops. According to FAOSTAT (2020), tomato production in Mexico represents 1.64% of the 251 million tons produced in the world, placing it in the tenth place, and also from the total Mexican exports, those for this vegetable represent 23.2%, equivalent to 2,538,501 thousand dollars, positioning it as a leading territory (TradeMap, 2022).

Given the economic and commercial importance of tomato in Mexico, this study has the objective of finding the optimal routes to trade the vegetable in the national and international market through the simplex method, with which a reduction in costs and an increase in profits will be determined.

MATERIALS AND METHODS

Because of the commercial importance of this vegetable for Mexico, this study suggests the optimization of a transport model for the tomato variants contemplated in tariff fraction 070200 (SIAMI, 2021), using the simplex method, which is considered a functional tool in the resolution of linear programming problems, evaluating the objective function (Ayllón

et al., 2015); it is practical to solve questions about transport optimization (Díaz and Cruz, 2006), an example of which is the one used in the hydrocarbons sector (García, 2014).

Among other applications, there are some related to perishable foods, an example of which is presented by Ayllón *et al.* (2015) for fresh prickly pears when its production exceeds the national demand, where the model for closed and open economy was used. Ramírez (2013) made a similar application for the transport model of onion in Mexico, and Toxqui (2013) did it for white corn.

In their presence, a model is suggested that allows minimization of transport costs from the offering to the demanding zones, both in closed economy and in open economy so that the distribution is efficient, making use of the simplex method, proposed by Dantzig in the 1940s (Gass, 2002), an algorithm that solves problems when they are of linear programming (Dantzig, 1990). That is, a procedure to optimize an objective function subject to restrictions of equality (=) and/or inequality (\leq, \geq), so that the maximum profits or the minimum costs are determined (Moncayo and Muñoz, 2018).

The resolution of the linear programming will be through the LINGO 19.0 software, designed for the optimization of linear functions. For this purpose, the variables and the restrictions of offer and demand were determined, which are expressed in the following way: origins (m) and destination (n), amount of the offer in the origin (i) is E_m and the demand in the destination (j) is D_n , the existing distance between origin (i) and destination (j) is C_{ij} , and finally X_{ij} is the amount transported from origin to destination.

The point of origin is the objective function, and it is represented in the following way:

$$Y = \sum_i^m \sum_j^n C_{ij} X_{ij}$$

Where $i=1, 2, \dots, m$ (producing regions); $j=1, 2, \dots, n$ (consuming regions), thus building the minimization function:

$$Min Y = C_{11} X_{11} + C_{12} X_{12} + \dots C_{mn} X_{mn}$$

Where C_{11} represents the distance from origin 1 to destination 1; C_{12} represents the distance from origin 1 to destination 2, and thus successively, until finishing with the origins and the destinations; these distances were obtained from the Digital Map (INEGI, 2022). The codes with letter X (X_{11}, X_{12}, \dots) will be the unknown variable to be solved with the application of the model so they will always be represented with letters. Then, the restrictions that condition the objective function are formed, denoting the amount available from each offeror and the amount needed by each consumer.

Offer

$$X_{11} + X_{12} + X_{13} \dots + X_{1n} = E_1$$

$$X_{21} + X_{22} + X_{23} \dots + X_{2n} = E_2$$

.....

$$\dots\dots$$

$$X_{m1} + X_{m2} + X_{m3} \dots\dots\dots + X_{mn} = E_m$$

These restrictions show that the production from each center exceeds its demand, sending to consuming centers an equal amount as their offer.

Demand

$$X_{11} + X_{21} + X_{31} + \dots\dots\dots + X_{m1} = D_1$$

$$X_{12} + X_{22} + X_{32} + \dots\dots\dots + X_{m2} = D_2$$

$$\dots\dots$$

$$\dots\dots$$

$$X_{1n} + X_{2n} + X_{3n} + \dots\dots\dots + X_{mn} = D_n$$

These restrictions indicate that the amounts sent from different producing centers should agree with the demand from each consumer center.

To apply the model in closed economy it was necessary to determine the deficit or surplus in the production, and therefore the national production from 2020 was taken up again, considering the 31 states and Mexico City, information that was obtained from the agricultural close; the population by state was consulted in the current population and housing census 2020 (INEGI).

The National Apparent Consumption (NAC) is the starting point that expresses the availability in the country of a specific consumption product in a certain period of time (Ramírez, 2016); it is obtained from the sum of national production and imports, minus exports. For the *per capita* consumption, the NAC is divided by the total population in Mexico, and then, this figure is multiplied by the number of inhabitants in each state, resulting in the apparent consumption by state, necessary for the determination of offerors and consumers.

Finally, the tomato consumption by state is subtracted from its production to identify whether the state is capable of satisfying its demand. If the result is positive after the operation, it will be an offeror, and in the contrary case it will be a consumer; 13 demanding states and 19 offerors were obtained with the calculation, and therefore, the codes for the restrictions of offer and demand have the following sequence:

Offer

$$X_{11} + X_{12} + X_{13} + \dots\dots\dots + X_{113} = E_1;$$

$$X_{21} + X_{22} + X_{23} + \dots\dots\dots + X_{213} = E_2;$$

$$\dots\dots$$

$$\dots\dots$$

$$X_{191} + X_{192} + X_{193} + \dots + X_{1913} = E_{19};$$

Demand

$$X_{11} + X_{21} + X_{31} + \dots + X_{191} = D_1;$$

$$X_{12} + X_{22} + X_{32} + \dots + X_{192} = D_2;$$

.....

$$X_{113} + X_{213} + X_{313} + \dots + X_{1913} = D_{13};$$

The aforementioned applies to a closed economy, although the intention of this article is for the model to be applicable also to an open economy where part of a country’s production is offered in the national territory and another is exported (Icomena, 2020).

For this purpose, it is necessary to add new destinations for offerors to send the tomato, and these new destinations are all the land customs offices that are located in the northern border, of which 19 in total are the ones that fulfill these characteristics resulting in 32 destinations in total.

The structure of the code for the tomato demand is presented in the following way:

$$X_{114} + X_{214} + \dots + X_{1914} > 0;$$

$$X_{115} + X_{215} + \dots + X_{1915} > 0;$$

...

$$X_{131} + X_{231} + \dots + X_{1931} > 0;$$

$$X_{132} + X_{232} + \dots + X_{1932} > 0;$$

This code represents that the amount to send from the 19 offerors to the consumers in the open market (from 14 to 32) should be higher than 0, and a specific amount cannot be used because the demand is unknown.

On the other hand, the offer is represented in the following way:

$$X_{114} + X_{115} + \dots + X_{132} = Em;$$

$$X_{214} + X_{215} + \dots + X_{232} = Em;$$

...

$$X_{1814} + X_{1815} + \dots + X_{1832} = Em;$$

$$X_{1914} + X_{1915} + \dots + X_{1932} = Em;$$

The same logic as in the closed market is applied, where the offer is the same as the surpluses once its territorial demand is covered.

RESULTS AND DISCUSSION

Tomato production in 2020 was 3,370,827 tons, exceeding by 46% the national apparent consumption estimated for the same year (1,544,366.65 tons), so there was a surplus, ideal situation to achieve exports of the product, as mentioned in the transport model for the distribution of guava in Mexico, where, once the national demand was covered there was a surplus for exports or transformation in the industry (Quintero *et al.*, 2016). The NAC divided by the total population in Mexico, which was 1,26,014,024 inhabitants in 2020, originated *per capita* consumption of 0.012255514 tons, equivalent to 12.25 kilograms.

Closed economy

The self-sufficient states, capable of covering their internal demand, were denominated origins, and instead the ones that had a deficit were called destinations, forming with them the restrictions both of offer and of demand. With this, 19 states were obtained with the ability to offer their surpluses to the rest, among them Sinaloa, San Luis Potosí, Zacatecas, Michoacán, Baja California Sur, Morelos, Querétaro, Sonora, Coahuila, Puebla, Oaxaca, Baja California, Durango, Aguascalientes, Guanajuato, Hidalgo, Chiapas, and Colima, since their total offer was 2,315,692 tons, even allowing them to export.

The rest of the states, that is, 13, did not manage to cover their internal demand, among them: Nayarit, Campeche, Tlaxcala, Guerrero, Quintana Roo, Yucatán, Tabasco, Tamaulipas, Chihuahua, Nuevo León, Veracruz, Estado de México and Mexico City, with a total demand of 489,232 tons.

According to the results obtained, the optimal solution represents the amount of tons that should be distributed from each origin (i) to each destination (j), which minimizes the distances between the offerors and the consumers both for the closed market and for the open market represented in Table 1.

Table 1. Optimal distribution in closed market

Origin (i)	Destination (j)
Zacatecas	Monterrey
Michoacán	Tamaulipas, México y Ciudad de México
Baja California Sur	Chihuahua
Morelos	Tlaxcala, Guerrero, Quintana Roo, Yucatán, Veracruz, Ciudad de México
Jalisco	Nayarit
Puebla	Veracruz
Oaxaca	Campeche, Yucatán, Tabasco
Durango	Chihuahua
Aguascalientes	Monterrey
Guanajuato	Tamaulipas
Hidalgo	Veracruz
Chiapas	Yucatán

Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap 2020.

The results from the analysis showed that 21% of the total offer is destined to the national market, where only 64% of the offerors supply tomato to the national consumers, with Morelos together with Michoacán being the states that supply 55% of the total demand, having the capacity to distribute to 8 states in deficit. As with the transport model for avocado, where, although they are not the states that cover the most demand, they are the best located to supply the largest guava consumer centers: Estado de México and Mexico City (Avendaño, 2019).

On the other hand, Oaxaca, Durango, Aguascalientes, Guanajuato and Puebla supply 7 states that represent 37% of the total demand, and finally, Zacatecas, Baja California Sur, Guadalajara, Hidalgo and Chiapas cover the remaining 8%, represented in Figure 1.

Open economy

The results show that only 45% of the destinations to which tomato can be exported in North America are optimal; the rest, due to the distance from producing states, are no longer optimal because they imply higher transport costs. It is also exposed that 79% of the national surpluses are destined to trade in foreign markets, and they are summarized in Table 2.

The percentage of surpluses in the total production of each state also stands out, which is destined to customs offices that are presented as optimal destinations, with the states of Sinaloa, Baja California Sur and Sonora being the ones that offer between 98% and 99% of the surplus of their production to the customs office in Nogales, Sonora. On the other hand, Zacatecas and Coahuila offer between 96% and 99% to the customs office in Ciudad Miguel Alemán, Tamaulipas; Baja California and Colima destine nearly 100% to the customs office in Mexicali, Baja California.

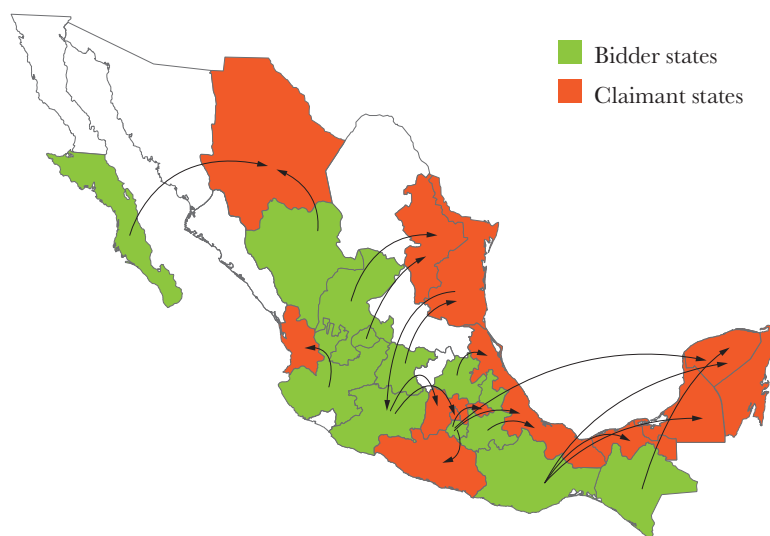


Figure 1. Optimal distribution in a closed economy. Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

Table 2. Optimal distribution in open market.

Origin (i)	Destination (j)
Sinaloa	Nogales
San Luis Potosí	Matamoros
Zacatecas	Ciudad Miguel Alemán
Michoacán	Matamoros
Baja California Sur	Nogales
Querétaro	Matamoros
Sonora	Nogales
Coahuila	Ciudad Miguel Alemán
Baja California	Mexicali
Colima	Mexicali
Guadalajara	Ciudad Reynosa

Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

There is a particular case for the offering state of Michoacán, since it only transports 31% of its surplus to the customs office in Matamoros, Tamaulipas; this is because the largest part of it is destined to national trade, although this destination is also supplied by San Luis Potosí and Querétaro. Finally, Guadalajara offers 98% of its surpluses of tomato just to the customs office in Ciudad Reynosa, Tamaulipas. The optimal transport routes for the open economy are illustrated in Figure 2.

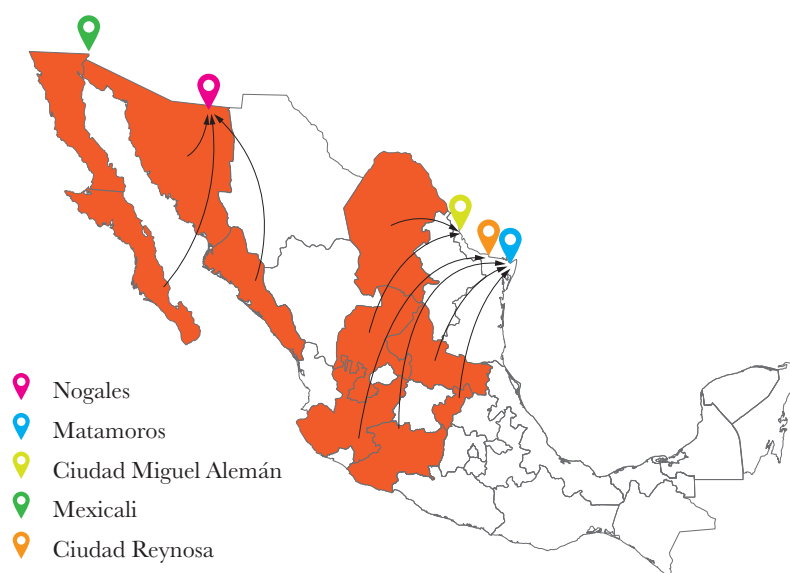


Figure 2. Optimal distribution in the open market
Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

CONCLUSIONS

In closed market conditions, the model seeks an efficient distribution for the country to cover its domestic demand, ensuring food security in its territory. Estado de México, Mexico City and Veracruz concentrate the highest demand due to their great population density.

On the other hand, in the open market, it is necessary for the producing states to present surpluses once their internal demand is covered and this way they may have the possibility of offering in foreign territory, optimizing their costs and obtaining greater profit. This is the case of Sinaloa and San Luis Potosí, which found it optimal to destine their total offer to the foreign market. Without a doubt, the presence of products from some states of the Mexican Republic in the foreign market depends, to a certain degree, on their geographic location.

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