1. Online Supplement

1.1. Data Collection Overview

This section presents additional detail on the types of data collected during site visits to the factor presented in the text of our paper. Table 1 presents these details.

Table 1 Overview of data collection.

Site Visit & Data Collection Overview	
Preliminary Site Visit	2 days
First Data Collection Site Visit	7 days
Second Data Collection Site Visit	10 days
Production Floor Observation	12 hours observation 2 hours participation
Semi-structured Interviews	8 with vice president 30 with engineers & managers 3 with trainers
Surveys	11 final product engineers 2 subcomponent engineers 3 trainers
Field Notes	112 typed pages
Archival Data Records	17.5GB of data from production and human resources databases from as early as 2001

1.2. Engineer Survey Questions

Background Information:

What is your name?

What is your position title at [firm]?

What is your email address and phone extension (will only be used for questions on survey)?

When did you start working at [firm]?

What production area do you work in (example: [stage 1, stage 2], etc.)

What types of products or processes have you worked on during your tenure at [firm]?

Questions on Processes & Products:

For questions that ask about specific product families, please only fill out information on products that you have worked with directly.

1. In your mind, what makes products similar during production (for example, [end use application], [attribute (A or B)], products that undergo certain process steps, products that have a specific form factor or component)?

2. Please describe your experience with implementing a new product on the production line. Please be as specific as possible.

3. Please rate each process step for each grouping of products based on difficulty for the line worker on a scale of 1-5 where 1 is very simple, 2 is simple, 3 is neutral, 4 is difficult, and 5 is very difficult.

Process Step	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**
Process Step 1								
Process Step 2								
...								
Process Step 77								

4. For your production area, what percentage of machines are used on both products in a given box below?
Example for bold box: x% of machinery used for 1a products is also used for 1b products.

	1a	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**
1a								
1b								
2a								
2b								
3a								
3b								
4a								
4b								

5. For your production area, what percentage of trainers have ever worked on both products in a given box below?
Example for bold box: x% of trainers who work on 1a products have also ever worked on 1b products.

	1a	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**
1a								
1b								
2a								
2b								
3a								
3b								
4a								
4b								

6. For your production area, what percentage of technicians have ever worked on both products in a given box below?
Example for bold box: x% of technicians who work on 1a products have also ever worked on 1b products.

	1a	1b	2a	2b	3a	3b	4a	4b
1a								
1b								
2a								
2b								
3a								
3b								
4a								
4b								

7. What percentage of engineers have ever worked on both products in a given box below? Example for bold box: x% of engineers who work on 1a products have also ever worked on 1b products

	1a	1b	2a	2b	3a	3b	4a	4b
1a								
1b								
2a								
2b								
3a								
3b								
4a								
4b								

8. For your production area, please list any major tool or equipment changes (if any) that have happened. (For example: new oven, more production lines, new soldering equipment, new automated machinery, etc.)

Year	Major tool or equipment changes
2001	
2002	
2003	
2004	
2005	
2006	
2007	
2008	
2009	
2010	
2011	

1.3. Trainer Survey Questions

Background Information:

What is your name?

What is your position title at [firm]?

What is your email address and phone extension (will only be used for questions on survey)?

When did you start working at [firm]?

What types of products or processes have you worked on during your tenure at [firm]?

Questions on Processes & Products:

1. Please describe each type of process (simple, skill-based, criteria-based, special case, hazardous, other) and list how long it takes on average to train a manufacturing specialist in that process.

Process Step	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**
Process Step 1								
Process Step 2								
...								
Process Step 77								

1.4. Robustness of Findings

This section presents additional regressions establishing robustness of findings presented in the text of our paper.

Equation A1 is our preferred model from Column 5 of Table 4 of the text. Hence, robustness is established by comparing results in each succeeding column to those in column A1.

Column A2 uses an alternate measure of capital. Recall that the capital measure used in column A1 is the cumulative number of testers. The alternate measure in column A2 is designed to allow for the possibility that a new piece of testing equipment is not fully utilized immediately. Instead, utilization of each new tester is assumed to ramp up linearly to full utilization, with full utilization occurring at the date when a subsequent tester arrives. Hence, this capital measure is an estimate of cumulative testers in use in each week. The coefficient and significance level for this variable are virtually identical to the coefficient and significance level for the capital variable in column A1. All other variables have virtually the same coefficients and significance levels in the two equations.

To investigate further the role of capital, equation A3 includes a variable that is the ratio of cumulative number of testers to labor. This variable is highly significant, demonstrating that an increase in the capital labor ratio increases productivity. Again, however, virtually identical coefficients for all other variables are obtained in columns A1 and A3. Still another robustness measure with respect to capital is provided in column A4. An indicator variable is included that is equal to one for each of the three weeks preceding the arrival of a new piece of capital equipment and zero otherwise. This coefficient is negative and significant showing that productivity is lower in the three weeks prior to arrival of a new piece of capital by roughly 5.5%. This is consistent with our expectation that an order for new testing equipment is made when intensity of use of existing testers begins to cause a decline in productivity. Again, coefficients and significance levels of all other variables in column A4 are virtually unchanged from those in column A1. Tests are required in fixed proportion to output. We expect that increasing the number of testing machines can have marginal benefit beyond the required minimum by limiting bottlenecks in which workers are waiting for each other to complete tests. The results summarized above are consistent with this expectation while also confirming that, regardless of the way we control for capital, our results with respect to learning are quite robust.

Next we turn to investigation of a time trend. As shown in column A5, the coefficient of the time trend is negligible in magnitude and statistically insignificant. All other coefficients and their significance levels are virtually the same as in column A1.

Column A6 investigates the robustness of the coefficients of the labor variable by allowing the effect of labor to differ when labor is increasing from when labor is decreasing. The motivation is the following. If adjustment of labor in one direction is more difficult than in the other direction, one would expect this to be reflected in differences in labor productivity. In the regression in column A6, dummy variable dlup equals one if labor increased during the current week relative to the previous week and zero otherwise. Dummy variable dldown equals one if labor decreased during the current week relative to the previous week and zero otherwise. The coefficients are identical to three significant figures. Hence, in this respect, the estimated effect of labor is strikingly robust.

Column A7 investigates potentially different coefficients for cumulative volume of focus-and non-focus products. The coefficient for cumulative volume of focus products (0.244) in column A7 is slightly higher than the coefficient (0.237) for cumulative volume of all products in column A1, and the coefficient for cumulative volume of non-focus products in column A7 is small (-0.043) and statistically insignificant. Coefficients and significance levels of all other variables differ little between columns A1 and A7.

Column A8 extends the specification in column A1 by allowing for first-order autocorrelation of the residuals. The estimated autocorrelation coefficient is negligible in magnitude and statistically insignificant. Coefficients and significance levels of all other variables are little changed from column A1.

Column A9 is estimated using labor hours rather than number of workers. The labor hours variable is available for a relatively short period of time compared to the overall sample period used to estimate the model in column A1. Hence, there is considerably less variation in most of the variables during this shorter timeframe than during the longer sample. Despite this, the estimated coefficients on the learning variable (cumulative volume), labor, and customization variables in column A9 are statistically significant. The estimated effect of labor hours (last row of column A9) is somewhat lower than the coefficient of labor (second row in column A1). The estimated impact of learning is somewhat higher in column A9 than in column A1. The estimated effects of generational overlap and share non-focus products are not significant, reflecting the reduced variability of these two variables in the subsample relative to the overall sample. Overall, the estimates in column A9 are quite reassuring, especially in demonstrating that this alternate hours variable does not yield a dramatically different estimate of the effect of labor than is obtained in column A1.

	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)	(A9)
β_1, Experience $\ln(Q_{t-1})$	0.242** (0.102)	0.237** (0.106)	0.285*** (0.041)	0.282*** (0.041)	0.236** (0.108)	0.237** (0.104)		0.236** (0.106)	0.357** (0.177)
β_3, Labor $\ln(L_t)$	0.251*** (0.071)	0.252*** (0.070)	0.257*** (0.075)	0.264*** (0.070)	0.251*** (0.072)		0.261*** (0.075)	0.251*** (0.070)	
β_4, Capital $\ln(S_t)$	0.052 (0.099)								
Capital, Number Testers		0.059 (0.104)			0.058 (0.102)	0.059 (0.104)	0.049 (0.107)	0.059 (0.104)	-0.111 (0.203)
β_5, Share Non-focus $s_{n,t}$	-0.658 (0.402)	-0.660* (0.400)	-0.664 (0.410)	-0.687* (0.414)	-0.662 (0.429)	-0.660* (0.397)		-0.662* (0.400)	-0.098 (0.376)
β_6, Generational Overlap $G_{f,t}$	-0.498*** (0.142)	-0.497*** (0.138)	-0.479*** (0.124)	-0.494*** (0.121)	-0.497*** (0.139)	-0.497*** (0.134)	-0.565*** (0.131)	-0.498*** (0.138)	0.056 (0.226)
β_7, Cust.: Focus $M_{f,t}$	-810.703*** (85.314)	-811.503*** (86.037)	-799.105*** (85.764)	-796.468*** (86.115)	-811.561*** (86.458)	-811.500*** (85.522)	-880.505*** (68.367)	-811.346*** (85.771)	-1536.457*** (97.959)
β_8, Cust.: Non-focus $M_{n,t}$	-23.877*** (4.934)	-23.898*** (4.929)	-23.609*** (4.992)	-23.336*** (4.859)	-23.915*** (5.199)	-23.899*** (4.830)	-18.028*** (2.792)	-23.891*** (4.948)	-21.599*** (6.173)
Testers per laborer $CapNum/L_t$			6.830*** (2.312)						
Capital Dummy				-0.056*** (0.018)					
Calendar Time					8.00E-06 (4.00E-04)				
Labor Increasing $DL_{up} * \ln(L_t)$						0.252*** (0.070)			
Labor Decreasing $DL_{down} * \ln(L_t)$						0.252*** (0.070)			
Experience Focus Prod. $\ln(Q_{f,t-1})$							0.244** (0.110)		
Experience Non-focus Prod. $\ln(Q_{n,t-1})$							-0.043 (0.085)		
Labor Hours									0.183** (0.082)
Observations	461	461	461	458	461	461	461	461	187
R^2	0.956	0.956	0.956	0.956	0.956	0.956	0.955	0.956	0.873