# Digitalization and Resilience to Disaggregate Shocks

Florentine Schwark* Andreas Tryphonides**

*Humboldt-University of Berlin

**University of Cyprus

July 14, 2022
CRETE 2022

# Motivation and contribution

- Recent experience with supply side shocks (pandemic related or not).
- "Resilience" and "Digitalization" have been at the forefront of policy discussions.
- "Digital Transition" as #2 target (20% of spending) of European Commission's Resilience plan.

In this paper:

- We take a step back and investigate which factors determine macroeconomic **resilience**, defined as the ability of a system to mitigate the effects of a persistent disaggregate shock.
- How **digitalization** may be mapped to these factors and what is the **empirical evidence**.

# What do we know about digitalization?

- **Heavy research attention on structural transformation and productivity effects, with mixed evidence on the latter**. ((Gordon (2015), Dauth, Findeisen, Suedekum, and Woessner (2021), Cette, Clerc, and Bres- son (2015), Brynjolfsson and Hitt (2003), Stiroh (2002), Graetz and Michaels (2018), Gallipoli and Makridis (2018)))
- **Little is known about its effects on other components of the production function e.g. the elasticity of factor substitution**.
- **Effects may depend on type of digital technology**.

# The raw data

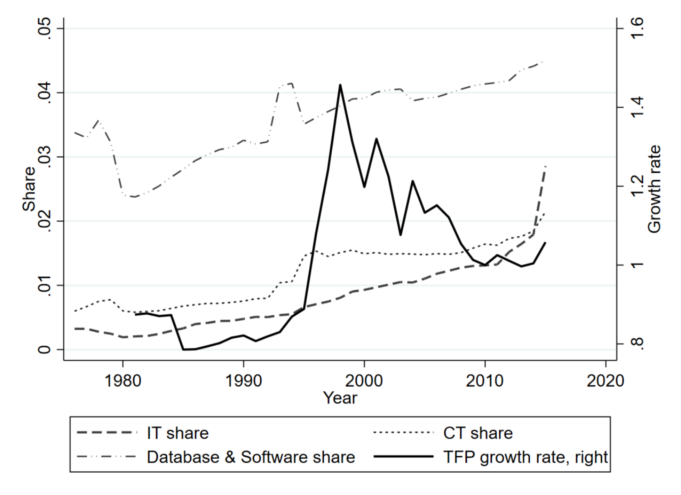



Figure: Digital capital stocks and Total Factor Productivity (EU KLEMS)

# Plan of talk

- Analytical Results for shock propagation.
- Empirical approach and results.
  - Effects of digitalization on production function parameters.
- Mapping digitalization to resilience.
  - Endogenous Technology Choice.

# General Equilibrium Model

- Producer problem

$$\max_{l_i, x_{i,j}} p_i y_i - w l_i - \sum_{j=1..n} p_j x_{i,j} \tag{1}$$

where

$$\begin{aligned} y_i &= e^{z_i} \left( (1-\lambda_i) l_i^{\frac{\sigma-1}{\sigma}} + \lambda_i \left[ \prod_{j=1..n} x_{i,j}^{\alpha_{i,j}} \right]^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} && (2) \\ &= e^{z_i} \left( (1-\lambda_i) l_i^{\frac{\sigma-1}{\sigma}} + \lambda_i X_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} && (3) \end{aligned}$$

with $\sum_{j=1..n} \alpha_{i,j} = 1$.

# Analytical Model

- Consumer Problem

$$\max_{l_i, c_i} \prod_{i=1..n} \gamma(l) c_i^{\beta_i}$$

$$s.t. \quad \sum_{i=1..n} p_i c_i = \sum_{i=1..n} w_i l_i$$

$$\sum_{i=1..n} l_i = l$$

- Goods market equilibrium:

$$y_i = c_i + \sum_{j=1..n} x_{j,i}$$

- Labor market equilibrium (Full mobility)

$$l^s = \sum_{i=1..n} l_i^d$$

- Aggregate Demand: Constant returns aggregator

$$Y_t = \prod_{i=1..n} c_{i,t}^{\star \beta_i}$$

# Defining Resilience

Hulten (1978)'s Theorem: The effect on GDP of a productivity shock in sector $i$ is equal to its sales share as a fraction of GDP (Domar weight):

$$\frac{dln(Y)}{dz_i} = \frac{p_i y_i}{\sum_{i=1..n} p_i c_i} \equiv d_i$$

- Non parametric result
- Generalized to second order effects by Baqaee and Farhi (2019)
- Our setup: Sales share not constant (so second order productivity effects present), but we focus on second order $\sigma-$ effects

# Domar Weights

**Proposition**

*In a nested-CES economy:*

$$\boldsymbol{d} = [I_n - \Phi]^{-1} \boldsymbol{\beta}$$

*where*
$$\Phi_{j,i} \equiv \alpha_{j,i} \frac{\lambda_j}{\lambda_j + (1-\lambda_j)\left(\frac{l_j}{X_j}\right)^{\frac{\sigma_j - 1}{\sigma_j}}} = \alpha_{j,i} \frac{p_{X,j} X_j}{w l_j + p_{X,j} X_j}$$

- The supply shock to sector $i$ propagates downstream to its customers $j \in 1..J$.
- When $\sigma = 1$ (Cobb Douglas), the Domar weight collapses to a constant (Hulten (1978), Baqaee and Farhi (2019))

# Intuition for amplification/dampening

▸ Analytical

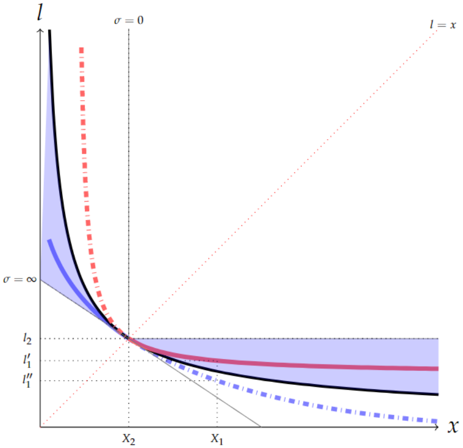



Figure: Shaded region: Dampening

# Empirical Evidence on the effects of Digitalization

- The downstream impact of the productivity shock depends on the share parameters and the elasticity of substitution between the factors.
- One way in which digitalization could play role in fostering resilience would be through its effects on these parameters of the production function.
- We find that:
  - **Higher digital intensity increases the elasticity of substitution between capital and labor, and between value added and intermediate inputs.**
  - We do not find robust effects on the share parameters.
  - Higher data intensity in investment increases labor productivity.

# Empirical Model

- Final Output

$$Q_{i,t} := \left( (1-\lambda_{i,t})(A^{va}_{i,t} VA_{i,t})^{\frac{\sigma_{i,t}-1}{\sigma_{i,t}}} + \lambda_{i,t}(A^{x}_{i,t} X_{i,t})^{\frac{\sigma_{i,t}-1}{\sigma_{i,t}}} \right)^{\frac{\sigma_{i,t}}{\sigma_{i,t}-1}}$$

- Value Added:

$$VA_{i,t} = \left( \alpha_{i,t}(A^{K}_{i,t} K_{i,t})^{\frac{\gamma_{i,t}-1}{\gamma_{i,t}}} + (1-\alpha_{i,t})(A^{L}_{i,t} L_{i,t})^{\frac{\gamma_{i,t}-1}{\gamma_{i,t}}} \right)^{\frac{\gamma_{i,t}}{\gamma_{i,t}-1}}$$

- Productivity:

$$A_{i,t} = A_{i,t-1} e^{g_i}, \quad A \in \{A^{va}, A^{x}, A^{K}, A^{L}\}, g \in \{g^{va}, g^{x}, g^{K}, g^{L}\}$$

# Estimating Equations

- Firm chooses capital, labor and intermediate inputs $(K, L, X)$ to minimize cost of production: Consistent with price rigidities and market power in the goods market.
- Resulting relative factor demands:

$$
\begin{aligned}
ln\left(\frac{K_{i,t}}{L_{i,t}}\right) &= \gamma_{i,t} ln\left(\frac{\alpha_{i,t}}{1-\alpha_{i,t}}\right) - \gamma_{i,t} ln\left(\frac{p^i_{K,t}}{p^i_{L,t}}\right) + (\gamma_{i,t}-1)\left[(g_i^K - g_i^L)t\right] \\
ln\left(\frac{VA_{i,t}}{X_{i,t}}\right) &= \sigma_{i,t} ln\left(\frac{1-\lambda_{i,t}}{\lambda_{i,t}}\right) - \sigma_{i,t} ln\left(\frac{p^i_{VA,t}}{p^i_{X,t}}\right) + (\sigma_{i,t}-1)\left[(g_i^{VA} - g_i^X)t\right]
\end{aligned}
$$

# Estimating Equations: Functional reduced form coefficients

$$ln\left(\frac{K_{i,t}}{L_{i,t}}\right) = c_0(Z_{i,t}) + c_1(Z_{i,t})ln\left(\frac{P^i_{K,t}}{P^i_{L,t}}\right) + c_2(Z_{i,t})ln\left(\frac{A^K_{i,0}}{A^L_{i,0}}\right) + c_3(Z_{i,t})t + \epsilon_{i,t}$$

$$ln\left(\frac{VA_{i,t}}{X_{i,t}}\right) = h_0(Z_{i,t}) + h_1(Z_{i,t})ln\left(\frac{P^i_{VA,t}}{P^i_{X,t}}\right) + h_3(Z_{i,t})t + \upsilon_{i,t}$$

# Estimating Equations: Final Specification

- Approximating these coefficients using a first order Taylor expansion around $\tilde{Z}$:

$$
\begin{aligned}
ln\left(\frac{K_{i,t}}{L_{i,t}}\right) \quad = \quad & c^i + c_0^T \tilde{Z}_{i,t} + c_{1,0} ln\left(\frac{P^i_{K,t}}{P^i_{L,t}}\right) + c_{1,1}^T \tilde{Z}_{i,t} \otimes ln\left(\frac{P^i_{K,t}}{P^i_{L,t}}\right) \\
& + c_{3,0} t + c_{3,1}^T \bar{Z}_i \otimes t + u_{i,t}
\end{aligned}
$$

where $c^i$ are fixed (time invariant) individual effects.

- Same approach for demand of value added relative to intermediate goods.

# Data

- We utilize (unbalanced) panel data from the KLEMS database: EU countries, including the UK.
- Yearly observations from 1995-2017 (extended dataset from 1970)
- Cross Sectional Units: Country-Sector
- $Z$: Digitalization measures:
  - Information Technology (IT) and Communication Technology (CT) capital as a share of total capital
  - Software and Databases (SoftDb) a shares of total investment and capital
- $Z$: Level of development (lagged capital to labor ratio), Research and Development, VIX

# Identification

- Relative prices are endogenous.
- Need instruments that are sufficiently correlated with prices but uncorrelated with unobservables (i.e. unobserved demand disturbances).
- We employ US prices as "Hausman"-type of instruments (supply shifters):
  - Relative prices in the US as proxy of marginal costs in Europe.
- Two requirements:
  1. Common unobserved relative marginal cost shocks for $\frac{K}{L}$ and $\frac{VA}{X}$ e.g. China.
  2. Absence of *common* global unobserved demand shocks. We control for global disturbances using the VIX index.
- We test both for weak identification and instrument exogeneity.

# Elasticities of Substitution

| | $\gamma$ $(K/L)$ | $\sigma$ $(VA/X)$ |
|---|---|---|
| *Constant* | **0.191** | **0.534** |
| | (0.105 , 0.277) | (0.105 , 0.688) |
| *Digitalization Measure* | | |
| Information Technology share | **0.0885** | **0.128** |
| | (0.0487 , 0.128) | (0.00656 , 0.249) |
| Communications Technology share | 0.0009 | -0.0154 |
| | (-0.00215 , 0.00399) | (-0.108 , 0.0775) |
| Software & Databases share | -0.00453 | **0.102** |
| | (-0.0787 , 0.00696) | (0.00454 , 0.200) |
| *Level of Development* | **0.0960** | |
| | [0.0529,0.133] | |
| Number of Observations | 4371 | 4106 |

# Impact of EoS on GDP Resilience

**Proposition**

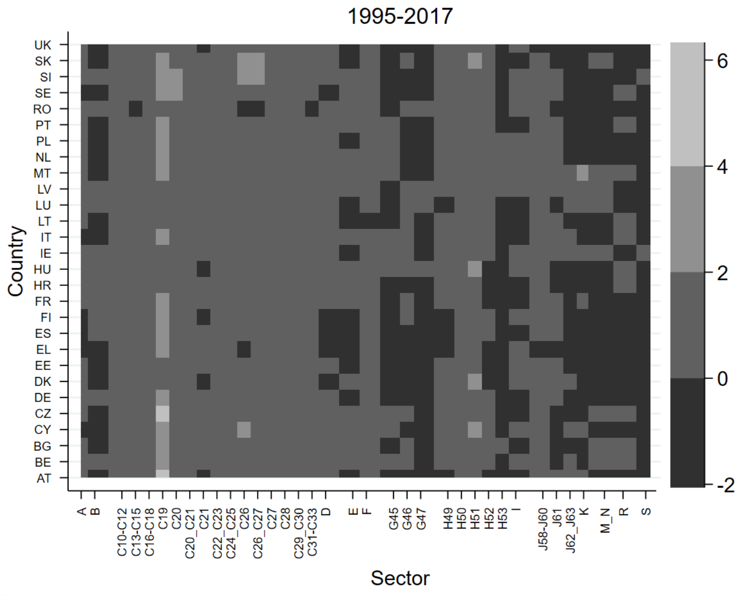
*Impact of higher elasticity of substitution:*

$$\frac{d\log\Phi_{j,i}}{dln\sigma_i} = -\frac{\Phi_{j,i}}{\sigma_i}\frac{(1-\lambda_i)}{\lambda_i}\left(\frac{l_{i,t}}{X_{i,t}}\right)^{1-\frac{1}{\sigma_i}} \ln\left(\frac{l_{i,t}}{X_{i,t}}\right) \tag{4}$$

- A higher elasticity of substitution dampens the propagation of the shock if the sector is labor (value added) intensive.
- The degree of gross substitution is irrelevant for the sign, relevant for the impact.

▸ Figure

# Relative abundance of intermediate inputs



# Mapping digitalization to the EoS

- How does digitalization increase the elasticity of substitution?
  - Endogenous Technology Choice (Growiec (2008, 2018), Jones 2005 , Caselli and Coleman (2006), Satchi and Ledesma (2019) )
  - Local versus global production functions.
  - For a fixed level of inputs, firms choose from a set of feasible technologies (productivities), with a technological frontier:

$$\left(e^{z_{i,t}^{VA}}\right)^{\omega_i} + \theta_i \left(e^{z_{i,t}^{X}}\right)^{\omega_i} = B_i \tag{5}$$

  - By varying the level of inputs and evaluating the local production functions at the optimal technology choice we can trace the global production function.

# Reduced Form Conditional Factor Demands

$$ln\left(\frac{VA_{i,t}}{X_{i,t}}\right) = \tilde{\sigma} ln\left(\frac{1-\lambda_i}{\lambda_i}\right) - \tilde{\sigma} ln\left(\frac{p^i_{VA,t}}{p^i_{X,t}}\right)$$

$$ln\left(\frac{K_{i,t}}{L_{i,t}}\right) = \tilde{\gamma} ln\left(\frac{\alpha_i}{1-\alpha_i}\right) - \tilde{\gamma} ln\left(\frac{p^i_{k,t}}{p^i_{l,t}}\right)$$

$$\tilde{\sigma} := \frac{\omega_{VA/X}\sigma_i - (\sigma_i - 1)}{\omega_{VA/X} - (\sigma_i - 1)}$$

$$\tilde{\gamma} := \frac{\omega_{L/K}\gamma_i - (\gamma_i - 1)}{\omega_{L/K} - (\gamma_i - 1)}$$

# Digitalization and Technology Substitution

$$\tilde{\gamma} := \frac{\omega\gamma - (\gamma_{-}1)}{\omega - (\gamma - 1)}$$

- A decrease in the curvature of the technology frontier leads to a higher effective elasticity of substitution
- **Intuition**: For a given elasticity of substitution between inputs:
    - If technologies are close substitutes, then their choice is irrelevant for the effective substitutability between the factors.
    - If technologies become less substitutable, then choosing them optimally boosts the substitutability between inputs.
- Digitalization makes technologies less substitutable. Specialization?

# Conclusions and Implications

- Our results suggest that investment in digital technologies can have an impact on the flexibility of production.
- Digitalization may increase resilience as it increases the elasticity of substitution, yet, it heavily depends on whether sectors that digitalize have relatively high value added.
- The type of digitalization seems to play an important role.

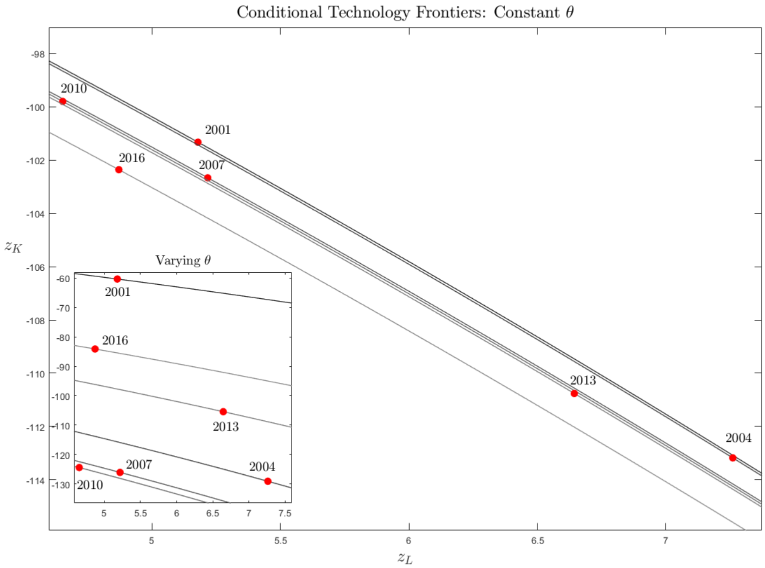
Thanks!

# Mapping digitalization to the EoS

- With gross substitutability between inputs $(\sigma > 1, \gamma > 1)$, it can be shown that firms will choose to boost the productivity of the abundant factor. The converse is true with gross complementarity $(\sigma < 1, \gamma < 1)$.

$$\left(\frac{e^{z_{i,t}^{VA}}}{e^{z_{i,t}^{X}}}\right)^{\omega_{VA/X}-\frac{\sigma_i-1}{\sigma_i}} = \frac{1-\lambda_i}{\lambda_i}\theta_{X/VA}\left(\frac{VA_i}{X_{i,t}}\right)^{\frac{\sigma_i-1}{\sigma_i}}$$

$$\left(\frac{e^{z_{i,t}^{K}}}{e^{z_{i,t}^{L}}}\right)^{\omega_{K/L}-\frac{\gamma_i-1}{\gamma_i}} = \frac{\alpha_i}{1-\alpha_i}\theta_{L/K}\left(\frac{K_{i,t}}{L_{i,t}}\right)^{\frac{\gamma_i-1}{\gamma_i}}$$


Conditional Technology Frontiers: Constant θ
2010
2001
2016
2007
2013
2004
z_K
z_L
Varying θ
2001
2016
2013
2007
2004
2010