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The Effect of Technology Choice on Automobile Assembly Plant Productivity

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Abstract: Productivity growth is usually represented by a continuous shift of the production or cost function. In the automobile industry, there is evidence of a more discrete change in the technology. I estimate a structural model of production and technology choice, using a panel of US automobile assembly plants from 1963 to 1996. New decomposition results suggest that plant-level changes, as opposed to compositional effects, are the most important determinant of aggregate productivity growth.

I UNDERSTANDING PRODUCTIVITY IS IMPORTANT

In recent decades, the US automobile industry has seen several important policy interventions. Voluntary export restraints were in effect for most of the 1980s, restricting Japanese imports; many states awarded significant subsidies to attract greenfield investments of both domestic and foreign firms; and a joint venture between General Motors and Toyota, with the exchange of technologies as an explicit goal, was given antitrust exemption in 1984.

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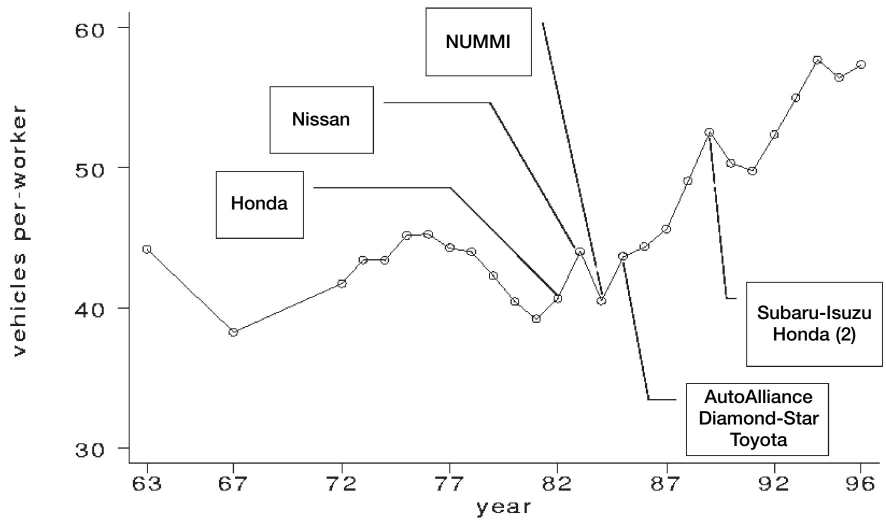
At the same time, the two most notable evolutions in the industry have been the entry of Japanese-owned assembly plants and the dramatic acceleration in labour productivity growth in subsequent years. Both trends are illustrated in Figure 1, which plots the evolution of a popular measure of labour productivity – vehicles produced per worker – for the industry as a whole. The entry of Japanese plants precedes the productivity surge, but it does not necessarily imply that entrants are more productive and that productivity growth is primarily driven by compositional effects. Calculating the vehicles per worker statistic separately for plants in operation before 1981 and newer plants suggests that most of the labour productivity gains arose in incumbent plants.

Figure 1: *The Two Stylised Facts: Productivity Growth and Entry of New Plants after 1981*



(1) The total number of vehicles produced per worker increased significantly from 1981 to 1996.
(2) Many Japanese plants entered right before the acceleration in (labour) productivity growth.

Source: All figures and tables are constructed using a plant-level data set that combines Census and industry data, see Van Biesebroeck (2000) for details.

I will argue, and present evidence, that estimating productivity and technology choice jointly generates a more nuanced view as to what is driving productivity growth. If we want policy interventions to stimulate productivity, it is important to properly understand the causes of productivity growth.

II THE USUAL SUSPECTS

A first explanation for the increase in labour productivity (LP) is provided by capital deepening. The increase in real wages makes it likely that firms have substituted workers for capital. As a result, LP growth will differ from total factor productivity (TFP) growth or technological change. The higher number of vehicles produced per worker in Japanese assembly plants, documented in Womack *et al*. (1990) and Krafcik (1988), is consistent with the higher capital-labour ratio in the (newer) Japanese plants.

Controlling for input substitution, a number of recent studies have decomposed aggregate TFP into the contribution of compositional and *real* productivity effects, to use the terminology of Levinsohn and Petrin (1998).[1] Reallocation of output between plants, a second explanation for aggregate productivity growth, relies explicitly on plant-heterogeneity. It contributes positively to productivity if resources move from below-average to above-average productive plants. The *real* productivity effect, a third explanation, measures changes at the firm-level, i.e. the shift in the production or cost function. Implicitly it is assumed that all heterogeneity can be captured by a Hicks-neutral productivity term. In a more general production function,

$$Q = \omega_{it} f_i (K, L, M, t), \qquad (1)$$

not only ω, the productivity level, but also $f(.)$, the production function, varies across plants (and is indexed by i).

A fourth explanation for the productivity surge is offered by a largely separate literature. Milgrom and Roberts (1990) and Kwoka (2001), among others, claim that entrants produce with a different technology, dubbed lean, or modern, manufacturing. Characteristics associated with modern manufacturing include team work, less standardisation, flexible equipment, decentralisation of decisions, less emphasis on scale economies, and increased flow in the production process.[2] Heterogeneity in technology is represented by the existence of two *systems* of production – lean and mass – each experiencing technological change at different rates and possibly with different factor-bias.

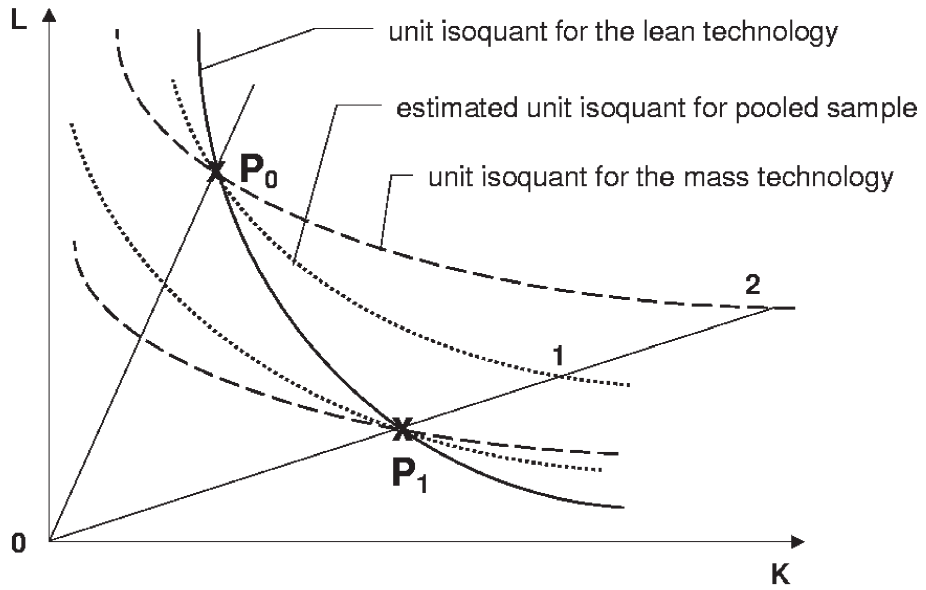
The adoption of a new technology by an existing plant can have a positive impact on productivity in two ways. There is potentially a level effect, a one-

[1] Earlier examples of such decompositions for the US include Bailey, Hulten, and Campbell (1992) and Bartelsman and Dhrymes (1998).

[2] Many articles from the International Motor Vehicle Program (IMVP) at MIT have described in great detail how Japanese plants differ from their American and European competitors along several dimensions. The book by Womack *et al*. (1990) summarises several findings of the programme.

time increase in productivity without long-run effect on productivity growth.[3] Alternatively, it is possible that the new technology experiences higher productivity growth. Switching will have a dynamic effect, because the plant will now produce according to a production function that shifts at a faster pace. The same two effects will apply if a plant with the old technology exits the sample, to be replaced by an entrant producing with the new technology.

Figure 2: *Neglecting the Existence of Two Technologies Biases Productivity Growth Estimates*



Productivity growth from production plan P_0 to P_1 is calculated to be *(P_1 1)/(0 1)* if the isoquant (or production function) is estimated on a sample that pools plants producing with the mass technology (depicted by the dashed isoquant) and lean technology (solid isoquant). Productivity growth is underestimated if plant *P* produces with the mass technology (it really is *(P_1 2)/(0 2)* and overestimated if plant *P* produces with the lean technology (growth is zero).

The existence of more than one technology matters for the estimation of productivity growth. Changes in a plant's production plan are decomposed into shifts along the production frontier or isoquant, interpreted as input substitu-

[3] It is not possible to compare two different production functions in terms of productive efficiency. It is nevertheless possible to compare the economic efficiency of two technologies, evaluated at current factor prices.

tion, and shifts of the frontier itself, interpreted as productivity growth. Figure 2 illustrates that one obtains biased results if plants that operate with different technologies are lumped together. One will, mistakenly, infer that all plants in the sample are able to substitute capital and labour along the dotted isoquant. An increase in the capital-labour ratio will, *ceteris paribus*, lead to an overestimate of productivity growth for the capital-intensive technology. My goal is to estimate both technologies consistently using a sample containing both types of plants and measure the contribution to productivity growth of the four explanations discussed in this section.

III MODERN MANUFACTURING REPLACES MASS PRODUCTION

I estimate a version of Equation (1) allowing for two sets of technology-specific coefficients. At one extreme, one could postulate that all plants in the sample produce with the same technology, as most of the literature has done. All observed heterogeneity is then attributed to measurement error or productivity differences. At the other extreme, one could assume a different technology for each plant and estimate (1) with random coefficients. This approach has not yielded satisfactory results; see Mairesse and Griliches (1990).[4]

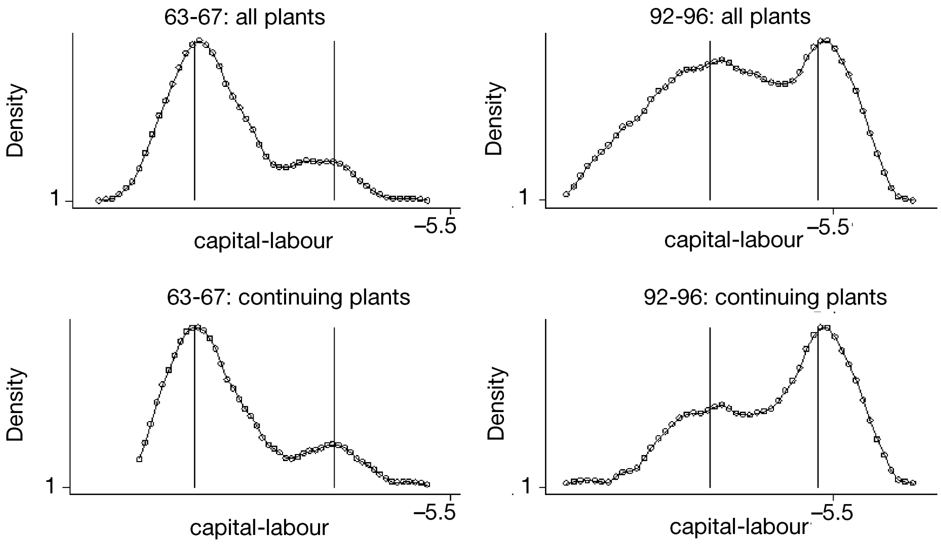
I take an intermediate approach by allowing for two – but only two – technologies. The trade press takes this stance by drawing a sharp distinction between lean and mass production. Milgrom and Roberts (1990) provide theoretical justification for this restriction by describing modern manufacturing as a set of activities that exhibit complementarities. The marginal product of adopting the new technology for one activity is increasing in adoption on other dimensions. It makes intermediary systems that are composed of elements of the old and new systems unstable.

In the data I find additional support for limiting the number of technologies to two. A Chow test for a structural break between two different samples, using a number of different criteria to separate plants into two groups, rejects the assumption of a uniform technology. The apparent bimodal distribution for the capital-labour ratio in Figure 3 lends credibility to the two-technology assumption.[5] In both time periods, 1963-1967 and 1992-1996,

[4] Diamond *et al*. (1978) show that it is impossible to identify the factor-bias in productivity growth from the elasticity of substitution using only time-series variation. Given the importance of capital-biased growth in this industry, it makes this approach inappropriate.

[5] The graphs can be interpreted as smoothed histograms for the average capital-labour ratio for a plant over a five year period. Confidentiality considerations preclude me from reporting the underlying distribution directly.

Figure 3: *Descriptive Evidence for the Existence of Two Technologies.*



The left panels plot the non-parametric density for the capital-labour ratio (per shift) for the first five years of the sample. The right panels plot the same graphs for the last five years of the sample. The top panels are based on all plants, while the bottom graphs are limited to plants that remained in the sample continuously from 1963 to 1996. The ratio has a bimodal distribution in both time periods and the popularity of the capital-intensive mode increased over time. The pattern holds up in the two bottom panels – evidence of plants switching technology.

plants can be separated into two groups, according to their capital intensity. Over time, the right mode – plants with a high capital-labour ratio – has increased in importance, accounting for a larger fraction of plants in the sample. The bottom two graphs, where the sample is limited to plants that operated continuously throughout the entire period, suggest that plants can also switch technology. We see the same increase in prominence for the capital-intensive technology over time, which now cannot be caused by entry.

It would be overly restrictive to assume that a plant's technology is exogenous. Firms choose what technology to employ at each of their plants, but the outcome of their choice is not directly observable. I get around this problem by using observable features of the production process to predict the technology for each plant. Both the probability of starting out with the new technology and the probability of switching technologies is allowed to vary across plants and over time. To estimate such a switching regression model with varying probabilities and unobserved states, it was necessary to make the new technology an absorbing state. Plants that are still operating with the

Table 1: *Properties of the Estimated Production Functions a Comparison of the Two-Technologies Model with a Single-Technology Translog Production Function*

	Two Technologies		*One Technology*
	Modern	*Mass*	
Capital share in cost per shift	0.104	0.144	0.349
Labour share in variable cost	0.695	0.882	0.796
Returns to scale	0.868	0.998	1.145
Returns to shifts	1.102	0.968	1.000 (fixed)
Elasticity of substitution	1.156	1.038	0.334
Hicks-neutral productivity growth	0.018	–0.009	0.004
Capital-biased productivity growth	0.010	0.034	0.007

old technology have the option to adopt the new technology or not to change. Once they operate with the new technology they will not switch back.[6]

The estimation results, in Table 1, for the two-technologies model are consistent with the often-made distinction between mass and modern manufacturing. The modern manufacturing technology is estimated to be relatively less labour intensive, it has higher returns to shifts and a greater elasticity of substitution, but exhibits lower returns to scale.[7] It is associated with higher capital-biased, but lower Hicks-neutral productivity growth. I also find that the mass production technology is disappearing from the industry. Entry of new plants, which are more likely to choose the new technology, and technology switching by existing plants both work in the same direction. Towards the end of the sample period the probability of a plant switching from the mass to the lean technology approaches zero, as gradually fewer plants remain that operate with a technology inappropriate for their product mix.

IV DECOMPOSING PRODUCTIVITY: ONE STEP BEYOND

The estimated model can be used to decompose aggregate labour productivity and explore the causes for the productivity surge depicted in Figure 1. The contribution of plant-level – *real* – changes, reallocation of resources – *the composition effect* – and the one-off effect of technology

[6] Details on the modeling of technology choice and the construction of the likelihood function are in Van Biesebroeck (2000).

[7] The higher degree of standardisation in mass production generates larger scale economies, making the older technology superior in some instances.

switching can be disentangled. Using the predicted probabilities for each technology as weights, I can further separate the contribution of plants operating with the mass and modern technology.

Table 2 illustrates that plant-level growth, especially by lean manufacturers, and the net entry of plants with the lean technology are the two most important components of aggregate productivity growth. The size of the effect attributed to plant-level changes can only be appreciated once we are able to separate the contributions of both technologies. The negative contribution of the composition effect for mass production plants captures the initial response of the Big Three American producers to the entry of Japanese competitors. They tried to fight off the challenge by increasing automation and upgrading equipment in plants that were lagging the most in productivity, incurring large investment costs. The composition effect picks up the relative relocation of capital from high to low productivity plants. The attempt to raise productivity failed and they later resorted to more far-reaching technology switching. The level-effect of technology switching is negative and small, which might be the result of learning-by-doing. It takes time to master a new technology.

Table 2: *Decomposition of Industry-Wide Labour Productivity Growth (average yearly change for 1963-96)*

	Lean/Modern Plants	*Mass Production Plants*	*Technology Switching*
ΔLP (full sample)	0.79		
Composition effect	0.06	–1.02	
Net entry effect	0.91	–0.49	
Plant-level effect ΔLP	1.14	0.20	–0.02
– Growth in K/L	0.45	–0.01	
– Hicks-neutral PG	–0.23	0.12	
– Capital-biased PG	0.81	0.07	
– Returns to scale	0.06	0.01	
– Returns to shifts	0.04	-0.00	

The plant-level labour productivity growth is decomposed further, revealing the importance of capital deepening and capital-biased productivity growth for the lean technology. Returns to scale are estimated to be slightly decreasing for the lean technology. Combined with a decrease in the average plant-size it generates a positive contribution to productivity growth. An improvement in capacity utilisation provides the final contribution, because returns to shifts exceed one. For the mass technology, most of the plant-level change can be explained by a Hicks-neutral shift in the production frontier, with capital-biased technological change a second important factor.

V CONCLUSION

The more nuanced picture explaining the surge in (labour) productivity in the US automobile industry relies explicitly on the modelling and estimation of two technologies and plants switching between them. It reverses the findings from earlier studies and concludes that the effect of plant-level changes outweighs the composition effect. Plant-level productivity growth also has different causes for both technologies. Labour productivity advancements for lean technology plants are mainly the result of capital deepening and capital-biased productivity growth. For mass technology plants, standard Hicks-neutral productivity change is the dominant explanation.

BIBLIOGRAPHY

BAILEY, M. N., C. HULTEN, and D. CAMPBELL, 1992. “Productivity Dynamics in Manufacturing Plants”, *Brookings Papers: Microeconomics*, Vol. 4, No. 1, pp. 187-267.

BARTELSMAN, E. J. and P. J. DHRYMES, 1998. “Productivity Dynamics: U.S. Manufacturing Plants, 1972-1986, *Journal of Productivity Analysis*, Vol. 9, pp. 5-34.

DIAMOND, P., D. MCFADDEN, and M. RODRIGUEZ, 1978. “Measurement of the Elasticity of Factor Substitution and Bias of Technical Change” in M. Fuss and D. McFadden (eds.), *Production Economics: A Dual Approach to Theory and Applications*, Volume 2, New York: North-Holland.

KRAFCIK, J. F., 1988. “Comparative Analysis of Performance Indicators at World Auto Assembly Plants”, Master’s Thesis, M.I.T., Cambridge.

KWOKA, J., 2001. “Automobiles: The Old Economy Collides with the New”, *Review of Industrial Organisation*, Vol. 19, No. 1, pp. 55-69.

LEVINSOHN, J. and A. PETRIN, 1998. “When Industries Become more Productive, Do Firms?: Investigating Productivity Dynamics”, NBER Working Paper No. 6893.

MAIRESSE, J. and Z. GRILICHES, 1990. “Heterogeneity in Panel Data: Are There Stable Production Functions” in P. Champsaur *et al*. (eds.), *Essays in Honor of Edmond Malinvaud*, Volume 3, Cambridge: MIT Press.

MILGROM, P. and J. ROBERTS, 1990. “The Economics of Modern Manufacturing: Technology, Strategy, and Organisation”, *American Economic Review*, Vol. 80, No. 3, pp. 511-528.

VAN BIESEBROECK, J., 2000. “Productivity Dynamics with Technology Choice: An Application to Automobile Assembly”, CES Discussion Paper 00-16.

WOMACK, J. P., D. T. JONES, D. ROOS, 1990. *The Machine that Changed the World*, New York: Rawson Associates.