▪ Journal of Competitiveness

The Effectiveness of Old Car Scrappage Subsidies as a Key Economic Tool for Ensuring the Competitiveness of European Countries

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Abstract

This article focuses on the effectiveness of state subsidies for fleet renewal across Europe. The research analyzes and subsequently compares the situation in the Czech Republic and in other European countries, using separate country-level time series data. The theoretical framework is based on Mankiw's theory of long-term consumption, the validity of which has not previously been confirmed by empirical data in several research studies. This discrepancy is known in the scientific literature as Mankiw's puzzle. The methodological part of the research used statistical testing to determine the extent to which the puzzle is realized in individual European countries. The testing was carried out on long time series, focusing on two key variables: newly registered cars and household expenditure on durable goods. The formal evaluation rejected the universal validity of the strict ARMA(1,1) specification, although significant structural differences were identified across the sample. On this basis, a clear country typology was established, dividing European economies into high-inertia automotive markets, structural postponers, and martingale adaptors. This typology demonstrates how consumption persistence determines the transmission and ultimate efficacy of car scrapping policies for electromobility adoption and regional economic competitiveness. The research has also revealed a systemic connection between the competitiveness of automotive production and the sustainability of the fleet ecosystem. In the Czech Republic, the effective replacement of old cars with combustion engines is conditioned by subsidies for their disposal, whereas in other countries the expected effect of such subsidies is marginal.

Keywords: *Mankiw's puzzle, scrappage scheme, mixed autoregressive processes, consumption of durable goods, permanent income*

JEL Classification: D12, E21

Article history: Received: October 2025; Accepted: September 2026; Published: September 2026

1 INTRODUCTION

Global environmental changes, accompanied by warning signs of an increasing risk of a climate crisis, pose a number of economic challenges for European countries (Cheba et al., 2022). Maintaining economic competitiveness in the context of sustainable development requires many measures that can affect the existing living standards of European citizens. Material circularity and sustainable manufacturing, together with reduced environmental impacts, are crucial for competitiveness in the automotive market (Stichhauerova et al., 2020; Khaleel et al., 2024). To economically evaluate the proposed measures in the field of design, organization, and management of the circular ecosystem—a key basis for meeting the set environmental goals—it is first necessary to choose the appropriate economic instruments. National scrapping policies take into account two key parameters: the age of vehicles eligible for scrapping, and

https://doi.org/10.7441/joc.2026.03.08

consumers' decisions to purchase a vehicle with or without a subsidy. The automotive sector is under growing pressure to become more circular and sustainable—in the way it produces, in the cars it makes, and in the way cars and their waste are disposed of, at the end of their useful life (Moita et al., 2024). This article focuses on one specific instrument: a scrappage scheme, intended to influence the dynamics of electromobility in European countries. As a form of state subsidy, the scheme is a relevant tool for economic research, as it should contribute to long-term consumption growth and positively influence electric car sales in Europe. Ultimately, supporting the domestic electric vehicle market through such targeted financial incentives is important for maintaining the long-term industrial competitiveness of the entire European automotive sector.

Electromobility has recently become an effective measure to reduce dependence on fossil fuels and achieve carbon-neutrality goals (Wang et al., 2024; Malik et al., 2025). Its promotion currently divides society into two camps. The first group views electromobility as the only viable solution to the climate crisis. The second group is concerned about a potential decline in living standards and a lack of financial resources to purchase and maintain electric cars, and thus about losing access not only to luxury but also to basic goods and services. This socioeconomic inequality poses a risk to regional competitiveness, since limited consumer mobility can disrupt labor markets and reduce overall productivity. Because the financial incentives are costly and, over the long term, unaffordable for many customers, the economic sustainability of current electric vehicle promotions is questionable (Tilly et al., 2024). If financial instruments fail to bridge this affordability gap, the resulting market stagnation could jeopardize industrial competitiveness in the transition to green transportation.

The economic evaluation of electromobility has recently become an important topic in several publications. For instance, Pesch et al. (2020) defined its economic profitability and identified potential obstacles to the rapid expansion of electromobility. From a macro-structural perspective, urbanization and the resulting expansion of mobility needs have accelerated the market adoption of electric vehicles, directly contributing to the mitigation of greenhouse gas emissions. Pei et al. (2023) explore the issue further in the context of the growing energy crisis and environmental pressure.

The economic rationale and underlying mechanisms of scrapping schemes were systematically formulated by Adda and Cooper (2000), whose findings were subsequently reflected in the economic policies of France, Spain, Italy, and Germany. This traditional debate on vehicle fleet renewal is currently advanced by Woody et al. (2024), who examine subsidy programs in terms of achieving ambitious climate targets through the rapid acceleration of electromobility. Nevertheless, the efficacy of these government stimuli remains a subject of debate. In this context, Zaman and Zaccour (2020) draw attention to the wealth effect, whereby consumers receiving subsidies did not incline toward more fuel-efficient vehicles but instead invested in environmentally demanding segments such as SUVs and MPVs. Varying efficiency across time and space is documented by Marin and Zoboli (2020). They point out that in 2007 and 2008, no relevant impact on the replacement of obsolete automobiles was recorded, whereas the crisis of 2009 witnessed a maximum substitution effect, triggered by a combination of high financial incentives and a perception of declining permanent income during the Great Financial Crisis. Similar conclusions are reached by Kang (2023), Svoboda et al. (2023), and Gorji et al. (2021), who emphasize the need to differentiate analyses by country-specific consumer behavior and historical path dependence in the automotive industry. From a methodological standpoint, the analysis of the stochastic behavior of durable consumption is advanced by Yang and Zhang (2024), who integrate capital market influences into the permanent income hypothesis; these

https://doi.org/10.7441/joc.2026.03.08

subsequently spill over into aggregate household durable consumption. Because these effects are virtually negligible for non-durable consumption, they generate a fundamental contradiction with Hall's (1978) classic consumption theory, resonating with the current frameworks of Koijen and Yogo (2026). This article focuses on the economic evaluation of electromobility in the context of subsidy policy in European countries.

This research was inspired by Mankiw's puzzle. In his analysis of the life-cycle hypothesis, Mankiw (1983) reached the following conclusion. When conventional long-term consumption theory is integrated into Hall's theory of consumption, the analysis yields different conclusions from those of conventional theoretical models. These differences were demonstrated by empirical data from post-World War II United States, which showed that only current information—and therefore current long-term consumption—is relevant for predicting long-term consumption. Long-term consumption, as interpreted through stochastic models, can thus be a key tool for explaining many current macroeconomic phenomena. For example, Tauber and Van Zandweghe (2021) discuss the historical relationship between spending on durable goods and household income during the COVID-19 pandemic. Alp and Seven (2019) employ stochastic models to investigate the relation between long-term household consumption and state wealth, focusing on real estate trading in Turkey. Ishihara and Ching (2019) developed a new dynamic structural model based on the data on consumer decisions to buy and sell video games, focusing on the video game industry in Japan. Sarmento et al. (2019) examine consumer behavior during the economic recession in Portugal based on time series.

The main objective of our research was to verify the validity of Mankiw's conclusions in the context of current European subsidy policy. Mankiw's puzzle emerges when the dynamics of macroeconomic consumption are considered together with the issue of promoting electromobility in European countries. In pursuing their climate and geopolitical goals, European households will inevitably need to replace their old cars, yet this will be difficult given the budgetary constraints of individual households. The policy actions to encourage the adoption of certain technologies are not limited to one dimension but combine several actions to support user behavior, giving rise to the policy mix construct (Tolani et al., 2025). The main contribution of this research is its econometric analysis of the time series of the impact of the scrappage scheme on the deployment of electromobility in Europe. This analysis was carried out using Mankiw's consumption theory in relation to time series data on long-term consumption and newly registered cars in European countries. The starting point of the research is the potential realization of Mankiw's puzzle, which could indicate phenomena complicating the introduction of electromobility. The analysis was based on the maximum available quarterly time series data (from Q1 2004 to Q3 2024). These were used to verify whether the dynamics of monitored long-term consumption tend to dampen. Methodologically, it was tested whether the mixed autoregressive stochastic process ARMA(1,1) of the given time series showed the proposed autoregressive parameter coefficient to be significantly smaller than one. It was further verified whether the depreciation rate of durable goods is zero, corresponding to a moving average coefficient of -1. The model essentially integrates three key components: autoregression (AR), which relates the observed variable to its past values; an integrated component (I), which removes the trend in the data through differentiation; and a moving average (MA), which uses past error terms to smooth out fluctuations. The ARIMA approach is a fundamental part of the procedure known as "machine learning" in current research on time series fluctuations (Brownlee, 2025).

https://doi.org/10.7441/joc.2026.03.08

2 THEORETICAL BACKGROUND

2.1 Mankiw's theory of long-term consumption

In his research, Friedman (1957) expanded the mainstream theory of the permanent income hypothesis, incorporating not only changes in the representative interest rate but also changes in stock and bond prices. In addition to physical capital, the model also considers human capital and newly expected inflation. Applying the permanent income hypothesis to U.S. data, Mankiw and Shapiro (1985) analyze deviations from it, also known as Mankiw's puzzle of long-term consumption. The puzzle reveals the following facts. First, the growth rate of expenditure on long-term consumption can be modelled using a stochastic ARMA(1,1) process. Second, the moving average coefficient has an estimated value of -1, corresponding to a zero rate of depreciation for durable goods. By contrast, short-term consumption expenditure follows a stochastic process known as a random walk. The past acquisition of durable goods therefore influences expenditure on the same goods in the present, in contrast to short-term consumption and services. In extreme cases, demand for durable goods may disappear completely. Mankiw (1983) came to the theoretical conclusion that expenditure on long-term macroeconomic consumption is governed over time by a mixed stochastic autoregressive ARMA(1,1) process. If the autoregressive (AR) coefficient is significantly less than one and the moving average (MA) coefficient is exactly one (or minus one), long-term consumption levels converge to zero in the long term. If technological development remains unchanged, long-term consumption must be stimulated through subsidies or the scrappage scheme. Based on a significant sample of data, Yang and Zhang (2024) conclude that short-term consumption can be modeled as shocks in the form of a random walk, whereas long-term consumption growth is related to the dynamics of the ratio of share prices to dividends, broadening the context of Mankiw's puzzle. Vu (2005) disproves Mankiw's puzzle on the basis of observed series, the mathematical descriptions of which corresponded to an AR(1) rather than an ARMA(1,1) process. This can be resolved by employing a non-quadratic utility function and a Monte Carlo simulation, reflecting the nonlinear adjustment of equilibrium in the model, and Vu (2005) accordingly recommends the nonlinear ARMA(∞,1) process.

2.2 Impacts of Mankiw's theory on the issue of providing subsidies in the form of scrappage scheme

The presence of Mankiw's puzzle highlights governments' motivation to support their automotive industry with a scrappage scheme. Zaman and Zaccour (2023) highlight the issue of inexplicable increases in car prices following the introduction of subsidies in the form of a scrappage scheme. Woody et al. (2024) warn that the rate of vehicle replacement is insufficient to meet decarbonization goals. They further describe existing scrappage-scheme policies, including the reasons for past successes and failures, and see a scrappage scheme as necessary to meet those goals. They note that periods of peak production of new electric cars in developed economies were also the periods with the highest average age of used vehicles in history, and that the scrappage scheme has always been designed to promote economic performance rather than to achieve environmental policy goals. Conversely, Zaman and Zaccour (2020) refer to governments' widespread application of scrappage schemes to replace old cars with newer and therefore more fuel-efficient electric cars. In practice, however, these expectations were not met, and the new cars were not more fuel-efficient.

In the context of cost–benefit analysis and the net benefits of subsidy programs, it is also necessary to take into account consumers who would replace their cars even without a subsidy,

https://doi.org/10.7441/joc.2026.03.08

and thus differences in consumers' willingness to do so (Sheldon & Dua, 2019; Zhou et al., 2020; Vining et al., 2026). Considering this heterogeneity of consumers' valuation of car replacement, Zaman and Zaccour (2020) examine a dynamic problem based on the life cycle optimization (LCO) approach. They demonstrate that increasing the level of subsidies motivates low-income consumers to replace their old cars earlier, but may also prompt consumers with a high net valuation of replacement to defer it. Some households thus speculate on the increased likelihood of profit from subsidies for scrapping old cars. According to their simulation, ignoring consumer heterogeneity could lead to an overestimation of the net benefits of the scrappage scheme.

To evaluate subsidies for the purchase of new electric cars and the scrapping of used vehicles with conventional combustion engines, Ankney and Leard (2024) developed a model for the purchase and disposal of obsolete vehicles. They found that linking purchase subsidies to a scrappage requirement should lead to higher sales of new electric cars, thereby reducing CO2 emissions compared with an unlinked policy. This finding arises both from the eligibility requirements for vehicle replacement and from the opportunity costs involved. They further demonstrated that the emission reduction from additional scrapping depends on the replacement of the remaining planned mileage of the scrapped vehicles.

Marin and Zoboli (2020) concluded that scrappage schemes are typically introduced to modernize the fleet and reduce the environmental burden of private transport. They also presented the combined use of two counterfactual techniques (RDD and DiD) to quantify the impact of the Italian scrappage schemes of 2007–2009 on the scrapping of old cars, with the discontinuity in the age of eligible cars allowing an empirical assessment of the policy's effectiveness. They also extended the DiD model by adding a variable representing "product innovation" in the car market as a factor determining the timing of the scrappage scheme. No impact was recorded for the programs implemented in 2007 and 2008, whereas the 2009 program, which offered relatively high incentives, had a significant impact on the replacement of old cars.

Kang (2023) analyzes the financial effectiveness of the system supporting the early retirement of obsolete diesel vehicles. The cost–benefit analysis shows that the benefit–cost ratio was greater than one before 2020 but the opposite thereafter, which suggests that the rate of improvement in air quality is slower than the increase in the system's operating costs. Kang (2023) found that shifting the scrappage-scheme period by five years would ensure financial efficiency for 98% of samples in the cost–benefit analysis. Governments should therefore reform the system to motivate owners of old diesel vehicles to scrap them.

Svoboda et al. (2023) examined the effectiveness of scrappage schemes introduced in the European Union during the 2009 economic crisis, focusing on their impact using monthly data on new car registrations in European countries. The results showed that the impact varied across countries, with statistically significant effects in Germany and Slovakia, followed by Greece and Italy. The effectiveness of the subsidies also depended on the duration of the program, the overall political environment, and the novelty of the implementation strategies.

Gorji et al. (2021) claim that the presence of end-of-life vehicles (ELVs) in cities causes irreparable environmental damage and conclude that a subsidy policy is an effective way to address them. Their study considers three stages: the take-back center for end-of-life vehicles, the inspection center, and the repair center. The decision variables are the purchase and sales prices of repaired vehicles, and the level of vehicle repairs. In such a supply chain model, the government pays a subsidy to take-back centers that supply it with used vehicles. The scenarios

https://doi.org/10.7441/joc.2026.03.08

examined include profit distribution, income distribution, and a mixed model. The results show that the mixed model performs best: it maximizes the number of ELVs, demand for repaired vehicles, consumer surplus, and the profit of the entire supply chain. The subsidies have the greatest impact on the profit of the take-back center and the supply of components, but do not affect the profit of the repair center.

3 OBJECTIVE, METHODOLOGY, AND DATA

3.1 Formulation of hypotheses and research questions

The studyverifies the validity of Mankiw's conclusions in the context of current subsidy policy.

Primary hypothesis:

The subsidies for scrapping old cars increase the pace of electromobility introduction.

This hypothesis will be verified through statistical testing of two secondary hypotheses.

H1: *The time series of newly registered cars in European countries follows a mixed autoregressive stochastic ARMA(1,1) process.*

H2: *The time series of long-term consumption expenditure in European countries follows a mixed autoregressive stochastic ARMA(1,1) process.*

Rejecting the first secondary hypothesis H1 would mean that Mankiw's theory of long-term consumption, on which the puzzle is based, is rejected for a given time series. In that case, subsidies for scrapping old cars would increase registrations of new cars, and the automotive industry would depend on a scrappage scheme for its survival. Rejecting the second secondary hypothesis H2 would likewise mean that Mankiw's theory is rejected for a given time series, so that subsidies for scrapping all durable goods would increase the necessary expenditure on them. Such subsidies would be essential not only for replacing new cars, but also for obsolete, environmentally unfriendly equipment used in residential heating, water distribution, energy, and sanitation, that is, for long-term household consumption as a whole.

The following research questions were asked:

Q1: *Are the effects of subsidies for scrapping old equipment different between richer and less developed European economies?*

Q2: *Through consumer perception of cars as completely new products, do continuous innovations ensure stable demand and sustained increments of newly registered cars?*

Q3: *Are subsidies for the scrappage scheme an essential environmental tool contributing to reducing harmful CO2 emissions in Europe?*

3.2 Econometric analysis of time series

To model stochastic processes, methods based on combined autoregressive and moving average processes were used (ARMA). The second approach is the vector autoregression (VAR) method. The time series had to be adjusted for seasonal effects and were non-stationary, but integrated to the first order. The primary time series of long-term consumption expenditure (in monetary terms) and the number of newly registered vehicles (in natural terms) were converted into logarithmic differences of the original time series. In economic time series, it is essential not to violate the basic BLUE (best linear unbiased estimator) assumptions and to avoid so-

https://doi.org/10.7441/joc.2026.03.08

called "false" regression. In the Box–Jenkins method (BJM), the focus is not on creating a single equation or a set of simultaneous equations, but on analyzing the probabilistic or stochastic properties of economic time series. The following methodological description, based on Pindyck and Rubinfeld (1998), focuses on modeling the economic, or rather financial, quantity Y_t. BJM-based models define Y_t as a function of its own past or delayed values and stochastic white noise, or as a function of present and past white noise values; the financial quantity Y_t is modeled as shown in equation (1).

$$(Y_t - \delta) = \alpha_1 \cdot (Y_{t-1} - \delta) + u_t \quad (1)$$

Here the variable δ represents the mean value of Y, while u_t is an uncorrelated innovation term of the i.i.d. type, with zero mean and constant variance. The model is a first-order autoregressive stochastic process, AR(1), in which Y at time t depends on its previous value and on the random term. The predicted value of Y at time t thus depends partly on its value at time t_{-1} (through the parameter α_1) and partly on a random shock at time t. The order of the autoregressive stochastic process can be analogously extended to a longer delay, AR(p). Conversely, the moving averages process MA(1) or MA(p) is defined in equation (2), where μ represents a constant quantity. In the MA approach, we work with the current and delayed values of stochastic white noise u_t, so that Y follows a first-order stochastic moving average process, or MA(1). This approach can again be extended to p lags to obtain MA(p). Combining the autoregressive approach with the moving averages process yields the ARMA(p,q) process, or for non-stationary but integrable economic time series ARIMA(p,d,q), where d is the order of integration (see equation (3)).

$$Y_t = \mu + \beta_0 \cdot u_t + \beta_0 \cdot u_{t-1} \quad (9)$$

$$Y_t = \theta + \alpha_1 Y_{t-1} + .. + \alpha_p Y_{t-p} + \beta_0 u_t + \cdots + \beta_0 u_{t-q} \quad (10)$$

The basic approach of BJM is to identify and estimate a statistical model that fits the real-world data of an economic time series sample. For reliable estimates of future values, the estimated model must exhibit stable properties over time. The key factors are stationarity, normality, homoscedasticity, and small—ideally zero—autocorrelation of the model's residuals.

BJM enables the dynamics of economic variables to be modeled using mixed autoregressive stochastic processes, in which both expected and unexpected information shocks play a significant role. For most economic variables, the best estimate of their future value is their present value. If constant variance is observed in the time series, the quantity is modeled as white noise; if variable variance is observed, it is modeled as a martingale; and if the variance drifts, a random walk is the most suitable method. In all three cases, the economic variable is highly volatile over time.

The evaluation of the analyzed time series was performed according to three criteria: white noise under the ARMA(0, 0) model; Mankiw's theory; and Mankiw's puzzle under the ARMA(p, q) model. The aim was to select the most suitable ARMA prediction. If the solution is ARMA(0,0), then Mankiw's theory/puzzle is rejected for the examined time series, and Hall's consumption theory is also rejected because the series is a martingale; the same applies if the confirmed model has a zero autoregressive coefficient. If a meaningful ARMA(p, q) model is obtained, it is then determined whether the autoregressive coefficient is less than one in absolute value and whether the moving average coefficient equals one. In this case, Mankiw's theory is confirmed and the puzzle rejected. A constant of one is therefore confirmed in the time series,

https://doi.org/10.7441/joc.2026.03.08

with oscillations around one related to the rate of depreciation, whose value in modern structural models is usually taken to be 0.025.

The procedure used to structure the observed states:

- The main criterion is the statistical confirmation of the AR and MA coefficients through their p-values in the ARMA(1,1) testing. If the statistically confirmed coefficients correspond to Mankiw's theory—an AR coefficient in the interval (0, 1) and a corresponding MA coefficient of -1—the scrappage scheme is confirmed most strongly.
- If Mankiw's theory is rejected—with the MA term insignificant but the AR term accepted—then Hall's theory of consumption applies, and Mankiw's puzzle is realized. The "automatic ARIMA estimation" procedure then offers various stochastic ARMA(p,q) processes as models of the analyzed time series, and the scrappage scheme is confirmed less strongly.

If both the AR and MA coefficients are statistically insignificant, the stochastic behavior of white noise (or a martingale, in the case of proven autocorrelated residuals) is confirmed, so that the partial statistical hypothesis of a zero coefficient cannot be rejected at the appropriate p-value. The "automatic ARIMA estimation" procedure then suggests ARMA(0,0) as the most suitable stochastic process for the analyzed time series. The series behaves completely randomly, and the effects of the scrappage scheme are minimal.

3.3 Database

The effect of scrappage subsidies is inferred indirectly from the stochastic properties of new car registrations and durable goods consumption. The approach is anchored in a demand-side analysis of household expenditure on durables, assuming that these total durable expenditures can be aggregated. The analysis does not exclude supply-side effects, aligning with both the (neo-)Keynesian tradition and Austrian economics.

A statistical analysis was performed on the current time series of all available European countries, with household expenditure on acquiring new cars included in long-term consumption. Time series on long-term consumption were therefore obtained from the Eurostat national accounts database (29 time series in total), and data on newly registered cars from the European Automobile Manufacturers Association database (31 time series in total), where national professional associations record them reliably. The sample of countries used for the analysis of total durable consumption therefore differs slightly from that used for the car registration analysis. For all time series, monthly data were converted to quarterly data. A total of 83 observations were obtained, from the data sample covering the first quarter of 2004 to the third quarter of 2024. These transformed quarterly data were included in the analysis in current prices. Seasonality, trend, and cyclical components were eliminated from the time series, and calendar adjustment was performed using the Census X-13ARIMA-SEATS procedure. The trend component was removed using the Hodrick-Prescott filter with multiplicative decomposition and automatic outlier detection, and calendar effects were adjusted for standard trading days. Given the country sample, the input data were not adjusted for public holidays, owing to their high heterogeneity across E.U. member states and other European countries.

https://doi.org/10.7441/joc.2026.03.08

3.4 Database for Mankiw's puzzle of long-term consumption in selected European countries

For basic comparison, descriptive statistics of the monitored time series (median, mean, variability, skewness, and kurtosis) were first determined and supplemented by statistical tests of stationarity and normality. Normality was verified with the Jarque–Bera (JB) test and stationarity with the augmented Dickey–Fuller (ADF) test. Based on the ADF p-values, the presence of a unit root (non-stationarity) cannot be rejected for the vast majority of the time series, whereas the JB test results indicate that normality cannot be rejected at the 5% significance level. The time series of newly registered cars in Ireland exhibited characteristics of an extreme outlier, with year-on-year relative changes in the tens of percent in both directions, and was therefore excluded from the input dataset.

The tables 1 and 2 evaluate the basic properties of the analyzed time series (descriptive statistics): the median, mean, variability, skewness, kurtosis, and the results of the JB and ADF tests. With a few exceptions, the non-stationarity of the analyzed time series cannot be rejected on the basis of the ADF p-values, and, according to the JB test, normality cannot be rejected at the 5% level of statistical reliability. The time series of newly registered cars in Ireland was again an outlier: its year-on-year relative changes (in %) were an order of magnitude greater than those of the other series, in the tens of percent, including both positive and negative values between the surveyed periods.

The presented time series are expected to follow the autoregressive stochastic ARMA(1,1) process with appropriate coefficients: the autoregressive coefficient significantly less than one, and the moving average (MA) coefficient of the white noise equal to -1. In this case, the depreciation rate of durable goods equals zero, and Mankiw's puzzle (or Hall's theory) holds. If the MA coefficient is statistically confirmed to lie within the range (-1, -0.9), Mankiw's theory is also confirmed.

Tab. 1 – Properties of time series studied in relation to newly registered cars. Source: custom processing of outputs from Eviews

New Reg Cars (Physical)	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB test	Probability	ADF test	p-value
AUSTRIA	80957,94	81281	102387	54680	11127,05	-0,085	2,681	0,255	0,88	-4,005	0,003
BELGIUM	129188,7	128761	169904	89189	24272,79	0,06	1,614	3,788	0,15	-1,272	0,638
BULGARIA	6502,574	5920	10935	3157	1926,732	0,575	2,452	3,18	0,204	-3,008	0,04
CROATIA	21882,15	13181	50699	5838	15956,81	0,586	1,618	6,427	0,04	-2,063	0,26
CZECHIA	50744,85	50194	76392	25014	13210,07	0,087	2,181	1,374	0,503	-1,681	0,437
DENMARK	35418,77	47752	66172	2096	23777,15	-0,509	1,496	6,462	0,04	-1,869	0,345
EFTA	91660,38	85600	135903	67258	18676,96	0,565	2,196	3,767	0,152	-2,111	0,241
ESTONIA	12916,15	6509	47781	3610	10999,85	1,25	3,605	12,957	0,002	-1,451	0,552
EU	1867165	820016	3920446	456327	1326028	0,188	1,196	6,652	0,036	-1,922	0,321
FINLAND	202574,6	30499	658376	19124	250349,8	0,781	1,745	7,865	0,02	-1,833	0,362
FRANCE	599223,9	549869	1191315	351119	179646,1	0,945	3,777	8,181	0,017	-2,104	0,244
GERMANY	544476	755102	968908	12944	379788,8	-0,558	1,454	7,12	0,028	-1,955	0,306
GREECE	18131,89	16375	39268	9270	6884,976	1,139	3,955	11,952	0,003	-2,245	0,193
HUNGARY	23692,89	23014	47958	2355	11912,38	0,116	2,22	1,298	0,523	-1,866	0,346
ICELAND	1766801	2800972	4273555	241	1772879	0,047	1,123	6,919	0,031	-1,454	0,551
IRELAND	173926	41877	668020	2476	213464,4	0,896	2,162	7,664	0,022	-2,093	0,248
ITALY	273593,9	355818	583164	1029	211480,5	-0,269	1,545	4,709	0,095	-1,47	0,543
LATVIA	3325,702	3322	5024	1375	902,09	-0,225	2,477	0,931	0,628	-4,067	0,002

https://doi.org/10.7441/joc.2026.03.08

LITHUANIA	8386,766	8338	16254	2739	3967,747	0,181	1,782	3,164	0,206	-2,921	0,048
LUXEMBOURG	49276,28	14094	180407	8843	55122,66	1,039	2,527	8,895	0,012	-2,016	0,28
NETHERLANDS	93818,55	91926	147942	54918	19287,73	0,329	3,193	0,923	0,63	-1,445	0,555
NORWAY	17639,3	9051	39724	1056	14850,55	0,133	1,177	6,644	0,036	-1,696	0,429
POLAND	82683,49	79757	144413	20879	38060,12	-0,008	1,763	2,999	0,223	-2,066	0,259
PORTUGAL	38676,17	37605	71332	13830	15396,87	0,367	2,224	2,233	0,327	-1,163	0,686
ROMANIA	22604,26	20039	52429	11233	9127,976	1,269	4,403	16,463	0	-2,68	0,084
SLOVAKIA	18835,4	18920	28178	10241	4575,215	0,171	2,084	1,872	0,392	-1,97	0,299
SLOVENIA	82718,32	16304	317995	10375	100000,3	0,919	2,204	7,864	0,02	-1,628	0,463
SPAIN	196963,2	214635	394355	43937	107464,5	-0,026	1,627	3,696	0,158	-2,094	0,248
SWEDEN	225413,6	94002	611548	56074	204063,9	0,767	1,748	7,678	0,022	-2,136	0,232
SWITZERLAND	54776,13	42946	97584	33696	19686,79	0,461	1,69	5,025	0,081	-2,133	0,233
UNITED KINGDOM	1294649	135811	4018682	105068	1551279	0,698	1,589	7,719	0,021	-1,713	0,42

Tab. 2 – Properties of time series studied in relation expenditures for durables. Source: custom processing of outputs from Eviews

Expenditures for Durables	**Mean**	**Median**	**Maximum**	**Minimum**	**Std. Dev.**	**Skewness**	**Kurtosis**	**JB test**	**Probability**	**ADF test**	**p-value**
AUSTRIA	4867,172	4794	5411,7	4298,2	284,818	0,228	2,081	2,063	0,356	-1,07	0,724
BELGIUM	3902,915	3822,2	4806,6	3424,2	272,319	0,762	3,885	6,077	0,048	-1,307	0,623
BULGARIA	604,985	607,6	825,4	476,8	71,657	0,858	4,506	10,212	0,006	-0,94	0,771
CROATIA	475,092	450,8	775,7	414,1	64,975	2,649	11,328	190,759	0	2,078	1
DENMARK	3083,185	2880,6	4522,2	2513,7	506,718	0,809	2,735	5,258	0,072	-1,182	0,679
ESTONIA	183,526	178,4	260,4	103,9	46,838	0,04	1,791	2,875	0,238	-0,336	0,914
FINLAND	2289,277	2302	2740	1877	164,989	-0,196	3,845	1,696	0,428	-2,933	0,046
FRANCE	24120,49	24122,2	28778,8	19590,5	1473,118	0,062	4,947	7,454	0,024	-3,73	0,005
GERMANY	36897	35144	49239	30056	4223,343	0,715	2,862	4,045	0,132	2,879	1
GREECE	1493,436	1411,4	2615,4	1084,6	399,91	1,304	4,054	15,496	0	-1,501	0,528
HUNGARY	937,515	833,5	1364	745,6	189,574	0,989	2,596	7,977	0,019	-0,295	0,92
ICELAND	131,14	117,9	240,7	48,1	62,965	0,222	1,599	4,229	0,121	-1,999	0,287
IRELAND	1305,228	1200,8	1734,5	960,4	263,192	0,076	1,479	4,578	0,101	-0,829	0,805
ITALY	19209,73	19342,6	22487,7	15221,3	1900,5	-0,139	2,002	2,101	0,35	-1,377	0,589
LATVIA	210,985	223,6	305,2	115,3	61,087	-0,16	1,629	3,88	0,144	-0,411	0,902
LITHUANIA	459,717	423,4	776,4	265,5	134,404	0,444	2,212	2,761	0,251	0,444	0,984
LUXEMBOURG	370,081	349,9	443,2	321,8	38,667	0,705	1,942	6,081	0,048	0,594	0,989
NETHERLANDS	7831,223	7624,4	10510,1	6762,6	768,647	1,272	4,628	17,856	0	0,755	0,993
NORWAY	4296,787	4324,7	4793,2	2968,3	363,197	-1,58	6,535	44,015	0	-2,797	0,063
POLAND	5236,111	5020,3	6952,6	3378,3	1101,197	0,09	1,817	2,804	0,246	-0,83	0,805
PORTUGAL	2537,979	2609,4	3216,2	1723,9	459,827	-0,256	1,884	2,951	0,229	-0,98	0,757
ROMANIA	2076,74	1812,8	3287,7	1179,5	581,051	0,692	2,233	4,905	0,086	2,139	1
SLOVAKIA	886,702	819,8	1149,7	738,4	121,395	0,751	2,178	5,748	0,056	0,454	0,984
SLOVENIA	494,413	490	681,6	374,6	74,969	0,277	2,438	1,218	0,544	0,679	0,991
SPAIN	10815,79	10827	13362	7299	1646,302	-0,062	1,952	2,182	0,336	-1,454	0,552
SWEDEN	4305,391	4255,9	5434,9	2748,8	626,363	-0,624	2,914	3,064	0,216	-1,197	0,672
UNITED KINGDOM	31445,26	32229,6	39937,4	22346,4	4902,356	-0,108	1,728	3,261	0,196	-1,96	0,304
CZECHIA	1716,015	1582,5	2250	1398,8	294,223	0,665	1,847	6,068	0,048	0,972	0,76
SERBIA	390,479	369,2	522,9	327,2	48,034	1,107	3,08	9,612	0,008	-0,058	0,95

The time series for some countries fully meet the requirements for the stochastic properties of a given category, while others were borderline. In borderline cases, the authors carefully

https://doi.org/10.7441/joc.2026.03.08

considered which group to assign a country to, usually classifying such series in a compromise group in which the puzzle is confirmed and Mankiw's theory rejected, but Hall's theory cannot be rejected either. Nevertheless, given the confirmed smoothing property in consumption, the impact of the scrappage scheme on the dynamics of replacing obsolete durable equipment was supported.

The research uses country-specific time-series analyses. Although preliminary testing evaluated the dataset within panel data frameworks, panel cointegration was rejected. This finding does not contradict the results of the individual country-level analyses; rather, it justifies the separate estimation approach, through which Mankiw's theory is confirmed for a specific subset of countries.

4 EMPIRICAL RESULTS

Tab. 3 – Verification of Mankiw's puzzle for European countries, ARMA (1, 1) analysis of long-term consumption. White noise was recorded according to ARMA(0,0) for countries marked with *. Mankiw's theory (or the scrappage scheme according to Mankiw's theory) was recorded for countries marked with **. For the remaining countries, Mankiw's puzzle was recorded according to functional ARMA (p, q). Source: custom processing in Eviews (p-values in brackets)

	CONSTANT	PARAMETER AR	PARAMETER MA/ DEPRECIATION RATE	AUTOCORRELATION OF RESIDUALS	ARMA* AIC
BULGARIA*	1,1 (0,00)	0,60 (0,46)	-0,504(0,55) / 0,496	NO (DW 2,05)	ARMA*(0,0) AIC= -3,59
DENMARK*	1,0 (0,00)	-0,094 (0,97)	0,035 (0,98)/ 1,035	NO (DW 1,98)	ARMA*(0,0) AIC = -4,94
IRELAND*	1,02 (0,00)	-0,02 (1,00)	0,02 (1,00)/ 1,002	NO (DW 1,99)	ARMA*(0,0) AIC = -3,84
SERBIA*	1,0 (0,00)	-0,30 (0,82)	-0,199 (0,881)/ 0,801	YES (DW 1,90)	ARMA*(0,0) AIC = -4,38
CZECHIA**	0,5 (0,00)	0,86 (0,00)	-1,000 (0,99)/ 0,000	NO (DW 2,029)	ARMA*(2,1) AIC= -4,76
ESTONIA**	1,0 (0,00)	0,77 (0,00)	-0,57 (0,007)/ 0,43	YES (DW 2,16)	ARMA*(4,1) AIC = -4,55
GREECE**	0,99 (0,00)	0,87 (0,03)	-0,78 (0,007)/ 0,22	YES (DW 1,85)	ARMA*(1,0) AIC = -4,15
HUNGARY**	1,0 (0,00)	0,84 (0,001)	-0,712 (0,006)/ 0,288	NO (DW 1,98)	ARMA*(1,0) AIC = -4,61
LATVIA**	1,0 (0,00)	0,76 (0,02)	-0,61 (0,151)/ 0,39	NO (DW 2,02)	ARMA*(0,0) AIC = -3,49
NORWAY**	1,0 (0,00)	0,77 (0,00)	-1,00 (0,99)/ 0,00	NO (DW 2,02)	ARMA*(3,3) AIC = -3,98
POLAND**	1,0 (0,00)	0,83 (0,00)	-1,00 (0,99)/ 0,00 /0,000	YES (DW 1,78)	ARMA*(0,4) AIC = -3,91
AUSTRIA	1,0 (0,00)	0,03 (0,93)	-0,416 (0,17) / 0,584	NO (DW 2,000)	ARMA*(3,0) AIC= -6,74
BELGIUM	1,0 (0,00)	0,12 (0,63)	-0,6 (0,0073) / 0,4	NO (DW 2,001)	ARMA*(0,1) AIC= -4,97
CYPRUS	1,0 (0,00)	-0,37 (0,89)	0,336 (0,90) / 1,336	YES (DW 1,96)	ARMA*(2,2) AIC = -4,21
FINLAND	1,0 (0,00)	0,036 (0,94)	-0,46 (0,217)/ 0,54	NO (DW 1,999)	ARMA*(2,3) AIC = -4,75
FRANCE	1,0 (0,00)	0,20 (0,45)	-0,76 (0,0012)/ 0,24	NO (DW 1,97)	ARMA*(0,2) AIC = -4,65
GERMANY	1,0 (0,00)	0,20 (0,1215)	-0,731 (0,00)/ 0,269	NO (DW 1,958)	ARMA(0,2) AIC= -5,35
ICELAND	1,0 (0,00)	0,59 (0,84)	-0,52 (0,87)/ 0,48	YES (DW 2,13)	ARMA*(0,2) AIC = -1,59
ITALY	1,0 (0,00)	0,34 (0,55)	-0,60 (0,27)/ 0,40	YES (DW 1,91)	ARMA*(2,0) AIC = -4,53

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LITHUANIA	1,0 (0,00)	-0,57 (0,02)	0,34 (0,18)/ 1,34	NO (DW 1,97) ARMA*(2,4) AIC = -4,55
LUXEMBOURG	1,0 (0,00)	-0,17 (0,69)	-0,31(0,47)/ 0,69	NO (DW 2,02) ARMA*(0,1) AIC = -5,48
MALTA	1,0 (0,00)	-0,65 (0,03)	0,43 (0,22)/ 1,43	NO (DW 1,98) ARMA*(1,0) AIC = -4,68
NETHERLANDS	1,0 (0,00)	0,19 (0,28)	-0,56 (0,003)/ 0,44	YES (DW 1,93) ARMA*(2,0) AIC = -5,28
PORTUGAL	1,0 (0,00)	-0,11 (0,88)	-0,09 (0,88)/ 0,91	NO (DW 2,01) ARMA*(0,3) AIC = -3,99
ROMANIA	1,0 (0,00)	-0,26 (0,85)	0,35 (0,81)/ 1,35	NO (DW 1,99) ARMA*(0,0) AIC = -4,17
SLOVAKIA	1,0 (0,00)	0,11 (0,71)	-0,342 (0,283)/ 0,658	YES (DW 1,96) ARMA*(1,4) AIC = -4,66
SLOVENIA	1,0 (0,00)	-0,29 (0,17)	-0,009 (0,972)/ 0,991	NO (DW 2,01) ARMA*(3,0) AIC = -4,36
SPAIN	1,0 (0,00)	0,17 (0,79)	-0,407 (0,52)/ 0,593	NO (DW 1,98) ARMA*(2,0) AIC = -3,92
SWEDEN	1,0 (0,00)	0,48 (0,60)	-0,387 (0,695)/ 0,613	YES (DW 2,07) ARMA*(3,1) AIC = -4,86
UNITED KINGDOM	0,99 (0,00)	-0,001 (0,99)	-0,21 (0,85)/ 0,79	YES (DW 1,78) ARMA*(2,1) AIC = -4,011

Tab. 4 – Verification of Mankiw's puzzle in other European countries, ARMA (1, 1) analysis of newly registered cars. White noise was recorded according to ARMA(0,0) for countries marked with *. Mankiw's theory (or the scrappage scheme according to Mankiw's theory) was recorded for countries marked with **. For the remaining countries, Mankiw's puzzle was recorded according to functional ARMA (p, q). Source: custom processing in Eviews (p-values in brackets)

	CONSTANT	**PARAMETER AR**	**PARAMETER DEPRECIATION RATE**	**MA/ AUTOCORRELATION OF RESIDUALS**	**ARMA* AIC**
BULGARIA*	0,99 (0,00)	-0,82 (0,246)	0,874 (0,181)/ 1,874	NO (DW 2,03)	ARMA*(0,0) AIC= -2,77
CROATIA*	0,99 (0,00)	-0,10 (0,953)	-0,135 (0,936)/ 0,865	NO (DW 2,03)	ARMA*(0,0) AIC= +0,34
DENMARK*	1,00 (0,00)	0,642 (0,839)	-0,582 (0,862)/ 0,416	NO (DW 2,08)	ARMA*(0,0) AIC= +2,55
FINLAND*	0,99 (0,00)	-0,57 (0,77)	0,49 (0,81)/ 0,51	NO (DW 1,99)	ARMA*(0,0)) AIC=2,40
GERMANY*	0,99 (0,00)	-0,31 (0,99)	0,285 (0,98)/ 0,715	NO (DW 1,99)	ARMA*(0,0) AIC= 1,74
GREECE*	0,99 (0,00)	-0,64 (0,40)	0,515 (0,53)/ 1,515	YES (DW 1,99)	ARMA*(0,0) AIC= -1,87
HUNGARY*	0,98 (0,00)	0,47 (0,77)	-0,512 (0,75)/ 0,488	YES (DW 1,96)	ARMA*(0,0) AIC= 1,74
IRELAND*	Outlier				
ITALY*	1,01 (0,00)	-0,59 (0,92)	0,54 (0,93)/ 1,54	NO (DW 1,96)	ARMA*(0,0) AIC= 0,21
LITHUANIA*	1,01 (0,00)	0,14 (0,89)	-0,34 (0,74)/ 0,66	YES (DW 1,96)	ARMA*(0,0) AIC= -0,93
LUXEMBOURG*	0,99 (0,00)	-0,67 (0,65)	0,55 (0,74)/ 0,45	YES (DW 1,91)	ARMA*(0,0) AIC= -0,99
NORWAY*	1,00 (0,00)	-0,175 (0,73)	-0,067 (0,89)/ 0,933	NO (DW 2,00)	ARMA*(0,0) AIC= 1,92
POLAND*	0,99 (0,00)	-0,067 (0,95)	-0,101 (0,93)/ 0,899	NO (DW 1,99)	ARMA*(0,0) AIC= -1,74
ROMANIA*	0,99 (0,00)	-0,31 (0,99)	0,285 (0,98)/ 1,285	NO (DW 1,99)	ARMA*(0,0) AIC= -1,12
SLOVENIA*	0,99 (0,00)	-0,54 (0,74)	0,43 (0,81)/ 1,43	YES (DW 1,93)	ARMA*(0,0) AIC= 2,24
SPAIN*	0,99 (0,00)	-0,316 (0,90)	0,233 (0,93)/ 1,233	NO (DW 1,98)	ARMA*(0,0) AIC= -0,86
SWEDEN*	0,99 (0,00)	-0,41 (0,86)	0,33 (0,89)/ 1,33	NO (DW 1,98)	ARMA*(0,0) AIC= -0,78

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UNITED KINGDOM*	0,99 (0,00)	-0,28 (0,91)	0,163 (0,96)/ 0,937	NO (DW 1,99) ARMA*(0,0) AIC= 2,25
AUSTRIA**	0,99 (0,00)	0,61 (0,046)	-0,797 (0,03)/ 0,203	YES (DW 1,71) ARMA*(4,4) AIC= -4,12
CZECHIA**	1,00 (0,00)	-0,99 (0,00)	0,905 (0,00)/ 0,095	NO (DW 1,99) ARMA*(1,1) AIC= -3,01
EFTA**	0,99 (0,00)	0,798 (0,00)	-1 (0,99)/ 0,0000	NO (DW 2,02) ARMA*(4,2) AIC=-3,16
EU**	0,99 (0,00)	0,924 (0,00)	-1,0 (0,999)/ 0,00	NO (DW 2,02) ARMA*(0,0)) AIC= -1,52
FRANCE**	0,99 (0,00)	0,83 (0,00)	-1,0 (0,991)/ 0,00	YES (DW 1,80) ARMA*(0,2) AIC= -2,76
LATVIA**	0,99 (0,00)	0,71 (0,002)	-0,482 (0,06)/ 0,518	YES (DW 2,09) ARMA*(4,3) AIC= -2,84
NETHERLANDS**	0,99 (0,00)	0,27 (0,21)	-0,705 (0,001)/ 0,295	YES (DW 1,95) ARMA*(1,2) AIC= -2,49
SWITZERLAND**	0,99 (0,00)	0,85 (0,00)	-1,00 (0,99)/ 0,00	YES (DW 2,08) ARMA*(0,0) AIC= -2,25
BELGIUM	0,99 (0,00)	0,26 (0,376)	-0,741 (0,003)/ 0,259	YES (DW 1,93) ARMA*(4,2) AIC= -3,48
ESTONIA	0,99 (0,00)	-0,175 (0,87)	-0,123 (0,912)/ 0,877	NO (DW 1,99) ARMA*(2,2) AIC= -1,14
ICELAND	1,03 (0,00)	-0,49 (0,89)	0,42 (0,91)/ 1,42	YES (DW 1,94) ARMA*(0,0) AIC= 1,42
PORTUGAL	0,99 (0,00)	-0,031 (0,87)	-0,442 (0,07)/ 0,558	NO (DW 2,02) ARMA*(2,0) AIC= -1,83
SLOVAKIA	1,00 (0,00)	0,27 (0,52)	-0,58 (0,125)/ 0,42	YES (DW 1,92) ARMA*(2,2) AIC= -3,30

Mankiw's puzzle was verified for all the time series that were considered, and the countries studied were divided into three subsets according to the stochastic properties of the time series. Table 3 shows these properties for percentage changes in long-term consumption, table 4 the division of the countries according to the properties of percentage changes in new car registrations, and table 5 a comparison of the resulting set as final results. These tables serve as a basis for the summary conclusions on the secondary hypotheses and research questions.

Tab. 5 – Final results. Source: authors' own work.

	Long-term consumption	**Newly registered cars**
White Noise, or Martingale according to ARIMA(0,0)	Bulgaria, Denmark, Ireland, Serbia	Bulgaria, Croatia, Denmark, Finland, Germany, Greece, Hungary, Iceland, Italy, Norway, Poland, Lithuania, Romania, Poland, Luxembourg, Spain, Sweden, United Kingdom, Slovenia
Functional ARMA(p,q)	Austria, Belgium, Cyprus, Finland, France, Germany, Iceland, Luxembourg, Netherlands, Portugal, Slovakia, Spain, Sweden, Lithuania, Malta, United Kingdom	Estonia, Portugal, Belgium, Slovakia
Scrapping premium, coefficient of the autoregressive term less than 1	Estonia, Greece, Hungary, Latvia	Latvia, Netherlands, Austria
➢ **Coefficient MA = -1, i.e. zero depreciation parameter**	Czech Republic, Poland, Norway	EFTA, European Union, France, Switzerland
➢ **Fully confirmed Mankiw's theory**		Czech Republic

If Mankiw's theory is rejected along with Hall's theory, or if the martingale model is confirmed, or if the influence of past long-term consumption values on expected dynamics cannot be confirmed, then any intensified development of the automotive industry alongside other durable goods producers is not possible without subsidies such as a scrappage scheme. This conclusion

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is independent of the reasons for stimulating the automotive industry, whether economic, strategic, or climate-related. In such a case, the development of the industry would be driven primarily by product innovations, an expected increase in population wealth, and individual consumer expectations. The analysis also points to the cyclical nature of the branch: Hall's principle of consumption describes the high dependence of future sales dynamics on current eventual declines, and in this scenario, Mankiw's theory may add further volatility and risk to those dynamics.

4.1 Synthesis of Empirical Results: Hypothesis Evaluation and Policy Typology

Based on the econometric analysis of the time series, this section evaluates the primary hypothesis and the corresponding secondary hypotheses. It also establishes a clear country typology, integrating consumption dynamics with scrapping policy, electromobility adoption, and long-term macroeconomic competitiveness.

Formal Evaluation of Hypotheses

- **Primary Hypothesis**: *The subsidies for scrapping old cars increase the pace of electromobility introduction*.
  - Status: Confirmed
  - Evaluation: Empirical evidence validates the primary hypothesis, although its functional mechanisms and efficacy are strongly conditioned by structure. Scrapping subsidies act as a crucial demand-side stimulus that compresses structural lags and shifts consumer purchasing toward electric vehicles. However, the ultimate efficacy of this policy depends on the structural characteristics of the specific country group.
- **Secondary Hypothesis H1:** *The time series of newly registered cars in European countries follows a mixed autoregressive stochastic ARMA(1,1) process*.
  - Status: Rejected (with regional exceptions)
  - Evaluation: The strict specification of the ARMA(1,1) model with theoretically restricted coefficients (where the MA term approaches -1) was rejected for the majority of the sample. In most European countries, increments in car registrations exhibit the properties of a martingale (differences characterized as white noise), supporting Hall's random walk hypothesis. However, this secondary hypothesis cannot be rejected for a specific group of countries (the Czech Republic, France, Switzerland, Latvia, and the Netherlands), where statistically significant autoregressive parameters indicate path dependence and structural inertia in consumer behavior (see table 4). Consequently, the theoretically proposed zero depreciation rate for newly acquired vehicles cannot be confirmed across the entire sample.
- **Secondary Hypothesis H2:** *The time series of long-term consumption expenditure in European countries follows a mixed autoregressive stochastic ARMA(1,1) process*.
  - Status: Rejected (at the aggregate sample level)
  - Evaluation: Although the broad aggregate model was rejected, the micro-foundations of aggregate durable consumption exhibit substantially higher persistence and backward-looking inertia than data from the automotive market alone. Behavior consistent with the ARMA(1,1) model (Mankiw's puzzle) was robustly confirmed in Estonia, Greece,

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Hungary, and Latvia, indicating that broader durable asset renewal is driven by cyclical constraints and structural delays in consumption (see table 3).

Based on the interaction between consumption persistence (Mankiw's puzzle) and market response, the analyzed European countries can be classified into three structural groups.

Country Typology: Scrappage Policy, Electromobility, and Competitiveness:

- **Group 1:** High-inertia automotive economies (the Czech Republic, France, Switzerland, Latvia, Netherlands) (see table 5).
  - Characteristics: These countries exhibit significant path dependence in new car registrations (statistically significant AR terms), and consumers react to macroeconomic shifts with substantial structural lags. The presence of Mankiw's puzzle in this sub-sample prevents the adoption of Hall's standard permanent income theory.
  - Link to scrappage policy and electromobility: In these markets, market forces alone are insufficient to trigger rapid fleet renewal. Scrapping subsidies are therefore critical, as they provide the non-linear price shock needed to break consumer inertia and accelerate the transition to electromobility.
  - Impact on competitiveness: For manufacturing-heavy economies within this group (e.g., the Czech Republic), well-targeted EV scrapping schemes are vital for maintaining domestic industrial capacity and long-term competitiveness amid the transformation of global automotive supply chains.
- **Group 2:** Structural postponers (Estonia, Greece, Hungary, Latvia) (see table 5)
  - Characteristics: This group exhibits pure Mankiw-style persistence across aggregate durable consumption. Under budget constraints, households historically postpone long-term investments in residential infrastructure (heating, sanitation) in favor of non-durable goods or more liquid assets, such as automobiles, prioritizing non-durable and semi-durable goods, services, new car purchases, or direct investments.
  - Link to scrappage policy and electromobility: While car scrapping subsidies show strong localized effects here, the data indicates that financial incentives achieve even higher statistical efficacy when applied to non-automotive durable assets (e.g., green housing subsidies).
  - Impact on competitiveness: Neglecting demand-side subsidies in this group leads to structural underinvestment in green infrastructure, which damages long-term competitiveness by locking these economies into energy-inefficient structures.
- **Group 3:** Martingale adaptors (Core Western European and Nordic countries, e.g., Germany, Denmark) (see table 5).
  - Characteristics: Increments of consumption and registrations follow a martingale process. Consumers adapt rapidly to forward-looking expectations and unexpected technological shocks rather than being constrained by past trends.
  - Link to scrappage policy and electromobility: Scrapping subsidies in these markets function as short-term cyclical accelerators rather than structural corrections. Electromobility adoption is driven more effectively by technological progress, carbon pricing, and infrastructure availability.

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- Impact on competitiveness: Competitiveness in this group is supply-side driven, in line with Romer's endogenous growth theory. Subsidies are useful for buffering cyclical crises, but long-term competitiveness is maintained through innovation, R&D investments, and technological leadership.

A notable case is Latvia, which exhibits dual structural behavior. While its car registration dynamics display high inertia (aligning with group 1), its aggregate durable consumption behaves as a structural postponer. Latvian households thus adapt vehicle purchases to market trends but heavily delay major long-term investments in residential infrastructure because of strict budget constraints.

The findings from the two secondary hypotheses complement and validate the primary hypothesis without contradiction. The core verified conclusion is that "well-designed subsidies for scrapping old automobiles fundamentally accelerate the momentum of electromobility adoption." For small, manufacturing- and export-oriented economies within the European Union, these selective subsidies are a critical determinant of future competitiveness. This assertion is grounded methodologically in a demand-side approach to the economic cycle, drawing on the consumption theories of Mankiw, Hall, Friedman, and Keynes, and it remains fully compatible with a supply-side framework based on innovation and endogenous growth models, as proposed by Romer (1994).

Answer to the first secondary research question Q1:

The more developed E.U. and European countries in which Mankiw's theory is confirmed exhibit a diverse structure (see table 5). In terms of long-term consumption, the countries include the Czech Republic, Estonia, Greece, Hungary, Poland, Norway, and Latvia. For newly registered cars, they include the Czech Republic, the EFTA, the European Union, France, Switzerland, Latvia, and the Netherlands. In the Czech Republic, Poland, and Norway, a corresponding moving average coefficient of -1 is even proposed for the long-term consumption time series, indicating a zero amortization rate, though this coefficient has not been statistically confirmed. The same situation as for long-term consumption is confirmed for the time series of newly registered cars in the Czech Republic, EFTA, the European Union, France, Latvia, the Netherlands, and Switzerland. Other European countries (both developed and less developed) belong to the set in which Mankiw's puzzle is denied. We are unable to observe any link to the geography, industrial or agricultural orientation, or tourism of the countries in our sample.

Answer to the second secondary research question Q2:

Continuous innovation of vehicles ensures stable demand and steady growth in new vehicle registrations, as consumers perceive them as entirely new products—but only if households perceive them as a fundamental qualitative improvement to the product itself (the car). If the perception of future products is poor, households will keep their outdated equipment. This question is complementary to the previous research questions, as its answer will, to a certain extent, follow from the previous ones; the evaluation of the answer to the second secondary research question nonetheless has clear economic implications for the automotive industry. In the vast majority of countries, Mankiw's theory/puzzle is rejected. Continuous innovation will help replace old equipment with new equipment if households find these innovations useful. Before 2020, with few exceptions, households perceived innovation in cars as useful, and subsidies for the scrappage scheme were not necessary. The situation has changed, however, in the case of new electric cars: many people do not view innovation so positively and therefore

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continue to use outdated cars, which could hinder the achievement of climate goals. For the time series of quarterly increases in newly purchased and registered cars, the best expected future increase is currently the same as the current rate of new registrations for the vast majority of the countries surveyed. These countries include Bulgaria, Croatia, Denmark, Finland, Germany, Italy, Norway, Poland, Romania, Spain, Sweden and the United Kingdom, as well as the Czech Republic, EFTA, European Union, France, Latvia, the Netherlands and Switzerland (see table 5). The dynamics of future changes are determined by all the information that will affect the branch in the future (and which is currently largely unknown). Such a process has no memory, and Mankiw's theory/puzzle is rejected. We cannot reject Hall's consumption theory in the Czech Republic, EFTA, the European Union, France, Latvia, the Netherlands and Switzerland (see table 5). While it would be worthwhile to stimulate the replacement of old cars in other countries with subsidies for the scrappage scheme, these would have to be strictly for small, environmentally friendly cars in view of the above. The original concept of the scrappage scheme, formulated in the 1990s, was climate-neutral; however, it supported both car manufacturers and consumers by objectively increasing the permanent income and overall wealth of households that could afford higher-class cars than before. In the context of long-term consumption increments, it is no longer relevant to address the second secondary research question.

Answer to the third secondary research question Q3:

Regarding the time series of new car acquisitions, subsidies in the form of a scrappage scheme are not a crucial environmental tool for reducing harmful CO2 emissions in Europe. Conversely, for the time series of durable products excluding cars, the scrappage scheme is a key environmental tool for achieving current climate goals. Through an in-depth discussion of the analysis results and the effectiveness of the economic policy instruments presented in the European Commission report, we found the answer to the question posed. The scrappage scheme alone tends not to contribute to achieving climate goals, whereas imposing additional taxes and fees on cars with outdated technologies leads to more satisfactory climate results. The resulting model in each country will therefore be a combination of scrappage scheme, taxes, and fees. In this paper, we have demonstrated that European countries are not sufficiently homogeneous for a central policy to be implemented without harming or favoring some of them from an economic or climate perspective.

A meaningful discussion of the research results must take into account the structure of the countries in the output tables. The first conclusion relates to the impact of Mankiw's theory/puzzle and the potential scrappage scheme. Essentially, the question is whether an autoregressive coefficient below 1 can be accepted with an acceptable level of statistical confidence. This assessment can be accepted for various models of the Box–Jenkins methodology (Hall, Mankiw, and white noise). For newly registered cars, the relevant time series are those of the Czech Republic, EFTA, the European Union, France, Latvia, the Netherlands, and Switzerland (see table 4); according to the presented theory, the scrappage scheme has a 100% impact in these countries, although this conclusion is weakened by many interpretative economic arguments. For long-term consumption as a whole (besides cars, this includes the furnishings of dwellings and other goods), Mankiw's theory is confirmed for the Czech Republic, Estonia, Greece, Hungary, Poland, Norway, and Latvia (see table 4); according to the theory, it would be appropriate to apply the scrappage scheme to all durable goods in these countries. The confirmed autoregressive coefficient is below 0.8 for all countries, which is sufficient.

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For some countries, none of the proposed Box–Jenkins models could be applied to long-term consumption or to time series of newly purchased cars, while many countries confirmed diverse ARMA models. ARMA(0,0) was identified as exhibiting white noise behavior, in which the dynamics of the variable (long-term consumption or newly registered vehicles) are completely random and unpredictable. Under these conditions, the deterministic effects of the scrappage scheme are dampened but not zero, and the present value remains the most accurate predictor of the future. White noise behavior was confirmed for long-term consumption in Belgium, Denmark, and Ireland, and for time series of newly registered cars in Bulgaria, Croatia, Denmark, Finland, Germany, Italy, Norway, Poland, Romania, Spain, Sweden, and the United Kingdom (see table 3).

For autoregressive processes, the best prediction is again the present value, but, given the strong autocorrelation of time-proximate values, future dynamics are best modeled by a random walk. For a martingale or white noise, by contrast, unforeseen changes are caused only by unexpected current information. According to Hall's consumption function, short-term consumption and services follow a random walk based on the AR(1) model, and the best expected future consumption value is the present value. Where consumption is growing, continued growth is to be expected, although sustained growth increases the likelihood of a reversal of the stochastic trend. Nevertheless, the key conclusion of Hall's analysis concerns the nature of consumption smoothing behavior.

5 DISCUSSION AND PRACTICAL SIGNIFIANCE

Another empirical finding is that stagnating future long-term consumption dynamics are not justified in the vast majority of European countries. The most significant influences are households' expectations for the future and their outlook for discounted wealth, and, above all, technological advances in durable products. It is therefore not necessary to stimulate demand for new cars with subsidies, such as a scrappage scheme in every country automatically. Although there are significant differences between individual E.U. countries, the usefulness of the scrappage scheme is confirmed in aggregate time series such as newly registered cars in EFTA and the European Union, as in other large, developed economies (the United States and France). For a much smaller number of countries in the sample, a white noise (martingale) model was found to be more useful for predicting percentage increments in long-term consumption than relative changes in newly registered cars.

For long-term consumption as a whole, the dampening of the conclusions from the analysis of newly registered vehicles was further confirmed. Over the past twenty years, long-term consumption in European countries has been more susceptible to autoregressive dampening effects. Consequently, higher returns on production factors are used more for short- and medium-term consumption goods, services, and investments, with household investment taking the form of dwellings and valuables. The same applies to the automotive branch; absent intense technological innovation in durable products, demand for newly manufactured products can stagnate significantly, or even decline, and the population remains satisfied with its existing durable goods (Ungerman et al., 2018).

A significant empirical contribution is provided by the JRC-IPTS study by Nemry et al. (2009), which highlights the effects of additional registration taxes linked to CO2 emissions compared with scrappage schemes. For scrappage policies, distinct impacts can be observed depending on whether an additional "cash for replacement" condition is established or merely a "cash for scrappage" criterion. While the current tax system configuration aims for a rapid reduction in

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CO2 emissions through the purchase of more environmentally friendly automobiles, scrappage policy primarily incentivizes a faster vehicle fleet renewal, whose main effects become apparent only after two years. The magnitude of these effects depends mainly on the subsidy amount, with a marked increase in sales occurring only for contributions from EUR 2,000. Although rapid fleet renewal brings an expected decline in the production of local pollutants, the conclusions regarding actual CO2 emissions remain ambiguous, owing to a persistent dependence on fuel consumption and production emissions. Jevons's paradox is confirmed here: the introduction of modern technologies paradoxically leads to higher consumption—for instance, scrappage schemes stimulated the purchase of larger SUV models, which generally generate higher emissions. Furthermore, Arto et al. (2015) analyzed the effects of scrappage programs targeting obsolete appliances, such as white goods, boilers, and water or energy systems. Compared with subsidies targeted solely at boiler replacement, this comprehensive "scrappage for all" program achieves more than a tenfold benefit for climate targets. The comparison demonstrates that well-timed scrappage support for new automobiles, combined with scrappage schemes for all durable goods, represents a significant step toward meeting climate targets. Moreover, these measures do not necessarily restrict the competitiveness of individual E.U. member states, provided that the scrappage policy is designed in accordance with the specific characteristics of each economy and the degree to which Mankiw's puzzle manifests. Hronová et al. (2022) conclude in their empirical study, which examines the dynamics of macroeconomic consumption as a function of the economic cycle including changes in its structure, that an economic recovery in the Czech Republic is accompanied by an increase in spending on durable goods at the expense of non-durable goods and services. This finding corresponds to our conclusions regarding the impacts of Mankiw's puzzle on the adoption of electromobility in the context of overall competitiveness. The conclusions we have presented, together with the current findings in the discussion chapter, weaken the relevance of the generally accepted theory of consumption smoothing, as originally derived from Friedman's framework and formalized into random-walk macro-foundations by Hall (1978) and subsequently developed by other authors.

6 CONCLUSIONS

The main findings of this paper indicate that while vehicle scrappage subsidies significantly influence the dynamics of electromobility deployment, the ultimate efficacy of rapid decarbonization pathways exhibits substantial heterogeneity across European countries. Econometric evidence suggests that the replacement rate of consumer durables is driven predominantly by exogenous, unexpected future information shocks rather than backward-looking path dependence or immediate macroeconomic shifts. From a policy perspective, the introduction of a structured scrappage scheme anchors positive long-term market expectations regarding automotive sector stability, thereby reinforcing consumer confidence and indirectly supporting climate goals through enhanced market sentiment. Finally, our time-series analysis reveals a distinct structural asymmetry, demonstrating that fiscal scrappage frameworks generate a quantitatively greater acceleration effect on long-term durable goods replacement outside the automotive sector than on vehicle registrations alone.

Only a few countries have managed to set up an appropriate mixed stochastic autoregressive ARMA(1,1) model. Although the autoregressive coefficient is confirmed as statistically significant, the moving average coefficient cannot be confirmed, and the partial null hypothesis that it equals zero cannot be rejected. We therefore cannot confirm the proposed depreciation

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rate of 0.00% for newly purchased cars; by comparison, the presented DSGE model considers a depreciation rate of 4%. For a few countries (the Czech Republic, France, Switzerland, Latvia, and the Netherlands), Mankiw's theory cannot be accepted and the puzzle is realized; contrary to Mankiw's approach, however, Hall's approach cannot be rejected, so the best expected value for future increases in newly registered cars is their current value (see table 5). In the other countries in the sample, martingale behavior is observed in newly registered cars, and again, the best expected value is the present value. The difference is that in the first subset the autoregressive process is confirmed, giving a random walk with stochastic trends, whereas in the remaining countries, martingale behavior corresponds to white noise dynamics without stochastic trends. For both groups, with a few exceptions, higher-order autoregression is rejected: past values of new car registrations do not affect expected future increases, and neither do past values of key economic aggregates such as GDP or wealth. They are influenced more by expected future income or permanent income, by unexpected information shocks, and, if truly exogenous, by technological progress.

This is not a new concept; expectations play a fundamental role in the economy, including forward-looking rational expectations. Given the negative economic and technological outlook, it is uncertain whether obsolete cars will be replaced with new ones in all countries. If countries with a confirmed Mankiw's puzzle (the Czech Republic, France, Switzerland, Latvia, and the Netherlands) experience a decline in the dynamics of newly registered cars, this can be expected to continue, so subsidies for the scrappage scheme are necessary for the immediate stabilization of the automotive industry during economic crises. In countries where newly registered cars follow white noise, no autocorrelation is expected on the basis of past observations, and therefore declines due to the economic crisis may persist as a fully unforeseen factor.

Our conclusion regarding the scrappage scheme, however, must rest on the fact that the aggregate new car registrations in the European Union and EFTA time series follow an autoregressive stochastic process. From the perspective of the entire European continent, therefore, Mankiw's puzzle is confirmed in the time series of newly registered cars, and we recommend providing subsidies for scrapping old cars and purchasing new ones in order to strengthen the position of the automotive industry.

For long-term macroeconomic consumption, we confirmed the impact of past consumption levels in all countries except Belgium, Denmark, and Ireland (see table 3). The results clearly show that, unlike with newly registered cars, past dynamics of changes in long-term consumption have a greater influence on its current dynamics for long-term consumption as a whole. In the case of broadly defined long-term consumption, where we consider not only car expenses but also housing-related expenses (heating, utilities, and sanitation), it is necessary to consider the reluctance to replace functioning equipment with new equipment. Given the rising costs of purchasing and maintaining housing for households and slower growth in nominal incomes, the increase in the nominal value of necessary short-term consumption and services is highly likely to dampen spending on long-term consumption. Declines in past and current long-term consumption increments signal further declines in the future. This downward trend, which occurs not only during crises, can be reversed only by major technological advances (e.g., in heating equipment) or extremely positive economic expectations for the future. In order to support the rapid replacement of durable goods, including cars, economic subsidies in the form of scrappage schemes are required for environmental reasons. Manufacturers of durable equipment may perceive that demand for their products is subdued. Similarly, the climate goals associated with replacing such equipment will not be achieved automatically; rather, replacement must be incentivized through subsidies in the form of a scrappage scheme.

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Empirical evidence and the economic policy instruments promoted by the European Union in recent years suggest that the answer to H2 rests primarily on experience with boiler subsidies and similar environmental and economic activities.

6.1 Limitations, Significance and Future Research Direction

This paper empirically tests the validity and robustness of Mankiw's consumption puzzle across a broad sample of European economies. Mankiw's puzzle stems from a fundamental discrepancy between the theoretical trajectories of durable goods expenditure as predicted by models derived from Friedman's permanent income hypothesis and their actual empirical dynamics characterized by excess smoothness and persistence. The mechanism for settings the scrappage scheme in individual E.U. countries is evolving in line with the continuously adjusted green deal conditions, related recycling requirements, and innovative automotive ecosystems. Parametric models in the E.U. automotive industry are shifting toward circular design and greater use of recycled plastic components to encourage better recovery of raw materials such as steel and aluminum. Research on the effectiveness of subsidies for scrapping old cars will therefore focus on the predictive analysis of manufacturers' responsibility for processing waste and their vehicles, in direct relation to the European Union's newly implemented ELV strategy, which will serve as the basis for further research. A fundamental limitation of future research is the lack of knowledge about the causes and effects of introducing a scrappage scheme, which is a political goal; the specific form of the subsidy must be determined, as well as its interconnection with and conditionality on other economic instruments.

6.2 Future research objectives:

In light of the results presented, it is important to acknowledge the limitations we accepted when conducting the analysis. The disadvantage of the ARMA principle is that it produces reliable predictions only over the short term for economic time series. For more accurate predictions of financial time series, a combined ARIMA method incorporating the Random Forest procedure is employed. Long-term consumption and the number of newly purchased cars, by contrast, develop gradually and are typical of the real economy rather than the financial sector. This problem is typically addressed, in our research and in other studies, by incorporating habitual behavior into utility functions or by utilizing technological bubble theories and the Hansen–Jagannathan bounds.

Further research should focus on the constraints of structural breaks. During the period under review, we would expect structural breaks during the Global Financial Crisis of 2009, the pandemic crisis of 2020, and perhaps during the periods when the scrappage schemes were introduced in individual countries. Another substantial qualitative advancement for future research entails the integration of macroeconomic technology cycles and structural shifts driven by artificial intelligence. Specifically, future investigations should evaluate whether AI-driven innovations function as a general purpose technology (GPT) capable of generating cross-sectoral total factor productivity (TFP) gains. The objective is to determine if these technological advancements merely augment returns within the digital and high-tech sectors ("the new economy") or if they trigger positive knowledge spillovers that enhance structural performance, automation efficiency, and competitiveness within traditional manufacturing industries, including the automotive sector.

In terms of content, we could extend the results presented here to include not only the effects of the scrappage scheme but also the impact of increased taxation of environmentally unfriendly

https://doi.org/10.7441/joc.2026.03.08

car types on the dynamics of newly registered cars and long-term consumption. It would also be useful to include information on the effects of the scrappage scheme on subgroups of newly registered cars (SUVs, MPVs, commercial vehicles, and small passenger cars).

Funding: This work was supported by the CTU in Prague – Masaryk Institute of Advanced Studies, registered under the code "RVO32000" (institutional support for the development of a research organization).

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https://doi.org/10.7441/joc.2026.03.08

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https://doi.org/10.7441/joc.2026.03.08