Technology Change in Manufacturing and Labor Outcomes: Not All Technologies are Equal

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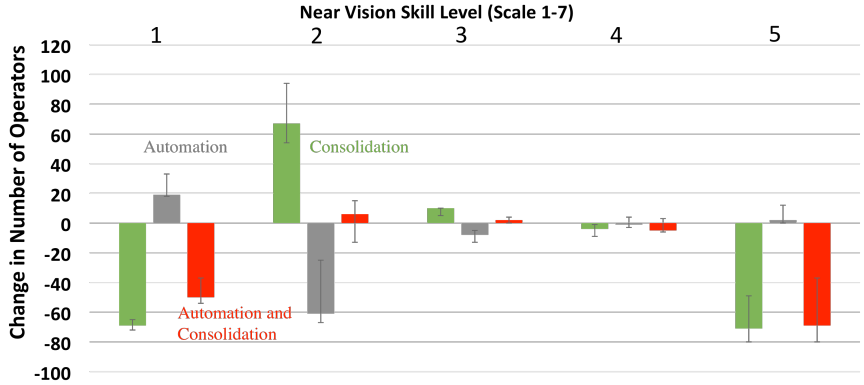
Technology change, including in manufacturing, may be raising global challenges for inequality and the future of work. Significant literature exists on skill-biased technological change and its influence on employment, wages, international trade and productivity (Autor et al 2003; Card and DiNardo 2002; Bartel et al 2007; Acemoglu and Restrepo 2017). Research, however, has largely been unable to distinguish between different types of technology change, and their possible relation to labor demand. While there is research on information technology (Bresnahan and Brynjolfsson 2002, Bartl et al 2007), robotics (Acemoglu and Restrepo 2007) and automation (Autor et al 2003; Autor and Dorn 2013), other forms of technology change that may influence the structure of labor demand, have been largely overlooked. We propose the need for a taxonomy of technology changes in the production of physical products, and how different emerging technologies may have different implications for labor outcomes.

As an initial proof-of-concept, we focus on disentangling two forms of technology change in manufacturing: monolithic production (e.g. consolidation of parts removing the need for assembly) and automation, both of which we hypothesize are economically significant and which we hypothesize may have different implications for labor outcomes. Part consolidation is a phenomena, enabled by a confluence of technology change in materials, process, and design, which has occurred for decades and is ongoing across a large number of economically significant industries, including aerospace, automotive, electronics, and optoelectronics. We use a combination of engineering and classical economics methods. Whereas classical production functions are limited to historic factor substitutions captured by statistical data (Pearl and Enos 1975), engineering and operations models and data make it possible to explicitly map current and future technology change – including expected future design decisions – to production processes and operations at scale, including the heterogeneity of equipment, labor and material inputs (Pearl and Enos 1975; Fuchs and Kirchain 2010). PI Fuchs has used engineering models to show how shifting from a developed to a developing country changes which advanced products it is profitable for firms to pursue, thus questioning traditional assumptions in gains from trade (Fuchs and Kirchain 2010, Fuchs 2014). Co-PI Whitefoot has used engineering models combined with industrial organization models to show the importance of industrial policy analyses incorporating how policy can influence engineering design decisions (Whitefoot et al 2017). Here, to begin to disentangle the labor implications of parts consolidation versus automation, we build on previous work by Fuchs (Fuchs and Kirchain 2010, Fuchs et al 2011) to undertake an in-depth empirical study in the semiconductor industry (monolithic production – e.g. parts consolidation – of optoelectronic transceivers). Although outside the scope of this proposal, we are preparing to also undertake a second project on parts consolidation in the automotive industry (specifically, the automobile body). By collaborating with labor economists Ales and Kovak, our goal is to eventually examine implications for state-of-the art economic production functions, and incorporate the insights from the engineering models into models of market equilibrium.

Preliminary work: Building on previous work by Fuchs et al 2011, we separate the effects of two emerging manufacturing technologies -- parts consolidation versus automation – on labor market outcomes. In summer 2017, four leading firms representative of the broader industry provided detailed design and process flow information (including detailed labor data), culminating in detailed process data on 400 production steps across four product designs and more than 23 variables per step. We focused initially on the low-education labor market: From each company, we collected the typical operational inputs to a engineering process-based cost model, including facility-wide inputs such as hours per shift, working days per year, building price, and facility-wide annual downtime as well as detailed per process step inputs such as equipment prices, yields, cycle times, material usage, labor usage, and wages. In addition, using a survey based on the O*NET survey instrument, we for the first time collect additional labor-specific data for each process step on the difficulty of the associated tasks in terms of different

aptitude types. Per O*NET's reference values, difficulty for each aptitude type (including skills such as dexterity, near vision, and operations and control) is measured on a 1-7 scale. Here, for example, a dexterity skill level of 2 corresponds to placing coins in a parking meter, 4 approximates attaching small knobs to stereo equipment on an assembly line, and 6 compares to assembling the inner workings of a wristwatch (O*NET). *Preliminary Findings:* The SBTC literature focuses on automation, and is largely limited to indirect measurement of effects of technology change on number of jobs and type of skills. It suggests returns to high skill, loss of routine and manual jobs and gains for high education, losses at mid-educational levels. Our research offers direct measurement of technology change in manufacturing and effect on skill requirements for low-education shop-floor workers. Our preliminary findings, by separating two simultaneous forms of technology change, find these two forms of technology change to have heterogeneous effects on skill requirements, absent in the current literature and not picked up by aggregate measures. Figure 1, for example, shows how an aggregate measure of technology change (shown in red) fails to pick up that automation (shown in grey) and consolidation (shown in green) have different directional effects on near vision skill demand within manufacturing operators. Overall across the aptitudes we measure, we find automation to polarize skill demands in low-education jobs, while with consolidation different job losses and aptitude requirements shift (in at least one case converging). In both cases, the jobs remaining require more training. *Next steps:* With the support of NBER funding we plan 1) to continue our data collection to complete the required detail on labor skills/training/education requirements at the low-end of the education spectrum (e.g. operators) preliminary results from which are shown above, and to add data collection on the skills required at higher levels in the organizational chart, including technicians, trainers, first-line supervisors, and engineers; 2) to calibrate labor economic models using these new data so as to be able to examine the implications for labor demand and workforce skill requirements.

Fig. 1: Disentangling Technology Change Effects on Labor Outcomes



Impact: We anticipate two main contributions of this research: (1) we disentangle and demonstrate heterogeneous labor demand effects of simultaneous technology change, possibly requiring targeted policy responses; and (2) we directly measure demand for labor characteristics for manufacturing shop floor operators in terms of detailed heterogeneous aptitude requirements. To our knowledge, this paper is the first of its kind to directly measure the effect of simultaneous technological change on demand for manufacturing operator skill. We expect multiple aspects of our approach to generalize: First, for our approach, where technology change manifests in process inputs, process flows, we demonstrate how engineering models may offer new insights in the economic study of skill requirement and other effects (e.g. training time of technology change. While it is unlikely such techno-economic models will be used broadly, they could be used to develop insights for alternative types of data that should be collected, for example, by the US Census Bureau to capture the implications of technology change for labor outcomes. Second, we expect our preliminary findings that different forms of technology change in manufacturing may have heterogeneous effects on skills requirements, that are currently unobserved in aggregate data to generalize.

Budget: $20,000: $18K - 6 months CMU Ph.D. Student stipend; 2K - travel for data collection

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Erica R.H. Fuchs is a Professor in the Department of Engineering and Public Policy at Carnegie Mellon University, and was the founding Faculty Director of Carnegie Mellon University's Manufacturing Futures Initiative – an initiative across six schools aimed to revolutionize the commercialization and local production of advanced manufactured products. Her research focuses on the development, commercialization and global manufacturing of emerging technologies, and national policy in that context. Dr. Fuchs was selected in 2012 as World Economic Forum Young Scientist (top 40 under 40, internationally). Over the past decade, Dr. Fuchs has played a growing role in national and international meetings on the future of advanced manufacturing, including being one of 23 participants in the President's Council of Advisors on Science and Technology workshop that led to the creation of the Advanced Manufacturing Partnership, and serving on the expert group that supported the White House in the 2016 Innovation Dialogue between the U.S. and China. She currently serves on the National Academies' National Materials and Manufacturing Board; the World Economic Forum's Future of Production Global Futures Council; the Academic Advisory Board for M.I.T.'s Institute for Data, Systems, and Society, of which M.I.T.'s Technology Policy Program is a part; and the Advisory Editorial Board for *Research Policy*. Before coming to CMU, Dr. Fuchs completed her Ph.D. in Engineering Systems at M.I.T. in June 2006. She received her Masters and her Bachelors degrees also from M.I.T. in Technology Policy (2003) and Materials Science and Engineering (1999), respectively. Dr. Fuchs spent 1999-2000 as a fellow at the United Nations in Beijing, China. She grew up and attended K-12 in the Reading Public School District in Reading, PA. Her work has been published among other places in *Science,* the *Nature* journals, *Research Policy*, and *Management Science;* and has been covered on National Public Radio and in the *New York Times*.

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Education

University of Michigan	Ann Arbor, MI	Mechanical Engineering	B.S., 2006
University of Michigan	Ann Arbor, MI	Mechanical Engineering	M.S., 2008
University of Michigan	Ann Arbor, MI	Design Science*	Ph.D., 2011

*Design Science is a degree program at the University of Michigan where students complete course requirements and have advisors in two disciplines, one in engineering and one in the social sciences (mechanical engineering and economics in this case). They prepare dissertations related to the study of product and process design that are evaluated by a committee split between the two disciplines.

Appointments

2016-Present	Assistant Professor, Department of Mechanical Engineering, and Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA
2011-2015	Senior Program Officer, National Academy of Engineering, Washington, D.C.
2010	Summer Fellow, Resources for the Future, Washington, D.C.
2007	Research Assistant, ICF International, Fairfax, VA

Selected Publications

Huang, R., E. Ulu, L. B. Kara, & K. S. Whitefoot. "Cost minimization in Metal Additive Manufacturing using Concurrent Structure and Process Optimization." *ASME Design Engineering Technical Conferences* 2 (2017).

Whitefoot, K. S., M. L. Fowlie, & S. J. Skerlos. "Compliance by Design: Influence of Acceleration Trade-offs on CO2 Emissions and Costs of Fuel Economy and Greenhouse Gas Regulations." *Environmental Science & Technology* 51, no. 18 (2017): 10307-10315.

Donofrio, N. M., & Whitefoot, K. S. (2015). *Making Value for America: Embracing the Future of Manufacturing, Technology, and Work*. Washington, DC: National Academy Press.

Morrow, W. R., Mineroff, J., & Whitefoot, K. S. (2012). Numerically Stable Design Optimization with Price Competition. *3*, 19.

Whitefoot, K. S., Grimes-Casey, H. G., Girata, C. E., Morrow, W. R., Winebrake, J. J., Keoleian, G. A., & Skerlos, S. J. (2011). Consequential Lifecycle Assessment with Market-Driven Design Decisions: Development and Discussion. *Journal of Industrial Ecology 15*(5), 726-742.

Frischknecht, B. D., & Whitefoot, K. S. (2011). Defining Technology-Adoption Indifference Curves for Residential Solar Electricity Generation Using Stated Preference Experiments. *5*, 10.

Whitefoot, K. S., & Skerlos, S. J. (2011). Design Incentives to Increase Vehicle Size Created from the U.S. Footprint-based Fuel Economy Standards. *41*(February), 402-411.

Frischknecht, B. D., Whitefoot, K. S., & Papalambros, P. Y. (2010). On the Suitability of Econometric Demand Models in Design for Market Systems. *132*(12), 11.

Selected Professional Activities

- Invited to brief the White House Council of Economic Advisors, the Department of Commerce, and the U.S. House of Representatives Committee on Science, Space, and Technology on technological advances in manufacturing, workforce outcomes, and manufacturing policy.
- Served as Guest Editor of the National Academy of Engineering's publication *The Bridge* for the Special Issue on Engineering, Technology, and the Future of Work (2015, Vol. 45, Issue 3).

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EMPLOYMENT AND AFFILIATIONS

Carnegie Mellon University, Heinz College, Associate Professor
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EDUCATION

Ph.D., Economics, University of Michigan (2010).
M.P.A., Indiana University (2004).
B.S., Computer Engineering, Penn State (2002).

JOURNAL ARTICLES

"Measuring Sub-national Migration Networks using *Matriculas Consulares*" *forthcoming,* ***Demography***. (with Brian Cadena and Maria Esther Caballero)

"Trade Liberalization and Regional Dynamics" (2017)*,* ***American Economic Review.*** Vol. 107 no. 10, p.1908-2946 (with Rafael Dix-Carneiro).

"Quality-Adjusted Price Measurement: A New Approach With Evidence from Semiconductors" (2017) ***Review of Economics and Statistics*** Vol. 99 no. 2, p. 330-342 (with David Byrne and Ryan Michaels).

"Immigrants Equilibrate Local Labor Markets: Evidence from the Great Recession" (2016) ***American Economic Journal: Applied Economics*** Vol. 8 no. 1, p.257-290 (with Brian C. Cadena).

"Trade Liberalization and the Skill Premium: A Local Labor Markets Approach" (2015) ***American Economic Review: Papers and Proceedings*** Vol. 105 No. 5, p.551-557 (with Rafael Dix-Carneiro).

"Regional Effects of Trade Reform: What is the Correct Measure of Liberalization?" (2013). ***American Economic Review***. Vol. 103 No. 5, p1960-1976.

"Overestimating the Effect of Complementarity on Skill Demand" (2011). ***B.E. Journal of Economic Analysis & Policy.*** Vol. 11: Iss. 1 (Topics), Article 65.

AWARDS AND GRANTS

Institute for the Study of Labor (IZA) Young Labor Economist Award (2014).
Russell Sage Fdn.: Race, Ethnicity, and Immigration Grant (2018-2019) (co-PI Brian C. Cadena).
Manufacturing Futures Initiative Grant, Carnegie Mellon (2017-2018)
Early Career Research Grant, W.E. Upjohn Institute for Employment Research (2014) (with Rafael Dix-Carneiro)
Science and Technology Fdn., Portuguese Ministry of Science (2013-2014) (with Ana Venancio)
Russell Sage Fdn.: Social and Econ. Effects of the Great Recession Grant (2012-2013) (co-PI Brian C. Cadena).
Young Investigator Grant, Univ. of Kentucky Center for Poverty Research (2011) (co-PI Brian C. Cadena).

PROFESSIONAL ACTIVITIES

Grant Proposal Reviewer: National Science Foundation, Russell Sage Foundation, IZA
Associate Editor, *Journal of Development Economics*
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Employent

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Education

Degree	Field	Institution	Year
Ph.D.	Economics	University of Minnesota	2008
Dottorato	Economia	University of Rome – Tor Vergata	2008
M.S.	Economics	University of Minnesota	2007
Laurea (*cum laude*)	Physics	University of Rome – Tor Vergata	2002

Publications

(8) "Taxing Atlas: Executive Compensation, Firm Size and Their Impact on Optimal Top Income Tax Rates" (with A. Andrés Bellofatto and Jessie Jiaxu Wang) *Review of Economic Dynamics*, Volume 26 (2017) 62 – 90

(7) "Optimal Award Scheme in Innovation Tournaments" (with Soo-Haeng Cho and Ersin Körpeoğlu) *Operations Research*, Volume 65 No. 3 (2017) 693 – 702

(6) "Non-Exclusive Dynamic Contracts, Competition and the Limits of Insurance" (with Pricila Maziero) *Journal of Economic Theory*, Volume 166 (2016) 362 – 395

(5) "Taxing Top CEO Incomes" (joint with Christopher Sleet), *The American Economic Review*, Volume 106 No. 11 (2016) 3331 – 3366

(4) "Technical Change, Wage Inequality and Taxes" (with Musab Kurnaz and Christopher Sleet), *The American Economic Review*, Volume 105 No. 10 (2015) 3061 – 3101

(3) "A Theory of Political and Economic Cycles" (Pricila Maziero and Pierre Yared), *Journal of Economic Theory*, Volume 153 (2014) 224 – 251

(2) "Revision Proofness" with Christopher Sleet, *Journal of Economic Theory*, Volume 152 (2014) 324 – 355

(1) "A Model of Banknote Discounts" (with Francesca Carapella, Pricila Maziero and Warren Weber), *Journal of Economic Theory*, Volume 142 (2008) 5 – 27

Grants & Awards

- The William H. and Frances S. Ryan Award for Meritorious Teaching, Carnegie Mellon University (2017)
- Richard M. Cyert Award for Excellence in Teaching, Tepper School of Business, Carnegie Mellon University (2012)
- With co-PIs Brian Kovak and Katie Whitefoot. *"Emerging Technologies, Labor Outcomes, and Policy Responses"* ($146,000), Manufacturing Futures Initiative, Carnegie Mellon University (2017)
- With co-PI Soo-Haeng Cho. *"Optimal Award Scheme in Innovation Tournaments"* ($20,000), Carnegie Bosch Institute, Carnegie Mellon University (2015)

Professional Activities

- Associate Editor for Macroeconomic Dynamics