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Article

Digitalization Level and Customs Clearance Time: A Segmented Interrupted Time Series (ITS) Analysis of Passenger Car Imports

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Abstract: *Background and objective:* Since 2019, Uzbekistan's customs system has processed passenger-car imports through an automated risk management system with green, yellow and red lanes. Whether the growing digitalization of import processing is related to the time needed to clear a car has not been quantified. The study estimates the relationship between the level of digitalization and the mean customs clearance time per passenger car. *Methods:* a segmented interrupted time series (ITS) model with Newey–West standard errors on 132 monthly observations (January 2015 – December 2025); digitalization is measured by DigitalIndex = GreenShare + 0.5·YellowShare; diagnostic tests, seven alternative specifications, a conditional scenario forecast for 2026–2030 and a pseudo-out-of-sample check. *Results:* before 2019 the clearance time rose by about 2.6% per month; after 2019 the underlying trend turned to a decline of about 1.0% per month ($p < 0.001$). A 0.1-point increase in DigitalIndex is associated with a roughly 20.5% shorter clearance time (95% CI: −11.7% to −28.4%; $R^2 = 0.778$). The annual mean time fell from 14.0 hours in 2019 to 2.7 hours in 2025. Under the baseline scenario the time per car is 1.56 hours in 2030 (90% interval 1.08–2.28); under the conservative scenario it stays near 2.7 hours. *Conclusions:* digitalization and clearance time are strongly and robustly associated, but the design has no control group and the index is highly correlated with the post-2019 trend (≈ 0.90); the estimates are therefore statistical associations, not causal effects, and the forecast is conditional.

Keywords: digital economy, customs clearance time, risk management, passenger car imports, segmented interrupted time series, DigitalIndex, trade facilitation.

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1. Introduction

Customs clearance time is one of the most visible results of a border agency's performance. Time in trade is treated as a cost-like barrier: Hummels and Schaur equated each additional day of delay with an ad valorem tariff [1], and Djankov, Freund and Pham showed that delays reduce trade volumes [2]. Article 7.4 of the WTO Trade Facilitation Agreement provides for the adoption of a risk management system, the concentration of customs control on high-risk consignments and the faster release of low-risk consignments [3]; the World Customs Organization (WCO) Risk Management Compendium offers practical guidance on this approach [4]. Article 7.6 of the Agreement encourages members to measure and publish average release times [1], and the WCO proposes the Time Release Study (TRS) methodology for this purpose [5]. Digitalization of customs processing is

therefore expected to shorten clearance time, but how large the relationship is in a national setting is an empirical question.

In this article, the level of digitalization is understood as the extent to which import declarations are processed through automated, risk-based selection rather than through full inspection. Passenger cars in Uzbekistan are a suitable case. The domestic car market grew from 236.6 thousand to 457.8 thousand units in 2021–2025, and the number of customs cargo declarations (CCDs) for passenger cars rose from 3,313 in 2020 (0.46% of all CCDs) to 33,992 in 2025 (3.83%) [6]. The import mix is also shifting: in 2022–2025 imports of fuel-powered cars fell to 0.7 of their level, while imports of non-plug-in hybrids (HEV), plug-in hybrids (PHEV), extended-range electric vehicles (EREV) and battery electric vehicles (EV) grew 3.3-, 43.4-, 72.3- and 11.1-fold, respectively [6]. Over the same period the national customs system moved from multi-copy paper documents (1999–2013) to electronic declaration (2014), the Single Window (2018), the lane-based risk management system (2019), digital integration with the State Road Traffic Safety Service of the Ministry of Internal Affairs (2022), and the "New customs inspection" (2022) and "Customs cargo operations" (2023) systems. The legal framework is set by the Customs Code [7] and recent presidential decisions on customs administration [8].

Previous studies of vehicle imports have mainly examined customs regulation and duties [9], [10]. Studies on the digitalization of customs administration in Uzbekistan are largely theoretical and descriptive, and the quantitative link between the level of digitalization and clearance time has not been estimated. A further methodological problem is that the green and yellow lanes did not exist in 2015–2018, so the parallel pre-period observations needed for a classical difference-in-differences design are not available. Segmented interrupted time series (ITS) regression, which compares the level and trend of an outcome before and after an intervention in a single series, is a standard alternative in such cases [11], [12].

This article estimates the relationship between the level of digitalization and customs clearance time for passenger car imports using monthly data. The aim is to quantify this relationship, to test its robustness and, on the basis of conditional scenarios, to determine the possible clearance time in 2026–2030. The study addresses three research questions: (RQ1) How did the mean clearance time per car and its underlying trend change after the introduction of the lane-based risk management system in 2019? (RQ2) Is a higher level of digitalization associated with a shorter clearance time once the trends are controlled for, and how robust is this association? (RQ3) What mean clearance time per car do conditional scenarios imply for 2026–2030, and how sensitive are they?

2. Materials and Methods

2.1 Study object and design

The study object comprises passenger cars cleared under the "release for free circulation (import)" customs procedure in Uzbekistan. The design is a single-series quasi-experimental ITS analysis [11], [12]. The intervention point is January 2019, when the risk management automated information system and the lane system (green, yellow, red) started to operate. No control group or randomised experiment is available for estimating causal effects. A difference-in-differences design was rejected because green and yellow lanes did not exist in 2015–2018, so parallel pre-period observations for a comparison group were not formed.

2.2 Data

The analysis uses monthly data for January 2015 – December 2025 (n = 132) calculated by the author on the basis of official statistical and departmental data of the State Customs Committee [13]. The outcome variable is the mean time spent on clearing one passenger car in a given month (recorded in days and converted to hours by multiplying by 24). Annual data on the number of CCDs for passenger cars and on the

number of clearance staff were used for the descriptive analysis (Table 2). The variables are defined in Table 1.

Table 1. Variables used in the ITS model

Variable	Definition	Note
Y_t	Mean clearance time per passenger car in month t, days	Outcome; modelled as ln Y_t
$GreenShare_t$, $YellowShare_t$	Shares of declarations routed to the green and yellow lanes in month t	Components of the index
$DigitalIndex_t$	$GreenShare_t + 0.5 \cdot YellowShare_t$	Equals 0 in 2015–2018 (no lanes)
$PreTrend_t$	Linear time trend up to January 2019	Pre-intervention slope
$PostTrend_t$	Linear time trend from January 2019	Post-intervention slope
N_t	Monthly number of cars (operational load)	Tested; excluded from the main model

2.3 Digitalization index

The level of digitalization was measured by an index that does not contain any time indicator, which removes a mechanical link with the outcome variable. The index combines control selectivity (the share of the flow eased on the basis of risk) and the degree of automation:

$$DigitalIndex_t = GreenShare_t + 0.5 \cdot YellowShare_t$$

The index is set to zero for 2015–2018, when lanes did not exist. The weight of 0.5 for the yellow lane is a normative choice (the equally weighted mean of the two components), not an estimated parameter.

2.4 Econometric model

The segmented ITS model was specified in logarithms:

$$\ln(Y_t) = \beta_0 + \beta_1 \cdot PreTrend_t + \beta_2 \cdot PostTrend_t + \beta_3 \cdot DigitalIndex_t + \varepsilon_t$$

Because PreTrend is held fixed after January 2019, β_2 measures the post-intervention slope. Coefficients are interpreted as percentage effects (see the formulas below). Standard errors were computed with the Newey–West heteroskedasticity- and autocorrelation-consistent (HAC) estimator with 12 lags [13]. Operational load (N_t) and a level shift in 2019 (Post2019) were initially included, but they were statistically insignificant ($p = 0.536$ and $p = 0.718$, respectively) and increased multicollinearity, so they were excluded from the main model; their reintroduction is reported in the robustness checks.

The percentage effect of a coefficient and the effect of a 0.1-point change in DigitalIndex are, respectively:

$$\%\Delta Y = \exp(\beta) - 1$$

$$\%\Delta Y_{0.1} = \exp(0.1 \cdot \beta_3) - 1 = \exp(0.1 \cdot (-2.2926)) - 1 \approx -0.205$$

2.5 Diagnostics and robustness checks

Serial correlation was tested with the Breusch–Godfrey test [14], [15], functional form with Ramsey's RESET test [16], and multicollinearity with variance inflation factors (VIF). Robustness was assessed with seven alternative specifications: three sub-samples (January 2019 – December 2025; January 2020 – December 2025; March 2019 – December 2025, a controlled ITS window), a COVID-19 dummy (March 2020 – December 2021), reintroduction of Post2019, a normalised load index (N_t/N_max) and $\ln(N_t)$.[14]

2.6 Scenario forecast

A conditional forecast was computed from the estimated model with an AR(1) residual correction ($\varphi = 0.329$). The 90% interval was obtained by 20,000 simulations of

parameter uncertainty (HAC covariance matrix) and AR(1) innovations. DigitalIndex was treated as an external scenario variable; the number of cars (N_t) is not in the model and was not forecast. Two scenarios were considered for 2026–2030: (A) baseline — the PostTrend continues and DigitalIndex stays at its 2025 mean (0.477); (B) conservative — the independent trend stops at its December 2025 level and the index stays there. A sensitivity analysis varied DigitalIndex in 2030 (0.35 and 0.60), and an additional conditional 15% effect of an integrated software platform was assumed as a scenario hypothesis, not as a historical coefficient, because the 2015–2025 observations do not cover the period when the platform operated. The forecast was checked by a pseudo-out-of-sample test: the model estimated on 2015–2023 data was evaluated for 2024–2025 using the actual index values.[15]

The AR(1) residual correction takes the form:

$$\varepsilon_t = \varphi \cdot \varepsilon_{t-1} + u_t, \quad \varphi = 0.329$$

where u_t is the innovation term drawn in the simulations.

3. Results

3.1 Descriptive dynamics (RQ1)

The annual mean of the monthly clearance time per passenger car fell from 0.583 days (≈ 14.0 hours) in 2019 to 0.114 days (≈ 2.7 hours) in 2025, a decline of about 80%. In the same years the number of passenger-car CCDs rose sharply while the number of clearance staff stayed constant at 220 from 2022 (Table 2). The number of CCDs per employee increased from 29.0 in 2022 to 154.5 in 2025, about 5.3-fold; in 2015–2021 it ranged between 2.8 and 11.6. This capacity gain was achieved without additional staff positions, but it cannot be attributed to digitalization alone: the lane system, the import mix and regulation also changed.

Table 2. Passenger-car CCDs and clearance staff, 2015–2025

Year	Passenger-car CCDs	Clearance staff	CCDs per employee
2015	5,205	450	11.6
2016	1,775	450	3.9
2017	1,254	450	2.8
2018	1,728	420	4.1
2019	4,087	388	10.5
2020	3,313	324	10.2
2021	3,340	324	10.3
2022	6,373	220	29.0
2023	32,139	220	146.1
2024	30,952	220	140.7
2025	33,992	220	154.5

Source: author's calculations based on [6]; CCDs per employee are defined below.

$$CCDs\ per\ employee_y = \frac{CCDs_y}{Staff_y}$$

where y denotes the year.

3.2 ITS estimates (RQ1 and RQ2)

The estimates of the main model are given in Table 3. Before 2019 the clearance time grew by about 2.6% per month ($\beta_1 = 0.0255$; approximate 95% CI: +1.9% to +3.3%). After 2019 the underlying trend turned into a decline of about 1.0% per month ($\beta_2 = -0.0100$; approximate 95% CI: −1.6% to −0.4%). A 0.1-point increase in DigitalIndex, other factors being equal, is associated with a shorter mean clearance time by about 20.5% ($\beta_3 = -2.2926$; 95% CI for a 0.1-point change: −11.7% to −28.4%). All three slope and index coefficients are significant at $p < 0.001$.

Table 3. Segmented ITS model estimates (n = 132; dependent variable ln Y_t)

Parameter	Coefficient	HAC st. error	p-value	Interpretation, exp(β) − 1
Constant (β_0)	−1.5679	0.1189	< 0.001	—
PreTrend (β_1)	0.0255	0.0033	< 0.001	≈ +2.6% per month until Jan 2019
PostTrend (β_2)	−0.0100	0.0029	< 0.001	≈ −1.0% per month after Jan 2019
DigitalIndex (β_3)	−2.2926	0.5371	< 0.001	+0.1 index point → ≈ −20.5%

Note: R^2 = 0.778; adjusted R^2 = 0.759; VIF = 1.69 / 5.06 / 5.62. Breusch–Godfrey LM = 30.61 (p = 0.002), which indicates serial correlation, so inference relies on HAC standard errors; Ramsey RESET F = 0.30 (p = 0.740), so the hypothesis of a misspecified functional form is not supported. The confidence intervals of β_1 and β_2 are approximate, computed from the reported HAC standard errors with a normal approximation. Source: author's calculations.

3.3 Robustness (RQ2)

The main finding was preserved in all alternative specifications (Table 4): β_2 and β_3 are negative in every variant, with $p \le 0.004$. In the sub-sample from January 2020 the PostTrend slope weakens (−0.0053) while the index coefficient strengthens (−2.6602), which suggests that the decline in recent years is mostly associated with the index. Because the two regressors are highly correlated, this separation is interpreted cautiously.

Table 4. PostTrend (β_2) and DigitalIndex (β_3) coefficients in alternative specifications

Specification	n	β_2	p	β_3	p	R^2
Main model (2015/01–2025/12)	132	−0.0100	< 0.001	−2.2926	< 0.001	0.778
(a) Sub-sample 2019/01–2025/12	84	−0.0099	0.001	−2.2150	< 0.001	0.795
(b) Sub-sample 2020/01–2025/12	72	−0.0053	0.002	−2.6602	< 0.001	0.825
(c) 2019/03–2025/12 (controlled ITS window)	82	−0.0088	0.001	−2.2872	< 0.001	0.791
(d) + COVID-19 dummy (2020/03–2021/12)	132	−0.0106	< 0.001	−2.2867	< 0.001	0.676
(e) + Post2019 reintroduced	132	−0.0099	0.001	−2.2150	< 0.001	0.668
(f) + load index reintroduced (N_t/N_{max})	132	−0.0112	0.004	−2.2546	< 0.001	0.668
(g) + ln(N_t) added	132	−0.0120	0.001	−2.2991	< 0.001	0.669

Source: author's calculations.

As a sensitivity check, the share of cars sent to the red lane fell from 39.4% in 2024 to 5.9% in 2025 (33.5 percentage points). Because the three lane shares sum to one, the change in DigitalIndex implied by this fall can be bounded:

$$G_t + Y_t + R_t = 1 \Rightarrow \Delta \text{DigitalIndex} = \Delta G + 0.5 \cdot \Delta Y$$

$$0.5 \cdot 0.335 = 0.1675 \le \Delta \text{DigitalIndex} \le 0.335$$

The lower bound applies if the whole change goes to the yellow lane, and the upper bound if it all goes to the green lane. Substituting the bounds into the percentage-effect formula gives:

$$\exp(-2.2926 \cdot 0.1675) - 1 \approx -0.32$$

$$\exp(-2.2926 \cdot 0.335) - 1 \approx -0.54$$

The model therefore associates this change with a 32–54% reduction in clearance time.

3.4 Scenario results (RQ3)

In the baseline scenario the mean time per car falls from 2.72 hours in 2025 to 2.53 hours in 2026 and 1.56 hours in 2030 (≈ 0.065 days; 90% interval 1.08–2.28 hours). In the conservative scenario it stays at about 2.7 hours (Table 5). If DigitalIndex rises to 0.60 by 2030, the baseline time falls to 1.19 hours; if it falls to 0.35, the time is 2.10 hours. A conditional 15% additional effect of an integrated platform would reduce the 2030 baseline result to about 1.33 hours. In the pseudo-out-of-sample test, the model estimated on 2015–2023 data reproduced the annual mean time with errors of −12.7% for 2024 and +4.7% for 2025.

Table 5. Projected mean clearance time per passenger car, hours (90% interval in brackets)

Year	Baseline scenario (A)	A + platform (15%)	Conservative scenario (B)
2025 (actual)	2.72	2.72	2.72
2026	2.53 (1.96–3.24)	2.15	2.70 (2.12–3.45)
2027	2.25 (1.71–2.94)	1.91	2.70 (2.11–3.46)
2028	2.00 (1.48–2.68)	1.70	2.70 (2.11–3.46)
2029	1.77 (1.26–2.47)	1.50	2.71 (2.11–3.47)
2030	1.56 (1.08–2.28)	1.33	2.71 (2.12–3.47)

Note: the projections are conditional; no interval is reported for the platform column, whose 15% effect is a scenario assumption. Source: author's calculations.

A further exploratory test of the effect of interstate data exchange (September 2022) in a controlled ITS model did not reveal a statistically reliable effect.

4. Discussion

4.1 Principal findings

First, the underlying trend of the clearance time changed its direction in 2019: it rose by about 2.6% per month before the lane-based risk management system and fell by about 1.0% per month afterwards, and the annual mean time per car fell from 14.0 to 2.7 hours between 2019 and 2025. Second, a higher DigitalIndex is associated with a shorter clearance time: +0.1 index point corresponds to about −20.5% (95% CI: −11.7% to −28.4%), and the sign and significance of the coefficient are stable across all seven alternative specifications. Third, the conditional scenarios put the mean time per car at 1.56 hours in 2030 if the existing trends continue and the index stays at its 2025 level, and at about 2.7 hours if the independent trend stops.

4.2 Interpretation

Gradual, cumulative effect. The ITS results show that the effect of the risk management system and the lane system did not appear instantly but built up step by step. This is consistent with the logic of Article 7.4 of the Trade Facilitation Agreement [1]: when control is concentrated on high-risk consignments, low-risk consignments are released faster, and the benefit grows as the profiles and the share of eased flows develop. The size of the effect matters in light of the evidence that time acts as a cost-like barrier to trade [3], [4].

Two effects are hard to separate. The correlation between DigitalIndex and PostTrend is about 0.90 (VIF ≈ 5.6). In the sub-sample from January 2020 the PostTrend slope weakens and the index coefficient strengthens, which suggests that the recent decline is mostly associated with the index, but because of the high correlation the two effects cannot be fully separated. The 20.5% point estimate should therefore be read as an order of magnitude, since its confidence interval is wide.

Other factors also operate. The abolition of the environmental certificate requirement (for all hybrid passenger cars from 1 May 2025 and for all passenger cars from

19 September 2025), the change in the import mix towards hybrids and electric vehicles, and the stable number of clearance staff may also have influenced the clearance time. The rise in CCDs per employee from 29.0 in 2022 to 154.5 in 2025 (Table 2) shows that throughput grew without additional staff, but this is not attributed to digitalization alone.

Volatility of the lane structure. The share of cars directed to the red lane fell from 39.4% in 2024 to 5.9% in 2025. Because the index itself depends on lane policy, such swings mean that part of the index variation reflects policy settings rather than technology.

4.3 Practical implications

The results support the following directions: (1) calculating DigitalIndex monthly and including it, together with clearance time, the lane shares, the error share, the amount of detected violations and CCDs per employee, in the key performance indicator (KPI) system; (2) reviewing risk profiles and criteria regularly, given the swings in the red-lane share; (3) measuring clearance time systematically by product sub-group, in line with the WCO TRS methodology [5] and Article 7.6 of the Trade Facilitation Agreement [1]; (4) evaluating the integrated software platform with control and treatment groups after its real introduction, instead of attributing a historical coefficient to it; and (5) tracking the effect of interstate data exchange separately, since the exploratory test did not detect a reliable effect.[16]

4.4 Limitations

First, the findings are statistical associations and are not interpreted as direct causal effects. Second, there is no control group, so ITS cannot fully separate the changes from other simultaneous factors, such as regulatory liberalization and changes in the import mix. Third, the index is undefined (set to zero) in 2015–2018, and the 0.5 weight of the yellow lane is a normative choice. Fourth, the correlation between DigitalIndex and PostTrend is high (≈ 0.90; VIF ≈ 5.6), which limits the separation of the two effects. Fifth, operational load is not included in the model. Sixth, the forecast is conditional and involves linear extrapolation beyond the observation window (PostTrend of 83–143 months); the baseline scenario should therefore be read as the upper bound of the improvement and the conservative scenario as the lower bound, and the index itself depends on lane policy. Seventh, the Breusch–Godfrey test indicates serial correlation; HAC standard errors correct the inference but not the possible dynamic misspecification.

5. Conclusions

A segmented ITS model estimated on 132 monthly observations for 2015–2025 shows that the underlying clearance time per passenger car rose by about 2.6% per month before 2019 and fell by about 1.0% per month after the lane-based risk management system was introduced ($p < 0.001$). A 0.1-point higher DigitalIndex (GreenShare + 0.5·YellowShare) is associated with a roughly 20.5% shorter clearance time (95% CI: −11.7% to −28.4%; $R^2 = 0.778$), and this association holds in all seven alternative specifications ($p \leq 0.004$). The annual mean time per car fell from 14.0 hours in 2019 to 2.7 hours in 2025. According to the conditional scenarios, the mean time could reach 1.56 hours in 2030 (90% interval 1.08–2.28) if the existing trends continue and the index stays at its 2025 level, and would remain near 2.7 hours if the independent trend stops. The results do not prove a causal link between digitalization and time: the design has no control group and the index is highly correlated with the post-2019 trend. The next steps are to evaluate new digital solutions with control and treatment groups, to add operational load and other covariates to the model, and to measure clearance time by product sub-group using the TRS methodology.

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