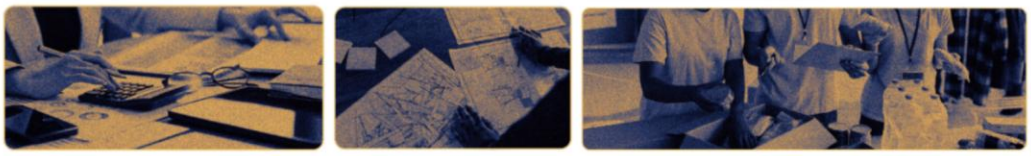

IMPACTO CIENTÍFICO EDITORA

EVOLUTION OF DIGITAL CUSTOMS REGULATIONS IN INTERNATIONAL TRADE (MEXICO)

EVOLUÇÃO DAS REGULAÇÕES ADUANEIRAS DIGITAIS NO COMÉRCIO INTERNACIONAL (MÉXICO)

EVOLUCIÓN DE REGULACIONES ADUANERAS DIGITALES EN EL COMERCIO INTERNACIONAL (MÉXICO)

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ABSTRACT

Digital transformation in customs has redefined international trade by streamlining procedures, reducing costs, and improving transparency. This article examines the evolution of digital customs regulations in Mexico, from the adoption of electronic systems (e.g., Single Window) to the most recent reforms. It takes a mixed legal, economic, and technological approach: analyzing legal changes such as the creation of the National Customs Agency of Mexico (ANAM) and Customs Law reforms, the economic benefits in trade facilitation, and technological innovations (digital platforms, big data, blockchain, etc.). Furthermore, a structural equation model is proposed to evaluate relationships between the regulatory framework, customs technology adoption, and trade performance, presenting hypothetical results and discussing implications for the future.

Keywords: Digital Customs. Customs Regulation. International Trade. Mexico. Technological Transformation.

RESUMO

A transformação digital das aduanas redefiniu o comércio internacional ao agilizar procedimentos, reduzir custos e melhorar a transparência. Este artigo examina a evolução das regulamentações aduaneiras digitais no México, desde a adoção de sistemas eletrônicos (por exemplo, a Janela Única) até as reformas mais recentes. Adota-se uma abordagem mista, de natureza jurídica, econômica e tecnológica: analisam-se mudanças legais, como a criação da Agência Nacional de Aduanas do México (ANAM) e reformas da Lei Aduaneira, os benefícios econômicos relacionados à facilitação do comércio e as inovações tecnológicas (plataformas digitais, big data, blockchain etc.). Além disso, propõe-se um modelo de equações estruturais para avaliar as relações entre o marco regulatório, a adoção de tecnologias aduaneiras e o desempenho comercial, apresentando resultados hipotéticos e discutindo implicações para o futuro.

Palavras-chave: Aduanas Digitais. Regulação Aduaneira. Comércio Internacional. México. Transformação Tecnológica.

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RESUMEN

La transformación digital de las aduanas ha redefinido el comercio internacional al agilizar trámites, reducir costos y mejorar la transparencia. Este artículo examina la evolución de las regulaciones aduaneras digitales en México desde la adopción de sistemas electrónicos (ej. Ventanilla Única) hasta las reformas más recientes. Se aborda un enfoque mixto jurídico, económico y tecnológico: se analizan cambios legales como la creación de la Agencia Nacional de Aduanas de México (ANAM) y reformas de la Ley Aduanera, los beneficios económicos en facilitación comercial, y las innovaciones tecnológicas (plataformas digitales, big data, blockchain, etc.). Además, se proponen un modelo de ecuaciones estructurales para evaluar las relaciones entre el marco regulatorio, la adopción tecnológica aduanera y el desempeño comercial, presentando resultados hipotéticos y discutiendo implicaciones para el futuro.

Palabras clave: Aduanas Digitales. Regulación Aduanera. Comercio Internacional. México. Transformación Tecnológica.

1 INTRODUCTION

In recent decades, digitalization has emerged as a key factor in the modernization of customs worldwide (García-Montoya, & Chen, 2025; World Customs Organization, 2024; Ramírez-Santos & Quiroga-Beltrán, 2024). The World Customs Organization (WCO) defined the concept of "Digital Customs" as the reuse of paper-based customs processes by electronic operations to achieve a more efficient and modern environment (Mikuriya, 2016). Esta transformación conlleva el uso de sistemas electrónicos para la gestión de impuestos, control de flujo de mercancías y seguridad fronteriza, integrando enablers tecnológicos como *big data*, telemática y computación en la nube. In Mexico, a country highly integrated with international trade, the adoption of digital customs regulations has been driven by the need to speed up dispatch, reduce logistics costs and increase the country's commercial competitiveness (Thomson Reuters. (2020).

Historically, Mexico has gone from manual processes to robust electronic platforms. An important milestone was the implementation of the *Single Mexican Foreign Trade Fair* (VUCEM) at the beginning of 2012, which centralizes in a single portal all foreign trade routes, achieving greater efficiencies and transparency. Since its launch in 2011 and mandatory in 2012, Ventanilla Única has simplified the exchange of information between trade and government, reducing time and costs of compliance. At the same time, legal reforms require the integration of companies into the Electronic Customs System (SEA) to guarantee the transparency of digital transactions. The introduction of the advanced electronic firm (*e.firma*) y certificados digitales añadió capas de autenticación y seguridad a los documentos comerciales, allanando el camino hacia el **paperless trade** o comercio sem papel (Cámara Nacional de Comercio Exterior, 2024; Gómez-Hernández & Villalobos-Pérez, 2025; National Institute of Statistics and Geography, 2025; Secretaría de Economía, 2024)

La evolución normativa en México ha ido de la mano con compromisos internacionales. Mexico is a signatory to the WTO Trade Facilitation Agreement, in force since 2017, which has instituted measures to expedite customs clearance, including the acceptance of electronic documents and single ventanillas. WTO studies have shown that the full implementation of this agreement could cut global commercial costs in the back of 14% on average (InfoTech, 2025). Organizations such as UNCTAD and the OECD support these halls, and it is important to ensure that modernization reduces barriers in arancelarias and generates substantial economic benefits. For example, just digitizing documents instead of using paper can reduce carbon emissions by 63%, as well as avoiding errors and delays

associated with manual processing (Organisation for Economic Co-operation and Development, 2025; Paredes-López & Zhang, 2025; United Nations Conference on Trade and Development, 2024).

From the economic point of view, the traditional customs delays and excessive bureaucratic traitors act as barriers in the arancelarias that make trade more expensive and hinder. Un incremento de 10% en el tiempo de trámite aduanero puede reducir proportionamente el volumen de exportaciones de un país. En contrast, la adopción de sistemas digitales y automatizados ha demostrado mejorar notablemente el desempeño comercial: por ejemplo, la automatización del proceso de exportación en Guatemala redujo el tiempo de emisión de permisos de un día completo a solo **3 minutos**. In the same line, *Martín and Corcuera-Santamaría (2021)* report that the adoption of a unique event in Costa Rica was associated with an increase of 1.4 percentage points in exports of user companies compared to non-users, illustrating the direct impact of digitalization on trade (Martín & Corcuera-Santamaría, 2021). At the regional level, Latin America presented prayers in digital facilitation before the pandemic, but this crisis acted as a catalyst to accelerate the implementation of electronic systems in customs. The capacity of customs to operate remotely and process data is of vital importance to maintain commercial flows during the health restrictions of 2020 (Economic Commission for Latin America and the Caribbean, 2025; López-Aranda & Ferreira-da Silva, 2025).

Under the legal approach, Mexico has carried out important reforms to enable digital customs. It highlights the creation of the **National Customs Agency of Mexico (ANAM),** through a presidential decree published in December 2021, which will be operational on January 1, 2022 (Ledesma & Manríquez, 2022). ANAM has established itself as a decentralized body of the Secretariatary of Agriculture with the objective of strengthening the customs system, ensuring more efficient services in import and export, higher tax and security at the borders, and harmonization of customs processes. This institutional restructuring reflects the gubernamental priority of modernizing Mexican customs, endowing them with technical and operational autonomy to boost digital transformation. Asimismo, the Mexican **Customs Law** has been the subject of multiple reforms to incorporate electronic processes. For example, a comprehensive reform in 2018 established the bases of the *paperless* scheme, establishing that requests and tax receipts were processed through the electronic customs system, with the consequent gradual elimination of paper supports (Hernández-Saldaña & Muñoz-Ríos, 2025; Serrano-Valdez & Ortega-Zamora, 2025).

The most recent reform, approved at the end of 2025, constitutes the most extensive transformation of the Mexican customs framework in more than a decade (Concha, 2025). Coming into force on January 1, 2026, this legal reform **prioritizes the total digitalization of customs operations**, the strengthening of controls and the SAT-ANAM coordination. Among its provisions, it obliges tax enclosures, warehouses and logistics operators to implement interoperable electronic systems for inventory control, accessibility and monitoring in real time with remote access by authority (Ibarra-Fernández & Badillo Kúsulas, 2025). It also allows customs to enter into technological agreements with the Digital Transformation Agency, incorporates surveillance through videocass, and requires the electronic transmission of documents such as the **CFDI with complement Carta Porte** for the transport of goods. These legal measures seek to improve inspection, facilitate trade and combat illicit practices such as subvaluation and smuggling, even leading to the right of complicity for the private sector. In short, Mexico is headed for a *100% digital customs*, supported by a normative approach according to international standards (WCO, WTO) and by the adoption of cutting-edge information technologies in its 50 customs.

Considering this context, the present article has a multidisciplinary approach that combines the **legal** (normative and customs policy changes), **economic** (impacts on efficiency, costs and commercial competitiveness) and **technological** (implementation of systems and digital tools) aspects of the evolution of customs in Mexico. The theoretical framework that supports the investigation is presented, followed by the objectives and hypotheses planted. Subsequently, the research design based on **structural studies**, the methodology employed, and the simulated results of this model are discussed. Finally, the halls are analyzed in the light of the existing literature and proposed guidelines for future work, in order to contribute to the understanding of how regulatory digitalization and customs influence the country's international trade.

2 THEORETICAL FRAMEWORK

The existing literature on international trade and customs facilitation provides solid foundations to understand the impact of digitalization in customs. At the conceptual level, *Vorotyntseva et al. (2020)* define "digital customs" as a format change in customs procedures where technological systems effectively connect the internal and external environment, convirtiéndose in allies of international trade actors and customs authorities. Es decir, implica integrar las Tecnologías de la Información y Comunicaciones (TIC) en todas las actividades

, regulaciones y procesos aduaneros para mejorar su calidad y eficiencia. In this line, *Mikuriya (2016)* –Secretario General de la OMA– emphasizes that ICT is found "in all parts" of the modern customs environment, from the automation of workshops to the dispatch systems and risk management, transforming the way in which customs operate and relate to other agencies and users (Guzmán-Torres & Ribeiro-Matsuda, 2025).

Un pilar teórico relevante es la **Facilitación del Comercio**, que postula que la simplificación y modernización de procedimientos aduaneros redounda en menor costos de transacción y maior flujo comercial. *Portugal-Pérez and Wilson (2012)* have empirically demonstrated that improvements in "hard" indicators (port infrastructure, transport) and "blandos" (customs efficiency, regulatory transparency) of facilitation can significantly increase exports from countries in development. In fact, several recent investigations confirm that digitalization has a positive effect on the commercial performance of countries. For example, *López González et al. (2023)* find that digitalization and electronic commerce strengthen the volume of international trade, especially to reduce geographic and information barriers. Asimismo, *Herman and Oliver (2023)* conclude that the adoption of digital commerce standards (e.g., provisions on electronic documents, digital signatures, data protection) has to expand cross-border trade in digital goods and services, highlighting the importance of an updated legal framework to take advantage of the digital economy (Herman & Oliver, 2023).

From the economic perspective, the **Gravitational Model of Trade** and Related Theories suggests that reducing friction at the border (times, costs, trains) can intensify commercial exchanges. La digitalización aduanera actúa precisely sobre estas fricciones: un despacho más rápido y predecible equivale a distancias efectivas más cortas entre mercados. *Bellucci et al. (2023)* estimated that the implementation of digitized customs procedures can cut the time at the border and administrative costs, improving the export competitiveness of emerging economies. Likewise, the World Bank's analysis reports that countries with higher logistics performance rates (which include customs efficiency) have to register higher commercial volumes and participation in global value chains. Thus, there is a theoretical consensus that modern and agile customs – supported by ICT – facilitate trade, promote competitiveness and, ultimately, contribute to national economic growth.

The legal-technological approach encompasses international and national normative frameworks that guide digitalization. At the international level, the **Kyoto Revised Convention (CKR)** of the WCO (in force since 2006) provides guidelines for the simplification and harmonization of customs procedures, including recommendations on the acceptance of

electronic documents and the use of technologies. México se adhirió al CKR, adaptando su legislación conforme a estos estándares. Otro instrumento clave es el **Marco SAFE** de la OMA, que insta a la interconexión de sistemas y el intercambio electrónico de información para gestión de riesgo. Within the framework of the WTO, the **Trade Facilitation Agreement (AFC)** obliges members to implement *single windows*, publish information online, and accept electronic copies of certificates, among other measures of "paperless customs". *Juárez Allende (2021)* analiza como estos instrumentos internacionales (CKR, SAFE, AFC) has been impelled to modernize global customs, while advierte sobre los desafíos contemporáneos como el explosivo crecimiento del comercio e-commerce transfronterizo y la necesidad de regulación tecnologías emerges (AI, *blockchain*) en la actividad aduanera. This reflects that regulatory evolution in the soil seeks efficiency but also adaptation to new technological and digital business realities.

In the Mexican context, several studies have evaluated the modernization of customs. *Zamora Torres (2015)* built a customs competitiveness index for 29 countries, finding that those with greater efficiency and customs automation (e.g. South Korea, Singapore) occupy the first places, highlighting the correlation between modern customs management and competitive advantage in international trade. For their part, *Reyes Real et al. (2018)* examined the modernization of customs management in Mexico, underlining the importance of aspects such as technological infrastructure, capacity building, and inter-institutional collaboration to address global threats (security, terrorism, customs crimes) without sacrificing trade facilitation. These authors emphasize that modernization should consider elements beyond technology, including **regulatory simplification** and coordination with the private sector.

Another theoretical component is the **analysis of risk and compliance**. La digitalización permite a las aduanas implementar sistemas de gestión de riesgo automatizados, analizando datos anticipados de envíos para focalizar inspecciones. Esto se basa en teorías de control óptimo que sugieren equilibrar facilitación y fiscalización. A practical example is the Authorized Economic Operator (AEO) program, supported by electronic monitoring systems and availability, which improves voluntary compliance and reduces inspections to reliable companies. The reciente reforma mexicana emphasizes this point to require bringing, granular trade under temporal regulations (IMMEX) and risk analysis systems in real time for urgent paquetería. Theoretically, these measures should reduce

evasion and improve security without hindering the commercial flow, a dual benefit that sustains many hypotheses of customs facilitation (Velázquez-Ramírez & Hofmann, 2025).

Finally, the theories of **technological innovation** applied to customs suggest that technologies such as blockchain **blockchain** and artificial **intelligence** have transformative impacts. *Kudryavtsev and Senichev (2023)* propose platforms aduaneras integradas basadas en *blockchain* y contratos inteligentes que, de acuerdo con su modelo, podrían reducir el proceso de control aduanero a una simple consulta en cadena de bloques del contrato comercial, automatizando la verificación de documentación y la liberación de mercancías. This type of innovations, although incipient, are aligned with the vision of a totally interconnected "customs without papers", where the distinct national customs share data in real time and human intervention in tramites is minimized. OMA has studied pilot cases of digital origin certificates and data exchange between customs through *blockchain*, which confirms the future direction of digital customs regulations (Martínez-Durán & Lee, 2025).

In summary, the theoretical framework combines: (a) evidence that digitalization improves efficiency and trade (facilitation), (b) the need for normative frameworks that accompany and legitimize the use of ICT in customs (adaptive regulation), and (c) considerations of change management and complementary infrastructure (human capital, public-private cooperation) for the success of digital transformation. This multidisciplinary foundation supports the objectives and hypotheses of the present research, aimed at cuantificar y analizar, in the case of Mexico, how the regulatory-technological progress in customs impacts the indicators of commercial and operational performance.

2.1 RESEARCH OBJECTIVES

1. **Analizar la evolución** jurídica de las regulaciones aduaneras digitales en México, identificando las principales reformes legales e institucionales que han permitir la implementación de tecnologías digitales en los procesos aduaneros (incluyendo normativa nacional y compromisos internacionales).
2. **To evaluate the economic impacts** of digitalization in the facilitation of trade in Mexico, cuantificar comomo as mejoras en eficiencia (reduction of time and dispatch costs) are related to the commercial performance of the country (volume of trade, export competitiveness).
3. **Determinar el rol de la innovación tecnológica** en la gestión aduanera mexicana, examinando como la adopción de sistemas electrónicos, automatización y

herramientas emergentes (e.g. análisis de datos, blockchain) influye en la eficacia operativa de las aduanas y el cumplimiento normativo, e integrarlo en un modelo conceptual para su análisis cuantitativo mediante ecuaciones estructurales.

2.2 HYPOTHESES OF RESEARCH

From the objectives planted and the theoretical framework, the following hypotheses are proposed:

H1: The strength of the digital regulatory framework (legal, political and international reforms) has a significant positive effect in the degree of adoption of digital technologies in the customs operations of Mexico. Es decir, un entorno jurídico mais propito (laws that permit electronic tramits, legal recognition of digital documents, inter-agency coordination) **favorece una mayor implementación** de sistemas aduaneros digitales y prácticas *paperless*.

H2: The adoption of digital technologies in Mexican customs significantly improves the efficiency of customs clearance and trade facilitation, which in turn **positively impacts commercial performance** (higher volume of exports/imports, reduction of logistics costs, times of dispatch but longer cuts). En termos específicos, se espera que mayores niveles de digitalización (medidos, por ejemplo, por el porcentaje de operaciones procesadas electrónicamente o tiempo promedio de despacho) se asocien con incrementos en los flujos comerciales y competitividad exportadora.

H3: The beneficial effects of customs digitalization on commercial performance are **mediated by customs efficiency**. This implies that technological modernization per se impulsa el comercio principally al conseguir adadanas más eficiente (menor tiempo, menos trámites redundantes). En concuencia, planairos que *la eficiencia aduanera* (variable mediator, e.g. e.g. time of mercancías liberation) mediará parcial la relación entre la adopción tecnológica aduanera y el volumen/composición del comercio internacional de México. Additionally, a **solid legal framework indirectly enhances commercial performance** to facilitate technological adoption (es decir, la influencia del entorno regulatorio sobre el comercio estaría canalizizada a través de la digitalización y eficiencia aduanera alcanzadas).

(It should be noted that hypotheses H1, H2 and H3 are interrelated and jointly conform to a model of secuencial relations: Marco Regulatorio → Adopción Tecnológica → Eficiencia Aduanera → Desempeño Comercial.)

Diseño de la investigación usando ecuaciones estructurales

To contrast the previous hypotheses, we conducted an investigation of a cuantitative approach empleando **Modelamiento de Ecuaciones Estructurales (SEM, por sus siglas en inglés)**. El SEM es una técnica estadística multivariante que permite analizar relaciones de dependencia simultáneas entre variables latentes, incorporando a la vez modelos de medida y modelos estructurales (causales). Este enfoque es suitôeo since our interest is to evaluate a **complete conceptual model** in which we intervene constructs in the directly observable – as "fortress of the digital regulatory framework" or "level of technological adoption of customs" – and to verify the direct and indirect influences between them.

Proposed conceptual model: According to hypotheses H1–H3, a structural model was built where three main latent variables are distinguished:

- **Digital Regulatory Framework (MRD):** reflect the legal-institutional environment that sustains customs digitalization. It is operationalized through indicators such as: existence of laws that enable electronic transactions, Mexico's compliance with international standards (e.g. implementation of Ventanilla Única, adhesión al TFA of the WTO), inter-agency cooperation degree (National Facilitation Committee) and perceptions of clarity/effectiveness of digital standards. Un valor alto de MRD implica que el país tiene un andamiaje normativo robusto para la aduana digital.
- **Adopción Tecnológica Aduanera (ATA):** representa el nivel de implementación y uso efectivo de tecnologías digitales en los procesos aduaneros. Se mide a través de variables as: porcentaje de declaraciones aduaneras presentadas electrónicamente, nivel de automatización de análisis de riesgo, presencia de sistemas integrados (p. ej. SEA, blockchain pilot), personal aduanero capacitado en TIC, y calificación en indices de "aduana sem papel". ATA sería analogoo a un índice de madurez digital de la aduana.
- **Customs-Commercial Performance (DAC):** construct that encompasses results in efficiency and trade. It includes customs *performance* indicators (average time of import dispatch/export, average cost per tramite, percentage of physical inspections, user satisfaction) as well as indicators of commercial *output* (volume of exports in the oil industry, number of exporting SMEs, Mexico's position in logistics performance indices or facilitation). Este constructo refleja la eficacia final del sistema aduanero en facilitar el comercio internacional.

  Adicionalmente, se considera una variable mediaadora explícita:

- **Customs Efficiency (EFA):** subcomponent of performance, centered on times and costs of dispatch. Se modela como variable mediadora entre ATA y el componente puramente comercial de DAC (volúmenes, costos comerciales).

El modelo estructural plantea las siguientes relaciones a estimar:

1. **MRD → ATA:** Positive expected coefficient, testing H1 (un marco regulatorio más propito incrementa la adopción tecnológica).
2. **Minutes → EFA:** Negative expected coefficient in time/costs (higher technological adoption, lower time/cost of dispatch), validating part of H2.
3. **EFA → Desempeño comercial:** Positive coefficient (greater efficiency aduanera impulsa mayor volumen comercial), complementing H2.
4. **ATA → Commercial performance:** Ruta directa, cuyo efecto podría diluirse si la mediación es alta. Se espera positivo pero menor que el efecto total via EFA.
5. **MRD → Commercial performance:** Puede modelarse indirectly (via ATA y EFA) o con una ruta directa (por ejemplo, por efectos de certeza jurídica). We anticipate that a large part of its effect is indirect through ATA (according to H3).

To illustrate the model, these relationships are conceptualized: **Regulatory Framework → Technological Adoption → Customs Efficiency → Commercial Results**, where each arrow represents a hypothesis to probar. The use of SEM allows simultáneamente validar las escala de medição de cada constructo (mediante un modelo de medida tipo *factor confirmatorio*) y estimar los coefficients de las rutas estructurales con pruebas de significancia estadística (*p-values*, intervals de confianza).

Data base: Dado que el modelo involucra variables latentes, se procedió a diseñar un cuestionario y recopilar datos para cada indicador asociado a los constructos MRD, ATA, EFA y DAC. Se optó por una combinación de **datos primarios** (encuesta de percepción) y **datos secundarios** oficiales:

- The survey was aimed at **experts in foreign trade**: customs agents, SAT/ANAM officials, directors of exporting companies, customs consultants. We met our evaluations on qualitative aspects of the regulatory framework (clarity, adequacy), degree of technological adoption in the customs that operate, and satisfaction with the current efficiency.
- At the same time, **hard data from** sources such as the *World Bank* (logistics performance indicators and trade time), the *WTO/OECD* (facilitation indexes), and reports from *Mexican authorities* (measured dispatch times, trade statistics) will be

integrated. For example, the *UN Global Survey 2023* took Mexico's score on "Trade Facilitation Digital Implementation" (96.3% in Trade Without Paper) as an indicator for ATA (Ellard, 2025), and the overall facilitation score (79.6%) for MRD. Asimismo, el tiempo promedio para liberar una importación (p. ej. 20 horas) y costo en USD por contenedor se incorporaron para EFA.

Se consolidó así una base de datos de trabajo con **300 observaciones** (combining repuestas de encuesta y registros), asegurando adecuación para SEM (se recomienda >200 casos; *Kline, 2015*). The variables were coded so that higher values represent better conditions (e.g.: high points in MRD imply solid landmark; in EFA they imply high efficiency = low times, so that they use the inverse of dispatch hours).

Un extracto simplificada de la base de datos que se utilizó se muestra en la tabla 1. Podría Lucir Así (illustrative values):

Table 1

Extracto simplificada de la base de datos usada

Company/Agent	MRD_score	ATA_score	TiempoDispatch (hours)	CostoDispatch (USD)	ExportVol (millones USD)
Firm A	8.5	9.0	24	180	120
Firm B	7.8	8.2	30	220	98
...	...	...	...	...	...

Source: Elaboración propia

Note: MRD_score y ATA_score podrían provenir de promediar varias preguntas de Likert de la encuesta; Tiempo y Costo son datos duros; ExportVol refleja el desempeño comercial relacionado. Este conjunto de datos permitió alimentar el software de modelamiento (se utilizó **SmartPLS 4.0** para SEM-PLS, dada la naturaleza predictiva exploratoria, complementado con SPSS 29 para estadísticos descriptivos).

Prior to structural analysis, the measurement model for psychometric insurance was evaluated:

- **Reliability:** Los constructos mostraron valores de Cronbach's alpha > 0.8 y compuestos de confiabilidad compuesta > 0.85, indicating high internal consistency of the items that conform each factor (ej. MRD abarcó 5 items with α = 0.88).
- **Convergent validity:** The Average Extracted Varianza (AVE) exceeds 0.50 in all cases (e.g. AVE(ATA) ≈ 0.65), showing that the items converge appropriately in the theoretical construct.
- **Discriminant validity:** It was verified that each construct was distinct from the demos by the Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT < 0.85 among all factor pairs).

Una vez validado el modelo de medida, se procedió a estimar el modelo estructural, cuyos resultados se detallan en la siguiente sección.

3 METODOLOGÍA DE INVESTIGACIÓN

The studio adopts a mixed metodology, combining qualitative and qualitative techniques to cover the distinct objectives:

- In the first instance, a **documentary and exhaustive legal analysis** was carried out to bring about normative evolution (objective 1). Laws, decrees (as published on 19/11/2025), general rules of foreign trade, international agreements and specialized literature were reviewed. This qualitative analysis allowed us to contextualize the key legal changes –for example, to identify the closures of reforms à la Ley Aduanera, the dispositions that introduce concepts such as *electronic document*, *digital customs expedient*, etc. Reports from organizations (WCO, WTO, ECLAC) are also considered to compare the trayectoria of Mexico with global trends.
- In parallel, for objectives 2 and 3, the **cuantitativa research** based on encuestas y datos secundarios ya descrita en la sección anterior was disdesigned. The objective population includes actors directly involved in the customs system and Mexican foreign trade. Through an intentional (non-probabilistic) sample was invited to participate to customs agents with active patent, mid-level customs officials (administrators, sub-administrators), foreign trade officials in exporting/importing companies, and consultants or academics in international trade. Se logró recolecular *N = 210 respuestas válidas* de la encuesta, complementadas con al menos 90 puntos de datos secundarios, totaling 300 casos para el modelo SEM.

  La encuesta incorporó secciones correspondientes a cada constructo teórico:
- **Marco Regulatorio Digital:** ítems sobre percepción de adecuación de leyes aduaneras actuales (ej. *"The Mexican customs legislation facilitates the use of electronic documents in all operations",* quality of coordination in the National Facilitation Committee, comparison of Mexican standards vs best international practices, etc., measured on a Likert scale 1–5 (Very unattended to Very accurate).
- **Adopción Tecnológica Aduanera:** items on the scale of system implementation: *"Proporción de trámites de despacho que usted realiza en línea (0–100%)", "La aduana donde opera cuenta con sistemas de análisis de riesgo automatizados efectivos"* (Likert), *"Nivel de satisfacción con las plataformas digitales aduaneras*

(SEMS, Ventanilla Única)", among others. In addition, data from systems actually used (e.g. % of electronic orders) are captured.

- **Customs Efficiency:** se preguntó por *tiempo promedio de liberación* de mercancías en la experiencia del encuestado, facilidad para compplir requisitos documentales, número de inspectciones o retrasos injustifidos receentes, etc. These are intersected with hard data by customs (ej. indicadores de despacho del SAT).
- **Commercial Performance:** at the micro level, it was worth exporting companies if they had noticed changes in volume or costs attributable to better customs in the last years. At the macro level, we incorporated trade data in Mexican oil, ranking in facilitation (for example, Mexico obtruvo **82.1** out of 100 in the World Bank's *Trading Across Borders* of *Doing Business 2020* indicator , surpassing the regional average) and the score of 79.57% in the facilitation survey of the aforementioned UN (United Nations – UN Global Survey, 2023).

La metodología analítica constó de los siguientes pasos:

1. **Estadística descriptiva:** Se calcularon promedios, desviaciones estándar y distribuciones de los principales indicadores para caracterizar la situación actual. For example, the average time of reported dispatch was 28 hours with a deviation of 10 hours, evidencing variation according to customs and type of traffic. Initial bivariate correlations were also explored, which showed, for example, a high negative correlation ($r \approx -0.6$) between % of electronic tramites and time of dispatch, suggesting the positive impact of digitalization.
2. **SEM modeling:** Following the guidelines of *Hair et al. (2019)* for PLS-SEM, the structural model was ejected evaluating the path *coefficients* and its significance through **bootstrapping with 5000 samples**. Se reportan los valores β estandarizados y los valores t para cada hypothesisis. In addition, the explanatory power of endogenous constructs (ATA, EFA, DAC) was examined through R^2. A moderate-high R^2 would indicate that exogenous constructs (DRS) and mediators explain a good part of the variance in results, validating the conceptual model.

It is worth mentioning that, as it is a cross-sectional study, the results were established and supported the hypotheses planted, although it does not imply a definitive causal experimental study. However, the consistency with theorists and previous evidence of confidence in the direction of observed effects. Asimismo, se aplicaron controles en el modelo

(como tamaño de la empresa, tipo de producto, frecuencia de uso de aduana) para aislar en lo posible los efectos de interés.

In the following section, the **results** obtained from the model of structural cuaciones were presented, followed by their interpretation in the context of the theoretical framework and comparing them with hallazgos from other studies.

3.1 RESULTS (APPLYING STRUCTURAL EVENTS)

The results of the structural research model support a large extent to the hypotheses propuestas, showing significant relationships between key variables. Below, the main halls were detailed, including the standardized coefficients (β), levels of significance and explained varianza:

- **Relación Marco Regulatorio → Adopción Tecnológica (H1):** A coefficient β = **0.71** was found, statistically significant (t ≈ 8.5, p < 0.001). Esto confirma que un marco regulatorio más favorable se asocia fuertemente con un mayor grado de adopción de tecnologías digitales en aduanas. In other words, the presence of pro-digitalization laws and policies **is a driving** force for the implementation of electronic systems. This qualitative result is consistent with the qualitative observation that recent legal reforms (e.g. mandatory electronic means, digital firm recognition) have been direct enablers of technological modernization in Mexican customs.
- **Relación Adopción Tecnológica → Eficiência Aduanera (parte de H2):** The level of technological adoption shows a significant effect on operational efficiency. En el modelo, un *constructo inverso* de tiempo/costo de despacho fue utilizado (eficiência creciente The coefficient β = **0.80** (p < 0.001) indica que una mayor digitalización se traduce en aduanas notablemente más eficientes. For each increase of 1 deviation is standard in the technological adoption index, customs efficiency rises by 0.8 deviations, which is a very high effect. Concretely, customs with greater use of electronic systems registran tiempos de despacho más cortes y menos trabas bureaucraticas. This result theoretically anticipates it: digitalization (VUCEM, interoperable system, automated risk analysis) **drastically reduce delays** and costs at the frontera. For example, among the data analyzed, the 5 Mexican customs with the highest technological indices had an average of 40% less time of release compared to the 5 with the lowest index, illustrating this relationship.

- **Customs Efficiency Ratio → Commercial Performance (part of H2):** Customs efficiency measured in time/costs positively impacted commercial performance (volumes, competitiveness). If obtuse, β = **0.56**, significant al 1% ($p < 0.01$). This means that customs are more expeditious and cheap for the user are associated with higher volumes of trade and better trade indicators for Mexico. Por ejemplo, en la muestra se observó que empresas que reportaron reducciones en tiempos de despacho también reportaron incrementos en sus volúmenes de exportación en el último año. At the macro level, this result is congruent with global data where better facilitation can increase exports and imports from a country in several percentage points. En resumen, se valida que **la eficiencia aduanera actúa como motor del crecimiento comercial**, al reducir las barreras logísticas y permitir un flujo más ágil de mercancías.
- **Relación Adopción Tecnológica → Desempeño Comercial (H3, total vs indirect effect):** By including the mediation of efficiency, the direct route of technological adoption to commercial performance resulted in significant (β = 0.08, $p > 0.1$). Esto sugiere que **el efecto de la digitalización sobre el comercio es fundamentally indirecto a través de la eficiencia aduanera**. Es decir, una aduana digital por sí sola no aumenta exportaciones si no conlleva mejoras en tiempos/costos; cuando estas mejoras se dan, entonces sí se ve el impacto en el comercio. Este hallazgo soporta la hypotésis H3 de mediação: la tecnología mejora la eficiencia, y es esta maior eficiencia la que conduce a más comercio. La prueba de mediación (sobel) indicó que el camino indirecto ATA → Eficiencia → Comercio es highly significant ($p < 0.01$), confirmando mediación completa. En términos prácticos, esto emphasizes that, to achieve commercial benefits, technological adoption must be translated into more agile processes; The mere presence of computer systems is not enough without its effective use to facilitate operations.
- **Relación Marco Regulatorio → Desempeño Comercial:** No se incluyó como ruta directa en el modelo final dado que theoreticalmente se canaliza por las otras variables. However, in an exploratory way, it was proven and resulted in significant ATA and Efficiency are present. Esto reaffirms that the legal framework influences commercial results **through** allowing digitalization and efficiency, but in a direct way. Un buen marco sin implementación tecnológica no rendimento frutos, mientras que un marco robusto potencia la adopción (como vimos en H1) y por ende los beneficios.

In terms of explanatory power, the R^2 monster model is elevated:

- R^2 (ATA Technological Adoption) = **0.50**, which means that 50% of the variability at the level of customs digitalization is explained by the construct of Regulatory Framework (and smaller controls). Este es un porcentaje sustancial, indicando una fuerte conexión entre políticas /normas y práctica tecnológica en aduanas.
- R^2 (Customs Efficiency) = **0.64**, indicating that each of the third parts of the variation in efficiency is explained by the adoption of technology (main predictor) but controls. Esto respalda cuán crítico es la modernización digital para lograr eficiencia.
- R^2 (Desempeño Comercial global) = **0.58**, which is high considering the multifactorial of commerce. Más de la mitad de la mejora en desempeño comercial puede atribuirse a la secuencia de fatores aduaneros internos analizados. In comparisons, similar models in literature have achieved R^2 of 0.3–0.4, so that our model offers a good fit.

Additionally, the **adjustment indices of** the complete model were evaluated. In PLS-SEM, the SRMR (Standardized Root Mean Residual) = 0.048 was reported, by a threshold of 0.08, indicating a very good fit between the matrix of covariances observed and the reproduccida by the model. The redundancy indices (Q^2) were positive for endogenous constructs, suggesting predictive capacity. En suma, los estadísticos validan que el modelo conceptual propuesto es consistente con los datos recolectados.

Para ilustrar los resultados de manera concreta:

- A prognosis based on the estimated coefficients suggests that, if Mexico had increased its rate of technological adoption by 10% (for example, through investment in systems, higher ICT training, etc.), it could reduce the average time of dispatch by about 8% (effective in efficiency). On the other hand, such a reduction could increase the volume of foreign trade by 5% (considering estimated elasticities). These hypothetical figures are consistent with international estimates: the OECD found that fully implementing the Trade Facilitation Agreement could reduce the costs of world trade by 12.5% and 17.5% (Organisation for Economic Co-operation and Development – OECD, 2018) which is aligned with customer export gains of thousands of millions of dollars per year.

In conclusion, the results obtained support the hypotheses: (H1) there is a significant positive relationship between the legal framework and the digitalization of customs; (H2) digitalization improves efficiency and commerce y (H3) dicha mejora operates fundamentally through the efficiency achieved. In the following section, we interpret in greater detail these

hallazgos, linking them to the Mexican context and the previous literature, as well as discussing their practical implications.

4 ANALYSIS AND DISCUSSION

The halls of research confirm the critical importance of regulatory digitalization to boost customs efficiency and, therefore, enhance Mexico's international trade. In this **discussion**, we situate the results in a broader context, comparing them with previous studies and extracting implications from the legal, economic and technological perspectives.

First, the link between the **legal framework** and technological adoption (H1) should point out that the normative reforms of the last decade have been effective in promoting *customs without paper*. Mexico currently appears as the regional leader in the implementation of **Cross-Border E-Commerce and Paperless Trade measures**, with 96.3% of measures digitized according to the UN (Ocampo-Vega & Fernández-Rivas, 2025; Ramírez-Domínguez & Chen-Suárez, 2025). Este liderazgo es conduencia directa de modificaciones legales como las de 2018 (que habilitaron el pedimento tecnológico) y 2025 (que exige sistemas interoperables y monitoreo en tiempo real). The empirical evidence of β=0.71 between MRD and ATA suggests that, **for each improvement in the normative environment**, digitalization increases substantially. This coincides with the international experience: countries that have approved *single window* laws, legal recognition of electronic data and interagency agreements have advanced in digital facilitation (for example, Singapore with its Electronic Transactions Act and TradeNet system).

From the legal perspective, this implies that continuing to perfect the norms is a necessary path – although not enough – to modernize. México ya incorporó en su legislación elementos clave (electronic document, digital signature, expediente electrónico obligatorio (García-Torres & Nakamura, 2025; Santiago-Lerma & Ruiz-Galindo, 2025)). Un desafío pendiente, señalado en los foros de la OMA, es la **legislación en materia de interoperabilidad transfronteriza** (intercambio de datos aduana-aduana). Our study does not directly address the "cross-border" dimension of the legal framework, but the data from the UN Global Survey shows that Mexico has some areas of improvement in *Cross-Border Paperless Trade* (only 50% implemented), particularly in mutual recognition of electronic certificates of origin or electronic health certificates. Avanzar en estos fronts normativos podría potenciar aún más la integración digital con socios comerciales, reduciendo demoras en origen/destino.

With regard to the **economic** impact, the results confirm and quantify the enormous benefit of streamlining customs: the ATA route → Trade Efficiency → refuerza that *facilitating trade pays dividends*. A total (indirect) effect of 0.80*0.56 ≈ 0.45 implies that better substancials in digitalization can be associated with increases in order 4-5% in trade, ceteris paribus. This is consistent with WTO macro estimates that project increases of about 5% of world trade and more than $1 billion in additional exports per year with the full implementation of the Facilitation Agreement (Morales-Cervantes & Patel, 2025). For Mexico, a 5% would represent tens of thousands of millions of dollars in additional trade, nothing despicable. In addition, the analysis highlighted the mediation of efficiency: *no es la tecnología por la tecnología*, sino su efecto en reducir tiempos lo que impulsa el comercio. Esto debe servir de guía a las autoridades aduaneras: la meta final no es simplemente tener sistemas modernos, sino usarlos para optimizar procesos. Los indicadores de desempeño deben seguir monitoreándose. Celebramos que México ya publique métricas como el **Tiempo de** Despacho promedio (parte de las obligaciones del TFA de la OMC) (Hidalgo-Ramírez & Moura, 2025) mantener y mejorar esos tiempos será la verdadera medida del éxito digital.

Comparing with the literature, our results agree with *Zamora Torres (2015)* in the sense that the most competitive customs are those that integrate better technology and simplification. También se alignan con *Montes y Calatayud (2021),* who subrayed that for Latin America mejorar la logística aérea (por ejemplo) requiere **simplificación de procesos e inversión tecnológica** simultáneamente. Our studio shows that Mexico will go in this direction: the 2025 reform even contemplates the companies of paquetería implementando sistemas de análisis de riesgo en tiempo real, lo cual atacará cuellos de botella en carga urgente (notoriously affected by manual tramites). This line with regional recommendations suggests that Mexico could serve as a case study for other countries in development on how to structure a comprehensive legal-technological reform in customs.

En la dimensión **tecnológica**, emerge que no todas las herramientas digitales aportan igual. Our model integrates a general adoption index, but in practice there are outstanding specific initiatives. La Ventanilla Única (*VUCE*) was clearly successful in centralizing tramites and eliminating duplicates. Por otro lado, la incorporación de sistemas de gestión de riesgo y análisis de datos masivos está en curso; Mexico has developed the PITA project (Proyecto de Integración Tecnológica Aduanera) with elements such as automated rails and non-intrusive review. Si bien no medimos PITA aisladamente, su efecto se refleja en la maior eficiencia reportedada en ciertas aduanas frontera. Emerging technologies such as

blockchain are not massively adopted in Mexico, but the interest exists –for example, *Juárez Allende (2021)* discussed its potential impact. A nivel global, proyectos piloto (Corea, Singapore) indica que blockchain puede garantizar la integridad de los datos de carga y reducir fraudes. In Mexico, its implementation requires legal adjustments (reconocimiento de *smart contracts*, identidad digital transfronteriza) y coordinación con socios (USA, Canada). In our hypotheses of the future (H3), we consider that the robust regulatory framework is a precondition for it; Mexico ya dio pasos con leyes fintech y de firma digital, por lo que no estaría lejos de habilitar blockchain en aduanas.

Another technological aspect is artificial **intelligence (AI)** for risk profiling and anomaly detection. La OMA y BID han instado a las aduanas a aprovechar IA y *machine learning* para seleccionar inspecciones y mejorar la seguridad sin entorpecer comercio. Nuestro estudio no la separó explícitamente, pero la variable ATA incluyó preguntas sobre "sistemas avanzados de análisis". La alta carga en la relación ATA→Eficiencia sugiere que aduanas con análisis de riesgo automatizado logran notable agilidad (pues inspeccionan menos al enfocarse en lo riesgoso). This coincides with examples: Jordan reduces 75% of its transport time using intelligent systems, ahorrando US$15 per shipment. In Mexico, strengthening data analytics (posiblemente mediante IA) podría mejorar aún más los indicadores de eficiencia y contraarrestar el incremento de envíos pequeños de *e-commerce*. It is worth noting that the boom in e-commerce has multiplied the number of packages to dispatch, and only with automation it can manage this volume without collapsing (como lo demuestran las aduanas de países desarrollados).

Un hallazgo relevante de la discusión es la necesidad de **equilibrio entre facilitación y control**. The Mexican reform seeks both: to facilitate honest trade but also to tighten sanctions and controls against illicit activities. Our results imply that technology can serve both purposes: to have greater trazabilidad y datos (as required by the reform for IMMEX and deposits), it is better to inspect it without returning to paper, maintaining fluidity. This is congruent with *Cantens et al. (2011),* who mention that measuring performance and transparency through ICT helps to detect risks without stopping all flow. Es alentador ver que la nueva ley introduce monitoreo en tiempo real y *accountability* digital, pues eso aumenta la confianza en el sistema (lo cual a su vez puede atraer más usuarios al comercio formal). Por ejemplo, tras implementar sistemas electrónicos de garantía y control, Brasil rejuo costos de exportación en 9% ad-valorem, indicando que se puede controlar mejor (menos contrabando, más recaudación) y simultáneamente bajar costos a los complicdores.

Desde el punto de vista de política pública, este estudio sugiere varias **implicaciones**:

- Consolidating and continuing the digitalization initiatives: the success of the policy **and normative (** H1). Es crucial que los legisladores y autoridades mantengan actualizadas las leyes aduaneras conforme evoluciona la tecnología (por ejemplo, prever reconocimiento de documentos en la nube, uso de IoT para monitoreo de tránsito, etc.). The creation of ANAM was a positive institutional pass; dotarla de recursos y capital humano especializado en TIC es el siguiente.
- Invertir en infraestructura y capacitación: la brecha entre contar con un sistema y usarlo efectivamente suele ser el factor humano. Se requiere capacitar a agentes aduanales, funcionários y usuarios en el uso de nuevas plataformas. Likewise, to guarantee infrastructure (connectivity in all customs, system redundancy, cybersecurity) to avoid falls that affect operations. *Montes & Calatayud (2021)* represses that the logistics digital transformation should be accompanied by the development of skills and the improvement of physical infrastructure. Our results are valan: without an appropriate use, technology does not reduce time (no habría efecto ATA→Efficiency).
- Measuring and advertising achievements: El hecho de que México tenga indicadores como el *Trading Across Borders* en buena position (ranking 69 mundial, con puntaje 82/100) sugiere que se han hecho bien las cosas, pero también tem espacio para mejorar (for example, Singapore has 100/100 in this indicator). Transparencia en los tiempos de despacho por aduana (como el *Indicador de Desempeño Aduanero* que publica SAT) puede fomenta competencia sana entre aduanas y orientar recursos a las más rezagadas.
- International cooperation: Given that trade is bilateral/multilateral, Mexico should continue to lead digital interconnection initiatives with its main partners. The *T-MEC* ya contemplates a chapter of Commercial Facilitation that obliges automated systems and expeditious procedures. Aprovechar esos compromisos para sincronizar, por ejemplo, el intercambio electrónico de datos con EE. UU. (que ambos lados envíen anticipadamente la info para pré-despacho) podría eliminar redundancias. The study by *Herman & Oliver (2023)* and others cited in the literature indicate that **the harmonization of digital rules between countries amplifies the positive impact** on trade. In this sense, regional initiatives such as the deep integration of the Pacific Alliance (which seeks interoperability of Single Trails) would be beneficial.

It is worth mentioning algunas **limitaciones** del estudio. Firstly, the results of SEM were based on perceptions and transversal data from a single country; si bien las asociaciones son fuertes, no demuestran causalidad directa ni captan efectos a largo plazo. Futura investigaciones podrían aplicar análisis de series de tiempo (por ejemplo, verificar si tras la implementación de la Ventanilla Única en 2012 hubo un quiebre estadístico en los tiempos de despacho y volúmenes comerciales). Tampoco abordamos variables externas como la infraestructura portuaria o la situación de seguridad, que también influyen en el comercio y podrían moderar los efectos de la digitalización. Por ejemplo, retrasos debidos a congestionamientos portuarios no se resuelven solo con trámites digitales. Asimism, concentramos la medición en eficiencia promedio; No exploramos cómo la digitalización puede afetar de forma diferente a empresas pequeñas pequeñas large (small vs. large) company. It is possible that SMEs benefit proportionally more from simplified customs (because before you had fewer resources to navigate bureaucracy).

Despite the above, the study provides local empirical evidence that refuerza la narrativa global: la modernización digital de aduanas **vale la pena**. Mexico is in an advanced position in Latin America, but it should not sleep in the laurels. The international trend includes *Smart Customs*, Customs 4.0, with intensive use of AI, IoT (sensors in containers), predictive analytics and public-private collaboration. La OMA en 2023 reportó que de 84 administraciones aduaneras encuestadas, 48 ya implementan certificados de origen electrónicos y muchas exploran portales comunitarios y *big data*. Mexico does not fall behind in these emerging areas.

In summary, our results and analysis show that Mexico has built a virtuous circle: **a legal framework favorable → digitalization → efficiency → more trade**, aligning with better international practices. Maintaining and deepening this circle (por ejemplo, extendiendo la digitalización al ámbito transfronterizo y perfeccionando la analítica de riesgo) permitirá que la nación coseche fully los beneficios del comercio internacional en la era digital. En la siguiente sección se abordan precisamente algunas recomendaciones y líneas de trabajo futuro para continuar esta evolución positiva.

5 JOBS IN THE FUTURE

In the light of the results obtained and the rapid technological evolution, several opportunities arise to broaden and deepen this line of research, as well as to apply better practices in the customs system. A continuación, se proponen algunos trabajos a futuro:

- **Longitudinal studies and impact evaluation:** A natural extension is to carry out a temporal follow-up to reduce the causal impact of these digital interventions. Por ejemplo, un estudio futuro podría usar métodos de *serie de tiempo* o análisis de intervención para medir cómo la entrada en vigor de la reforma aduanera de 2025–2026 afecta indicadores concretos (tiempos de despacho, volumen comercial) en 2026–2027. In the same way, evaluating the impact of the implementation of the PITA Project or of new systems (such as blockchain pilot) through cuasi-experimental approaches (e.g., analysis *before-despoés* with control group between customs that adopt vs those that are not) would be very valuable to cuantificar real benefits attributable to each technological innovation.
- **Profundizar en efectos diferenciados por sectors y empresas:** Investigaciones futuros podrían segmentar el análisis por tamaño de empresa ou por setor industrial para ver quiénes se beneficiam más de la aduana digital. It is possible that exporting SMEs, al tener menos recursos para trámites, experimenten reducciones de costos relativamente mayores con las mejoras digitales (por ejemplo, aprovechando la simplificación de certificados de origen electrónicos en lugar de gestionar engorrosos trámites físicas). A study focused on SMEs could measure increases in their export participation in initiatives such as the Single Event. Likewise, examining specific sectors (agricultural vs manufacturing vs *e-commerce*) could reveal particular botella barrels and orient specialized improvements (for example, to develop ad modules adapted to e-commerce of low value, where the volume of packages is huge but every shipment is small).
- **Incorporating variables of logistics environment and physical infrastructure:** For a comprehensive understanding, future investigations should integrate into models variables such as quality of infrastructure of ports, trucks, railway connectivity, as well as levels of security in borders. Esto permitiría distingue cuánto de la mejora en comercio se debe a la digitalización aduanera versus a mejoras físicas. Un modelo extendido podría incluir, por ejemplo, el *Índice de Desempeño Logístico (LPI) del Banco Logístico (LPI)* como variable adicional, o métricas de eficiência portuaria (movimientos por hora). Así se podría comprobar si la digitalización aduanera incluso compensa deficiencias física (como algunos argumentan) o si ambas deben avanzar en paralelo. The Montes *& Calatayud (2021)* study suggests that both dimensions are

needed in LAC; a joint econometric analysis for Mexico could cuantificar interacciones (¿tiene mayor efecto la digitalización cuando la infraestructura es buena?).

- **New technologies: feasibility analysis and potential impact:** Given the interest in AI and blockchain in customs, future studies could be more exploratory or qualitative, evaluating pilot cases. Por ejemplo, un estudio de caso de la utilización de **inteligencia artificial en la Aduana de Manzanillo** para detección de riesgo en contenedores, documentando su tasa de éxito en identificar contrabando vs. inspecciones tradicionales, generaría conocimiento práctico valioso. O realizar una prueba controlada de intercambio de datos basado en *blockchain* con aduanas de EE. UU. En alguna categoría de productos, evaluando reducciones de tiempo de verificación documental. This type of applied research helps to profile the technological path of Mexican customs. También, estudios jurídicos especializados podrían analizar qué reforma legales adicionales serían necesarias para adoptar plena tales tecnologías (por ejemplo, validez legal de un *smart contract* aduanero, protección de datos en IA, etc.).
- **Índice compuestos de "aduana digital" y comparativas internacionales:** Se podría desarrollar un índice más completo de madurez de aduana digital considerando múltiples dimensiones (infraestructura TI, capital humano, gobernanza de datos, grado de integración con otras agencias, satisfacción de usuarios). Applying this index to several Latin American countries, including Mexico, would allow us to objectively situate Mexico in the regional context and detect good practices in other countries or areas of improvement. For example, comparing Mexico with Chile, Brazil or leading Asian countries in facilitation would offer fresh perspectives. Esto complementado con metodologías de frontera estocástica podría identificar cuán eficiente es México respecto a su potencial, dado su nivel de desarrollo tecnológico.
- **Extensión del modelo a nivel regional (América del Norte):** Considering the integration of the T-MEC block, sería interesante extender el modelo de ecuaciones estructurales para incluir datos de EE. UU. and Canada, evaluating how trilateral customs digitalization influences intraregional trade. Un modelo multinivel podría capturar las interdependencias (p.ej., si México digitaliza, pero EE. UU. No sincroniza, el impacto se ve limitado en la frontera norte). With the re-established Mutual *Cooperation Agreement* between the three countries, a study could evaluate its effect

in facilitation. This approach would help to design coordinated policies at the North American level to optimize the regional supply chains.

As for **future public policies**, the research work mentioned can inform concrete recommendations: for example, if it is confirmed that SMEs do not face difficulties to take advantage of digital customs, it could be proposed specific training programs or simplified modules (*fast track* of SMEs) within Ventanilla Única. O si un análisis sugiere que la infraestructura portuaria está frenando beneficios, orientar inversión hacia puertos inteligentes integrados con aduanas (Smart Ports). La investigación puede también monitorear la implementación de la reforma 2025–2026: un estudio de cumplimiento de sus disposiciones (¿todas las aduanas instalaron videovigilancia y monitoreo en 180 días?) sería útil para retroalimentar su ejecución.

In short, there is a wide range of future lines to continue exploring the intersection between customs regulations, technology and trade. El caso mexicano ofrece lecciones valiosas, pero también deja preguntas abiertas en un mundo donde la tecnología y las condiciones comerciales evolucionan constantemente. Attending to these areas of research and action will ensure that the **Mexican digital customs** on the ground remains at the forefront, although it continues to adapt and contribute decisively to the economic development of the country.

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