Online Appendix

LEARNING BY NECESSITY:

GOVERNMENT DEMAND, CAPACITY CONSTRAINTS, AND PRODUCTIVITY GROWTH

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June 24, 2024

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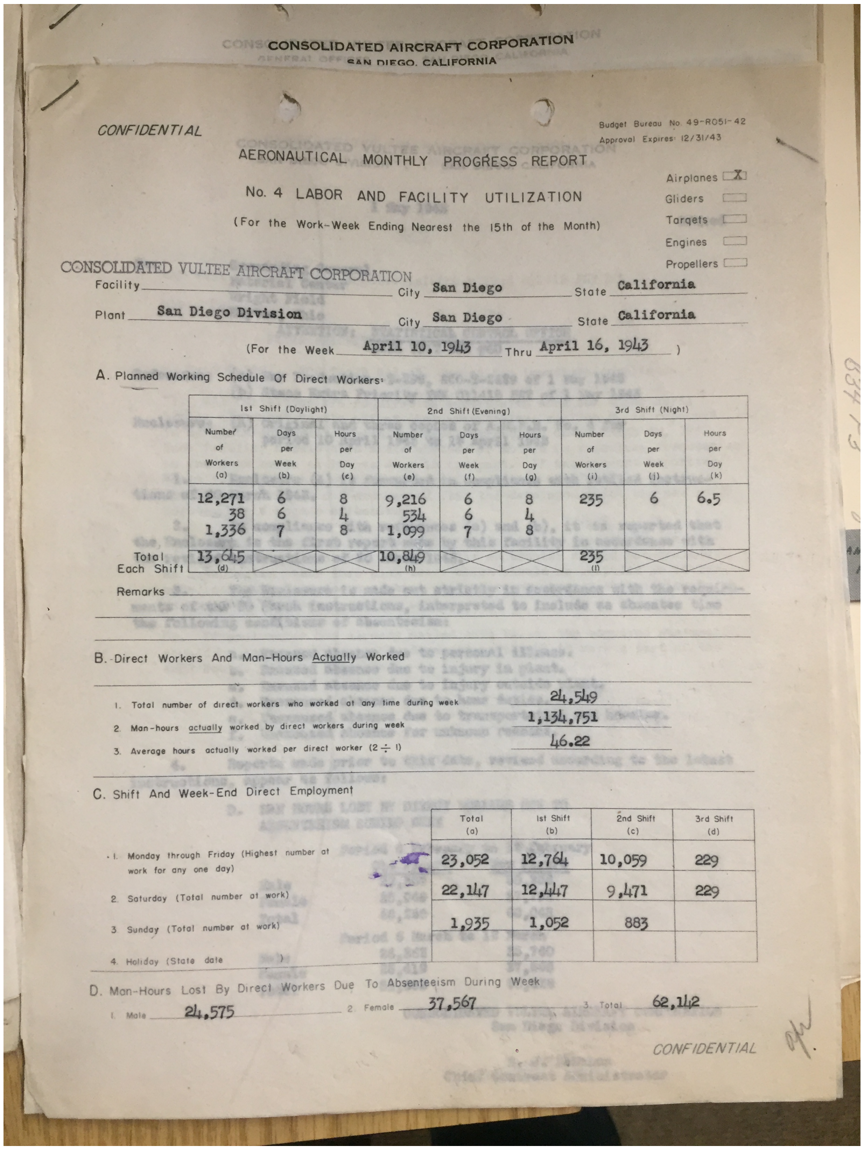
A Appendix Figures & Tables (For Online Publication)

Figure A.1: AMPR Form Filled by an Airframe Manufacturer



CONSOLIDATED AIRCRAFT CORPORATION
SAN DIEGO, CALIFORNIA

CONFIDENTIAL

Budget Bureau No. 49-R051-42
Approval Expires: 12/31/43

AERONAUTICAL MONTHLY PROGRESS REPORT

No. 4 LABOR AND FACILITY UTILIZATION

(For the Work-Week Ending Nearest the 15th of the Month)

Airplanes [X]
Gliders [ ]
Targets [ ]
Engines [ ]
Propellers [ ]

CONSOLIDATED VULTEE AIRCRAFT CORPORATION
Facility ______ City San Diego State California

Plant San Diego Division City San Diego State California

(For the Week April 10, 1943 Thru April 16, 1943)

A. Planned Working Schedule Of Direct Workers:

	1st Shift (Daylight)			2nd Shift (Evening)			3rd Shift (Night)		
	Number of Workers (a)	Days per Week (b)	Hours per Day (c)	Number of Workers (e)	Days per Week (f)	Hours per Day (g)	Number of Workers (i)	Days per Week (j)	Hours per Day (k)
	12,271 38 1,336	6 6 7	8 4 8	9,216 534 1,099	6 6 7	8 4 8	235	6	6.5
Total Each Shift	13,645 (d)			10,849 (h)			235 (l)		

Remarks ______

B. Direct Workers And Man-Hours Actually Worked

1. Total number of direct workers who worked at any time during week 24,549
2. Man-hours actually worked by direct workers during week 1,134,751
3. Average hours actually worked per direct worker (2 ÷ 1) 46.22

C. Shift And Week-End Direct Employment

	Total (a)	1st Shift (b)	2nd Shift (c)	3rd Shift (d)
1. Monday through Friday (Highest number at work for any one day)	23,052	12,764	10,059	229
2. Saturday (Total number at work)	22,147	12,447	9,471	229
3. Sunday (Total number at work)	1,935	1,052	883	
4. Holiday (State date)				

D. Man-Hours Lost By Direct Workers Due To Absenteeism During Week

1. Male 24,575 2. Female 37,567 3. Total 62,142

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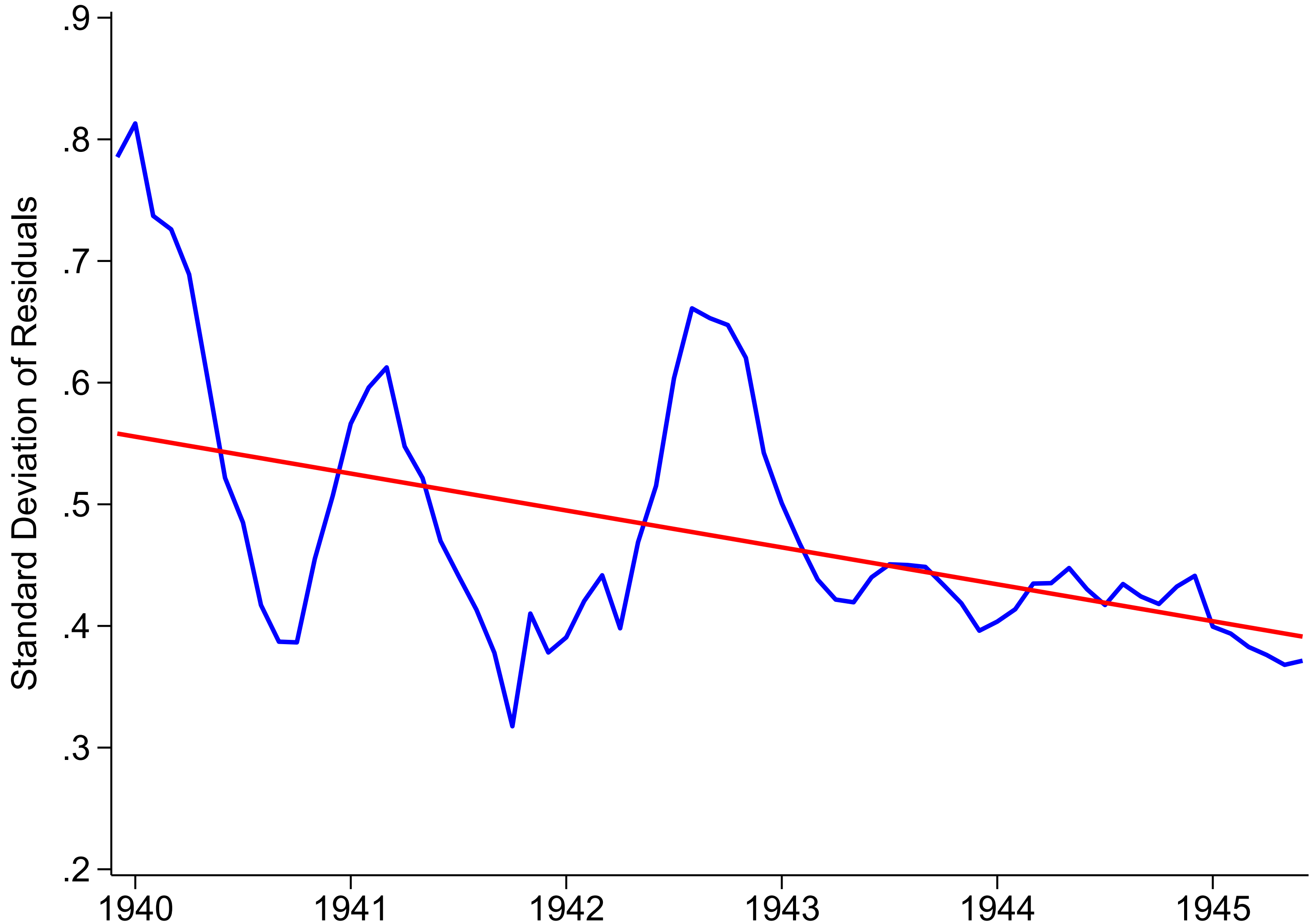
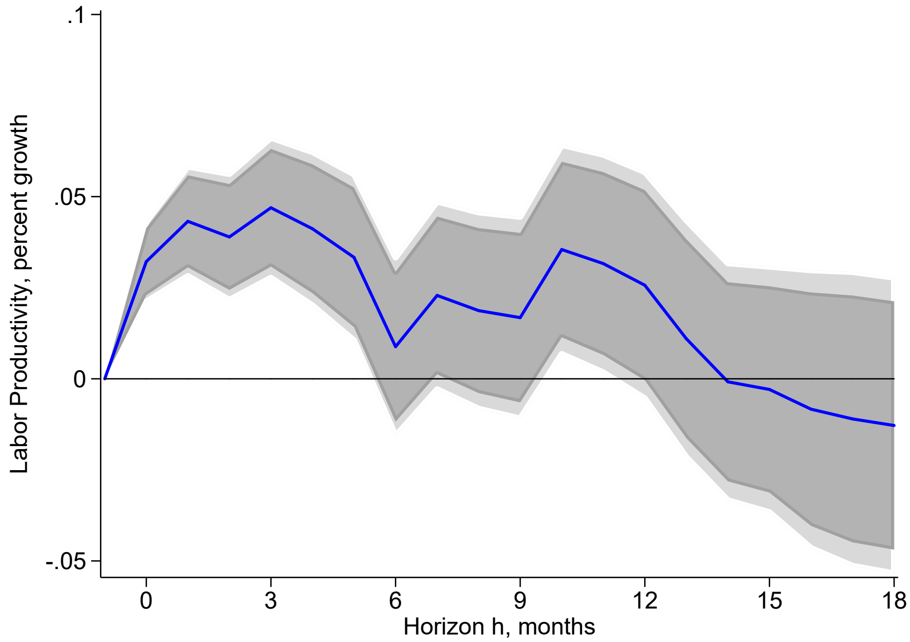
Note: Sample page from Aeronautical Monthly Progress Report (AMPR) form of Consolidated Vultee Aircraft Corporation, San Diego, in April 1943. This was a standardized form filled out by all aircraft manufacturers during the war. The sample comes from AMPR No. 4, which gives details on shift utilization. Source: Consolidated Vultee archives, San Diego Air and Space Museum, Box 34.

Figure A.2: Standard Deviation of (log) Aircraft Per Hour Worked Across Aircraft Plants

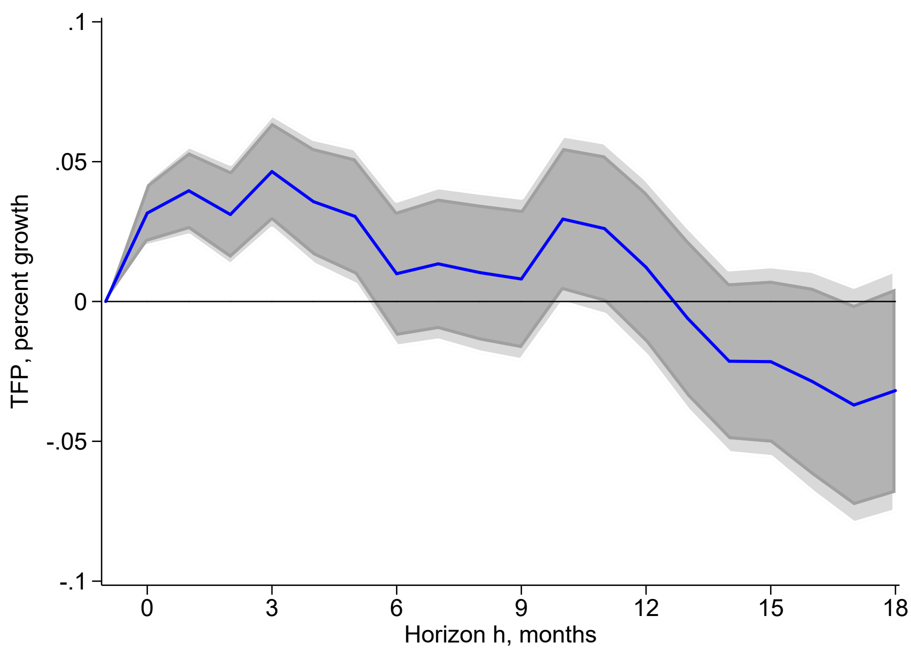


Note: The figure shows the standard deviation of log aircraft per hour worked (labor productivity) across airframe manufacturers in each month, 5-month moving average. Labor productivity is residualized from time and aircraft model fixed effects. The model fixed effects are crucial to absorb differences in aircraft per worker across aircraft models of varying size and complexity. Results are similar when excluding time fixed effects. Source: AMPR and the author.

Figure A.3: Response to a 1% Shock to Aircraft Demand (OLS)



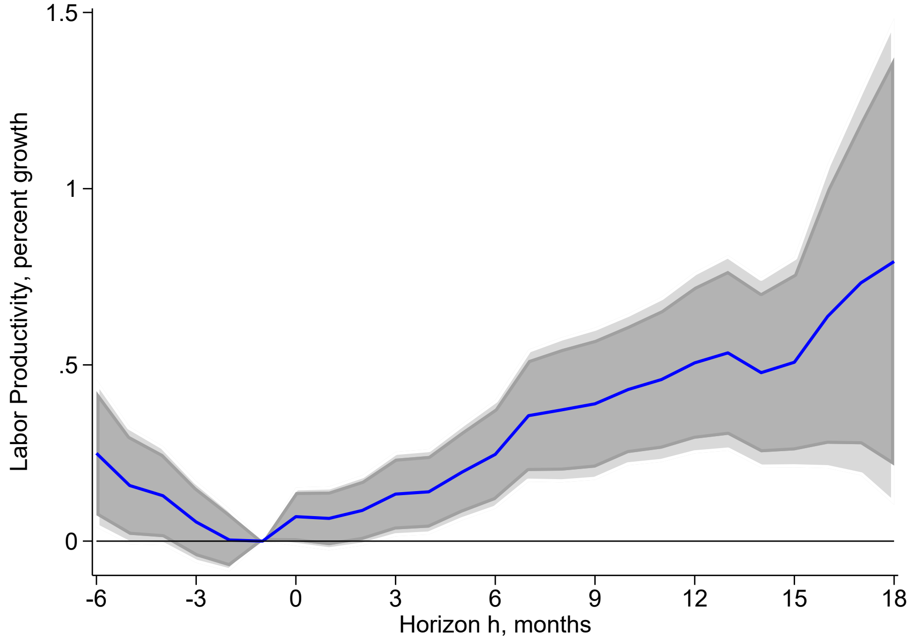
(a) Output per Hour Worked



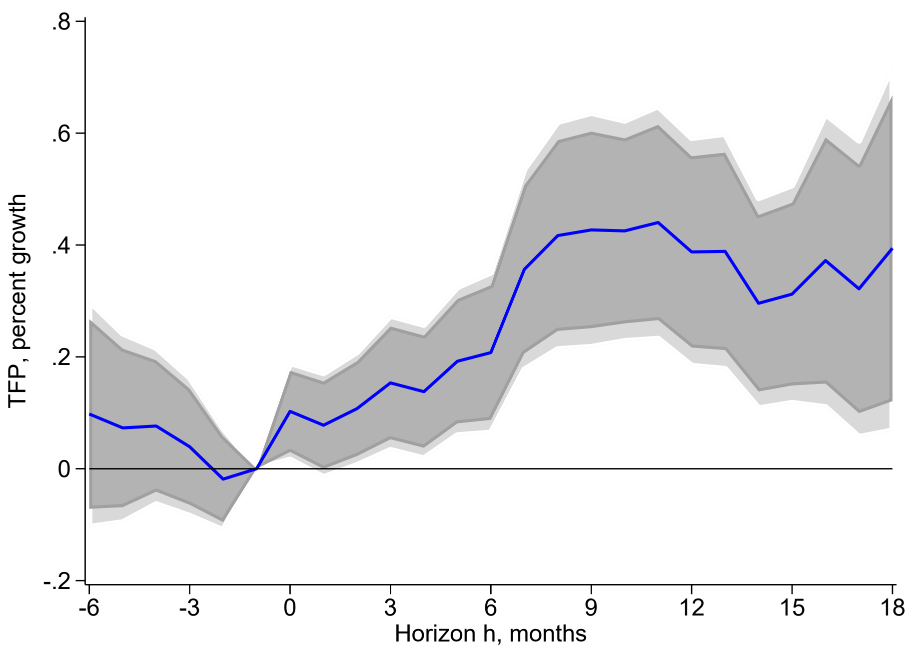
(b) TFP

Note: The figure shows the response of (a) log aircraft per hour worked and (b) TFP (adjusted for capital utilization). The shaded areas show 90% and 95% Newey-West confidence intervals. Responses are the β_h^{LBD} coefficients of OLS local projections estimates of (6), with $\beta_h^{LBN} = 0$ imposed.

Figure A.4: Pre-trends in Labor Productivity and TFP



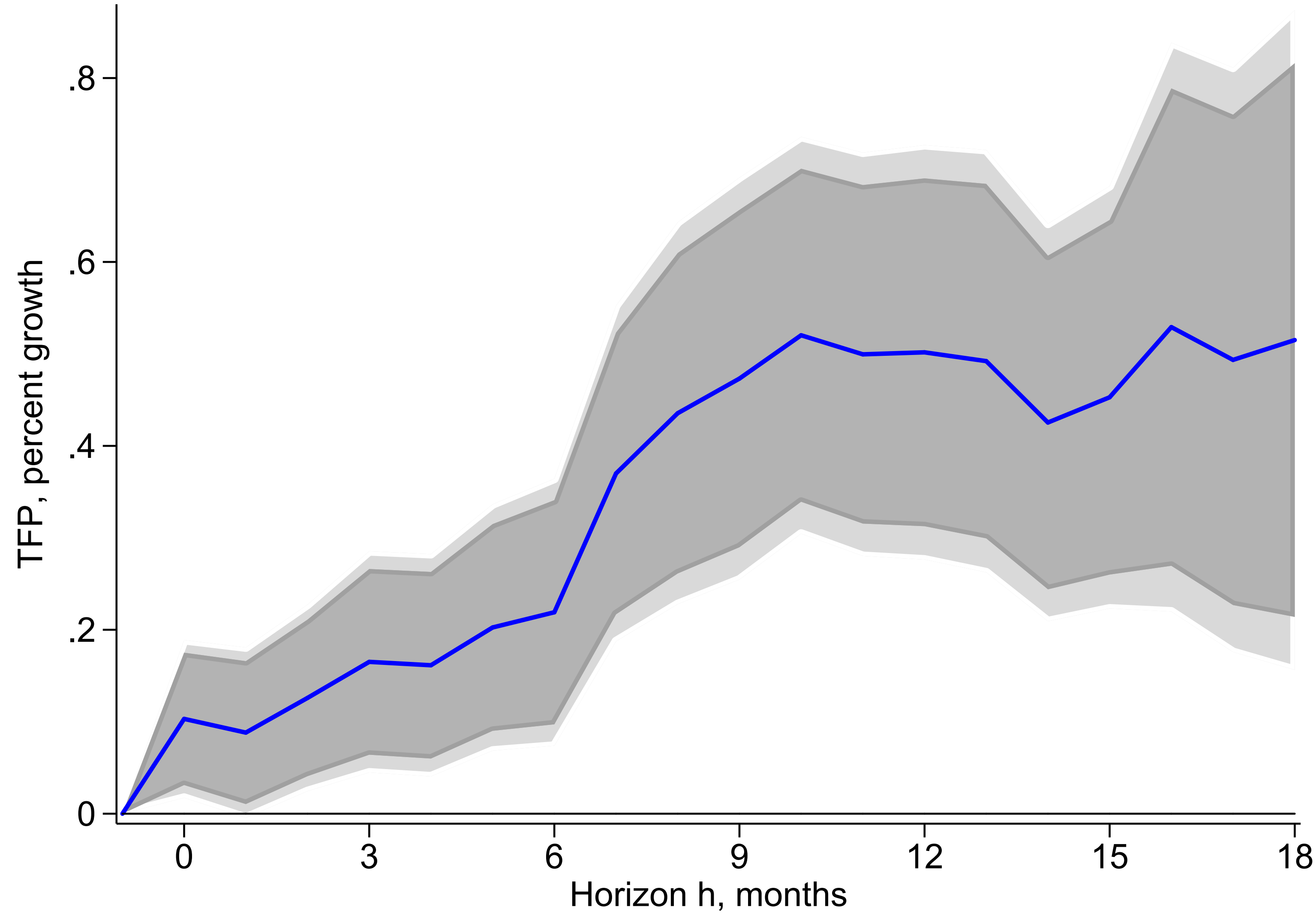
(a) Output per Hour Worked



(b) TFP

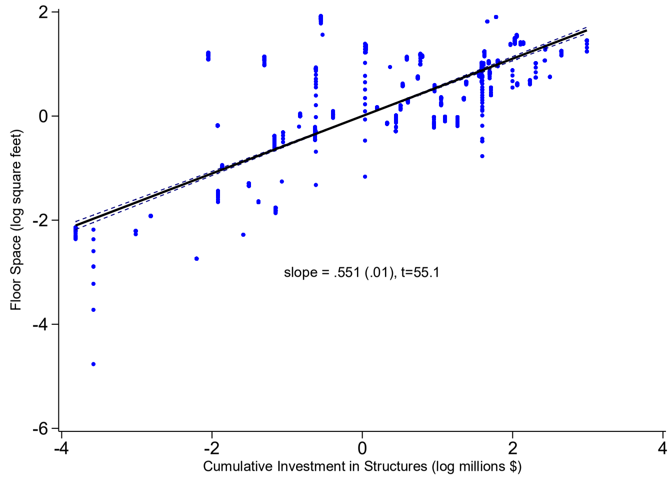
Note: The figure shows the response of (a) log aircraft per hour worked and (b) TFP (adjusted for capital utilization). Responses are the β_h^{LBD} coefficients of local projections estimates of (6), with $\beta_h^{LBN} = 0$ imposed. Aircraft demand is predicted by the instrument described in Section 2. Shaded areas show 95% Newey-West confidence intervals. First stage F-statistic at 12-month horizon = 24 and 30 in the two panels. Negative horizons are before the shock to demand and show pre-trends, evaluating differential trends of plants receiving a demand shock at time zero.

Figure A.5: Response of TFP (not adjusted for Capital Utilization) to a 1% Shock to Aircraft Demand

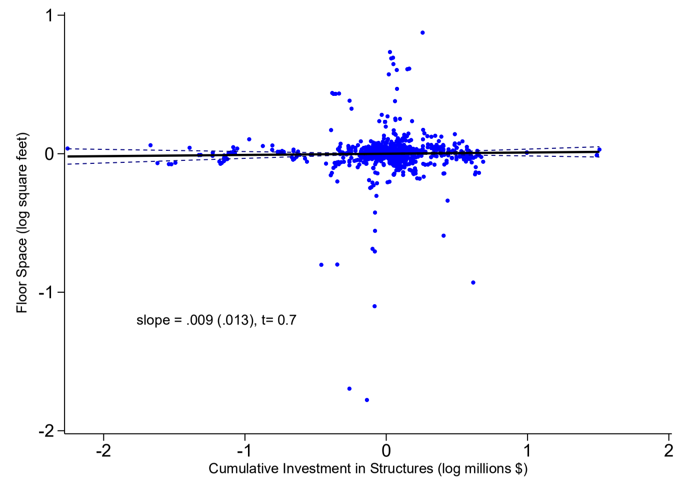


Note: The figure shows the response of TFP (not adjusted for capital utilization) to a one percent shock to aircraft demand. Estimates are based on local projections, with aircraft demand instrumented with the instrument described in Section 2, and laid out in (6). Shaded areas show 90% and 95% Newey-West confidence intervals. First stage F-statistic at 12-month horizon = 32.

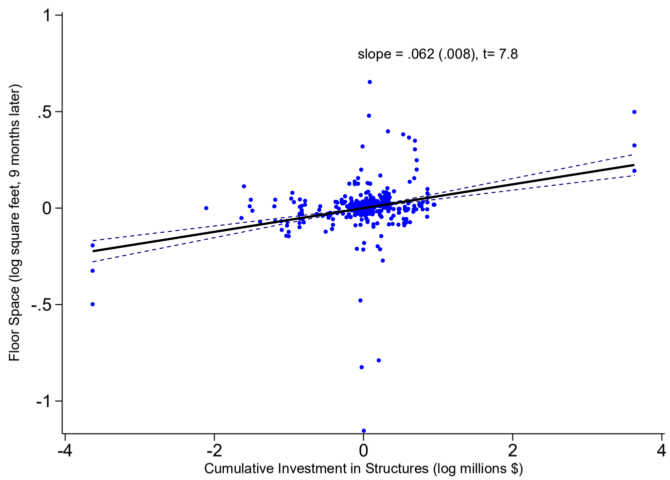
Figure A.6: Comparing Measures of Plant Capital



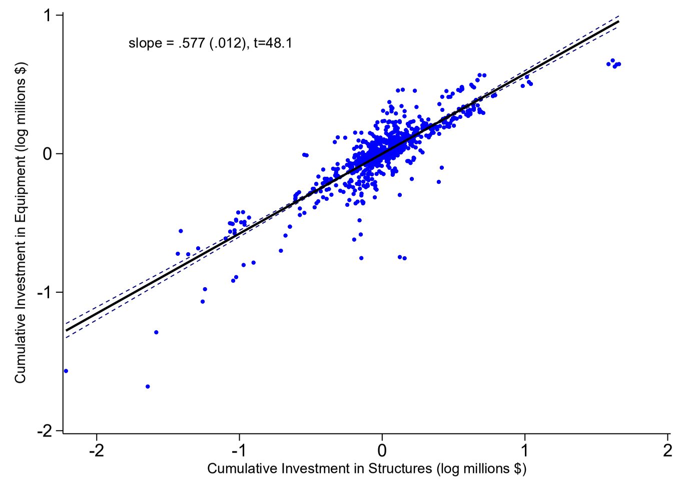
(a) Floor Space vs. Capital Investment in Structures



(b) Floor Space vs. Capital Investment in Structures with 2 way fixed effects



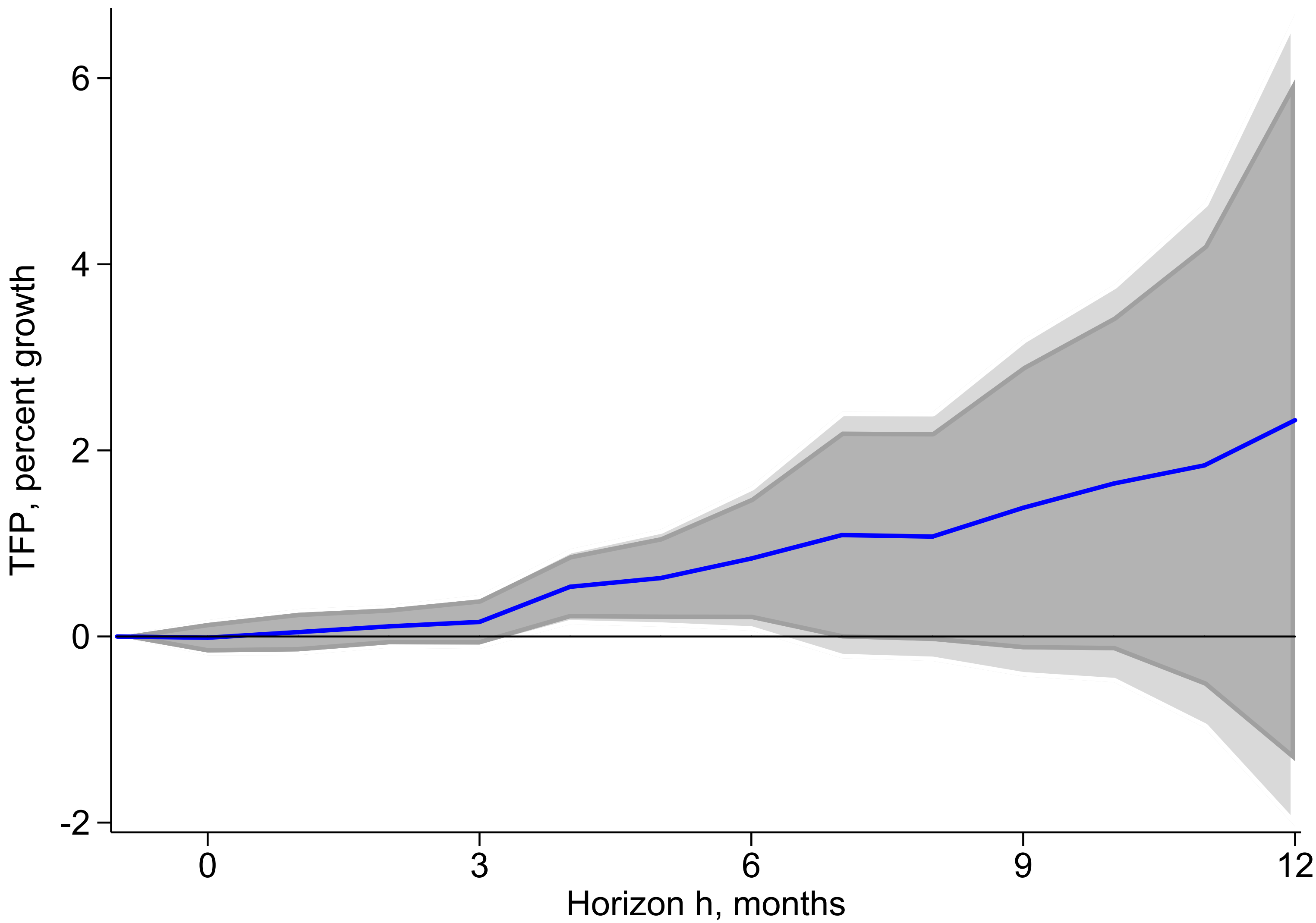
(c) Floor Space with 9 month lag vs. Capital Investment in Structures with 2 way fixed effects



(d) Capital Investment in Equipment vs. in Structures 2 way fixed effects

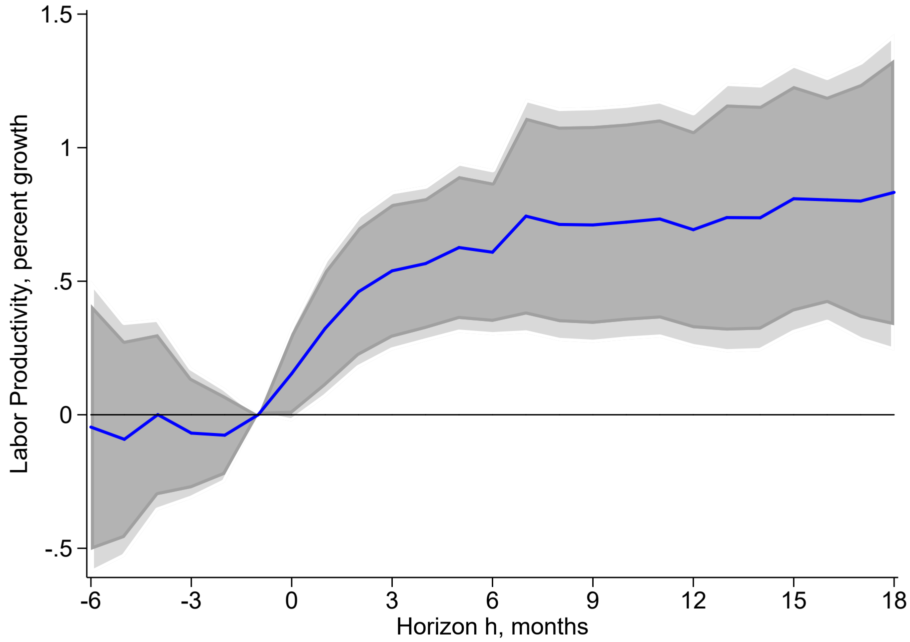
Note: Panel (a) shows a scatter plot of floor space in (log) square feet and cumulative investment in structures in (log) millions of US$. Each observation is a monthly reading of the two variables for a specific plant. Panel (b) shows the same figure residualized from monthly and plant fixed effects. The zero correlation in panel (b) means that the raw correlation in panel (a) is driven by plants having consistently different quantities of floor space and investment in structures over the war's duration; and by the across-the-board growth in both capital and in floor space over the duration of the war. Panel (c) then shows a scatter plot of current cumulative investment in structures and floor space in use *9 months later*. Despite two-way fixed effects there is a strong correlation between the two, reflecting that investments in structures only lead to increased floor space with a substantial lag. Panel (d) shows a strong contemporaneous correlation between cumulative capital investments in structures and capital investments in equipment. A 1% increase in the value of structures is associated with a 0.6% increase in the value of equipment. The figure is similar when looking at investment flows rather than cumulative stocks. Sources: USAAF (1952) Vol. 1, Table 5 and "War Manufacturing Facilities Authorized by State and County,"War Production Board Program and Statistics Bureau, June 15, 1945. RG 179, box 984, NARA College Park.

Figure A.7: Response of TFP to a 1% Shock to Aircraft Demand, Using Demand Shocks Only from First Half of Sample

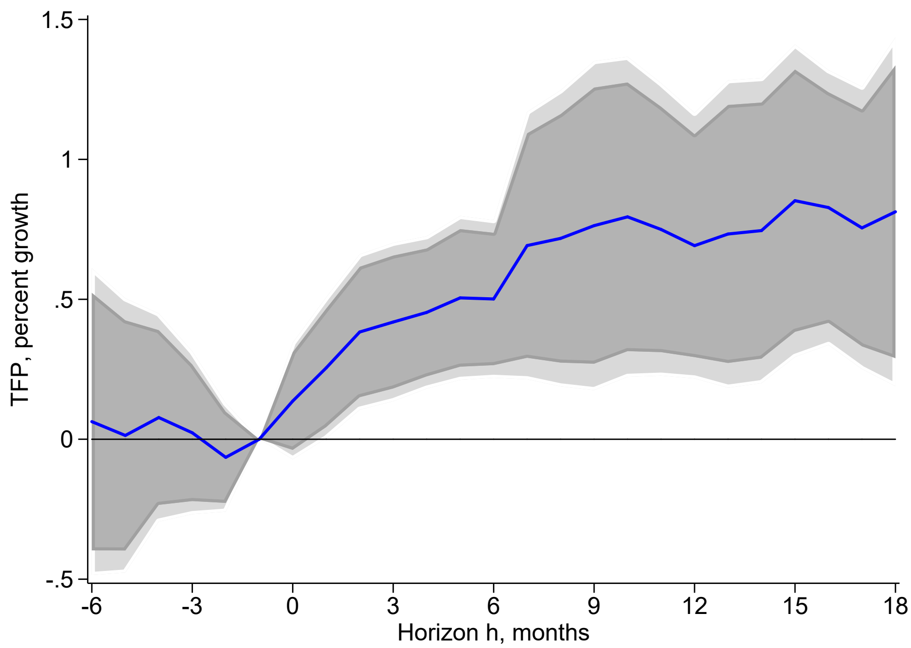


Note: The figure shows the response of TFP (not adjusted for capital utilization) to a one percent shock to aircraft demand. Estimates are based on local projections, with aircraft demand instrumented with the instrument described in Section 2, with estimating equation (6). The leave-one-out instrument is interacted with a dummy equaling one for months in the first half of the sample. This specification limits bias that could potentially arise when comparing plants receiving demand late in the war (“late treatment”) with plants receiving demand early in the war (“early treatment”) in months late in the war, following Goodman-Bacon (2021). Shaded areas show 90% and 95% Newey-West confidence intervals. First stage F-statistic at 5-month horizon = 7.5.

Figure A.8: Response of Productivity to a 1% Shock to Aircraft Demand in high vs. low capital utilization plants: Controlling for Plant Age



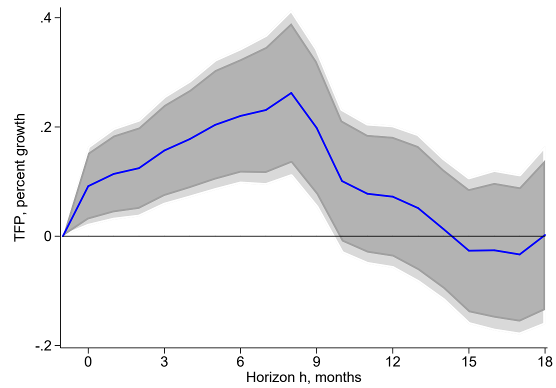
(a) Output per Hour Worked



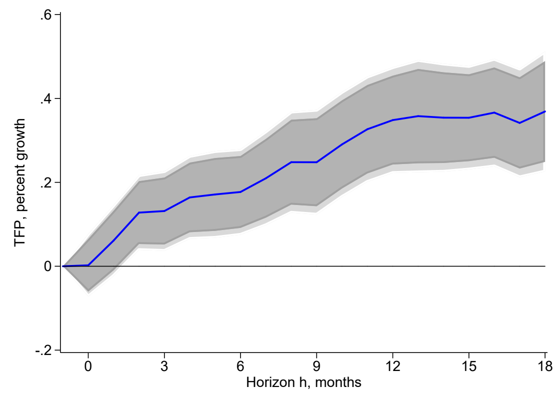
(b) TFP

Note: The figure shows responses of (a) (log) aircraft per hour worked and (b) TFP (adjusted for capital utilization) to a one percent shock to aircraft demand in plants with above median initial capital utilization relative to those with below median utilization. Responses are the the β_h^{LBN} coefficients of local projections estimates of (6). Aircraft demand and its interaction with initial capacity utilization are jointly predicted by the instrument described in Section 2 and its interaction with initial capacity utilization. The specification includes controls for plant age and the interaction between demand and a dummy equaling one if the plant was above median in age. Negative horizons are before the shock to demand and show pre-trends, evaluating differential trends of plants receiving a demand shock at time zero. Shaded areas show 90% and 95% Newey-West confidence intervals. First stage F-statistic at 12-month horizon = 3 in both panels.

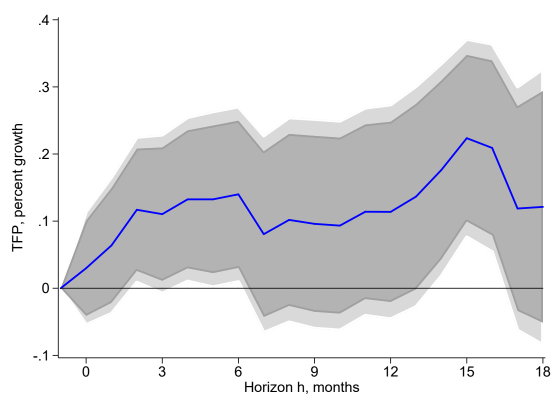
Figure A.9: Response of TFP to 1% Aircraft Demand Shock in Tight vs. Looser Labor Conditions



(a) Heterogeneity Based on Hours per Worker



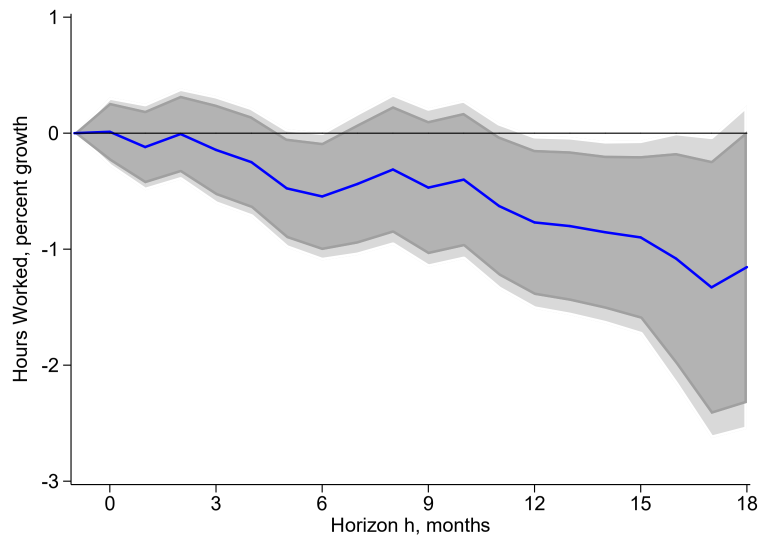
(b) Heterogeneity Based on Local Wages



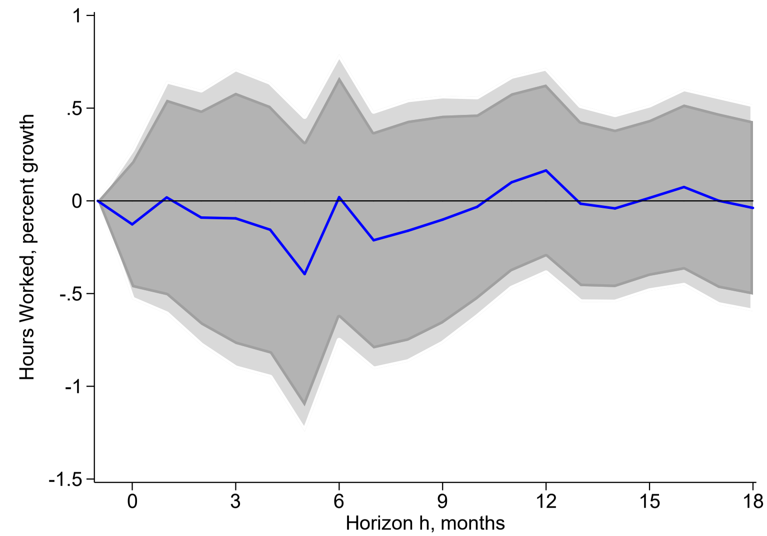
(c) Heterogeneity Based on War Manpower Commission Classification

Note: The figure shows responses of TFP to a one percent shock to aircraft demand in plants with tight labor conditions relative to those with looser labor conditions. Panel (a) shows response in plants that had above median hours per worker at the beginning of the war relative to those below the median. Panel (b) shows plants in labor markets with above median wages with our sample (wages were above the national median in most regions that had aircraft plants) at the beginning of the war relative to those below the median. Panel (c) shows plants in labor markets classified in group 1 (highest) labor market tightness by the War Manpower Commission at the beginning of the war, relative to those in categories 2-4. (Most aircraft plants were in labor markets classified in groups 1 and 2). Responses are the the β_h^{LBN} coefficients of local projections estimates of (6). Aircraft demand and its interaction with the indicators of labor market tightness are jointly predicted by the instrument described in Section 2 and its interaction with the labor market indicator. Shaded areas show 90% and 95% Newey-West confidence intervals. First stage F-statistic at 12-month horizon = 16, 17, and 12 in the three panels, respectively.

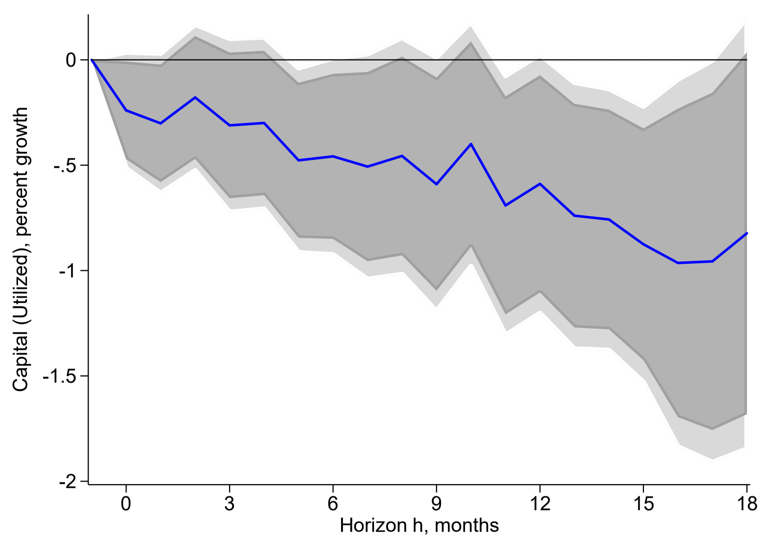
Figure A.10: Response of Factors of Production



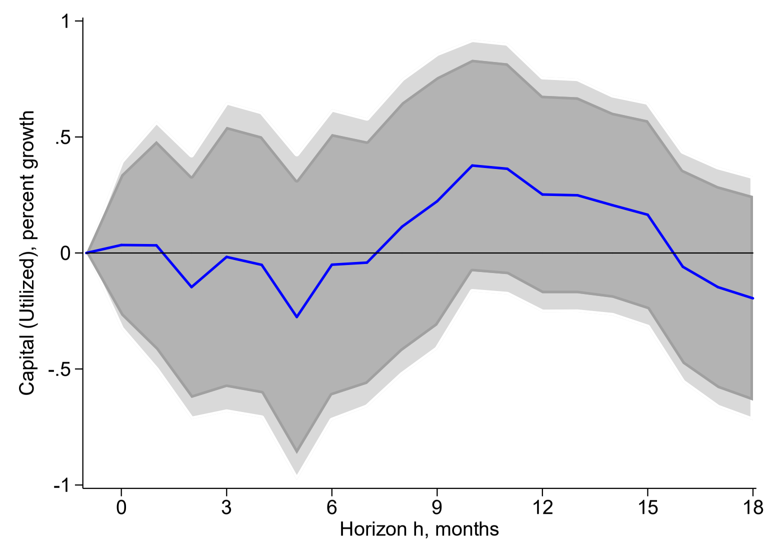
(a) Response of Labor, Hours



(b) Response of Labor, Hours, High vs. Low Capital Utilization Plants



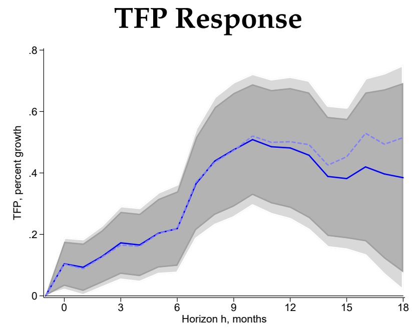
(c) Response of Utilization-Adjusted Capital

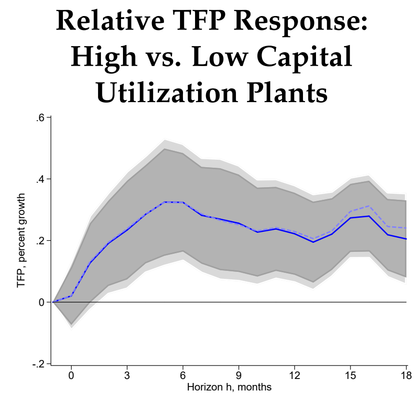


(d) Response of Utilization-Adjusted Capital, High vs. Low Capital Utilization Plants

Note: The figure shows the response of factors of production to a one percent shock to aircraft demand: local projections estimates of (6). Panels on the left-hand side show responses in the average plant: the β_h^{LBD} coefficients when $\beta_h^{LBN} = 0$ is imposed in (6). Panels on the right-hand side show responses in plants with above median initial capital utilization relative to those with below median utilization: β_h^{LBN} in an unrestricted version of (6). Aircraft demand and its interaction with initial capacity utilization are jointly predicted by the instrument described in Section 2, and its interaction with initial capacity utilization. In the top-row panels, the dependent variable is labor measured by (log) hours worked. In the bottom-row panels, the dependent variable is capital measured by (log) floor space multiplied by capital utilization, measured through shift utilization. Shaded areas show 90% and 95% Newey-West confidence intervals. First stage F-statistic at 12-month horizon = 28, 15, 34 and 16 in panels (a) to (d).

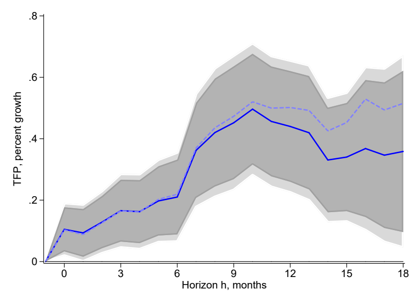
Figure A.11: Controlling for Spillovers from Peer Production Lines

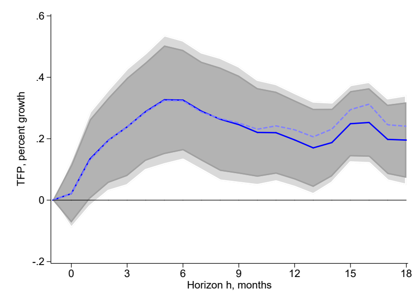




(a) Control: Average Productivity Growth of All Other Production Lines Producing Same Broad Type

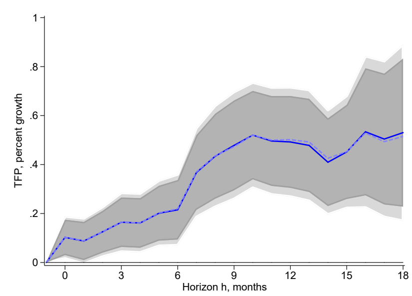
(b) Control: Average Productivity Growth of All Other Production Lines Producing Same Broad Type

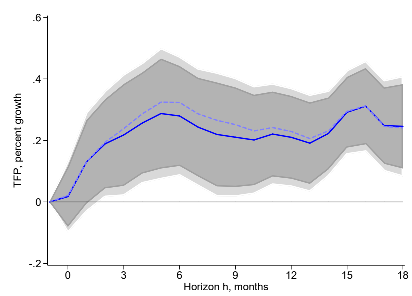




(c) Control: Average Productivity Growth of All Other Production Lines Using the Same Motor Manufacturer

(d) Control: Average Productivity Growth of All Other Production Lines Using the Same Motor Manufacturer



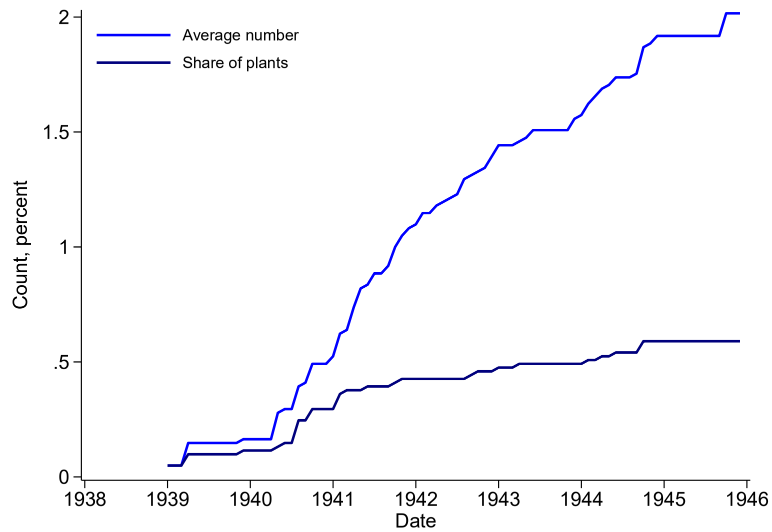


(e) Control: Average Production of All Other Production Lines Using the Same Motor Manufacturer

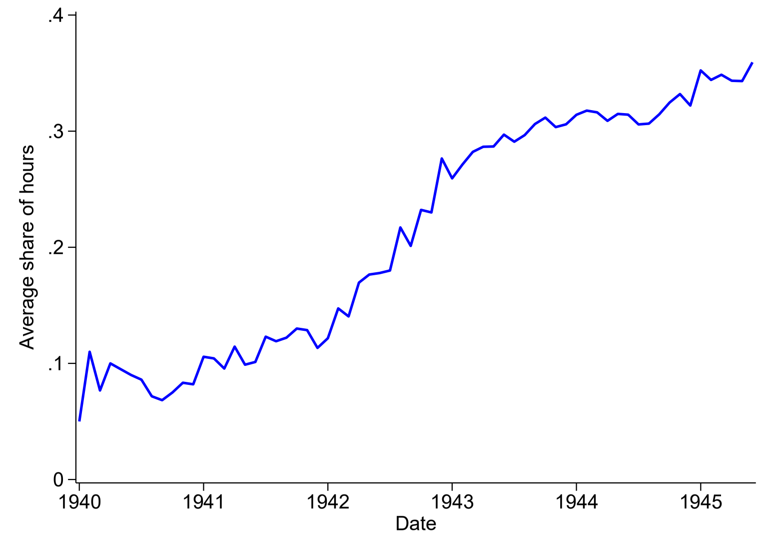
(f) Control: Average Production of All Other Production Lines Using the Same Motor Manufacturer

Note: The figure shows the response of TFP to a one percent shock to aircraft demand: local projections estimates of (6). Panels on the left-hand side show responses in the average plant: the β_h^{LBD} coefficients when $\beta_h^{LBN} = 0$ is imposed in (6). Panels on the right-hand side show responses in plants with above median initial capital utilization relative to those with below median utilization: β_h^{LBN} in an unrestricted version of (6). Aircraft demand and its interaction with initial capacity utilization are jointly predicted by the instrument described in Section 2, and its interaction with initial capacity utilization. Specifications in the top row include a control for the average growth in labor productivity for all production lines producing the same broad aircraft type excluding the production line studied, from month $t-1$ to month $t+h$. Specifications in the middle row include a control for the average growth in labor productivity for all production lines using the same motor manufacturer, excluding the production line studied, from month $t-1$ to month $t+h$. Specifications in the bottom row include a control for the number of airframes produced in all production lines producing using the same motor manufacturer, excluding the production line studied, in month t . Shaded areas show 90% and 95% Newey-West confidence intervals. Dashed lines show the regression coefficients in the baseline regressions without controls, as in Figures 6 and 7. First stage F-statistic at 12-month horizon = 29, 15, 30, 14, 32, and 16 in panels (a) to (f), respectively.

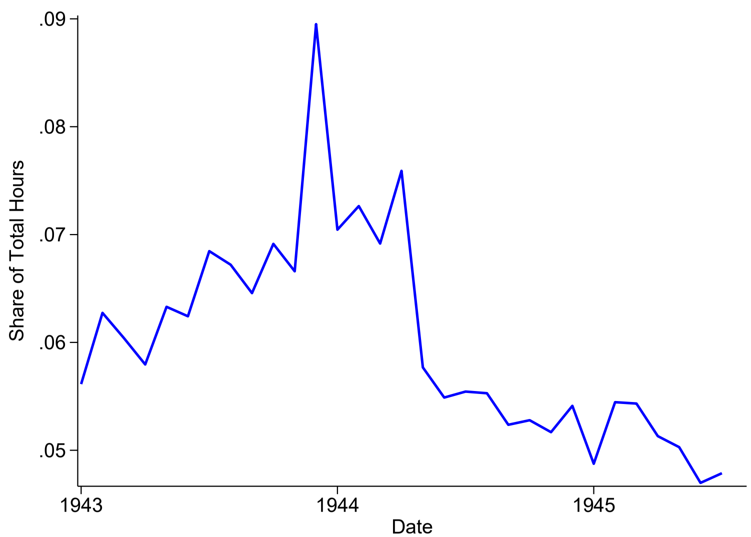
Figure A.12: Factors Affecting Productivity in Airframe Plants (Time Series)



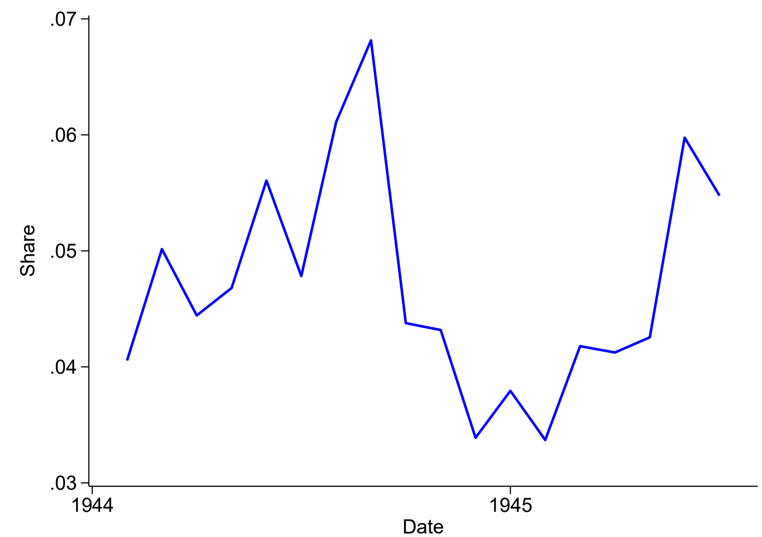
(a) Mass Production Methods Adopted:
share of plants and average number



(b) Outsourcing (average share of hours)



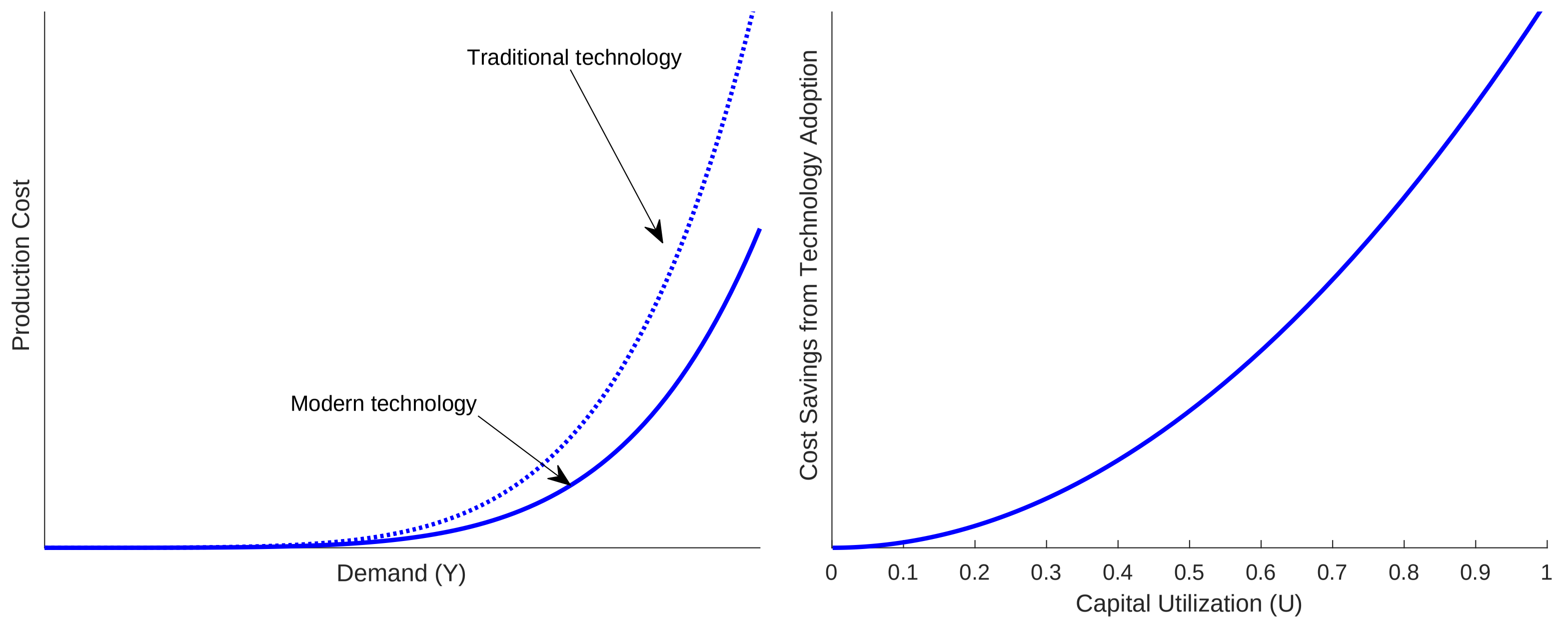
(c) Absenteeism



(d) Quit Rates

Each panel shows one statistic that has been suggested to have affected productivity in airframe plants during World War II. Panel (a) shows the cumulative share of plants (lower line) adopting mass production methods and the number of methods adopted by the average plant (top line). Source: Newspaper reports, corporate annual reports, and the author, as described in Section 4. Panel (b) shows the share of work hours in the assembly of aircraft that were outsourced to feeder plants from the median airframe plant. Source: USAAF (1952) Vol. 1, Table 3. Panel (c) shows the share of worker-hours lost due to worker absence in the median plant. Panel (d) gives the quit rate, the percent of workers quitting, in the median plant. Sources: Bureau of Labor Statistics, "Labor Statistics for the Aeronautical Industry," Reel 2237, PDF pp. 2210-2284; and Army Air Force Material Command, "Aircraft Program Progress Report," several volumes, Reel 2237, PDF pp. 2285-2648; both from the archives of the Air Force Historical Research Agency, Maxwell Air Force Base, AL

Figure A.13: Cost Curves in a Theory of Learning by Necessity

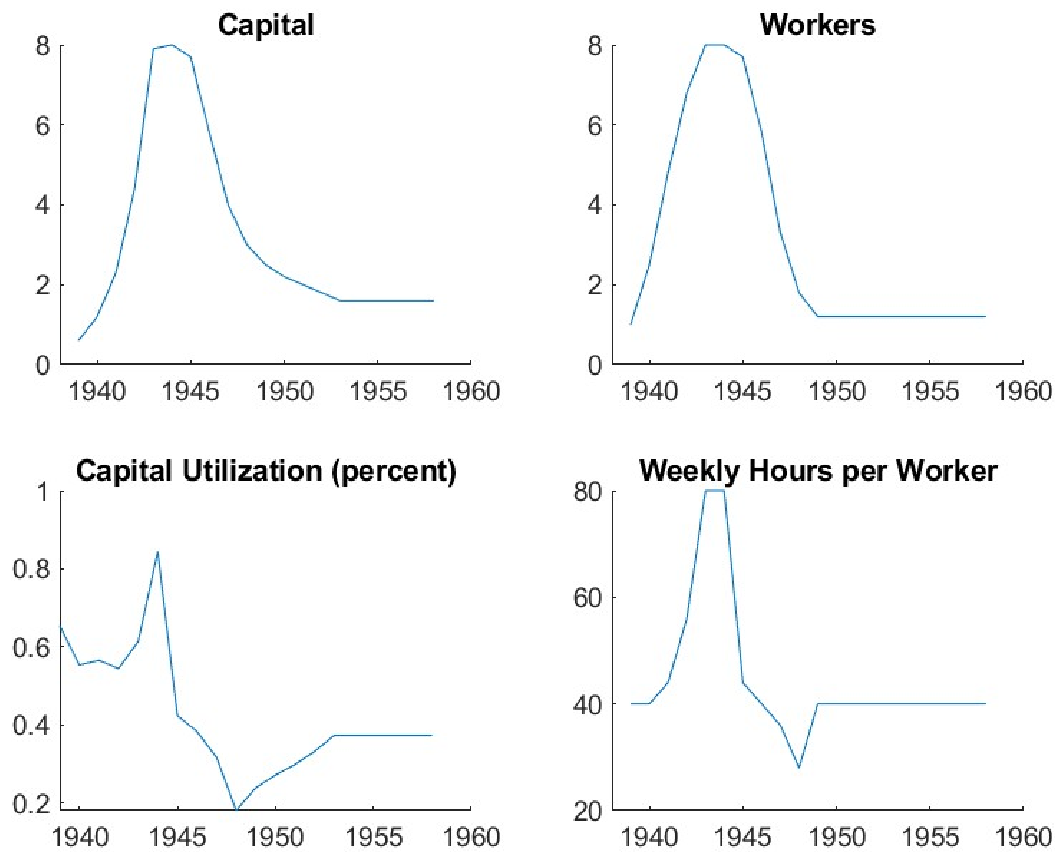


(a) Utilization Cost as a Function of Demand

(b) Cost Savings due to Technology Adoption, by Utilization

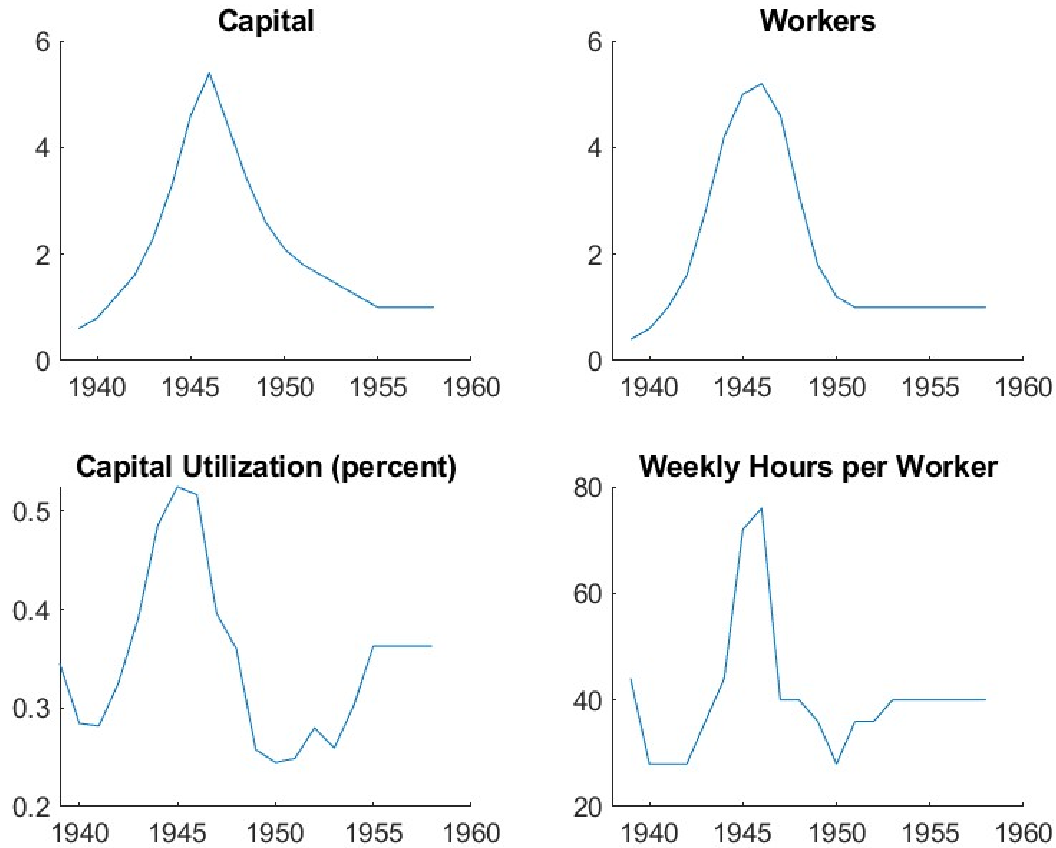
Note: The panels show cost curves arising from the theory of learning by necessity outlined in Appendix B. Panel (a) shows production (utilization) costs as a function of demand Y. The top curve represents a cost function using a traditional technology with TFP of z^T. The bottom curve represents a cost function using a modern technology with TFP of $z^M > z^T$. The gap between the curves gives the (gross) cost savings obtained if the modern technology is adopted. While the X-axis shows demand, what matters is demand relative to (maximal) production capacity. Panel (b) shows the cost savings of modern technology adoption as a function of capital utilization. Utilization is endogenous, but uniquely determined by–and monotonically increasing in–demand relative to existing capacity.

Figure A.14: Model Simulation: Average Plant



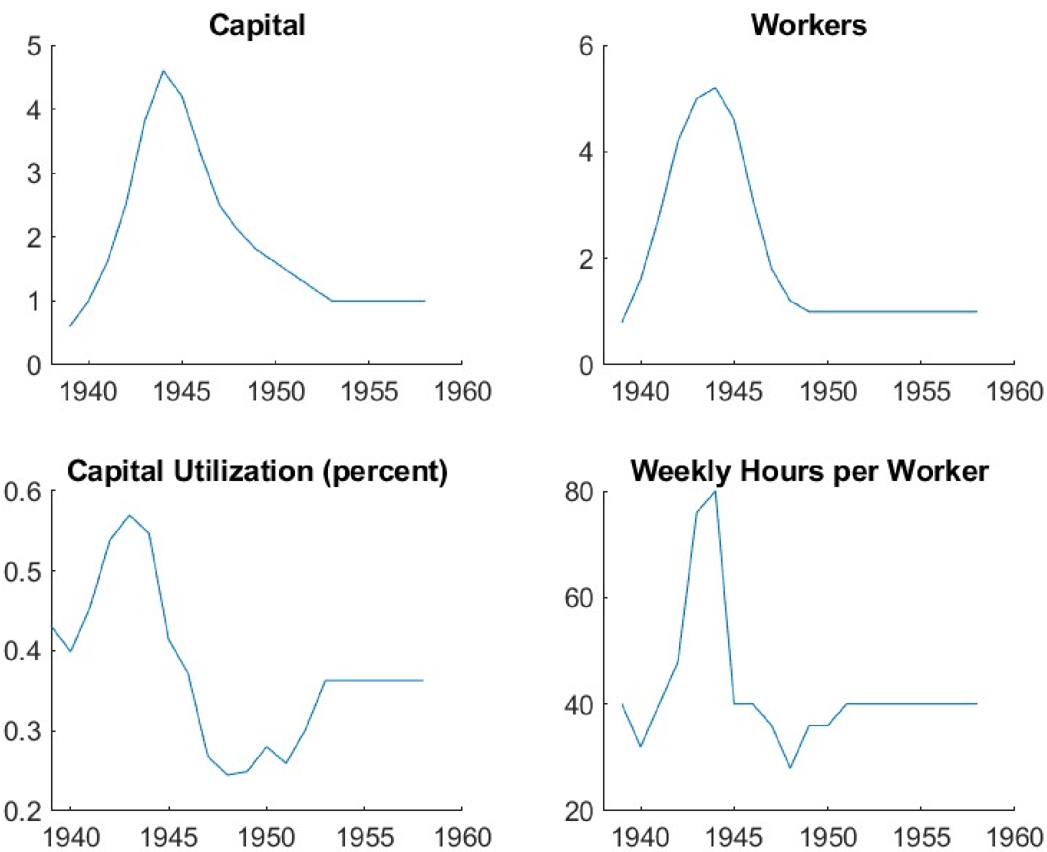
Model response of a plant to an unanticipated increase in demand announced in 1938, and matched to the production path of the average airframe plant in World War II. Full model presented in Appendix B. The top panels give the capital stock and number of workers as a multiple of the post-war steady state (calibrated to match the average of 1944-48 in the data). The bottom two panels give capital utilization in percent and hours per worker (in hours).

Figure A.15: Model Simulation: Low Demand Plant



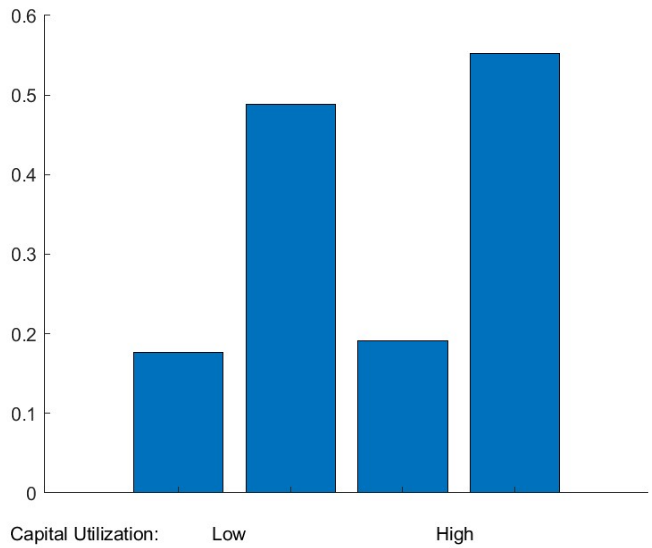
Model response of a plant to an unanticipated increase in demand announced in 1938, and matched to the production path of 25^{th} percentile plant ("low demand"). Full model presented in Appendix B. The top panels give the capital stock and number of workers as a multiple of the post-war steady state (calibrated to match the average of 1944-48 in the data). The bottom two panels give capital utilization in percent and hours per worker (in hours).

Figure A.16: Model Simulation: Low Capacity Utilization Plant

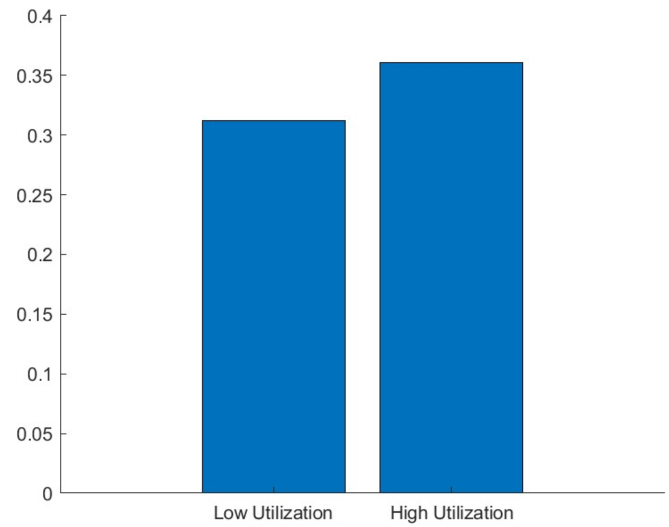


Model response of a plant to an unanticipated increase in demand announced in 1938, and matched to the production path of the average plant, but postponed by two years, reflecting a plant whose demand peaked in 1945 rather than 1943. This matches the utilization rate of the 25th percentile plant. Full model presented in Appendix B. The top panels give the capital stock and number of workers as a multiple of the post-war steady state (calibrated to match the average of 1944-48 in the data). The bottom two panels give capital utilization in percent and hours per worker (in hours).

Figure A.17: Cost Savings from Technology Adoption: Model Results



(a) Cost Savings



(b) Difference in Cost Savings

Panel (a) gives the cost savings achieved from adopting a technology that increases TFP by 35% in the model of Appendix B. Savings are given as a fraction of the net present value of all variable costs over the 100 years of model simulation. The four scenarios, from left to right, are high initial utilization and low demand; high initial utilization and high demand; low initial utilization and low demand; low initial utilization and high demand. High and low demand and high and low utilization are set to match the 25th and 75th percentiles, respectively, of these two variables. Panel (a) gives the difference between the high demand and low demand cases (as a percent of the NPV of costs) for the high (left bar) and low (right bar) utilization scenarios. These are the differences between the second and first bars and the fourth and third bars, respectively.

Table A1: Robustness Checks: Labor Productivity and TFP Responses

Dependent Variable: log Aircraft per Hour Worked

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
log Aircraft Demand	0.026	0.506***	0.506***	0.421***	0.532***	0.506***	0.416***
	(0.017)	(0.131)	(0.111)	(0.098)	(0.172)	(0.131)	(0.096)
Observations	958	958	847	942	944	958	958
Adjusted R^2	0.705	0.423	0.449	0.570	0.402	0.423	0.459
First Stage F-stat		24.7	32.5	38.5	15.4	24.7	47.3

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent Variable: TFP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
log Aircraft Demand	0.015	0.502***	0.537***	0.435***	0.549***	0.502***	0.379***
	(0.017)	(0.115)	(0.119)	(0.091)	(0.162)	(0.115)	(0.078)
Observations	867	867	859	852	861	867	867
Adjusted R^2	0.712	0.417	0.354	0.540	0.356	0.417	0.508
First Stage F-stat		32.1	31.9	46.6	18.3	32.1	70.8

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Regression results showing the response of labor productivity (top panel) and TFP (bottom panel) to a 1% increase in aircraft demand. Coefficients are the β_{12}^{LBD} coefficients of local projections estimates of (6), with $\beta_{12}^{LBN} = 0$ imposed. Column 1 shows an OLS specification, as in Figure A.3 in the appendix. Column 2 uses (and the remaining columns use) IV, with aircraft demand predicted by the instrument described in Section 2. Column 3 controls for the growth of factors of production from time $t - 1$ to $t + 12$, as in Figure 8. Column 4 controls for (log) cumulative production, or "experience". Column 5 controls for cumulative capital investment in equipment. Column 6 controls for plant age. Column 7 weights observations by each plant's total production over the duration of the war. Anderson-Rubin p-stat < 0.01 in all specifications.

Table A2: Robustness: Heterogeneity with Capacity Utilization

Dependent Variable: log Aircraft per Hour Worked

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log Aircraft Demand	-0.027	0.281**	0.284**	0.248**	0.247	0.105	-0.091	0.141
	(0.022)	(0.130)	(0.114)	(0.110)	(0.159)	(0.108)	(0.192)	(0.297)
Demand × Capacity Util.	0.082***	0.236***	0.249***	0.187**	0.255***	0.371***	1.345***	0.535
	(0.025)	(0.087)	(0.083)	(0.076)	(0.083)	(0.078)	(0.398)	(0.510)
Observations	958	958	847	942	944	958	958	805
Adjusted R^2	0.708	0.492	0.531	0.610	0.524	0.460	0.506	0.530
First Stage F-stat		13.1	16.8	19	8.2	24.1	12.9	11.3

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent Variable: TFP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log Aircraft Demand	-0.059***	0.272**	0.312**	0.270**	0.285*	0.092	-0.171	0.428
	(0.022)	(0.120)	(0.124)	(0.110)	(0.151)	(0.421)	(0.198)	(0.339)
Dem. × Capacity Util.	0.123***	0.229***	0.226***	0.171**	0.232***	0.302***	1.484***	0.209
	(0.025)	(0.082)	(0.084)	(0.078)	(0.083)	(0.242)	(0.406)	(0.583)
Observations	867	867	859	852	861	867	867	804
Adjusted R^2	0.720	0.519	0.464	0.597	0.503	0.578	0.549	0.367
First Stage F-stat		16.3	16.2	20.6	9.6	33.2	15.3	11.3

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Regression results showing the response of labor productivity (top panel) and TFP (bottom panel) to a 1% increase in aircraft demand their interaction with a dummy indicating whether capital utilization was above median at the beginning of the war. The first row has gives the response of productivity in plants with below average capital utilization and the second row gives the added productivity response in plants with above median utilization. Coefficients are the β_{12}^{LBD} and β_{12}^{LBN} coefficients of local projections estimates of (6). Column 1 shows an OLS specification, as in Figure A.3 in the appendix. Column 2 uses (and the remaining columns use) IV, with aircraft demand predicted by the instrument described in Section 2. Column 3 controls for the growth of factors of production from time $t-1$ to $t+12$, as in Figure 8. Column 4 controls for (log) cumulative production, or "experience". Column 5 controls for cumulative capital investment in equipment. Column 6 weights observations by each plant's total production over the duration of the war. Column 7 interacts demand with capital utilization at the beginning of the war (a continuous measure), instead of above median capital utilization, so that the first row represents the projected effect of demand on productivity for a plant with zero utilization and the second row gives the marginal effect of an additional percentage point of capital utilization times 100. Column 8 interacts demand with a time varying measure of capital utilization (12 month lagged) instead of initial capital utilization. Anderson-Rubin p-stat < 0.01 in all specifications.

Table A3: Summary Statistics: Airframe Plants by Capacity Constraint Measures

	Capital Utilization		Hours/Worker		Wages		WMC	
	Low	High	Low	High	Low	High	2-4	1
$\Delta_{\%}$ Output per Worker	127%	104%	107%	114%	117%	103%	112%	108%
Firm Age (Months)	172	191	168	200*	178	190	183	184
Plant Age (Months)	65	137***	132	84**	110	108	92	129*
Hours per Pound	3.2	3.1	2.4	3.7	3.0	3.4	3.5	2.7
Airplanes Produced	38	77	67	60	77	54	56	72
Unit Cost (000's USD)	107	124	109	131	87	147	88	138
Wing Span (Meters)	21.8	19.7	17.5	23.5**	20.9	19.8	20.8	20.1
Public Plant Financing (mln USD)	15.0	14.5	10.3	18.7	16.9	11.9	14.7	14.7

Note: Summary statistics for airframe plants along sample splits reflecting different dimensions of capacity constraints. These are (1) capital utilization as measured by shift utilization, (2) weekly hours per worker, (3) county-level wages, and (4) War Manpower Commission local labor market classification (1 to 4, decreasing in labor shortages). "High" columns give averages for plants above median by the metric in question in January 1943. Averages are for January 1943, except for plant financing (cumulative to January 1945), hours per pound (January 1945), growth in aircraft per hour worked (log change from Jan 1943 to Jan 1945). Asterisks reflect statistical significance of the t-test of differences between the two categories: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Sources: AMPR War Production Board *War Manufacturing Facilities Authorized*, and the author.

Table A4: Correlation Between Measures of Aircraft Plants' Capacity Constraints

	Capital utilization	Hours per worker	Wages	Labor market priority
Capital utilization	1			
Hours per worker	0.32 *	1		
Wages	0.11	-0.02	1	
Labor market priority	0.29 *	-0.04	0.42***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: The table gives correlations between various indicators of capacity constraints. The variables are capital (shift) utilization, hours per worker, wages in the local labor market (excluding aircraft plants), and a dummy equaling one if the Manpower Commission classified the labor markets as facing labor shortages. Sources: AMPR, War Production Board, War Manpower Commission.

Table A5: Correlates with Modification Center Employment

	(1)	(2)	(3)	(4)	(5)
Dependent Variable	Hours in plant	Productivity	Productivity	Productivity	Productivity
Mod. Ctr. Employment	0.912***		-0.018	0.033	-0.021
	(0.040)		(0.051)	(0.121)	(0.086)
Hours in Plant		-0.002		-0.047	
		(0.008)		(0.101)	
Mod. Ctr. ×					0.005
High initial capacity Util.					(0.104)
N	179	2550	153	153	153
adj. R^2	0.830	0.138	-0.035	-0.042	-0.044

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Regressions of the growth in log hours worked in a production line (column 1) or the growth in log aircraft per hour worked (columns 2 to 5) against the growth of log employment at the corresponding modification center. All regressions include month and plant × model fixed effects. In multi-product plants, modification center employment allocated to production lines according to the relative growth in output. Results are robust to regressions at the plant level. Column (1) shows a strong correlation between hours worked at the plant and at the modification center. Columns (2) to (4) show little correlation between productivity growth and employment growth at the modification center, suggesting that productivity growth at the plant isn't due to additional work at the modification center. Sources: Hours and productivity at the production line from USAAF (1952) Vol. 1: Direct Man-Hours - Progress Curves, Table 2. Modification center employment from *Total Labor Requirements for the Aircraft Industry WL-8*, RG 179, Boxes 2471-5, NARA College Park.

B A Simple Model of Learning by Necessity (For Online Publication)

This appendix outlines a theory of "learning by necessity" that illustrates why plants might increase productivity in face of high demand when facing tight capacity constraints. The theory highlights that demand *relative* to plants' existing capacity affects the choice of innovation or technology adoption. This leads to an interaction between demand and capacity utilization. Plants adopt productivity-enhancing methods when their benefits justify their adoption costs. If operating at high capacity is costly (formally, if utilization costs are convex), cost reductions will be more beneficial when demand is high relative to existing capacity. New techniques are therefore adopted when demand is high relative to installed capacity.

The intuition of the model can be fully captured in a one-period model, with which I begin. A full calibrated model follows.

B.1 Static Model

A plant operates using a Cobb-Douglas production function of the form

$$Y_t \leq z\left(H_t L_t\right)^{\alpha}\left(U_t K_t\right)^{1-\alpha}, \tag{B.1}$$

where z is total factor productivity, L_t the number of workers, K_t the quantity of physical capital, H_t hours worked as a fraction of a full week and U_t the work week of capital (capital utilization). Both utilization variables range from zero to one. In the dynamic model, the plant can only adjust capital and labor over time and faces adjustment costs if it wishes to do so. The static model presented here takes these costs to the extreme and both these factors of production are in fixed, pre-determined, quantities. In contrast, the plant can choose labor and capital utilization, H_t and U_t, respectively, but faces convex costs to utilization. Concretely, monthly wages $w(H_t)$ are not only increasing, but also convex in hours worked. Overtime pay was prevalent (typically at a 50% premium) in the aircraft industry, so that the marginal cost of work hours was increasing in the length of the work week. Similarly, capital may depreciate more when highly-utilized, so that the cost of capital utilization is a convex function $\delta(K_t)$.

The production function and the plant's decision problem that follows are similar to those in Basu *et al.* (2006), with one twist. The plant begins with a traditional technology from which it derives total factor productivity $z = z^T$. (I use the term "technology" generically for all factors affecting TFP). After the plant receives demand $Y_t = \bar{Y}$ for its product, it chooses not only how intensively to utilize workers and capital, but also whether it wants to pay a cost A to adopt a new (modern) technology with TFP $z = z^M > z^T$. This simple discrete jump will be undertaken if the savings in utilization costs exceed the adoption cost A.

Given its chosen technology, the plant chooses utilization H_t and U_t so as to minimize utilization costs

$$\min_{H_t,U_t} w\left(H_t\right) L_t + \delta\left(U_t\right) K_t$$

subject to satisfying demand $\bar{Y}$

$$z\left(H_t L_t\right)^{\alpha}\left(U_t K_t\right)^{1-\alpha} \geq \bar{Y} \tag{B.2}$$

Optimal utilization equates the marginal cost of utilizing the two factors:

$$w'(H_t) H_t L_t = \delta'(U_t) U_t K_t. \tag{B.3}$$

Marginal costs of both forms of utilization increase in tandem and are both increasing in the term

$$\text{Demand/Capacity} = \frac{\bar{Y}}{z L_t^{\alpha} K_t^{1-\alpha}}. \tag{B.4}$$

This term scales demand by the plant's current (maximal) capacity. It follows directly from (B.2) that this ratio determines–and increases–utilization.

A surge in demand $\bar{Y}$ increases utilization and marginal costs and more so the lower is TFP z, because the demand is pressing against lower productive capacity, as in (B.4). This is illustrated Figure A.13a, which shows cost curves: utilization costs as a function of demand $\bar{Y}$. The two curves represent high and low values of TFP, corresponding to the modern and traditional technologies, respectively. Costs are convex by assumption and the gap between the two is increasing in demand, per (B.2) to (B.4). The figure shows that the cost savings due to technology adoption is increasing in demand. Technology is optimally adopted if the gap between the two curves is larger than the adoption cost A, so when demand is sufficiently high, all else equal.

But this is only part of the story. It isn't merely the absolute level of demand, but rather demand relative to the plant's capacity that determines where we are along the cost curves in the figure. Utilization is endogenous, but equations (B.2) and (B.4) indicate that it is a sufficient statistic in equilibrium for demand pressures relative to capacity. A plant operating at low levels of utilization will be on the flat portion of the cost curves in Figure A.13a, where an increase in demand $\bar{Y}$ will have little impact on costs and therefore on technology adoption. In contrast, a plant operating at high utilization will be further to the right along these curves, were an increase in demand has a larger impact on marginal costs and on the benefits of technology adoption. Here a demand shock is more likely to tip the scales towards the modern technology.

This is shown in Figure A.13b, which now shows the cost savings due to technology adoption (the gap between the curves in Panel A) as a function of utilization. Utilization is of course endogenous, but governed by initial capacity, as in (B.4). The gains to technology adoption are increasing and convex in utilization, so that technology adoption is more likely at high utilization rates, and more so in face of surging demand. This is the theoretical counterpart of the triple difference in differences specification of Section 3.2 and describes "learning by necessity" in a nutshell.

Basu *et al.* (2006) use a similar framework to show that *measured* TFP will increase when demand is high. This is because utilization increases with demand but is typically unobserved in the data, giving the semblance of higher output with the same means of production. The theory here suggests that not only measured, but *actual* TFP may increase with demand, now because high utilization induces firms to adopt productivity-enhancing measures. This is supported by the empirical results, where TFP adjusted for capital utilization increases in demand, and more so when utilization is high .

B.2 Dynamic Model

We now turn to the dynamic model. The length of a period t is one year. The production function remains as in (B.1). However, now plants can invest (or dis-invest) in new capital I_t and hire (or lay off) workers, with D_t denoting the net change in workers employed. Capital and labor evolve according to the following two constraints:

$$K_{t+1} \leq I_t + (1-d)\, K_t; \tag{B.5}$$

$$L_{t+1} \leq L_t + D_t; \tag{B.6}$$

where d is the capital depreciation rate. The plant rents capital K_t at an interest rate r_t, a rate that also serves as the plant's discount rate. In addition to the convex costs to capital and labor utilization, described above, there are also adjustment costs to investment $I_t \equiv K_t - K_{t-1}$ and hiring (or firing) $D_t \equiv H_t - H_{t-1}$. These costs are given by $K_t J\left(I_t/K_t\right)$ and $w_t L_t \Psi\left(D_t/L_t\right)$ respectively, where $J\left(.\right)$ and $\Psi\left(.\right)$ are both convex functions; and w_t are annual wages per worker.

Wages have two components. There are monthly fixed costs to employ a worker of W_t, and each worker is paid annual wages of $w(H_t)$ that are a function of annual hours. Hence $w_t = W_t + w(H_t)$. A linear $w(H_t)$ function would represent hourly wages, while a convex function would represent wages that are increasing in hours worked, e.g. overtime pay.

The plant faces a discrete choice at time zero between one of two technologies $z = z^M$ or $z = z^T$ (modern or traditional), with $z^M > z^T$. Using the traditional technology is free (or a sunk cost), but using the modern technology incurs an adoption cost A (which could incorporate the net present value of any recurring costs to the technology's use).

The model has perfect foresight. A model with uncertainty would yield qualitatively similar results, but may lead to a smaller probability of adopting the modern technology depending on the nature of the uncertainty (about the duration of the war, the magnitude of the shocks, demand in the post war period). As we will see, the war shock gives such large incentives to upgrade technology that it would overwhelm any such hesitations and is unlikely to change the qualitative predictions of the model. With this in mind, the plant's cost minimization problem is

$$\min_{D_t, L_{t+1}, I_t, K_{t+1}, H_t, U_t, z_t \in \{z^T, z^M\}} \sum_{t=0}^{\infty} \prod_{j=0}^{t-1} \left(\frac{1}{1+r_j}\right) \begin{bmatrix} W_t L_t + L_t w(H_t) + \\ L_t \left[W_t + w(H_t)\right] \Psi(D_t/L_t) + \\ K_t \delta(U_t) + K_t J(I_t/K_t) + r_t K_t \end{bmatrix} + AI(z = z^M)$$

s.t (B.1) and (B.5) (B.6). $I(.)$ is an indicator function that takes on the value of 1 if the modern technology is chosen and zero otherwise.

The first order conditions (on D_t, I_t, L_{t+1}, K_{t+1}, H_t, and U_t, respectively) are as follows:

$$\Psi'(D_t/L_t) = \frac{\lambda_t^L}{W_t + w_t(H_t)} \tag{B.7}$$

where $\lambda_t^L = \frac{\tilde{\lambda}_t^L}{B_t}$ and $\tilde{\lambda}_t^L$ is the Lagrange multiplier on (B.6) at time t and $B_t \equiv \prod_{j=0}^{t-1}\left(\frac{1}{1+r_j}\right)$.

$$J'(I_t/K_t) = \lambda_t^K, \tag{B.8}$$

with $\lambda_t^K = \frac{\tilde{\lambda}_t^K}{B_t}$ and $\tilde{\lambda}_t^K$ representing the Lagrange multiplier on (B.5).

$$
\begin{aligned}
& w_{t+1}\left[1+\Psi\left(D_{t+1}/L_{t+1}\right)-\frac{D_{t+1}}{L_{t+1}}\Psi\left(D_{t+1}/L_{t+1}\right)\right] \\
= \quad & \lambda_{t+1}^{L}-\left(1+r_{t}\right)\lambda_{t}^{L}+\alpha\frac{z\left(H_{t+1}L_{t+1}\right)^{\alpha}\left(U_{t+1}K_{t+1}\right)^{1-\alpha}}{L_{t+1}}\lambda_{t+1},
\end{aligned} \tag{B.9}
$$

where λ_t is the Lagrange multiplier on (B.1).

$$
\begin{aligned}
& \delta\left(U_{t+1}\right)+J\left(I_{t+1}/K_{t+1}\right)-\frac{I_{t+1}}{K_{t+1}}J'\left(I_{t+1}/K_{t+1}\right)+r_{t+1} \\
= \quad & (1-d)\,\lambda_{t+1}^{K}-\left(1+r_{t}\right)\lambda_{t}^{K}+(1-\alpha)\frac{z\left(H_{t+1}L_{t+1}\right)^{\alpha}\left(U_{t+}K_{t+1}\right)^{1-\alpha}}{K_{t+1}}\lambda_{t+1}
\end{aligned} \tag{B.10}
$$

$$
L_{t}w'\left(H_{t}\right)\left[1+\Psi\left(D_{t}/L_{t}\right)\right]=\alpha\frac{z\left(H_{t+1}L_{t+1}\right)^{\alpha}\left(U_{t+1}K_{t+1}\right)^{1-\alpha}}{H_{t+1}}\lambda_{t+1} \tag{B.11}
$$

$$
K_{t}\delta'\left(U_{t}\right)=(1-\alpha)\frac{z\left(H_{t+1}L_{t+1}\right)^{\alpha}\left(U_{t+1}K_{t+1}\right)^{1-\alpha}}{U_{t+1}}\lambda_{t+1} \tag{B.12}
$$

The first order conditions above apply for any value of z and the plant chooses the modern technology if it leads to cost savings greater than A.

The first order conditions equate the marginal costs of capital and labor utilization and both of these to the marginal costs of capital and labor adjustment. The former two costs are static, while the latter have dynamic implications. An increase in demand in the distant future can be accommodated by gradual accumulation of factors of production, incurring only small marginal adjustment costs in each period along the way, and without necessitating large increases in utilization at any stage. In contrast, front loaded demand, or a large MIT-style demand shock, will require large factor adjustments and the plant will optimally increase utilization to limit adjustment costs. The plant will choose the modern technology if the net present value of these costs are high. Because costs are convex, they will be higher if unanticipated and concentrated in early years.

Functional Forms

We assume the following functional forms for adjustment costs. Adjustment costs for capital and hiring/firing take on standard quadratic forms:

$$J\left(\frac{I}{K}\right)=\frac{\varphi}{2}\left(\frac{I}{K}-d\right)^{2}.$$

$$\Psi\left(\frac{D}{L}\right)=\frac{\psi}{2}\left(\frac{D}{L}\right)^{2}.$$

Capital utilization costs take the form

$$\delta\left(U\right)=\delta_{0}\frac{U}{1-U}, \tag{B.13}$$

which bounds utilization between zero and one in equilibrium. Overtime pay is the most direct reason for convex labor utilization costs:

$$w\left(H\right)=\bar{w}\left[H+\omega\left(H-FT\right)\Xi\left(H>FT\right)\right], \tag{B.14}$$

where ω is the overtime rate, FT is full-time weekly hours, and Ξ is an indicator function equal to one if hours exceed full time and zero otherwise. Because labor costs are piece-wise linear in hours, hours may be unbounded in equilibrium. I impose a limit of 80 hours per week.

Calibration

The model will be simulated so that that it begins from a steady state calibrated to features of the pre-war aircraft industry, is then hit but a one-off, unanticipated shock matching the features of World War II, and then converges to a new steady state (with a higher level of TFP) that matches features of the post-war economy. The model is parametrized to match the post-war economy and initial conditions are then adjusted to shrink the industry to its pre-war levels.

I normalize the the stock of capital, labor and TFP to one, $z=\bar{K}=\bar{L}=1$, in the post-war economy steady state. Most remaining parameters are calibrated externally. Parameters of the utilization cost functions can be calibrated to match post-war utilization rates exactly in steady state. Capital and labor adjustment costs are zero in steady state, but govern the rate of investment and hiring along a dynamic path. They are calibrated to match the rate of capital dis-accumulation

Table A6: Calibration

Parameter		Value	Method	Target
d	Depreciation rate	0.08	external	Post-war estimates
r	Real interest rate	0.03	external	Post-war value
W	Fixed costs per worker	$= 0.25\bar{w}FT$	external	25% overhead per worker, typical estimates
$\bar{w}$	Hourly wage	0.658	internal	To match $\bar{H} = FT = 0.24$ to a 40-hour work week (out of 168 hours), full time
ω	overtime rate	0.5	external	Typical 50% overtime rates in aviation industry
δ_0	K Utilization cost param.	0.0967	internal	to match $\bar{U} = 0.36$
				1.5 8-hour shifts, 5 days a week, post war average
α	labor share	$\frac{2}{3}$	external	Typical value in the literature
ϕ	K adj. cost param.	1.2	internal	To match 1.2 log point decline in capital stock 1944-48
ψ	L adj. cost param.	0.975	internal	To match 1.65 log point decline in capital stock 1944-48

labor force decline in the airframe industry following the war. Table A6 shows calibrated values and calibration targets. Steady state variables are denoted with bars. Aggregate data on the pre- and post-war airframe industry are from Kupinsky (1954) and Lee (1960).

Simulation

The plant in the model is confronted by a sequence of aircraft demands Y_t, matched to the actual production path during the war. For the average plant, this is set as follows. With $z = \bar{K} = \bar{L} = 1$ (normalized to 1) and hours worked and utilization set at the targets shown in Table A6, the post-war steady state level of production is $\bar{Y} = 0.274$, from (B.1). Demand Y_t in all other years is set relative to this index, and taken from the data. Specifically, this gives $Y_{1938} = 0.1$, which we treat as initial conditions and assume that the airframe industry had this level of production in the pre-war steady state. TFP in the average plant grew by 35% during the war (see Figure 2). Accordingly, we set TFP in the pre-war period to $z = 0.75$. Capital and labor utilization rates are the same in the pre-war and post-war steady states. This gives $K_{1938} = L_{1938} = 0.3$, 30% of their post-war value, which is also consistent with the data. In 1938, at its pre-war steady state, the plant is informed of the future demand it will face in all future periods. For simplicity we ignore the Korean War, and the plant expects to be at the 1944-48 levels of aircraft demand for the remainder of history.

Simulations compare a scenario when the plant chooses to invest in the modern technology, which increases its TFP to one, as in the post war steady state, to a scenario where it retains its pre-war level of TFP of $z^T = 0.75$. In the former case we assume for simplicity that the productivity gains come immediately, so that $z = 1$ throughout.

Figure A.14 shows how a plant facing the average demand facing World War II aircraft plants responds to this demand shock, absent any increase in TFP during the war. The demand shock is enormous, with production peaking at 25 *times* its pre-war levels. Although capital and labor adjustments are costly, the plant has no choice but to rapidly accumulate capital and hire workers, even knowing that it will have to dispose of the capital and lay off the workers after the war. Capital and labor grow roughly 6-fold, compared to a 3-fold increase in the data, but this is partly because the simulation doesn't allow plants to increase TFP. This demonstrates the massive costs that would be incurred absent productivity-enhancing measures. As in the data, the simulated firm accumulates factors gradually, to economize on adjustment costs. It is therefore compelled to utilize capital and labor intensely during the the war. Capital utilization gives a rough sense of the evolution of marginal costs over the simulation, because capital utilization costs are convex according to (B.13), and marginal costs are equalized across all margins.[1] Higher productivity z would lower these adjustment and utilization costs and might justify the fixed cost to technology adoption A.[2]

FigureA.15 repeats this exercise, but now for a plant with lower demand. Specifically, it scales the war shock down by 28% to match the the production of the plant at the 25% percentile. The lower demand implies that the plant needs to expand capital and employment "only" five-fold and can do so with lower utilization. Capital utilization peaks briefly at over 50%. In comparison, the average plant in Figure A.14 has such utilization rates throughout the war. Lower demand leads to a substantially lower net present value of costs, giving a smaller incentive to adopt the technology.

Figure A.16 now brings demand back up to that of the average plant and simulates the case of low capacity utilization. Utilization is endogenous and one needs to consider an exogenous force driving utilization. In the data, high utilization plants were those whose demand was front-loaded, leading to high utilization early in the war. To replicate this in the simulation, I give the plant a 2-year "advance notice" of the demand. The advanced notice allows the plant to ramp up capacity more gradually, economizing on adjustment costs. The plant utilizes capital less intensely and also saves on utilization costs. This plant will have lower costs and less of an incentive to adopt the modern technology.

Relating these simulations to the triple difference specification in Section 3.2, I conduct the

[1] Labor utilization costs are convex, but piece-wise linear, so that hours worked shoot up dramatically–more so than in the data. This may indicate that labor utilization costs are convex beyond the costs of overtime pay.

[2] The figure also shows very low utilization in the post-war period because demand has declined, but plants still have an overhang of capital and workers from the the war. This is consistent with the minor recession in the US economy in late 1945 and early 1946. In the model, as in the data, utilization rates return quickly to normal.

following experiment. The model is simulated with low and high demand; with low and high utilization; and with or without adopting the modern technology, as described above ($2 \times 2 \times 2$ simulations in total). High and low demand are matched to the 75$^{\text{th}}$ and and 25$^{\text{th}}$ percentile plants representing demand that is 2.9 times higher and 28% lower than the average plant, respectively. High and low utilization are matched to the 75$^{\text{th}}$ and and 25$^{\text{th}}$ percentile plants in terms of utilization. I then calculate the cost savings arising from technology adoption in all four scenarios, that is the cost difference between the high and low TFP simulation in each case. This gives the plant's (maximal) willingness to pay to obtain a 35% TFP increase, as observed in the average plant during the war.

Figure A.17a shows the results. All bars give the net present value of the savings a plant obtains by adopting a technology that increases TFP by $\frac{1}{3}$. These are given as a fraction of the net present value of variable (capital rental, wages, adjustment, and utilization) costs, calculated over a 100-year horizon. The first two bars from the left are simulations of a high utilization plant; the next two bars are a low utilization plant. In each case, the bar on the left is the case of low demand and the bar on the right the case of high demand. The first feature that stands out is the sheer magnitude of the bars. Costs in the 6-year wartime period are so large that technology adoption could lower the plant's net present value of costs by as much as 50% *over the course of an entire century*. A second result is the big difference in costs, and therefore cost-savings due to technology adoption, depending on demand. A high demand plant is willing to pay more than twice as much as a low demand for the modern technology. Finally, willingness to pay is increasing in utilization.

Figure A.17b represents this same information a triple difference-in-differences. It gives the difference in savings (due to high rather than low TFP, as a percent of the net present value of costs) between the high- and low-demand scenarios, for simulations with high and low initial capital utilization. High demand incentives technology adoption, and more so at high rates of utilization, as in the empirical results of Section 3.

C Derivations for Section 2.1 (for online publication)

Cost savings can be rewritten as

$$C_{mp,t} = K_{mp}\delta\left(\frac{1}{K_{mp}}\left(\frac{Y_{mp,t}}{z^T}\right)^{\frac{1}{1-\alpha}}\right) - K_{mp}\delta\left(\frac{1}{K_{mp}}\left(\frac{Y_{mp,t}}{z^T}\right)^{\frac{1}{1-\alpha}}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right),$$

and this can be linearized around $t-1$ values gives as

$$\Delta C_{mp,t} \cong K_{mp}U_{mp,t-1}\left[\delta'\left(U_{mp,t-1}\right) - \left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\delta'\left(U_{mp,t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right)\right]\Delta\log Y_{mp,t},$$

giving (2)

Further, (3) can be log-linearized around $t-1$ values as

$$\begin{aligned} E\Delta\log z_{mp,t} &= g\left(C_{mp,t}\right)\log\frac{z^M}{z^T}\Delta C_{mp,t} \\ &= \frac{1}{\bar{A}}\log\frac{z^M}{z^T}\Delta C_{mp,t}, \end{aligned}$$

giving (4).

Combining (2) and (4) gives

$$E\Delta\log z_{mp,t} \cong \Upsilon\left(U_{mp,t-1}\right)\Delta\log Y_{mp,t},$$

where

$$\Upsilon\left(U_{mp,t-1}\right) \equiv \frac{K_{mp}U_{mp,t-1}}{\bar{A}}\log\left(\frac{z^M}{z^T}\right)\left[\delta'\left(U_{mp,t-1}\right) - \left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\delta'\left(U_{mp,t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right)\right].$$

Log-linearizing $\Upsilon\left(U_{mp,t-1}\right)$ around the value in the average plant gives

$$\Upsilon\left(U_{mp,t-1}\right) \cong \Upsilon\left(\bar{U}_{t-1}\right) + \Upsilon'\left(\bar{U}_{t-1}\right)\left[U_{mp,t-1} - \bar{U}_{t-1}\right],$$

which motivates the estimating equation.

It is always the case that $\Upsilon\left(U_{t-1}\right) > 0$. This follows directly from the convexity of the cost function $\delta''(.) > 0$, which gives that

$$\delta'(\bar{U}_{t-1}) > \left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}} \delta'\left(\bar{U}_{t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right),$$

because $\frac{z^T}{z^M} > 0$.

Taking the derivative of the function with respect to U:

$$\begin{aligned}\Upsilon'(\bar{U}_{t-1}) \equiv{} & \frac{K_i}{\bar{A}} \log\left(\frac{z^M}{z^T}\right)\left[\delta'(\bar{U}_{t-1}) - \left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}} \delta'\left(\bar{U}_{t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right)\right] \\ & + \frac{\bar{U}_{t-1}K_i}{\bar{A}} \log\left(\frac{z^M}{z^T}\right)\left[\delta''(\bar{U}_{t-1}) - \left(\frac{z^T}{z^M}\right)^{\frac{2}{1-\alpha}} \delta''\left(\bar{U}_{t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right)\right].\end{aligned}$$

The term on the first line is always positive, again because $\delta''(.) > 0$. The second line is positive if $\delta'''(.) \geq 0$ because then we can unambiguously state that

$$\delta''(\bar{U}_{t-1}) - \left(\frac{z^T}{z^M}\right)^{\frac{2}{1-\alpha}} \delta''\left(\bar{U}_{t-1}\left(\frac{z^T}{z^M}\right)^{\frac{1}{1-\alpha}}\right) > 0.$$

However, this last inequality may even hold when $\delta'''(.) < 0$ because the $\left(\frac{z^T}{z^M}\right)^{\frac{2}{1-\alpha}}$ term decreases the negative term on the left hand side. Overall, we conclude that $\delta'''(.) \geq 0$ is a sufficient (but not necessary) condition for $\Upsilon'(\bar{U}_{t-1}) > 0$ for all $\bar{U}_{t-1}$.

Utilization is bounded between zero and one. The condition $\delta'''(.) \geq 0$ means that the cost of utilization is (weakly) increasingly convex. This condition will hold for cost functions that go to infinity when $U \to 1$ and ensure that it is bounded. For example, in the calibrated model in Appendix B we use $\delta(U) = \frac{U}{1-U}$, which satisfies $\delta'''(U) > 0$. A simple quadratic cost would have $\delta'''(.) = 0$ and would also satisfy this equation.

D External Validity

How specific are the results reported here to the peculiar circumstances of the Second world War? I now discuss several facets of the historical context that help evaluate the external validity of the paper's findings.

Aircraft Standardization

A major shift during the war was was the move from made-to-order aircraft to standardized airplanes and this was crucial to satisfy the growing demand for aircraft (Middleton 1945, Claussen (1951) p. 23, Klein 2013, p. 52). Standardization, however, makes the wartime airframe industry similar to modern civilian industries. Standardization is in itself standard. Product standardization pre-dated the war: Henry Ford famously reports instructing his sales-force in 1909 that "Any customer can have a car painted any color that he wants so long as it is black" (Crowther & Ford 1922). The auto industry froze standard designs for extended periods of time and its production line methods went hand in hand with product standardization (Mawdsley 2020, p.270). Mishina (1999) compares the wartime airframe industry with the "just in time" production methods that proliferated in post-war era. However, the aircraft industry may have been on the cusp of a transition to standardization and mass production and large wartime demand may have merely nudged the industry into its next developmental stage. It is reassuring that learning curves appear no steeper in this industry than in others (see below). Nevertheless, further research is needed to adjudicate whether "learning by necessity" is particularly strong in an industry at this developmental stage.

Price Controls

The aircraft industry was exempt from the the Emergency Price Control act of 1942, an exemption that covered everything from "the raw material up to the finished product" (Smith 1991, p. 404). Static price caps would have had little effect given that aircraft prices (for a given model) dropped precipitously and across the board between 1942 to 1945.

Most aircraft were purchased through cost-plus-fixed-fee contracts. The government would typically offer a contract for a fixed quantity of an aircraft model, commit to toe the bill for the plant's variable costs, and to pay a pre-determined payment per aircraft delivered. This contrasts with the fixed-price contracts, prevalent in modern procurement. The former provides weaker incentives for cost-reductions, because these are passed through to the government, rather than accruing as profits. An excess profit tax of 90% was imposed on profits exceeding 4% of costs, and these might seem like a back-door price control. In fact, caps on markups reduced producers' incentives to lower costs further.

The modern literature on optimal procurement sheds further light on the perverse incentives due to cost-plus-fixed-fee contracts and markup caps. The literature focuses on asymmetric information between buyers and contractors, either regarding the contractor's private information about production costs, or about its unobserved effort to reduce costs. Regarding unobserved effort, Bajari & Tadelis (2001) show that cost-plus-fixed-fee contracts provide lower incentives to reduce costs than fixed-fee contracts. The logic is that in the latter, the contractor captures all surplus due to cost reductions for a given project (number of aircraft, in this paper's context). In contrast, when offering a cost-plus-fixed-fee contract, cost reductions are fully captured by the buyer. (There are some additional subtleties when costs are uncertain to both buyer and contractor, or when the buyer and contractor interact repeatedly, as in Laffont & Tirole (1988), but the general point still remains.) This implies that the contracts used during World War II provide weaker incentives to reduce costs and increase productivity than do the fixed-price contracts that are the default in modern procurement.[3]. McCall (1970) adds that cost-plus-fixed-fee contracts may lead to adverse selection because high-cost firms have the incentive to submit lower cost estimates when bidding for contracts, knowing that their costs will be covered either way.

Later in the war, whenever the profit cap was binding, the resulting contract was equivalent to a cost-plus-*percentage*-of-cost contract, where the government reimbursed 104% of production costs per aircraft delivered. This contract structure dis-incentivized cost reductions further. Relative to cost-plus-fixed-fee, any cost reductions were not only passed on to the government, but also reduced the contractor's profits in dollar terms. The literature on optimal procurement contracts is essentially unanimous that this contract structure provides highly perverse incentives, and this contracting structure has long been abandoned. Writing about cost-plus-percentage-of-cost (CPPC) contracts during World War I, Reda (1968) notes that "CPPC contracts, whatever their merits, quite naturally encouraged wasteful and costly performance... suspicions grew that contractors were not being merely indifferent to costs, but, indeed, were actively seeking ways to increase them." Smith (1991) , p. 276, discusses how the excess profit tax dis-incentivized cost reductions during the Second World War.

[3]See https://www.acquisition.gov/far/part-16

There is a separate question of whether demand induced by government procurement is informative about demand surges more generally. Firms with market power may have lower incentives to reduce costs when facing high market demand because increased production partly cannibalizes existing profits. In contrast, the government, a monopsonistic buyer of military materiel, has greater power to dictate quantities produced, and negotiate contracts that incentivize productive investments.

The Office of Price Administration attempted freeze wages at March 1942 levels, but frequent pay raises were negotiated between the OPA, management and labor. Wages in aircraft-manufacturing counties increased by 20% from 1942 to 1945.[4] Wage controls led to some labor shortages (Fairchild & Grossman 1959 pp. 135-36), but wages were strongly correlated with labor shortages, (Table A4 in the appendix), indicating that the price mechanism was operating at least to some extent. I exploited variation in labor shortages as markers of labor pressures at the plant level in Section 3.2, but results were robust and even stronger when considering variation in wages instead (Figure A.9 in the appendix), so results appear to hold whether prices or quantities are used to measure labor market pressures.

Patriotism

While patriotism may have affected productivity growth during the war, it is easy to understate the persistence of mundane incentives. Absence rates were high, averaging 6% in aircraft plants, and peaking at nearly 10% at the median plant at the end of 1943 (see Figure A.12 in the appendix). More than a quarter of Boeing's workforce were absent on the day after Christmas, 1943; the day following payday was also a common day of absence (Klein 2013 pp. 542-43). Klein (2013) claims that absenteeism was high due workers' strong bargaining power, with this being a "sellers market".

Quit rates were also high, averaging 4% per month. These were as high as 50% per month at Ford's celebrated Willow Run plant (Klein 2013, p.534). Eiler (1998) (p. 379) calculates that the turnover rate for US industry was as a high 100% per year. He quotes Hap Arnold, Commanding General of the Army Air Force, lamenting that patriotism was insufficient to avoid high quit rates. War Production Board chief Bill Knudsen also complained that "both managers and workers were unwilling to work flat-out–in fact, people were feeling more and more free to take time off"

[4]Source: "Summary of WBP-732 for Large Metal Products Manufacturing Plants," Record Group 221, Box 986, NARA College Park.

(Herman 2012, p. 414).

At the war's onset, labor leaders pledged to avoid strikes and walkouts (Atleson 1998, p. 3). However, Brecher (1997) documents that this cohesion didn't last and that unofficial strikes increased from 1942 to 1944, the latter having more strikes than in any year in US history (p. 240). According to Senate documents, 2,116,000 workers took to the picket line that year across 4,956 strikes (Swafford 1947).

In summary, while patriotism may have motivated workers to some extent, it doesn't appear that the workforce abandoned self-interest.

Aircraft Quality

Aircraft model fixed effects reflect narrowly defined aircraft, alternating with each design change. For example, Bell Buffalo's P63 models A and C are coded separately from models E and F and from G and I. Any changes in aircraft design would be captured by the model fixed effects. It is possible that aircraft quality declined *within* model, but there is no quality control record for World War II aircraft, to my knowledge.

There were a handful of sensational cases of plants attempting to cut corners to meet production targets. In January 1943, the Truman committee investigated and confirmed allegations that a subsidiary of Curtiss-Wright corporation had delivered defective engines.[5] However, by its March 1944 report, the committee informed that at Curtiss-Wright "improvements have been substantial, that the engines are being properly inspected and produced in great quantity." The committee also investigated complaints at the Curtiss-Wright Buffalo plant producing C-46 transport aircraft, but it was unable to confirm cases of defective planes.[6] The Truman Committee's reports mention no quality control problems in other airframe plants. Rae (1968) (p. 142) concludes in his history of the US aircraft industry that the "risk of exaggerating quantity at the expense of quality... did not in fact materialize in any serious proportions." Riddle (1964), p. 137, also concludes that cases of this sort were rare.

Data from modification centers provide further suggestive evidence that measured productivity didn't come at the expense of quality. Modification centers adapted the standardized aircraft to specific operational purposes, but also checked for and repaired production flaws. If produc-

[5]"Additional Report of the Special Committee Investigating the National Defense Program, Report 10, Part 10, 78th Congress, 1st session, pp. 107-111.

[6]"Additional Report of the Special Committee Investigating the National Defense Program, Report 10, Part 16, 78th Congress, 2nd session, pp. 107-111; United States Senate "Hearings before a Special Committee Investigating the National Defense Program," S. Res. 55, 79th Congress, 1st session, July 10-13, 1945.

tivity was associated with diminished quality, we'd expect to see increases in modification center employment as productivity grew. Table A5 in the appendix investigates this for the few modification centers that can be uniquely associated with a single plant. There is a nearly one to one relationship between modification center employment and hours worked in the plant, even controlling for two-way fixed effects, suggesting that the former didn't substitute for shirking in the latter. Further, there is essentially a zero correlation between growth in labor productivity and in modification center employment.

Was Aircraft Special?

Although studies of other industries use different methodologies, they report reassuringly similar learning effects. Thompson's OLS estimates of the Liberty Ship learning curve (0.26 in Table 2 and 0.21 in Table 3, last columns in both) are of similar magnitude to that found in here. Lafond *et al.* (2022) estimate an OLS regression of the learning (cost) curve, pooling the aircraft, shipbuilding, and trucking industries during the war and obtain an almost identical coefficient (-0.32 in their Table 3). While the aircraft industry was poised for mass production, the shipping and trucking industries were more mature. Of course, the existing literature doesn't investigate "learning by necessity', so it is difficult to adjudicate whether this phenomenon depends on the industry's developmental stage.

E Case Studies (for online publication)

This appendix gives narratives of the changes that occurred at a few plants in response to demand pressures.

Boeing, Seattle

This history draws on Mishina (1999), who gives a case study of the learning curve in B-17 production at the Boeing plant in Seattle. His main conclusion is that the learning process was one of "learning by stretching," a notion that anticipates and inspired the notion of "learning by necessity" of this paper. Mishina's "learning by stretching" refers to months in which a plant receives a previously unprecedented record of orders. Conceptually, this puts pressure on the plant's limited capacity, as in "learning by nececessity" but he had to rely on this indirect measure of production peaks, absent data on capital utilization.

Labor productivity in B-17 production in this plant increased by 240% from Pearl Harbor to the end of the war. The capital to labor ratio increased by 60% and production scale remained roughly constant over this period, so that TFP increased substantially with any reasonable production function parameterization. This was one of the highest capital utilization plants, with utilization peaking at more than 60% in early 1942; workers worked 50 hour average work weeks at that time.

Mishina (1999) (pp. 162-3) highlights how high bomber demand a plant with already high utilization motivated the need for technological change:

> After February 1942, turnover either outpaced or matched hiring, and the number of direct workers consequently fluctuated around 17,000 for the rest of the B-17 program. In fact, the chronic labor shortage was so severe that Boeing set up feeder plants in the summer of 1943 to tap into labor supplies outside the immediate Seattle area... It did not take long to exhaust this source, however: the subcontracting ratio already reached 28 percent with the B-17E and never exceeded 33 percent thereafter.

However, he rejects conventional human capital explanations for "learning" (p. 163). In fact,

> Unlike the plant and equipment, the workforce underwent significant qualitative changes during the mass-production phase and its skill deteriorated considerably. The early variants of the B-17 were built by a group of skilled craftsmen who had learned the ins

> and outs of airframe production through trial and error. With the outbreak of the war, these men either enlisted or were promoted to supervisory positions, and Boeing had to tap into entirely new labor pools to staff [Seattle] Plant No.2... Moreover, whatever labor Boeing was able to employ did not stay with the company long enough to acquire new craft skills. For example, Boeing started hiring female workers for the first time in its history to cope with the chronic labor shortage... [these workers] had a factory job only for a year or two when Plant No.2 recorded its best performance.

Instead, Mishina (1999) (p. 165) points to the same processes of specialization and interchangeability of parts that Adam Smith observed two centuries earlier, and more modern notions of "just in time" (JIT) production: "A primary cause of the rising velocity at Plant No.2 was the tighter implementation of JIT production." Concretely:

> The shop floor's crowded condition caused wastefulness, confusion, and inefficiency with increase in orders. Their solution was to streamline the process so that the right number of fabricated parts could reach the right place at the right time and the entire flow could be in a direct line to the last operation. They abolished the central finished-parts stockroom and made sure that the small stock bins carried only eight to ten days' supplies. This story amounts to a prefiguration of today's just-in-time (JIT) production... Plant No.2 divided the subassembly area into an ever larger number of smaller sections. As a result, the direct workers could work on a larger number of airframe segments of a given airplane at any given moment in the factory without interfering with one another.

Officials at Boeing credited this "production density" system for its production achievements.[7] This flexible technique was the brainchild of executive vice-president H. Oliver West. Improvement of procedures to limit human error was another administrative improvement:

> [M]uch had to do with procedures and simple devices. Plant No.2 reduced these opportunities for human errors with production illustrations, templates, and revisions of tooling development procedures.

In summary, the Boeing Seattle plant relied on new managerial and organizational procedures to increase productivity in face of high demand against constrained capacity.

[7] "There's No Single Long Assembly Line in Boeingâs Production of Fortresses," *Wall Street Journal*, 28 September 1942.

Douglas, Santa Monica

This history draws on contemporary Wall Street Journal reporting. This plant also illustrates the importance of managerial innovations to facilitate mass production. It's largest product by volume was the A-20 light bomber. Although this was a relatively mature product, the plant's labor productivity more than doubled from 1942 to 1945. The plant's scale was roughly constant, but it's capital to labor ratio declined and then recovered, over the course of the war. The plant operated at a 67% rate of capital utilization in 1943–exceedingly high for the time, but brought this down to 46% by the end of the war. Worker's weekly hours were more stable at around 45 throughout the war.

Reporters detailed how Douglas Aircraft increased its output in its Santa Monica plant by implementing a new system of drawing blueprints that made them easier to interpret without high levels of prior knowledge. The firm developed the "cutaway three dimensional" drawing, and this new type of drawing was adopted across the industry. Douglas vice-president Arthur E. Raymond claimed that the new drawings were so effective that they had "greatly sped the planning and the operation of assembly lines for the mass production of fighting aircraft."[8]

North American, Kansas City

This history draws on Macias (2005). The North American plant in Kansas City was built in 1941 to produce B-25 bombers. It's labor productivity grew almost threefold from the beginning of 1943 to mid-1945. The capital to labor ratio nearly doubled, but scale remained roughly constant. From 1943 to 1945, the plant operated reduced its capital utilization rate from 55% to 47% and weekly hours per worker from 50 to 45.

The plant saw a big increase in productivity in 1943, after Harold R. Raynor was appointed as the new plant manager. Raynor introduced new sub-assembly methods to B-25 production. "Engineers applied sub-assemblies, an assembled unit designed to be incorporated with other units, to the [B-25] Mitchell. Five sections - front, center, rear fuselage, wings, and empennage - were broken down into assemblies, split into sub-assemblies, and further divided into component parts" (Macias 2005 p. 257).

New management also focused on labor relations. In the first month of 1943 the plant had an average rate of absenteeism of 8.2%. North American established several incentives to address

[8] "Douglas Speeds Output with New Type of Drawings for Mechanics," *Wall Street Journal*, 22 September 1941.

this, including rewarding workers with the best attendance records with free war bonds, awarding cash prizes to workers who came up with the best patriotic slogans emphasizing the importance of staying on the job, and changing the work schedule to allow workers more time off. The plant moved from running two ten-hour shifts, six days per week to two ten-hour shifts, five days a week plus a rota-based weekday off. Absenteeism decreased to an average of 3.2% by 1945.

Bell, Marietta

This history draws on Combes (2001); "Appendix No. 1, Statement by Lawrence D. Bell, President, Bell Aircraft Corporation", October 10, 1945, before the Sub-Committee on Aircraft and Light Metals of the Special Committee Investigating the National Defense Program, United States Senate," Airforce Historical Research Agency, REEL A2169; and "Outline History of B-29 Program at Bell Bomber Plant," 22 Dec. 1941 to 31 Dec. 1943, REEL A1513. The Bell plant in Marietta, Georgia was founded to produce B-29 bombers. Labor productivity increased by a factor of 7 from the beginning of large-scale production in early 1944 to the end of the war. TFP increased by at least as much based on reasonable calibrations: the capital to ratio more than halved over this period, even as production scale doubled. Workers had 47 workweeks on average as production began, but this came down to 40 hours by mid 1944. Capital utilization was 48% in early 1944, slightly above the national average at that time.

The Marietta plant saw many of the improvements in production techniques documented elsewhere, but Combes (2001) emphasizes the role of labor conditions in the plant's success at exceeding its expected throughput. The company built hundreds of houses adjacent to the plant, constructed of car parks to facilitate commuting, and a traffic management system to make shift changes run smoothly. The firm also transported workers by bus from as far away as sixty miles. Recognizing the particular need of new women workers, Bell ran day care centers and held family days. The plant operated sports programs, rewarded worker suggestions with cash awards, opened a cafeteria to feed workers, gave workers a Christmas bonus in December 1944, and a day off for Christmas shopping as a reward for obtaining the plantâs monthly production target.

General Histories

I turn now to general histories of the period, that give an account of the importance of new production techniques, outsourcing, and labor relations in enhancing productivity.

Before 1940, aircraft production was a handicraft process. Aircraft were custom made to the client's (mostly the US- or a foreign-government's) specifications, limiting the pace of production. Visiting the Consolidated Aircraft factory in San Diego–a plant that later produced the greatest number of planes–George E. Sorensen, a Ford Motor Company executive, observed: "Here was a custom made plane, put together as a tailor would cut and fit a suit of clothes," (Sorensen & Williamson 1957). Mass production methods had already been in use in the automotive industry for decades, but management in the aviation industry insisted that these methods couldn't be adopted in the more complex process of airframe assembly, where each aircraft required hundreds of thousands of separate parts. As Klein (2013) puts it: "Nobody had yet found a way to bring mass-production techniques to airplane building, and prospects for doing so did not look promising" (p. 71).

The war modernized this industry. Aided in part by advice (and management hired) from the automotive industry, the aircraft industry adopted new production methods over the course of the war. Klein (2013) describes the innovation thus: "Mass production of anything consisted of a few well-defined principles. The first step was to break the product down into as many interchangeable parts as possible. Those parts could then be manufactured in quantity and fitted together on an assembly line where the machines were arranged in proper order" (p.67). This was both driven and enabled by the surge in demand for their products: "The rush of orders finally compelled many [aircraft] companies to rethink how they made their product" (Klein 2013). Craven & Cate (1955) concur that the industry "remained a handwork industry until the enormous demands of 1940-41 forced a conversion to mass-production methods." They contrast this to the the pre-war period, when "business [orders from the government] was too erratic to encourage plant expansion or the adoption of elaborate production-line techniques." In a post-war study of production problems in wartime aircraft manufacturing, Lilley *et al.* (1955) write: "In peacetime, the aircraft industry had had no opportunity to acquire familiarity with line production techniques; these techniques were not needed to meet peacetime production demands and were not used because of their high cost at peacetime volumes of output" (p. 2).

Line methods required new equipment but not all technological progress was embedded in capital and much of the progress was organizational.[9] Here is how Lilley *et al.* (1955) (p. 40-41) describe the transition to line production methods:

> The most dramatic evidence of line production in 1944 was the arrangement of equip-

[9]Indeed, they were often associated with hiring new middle management from the automotive industries. This resonates with the Acemoglu *et al.*'s (2022) finding that hiring innovative managers is associated with radical innovation in modern data.

> ment in both airframe and engine plants so that a progressive sequence of operations could be carried out. This arrangement of equipment constituted the fist element needed to achieve quantity production. Channels were established so that production could flow without the back-tracking so characteristic of job-shop work....
>
> Controlled flow was the second important element needed to achieve the peak production of 1944. Steady flow along the final assembly lines required careful production control in the assembly, subassembly, and fabricating departments. Scheduling assumed new prominence. In order to supply assembly lines with the thousands of parts entering into aircraft production, and enormous amount of detailed clerical work was required...
>
> The third essential element in the peak production year of 1944 was the careful balancing of operations in each production line... [T]he various feeder and final assembly lines were so geared together that each production line turned out the right number of components to maintain balance with the others.

Outsourcing annother factor to which contemporary reports attributed large productivity gains. Aircraft plants of the 1930s assembled the entire aircraft in house. However, with the introduction of mass production techniques, with interchangeable parts produced with narrow tolerances, it became possible to farm out parts of the production process to feeder plants.

These plants assembled specific parts of the aircraft–wingtips, for example–that were then transported to the airframe assembly plant, which integrated these parts in to the final assembly. Taylor & Wright (1947) (p. 75) describe this managerial practice, new to the airframe industry, writing:

> One ingenious form of expansion was the multiplicity of small feeder plants nurtured by the major companies in small suburban or rural communities, miles away from the congested central plants... Trucks brought fabricated parts from the main factories, and returned with the completed assemblies. Tooling made the pieces fit, no matter where they originated.

Craven & Cate (1955) (p. 25) continue: "The prime contractors had not used before 1939 the system of purchasing parts and sub-assemblies, so common among other industries, and in general they had little liking for it... This system allowed the use of a pool of unskilled labor... but it put a heavier burden on management and proved more difficult to schedule accurately than had previous methods." They add that this greater managerial burden was a cost not worth bearing until the scale of wartime demand made it viable: "It was not until 1940 that the volume of production required reached a point which seemed to justify putting official pressure on the industry to overcome its reluctance," they write (p. 546), indicating that in some cases it was War Production Board officials (often from the automotive industry) that nudged management in aircraft firms towards more outsourcing. A memo from the War Production Board to the National War Aircraft Council (a private-sector consortium of aircraft manufactures) urges greater reliance on outsourcing: "Most of the aircraft plants on the West Coast have recently developed feeder shops, employing 250 to 500 people... Turnover and absenteeism in these shops are at a minimum. We would suggest a further probing into the possibilities of sub-contracting a greater proportion of work."[10]

As the war progressed, outsourcing to more distant feeder plants was used to overcome labor shortages in the tight labor markets of many aircraft plants: "The dispersal of subcontracts outside the critical area [of tight labor markets] was encouraged, with the result that in September the Boeing Company placed subcontracts for approximately 40 percent of its work and made plans to let out subcontracts for an additional 20 percent." (Fairchild & Grossman 1959, p. 132). FigureA.12b in the appendix shows the increasing reliance on sub-contracting during the war. It shows the share of worker-hours in the production of each aircraft that was conducted in feeder plants, in the median aircraft plant. This increased dramatically from 10% to 30%, beginning immediately with the demand surge following the attack on Pearl Harbor.

Finally, labor relations have also been emphasized as a factor affecting productivity. Strain on workers and worker dis-satisfaction are certainly plausible drags on productivity in the context of a high pressure economy with workers working 50 to 60 hours a week at a quarter of all plants in 1942.

Histories of the war economy emphasize the labor problem in this high-pressure economy. Klein (2013) writes:

> Absenteeism remained a serious problem despite dogged efforts to curb it. Fortune called it "The New National Malady." The aircraft industry seemed especially prone to it. On the day after Christmas [1943], 26 percent of all Boeing employees failed to show

[10] Irving J. Brown and Roy L. Reuther (Aircraft Labor Office, War Production Board) to Clinton S. Golden and Joseph D. Keenen (War Aircraft Council), August 25, 1943. *Box 7, Archives of the National Aircraft War Production Council, Truman Library.*

> up for work, as did 11,000 workers at Douglas. The following month the Bureau of Labor Statistics estimated absenteeism for all industries at about 7 percent, many times the normal rate in peacetime.

Taylor & Wright (1947) describe the problem of absenteeism:

> To maintain delivery schedules, companies were forced to hire more workers than were needed, knowing that a percentage of them would be absent every day. But a time came when this "safety margin" of surplus workers could no longer be recruited. The factories had to reduce absenteeism or reduce the output of planes.

A report written by Douglas Aircraft management writes of the costs of turnover:[11]

> Mass labor turnover constitutes the industry's most serious manpower problem. The reduction of this turnover would relieve the pressure on present and future manpower requirements. Another advantage would be the greater efficiency that results from employees who remain on the job because the cumulative experience of these trained workers would not be lost by the individual plants.

Wages were only one of many tools used to retain workers and ensure they show up:

> Many and ingenious were the devices used to cope with the problem. Factories sent telegrams to the homes of absentees, inquiring after their welfare and telling them how they were needed in the war. Others sent visiting nurses to make first hand check-ups... Surveys searched for the causes of absenteeism... Working conditions were improved... Transfers to new jobs were arranged when work was uncongenial or unsuitable... Safety engineers fought to cut down absences caused by accidents... Ryan Aeronautical in San Diego reduced absenteeism by twenty-four percent by publishing [charts] in the company magazine and in daily papers... revealing the peaks and lows of daily attendance... Convair [initiated] a sweepstakes for employees with perfect attendance records, with prizes totalling $10,000 in War Bonds every month. (Taylor & Wright 1947, p. 137)

[11] *Experience Incentives*: Undated report by Douglas Aircraft, prepared for the National War Production Council, *Box 8, Archives of the National Aircraft War Production Council, Truman Library*.

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