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# Is smuggling welfare-improving?

## Evidence from avocados in Costa Rica


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**Notices**

# Is smuggling welfare-improving? Evidence from avocados in Costa Rica[1]

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**Abstract**

Does smuggling improve economic welfare? This paper provides a theoretical model of illegal trade and determines the impact of smuggling on economic welfare. We focus on Costa Rica's recent prohibition of avocados imported from Mexico. Using unique data on trade, production, and the price of Costa Rican and Mexican avocados, we find that the quantity of avocados smuggled into Costa Rica on an annual basis ranges from 4,668 to 10,232 metric tons, representing up to four times the quantity of locally produced avocados. Furthermore, we demonstrate that smuggling is necessarily welfare-improving compared to the ``no-smuggling situation''. Compared to the ``free-trade situation'', smuggling does not always compensate for the negative effects arising from the restrictive trade measure. In most cases, welfare is lower after the prohibition and smuggling than prior to the implementation of the prohibition. In some cases, however, smuggling results in a gain in terms of trade that offsets the harmful effects associated with the trading cost of smuggling. We find that such situations occur when the trading cost of smuggling is low, and thus when enforcement of the prohibition by public authorities is weak.

**JEL codes**: D60, F13, F14.

**Keywords:** Partial Equilibrium Model, Welfare, Smuggling.

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## 1. Introduction

In May 2016, Costa Rican customs authorities seized 4,100 kilograms of Mexican avocados that had been smuggled through Panama. One year earlier, the Ministry of Agriculture and Livestock of Costa Rica had suspended the issuing of phytosanitary import certificates for avocados from several of its trading partners, including Mexico. Within a few months of the ban, the local price of avocados in Costa Rica doubled. Thus, the restrictive trade measure imposed by the Costa Rican government created an opportunity for smugglers.

Smuggling is defined as international trade by firms or individuals that either partially or fully evades trade regulations and border duties, either by avoiding official border crossing posts (full evasion) or by resorting to illegal means like under-invoicing, misclassification, underpricing, etc. (partial evasion). In this paper, we focus on the full-evasion type of smuggling, also called the Bhagwati-Hansen type of smuggling (Martin and Panagariya, 1984). Throughout the paper, we use the terms ``smuggling'' and ``illegal trade'' to refer to trade in products between two countries that forbid such trade. We do not use these terms to refer to illicit trade (trading of illicit products, such as drugs or counterfeits) or to informal trade (unorganized, small-scale trade generally conducted by self-employed traders to avoid import duties, bribes, administrative paperwork, etc… see Bouët et al., 2018, for a survey).

Smuggling occurs when a price disparity that is not caused by natural trading costs exists for the same good sold at two different locations. When governments implement a trade prohibition, smuggling may arise due to the difference between the price at which smugglers can buy a good and the price at which consumers are willing to buy that good, the latter not being an official market price. As a consequence, policies hampering trade, such as tariffs, quantitative restrictions, administrative regulations, and sanitary and phytosanitary rules, are key determinants of the emergence of smuggling. Therefore, smuggling activities prevail in many countries worldwide and throughout economic history.

In this paper, we build a simple method for evaluating the trade and welfare consequences of smuggling. Such an evaluation can be difficult due to a lack of data. Furthermore, we propose a direct application of our model to the ongoing case study of the smuggling of avocados occurring in Costa Rica. We contribute to both the theoretical and the empirical literature on illegal trade in several ways. First, while previous researchers have mostly considered the welfare effects of smuggling on economies in which a tariff has been imposed, either on exports or on imports,[4] we focus on the welfare consequences of smuggling arising after the implementation of a ban on imports. To the best of our knowledge, this perspective has never been analyzed.

[4] With the exception of Falvey (1978), who assumes that a home country implements a quantitative restriction on imports from all sources. Falvey (1978), however, adopts a model similar to that presented by Bhagwati (1973a).

Second, all theoretical analyses of illegal trade so far conducted apply general equilibrium models.[5] We build a partial equilibrium model to study the welfare effects of smuggling. A partial equilibrium model appears to be the most appropriate tool with which to conduct our analysis for several reasons. First, it allows us to focus on a specific market by assuming that other markets are in equilibrium throughout the analysis. We are therefore able to isolate the impact of smuggling of a specific commodity on domestic welfare. Second, thanks to its theoretical simplicity, a partial equilibrium model offers greater tractability and transparency than a general equilibrium model. Finally, our model permits a more detailed analysis of complex policy instruments, such as a prohibition on imports or sanitary and phytosanitary norms.

Third, results from previous models are all based on certain restrictive assumptions. Among others, Bhagwati(1973a), Sheikh (1977}, Pitt (1981}, and Martin and Panagariya (1984) assume that the country under study is small and that legally and illegally traded goods are homogeneous. In this paper, we relax both assumptions.

Finally, this paper contributes to the theoretical literature on smuggling, as well as to the empirical literature on illegal trade (see Section 2), by providing an empirical estimation of the quantity of avocados smuggled in Costa Rica (see Section 7). Furthermore, it also contributes to the literature on agricultural economics by specifying an empirical estimation of price elasticities of demand and supply of avocados produced in, and imported to, Costa Rica (see Section 6). Avocado presents an interesting commodity, as its trade is becoming very lucrative in some countries, especially in Latin America. The data collected in this paper may thus prove useful for future research on this good.

The rest of this paper develops as follows. Section 2 proceeds to the review of the literature. Section 3 explains the context in which smuggling occurs in Costa Rica. Section 4 thoroughly describes the theoretical model used in this analysis. Section 5 presents the estimation of the parameters used in the model. Section 6 reports the results obtained from the empirical application of our model. Section 7 concludes.

## 2. Review of Literature

Through empirical analyses of illegal trade, researchers have revealed the presence of this phenomenon in many economies worldwide. Although these studies may suffer from a lack of accurate data on smuggling, they provide rough estimates of its magnitude.

Bhagwati (1974) carries out one of the first empirical studies on smuggling and under-invoicing of imports. He compares the f.o.b. values of exports recorded by Turkey's main trading partners to the c.i.f. values of imports recorded by Turkey in 1960 and 1961. Bhagwati (1974) finds strong evidence supporting under-invoicing of imports in manufactures. Although these results

[5] Except Sheikh (1977), who adopts a partial equilibrium model; however, the author uses restrictive assumptions that we relax in this investigation.

are limited in scope, Bhagwati (1974) provides a methodology to estimate illegal trade called the "reconciliation" approach.

Using this methodology, many researchers have assessed the magnitude of illegal trade in various countries (Smith, 1969; C.G.F., 1970; Sheikh, 1974a; Connolly, 1995; Van Dunem and Arndt,2009; Jean et Mitaritonna, 2010; Levin, 2014, among others). These studies, however, estimate the partial-evasion type of smuggling (e.g. under-invoicing, misclassification, under-pricing, etc.).

Few recent empirical studies evaluate the full-evasion type of smuggling (i.e., avoidance of official border crossing posts). These include statistical investigations and surveys (Golub, 2009; INSAE, 2012; Ackello, 1996).

Finally, one study econometrically explores the determinants of illegal trade. Bensassi, Jarreau and Mitaritonna (2016a) find that agricultural products, goods facing higher tariffs or an import ban, and time-sensitive products are mainly smuggled, while other goods are legally traded. Bensassi, Jarreau and Mitaritonna (2016a) confirm these results in the case of Benin, Togo and Nigeria.

Empirical studies can be useful in showing that illegal trade forms a major component of the economy in many parts of the world. However, due to difficulties in compiling data on contraband products, researchers have produced a wide range of estimates of the quantities and values smuggled. In addition, compared to theoretical studies, these investigations do not analyze the welfare effects of smuggling activities.

Early theoretical studies highlight the willingness of trade theorists to integrate smuggling activities within the traditional framework of international trade theory. Bhagwati (1973a) propose a general equilibrium model based on the Hicks-Samuelson value framework to evaluate the welfare effects of smuggling. Bhagwati (1973a)'s model (BH model) assumes that smuggling imposes a terms of trade loss due to the real cost involved with smuggling. Bhagwati (1973a) conclude that when legal and illegal trade coexist, smuggling results in a decrease in welfare (due to the loss in terms of trade).[6] However, this result depends largely on the strong assumption previously stated.[7] Modifying some assumptions of the BH model, Kemp (1976), Sheikh (1974b) and Deardorff (1990) obtain results that oppose those found in Bhagwati (1973a).

Despite suffering from other imperfections,[8] the BH model has provided the basis for many other investigations into the theory of smuggling. For example, Bhagwati (1973) and (Ray

[6] This proposition holds true regardless of the market structure of smuggling activities (monopolistic or perfect competition).
[7] Cooper (1974), among others, questions the assumption that illegal trade is socially more costly than legal trade, even when smuggling occurs at illegal entry points.
[8] The BH model does not assume risk premium compensations from smuggling activities, does not consider welfare implications of induced shifts in income distribution, and relies only on two goods (Gray, 1975).

(1978) exploit the BH model to explore diverse questions related to illegal trade from a policy-oriented perspective, while Falvey (1978) investigates the welfare effects of smuggling resulting from quantitative restrictions. We also analyze the welfare impact of smuggling in the context of more modern forms of protectionism, such as a prohibition on imports for sanitary and phytosanitary (SPS) reasons, but build our own model of illegal trade.

Another important contribution to the theoretical literature on smuggling is that of Pitt (1981). According to this author, legal trade may be conducted at a loss if it serves as a camouflage activity for smuggling. In this sense, Pitt (1981) provides an explanation for the coexistence of both legal and illegal trade and of price disparity, which was not explained by the BH model.[9] Pitt (1981) concludes that smuggling may be welfare improving and that smuggling is "unambiguously welfare increasing" if the cost of smuggling corresponds to fines and confiscations.

Finally, reconciling previous results, Bhagwati (1981) models different configurations of smuggling in order to account for the fact that illegal trade may take place at both legal and illegal entry points. The models used are based on the BH model but reach diverse outcomes regarding the welfare effects of smuggling.

As emphasized by the above-mentioned studies and by the work of Bhagwati (1981), smuggling represents a complex phenomenon that can take various forms. Theoretical analyses of smuggling within the traditional international trade theory do not lead to clear and systematic conclusions regarding the welfare consequences of illegal trade. As a result, economists have developed new approaches through which to investigate the theory of smuggling.

Martin and Panagariya (1984) suggest that the real costs of smuggling represent a choice variable for the firms. Martin and Panagariya (1984) also model the uncertainty associated with smuggling by introducing a probability of detection. Martin and Panagariya (1984) confirm Pitt (1981)'s results in regard to price disparity, however, their results in terms of welfare are ambiguous. We build on Martin and Panagariya (1984), as we also introduce the probability of detection in our model. However, since we do not permit legal trade in our model, this rate of detection is exogenous.

Lovely (1995) model smuggling as a directly unproductive, profit-seeking activity (DUP) since it produces pecuniary returns but does not produce goods or services that enter a conventional utility function directly. Contrary to Bhagwati (1973a), Lovely (1995) demonstrate that smuggling does not necessarily decrease welfare, even when smuggling is considered a resource-using activity.

Following Martin and Panagariya (1984), Norton (1988) integrates risk in the analysis of smuggling and introduces transport costs, which were assumed to equal zero in the BH model

[9] Price disparity is defined by Pitt (1981) as the difference between domestic market price and the tax-inclusive world price of an exported commodity.

and in Pitt (1981)'s model. Norton (1988) validates Pitt (1981)'s conclusion that smugglers located within a certain distance from the frontier use legal trade as a cloaking activity for illegal trade.[10]

Sheikh (1989) provides a more realistic application of risk in the analysis of smuggling. Understanding that smugglers are not risk-neutral, as assumed in all previous studies, Sheikh (1989) models risk-averse smugglers by applying Tobin (1958)'s analysis of risk. Sheikh (1989) confirms the results of Martin and Panagariya (1984), stating that the presence of smuggling may increase or reduce welfare if there are real resource costs associated with smuggling. Smuggling is welfare-increasing only if custom officials are bribed or if the government ignores the illegal activity. Finally, Sheikh (1989) shows that smuggling through legal entry points (e.g., under-invoicing of imports) may lead to smaller welfare losses than smuggling through illegal entry points.

Our analysis brings together previous research and offers an original perspective on the impact of illegal trade on welfare. We provide both a theoretical analysis of illegal trade emerging from a prohibition on imports (rather than tariffs) and an empirical application of this theory to an existing case. In the theoretical analysis, we present a simple and transparent model of illegal trade, rather than a more complex general equilibrium model, as those developed in the previous literature.

Our model is based on the study by Sheikh (1977), who presents the first and, to our knowledge, only partial equilibrium model of smuggling.[11] In his model, he assumes that consumers of illegally traded goods face a risk. We relax this assumption in our model, as it was unrealistic in the case examined.[12]

Furthermore, producers of smuggled goods face a real resource cost and a risk cost. Sheikh (1977) finds that smuggling results in a "two tier price system", as the price of the smuggled good in the domestic market is inferior to the legal price (tariff-inclusive price). His results in terms of welfare are ambiguous. Although Sheikh (1977) provides a simple model of smuggling, he assumes that the smuggled and legally imported products are homogenous and that the country in which illegal trade occurs is small. In our analysis, we relax both assumptions.

## 3. Background

On May 5, 2015, the State Phytosanitary Service of the Ministry of Agriculture and Livestock of Costa Rica submitted a notification of emergency measures to the Committee of Sanitary and Phytosanitary Measures (SPS Committee) of the WTO. The notified document temporarily

[10] Norton (1988) also provides an empirical test of his model, using data on illegal trade of cattle and pigs from 1974 to 1982 and of barley from 1978 to 1982 between the Republic of Ireland and Northern Ireland. The author provides evidence that legal trade has been used as a camouflage activity for illegal trade.

[11] All previous models on the theory of smuggling consist of general equilibrium models.

[12] Discussions with customs authorities from Costa Rica confirmed that consumers of smuggled avocados are not punished by law.

suspended the issuing of phytosanitary import certificates of avocados from the following eight countries: Australia, Spain, Ghana, Guatemala, Israel, Mexico, South Africa and Venezuela.[13] On May 12, 2015, Costa Rica submitted an addendum to the SPS Committee that added the U.S. State of Florida to the list of countries affected by the measure (World Trade Organization, 2015b).

With this precautionary measure, Costa Rica officially aims to prevent the spread of plant pests and disease to protect human, animal, and plant health and food safety. Costa Rican authorities seem particularly worried about the presence of *avocados Sunblotch Viroid* in various avocados-producing countries (World Trade Organization, 2015a). Costa Rica is, however, the only country that has implemented a sanitary and phytosanitary measure prohibiting the importation of avocados from the above-mentioned countries. Thus, it appears that the Costa Rican government implemented this prohibition for protectionist rather than pest-risk avoidance motives.

Costa Rica's local production of avocados is not sufficient to satisfy local demand. Prior to the implementation of the import ban, Costa Rica imported more than 90 percent of its avocados from Mexico (United Nations COMTRADE, 2017).[14] After the implementation of the ban, the price of avocados grown in Costa Rica went up.[15] The price for kilogram of Hass avocados grown in Costa Rica averaged 2.12 constant 2010 US$ in July 2014, compared to 3.74 constant 2010 US$ in July 2015.[16] As a result of this rapid and large increase in the price of locally produced avocados, illegal trade of avocados emerged in Costa Rica. In May 2016, the State Phytosanitary Service of the Ministry of Agriculture and Livestock of Costa Rica reported that customs authorities had seized 4.1 metric tons of Hass avocados illegally imported through Panama (Cortes, 2017).

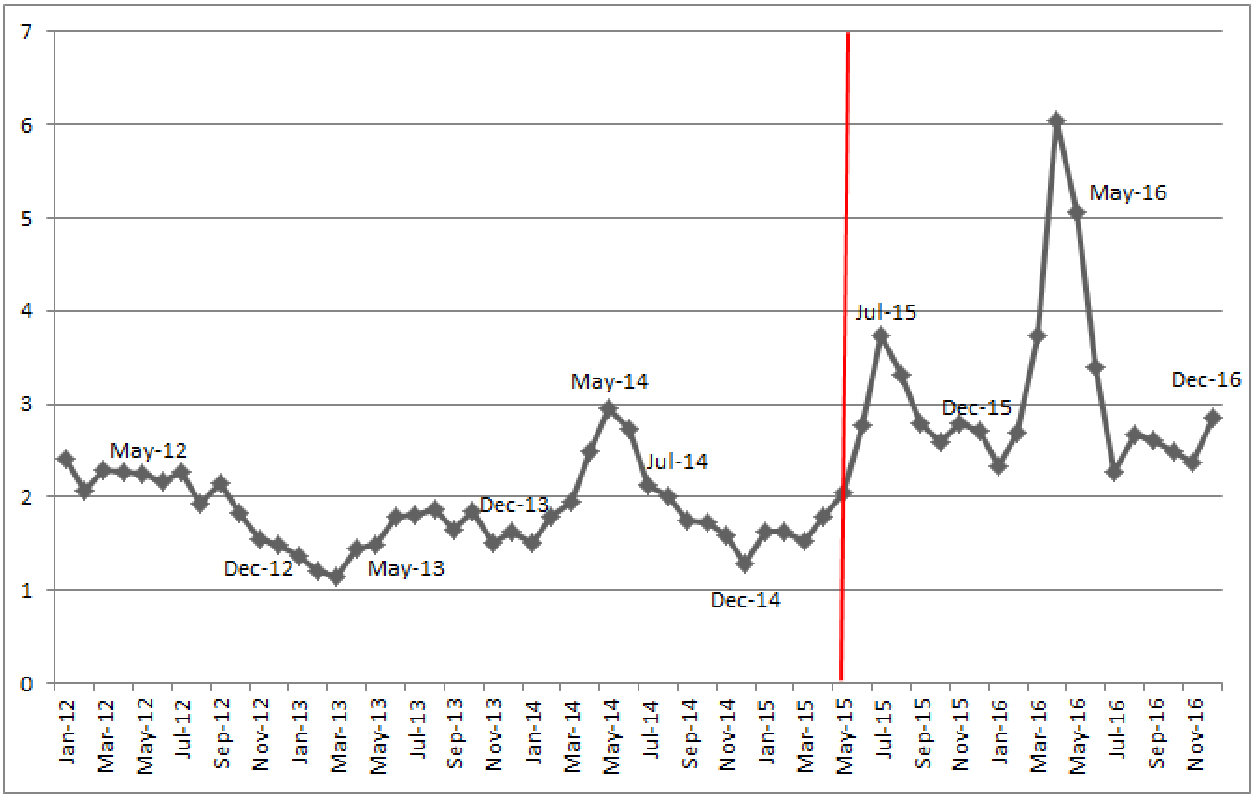
[13] Resolution DSFE 03-2015 on phytosanitary measures applicable to imports of Persea americana Mill.

[14] Other suppliers include Guatemala, Peru and Chile, although to an almost negligible extent.

[15] It is difficult to estimate the increase in local production due to the ban. According to data from the Ministry of Agriculture and Livestock (Sistema de Información del Sector Agropecuario Costarricense from Direciones Regionales del Ministerio de Agricultura y Ganaderia), local production of avocados rose from 1.185 metric tons in 2014 to 12.313 metric tons in 2015 and to 12.042 metric tons in 2016. This swift increase does not only reflect an increase in local production of avocados but also reflects changes in data collection. Prior to 2015, data from the Ministry of Agriculture and Livestock only included the area of Los Santos, rather than all avocado-producing areas avocados in Costa Rica. Moreover, estimation of average local yield was established at four tons per hectare, which is rather low compared to the world average of approximately 10 tons per hectare (Ministry of Agriculture and Livestock, 2017).

[16] We focus the price analysis on Hass avocados since this represents the most produced variety of avocados in Costa Rica. Seventy-five percent of avocados grown in Costa Rica are of the Hass variety, while the remaining 25 percent includes several varieties such as Simmonds, Catalina, Booth, etc. (Secretaria Ejecutiva de Planificacion Sectorial Agropecuaria, 2017)

**Figure 1.** Price of Costa Rican Hass avocados (monthly average, in constant 2010 US$ per kg)




Source: Author's calculations based on data from Programa Integral de Mercadeo Agropecuario (PIMA) and Sistema de Información de Mercados Mayoristas (SIMM)

In addition to these economic consequences, the trade measure also has legal consequences. In July 2015, Mexico and Guatemala raised a specific trade concern (STC) about this measure, arguing that it halts trade and is not justified by scientific evidence (World Trade Organization, 2015c). Ghana, Venezuela, South Africa and the United States of America (USA) supported Mexico and Guatemala. Costa Rica indicated that a risk assessment was under way and that it would remain open to dialogue with its trading partners. However, faced with inertia on the part of the Costa Rican government, the complaining countries reiterated their STC in October 2015, March 2016, June 2016, and October 2016 to ask for a withdrawal of the measure.

On March 8, 2017, Mexico requested consultations with Costa Rica regarding measures it had implemented to restrict or prohibit the importation of avocados from Mexico (World Trade Organization, 2017). These measures appear to be inconsistent with several articles of the SPS Agreement and of the GATT 1994.[17] As of June 2018, the dispute led by Mexico against Costa Rica remains in consultation.

[17] Articles 2.1, 2.2, 2.3, 3.1, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 6.1, 6.2, 7, 8, and paragraphs 2, 5 and 6 of Annex B and paragraph 1 of Annex C to the SPS Agreement; and articles I:1, III:4, X and XI of the GATT 1994.

## 4. Theoretical Model

In this paper, we aim to investigate the welfare effects of smuggling arising from the implementation of a restrictive trade measure, specifically a prohibition on imports. In this section, we develop a simple partial equilibrium model with one sector and two trading partners: Home (H) and the rest of the world (RoW).[18] We relax two assumptions from (Sheikh, 1977): (i) the home country is not a small country and (ii) legally and illegally traded goods are not homogeneous but are differentiated by their country of origin.

Throughout the paper, the first stage of the model represents a situation in which free trade exists between the home country and the rest of the world. In the second stage, the home country imposes a restriction on imports from the rest of the world in the sector under study. This simple step is necessary to identify the welfare effects of smuggling and to compare welfare gains and losses associated with i) a ban without smuggling and ii) a ban with smuggling. It is worth mentioning that when computing welfare effects throughout the different stages of the model, we do not account for the potential sanitary and phytosanitary effects of consuming avocados imported from Mexico.[19] As previously mentioned, we assume the Costa Rican government implemented this measure for protectionist reasons rather than to address market failures. Finally, the third stage of the model introduces illegal trade.

We successively present the full equations of the model for each stage. Throughout the description of the model, each variable is associated with a subscript, from 1 to 3, representing each stage of the model. For example, $pl_t$ represents the local price computed at stage t of the model. Variables computed at stage t of the model serve as initial data for stage t+1. We adopt standard notations for elasticities, with $\eta$ for demand elasticities, and $\varepsilon$ for supply elasticities.

### Stage 1: Situation of free trade

We start from a situation of free trade between the home country and the RoW (Equations (1) through (6)).

$$Apm_1{}^{-\eta_m} pl_1{}^{\eta_{ml}} = K_{md} + md_1 \quad (1)$$

$$Bpl_1{}^{-\eta_l} pm_1{}^{\eta_{lm}} = K_{ld} + ld_1 \quad (2)$$

$$K_{ms} + ms_1 = Cpm_1{}^{\varepsilon_m} \quad (3)$$

$$ls_1 = Dpl_1{}^{\varepsilon_l} \quad (4)$$

$$md_1 = ms_1 \quad (5)$$

[18] The model includes only two trading partners since, as previously mentioned, Costa Rica imports over 90 percent of its avocados from Mexico.

[19] First, the presence of *avocados Sunblotch Viroid* in Mexico has not been scientifically proven and thus remains highly contested. Second, we lack knowledge regarding the potential health effects of Costa Ricans consuming avocados imported from Mexico.

$$ld_1 = ls_1 \quad (6)$$

Equations (1) and (2), respectively, determine the quantity of the imported good demanded in stage 1 ($md_1$) and the quantity of the locally produced good demanded in stage 1 ($ld_1$). $A$ constitutes the scale parameter of the demand function for the legally imported good, $pm_1$ is the world price, $\eta_m$ is the constant price elasticity of demand of the imported good, $pl_1$ is the price of the locally produced good, $\eta_{ml}$ is the constant cross-price elasticity of demand of the imported good, $K_{md}$ is a constant associated with the demand of the legally imported good, and $md_1$ is the quantity of the legally imported good demanded in the home country in stage 1.

Similarly, in Equation (2), $B$ is the scale parameter of the demand function for the locally produced good, $\eta_l$ is the constant price elasticity of demand of the locally produced good, $\eta_{lm}$ is the constant cross-price elasticity of demand of the locally produced good, $K_{ld}$ is a constant associated with the demand of the locally produced good, and $ld_1$ is the quantity of the locally produced good demanded in stage 1.

In Equations (1) and (2), respectively, we add a constant associated with the demand for the imported good ($K_{md}$) and a constant associated with the demand for the locally produced good ($K_{ld}$) in order to allow for positive prices of locally produced and imported goods when the quantity of the imported good demanded and the quantity of the locally produced good demanded, respectively, equal zero.

To estimate $K_{md}$ and $K_{ld}$, we make the following assumptions:

- If the price of the imported good is tripled, then imports equal zero. This is equivalent of a prohibitive tariff of 200 percent. We conduct a sensitivity analysis on this assumption.

- If the price of the imported good equals the price of the locally produced good, then domestic demand for the locally produced good equals zero. We suppose a vertical differentiation, with the imported avocados having higher quality. This assumption is actually reflected in the price of Mexican Hass avocados, which is higher than the price of Costa Rican Hass avocados.[20] Vertical differentiation can be explained by the fact that when two vertically differentiated goods are presented at the same price, sales of the lower quality good are zero.

Using these two assumptions in combination with the initial data, we are able to estimate $K_{md}$ and $K_{ld}$. By including these parameters, we can maintain the same specification across all stages of the model.

Next, Equation (3) defines the quantity of the imported good supplied by the RoW to the home country in stage 1, $ms_1$. $K_{ms}$ is a constant associated with the supply of the imported good, $C$ is the supply function parameter of the imported good, and $\varepsilon_m$ is the constant price elasticity of supply of the imported good. Moreover, we add a constant, $K_{ms}$, to the equation so that when

[20] Discussions with Costa Ricans also confirmed that Mexican Hass avocados are of higher quality than Costa Rican Hass avocados.

imports equal zero due to the prohibition on imports implemented by the home country, the price of imports remains positive. To estimate $K_{ms}$, we assume that when imports become zero, the world price decreases from 2.04 to 2.0 constant 2010 US$. We also conduct a sensitivity analysis on this assumption.

Equation (4) defines the quantity of the locally produced good supplied domestically in stage 1, $ls_1$, in which $D$ is the scale parameter of the supply function of the locally produced good and $\varepsilon_l$ is the constant price elasticity of supply of the locally produced good.

Finally, equations (5) and (6) represent price linkage equations and define, respectively, the price of the imported good ($pm_1$) and the price of the locally produced good ($pl_1$), obtained in stage 1.

In this first stage, we can compute all variables of interest, such as quantities of locally produced and imported goods demanded and local and world prices, under a situation of free trade. Through this first stage, we establish a background situation to which we will compare the results from stages 2 and 3 of the model.

**Stage 2: Situation of prohibition on imports prior to any smuggling**

In stage 2, we aim to identify the impact of smuggling on the economic welfare of the home country. To do so, we compare the welfare effects resulting from a prohibition on imports prior to any smuggling activity to the welfare effects resulting from a prohibition on imports followed by illegal trade. Consequently, in stage 2, we model a situation in which the home country implements a ban on imports coming from the RoW in the sector under study. However, in this stage, this ban does not yet lead to any smuggling activity. As a result, the home country becomes an autarky in this sector since legal imports equal zero and illegal trade does not yet occur.

$$Bpl_2{}^{-\eta_l}pm_f{}^{\eta_{lm}} = K_{ld} + ld_2 \tag{7}$$

$$K_{ms} = Cpm_2{}^{\varepsilon_m} \tag{8}$$

$$ls_2 = Dpl_2{}^{\varepsilon_l} \tag{9}$$

$$ld_2 = ls_2 \tag{10}$$

Equation (7) defines the quantity of the locally produced good demanded in stage 2, $ld_2$, in which $pl_2$ is the price of the locally produced good in stage 2 and $pm_f$ is a parameter derived from Equation (1) with $md_1 = 0$. We want to estimate the impact of the prohibition on imports on domestic demand using the same specifications across all stages of the model. Therefore, we adapt the model in stage 2 so that the quantity of the locally produced good demanded depends on the parameter $pm_f$ rather than on the world price, since imports equal zero in stage 2. We estimate parameter $pm_f$ so that with a fixed price of the locally produced good, imports become zero.

Since imports equal zero, the world price in stage 2, $pm_2$, is defined by Equation (8), which represents the RoW's supply function.

The local producers' supply function is defined in Equation (9), in which $ls_2$ is the quantity of the locally produced good supplied in stage 2.

Finally, the price equation is defined by setting the quantity of the locally produced good demanded ($ld_2$) equal to the quantity of the locally produced good supplied ($ls_2$).

After the implementation of the ban, imports equal zero. We thus expect the demand for the locally produced good to increase. Production of the locally produced good should also increase, as should its own-price. On the other hand, the prohibition implemented by the home country on goods imported from the RoW should decrease the world price. These effects on quantities and prices of the locally produced good should lead to a decrease in consumer surplus and to an increase in producer surplus.

**Stage 3: Situation of prohibition on imports from which illegal trade emerges**

In stage 3, smuggling activities emerge due to the prohibition on imports from the RoW implemented by the home country in stage 2.

$$Aps_3{}^{-\eta_m} pl_3{}^{\eta_{ml}} = K_{md} + sdt_3 \tag{11}$$

$$Bpl_3{}^{-\eta_l} ps_3{}^{\eta_{lm}} = K_{ld} + ld_3 \tag{12}$$

$$ls_3 = Dpl_3{}^{\varepsilon_l} \tag{13}$$

$$\pi = (1-\alpha)\left[(ps_3 - pm_3)ss_3 - K\frac{ss_3{}^2}{2}\right] - \alpha\left(pm_3 ss_3 + K\frac{ss_3{}^2}{2}\right) \tag{14}$$

$$Kss_3 - (1-\alpha)ps_3 + pm_3 = 0 \tag{15}$$

$$sst_3 = Iss_3 \tag{16}$$

$$sst_3 = (1-\alpha)md_3 \tag{17}$$

$$K_{ms} + ms_3 = Cpm_3{}^{\varepsilon_m} \tag{18}$$

$$(1-\alpha)ps_3 ss_3 = pm_3 ss_3 + K\frac{ss_3{}^2}{2} \tag{19}$$

$$sdt_3 = sst_3 \tag{21}$$

$$ld_3 = ls_3 \tag{21}$$

$$md_3 = ms_3 \tag{22}$$

We define the total quantity demanded of the smuggled good in Equation (11) in a similar manner as we define the quantity demanded of the legally imported good in Equation (1). In particular, $ps_3$ is the local price of the smuggled good in stage 3 and $sdt_3$ is the total quantity demanded of the smuggled good in stage 3.

Equations (11) and (12) respectively determine the quantity demanded and supplied of the locally produced good in stage 3, $ld_3$ and $ls_3$. Here, we use the same approach as in stage 1.

When introducing smuggling in the model, we assume that:

- Smugglers, rather than consumers, face a cost.[21] This cost represents the real resource cost of smuggling discussed in Section 2 and the risk cost associated with smuggling.[22] The real resource cost of smuggling is introduced in the profit function of smugglers and in Equation (19) by the parameter $K$, while the risk cost of smuggling is represented in these equations by the parameter $\alpha$. In particular, $\alpha$ is the probability that smugglers are caught by public authorities.
- There are $I$ smugglers who are risk neutral.

Marginal cost of smuggling increases because of the rising real resource cost.

Note that the risk attached to smuggling is supported only by smugglers and not by consumers. If legal and illegal trade coexisted, the local price of smuggled avocados should be equal to the price of legally imported avocados. However, in this study, legal trade is prohibited and we do not know the local price of smuggled avocados.

The profit function of an individual smuggler is given by Equation (14), in which $\pi$ is the profit of an individual smuggler, $ps_3$ is the local price of the smuggled good in stage 3, $pm_3$ is the world price in stage 3, and $ss_3$ is the quantity of the smuggled good supplied by an individual smuggler in stage 3. For the sake of simplicity, we assume that public authorities only penalize smugglers by confiscating the smuggled goods.

The first term of Equation (14) computes the profit of an individual smuggler, assuming that she or he is not caught by public authorities. In this case, total revenue equals the price differential between the price at which the smuggler sells the smuggled good in the local market and the price at which she or he buys the good (i.e. the world price) times the quantity of smuggled goods sold ($(ps_3 - pm_3)ss_3$). The total cost equals the total real resource cost of smuggling ($K\frac{{ss_3}^2}{2}$) and implies an increasing marginal cost of smuggling.[23]

[21] Sheikh (1977) assumes that consumers of smuggled goods also face a cost because of the existence of law enforcement or because of the moral standards of society. This cost, however, appears to be negligible; law enforcement at the consumer level is generally weak or nonexistent. Moreover, moral standards of society may not play a role when it comes to agricultural, and thus necessary, products.

[22] Following Sheikh (1977).

[23] The cost of buying the goods is already included in the computation of an individual smuggler's total revenue.

The second term of Equation (14) computes the profit of an individual smuggler, assuming that she or he is caught by public authorities. In this latter case, the individual smuggler's total revenue equals zero since she or he is not able to sell any smuggled good, and her or his total cost includes the cost of buying the goods ($pm_3 ss_3$) plus the total real resource cost of smuggling ($K\frac{{ss_3}^2}{2}$). As in Martin and Panagariya (1984), we suppose that when smugglers are caught, all smuggled goods are confiscated.

Smuggling occurs as long as a smuggler earns a profit ($\pi = 0$). Using the first derivative of the profit function (Equation 14), Equation (15) defines the supply function of an individual smuggler. The quantity supplied by all smugglers of smuggled good in stage 3, $sst_3$, is given by Equation (16), in which I is the number of smugglers smuggling goods between Home and RoW.

The relationship between the total quantity supplied of smuggled good, $sst_3$, and the world demand, $md_3$, is defined by Equation (17). Aggregate supply of smuggled good at Home, $sst_3$, represents the portion ($(1-\alpha)$) of the world demand that has not been seized by Home's public authorities.

Similarly to stage 1 of the model, Equation (18) determines the world supply of avocados in stage 3, $ms_3$.

Equation (19) corresponds to the zero profit condition and allows us to compute the total number of smugglers, $I$.

Finally, Equations (21), (22), and (23) present price linkages. Equation (21) sets the total quantity of the smuggled good demanded at Home ($sdt_3$) equal to the total quantity of the smuggled good supplied at Home ($sst_3$). Equation (22) sets the quantity of the locally produced good demanded ($ld_3$) equal to the quantity of the locally produced good supplied ($ld_3$). Similarly, Equation (23) sets the world supply of avocados ($ms_3$) equal to the world demand for avocados ($md_3$).

We expect the prohibition implemented by Home on the good imported from the RoW to lead to the emergence of smuggling activity. Consequently, we expect demand for the locally produced good to decrease. Production of the locally produced good should also decrease, as should its own-price. Since the RoW produces the good smuggled, the world price should increase. Therefore, we expect consumer surplus to increase between stage 2 and stage 3 and producer surplus to decrease between stage 2 and stage 3. Successful smugglers also earn a positive surplus.

## 5. Empirical Estimation of Parameters Used in the Model

The model presented in Section 4 comprises 16 parameters. First, we estimate four price elasticities and two cross-price elasticities: price elasticity of demand for the locally produced good ($\eta_l$), price elasticity of supply for the locally produced good ($\varepsilon_l$), price elasticity of demand for the imported good ($\eta_m$), price elasticity of supply for the imported good ($\varepsilon_m$), cross-price elasticity of demand of the locally produced good ($\eta_{lm}$), and cross-price elasticity of demand of the imported good ($\eta_{ml}$). Second, we compute initial values of the price of the locally produced good ($pl_3$), the world price ($pl_0$), the quantities of locally produced good both demanded and supplied ($ld_0$ and $ls_0$), and imported goods ($md_0$ and $ms_0$). Finally, we need values for four smuggling parameters: the probability that smugglers get caught ($\alpha$), the cost parameter of smuggling ($K$), the initial number of smugglers ($I$), and the initial quantity of avocados supplied by an individual smuggler ($ss_0$).

### 5.1 *Price Elasticities of Demand and Supply of Locally Produced Avocados*

Data on prices and quantities of avocados produced or consumed at the national level in Costa Rica remain scarce. The Food and Agriculture Organization of the United Nations does not have data on producer or consumer avocado prices that could be related to data on national production. The National Institute of Statistics and Census of Costa Rica provides monthly consumer price index for avocados; however, as previously mentioned, this institute has changed its methodology for estimating the local production of avocados since 2015.

Therefore, in order to estimate the price elasticities of demand and supply of the locally produced good, we collected data on prices and quantities of locally produced avocados sold at the main wholesale center in Costa Rica: el Centro Nacional de Abastecimiento y Distribución de Alimentos (CENADA)(National Center for Food Supply and Distribution) (Programa Integral de Mercadeo Agropecuario. Información de mercados, 2017).[24,25] In particular, we use the logged values of the average wholesale price (in constant 2010 US$ per kg), $ln(p)$ and of the total quantity (in kg), $ln(q)$, of Costa Rican avocados sold at el CENADA each month from January 2001 to April 2015 (prior to the implementation of the prohibition).[26] Our sample thus comprises 172 observations.

However, information on prices and quantities is not sufficient to identify both demand and supply price elasticities. We solve this identification problem by including additional variables in both the demand and the supply equations to help to identify the individual relations (Santeramo, 2014). In particular, we use instrumental variables.

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[24] Costa Ricans sell and buy fruits and vegetables at three main locations: el CENADA, BORBON (a market in Costa Rica), and the FERIAS del agricultor (farmers' trade fairs). We estimate that around 15 percent to 20 percent of domestic production of fruits and vegetables, including avocados and other main commodities produced in Costa Rica (such as banana, chayote, and papaya), is sold at el CENADA. Unfortunately, data on prices and quantities of avocados sold at the other two locations are not available.

[25] Data on avocados sold and bought at el CENADA are disaggregated by varieties. To estimate price elasticities of demand and supply of locally produced avocados, we use data on Hass avocados. As previously mentioned, Hass avocados represent 75 percent of total avocado production in Costa Rica. Furthermore, Mexico only exports Hass avocados to Costa Rica. In the following sub-section, we thus estimate price elasticity of imported Hass avocados from Mexico. Finally, previous estimations of price elasticities of avocados have also used data on Hass avocados (Carman, 1993; Carman, 1998; Carman, 2006; Peterson, 2008).

[26] Data prior to 2001 is not available.

In the estimation of the price elasticity of demand for locally produced goods, $\eta_l$, we include the log of the adjusted net income per capita (in constant 2010 US$), $ln(y)$ (World Development Indicators, 2017), and $Season$, a dummy variable. Costa Ricans consume more avocados on average from July to December than from January to July. The dummy variable thus takes on a value of 1 from July to December and 0 otherwise.[27] Furthermore, we account for the potential endogenous behavior of prices vis-à-vis quantities by using data on temperature in Costa Rica. In particular, in the demand equation, we include the log of the monthly average temperature in Costa Rica (in degree Celsius), $ln(T)$ (The World Bank Group, 2017), as an instrumental variable for the log of the average wholesale price of Costa Rican avocados (Equation 23). In agricultural economics, researchers commonly use weather variables as supply shifters. We verify the relevance of $ln(T)$ as an instrumental variable in the first stage regression of the two-stage least squares (2SLS) and of the three-stage least squares (3SLS) estimations. Monthly average temperature in Costa Rica appears to be a strong instrument. We also believe this is exogenous since the demand for avocados in Costa Rica does not depend on the temperature.

$$ln(q_t) = \beta_0 + \beta_1 ln(p_t) + \beta_2 ln(y_t) + \beta_3 ln(Season_t) \qquad (23)$$

In addition to data on prices and quantities, the supply equation of locally produced avocados comprises the log of the monthly average temperature in Costa Rica (in degree Celsius), $ln(T)$, and the log of the monthly total quantity of Costa Rican avocados sold at the CENADA (in kg), lagged by one month, $ln(q_{t-1})$. We use the log of the adjusted net income per capita (in constant 2010 USD), $ln(y)$, as an instrumental variable for the log of the average wholesale price of Costa Rican avocados (Equation 24). The former variable shifts the demand curve but does not shift the supply curve. From the first-stage regression of the 2SLS and 3SLS estimations, this variable also appears to be a strong instrument. Furthermore, the net income per capita does not affect the quantity of avocados offered. Thus, this appears to be a valid instrument.

$$ln(q_t) = \beta_4 + \beta_5 ln(p_t) + \beta_6 ln(T_t) + \beta_7 ln(q_{t-1}) \qquad (24)$$

Table 1 summarizes the results obtained for both price elasticities of demand and supply of the locally produced good, using 2SLS and 3SLS estimations.[28] We find that:

[27] In another version of the model, we also included data on prices of potential complements or substitutes of avocados (viz. tomato, lemon, and lettuce) in the list of independent variables. These variables were not statistically significant so we dropped them from the analysis. These results are consistent with existing literature on avocados: no substitute nor complementary product for avocados has been identified as statistically significant (Carman, 1998; Carman, 2006; Vanzyl, 1988).

[28] We did not use ordinary least squares (OLS), as $ln(p_t)$ appears as endogenous. This was confirmed by post-estimation tests run.

- the price elasticity of demand of the locally produced good equals -1.22 and is significant at the 5 percent level using 2SLS and equals -2.16 and is significant at the 1 percent level using 3SLS and:
- the price elasticity of supply of the locally produced good equal 1.98 and is significant at the 5 percent level using 2SLS and equals 1.56 and is significant at the 1 percent level using 3SLS. These results are consistent with economic theory.

Furthermore, all other variables included in either the demand or the supply equations are significant at the 1 percent level (except $ln(T_t)$, which is significant at the 5 percent level in the 2SLS estimation and loses its significance in the 3SLS estimation). Moreover, all other variables' respective coefficients are of expected signs.

Table 1.**Estimation of price elasticity of demand and of supply of locally produced avocados**

| | $\eta_l$ 2SLS | $\eta_l$ 3SLS | | $\varepsilon_l$ 2SLS | $\varepsilon_l$ 3SLS |
|---|---|---|---|---|---|
| ln p | -1.22** | -2.16*** | ln p | 1.98** | 1.56*** |
| | (0.499) | (0.646) | | (0.849) | (0.548) |
| ln y | 6.32*** | 6.81*** | ln T | -4.98** | -2.47*** |
| | (0.359) | (0.546) | | (2.051) | (1.678) |
| Season | 0.46*** | 0.57*** | ln $q_{t-1}$ | 0.77*** | 0.88*** |
| | (0.076) | (0.099) | | (0.088) | (0.071) |
| R2 | 0.6756 | 0.3531 | R2 | 0.3442 | 0.5166 |
| Obs. | 171 | 169 | Obs. | 169 | 169 |

Source: Authors
Note: In parentheses are robust standard errors. ***, **, and * denote variables statistically different from 0 at the 1 percent, 5 percent, and 10 percent levels, respectively. Estimated constant parameters not reported.

### 5.2 *Price Elasticities of Demand and Supply of Imported Avocados*

To estimate the price elasticity of demand for imported avocados, we gathered monthly data on prices and quantities of avocados from Mexico imported into Costa Rica. In particular, we use the logged values of the average unit price of imports of avocados from Mexico to Costa Rica (in US$ per kg), $ln(pm)$, and of the quantity (in kg), $ln(qm)$, of Mexican avocados imported into Costa Rica each month from January 2001 to April 2015 (Secretaría Ejecutiva de Planificación Sectorial Agropecuria). This dataset also comprises 172 observations.

In the demand equation, we include the log of the adjusted net national income in Costa Rica (in US$), $ln(y)$, and the log of the monthly quantity imported of Mexican avocados (in kg), lagged by one month, $ln(qm_{t-1})$. We use the log of the monthly average temperature in Mexico (in degree Celsius), $ln(Tm)$, and the ad valorem tariff rates implemented by Costa Rica on avocados from Mexico as instrumental variables for the price of Mexican avocados.

These variables appear to be relevant since they influence the price of imported avocados and appear to be exogenous since they do not directly affect the quantity of imported avocados demanded. We thus consider them to be valid instruments.[29]

$$ln(qm_t) = \beta_8 + \beta_9 ln(pm_t) + \beta_{10} ln(y_t) + \beta_{11} ln(qm_{t-1}) \quad (24)$$

Table 2 summarizes the results obtained for the price elasticity of demand for the imported good, using 2SLS and OLS estimations.[30] We find that the price elasticity of demand for the locally produced good equals -0.87 and -0.65, respectively, using 2SLS and OLS estimations and is significant at the 1 percent level. These results are consistent with economic theory. The coefficients associated with all other variables are significant and of expected signs.

Table 2.**Estimation of price elasticity of demand for imported avocados**

| | $\eta_m$ 2SLS | $\eta_m$ 3SLS |
|---|---|---|
| ln pm | -0.87*** | -0.65*** |
| | (0.104) | (0.089) |
| ln y | 0.69*** | 0.53*** |
| | (0.072) | (0.053) |
| ln $qm_{t-1}$ | 0.51*** | 0.62*** |
| | (0.60) | (0.054) |
| $R^2$ | 0.7144 | 0.8039 |
| Obs. | 171 | 170 |

Source: Authors

Note: In parentheses are robust standard errors. ***, **, and * denote variables statistically different from 0 at the 1 percent, 5 percent, and 10 percent levels, respectively. Estimated constant parameters not reported. Column 3 reports Cochrane-Orcutt estimates.

We were not successful in obtaining monthly data regarding exports of Mexican avocados into Costa Rica with which to estimate the price elasticity of supply of exported Mexican avocados in Costa Rica. We only collected data on total Mexican exports of avocados. This estimation is not common in the literature. In most models, the authors assume that the country is price-taker so that the export supply price elasticity is infinite and the world price is exogenous. In this study, we suppose that the export supply price elasticity equals 16 ($\varepsilon_m = 16$) and conduct a sensitivity analysis on this parameter.

[29] Post-estimation tests have also been run to confirm our hypothesis regarding the validity of these instrumental variables.

[30] We also use OLS estimation for the price elasticity of demand for the imported good because it appears to be exogenous at the 5 percent level of significance, based on post-estimation tests. Since the Durbin-Watson statistic indicates significant serial correlation at the 5 percent level, we perform a Cochrane-Orcutt transformation. Column 3 of Table 2 reports Cochrane-Orcutt estimates.

Table 3 summarizes results found for price elasticities of demand and of supply of locally produced and imported goods, using different estimation methods.

Table 3. **Estimations of price elasticities of demand and of supply of locally produced and imported goods}**

| Elasticities | OLS (1) | 2SLS (2) | 3SLS (3) |
|---|---|---|---|
| $\eta_l$ | n.a. | -1.22** | -2.16*** |
| $\varepsilon_l$ | n.a. | 1.98** | 1.56*** |
| $\eta_l$ | -0.65*** | -0.87*** | n.a. |
| $\varepsilon_l$ | n.a. | n.a. | n.a. |

Source: Authors'calculation based on PIMA (2017)
Note: ***, **, and * denote variables statistically different from 0 at the 1 percent, 5 percent, and 10 percent levels, respectively; n.a.: not available.

Results are consistent with economic theory: price elasticities of demand are negative, while price elasticities of supply are positive. Estimates are of the same order of magnitude, except for $\eta_l$, which is slightly higher when we use the 3SLS estimation. We later perform robustness tests on those elasticities. Since the 2SLS method provides more estimations, we base our central estimation on elasticities provided by this method.

Prior to this study, no researcher had estimated price elasticities of demand and supply of locally produced avocados in Costa Rica and of avocados imported from Mexico into Costa Rica. It is thus difficult to compare our results with previous estimations of price elasticities from the literature. Nonetheless, the price elasticity of avocados has been estimated for the California avocado industry. In particular, (Carman and Green, 1993) report a price flexibility of demand for the California avocado industry equal to -1.16, corresponding to a price elasticity of -0.86. (Carman and Cook, 1996) use a revised version of the (Carman and Green, 1993) model and find a price flexibility of demand for the California avocado industry of -1.53, corresponding to a price elasticity of demand of -0.65.

Carman and Craft (1998) estimate the annual and monthly price flexibilities of demand for the California avocado industry at -1.33 and -1.54, respectively, corresponding to an annual price elasticity of demand of -0.75 and a monthly price elasticity of demand of -0.65. The USDA's APHIS uses a price elasticity of demand of -0.86 in its 2001 and 2003 reports and of -0.57 in its 2004 study.[31] Carman (2006) derives a price elasticity of demand for California avocados of -0.387.

Finally, Peterson and Orden (2008) find a price elasticity of demand for California avocados of -2.06.[32] Estimates of price elasticity of demand for California avocados thus varies from -0.4 to -

[31] U.S. Department of Agriculture, 2001, 2003 and 2004.
[32] As previously mentioned, price elasticities of demand estimated in the above-mentioned analyses are estimated for Hass avocados, similar to our study.

2.06. Our estimates of Costa Rican price elasticity of demand for Costa Rican and Mexican avocados are of the same order of magnitude.

### 5.3 *Cross-price Elasticities of Demand of Locally Produced and Imported Avocados*

Since we have already produced estimations of price elasticities of demand and of supply of locally produced and imported goods, we use Roussland and Suomela (1985)'s methodology to compute cross-price elasticities of locally produced and imported goods. In particular, we define the cross-price elasticity of demand for the locally produced good, $\eta_{lm}$, as follows:

$$\eta_{lm} = \frac{(\eta_l - \eta_m)V_m}{(V_l - V_m)} \qquad (26)$$

in which $\eta_{lm}$ is the cross-price elasticity of demand for locally produced avocados, $\eta_l$ is the own-price elasticity of demand for locally produced avocados, $\eta_m$ is the own-price elasticity of demand for imported avocados, $V_m$ is the value of imported avocados, and $V_l$ is the value of locally produced avocados.

Similarly, we define the cross-price elasticity of the demand for imported good as follows:

$$\eta_{ml} = \frac{(\eta_m - \eta_l)V_l}{(V_m - V_l)} \qquad (26)$$

in which $\eta_{ml}$ is the cross-price elasticity of demand for imported avocados.

We respectively compute $V_m$ and $V_l$ as the quantity of imported Mexican avocados and of locally produced Costa Rican avocados times their respective price, on average, from May 2012 to April 2015. We find $V_m$ to equal 21,062,812 constant 2010 US$ and $V_m$ to equal 4,334,882 constant 2010 US$.

Table 4 reports the estimated cross-price elasticities of demand of locally produced and imported avocados, using Roussland and Suomela (1985)'s method.

Table 4. **Estimated cross-price elasticities of demand for locally produced and imported avocados}**

| Elasticities | Values |
|---|---|
| $\eta_{lm}$ | 0.441 |
| $\eta_{ml}$ | 0.091 |

Source: Authors

### 5.4 *Initial Values*

We compute the initial values of the price of the locally produced good, the world price, and the quantity of locally produced and imported goods demanded and supplied by calculating their average values from May 2012 to April 2015 (three years prior to the implementation of the ban). Table 5 presents results obtained for these initial values of the variables of the model.

Table 5. **Initial values of the variables of the model**

| Variables | Initial values |
|---|---|
| $pl_0$ | 1.8 constant 2010 US$ |
| $pm_0$ | 2.04 constant 2010 US$ |
| $ld_0$ | 2,506,180 kgs |
| $ls_0$ | 2,506,180 kgs |
| $md_0$ | 10,373,436 kgs |
| $ms_0$ | 10,373,436 kgs |

Source: Authors

### *5.5 Smuggling Parameters*

In order to evaluate the consequences of smuggling, we need to compute four smuggling parameters: the probability of being caught ($\alpha$), the smuggler's cost parameter ($K$), the initial quantity of smuggled avocados supplied by an individual smuggler ($ss_0$), and the initial number of smugglers ($I_0$).

With regard to the initial quantity of smuggled good supplied by an individual smuggler, we have anecdotal evidence regarding a police confiscation of 4,100 kgs of avocados smuggled from Mexico into Costa Rica in May 2016. We hence set $ss_0 = 4{,}100$ kgs. Since data on the three other parameters is not available, we calibrate the initial number of smugglers ($I_0$), based on different values of $\alpha$ and $K$. We run the model $3{,}900$ times, allowing $\alpha$ to vary by $1$ percent in a range from $1$ percent to $39$ percent and allowing $K$ to vary by $1e-12$ in a range from $1e-12$ to $1e-10$. This allows us to obtain results based on a large range of values of $K$ and $\alpha$ rather than providing a single result based on an approximation of these two parameters.

## **6.** Results

This section discusses results obtained at the end of the second and third stage of the model.

First, after the implementation of the ban but prior to the emergence of smuggling activity, the demand for Costa Rican avocados rises by 83 percent (from 2,506 metric tons to 4,590 metric tons). As a result, the price of Costa Rican avocados rises by 36 percent, from 1.8 to 2.44 constant 2010 US$. The quantity of avocados imported from Mexico to Costa Rica equals zero, leading to a decrease in the quantity of Mexican avocados demanded and thus to a decrease in the world price (from 2.04 to 2.0 constant 2010 US$). Total consumer surplus decreases by 89 percent (from about 41 million constant 2010 US$ to 4.6 million constant 2010 US$). These results are not surprising since, as previously mentioned, imports represent about 90 percent of the avocados consumed in Costa Rica. This loss is supported by consumers of imported avocados who now have to pay a greater price for lower quality, locally produced avocados.[33]

[33] Variations in consumer surplus are calculated separately for both consumers of locally produced and imported goods. Just et al. (2004) demonstrates that in a multiple-price-change case, the order in which prices change does not affect the compensating and equivalent variations in consumer surplus. We thus compute total consumer surplus as the sum of consumer surpluses of locally produced and imported goods. We note, however, that due to a

On the other side, the producer surplus increases by 149 percent (from approximately 1.5 million constant 2010 US$ to 3.8 million constant 2010 US$). The net welfare effect is negative. Costa Rican welfare decreases by 81 percent (from around 43 million constant 2010 US$ to 8.4 million constant 2010 US$), representing a loss of 0.06 percent of Costa Rican GDP in 2016.

Second, Table 6 presents the results obtained when we allow for some smuggling activity. As mentioned in Section 5, we run the model for a large number of values of the probability of being caught ($\alpha$) and of the cost parameter of smuggling ($K$). While results are not sensitive to $K$, they vary with $\alpha$. We thus present in Table 6 the results obtained for several values of $\alpha$.

As expected, the number of smugglers, $I$, decreases with $\alpha$: from 2,496 for $\alpha$ equal to 1 percent to 1,138 for $\alpha$ equal to 39 percent. The total quantity of avocados smuggled decreases with $\alpha$: from 10,232 metric tons for $\alpha$ equal to 1 percent to 4,668 metric tons for $\alpha$ equal to 39 percent. The price of smuggled good increases with $\alpha$: from 2,06 constant 2010 US$ for $\alpha$ equal to 1 percent to 3,33 constant 2010 US$ for $\alpha$ equal to 39 percent. Thus, an increase in the probability of an individual smuggler being caught increases the price of the smuggled good; a higher risk brings more profitable activity.

On the other side, both the quantity of the locally produced good supplied and the price of that good increase with $\alpha$: from 2,521 metric tons for $\alpha$ equal to 1 percent to 3,310 metric tons for $\alpha$ equal to 39 percent, and from 1,81 constant 2010 US$ for $\alpha$ equal to 1 percent to 2,07 constant 2010 US$ for $\alpha$ equal to 39 percent, respectively. Thus, an increase in the probability of being caught serves the interest of local producers.

Table 6.**Results (stage 3)**

| *α* | *I* | *sst* | *ps* | *ls* | *pl* |
|---|---|---|---|---|---|
| (%) | (Count) | (kgs) | (Constant US$ 2010) | (kgs) | (Constant US$ 2010) |
| 1 | 2,496 | 10,232,060 | 2.06 | 2,520,773 | 1.81 |
| 10 | 2,183 | 8,949,447 | 2.27 | 2,662,658 | 1.86 |
| 20 | 1,829 | 7,500,896 | 2.55 | 2,846,894 | 1.92 |
| 30 | 1,469 | 6,024,383 | 2.91 | 3,068,003 | 1.99 |
| 39 | 1,138 | 4,668,032 | 3.33 | 3,309,887 | 1.07 |

Source: Authors

Tables 7 and 8 present the percentage change in the different variables of interest. Specifically, Table 7 reports variations from stage 2 to stage 3, while Table 8 reports variations from stage 1 to stage 3 of the model.

As seen in Table 7, the emergence of smuggling activity decreases the demand for Costa Rican avocados from 45 percent to 28 percent as $\alpha$ increases from 1 percent to 39 percent. As a

lack of data on income elasticities, these elasticities are not included in our calculations of total consumer surplus. We still expect the calculation error to be small since income elasticities of fruit and vegetable products are often less than one (Abler, 2010).

result, the price of locally produced avocados also decreases from 26 percent to 15 percent as $\alpha$ increases from 1 percent to 39 percent. Consumer surplus (CS) largely rises with the emergence of smuggling compared to an absence of smuggling under the import ban. Specifically, CS increases from 1004 percent to 585 percent as $\alpha$ increases from 1 percent to 39 percent.[34] Consumers are now able to buy higher-quality avocados. On the other hand, producer surplus (PS) decreases from 59 percent to 39 percent as $\alpha$ increases from 1 percent to 39 percent.

At this stage, we compute two values of welfare. $\Delta_{WEL_1}$ represents the variation in Costa Rican welfare between stage 2 and 3 of the model, assuming that smugglers are not Costa Ricans; $\Delta_{WEL_2}$ represents the variation in Costa Rican welfare between stage 2 and stage 3 of the model, assuming that smugglers are Costa Ricans. Since smugglers earn a profit on goods that are successfully smuggled, their surplus is positive and $\Delta_{WEL_2}$ is greater than $\Delta_{WEL_1}$. Both welfare variables increase after the emergence of smuggling. $WEL_1$ increases from 8.4 million to 52 million constant 2010 US$ for $\alpha$ equal to 1 percent, representing a 526 percent increase, and increases from 8.4 million to 34 million constant 2010 US$ for $\alpha$ equal to 39 percent, representing a 304 percent increase. Similarly, $WEL_2$ increases from 8.4 million to 52 million constant 2010 US $ for $\alpha$ equal to 1 percent, representing a 527 percent increase, and increases from 8.4 million to 37 million constant 2010 US $ for $\alpha$ equal to 39 percent, representing a 340 percent increase. Regardless of whether we include smugglers' welfare in the computation of Costa Rican welfare, we find a large and positive impact of smuggling on Costa Rican welfare.

Table 7. **Results (percentage change from stage 2 to stage 3)**

| $\alpha$ | $\Delta ld$ | $\Delta pl$ | $\Delta CS$ | $\Delta PS$ | $\Delta WEL_1$ | $\Delta WEL_1$ |
|---|---|---|---|---|---|---|
| (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| 1 | -45 | -26 | 1004 | -59 | 526 | 527 |
| 10 | -42 | -24 | 923 | -56 | 482 | 494 |
| 20 | -38 | -21 | 821 | -51 | 429 | 451 |
| 30 | -33 | -18 | 705 | -45 | 367 | 399 |
| 39 | -28 | -15 | 585 | -39 | 304 | 340 |

Source: Authors

Similarly, Table 8 reports the percentage change in the variables of interest from stage 1 to stage 3 of the model. Overall, the prohibition leads to an increase in the quantity of locally produced good demanded (by 1 percent to 32 percent, depending on the value of $\alpha$), thus raising the price of locally produced avocados (by 0.3 percent to 15 percent, again depending on the value of $\alpha$). The prohibition favors producers, as producer surplus increases by 1 percent for $\alpha$ equal to 1 percent and by 52 percent for $\alpha$ equal to 39 percent.

[34] Although such an increase appears large, recall that consumer surplus decreases by 89 percent from stage 1 to stage 2 of the model. Thus, for an initial value of 100, consumer surplus equals 11 at stage 2 and equals $11(1 + 1004/100) = 121.44US\$$ at stage 3, which results in an augmentation of only 21 percent between stages 1 and 3 of the model.

On the other side, the implementation of the prohibition with smuggling imposes a trading cost on consumers, who pay a higher price for Mexican avocados than they did prior to the prohibition. Thus, the consumer surplus generally decreases between stage 1 and stage 3 of the model. We observe a similar effect with regard to Costa Rican welfare.[35] Therefore, while smuggling is welfare-improving compared to the "no-smuggling situation", it does not always compensate for the harmful effects of the import prohibition.

It is, however, worth noting that for low levels of enforcement ($\alpha < 0.22$), the consumer surplus is greater in stage 3 than in stage 1 of the model.[36] As smugglers' probability of being caught decreases, the risk premium associated with smuggling also decreases, resulting in lower prices for the smuggled good. Moreover, the prohibition with smuggling leads to a decrease in the world price compared to the free trade situation, which results in a gain in terms of trade for Costa Rica. For low levels of enforcement ($\alpha < 0.23$), the terms of trade gain offsets the negative effects associated with the trading cost of smuggling.[37] Consequently, Costa Rican welfare may be greater under the prohibition with smuggling than under free trade.

This latter result is, however, unlikely in the case of Costa Rica, which remains a relatively small player in the market for avocados compared to countries such as Mexico and the United States. Nonetheless, it shows that in the case of a large country implementing this type of protectionist measure, the prohibition and smuggling may be beneficial.

Table 8. **Results (percentage change from stage 1 to stage 3)**

| $\alpha$ | $\Delta Id$ | $\Delta pl$ | $\Delta CS$ | $\Delta PS$ | $\Delta WEL_1$ | $\Delta WEL_1$ |
|---|---|---|---|---|---|---|
| (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| 1 | 1 | 0.3 | 23 | 1 | 22 | 22 |
| 10 | 6 | 3 | 14 | 10 | 14 | 16 |
| 20 | 14 | 7 | 2 | 21 | 3 | 8 |
| 30 | 22 | 11 | -11 | 36 | -9 | -3 |
| 39 | 32 | 15 | -24 | 52 | -21 | -14 |

Source: Authors

We conclude that smuggling is welfare-improving when compared to the "no-smuggling situation". The positive impact of smuggling on welfare may, however, not always offset the loss incurred from the implementation of the protectionist trade policy. Smuggling does offset these losses for lower levels of enforcement by public authorities and for an improvement in the terms of trade.

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[35] Costa Rican welfare decreases by 21 percent when the probability that smugglers get caught equals 39 percent (high enforcement), representing a decrease in Costa Rican welfare roughly equal to 9.1 million constant 2010 US$.
[36] Welfare increases by 22 percent when the probability that smugglers get caught equals 1 percent (very low enforcement), representing an increase in Costa Rican welfare roughly equal to 9.4 million constant 2010 US$.
[37] If we include smugglers' surplus in the calculation of Costa Rican welfare ($WEL_2$), the threshold value for $\alpha$ below which welfare is higher in the third than in the first stage of the model rises to 28 percent.

## 7. Sensitivity Analysis

In this section, we perform a sensitivity analysis of our previous results; however, for the sake of brevity, we will only report the main results from our sensitivity analysis.[38] First, we allow for changes in the assumption made to compute the constant associated with the demand for imported good, $K_{md}$. In Section 4, we assumed that if the price of the imported good tripled, then imports equal zero. We test for the robustness of our results subject to changes in $K_{md}$ by assuming that i) if the price of the imported good doubled, then imports equal zero and ii) if the price of the imported good quadrupled, then imports equal zero. These assumptions provide us with two additional values for $K_{md}$, which are respectively equal to 12,533,407 and to 4,432,426 compared to 6,480,435 in the original model. However, these large variations in the value of $K_{md}$ result in little variation in terms of prices, quantities, surpluses, or welfare effects. While the precise values of our variables of interest vary, they remain of the same magnitude and the effects of smuggling on these variables remain in the same direction as our initial results.

For example, Costa Rican economic welfare increases between stage 2 and stage 3 from 179 percent to 542 percent for values of $\alpha$ ranging from 1 percent to 39 percent under the second assumption and by 338 percent to 507 percent for the same values of $\alpha$ under the third assumption. Costa Rican welfare increases by 304 percent to 526 percent for the same values of $\alpha$ under our initial assumption. We reach similar conclusions for all other variables of interest ($pl$, $pm$, $ps$, $ls$, $st$, among others) from stage 1 to stage 3 and under the third hypothesis. The only noticeable change appears in the threshold value of $\alpha$. Under the initial assumption, variation in welfare between stage 1 and stage 3 of the model became negative for $\alpha$ equal to 23 percent, while it became negative for $\alpha$ equal to 13 percent, under the second assumption and for $\alpha$ equal to 30 percent under the third assumption.

In other words, Costa Rican welfare is lower after the emergence of smuggling compared to the "free-trade situation", when the probability that smugglers get caught rises above 23 percent under the initial assumption, above 13 percent under the second assumption, and above 30 percent under the third assumption.

Second, we allow for changes in the constant associated with the supply of imported good, $K_{ms}$. In Section 4, we assumed that when imports become zero, the world price decreases from 2.04 to 2.0 constant 2010 US$. Under this scenario, we assumed that variations in Costa Rican imports had a limited effect on the world price. Considering the size of the Costa Rican avocado market, we test the hypothesis that variations in Costa Rican imports have almost no effect on the world price (i.e., when imports become zero, the world price decreases from 2.04 to 2.03 constant 2010 US$). In the model, $K_{ms}$ is the constant associated with the supply of imported good and appears in the equations determining supply of legally and illegally imported good

[38] Additional information may be requested from the authors.

from Mexico. We thus expect a change in this parameter to affect the quantity and the price of the good imported from Mexico ($ms$ and $pm$). However, we do not observe any change in the quantity or in the price of the imported good when we move from assumption 1 to assumption 2. As expected, results in terms of welfare remain unchanged.

As a further robustness check, we also test the opposite hypothesis that variations in Costa Rican imports have a larger effect on the world price (i.e., when imports become zero, the world price decreases from 2.04 to 1.95 constant 2010 US$). However, this test does not affect our results. Thus, we conclude that our results are robust to various changes in $K_{ms}$.

Third, we perform a sensitivity analysis on the price elasticity of demand for the locally produced good ($\eta_l$). Recall that in Section 5, we found $\eta_l = -1.22$. Using a lower elasticity of demand for the locally produced good, $\eta_l = -0.9$, we find that smuggling leads to lower variations in the quantity and price of locally produced good ($pl$ and $ld$).

However, this decrease in $\eta_l$ has no effect on the price of the smuggled good. Variations in welfare between the second and the third stage of the model are also similar to those found with $\eta_l = -1.22$. Variations in welfare between the first and the third stage of the model are slightly lower than those found with the higher $\eta_l$; under the initial assumption, variations in welfare between the first and the third stage of the model range from 22 percent to -21 percent as $\alpha$ increases from 1 percent to 39 percent, while under the second hypothesis, variations in welfare between the first and the third stage of the model range from 3 percent to -34 percent as $\alpha$ increases from 1 percent to 39 percent.

Using a higher elasticity of demand for the locally produced good, $\eta_l = -1.5$, we find that smuggling has effects comparable to those seen when $\eta_l = -1.22$: welfare between stage 2 and stage 3 increases from 282 percent to 480 percent depending on the value of $\alpha$, while it increases from 304 percent to 526 percent depending on the value of $\alpha$ under the initial assumption. Between stage 1 and stage 3 of the model, Costa Rican welfare varies from 24 percent to -18 percent depending on the value of $\alpha$ under the third assumption, while it varies from 22 percent to -21 percent depending on the value of $\alpha$ under the initial assumption. Thus, our results are robust to variations in the price elasticity of demand for locally produced goods.

Fourth, we test whether our results are sensitive to changes in the price elasticity of demand for the (legally or illegally) imported good, $\eta_m$. In Section 5, we found $\eta_m = -0.87$. We run the model assuming that i) $\eta_m = -0.5$ and ii) $\eta_m = -1.2$.

For $\eta_m = -0.5$, we find that the number of smugglers, and therefore the quantity of smuggled avocados supplied, are greater than when we use $\eta_m = -0.87$. However, other variables are not much affected by this change in price elasticity. As a result, increases in consumer surplus and in welfare between stage 2 and stage 3 of the model are also greater under this assumption.

Similarly, increases in consumer surplus and in welfare from stage 1 to stage 3 of the model are higher when $\eta_m = -0.5$. Interestingly, variations in welfare between stage 1 and stage 3 are always positive, regardless of the value of $\alpha$. Consequently, smuggling is welfare-improving both vis-à-vis the "no-smuggling situation" (as previously found) and the "free-trade situation". We conclude that when demand for the imported good is price inelastic, smuggling necessarily improves welfare.

We also conduct the analysis for a higher price elasticity of demand ($\eta_m = -1.2$). By switching from $\eta_m = -0.87$ to $\eta_m = -1.2$, we observe slightly lower values in both the price and the quantity supplied of the locally produced good. However, variations in welfare between stage 2 and stage 3 of the model are similar to the ones seen when $\eta_m = -0.87$. Variations in welfare between stage 1 and stage 3 are lower than those found under the first assumption; welfare varies from 0.4 percent for $\alpha$ equal to 1 percent to -39 percent for $\alpha$ equal to 39 percent under the third hypothesis, while it varies from 22 percent for $\alpha$ equal to 1 percent to -21 percent for $\alpha$ equal to 39 percent under the first hypothesis. The threshold value for $\alpha$ above which welfare is lower after the emergence of smuggling than prior to the import prohibition is smaller (2 percent compared to 23 percent).

In other words, assuming a larger price elasticity of demand for the imported good, we find that smuggling is welfare-improving, compared to the "free-trade situation", when the probability that smugglers get caught is below 2 percent (low enforcement).

Fifth, we test for the impact of a change in the price elasticity of supply of the locally produced good ($\varepsilon_l$) on our results. We expect a change in $\varepsilon_l$ to affect both the price and the quantity supplied of locally produced avocados. In Section 5, we found $\varepsilon_l = 1.98$. We run the model assuming that i) $\varepsilon_l = 1.5$ and ii) $\varepsilon_l = 2.5$. Results in terms of quantities and prices of locally produced and smuggled goods, and in terms of variations in welfare, hold under both assumptions. Furthermore, the threshold value of $\alpha$ remains at 23 percent under all three assumptions. Our results are robust to variations in the price elasticity of supply of the locally produced good.

Finally, we also test the robustness of our results to variations in the price elasticity of the supply of Mexican avocados exported to Costa Rica ($\varepsilon_m$). In Section 5, we assumed that $\varepsilon_m = 16$. We run the model assuming that i) $\varepsilon_m = 8$ and ii) $\varepsilon_m = 24$. Results in terms of prices, quantities and welfare remain unchanged under both alternative assumptions. As previously mentioned, variations in imports of Mexican avocados into Costa Rica lead to limited changes in the world price. Thus, modifying the value of the price elasticity of supply of Mexican avocados exported to Costa Rica does not affect our result. Furthermore, we do not include Mexican supplier surplus in our calculation of Costa Rican welfare, so our results in terms of welfare also remain unchanged. We conclude that our results are robust to variations in $\varepsilon_m$.

Overall, our results are robust to changes in the values of $K_{ms}$, $K_{md}$, $\eta_l$, $\eta_m$, $\varepsilon_l$, $\varepsilon_m$. The only noticeable variation in our results comes from the fact that for small values of $\eta_m$, smuggling is always welfare-improving.

## 8. Conclusion

In this paper, we provide a transparent and simple theoretical model of trade with smuggling and heterogeneous goods. We empirically apply this model to the current situation of avocado smuggling in Costa Rica. To do so, we compute a number of parameters, including price elasticities of demand and of supply for locally produced and (legally or illegally) imported avocados, that may prove useful for future research. We also provide results based on various values of smuggling parameters, which were, by definition, not available.

The model finds that between 1,138 and 2,496 smugglers illegally import between 4,668 metric tons and 10,232 metric tons of avocados from Mexico into Costa Rica each year. Variations in these results depend on the probability that smugglers get caught ($\alpha$) and thus on the level of enforcement of the prohibition by Costa Rican public authorities. The price of the locally produced good ranges from 1.81 to 2.07 constant 2010 US$ for values of $\alpha$ increasing from 1 percent to 39 percent. The price of the smuggled good ranges from 2.06 to 3.33 constant 2010 US$ for values of $\alpha$ increasing from 1 percent to 39 percent. The higher price of the smuggled good compared to the locally produced good is expected since we assumed that these products are vertically differentiated, with imported avocados being of higher quality than locally produced ones.

In terms of welfare, we find that smuggling largely improves Costa Rican welfare compared to the “no-smuggling situation. The consumer surplus increases after the emergence of smuggling, as consumers enjoy higher quality avocados illegally imported from Mexico. Furthermore, smuggling reduces the price of locally produced avocados.

Although the producer surplus decreases after the emergence of smuggling, this decrease does not offset the positive effects of smuggling on overall welfare in Costa Rica, which increases from 304 percent to 526 percent as $\alpha$ rises from 1 percent to 39 percent. When we include smugglers' surplus in the analysis, the increase in welfare between stage 2 and stage 3 of the model is even larger.

Recall, however, that our analysis does not take into account the potential sanitary and phytosanitary effects of consuming avocados imported from Mexico nor does it take into account the risk of contamination of local avocados by imported Mexican avocados. If such effects and risk proved to be real, smuggling could have a negative impact on welfare. Measuring potential sanitary and phytosanitary effects of consuming avocados imported from Mexico and measuring the risk of contamination would, however, require a fully-fledged investigation and is not the purpose of our analysis.

Our results converge with Deardorff and Stolper (1990), who conclude that smuggling is a "healthy reaction to bad situations caused by bad policies". Once a restrictive trade policy has been implemented, smuggling is necessarily welfare-improving. This paper, however, goes one step further by demonstrating that smuggling may also be welfare-improving when compared to the "free-trade situation". This peculiar situation occurs when the gain in terms of trade following the prohibition with smuggling offsets the negative effects of the trading cost of smuggling.

Indeed, compared to the "free-trade situation", Costa Rican welfare may be either higher or lower after the emergence of smuggling than prior to the prohibition, depending on the level of enforcement by Costa Rican public authorities. In particular, we find that welfare increases by 22 percent when the probability that smugglers get caught equals 1 percent (very low enforcement) and decreases by 21 percent when this probability equals 39 percent (high enforcement). This represents an increase (decrease) in Costa Rican welfare roughly equal to 9.4 (9.1) million constant 2010 US$. Smuggling increases welfare compared to the "free-trade situation" when the probability that smugglers get caught is below 23 percent. When including smuggler surplus in the analysis, we find that smuggling increases welfare compared to the "free-trade situation" when the probability that smugglers get caught is below 28 percent. It is worth noting that for small values of price elasticity of demand for the imported good, $\eta_m$, smuggling is necessarily welfare-improving, regardless of the level of enforcement.

However, these latter results do not mean that governments aiming to maximize their own country's overall welfare should implement protectionist measures and let smugglers trade freely or that they should implement protectionist measures on foreign products for which the price elasticity of demand is very low. Indeed, implementing such restrictive measures may have political and judicial costs that are not included in the analysis. As previously mentioned, Mexico has established a complaint against Costa Rica in the WTO's Dispute Settlement Body. Settling such a trade dispute may turn very costly for Costa Rica, especially if the Costa Rican government decides to maintain the restrictive policy.

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