

Automation and the upgrading of production: firm level evidence on direct and network effects

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Motivation and Research question

- ▶ The process of firm level upgrading, especially in developing countries, deserves more research (Verhoogen, 2023). What are the drivers that can explain firms' upgrading?
- ▶ Automation technologies are expected to become more and more important in the upcoming years. Between 2016 and 2021, the number of robots per 10,000 employees in Europe increased by 47% from 88 to 129 (IFR, 2022).
- ▶ But automation adoption remains limited among firms (Acemoglu et al, 2022)

⇒ **Our research question: What are the consequences of importing automation on firms' production and upgrading in a middle income country? How do these effects propagate through the production network?**

Related Literature


- ▶ literature on the **consequences of automation** (especially robot) adoption - Graetz and Michaels, 2018; Faber, 2020; Acemoglu et al., 2020; Bonfiglioli et al., 2020; Dauth et al., 2021; Krenz et al., 2021:
 - ▶ employment and wages; skill composition of jobs; job stability
 - ▶ productivity
 - ▶ trade and reshoring strategies
- ▶ literature on **product networks** and the propagation of shocks (Bigio, 2020; Barrot and Sauvagnat, 2016; Bohem et al., 2019; Carvalho, 2021; Demir et al., 2024).
- ▶ contributions studying **the role of - both domestic and imported - inputs** in affecting firm upgrading (Kugler and Verhoogen, 2011; Bas and Strauss-Kahn, 2015; Bas and Paunov, 2021; Boehm et al., 2022).

Our contribution

- ▶ We provide evidence on **the effects of automation on firms'** production
 - ▶ **product quality and price**, product scope.
- ▶ We test whether automation effects on upgrading **propagate along the supply chain**.
- ▶ We provide evidence on a **middle-income country (Turkey)**, where the benefits and costs caused by automation could differ compared to advanced countries.

Data-I

We focus on Turkish manufacturing and we exploit different firm level data sets provided by **TurkStat** for the period 2006-2020.

- ▶ **Foreign Trade Statistics:** Export/import flows of the universe of Turkish firms by 12 digit GTIP product and country.
 - ▶ we proxy firms' automation adoption with the **imports of capital goods that are associated with automation technologies** (Acemoglu and Restrepo, 2022).
- ▶ **AIPS:** Firms' production (value and volume) at 10-digit PRODTR level over the 2006-2020 period for all firms with more than 20 employees.
 - ▶ we estimate **quality and quality-adjusted price** (hereinafter, price) for each firm-product pair (Khandelwal et al., 2013 ).
- ▶ **Balance Sheet Data**
- ▶ **Employer-Employee Data**

Data-II

In addition to trade flows, employer-employee data and balance sheet information, the **MoIT** (Ministry of Industry and Technology) also provides data on:

- ▶ **Firm-to-Firm Domestic Transactions:** the supply network of Turkish firms which covers all domestic transactions for a seller-buyer pair that are above 5,000 Turkish liras.
 - ▶ we identify **the set of domestic suppliers and customers** for each firm over time.
- ▶ TurkStat data: the direct impact on a firm's product quality and price
- ▶ MoIT data: the propagation of the automation impact through the network.

Distribution of automation imports by 2-digit NACE manufacturing sector (2009-2019)

NACE Rev.2 sector: Manufacture of		%
10	food products	0.45
11	beverages	0.12
12	tobacco products	0.30
13	textiles	21.23
14	wearing apparel	2.30
15	leather and related products	0.28
16	wood and of products of wood	1.14
17	paper and paper products	0.98
18	Printing and reproduction of recorded media	0.06
19	coke and refined petroleum products	0.59
20	chemicals and chemical products	2.29
21	basic pharmaceutical products and preparations	0.82
22	rubber and plastic products	1.80
23	other non-metallic mineral products	2.95
24	basic metals	3.48
25	fabricated metal products	5.66
26	computer, electronic and optical products	2.74
27	electrical equipment	7.31
28	machinery and equipment	12.82
29	motor vehicles, trailers and semi-trailers	28.94
30	other transport equipment	2.62
31	furniture	0.57
32	Other manufacturing	0.53
		100

Firm propensity to import automation (2009-2019)

NACE Rev.2: Manufacture of		All firms	Our sample
		[1]	[2]
10	food products	0.44	4.57
11	beverages	4.77	13.87
13	textiles	3.85	22.89
14	wearing apparel	0.36	3.94
15	leather and related products	1.11	9.70
16	wood and of products of wood	0.30	8.15
17	paper and paper products	3.32	12.53
18	Printing and reproduction of recorded media	0.32	4.64
20	chemicals and chemical products	2.83	13.49
21	pharmaceutical products	17.47	35.20
22	rubber and plastic products	1.87	11.45
23	other non-metallic mineral products	1.57	8.25
24	basic metals	4.78	19.67
25	fabricated metal products	1.17	13.11
26	computer, electronic and optical products	13.28	40.28
27	electrical equipment	4.34	24.89
28	machinery and equipment	6.38	23.74
29	motor vehicles, trailers and semi-trailers	6.65	23.85
30	other transport equipment	9.62	26.58
31	furniture	0.35	5.01
32	Other manufacturing	1.32	13.88
		1.57	13.15

Preliminary evidence

Firm level variables

	[1]	[2]	[3]	[4]	[5]	[6]
	size	sales	tfp	import_dummy	export_dummy	uwage
adopter	0.162a	0.104a	0.040a	0.180a	0.047a	0.030a
	[0.008]	[0.008]	[0.006]	[0.006]	[0.006]	[0.003]
$size_{t-1}$		0.574a	-0.060a	0.073a	0.066a	0.019a
		[0.007]	[0.004]	[0.003]	[0.003]	[0.002]
Observations	234,139	210,182	195,073	211,015	211,015	211,015
R-squared	0.906	0.945	0.906	0.731	0.714	0.897
firm f.e.	y	y	y	y	y	y
4-dsec-year f.e.	y	y	y	y	y	y

Firm-product level variables

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	All available firms				Importers			
	quality	quality-adjusted price			quality	quality-adjusted price		
adopter	0.232a	0.051a	-0.159a	-0.041a	0.194a	0.051a	-0.140a	-0.040a
	[0.020]	[0.016]	[0.013]	[0.009]	[0.021]	[0.016]	[0.014]	[0.009]
$size_{t-1}$	0.313a	0.218a	-0.302a	-0.196a	0.299a	0.215a	-0.290a	-0.196a
	[0.009]	[0.011]	[0.007]	[0.007]	[0.010]	[0.012]	[0.007]	[0.009]
Observations	312,312	292,775	312,312	292,775	254,113	238,806	254,113	238,806
R-squared	0.167	0.795	0.921	0.985	0.173	0.804	0.92	0.985
firm-prod. f.e.	n	y	n	y	n	y	n	y
prod-year f.e.	y	y	y	y	y	y	y	y

Standard errors in parentheses: **a** for $p < 0.01$; **b** for $p < 0.05$ and **c** for $p < 0.10$.

Empirical strategy

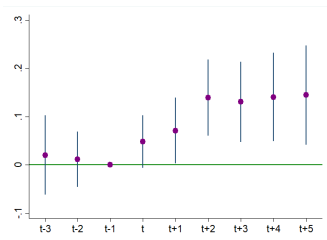
- 1. Automation adoption:** i) the firm imports automation-related capital goods at time t ii) the firm did not import them in, at least, three previous years, and in any preceding year for which we can observe the firm, iii) the firm remains in the dataset and is active in the year following the adoption:
⇒ 1,358 treated units from 2012 to 2019.
- 2. Propensity score matching:** for each treated firm, we select the nearest neighbour among those firms which do not adopt automation ever in the period of our analysis (sample of importers - Acemoglu et al, 2023).
 - ▶ covariates in the probit model: *employment, output, TFP level, import status, export status, unit wage, capital stock, import share of intermediate goods, import share of other capital goods; # of products (routinary intensity of suppliers); year and sector FE.*
Covariates in $t - 1$ ($t - 2$ and $t - 3$)
 - ▶ matching by year and 3-digit NACE sector (Balancing)

Empirical strategy

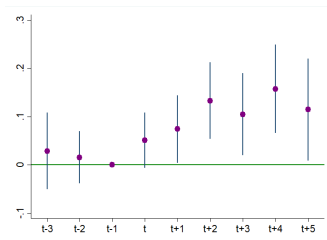
3. **Event study** analysis on the matched sample and we control for firm-product (firm) FE. Favourite approach: Sun and Abraham (2021).

$$y_{ipt} = \alpha_{ip} + \sum_{l < -3}^{-2} \mu_l D_{it}^l + \sum_{l=0}^5 \mu_l D_{it}^l + \lambda_t + \epsilon_{ipt}$$

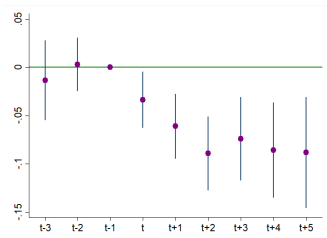
Firm-Product Level Price & Quality



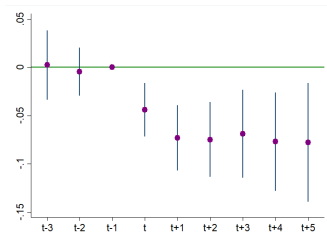
Quality - All products



Quality - Top 3 products



Price - All products

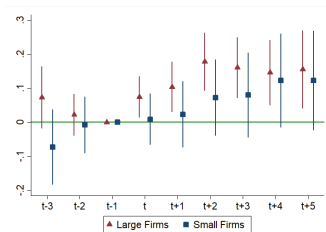


Price - Top 3 products

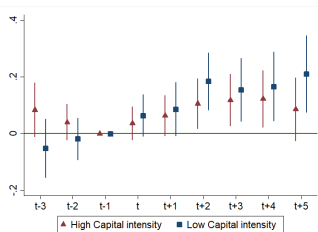
Sensitivity Checks

- ▶ no caliper or a narrower caliper equal to 10% of the pscore std
- ▶ exclusion from the sample of firms which record exports of automation-related capital goods
- ▶ focus on all firms (both importers and non importers)
- ▶ matching by 4 digit sector-year; matching by 2 digit sector-year
- ▶ a stricter definition of automation adopters based on past 4 years
- ▶ focus on treated firms with relevant investments in automation
- ▶ different estimators for the event study analysis (Callaway and Sant'Anna, 2021; Borusyak et al, 2023)
- ▶ focus just on products produced in the pre-treatment period.

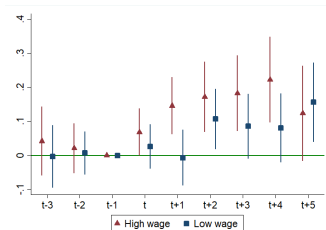
Heterogeneous effects across firms I



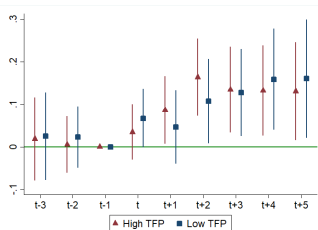
Quality - Small/Large Firms



Quality - High/Low K intensity

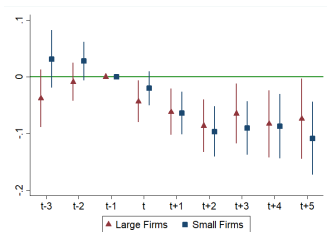


Quality - High/Low Wage

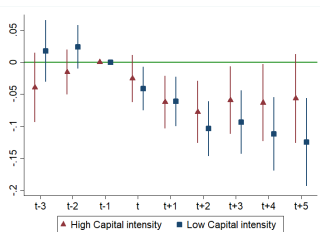


Quality - High/Low TFP

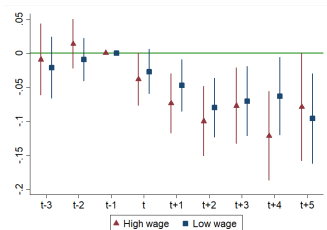
Heterogeneous effects across firms II



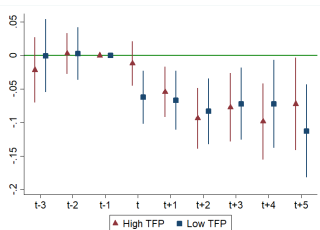
Price - Small/Large Firms



Price - High/Low K intensity



Price - High/Low Wage



Price - High/Low TFP

Automation-upgrading nexus: an IV approach

$$\Delta^{\tau_1/\tau_0} \text{quality}_{ip}^{\text{average}} = \alpha + \beta \text{Automation}_{\tau_1,i} + \iota X_{i\tau_0} + \epsilon_{ip}$$

where $\tau = 5$ -year time span (1: 2015-2019; 0: 2010-2014).

- ▶ $\Delta^{\tau_1/\tau_0} \text{quality}_{ip}^{\text{average}}$: the change between τ_1 and τ_0 in the average quality of product p produced by firm i .
- ▶ $\text{Automation}_{\tau_1,i}$: a dummy denoting whether firm i has imported automation-related capital goods over the period τ_1 .
- ▶ **Instrument**: the share of French firms importing automation technologies in the time span τ_0 among all French firms producing the same CPA products as Turkish firm i , \hat{p}_i (INSEE and French custom data).

Automation-upgrading nexus: an IV approach

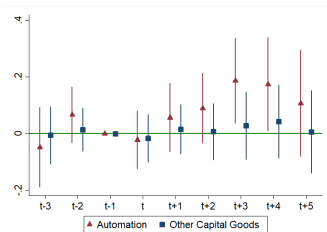
Panel A: All firms					
	[1]	[2]	[3]	[4]	[5]
	ols	2sls	ols	2sls	1st stage
	$\Delta\tau_1/\tau_0$	quality	$\Delta\tau_1/\tau_0$	q-adjusted price	Automation $_{\tau_1,i}$
Automation $_{\tau-1,i}$	0.221a [0.016]	0.306a [0.045]	-0.093a [0.012]	-0.218a [0.033]	
shfirms_Automa $_{\hat{\rho}_i\tau_0}^{FRA}$					0.009a [0.000]
Observations	10.799	10.799	10.799	10.799	10.799
Shea		0,121		0,121	
1st stage Ftest		548,5		548,5	
Panel B: Importers					
	ols	2sls	ols	2sls	1st stage
	$\Delta\tau_1/\tau_0$	quality	$\Delta\tau_1/\tau_0$	q-adjusted price	Automation $_{\tau_1,i}$
Automation $_{\tau_1,i}$	0.203a [0.017]	0.261a [0.049]	-0.075a [0.012]	-0.171a [0.036]	
shfirms_Automa $_{\hat{\rho}_i\tau_0}^{FRA}$					0.009a [0.000]
Observations	9.758	9.758	9.758	9.758	9.758
Shea		0,113		0,113	
1st stage Ftest		456,7		456,7	

Notes: a $p < 0.01$, b $p < 0.05$, c $p < 0.1$.

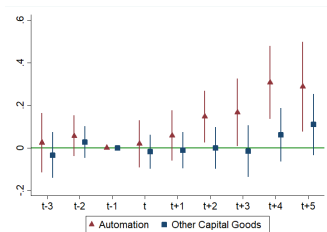
Automation vs. Other Capital Goods

- ▶ We consider as treatment the first-time import of any kind of capital goods instead of just focusing on automation-related capital goods.
- ▶ We implement a similar propensity score matching approach.
- ▶ We split treated firms into two mutually exclusive groups: i) firms that start importing just automation-related capital goods at time t ii) firms that start importing just other kinds of capital goods, but automation capital.
- ▶ Event study for the two treatments.

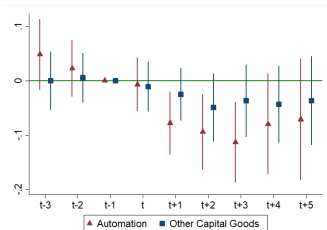
Automation vs. Other Capital Goods



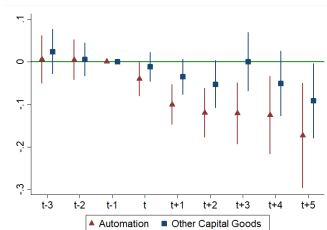
Quality - All products



Quality - Top 3 products



Price - All products



Price - Top 3 products

Propagation to Customers

Focus on exporters (export share $\geq 10\%$)

$$y_{jpt} = \alpha + \beta shPurch_{j,t}^{K_automation} + \iota X_{jt-1} + \gamma_{jp} + \phi_t + \epsilon_{jpt}$$

- ▶ y_{jpt} : quality or q-a price of product p (6digit HS2007) exported by firm j
- ▶ $shPurch_{j,t}^{K_automation}$: share of purchases from suppliers that are automation adopters
- ▶ or $K_automation_{j,t}^{Suppliers}$: average automation capital of manufacturing suppliers

Suppliers' automation and downstream buyers' quality and price

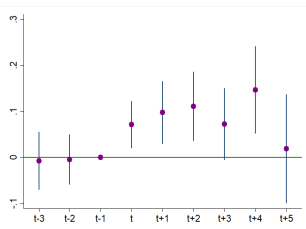
	quality			price		
	[1]	[2]	[3]	[4]	[5]	[6]
$shPurch_{i,t}^{K_automation}$	0.086b [0.036]			-0.103a [0.025]		
$K_automation_{j,t}^{Suppliers}$		0.010a [0.002]	0.008a [0.002]		-0.011a [0.001]	-0.008a [0.002]
$K_other_{j,t}^{Suppliers}$			0.003 [0.002]			-0.004a [0.002]
Observations	534,762	534,762	534,762	534,762	534,762	534,762
R-squared	0.809	0.798	0.798	0.948	0.948	0.948
firm covariates	yes	yes	yes	yes	yes	yes
firm-product FE	yes	yes	yes	yes	yes	yes
year FE	yes	yes	yes	yes	yes	yes

a $p < 0.01$, b $p < 0.05$, c $p < 0.1$. Standard errors clustered by firm.

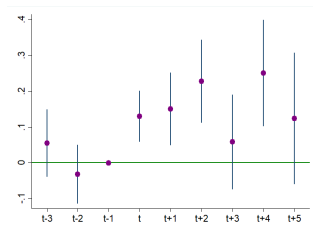
Propagation to Customers: customers of the matched sample

1. We consider the matched sample made up by automation importers and their controls.
2. We identify manufacturing firms which are **customers** of the above selected sample of firms in t .
3. We split these customers into two groups: (i) firms that purchase inputs in t from a supplier that start importing automation-related capital goods at time t ($Treated_i^{SUPPLIER} = 1$) (ii) firms that purchase inputs in t from suppliers that did not import automation technologies ($Treated_i^{SUPPLIER} = 0$).
4. We test whether automation adoption (imports) by a supplier has a significant impact on customers' quality and adjusted price since time t .
5. Focus on exported products. Focus on firm-to-firm linkages accounting for at least 1% of the customer's purchases.

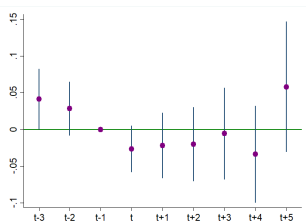
Propagation to Customers: customers of the matched sample



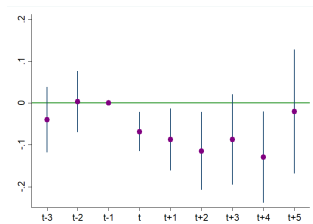
Quality - purchase share > 1%



Quality - purchase share > 5%



Price - purchase share > 1%



Price - purchase share > 5%

Propagation effects: robustness

Sensitivity checks:

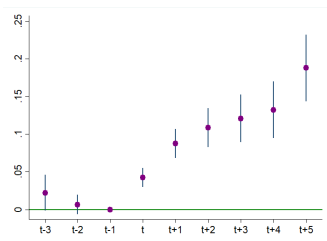
- ▶ focus on those firms that are buyers at least in: t and $t - 1$; t , $t - 1$ and $t + 1$; from $t - 3$ to $t + 3$
 - ▶ control for the customers' adoption of automation
 - ▶ inclusion of the automation adoption by customers and by suppliers as additional pre-treatment covariates in the matching strategy
 - ▶ control for a set of customers' covariates in $t - 1$ interacted by a time trend.
-
- ▶ **The same analysis implemented for firms supplying the matched sample (either treated units or their matched controls) does not show any significant effect.** supp

Conclusions

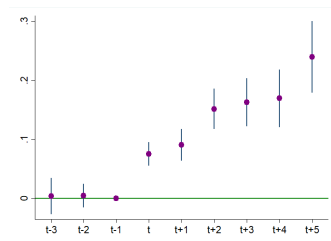
- ▶ We have analysed the impact of automation on firms' product upgrading and the propagation effects along the supply chain. Focus on the Turkish manufacturing.
- ▶ Our findings:
 - ▶ Automation adoption increases the quality and reduces the quality-adjusted price of a firm's products.
 - ▶ Quality effects are stronger and more significant for: large firms, firms with low capital intensity and high wage firms. Price reduction is experienced by all firms.
 - ▶ Quality and price effects of automation propagate downstream to manufacturing customers. No significant and relevant effect on upstream manufacturing suppliers.
 - ▶ Further effects: positive direct effects on firm level performance (output, employment, capital intensity, wage, productivity); no robust effect on the product scope.

THANK YOU!

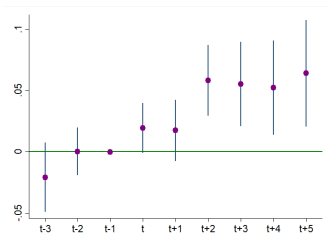
Automation and firm economic outcomes I



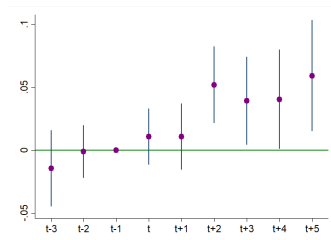
Employment



Sales

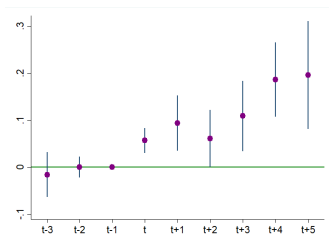


Labour Productivity

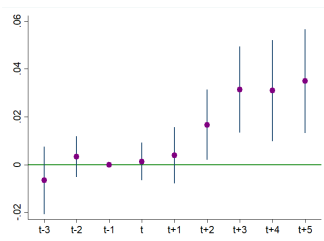


TFP

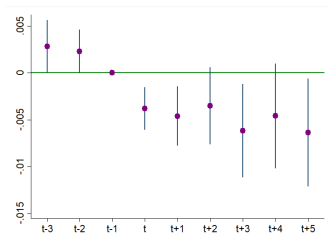
Automation and firm economic outcomes II



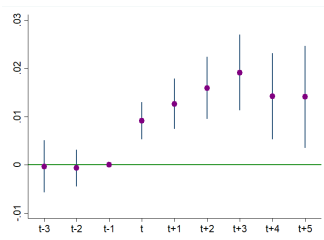
Capital Intensity



Unit Wage



Employees - Over 50



Employees - Under 35 **B**

Quality estimation

$$\ln q_{ipt} + \sigma_s \ln p_{ipt} = \alpha_p + \alpha_t + \epsilon_{ipt}$$

where q_{ipt} and p_{ipt} are the quantity and price (unit value) of a 10-digit product p produced by firm i at time t and σ_s is the median elasticity of substitution at sector s level retrieved from Broda and Weinstein (2006).

$$\ln Adj - p_{ipt} = \ln p_{ipt} - \ln q_{ipt}$$

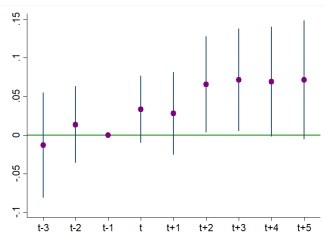
Back

Balancing Tests of covariates

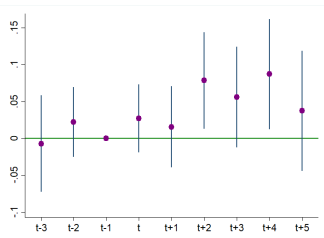
	Unmatched Sample			Matched Sample		
	Treated firms	Control firms	t	Treated firms	Control firms	t
lab _{t-1}	4.013	3.817	11.69	3.920	3.926	-0.22
lab _{t-2}	3.930	3.784	8.75	3.843	3.843	0.03
lab _{t-3}	3.832	3.724	6.24	3.750	3.744	0.24
tfp _{t-1}	8.809	8.788	1.04	8.754	8.747	0.21
tfp _{t-2}	8.791	8.789	0.10	8.740	8.734	0.18
tfp _{t-3}	8.777	8.785	0.39	8.735	8.715	0.61
output _{t-1}	15.546	15.333	8.37	15.399	15.359	1.09
output _{t-2}	15.418	15.270	5.85	15.279	15.234	1.18
output _{t-3}	15.265	15.173	3.57	15.140	15.084	1.43
import_dummy _{t-1}	0.785	0.509	22.60	0.740	0.716	1.38
export_dummy _{t-1}	0.703	0.589	9.48	0.675	0.687	-0.66
unit_wage _{t-1}	9.140	9.082	7.18	9.090	9.099	-0.67
capital _{t-1}	14.321	13.919	13.97	14.184	14.148	0.91
# products _{t-1}	0.504	0.666	8.75	0.499	0.487	0.45
imp_share _{t-1} ^{interm}	0.089	0.041	17.28	0.068	0.067	0.26
imp_share _{t-1} ^{otherK}	0.015	0.004	17.35	0.009	0.010	-0.7

Back

Impact on Product Unit Value

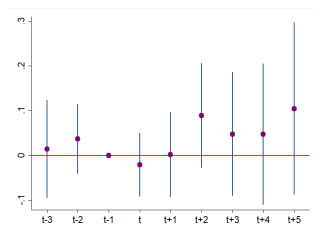


Unit Value - All products

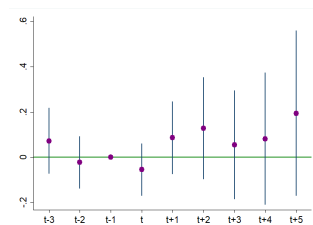


Unit Value - Top 3 products [back](#)

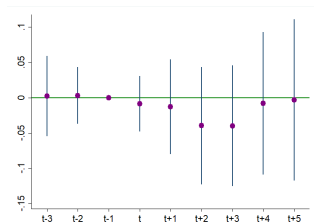
Propagation to Suppliers: suppliers of the matched sample



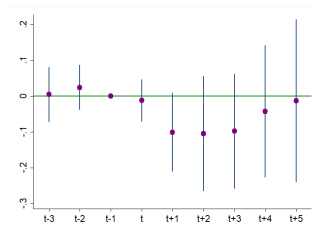
Quality



Quality - purchase share > 5%



Price



Price - purchase share > 5%

[Back](#)

THANK YOU!